THE BULALO GEOTHERMAL RESERVOIR MAKILING-BANAHAO AREA, PHILIPPINES

Philip H. Messer and Val F. de las Alas
Philippine Geothermal, Inc.
P.O. Box 7336, Airport, Metro Manila, Philippines

The Bulalo field, located within the Makiling-Banahao geothermal prospect, is being explored and developed by Philippine Geothermal Incorporated (PGI), a branch of the Union Oil Company of California. During the past four years, twenty-eight wells have been drilled and completed in the Bulalo heat anomaly. These wells have defined a large geothermal reservoir characterized by a high-temperature effluent which can be spontaneously produced to generate commercial power.

An extensive flow testing program has resulted in the production of over thirteen billion pounds of reservoir effluent. After flashing the steam to atmospheric conditions, nearly seven billion pounds of produced reservoir fluid have been reinjected into the Bulalo reservoir. In spite of the large quantity of reservoir effluent that has been produced and reinjected, insufficient testing has been conducted to determine the total commercial power generating capacity of this large liquid-dominated reservoir.

The preliminary estimate of generating capacity has led to the current installation of 220 MW. Field development for the installation of four 55 MW units is in progress. The initial 55 MW unit is scheduled for operation in July, 1979, with Unit 2 to operate in the fourth quarter of 1979. Continued drilling and production testing up to the initiation of commercial operation will afford periodic reserve updating and confirmation for additional power- generating units. After commercial power generation commences, data will be available to establish a more reliable estimate of the Bulalo field potential.

INTRODUCTION

As a result: of the increasing worldwide energy crisis, the economic harnessing of alternate energy sources has become more attractive. Of particular interest in the Philippines is the development of gcothermal energy which has been encouraged because of its relatively large potential. Several geothermal areas have been appraised and recognized by the Philippine government as having potential €or power generation. One such area, the Makiling-Banahao region, has been contracted to PGI for further exploration and subsequent devc1opment.

The Bulalo geothermal anomaly is one field within the Makiling-Banahao area that has been discovered and is being developed by PGI. During the past four years, twenty-eight wells have been drilled and completed in the Bulalo heat anomaly. These wells have defined a large, liquid-dominated geothermal reservoir characterized by a high-temperature effluent which can be produced to generate commercial power.

PGI has developed an active drilling and exploration program which has investigated approximately 7.3 square kilometers (1800 acres) of the Bulalo field prospect. Continual expansion of this exploration acreage is augmented by the drilling and completion of an additional well nearly every month. A comprehensive well testing program has been developed to understand and define the geothermal reservoir characteristics. However, the ultimate productive capacity and extent of the Bulalo anomaly will only be determined by future drilling and long-term production. This report describes what is currently known about the Bulalo field within the Makiling-Banahao area.

GEOLOGY

The Makiling-Banahao contract area, as shown in Figure 1, is located in the Laguna province southeast of Manila, below the Laguna de Bay. The area is characterized by surface hot springs most prevalent near the town of Los Baños at the northern base of the Makiling volcano. Spas and thermal baths are popular in this area. Other hot springs and geothermal surface manifestations are widely spread between the Makiling and Banahao volcanoes in an area of several hundred square kilometers.

The Bulalo field is located to the south of the Makiling volcano. The prospect is currently the southernmost geothermal anomaly that is being actively developed by PGI within the Makiling-Banahao contract area. The Bulalo field is located approximately sixty kilometers southeast of Manila as shown in Figure 1. The area lies between the Banahao and Makiling volcanoes and is, in general, characterized by tuffs, lahars and lava flows of the basaltic-andesite type. The Makiling volcanics are older and are overlain in areas by the Banahao volvanics leading to difficulty in accurately defining the stratigraphy.

The drilling and production testing programs have defined the subsurface Bulalo structure as a large heat anomaly principally composed of a fractured andesite formation in the north and central portions, and a fractured tuff to the southeast. The fracture system within the reservoir is believed to be controlled by major faulting, oriented according to the main north-south regional trend, with transverse faulting trending in the east-northeast direction.

SUYMARY OF DRILLING OPERATIONS

Twenty-eight wells have been completed in the Bulalo field by PGI since January, 1975. These completions comprise the total Bulalo field exposure to date., The wells have been drilled on a 0.26 square kilometer (65 acre) pattern, in general, with approximately 7.3 square kilometers (1800 acres) of total reservoir exposed to date. The degree of infill drilling over the economic project life will be dependent upon a more accurate assessment of the reservoir. Each completion is composed of a seven-inch perforated liner suspended in a 9-5/8-inch cemented casing. Total depths range from nearly 3,000 feet for completions located in the central portion of the field, to over 9,000 feet in the flank completions. Wellbore exposures reflect the commercial temperature gradients and productive intervals encountered in each completion.

Cooling of the geothermal formation results from the circulation of the mud fluids during drilling. Normally, several months of a static wellbore condition must follow the drilling and completion phases of a well to adequately define the static bottomhole temperature profile. Maximum static bottomhole temperatures range from 520°F to 655°F. Individual well production is a result of the fluids associated with the most permeable zones exposed to the wellbore, which may not be of maximum exposed temperature.

SUMMARY OF WELL TESTS

Production testing has been regarded. as an important phase in the assessment of the Bulalo reservoir. Surface production equipment has been constructed to afford a variety of flow testing conditions to characterize each completion. During each test the well is generally produced at commercial operating conditions for sufficient flow periods to define the stable flow characteristics of each well.

Most of the Bulalo completions have been subjected to several flow tests; however, three flank completions were initially assessed as having marginal productive capacity and were converted to injectors. The produced fluid in the Bulalo field has always been reinjected into the reservoir. This produced effluent has been flashed to atmospheric conditions and subsequently reinjected.

RESERVOIR ASSESSMENT

The twenty-eight completions in the Bulalo field have defined two types of geothermal formations. The northern and central completions have defined a highly productive andesite formation, with an apparently well-defined fracture network of

good permeability and commercial temperature. The southeastern completions have exposed a fractured tuff formation of high temperature and lower flow capacity. Both formations are believed to have similar fluid-in-place characteristics and the reserve potential is comparable for both types of formation.

Productivity Characteristics The production testing program has defined the stable total mass flow rates at a commercial operating pressure of 140 psia. Production at this pressure is a mixture of steam and water, the relative proportions depending primarily upon the reservoir fluid enthalpy. Commercial total mass flow rates for the Bulalo field vary from 130,000 lbs/hr to 833,000 lbs/hr. Commercial steam rates for individual completions range from 50,000 lbs/hr to over 275,000 lbs/hr.

Individual steam rates have been found to vary moderately within a controlled range of economic pressure conditions. The first 110 MW plant, composed of Units 1 & 2, will require 2.1 million lbs/hr of steam. Nineteen producers have been allocated to supply the required steam for Units 1 & 2 operation.

Injectivity Characteristics. The produced water from all the flow testing has been reinjected into the reservoir. No measurable injectivity loss or static reservoir pressure alteration has been detected. Although the temperature of the reinjection fluid to date has been 135°F, commercial operation will involve the disposal of produced fluid at 325°F. The reinjection of fluid at the elevated temperature will have the benefit of reducing any long-term damage phenomena; and less fluid heat-up will be required prior to any subsequent production of the reinjected fluid, if such occurs.

The steam production requirements for Units 1 & 2 will lead to a reinjected demand of 6.0 million lbs/hr of produced fluid. Five injection wells are currently planned to dispose of the 3.0 million lbs/hr of produced fluids associated with Unit 1. Additional injection capacity will be required for commercial operation of subsequent units.

Long-Term Production Test. A long-term production test involving the production of four wells and reinjection into one well has just been completed. The production for over six months demonstrated the very stable flowing conditions of the Bulalo completions. Sensitive reservoir pressure recording instruments were located in three idle wells surrounding the producers. Pressure data monitored in esch observation well indicated a pressure response resulting from the production test. Analyses of this pressure interference test are ongoing.

Reservoir Definition. Along with the extensive production testing, a comprehensive reservoir engineering program has been developed to define the productive formation characteristics. Pressure response data following the majority flow tests have been monitored and the analyses of the results have indicated a definite trend. The central completions, which are generally the shallower wells, behave as a radial flow system with high flow capacity.

The deeper flank completions are generally dominated by vertical fracture behavior with less flow capacity. These results have led to the current feeling that the central reservoir portion is composed of a fractured matrix with well-defined horizontal and vertical fracture exposure. The deeper flank completions are believed to expose primarily a vertically fracture-dominated system. Pressure buildup analysis has indicated that these flank completions expose vertical fractures ranging from 25 to 175 feet in fracture half-length.

Chemical analyses of the produced fluids have defined a reservoir brine characterized by 2330 ppm chlorides, 16 ppm calcium, 385 ppm potassium, and 615 ppm silica with pH of 6.6.

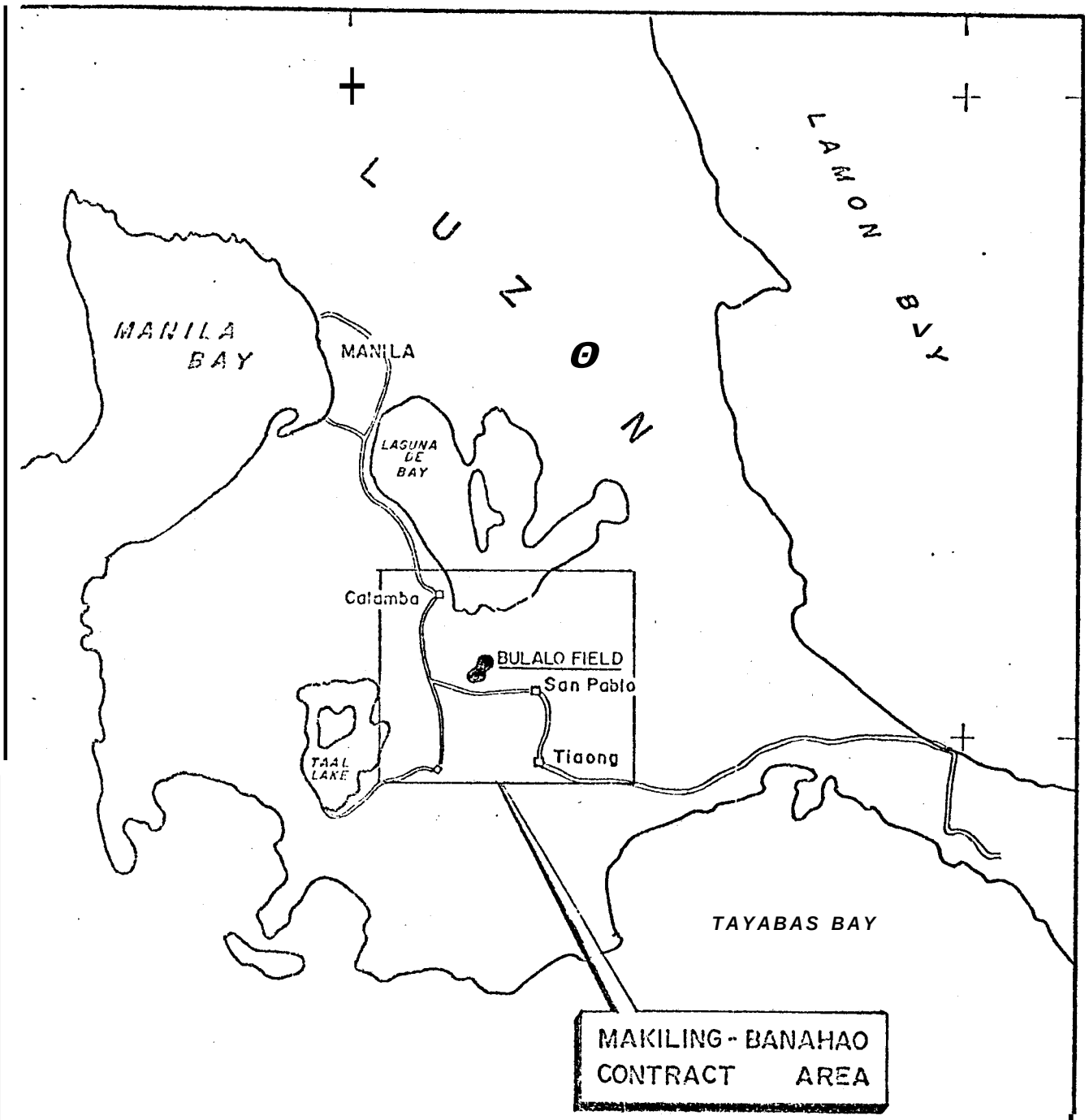

FIGURE 1

PHILIPPINE GEOTHERMAL, INC.

INDEX MAP

MAKILING - BANAHAO

CONTRACT AREA

0 10 20 30 40 50 KMS.

SCALE 1:1,000,000