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PRELIMINARY ASSESSMENT OF THE GEOLOGY AND RESERVOIR CHARACTERISTICS OF THE GEOTHERMAL FIELD ON NISYROS ISLAND, GREECE

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ABSTRACT

Nisyros Island, a member of the Dodecanese group of islands in Greece, is part of the active Aegean volcanic arc which extends from Methana (on the west) to Nisyros (on the east). McKenzie[1] described the active tectonics of the Mediterranean region. The volcanic rocks of the Aegean appear on Figure 1.

Drilling of the Nisyros 1 exploratory well, all funded by the European Economic Community, confirmed the economic geothermal potential of this island. The well, drilled at 1816 m, encountered a 350°C geothermal reservoir, which produced 13 tons/hr of two-phase fluid (about 80% vapor).

This paper describes the geology, the drilling, the geochemistry, and the well testing results of Nisyros 1 and attempts to draw conclusions on the geothermal potential of the island. This paper is a summary of internal reports within the Public Power Corporation in Greece. Most of the data were gathered by Geotermica Italiana, who acted as the main contractors for the project.

INTRODUCTION

Nisyros 1, an exploratory geothermal well, was drilled on Nisyros Island during the summer of 1982.

The well, drilled at 1816 m, encountered four distinguishable main strata, of which the bottom (between 1400 m and TD), consisting of metamorphic and igneous rocks, produced high temperature, high enthalpy fluid that is considered to be commercially exploitable.

The well was drilled in the caldera of the Nisyros Volcano, which is of late Quaternary age and displays the calc-alkaline affinity typical of island arcs. The summit of the volcano has experienced caldera collapse along with several periods of dome building.

Geologic evidence suggests that a high temperature source (magma chamber) is located at relatively shallow depth, and that fluid circulation has taken place. First, phreatic craters (which are formed by the explosive interaction of hot magma and cool surface water) on the caldera floor suggest the existence of abnormally high subsurface temperatures and a shallow geothermal aquifer. Second, geochemical data from fumaroles and hot springs within the caldera indicate reservoir temperatures of 200°C to 225°C. Third, petrographic analysis and xenoliths in the volcanic rocks demonstrate the typical sequence of hydrothermal aureoles (argillitic-phyllitic-propylitic), which usually indicates the circulation of fluids over 100° C.

DRILLING RESULTS

The well was drilled with four different diameter drill bits. Table 1 lists the bit diameters, and the drilling fluids used.

Table 1

DRILLING SUMMARY FOR NISYROS 1

Interval	Bit Diameter	Drilling Fluid
0-151 m.	24"	Bentonite Mud
151-418 m.	17-1/2"	Bentonite Mud
418-799 m.	12-1/4"	Seawater/Mud Pillows
799-1350 m.	12-1/4"	Bentonite Mud
1350-1816 m.	8-1/2	Seawater/Mud Pillows

Drilling revealed four distinct strata. Of these, two are impermeable and two permeable. The latter are capable of producing geothermal fluids.

1. 0 to 400 m: Impermeable layer of altered volcanic rocks. Temperature gradients within this layer are 35°C/100 m. This formation represents the Argillitic zone of hydrothermal alteration, with clay mineral assemblages indicating that temperatures are below the 120 to 150°C range.

2. 400 to 700 m: A permeable layer containing fluid. The formation consists of altered (hydrothermalized) lavas, breccias and tuffs which range in composition from basic andesite to dacite. This represents the Phyllitic zone, with abundant chlorite and lesser amounts of quartz, sericite, pyrite and carbonates. This mineral assemblage is characteristic of temperatures between 150 to 200°C. High permeability was evident by the frequent loss of circulation of the drilling fluid (sea water).

3. 700 to 1400 m: Impermeable sequence of limestone and marble. Temperatures rapidly increased to over 300°C right at 1400 m.

4. 1400 to TD? A thick productive section of epidote, adularia, albite, tremolite and pyrrhotite. This assemblage is indicative of the Propylitic zone; which develops only with high temperatures (230 to 400°C). A temperature of 317°C was recorded at 1400 m while a temperature of 349°C was recorded at 1550 m.

The lithologies encountered suggest a reservoir model characterized by two productive zones of high temperature, high enthalpy fluid. Between 1400 m and 1550 m, there is a reservoir with a temperature approaching 350°C. An even hotter reservoir is located below the 1600 m level. However, due to well damage it was impossible to record its temperature.

GEOCHEMISTRY

The upper hot reservoir (1400-1550 m) shows "reverse" chemical composition, in that it is enriched in boric acid and ammonia and depleted in Na, Cl and Li. The presence of mineral assemblages different from those for which the widely used alkali geothermometers (Na/K, Ca/K and Ca/Na) have been calibrated, precluded their use as temperature indicators. Silica geothermometers could not be utilized due to silica precipitation. The enthalpy of this reservoir (560 kcal/kg) indicates two-phase, in-situ conditions.

The deeper reservoir (below 1600 m) is believed to be a hot water system with few noncondensable gases.

WELL TESTING

While no transient pressure analysis tests were run, four flow tests were undertaken. The first test, conducted for approximately six hours, deposited an extremely large quantity of sodium, calcium, and iron chlorides and iron sulfide completely plugging and obstructing the open air separator. During this test high wellhead temperatures (>400°C) and wellhead pressures (41 bars) were observed. Casing collapsed reducing the useful depth of the well to 1745 m.

During the second test, the well produced unaided with stabilized wellhead conditions of 240°C and 15 bars. Few solids were deposited on the surface during this test, although a solid plug was formed at about 540 m, killing the well. Again, damage occurred at the bottom of the well reducing its effective depth to 1640 m.

Following a time interval of one month, a third test was conducted. An hour of air lift was needed to start the well which produced for 36 hours. The bottom hole was again damaged due to plugging reducing the TD to 1570 m.

A fourth test, fully monitored, was conducted between November 28 and December 3, 1982. A 22 hour air lift was needed to start it up. The well then flowed for 96 hours. Again, bottom hole damage reduced to TD to 1534 m. Using the Russell James Method the well productivity was obtained. Table 2 contains the results using a 2 inch and 3 inch lip.

Table 2

NISYROS 1 PRODUCTIVITY DATA
FLOW TEST #4

	Lip 2"	Lip 3"
Wellhead Presure, p_{tf} (bars)	9.6	4.7
Critical Presure, p_c (bars)	3.85	1.25
Wellhead Temperature, T_{tf} (°C)	185	160
Liquid Flow Rate, W_ℓ (t/h)	2.2	1.6
Vapor Flow Rate, W^v (t/h)	10.1	10.9
Total Flow Rate, W^v (t/h)	11.7	12.2
Steam Quality, x	.86	.86
Specific enthalpy, h (kcal/kg)	564	564
Weight % of Noncondensable Gas (in vapor)	1.7	1.6

CONCLUSIONS

The Nisyros 1 well drilled in the caldera of the Nisyros Volcano has confirmed the existence of a productive zone (below 1400 m) of high temperature, high enthalpy geothermal fluid.

This fluid contained phenomenally large quantities of suspended solids that hindered flow tests and plugged the well. Different completions are indicated in future wells, such as open hole completions.

The Nisyros 1 well has exhibited problems of restarting apparently due to fines deposition and the condensation and cooling of fluids in the wellbore.

REFERENCES

[1] McKenzie, D.P.: "Active Tectonics of the Mediterranean Region: R. Astron. Soc., Geophys. J., v. 30, no. 2, p. 105-185, 1972.

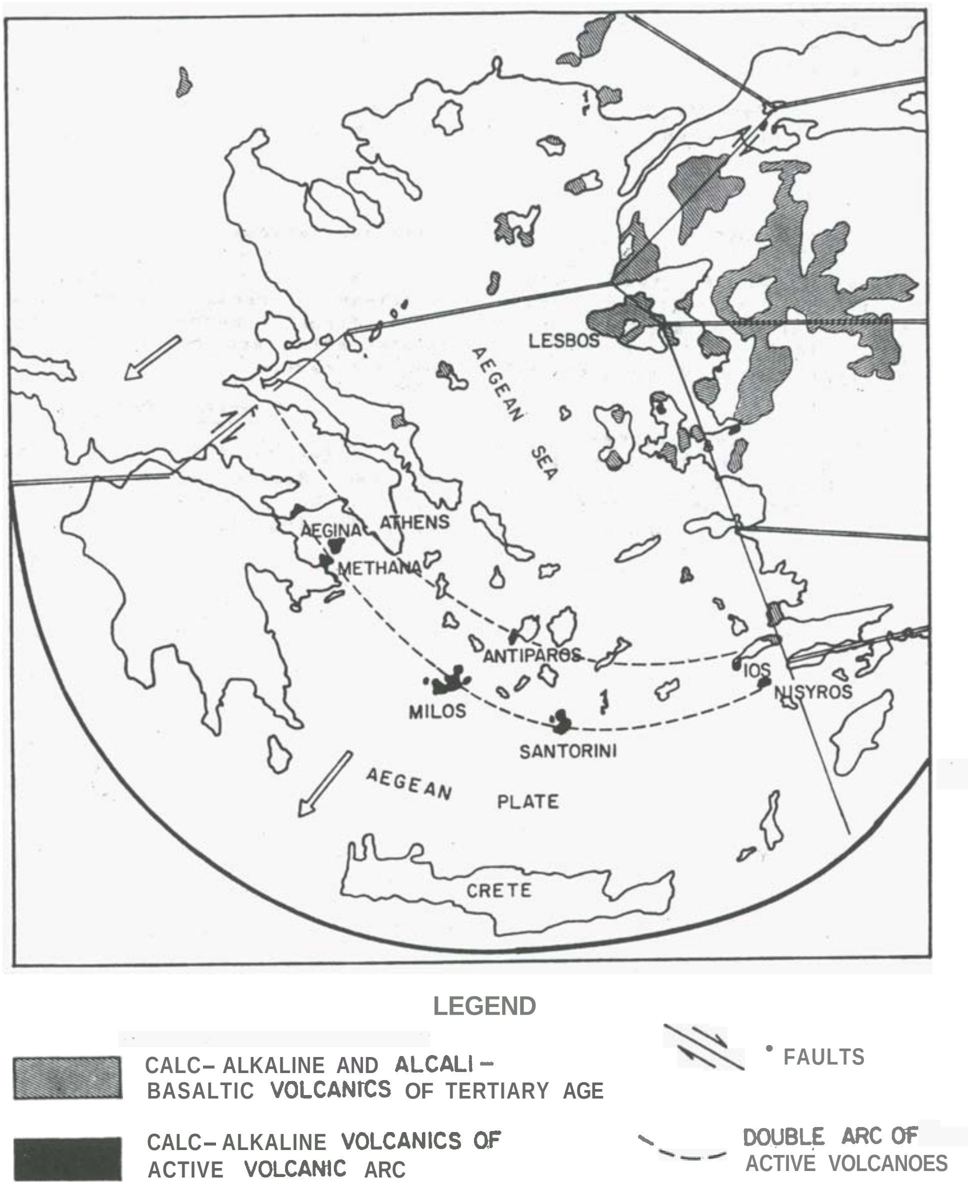

Figure 1. Distribution of Volcanic Rocks of Tertiary and Quaternary Age in the Aegean Region.