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THERMAL AREAS OF THE PHILIPPINES

Ruel T. Malapitan and Alicia N. Reyes
Geothermal Division, Energy Resource Development Bureau
Department of Energy, Energy Center, Merritt Road
Fort Bonifacio, Metro Manila Philippines

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ABSTRACT

Through the years of Philippine experience in geothermal exploration, development and production, prospectors and major players in steamfield development have defined three (3) major geological environment contributing to the development of geothermal resources. These are as follows: a) along volcanic belts; b) along major structures and other structures, and c) along plutonic occurrences. The most important among these three environments is along volcanic belts for high-temperature producing and potentially exploitable geothermal fields are found near Quaternary volcanoes.

Using available data, geothermal reserve of the country is estimated through volumetric method at 4537MWe.

1. INTRODUCTION

The Philippine has consistently been an important country in the world geothermal arena for the past twenty (20) years considering the high installed geothermal capacity in the country. Under the Geothermal Service Contract (GSC) system there are nine (9) high-temperature geothermal fields under various stages of development and production (Figure 1). Six (6) of these fields are under production: Tongonan, Bacman, Palinpinon, and Mindanao are operated by Philippine National Oil Company-Energy Development Corporation (PNOC-EDC) while Tiwi and MakBan are operated by Philippine Geothermal Inc. (PGI) under an interim agreement with National Power Corporation (NPC) pending sale of the fields (Table 1). Northern Negros, Mt. Labo and Mt. Cabalian geothermal service contract areas are still under development by PNOC-EDC. These three (3) fields are scheduled to produce in the next ten (10) years.

Previous workers such as the Philippine Institute of Volcanology and Seismology (PHIVOLCS) (Aguila, et.al, 1987), PNOC-Energy Development Corporation (PNOC-EDC) and the then Bureau of Energy Development (BED)(ElectroConsult, 1979) have identified several prospects including the current service contract areas. The Department of Energy (DOE) currently re-assessed the country's geothermal resources and identified several other new prospects in the course of the inventory.

In this paper, the authors aim to supplement the information generated through the years of geothermal activities on the aspect of geological environment, new area for exploration and current geothermal resources estimate.

2. GENERAL GEOLOGY

Rocks found in the island are typical of an island arc. The disposition of the rock types are generally in accordance to the trend of the trenches responsible for the formation of the island arc. The lithology consists of intrusive rocks (including ophiolite complexes) and their corresponding extrusive equivalents, metamorphic and sedimentary units.

The intrusive rocks are divided into two groups: the granitic-dioritic and the mafic-ultramafic suites (BMG, 1982). The granitic-dioritic intrusives are predominantly diorite and are associated with metallic mineralization and geothermal resources. The age ranges from Permian to Tertiary (Miocene). The mafic-ultramafic suites define ophiolite complexes occurring as ridges near trenches and troughs (maybe as obducted oceanic slabs consequent to the subduction of the oceanic plates i.e. Philippine, Manila, Cotabato and Sulu Sea).

The composition of the extrusive igneous rock units varies from basaltic to dacitic. The age ranges from Carboniferous to Quaternary. The plotted locations of Pliocene to Recent volcanics outline nine (9) volcanic belts (BMG, 1982) that parallel the trenches believed responsible for the volcanism.

Metamorphic rock units found to occur in the country may be categorized as groups, which are related to structures, and to igneous intrusions. The metamorphics are dominated by the greenschist facies. Eclogites, contact and cataclastic metamorphic units, however, are also found. Their distribution shows close affinity to major structures such as faults and trenches. The contact metamorphic units consist of marbles, skarns and quartzites are localized along the peripheries of plutons. Cataclastic units consist of cataclasites and mylonites which are localized within fault zones. The greenschists are disposed adjacent to the trenches and may represent the base of obducted oceanic slabs in the form of ophiolite complexes.

Sedimentary rock sequences fill up depositional basins and valleys consequent to the tectonic and erosional processes acting in the island.

3. STRUCTURAL FRAMEWORK OF THE ARCHIPELAGO

The shape of the Philippine archipelago is controlled by the subduction zones bounding the island's extremities (Figure 2). The northern trend of the Northern Luzon mainland is influenced by the orientation of the East Luzon Trench in the east and the Manila Trench in the west. The northwest orientation of the islands south of Northern Luzon extending to Mindanao is very well defined by the attitude of the

Philippine Trench on the east. The skews on the western side of the Visayas and Mindanao region are due to the differing trends of the Negros, Sulu and Cotabato trenches. The development of these trenches was attributed to the collision of the Philippine archipelagic landmass with the Eurasian plate in the west and the oceanic Philippine Sea Plate. The trenches are located where the dense oceanic basins – the South China Sea, Sulu Sea and Celebes Sea basins in the west and the Philippine Sea in the east – are subducting underneath the archipelago as a consequence of inter-plate collisions.

Consequent to movements in these trenches, a major fracture running 1,300 km. along the length of the archipelago is developed as a response to the oblique compressional forces of the subduction at the trenches (David, 1996). The fracture is a left-lateral transcurrent fault called the Philippine Fault. The same mechanism holds for the development of the Mindanao fault in response to the compressive forces of subduction along the Cotabato Trench.

It is interesting to note that thrust faults mapped in the country are situated mostly along the archipelago's western and eastern extremities. The thrust fault locations coincide very well with the occurrences of ultramafic/ophiolite sequences which are evidences of obducted oceanic slabs in a collision/subduction zone. Therefore, these thrust faults and ophiolitic zones are also due to the above-discussed tectonism.

In effect, these fractures/faults provide good conduits for geothermal fluid ascent to the surface facilitating formation of several hot springs in the country, the heat emanating from the different volcanic centers and young plutonic occurrences spread widely in the country.

Consistent with the structural trend, fold patterns also follow the orientation of the compressional forces brought about by the plate collisions along the trenches. The fold pattern is dominantly trending N-S in Northern Luzon and Southern Mindanao, NW-SE in Southern Luzon to Northern Visayas, and NE-SW in Central Visayas to Western Mindanao.

4. Distribution of geothermal resources

The Philippine archipelago is a complex assemblage of island arcs, which has been accreting between the two opposing major tectonic plates - the Eurasian and the Philippine Sea Plates (Divis, 1980;Sussman, et.al, 1993). Collision boundaries of these tectonic plates with the Philippine archipelago are defined by subduction zones, to wit: the Manila, Negros, and Cotabato Trenches on the west, and the Philippine Trench on the east. The opposing subduction zones have generated a discontinuous belt of Pliocene to Quaternary Volcanoes which extends the length of Philippines, from northern Luzon to southern Mindanao (Karig, 1983). An active, left-lateral, strike-slip fault called the Philippine Fault, extending more than 1,300 km. long, also occurs between subduction zones (David, 1996). Most of the known high temperature (>240^{o}C) geothermal systems in the Philippines are associated with Quaternary to Recent volcanism and dense fracturing related to the Philippine Fault or its subsidiary faults. This explains the presence of so many large (>100 MWe) fracture-dominated geothermal systems in the country. Steeply dipping normal faults are the most common structures in Philippine geothermal areas which generally provide the major source of permeability in the wells (Reyes, 1990).

Through the years of Philippine geothermal energy exploration, development and production has classified the present systems to be related to volcanism, plutonism and tectonism (Figure 2). In this report, the regional distribution of Philippine thermal areas have been adopted and modified from Troncales (1979).

4.1 Along Volcanic Belts

These refer to regions of active volcanism where geothermal activities are dominantly confined along foothills or the base of younger Quaternary volcanoes. Along these volcanic centers there are deep tectonic fissures responsible for the trapping of magma reservoir and ascent of high-temperature magma fluid.

Geothermal manifestations more commonly occur in andesite-dacite volcanic terrains compared to basaltic ones because a higher rate of heat flow into the country rocks is attained with increased viscosity of the intruding magma. Also because basalts rarely make shallow magma chambers. Moreover, the progressive concentration of volatiles in the liquid phase of andesite-dacite magma at its outer shell could cause an explosive discharge of gases accompanied by successive episodes of rock fracturing necessary in the formation of secondary permeability.

4.1.1 Santa Ana Volcanic Belt - Luzon Central Cordillera Belt - Central Luzon Belt - Cuyo Belt (Vasquez, N.C. et.al. 1997)

The Manila Trench located west of Luzon with several associated onshore and offshore volcanic belts bound this belt. The Santa Ana Belt originated in Batanes Group of Islands terminating at the northernmost tip of the Central Cordillera. From the central northern Luzon, the belt passes through the central portion of the Northern Luzon Cordillera (Luzon Central Cordillera), and swings westerly traversing western Luzon Island and then abruptly terminated by the Tablas Lineament in the south to include Marinduque Island (Luzon Central Belt).

This belt consists of a heavy concentration of active and inactive volcanoes hosting geothermal resources. In the north are the offshore and on-shore geothermal prospects of Camiguin de Babuyanes and Mt. Cagua, respectively, in the province of Cagayan. At the Luzon Central Cordillera Belt, it follows the axis of the Luzon Northern Cordillera and it swings eastward to include the Pliocene-Pleistocene volcanic centers in the Caraballo Mountains. Geothermal prospects in this belt includes; Batong-Buhay, Kalinga; Bontoc-Sadanga in Mt. Province; Tinoc, Ifugao; Daklan, Acupan, Buguias and Asin, all in Benguet of the Luzon Central Cordillera and several thermal springs in the provinces of Aurora, Nueva Ecija, Nueva Vizcaya and Nueva Vizcaya in the Caraballo and Sierra Madre Mountain Ranges.

At the western swing of the belt to the west of Luzon, the belts consist of heavy concentrations of volcanic centers marking the eastern foothills of Zambales down to Marinduque Range until it terminated abruptly by the Tablas Lineament in the south. It covers the extensive volcanic region of Southern Tagalog including Taal Volcano and the highly productive

Makiling-Banahaw geothermal field. Elsewhere to the north are a number of hot geothermal prospects in this belt. However, none has yet been developed due to poor permeability, and in some cases, e.g. Mt. Pinatubo, the presence of pervasive acidic and magmatic fluids. The belt may also be extended further across the channel linking the Manila and Negros trenches to include Pliocene centers in Cuyo Island Group.
Aside from the above-mentioned prospects, the following are also located within: Manleluag, Mangatarem, Balungao and Rosales in Pangasinan; Lemery, Nasugbu, San Juan, Mabini in Batangas; Talim Island and Jala-Jala in Rizal; Mt. Banahaw and Alabat in Quezon; Buenavista in Marinduque; Puerto Galera, Buloc-Buloc, Naujan, and Montelago in Oriental Mindoro; Islands of Banton, Simara and Tablas (Odiongan and Sta. Maria) in Romblon.

4.1.2 Bicol Belt - Mindanao Central Cordillera

It covers the eastern margin of the Philippines running parallel to the Philippine Trench on the eastern coasts of Luzon covering the entire Bicol Peninsula, Samar, Leyte and thence through the western foothills of Diwata Range. This belt defines several major onshore volcanic belts which host the biggest geothermal developments in Philippines - The Tiwi and BacMan Fields in Southern Luzon and a number of fields in Leyte, including Tongonan.

Other geothermal prospects found along this belt include Mts. Labo, Caayunan, Isarog and Bulusan in Bicol peninsula; Biliran, Alto Peak, Mahanagdong, Anonang, Bato Lunas, Mt. Cabalian, in Leyte; Mainit and Placer in Surigao del Norte; and Manat Amacan in North Davao.

4.1.3 Negros Belt - Sulu Belt

The Negros trench to the west of Negros Island defines a volcanic belt which ranges from mature and dissected volcanic complex of Cuernos de Negros in Southern Negros, where the Palinpinon Field in the south is located and Mt. Canlaon in the north is undergoing development activities. This relatively short volcanic arc extends to northwest Mindanao. The arc is probably related to eastward subduction of the South China Sea Plate along the Negros Trench (Sussman, et. al. 1993).

The arc lies parallel to major trenches: the Negros, Sulu Sea and Cotabato Trenches. This indicates a causative relationship between magmatic activities along the belts with tectonic activities along the trench.

Geothermal fields along these belts include Mambucal and Mandalagan-Silay in Negros Occidental; Mts. Malindang-Ampiro in Misamis Occidental, and Lakewood in Zamboanga del Sur.

4.1.4 Central Mindanao Belt - Cotabato Belt

In Mindanao, there are several trench and subduction zone systems. The most significant of these is an extension of the Sangihe volcanic arc from Indonesia northward into Central Mindanao. Volcanic activity on this arc has given rise to the Mt. Apo volcanic complex where PNOC-EDC is developing the Mindanao Geothermal Field. This volcanic arc occurs in Southeast and Central Mindanao. This area is the northernmost collision zone between two facing island arc systems. There are three (3) identified quaternary volcanoes and a few plug domes along the Pacific Cordillera, a mountain belt along the eastern coast of the island. This mountain belt is composed of Tertiary volcanic and plutonic rocks.

These areas show no obvious relationship with the trenches. The Mindanao Central Cordillera Belt can, however be related to a possible suture trench along the Agusan-Davao Trough. It is also interesting to note the unique occurrences of flood basalt in the Lanao Highlands in contrast with strato-volcanic structures prevalent in other volcanic belts.

Prospects found in this belt include Mambajao, Camiguin; Balingasag, Misamis Oriental; Mts. Kitanglad-Kalatungan, Bukidnon; Datu Odin Sinsuat and Tuayan-Maganoy, Maguindanao; Mts.Parker-Matutum, South Cotabato; and Digos and Balut Island, Davao del Sur.

4.2 Along Major Structures and other structures (Datuin & Troncales, 1986; Malapitan & Reyes, 1997)

A number of potential geothermal fields are concentrated along the easterly convex volcanic front where it traverses the eastern block of the Philippines Master Fault. This continuos transcurrent movement in the master fault generated intense volcanic activity in the Late Tertiary and throughout the Quaternary. This activity could have induced the extensive crustal fracturing and high heat flow required for the development of the geothermal resources in this region.

Based on concepts of tectonics, however, there is strong affinity between volcanism and tectonism as volcanic chains form due to melting of the crust at the base of subduction zones. This explains why the distribution/clustering of significant geothermal areas follows the trend/route of the Philippine Fault and parallels the trenches responsible in the configuration of the Philippine islands.

It is evident that continued activity along the Philippine Fault system has exerted considerable shattering of host rocks which induced voluminous quaternary andesitic volcanism and helped in the development of secondary permeability - a requirement for the existence of geothermal field. In 1979, ElectroConsult of Italy suggested that other dormant volcanoes in solfataric stage of unknown affinity occur in Mindanao and Jolo islands, these dormant and active volcanic chains are largely controlled by the horsetailing of the N-NW trending Philippine Fault and its subsidiary.

Some of identified prospects related to these zones include Rosario, Northern Samar; Calbayog, Samar; San Nemesio, Catmon, and Asturias, Cebu; Hamtik and Anini-y, Antique; Santiago, Agusan Del Norte; Rosario, Bunawan, San Francisco, Prosperidad, Sibagat in Agusan Del Sur; Sapad-Salvador, Lanao Del Norte; Tagburos-Iwahig, Narra-Labog, Española in Palawan, and; Leon Postigo, Zamboanga Del Norte.

4.3 Along Plutonic Occurrences

Intra-Miocene quartz diorite bodies commonly occur in all parts of the country either as large-to-medium sized batholiths or as stock forms. The majority of these diorite plutons could have multiple stages of intrusions as evidenced by the nesting and clustering of diorite stocks and widespread distribution of their effusive Plio-Quaternary volcanic equivalents.

The distribution of Neogene dioritic/granitic intrusives is confined to the main Philippine Arc. On the basis of proximity and similarity in trend, Balce (1976) divided the intrusives into the following belts: Luzon Central Cordillera, Marinduque, Tablas, Eastern Mindanao, Mindanao Central Cordillera, Cotabato, Zamboanga and Eastern Bohol. The Neogene dioritic/granitic intrusives are confined mainly in Central Cordillera. The belt defined by those intrusives in Central Cordillera can be extended to cover the occasional occurrence of Neogene quartz diorite in Southern Sierra Madre.

The Miocene diorites in Marinduque and Batangas comprise the NW-SE Marinduque Belt. Immediately south is the N-S trending Tablas Belt which runs from Antique Range and if extended further north from Tablas, would connect with the Marinduque Belt.

The Neogene dioritic/granitic intrusive masses in the Paracale District, Camarines Norte and Samar are considered to be contagious with the Eastern Mindanao Belt. After the widespread Neogene diorites in Surigao and Davao, the Mindanao Central Cordillera is widely intruded by Neogene diorite; the diorites are generally aligned along the axes of the Cordillera forming the Mindanao Central Cordillera Belt. This belt is roughly parallel to the eastern Mindanao and the Cotabato Belts. The trend is NW-Se until it reaches Misamis Oriental where it bends to NE-SW to include the Neogene diorite masses in the area. The NE-SW trend of Zamboanga and Bohol Belts are in contrast to the NW-SE trends of the other Neogene diorite belts in Visayas and Mindanao.

Geothermal prospects related to Paleogene diorite/granitic intrusives include Dipaculao and Casiguran in Aurora, and; Maayon, Capiz. Geothermal prospects related to Neogene diorite/granitic intrusives include Boliney-Salapaddan, Pilar-Danglas and Tubo-Bucloc in Abra; Acupan, Daklan, Tublay and Buguias in Benguet; Agoo, La Union; Cabarroguis, Quirino; Naga-Carcar, Cebu; San Miguel, Surigao Del Sur.

5. GEOTHERMAL RESERVES AND RESOURCES

The DOE has calculated some 2,047 MW of proven reserves, 590 MW of probable reserves and 1,900 MW of possible reserves (Table 2). The reserves were classified based on the depth of study of the area and the economic and technical viability of the prospects. The proven reserves were calculated to be economically recoverable with the present available technology and economic conditions. They were identified by delineation/development drilling and integrated geoscientific surveys. The possible reserves were estimated based on data gathered from integrated geoscientific surveys consisting of geophysical, geological and geochemical surveys. The classification of the possible reserves may improve should drilling be conducted in the areas for in-depth exploration and assessment.

The remaining geothermal resources were classified as hypothetical and speculative resources. The hypothetical resources were geothermal prospects subjected to geological and geochemical surveys while speculative geothermal resources are unverified suspected thermal areas. There are about thirty-five (35) prospects categorized as hypothetical geothermal resources and these are the same areas that DOE needs to cover/promote for further exploration. For DOE to be able to at least conduct geophysical surveys in these areas would mean reduced risks for probable investors in geothermal development. Speculative geothermal resources normally are suspected within areas closed for mining i.e. national parks, protected areas, and in areas situated within tribal domains where modernization and development are not welcome.

6. CONCLUDING REMARKS

The collision of Philippine Plate and Eurasian Plates have given rise to deep trenches, faults, volcanoes, plutons and similar geological and structural features common in an island arc system. These features are essential components in the development of geothermal resources nationwide. Producing geothermal fields in the Philippines are mostly located or seated in major volcanic centers or belts (i.e. MakBan at Central Luzon Volcanic Belt, and BacMan, Tiwi and Tongonan along the Bicol-Mindanao Central Cordillera Volcanic Belt). A.G. Reyes (1990) shares this observation stating geothermal systems in the Philippines are associated with Quaternary to Recent volcanism with dense faulting.

An inventory/study of these geothermal resources resulted to estimates of 4537MW of geothermal potential ready for direct and indirect utilization. And still, more prospects await detailed study.

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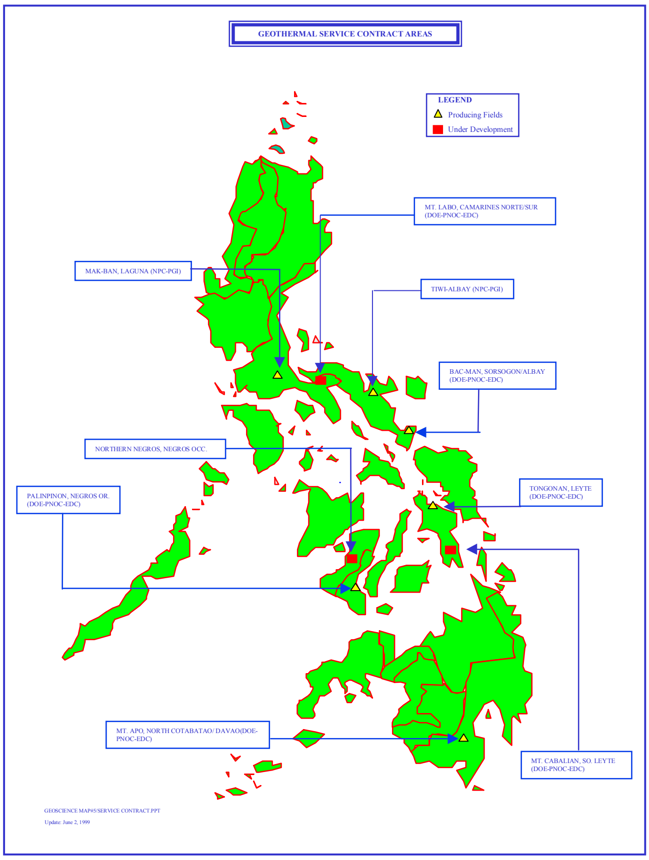

Figure 1: Philippine Geothermal Service Contract Areas

Table 1: Producing Geothermal Fields of the Philippines

Field	Operator	Installed Capacity (Mwe)	Status
1. MakBan,	PGI/NPC	425.73	Producing
2. Tiwi, Albay	PGI/NPC	330	Producing
3. Bacman	PNOC-EDC/NPC	151.50	Producing
4. Palinpinon	PNOC-EDC/NPC	194	Producing
5. Tongonan	PNOC-EDC/NPC; PNOC-EDC/CAL ENERGY	707.75	Producing
6. Mindanao	PNOC-EDC/Oxbow-Marubeni	100.25	Producing
7. Mt. Labo	PNOC-EDC		Under development
8. Northern Negros	PNOC-EDC		Under Development
9. Mt. Cabalian	PNOC-EDC		Under Development

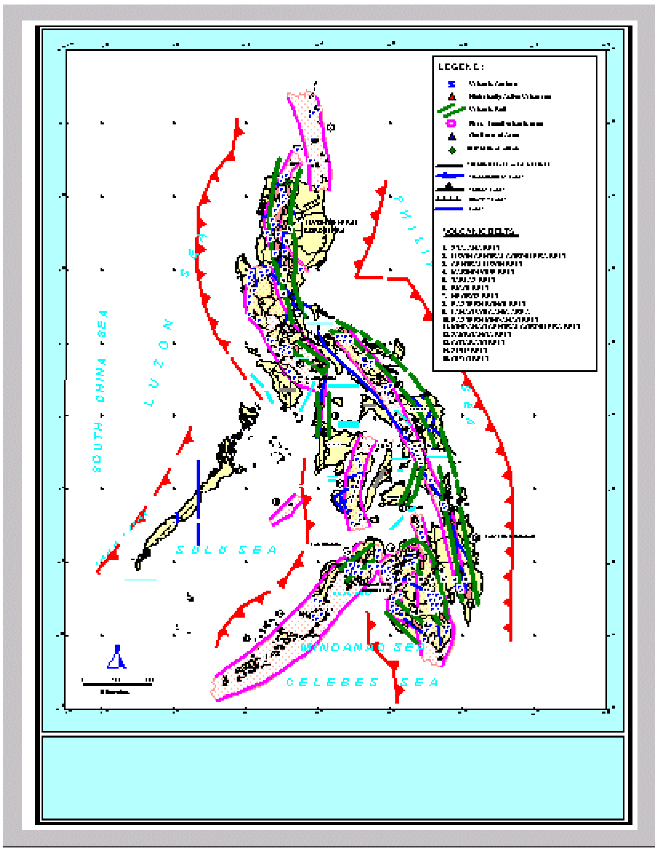

Figure 2: Structural Frameworks of the Philippines

Table 2: Summary of Philippine Geothermal Reserves

TYPES OF RESERVES	AREA	TOTAL
PROVEN RESERVES (Total Mwe) 2047.02	Bacman, Albay Sorsogon	202.90
	Del Gallego (Mt. Labo)	10.90
	Bulalo, Laguna	367.42
	Maibarara	30.00
	Tiwi, Albay	284.40
	Tongonan, Leyte	807.90
	Mambucal	8.00
	Palinpinon	234.00
	Mt. Apo, Davao/N. Cotabato	101.50
PROBABLE RESERVES (Total Mwe) 590.00	Acupan-Itogon	10.00
	Daklan, Benguet	30.00
	Bacman, Albay/Sorsogon	60.00
	Del Gallego (Mt. Labo)	65.00
	Mt. Cagua, Cagayan	25.00
	Mt. Natib, Bataan	15.00
	Biliran, Leyte	25.00
	Alto Peak, Leyte	60.00
	Mahagnao, Leyte	30.00
	Mt. Cabalian (Anahawan), Leyte	20.00
	Mambucal, Northern Occidental	50.00
	Baslay-Dauin, Negros Oriental	30.00
	Lagunao, Negros Oriental	60.00
	Manat-Amacan, Davao del Norte	60.00
	Mt. Apo, Davao/North Cotabato	50.00
POSSIBLE RESERVES (Total Mwe) 1900.00	Acupan-Itogon	10.00
	Buguias-Tinoc, Benguet/Ifugao	190.00
	Daklan, Benguet	30.00
	Batong-Buhay, Kalinga	200.00
	Del Gallego (Mt. Labo)	65.00
	Mabini, Batangas	40.00
	Mainit-Sadanga, Mt. Province	120.00
	Montelago, Oriental Mindoro	40.00
	Mt. Bulusan, Sorsogon	150.00
	Mt. Cagua, Cagayan	135.000
	Mt. Isarog, Camarines Sur	60.00
	Mt. Natib, Bataan	185.00
	Biliran, Leyte	15.00
	Anonang, Leyte	15.00
	Mahagnao, Leyte	40.00
	Mt. Cabalian (Anahawan), Leyte	40.00
	Bato-Lunas, Leyte	65.00
	Mambucal, Negros Occidental	50.00
	Mts. Mandalagan-Silay, Negros Occ.	120.00
	Mt. Malindang, Misamis Occ.	40.00
	Lakewood , Zamboanga Del Norte	115.00
	Mainit, Surigao Del Norte	55.0
	Manat-Amacan, Davao Del Norte	30.00
	Mt. Apo, Davao North Cotabato	30.00
	Mts. Matutum-Parker, South Cotabato	60.00