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DEVELOPMENT OF PETROLOGICAL TECHNIQUES IN THE EXPLORATION AND EXPLOITATION OF PHILIPPINE GEOTHERMAL SYSTEMS

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ABSTRACT

Unlike most countries where petrological studies are confined to a research laboratory, such investigations in the Philippines have largely been geared towards providing, as soon as possible, practical information necessary for immediate management decisions on the development and exploration of geothermal resources. Since 1978, petrological research and applications have become an integral part of every phase of geothermal development in the country. Petrographic microscopy and fluid inclusion studies are done in tandem with drilling, especially of exploration wells; and the results and interpretations are immediately relayed to the site staff. After drilling, petrology is extensively used in developing field-wide hydrological models and, in so doing, assist in assessing the viability of a system, enabling geoscientists to site future production, replacement and reinjection wells. During exploitation, the petrological study of scales in geothermal installations can provide some insight on material corrosion, may pinpoint sources of plant upsets such as occasional surges of entrained water in steam fed into the turbines and describe flow regimes in the pipelines. The petrological interpretative skills honed from studying geothermal systems have been extended to the exploration of relict hydrothermal systems such as epithermal gold deposits and the unravelling of diagenetic processes in hydrocarbon systems in sedimentary basins.

1. HISTORY OF GEOTHERMAL DEVELOPMENT IN THE PHILIPPINES

The success of geothermal development in the Philippines is closely linked to (a) the vast geothermal resources of the country; (b) the vision and tenacity of one man, A.P. Alcaraz, to initiate geothermal studies in the early 1960's, provide the driving force for more than 30 years in the exploration of Philippine geothermal systems and inspire a generation of geoscientists and engineers to pursue work in geothermal technology and (c) the willingness and open-mindedness of the Philippine government to promulgate laws, establish institutions, provide funding for the study and development of an unconventional source of energy, support an extensive manpower development programme and facilitate links with foreign experts.

The Philippines is the second largest producer of geothermal power after the USA, achieving and maintaining this second rank since 1980, less than eight years after the first commercial well was completed in Tiwi. At present the country has an installed capacity of 1861 MWe produced from six geothermal systems (Arevalo, pers. comm., 1998). From 1977 to 1984, the installed capacity rose phenomenally from 3 to 894 MWe (Vasquez, 1986), a rate of 127 MWe/year, compared to 73 MWe/year from 1984 to 1998. Proven geothermal reserves amount to about 2047 MWe whilst probable and possible resources total to about 2490 MWe (Arevalo, pers. comm.,1998). Most geothermal areas are associated with Pleistocene to Recent andesitic to dacitic volcanic complexes and at least six sites have been drilled in the vicinity of volcanoes that had either historical eruptions or very high magmatic contents. In fact the geothermal wells drilled in one area, Mt Pinatubo, were completely annihilated by the 1991 eruption.

The possibility of harnessing geothermal energy from volcano-related hot springs was noted in the early 1950's by the then newly-appointed head of the Commission on Volcanology, A.P. Alcaraz. Unlike most of his countrymen who simply reeled from the catastrophes wrought by volcanic eruptions, this man viewed volcanoes as benefactors rather than cut-and-dried malefactors. Influenced by several conferences on unconventional energy sources in the 1950' and 1960's, Alcaraz decided to pursue thermal studies of hot springs in Tiwi and Los Banos in 1962 as part of his mandate to study volcanic activity in the Philippines. By 1966, without any help from foreign experts, his team was able to site and drill a 168 m deep slim hole with a bottomhole temperature of 103°C. In 1967 this was attached to an experimental 2.5 kW turbo generator and several electric bulbs were, for the first time in the country, lighted by geothermal energy (Itchon et al., 1986). Through his perseverance and resourcefulness this man initiated the geothermal industry in the country and enticed the government to view geothermal as an energy source of the future. In 1967, the government passed a law stating that geothermal resources, natural gas and methane were the property of the state.

Thus even before the world-wide energy crisis of the 1970's, because of the efforts of this man, the Philippine government had already implicitly decided to explore and develop an indigenous and unconventional source of energy. In 1968 a 3 kW generating unit was installed in Tiwi, proving that geothermal is a viable source of power. After signing an accord with the Philippine government in 1971 the Philippine Geothermal Incorporated, a subsidiary of UNOCAL of the USA, proceeded to drill deep wells in the resource for commercial exploitation.

In response to the world-wide energy crisis the Philippine National Oil Company (PNOC), a government-owned energy corporation, was created in 1974. One of its subsidiaries, the Energy Development Corporation (PNOC-EDC) had the responsibility for exploring and developing geothermal resources. To delineate the financial and physical obligations of any group exploring and developing geothermal systems, the Presidential Decree (PD) 1442 of 1978 was passed (Vasquez, 1986). Under this decree, only PNOC had an approved service contract until the Build-Operate-Transfer (BOT) legislation was introduced in 1990. This law allows "international power utilities to fund, construct and operate geothermal power plants" and enables the country to "rapidly increase much needed electrical generation without increasing national debt" (Javellana, 1995). Furthermore, the Geothermal Development Act was revised "to make geothermal exploration and development more attractive to private investors" (Javellana, 1995). The aggressive and far-sighted stance of the country, in developing an indigenous power source, is a concerted effort amongst scientists, engineers and bureaucrats that has weathered several changes in government administrations. The exceptional influence of technical research and information on government policies was initiated by A.P. Alcaraz and continues to the present.

2. THE WORKFORCE

In tandem with the remarkable attainment in geothermal production of the country, within a short span of time, was the rapid growth in the number of Filipino geothermal specialists (Figure 1), rising from 58 in 1975 to 460 in 1985 to >1200 in 1994 (Datuin, 1990; Fridleifsson, 1995). The key elements to this accelerated growth in manpower capabilities lie in the judicious recruitment of often young technical personnel with at least basic academic training in their respective professions, a discerning yet open-minded outlook towards

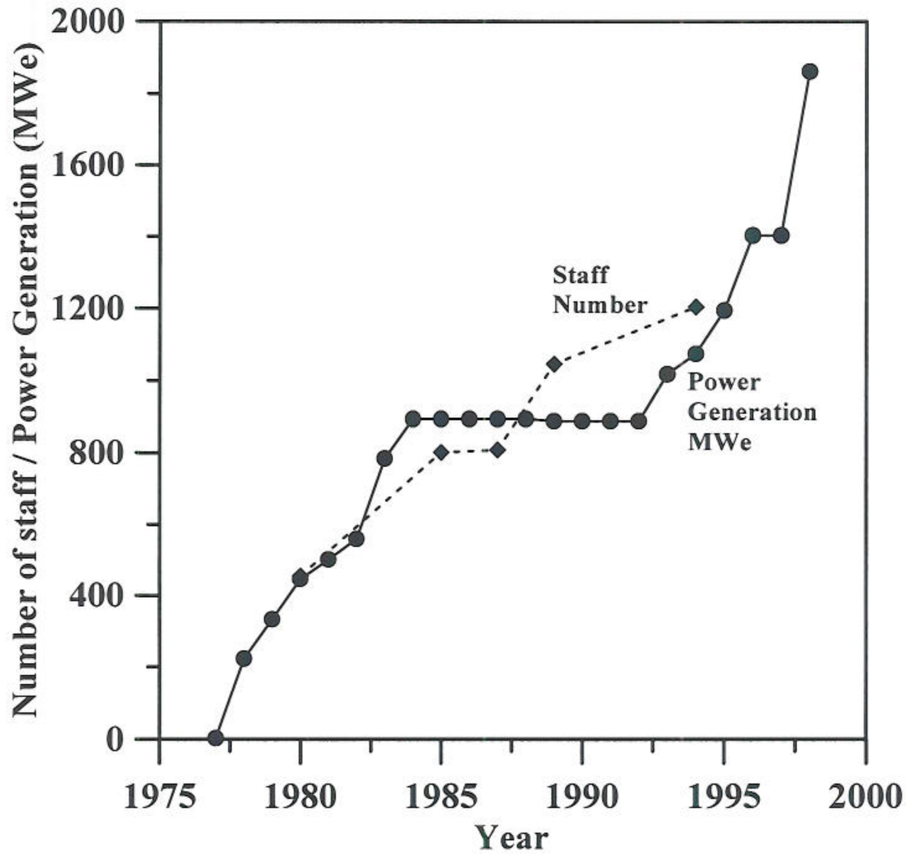

Figure 1: Variations in the installed geothermal capacity and the number of people working in the geothermal industry, in the Philippines, with time (data from Datuin (1990), Fridleifsson (1995) and Arevalo (pers. comm.))

technology transfer by Filipinos and an extensive manpower development programme fully-sanctioned by the government. The manpower development programme included on-the-job training with foreign experts, special studies ranging from short training missions to masteral and doctoral degrees; and in-house development programmes (Itchon et al., 1986; Tolentino and Buning, 1985). Short courses included training programmes in Iceland, New Zealand, Pisa and Kyushu. Masteral and doctoral degrees for geothermal technical people were offered by the University of Auckland in New Zealand, Stanford University and the University of California in Berkeley in the USA (Fridleifsson, 1995). Courses in drilling technology led mainly by Filipinos and a UN-sponsored course on reservoir assessment and management are some of the examples of in-house development programmes held at PNOC-EDC. One of the factors that continually honed the mettle of various local technical experts is the holding of the annual PNOC-EDC geothermal workshop and conference commencing in 1978. The initial purpose in holding this meeting was to gather in one place geoscientists and engineers of PNOC-EDC to review and discuss new exploration areas, resource strategies and assessments, technical advances in engineering and geoscience, and development and exploration problems during the past year. Since then, this conference has evolved into a yearly international event.

Foreign consultants, especially the New Zealanders, had to be relied on in the absence of indigenous geothermal manpower capabilities, during the early stages of geothermal development. However, by the mid-1980's the Philippines had already attained local self-sufficiency and the number of foreign consultants working hands-on in the various geothermal areas dwindled. Since then, foreign experts have been hired mainly to offer second opinions on matters needed for management decisions.

The increasing capabilities of the local manpower and their rise as experts in their own right can be measured by the number of papers published through the years. In the 1985 International Geothermal Congress in Hawaii, only three papers on Philippine geothermal technology, by Filipino authors, were contributed. By

1995, during the WGC in Florence, 11 papers were presented. In 1993 a Geothermics Special issue on various aspects of Philippine geothermal systems was published and hailed as a "landmark publication that documents the scientific and engineering basis for the impressive geothermal development in the Philippines" (Muffler, 1993). Thus behind the impressive geothermal programme of the Philippines is a hard-working, skilled and dedicated technical workforce.

3. THE PETROLAB

The establishment of the Petrolab at PNOC-EDC in 1978 coincided with the hiring of the company's first female technical staff member, unbeknown to PNOC-EDC management who, at that time, refused to hire women. Little did the management realize that this started a tradition, for the next 19 years in the Petrolab, where the females are the scientists and the males, the technicians to assist them. The Geoscientific Group of PNOC-EDC is a microcosm of the rising number of female technical staff in the geothermal sector. From 1979 to 1998, the percentage of female technical staff rose from <5% to as much as 30% at present.

Of all the technical sections in PNOC-EDC, the Petrolab was the only one which did not find the need to hire a foreign consultant to improve the capabilities of the staff. Instead the petrological techniques were developed in-house, hands-on, and assisted in part by the training on Borehole Geology for six months of one petrologist in Iceland in 1979 and another one, on fluid inclusion studies, for two months in New Zealand. In the case of the Petrolab, necessity bred self-reliance. During the late-1970's to 1980's, when at least four deep wells were being drilled at one time and surface geoscientific activities were being carried out simultaneously, there was a need to rapidly develop practical applications of petrology in interpreting drillhole and surface material and also for adapting techniques for use in the rig or on-site where equipment is scarce. During that time, it was demonstrated that petrology can be a potent and reliable technique during the exploration and exploitation of a geothermal resource and can be viewed as an operation as well as a research tool.

4. PRACTICAL APPLICATIONS OF PETROLOGY

The main petrographic techniques used in the study of geothermal systems in the country consist of transmitted and reflected light microscopy, X-ray diffractometry and fluid inclusion heating/freezing measurements. By integrating results obtained from these various methods, petrological studies can provide information on well temperatures; the depth and type of permeability and the approximate fluid chemistry in terms of relative gas contents, salinity, acidity and corrosivity. Petrological results can also assist in defining or locating possible zones or depths where there may be cold water incursion, hot fluid influx, direct magmatic input, steam-dominated zones or temperature reversals in a well. These basic results can be extended to define the hydrology of an individual well or a geothermal resource since upflow and outflow regions can be identified and the faults cutting across the field characterized in terms of permeability and the fluids they channel. Basic petrology has also been used in the study of scales from wells, the fluid collection and disposal pipelines and turbines; drilling mud; and drilling cement.

Unlike most countries where petrology is used more as a research tool and as a source of information on hindsight, petrological studies in the Philippines have always been done proactively, geared towards providing practical information necessary for immediate management decisions. The technique had been used extensively during exploration drilling and is considered a highly reliable method in defining the outcome of a well, prior to actual well measurements and the availability of chemical analysis of well fluids. Cuttings, sampled every 3 to 5 m, and cores which are cut only during blind drilling, are regularly sent to the main office during drilling for petrographic analysis to supplement the studies done by the rig geologist. In the case of critical wells where, for example, magmatic input is suspected, a petrographic microscope, a fluid inclusion heating stage and thin-section making equipment are brought to the site. Thus petrographic analysis and data interpretation from cuttings and cores are done in tandem with well drilling and in so doing, petrological findings often considerably influence the outcome of a well. In exploration wells, the depth of the production casing shoe, the total depth, the well track and even the drift angle may be changed from the well plan, according to the petrographic findings. During drilling, problems such as stuck pipes and short bit lives, can sometimes be explained by employing petrography. Stuck pipes have been caused by abundant swelling clays in the formation or the sloughing of shaly sedimentary rocks. On the other hand, short bit lives have been found to be due to the intersection of thick intensely silicified zones or fresh microdiorite dikes, or extremely high temperatures and corrosive gases associated with magmatic-hydrothermal systems. As long as samples can be obtained, petrographic techniques have been used to try to explain well conditions. The advantage of petrology is that results can be easily, cheaply and rapidly obtained for decision-making especially during drilling. In the absence of other geoscientific or engineering data, the results offer a first approximation of the condition of a well or reservoir. The integral role petrology holds in the geothermal industry culture in the Philippines can be gauged by its extensive use in all stages of resource development. Its success as an operations and research tool was stressed when site engineers started to rely on the Petrolab for advice on how to proceed with drilling, only three years after the laboratory was set up. One of the best accolades, for the practicality of petrology, came when a driller collected cuttings, looked at them and said, "Anhydrite - we just hit a permeable zone."

After exploration drilling, petrological data are used, in collaboration with other geoscientific and engineering results, to develop a hydrological model for the resource and to determine its viability. If further development is warranted, petrology can assist in siting production, replacement and reinjection wells by pinpointing, for example, target faults.

Petrological techniques have also found a role during the exploitation of a geothermal system, especially in the study of scales from turbines and the fluid collection and disposal system. Scale analysis may help settle disputes between the provider of steam and the buyer, often two separate entities in the Philippines, regarding the purity of steam passing through the turbines. Sometimes surges within the pipeline system, which may entrain water, may go undetected by regular chemical analysis of steam quality. These entrained solutions leave their marks as scales of calcite and halite associated with pyritization and the formation of goethite on the turbine blades. Unfortunately for the steam-buyer, these scales are detected only during the servicing of the turbines.

Since its inception in 1978, the petrological techniques developed in the Petrolab of PNOC-EDC have been widely used in the exploration, development and exploitation of geothermal systems, relict hydrothermal systems such as epithermal gold deposits and hydrocarbon systems in sedimentary basins. Aside from the Philippines, these interpretative methods have been used to study geothermal resources in Japan, Indonesia and New Zealand.

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