EXPLORATION OF THE OKOY GEOTHERMAL FIELD, NEGROS, PHILIPPINES

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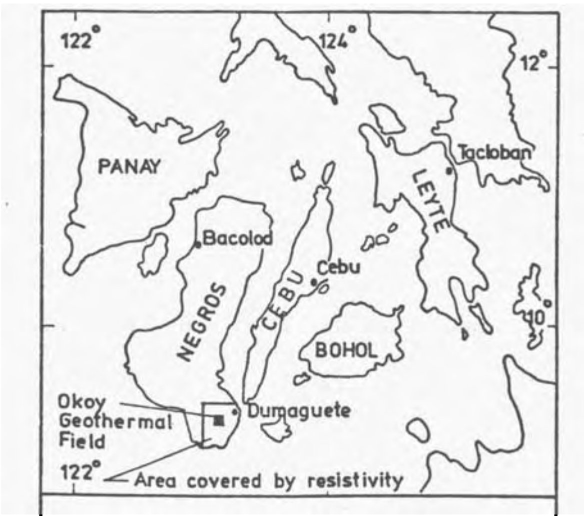
ABSTRACT

Resistivity surveying using the Schlumberger method has covered an area of approximately 800 km^2 in the southern part of the island of Negros. The results indicated a possible subsurface flow of hot water in the Okoy valley. The regional geological setting and geochemistry of surface spring waters gave credence to this interpretation which was then confirmed by drilling. Further exploratory drilling has shown this resource to be hydrologically complex.

INTRODUCTION

Figure 1 shows the project area in relation to the Visayas region of the Philippines. The area is characterised by a coastal plain which rises to the volcanic peak of Cuernos de Negros, more than 1600 m above sea level. This high country is heavily forested and ground slopes of up to 45° may be encountered.



PROJECT LOCATION MAP
SCALE 0 50 100 km
FIGURE 1

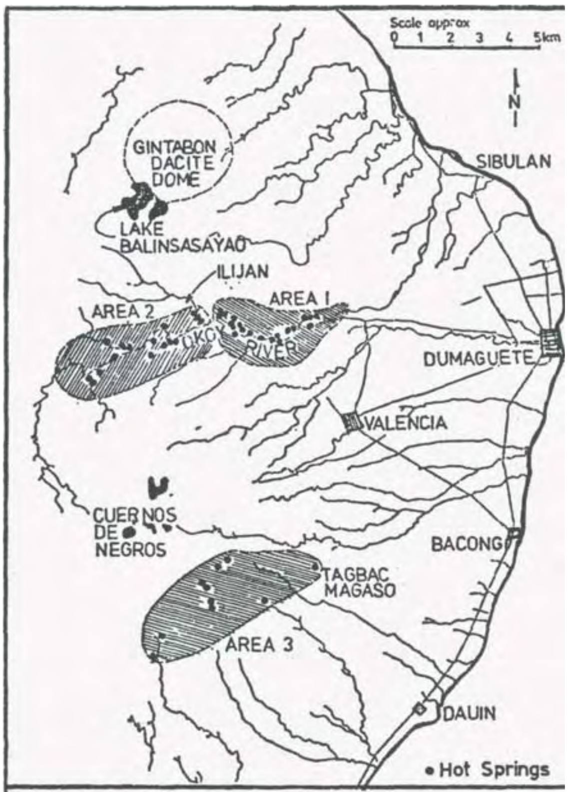
Interest in Southern Negros as a geothermal prospect was first aroused by the presence of hot springs and other thermal manifestations in the Okoy Valley, Valencia, and at Tagbac-Magaso, Dauin. Sampling by Philippine Commission on Volcanology scientists indicated high chloride waters in this area and suggested a need for further investigation. Smith & Grindley visited Southern Negros in June 1973 and subsequently recommended a programme of geological investigation, geochemical sampling, and resistivity survey.

SURFACE INVESTIGATIONS

The oldest exposed rocks are volcanic sediments of Miocene to Pliocene age, classified as Southern Negros Formation. (S.N.F.). These rocks are unconformably overlain by volcanics of andesite to dacite composition, thought to be Pliocene to Pleistocene and derived from the Balinsasayao volcanic centre to the north and the Cuernos de Negros centre to the south,

During the surface investigations it was noticed that hydrothermal alteration was limited essentially to exposures of S.N.F. rocks. Alteration assemblages of chlorite and clay were observed in the lower Okoy valley (fig. 2). These were considered to have resulted from near neutral, carbonate saturated waters at temperatures up to 230°C. To the west, a kaolinite, pyrite/marcasite assemblage indicated acid alteration. This assemblage is thought to have resulted from the action of H_2S present in steam that had separated from deep geothermal water. Massive silicification of the S.N.F. was noted along the western reaches of the Okoy River within the area later investigated by drilling,

Two distinct spring chemistries were evident within the Okoy River area. Neutral, high chloride springs (1500 to 3000 mgℓ^{-1} chloride) occur at moderate elevations where the S.N.F. is exposed. (area 1, fig. 2). To the west, (area 2) at higher elevations, there is an abrupt change in spring composition to neutral or slightly alkaline, low chloride, high sulphate water. An exception is the Ilijan spring (Table 1). The composition of the Malaunay and Lagunao springs suggested that they discharge steam heated meteoric waters. They were also thought to be considerably displaced from the point at which steam first separates.



PROSPECT AREA FIGURE.2

The springs to the south in area 3, figure 2 were shown by isotope analysis and silica geothermometry to be composed mainly of meteoric water. Representative results for each area are given in Table 1.

Table 1: Spring Chemistry

LOCATION	SPRING	°C	pH	Li	Na	K	Rb	Ca	Mg	Cl	SO_4	B	SiO_2	CO_2	HCO_3	NH_3
AREA 1	Palinpinon	98	7.85	8.3	2090	195	1.38	176	0.26	3646	63	40.7	195	3	22	5.2
	Cambucal	92.5	7.87	7.91	1887	167	1.28	175	5.5	3500	64	40.4	175	2	58	13
AREA 2	Malaunay	49	7.87	0.02	41	4.5	0.03	390	23	2.1	778	0.04	75	10	216	0.08
	Lagunao	53	8.14	0.02	30	4.8	0.02	425	25	1.7	840	0.04	44	3	147	0.06
	Ilijan	39.5	2.83	0.05	14.5	2.6	0.02	60	7.1	0.3	480	0.13	85	-	-	0.3
AREA 3	Lipayo R.	61	2.6	0.07	85	22.5	0.10	150	53	382	600	2.73	220	-	-	0.06
	Basley 1	58	2.05	0.05	112	37	0.13	120	35	780	2090	5.3	202	-	-	0.46
	Nagpantaw 1	34.5	3.45	0.02	27.3	3.6	0.02	345	28	41	784	0.38	92	-	-	0.10
	Nagpantaw 2	43	3.73	0.02	45	4.6	0.03	530	44	110	1230	0.84	‘60	-	-	0.10

All concentrations in mg ℓ^{-1}

Between 1975 and 1978 an extensive d.c. resistivity survey was conducted using a Schlumberger configuration with current electrode half spacings (AB/2) of 250,500 and, in same areas 750 m. Approximately 1160 stations were read with some stations re-read to test the repeatability of the results.

A region of the relatively low apparent resistivities, 10 ohm metres and less, coincided with the thermally active area in the valley of the Okoy River (fig. 3). The apparent resistivity gradient is high to the south and moderately high to the north of the east-west trending anomaly. The lower gradient to the east was believed to reflect a subsurface flow of geothermal fluids toward the low lying coastal plain. To the west the anomaly bifurcates. One limb extends north toward a dacitic dome at Balinsasayao and the other south west toward Cuernos de Negros.

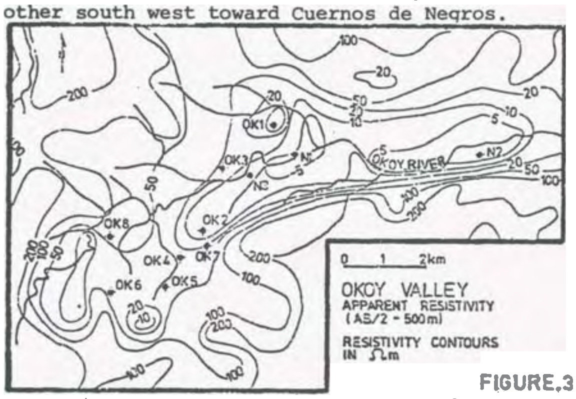


FIGURE.3

The concept formed from the results of these investigations was of a deep body of hot, high chloride water beneath the high country to the west with a subsurface flow of mineralised water to the Okoy valley.

SUBSURFACE INVESTIGATIONS

Two phases of drilling have been completed and a third is in progress.

In the first phase, wells Negros 1, 2 and 3 (N1, N2, N3) were drilled to moderate depths (less than 1000 m) within the Okoy River geophysical anomaly (fig. 3). Both N1 and N2 discharged a geothermal brine with chloride contents of 4397 mg ℓ^{-1} and 4414 mg ℓ^{-1} respectively. The slightly increased chloride content of the well discharge relative to that of the springs (3823 mg ℓ^{-1}) was considered to indicate that the well water originated at depth and had not mixed with near surface meteoric water. Chemical geothermometers indicated cooler conditions in N2 relative to N1 (183°C cf 201°C for SiO_2 and 193°C for Na/K/Ca). This was considered evidence for a subsurface flow from N1 toward N2.

Changes in the discharge chemistry indicated that calcite scaling would be a problem. This was later confirmed by a declining total mass flow in N1.

Well N3 was drilled to test conditions upstream of N1 but still within the area outlined by the 10 ohm metre resistivity closure. This well was drilled entirely within the Southern Negros Formation and has a maximum measured temperature of 234°C. Power potential is 4 MWe.

The results of the early drilling were considered sufficiently encouraging to warrant testing to greater depth. Between 1978 and 1979 wells Okoy 1 to Okoy 5 were drilled to depths ranging from 1164 m to 2130 m.

greater depth to search for better permeability.

Subsequent exploration drilling has been undertaken in the upper reaches of the Okoy River to depths in excess of 2500 m. Results have been encouraging and are given in Table 2. It is now known that the andesitic rocks of the S.N.F. are underlain by sequences of shale and sandstone with sane intercalation of igneous rocks. Difficulty encountered in maintaining circulation has limited the amount of geological information obtained from the deeper wells.

Physical downhole measurements suggest that the resource may be layered with permeable horizons occurring in intervals rather than there being a gross permeability throughout the depth drilled. All the permeable horizons are underpressured with respect to hydrostatic.

Table 2: Okoy Geothermal Field Well Results

WELL	N1	N2	N3	OK1	OK2	OK3	OK4	OK5	OK6	OK7	OK8
Surface Elevation (m)	300.7	132.2	417.5	587.9	704.4	468.0	827.3	932.2	1105.6	760.1	1004.0
Total Depth (m)	607.5	610.5	970.9	1978.1	1164.4	1521.8	2130.0	1975.2	2770.8	2882.8	2981.8
Mass Flow (Kg/s)	26	5	40		12			32	81	60	
Enthalpy (J/g)	855	415	1110		1400	-	-	2000	1300	1400	-
Depth Main Production Zone (m)	433 to 470		575		939 to 950	575 to 700	980 to 1065	1450 to 1700	2300 to 2700	2700 to 2882	
Maximum Temperature	203	170	234	190*	243	224	299*	310*	283	303	
Estimate Power Potential (MWe)			4		2			9.9	11	10	

Note: Mass flow and enthalpy figures are quoted for a wellhead pressure of 0.7 MPa.

* Temperature is measured before discharge. All other temperatures are after discharge.

Okoy 1 was drilled to test conditions below the north west trending limb of the geophysical anomaly. Results were disappointing and an abrupt temperature inversion below 730 m suggested the source of the hot springs to be a thin permeable horizon, which had been cased off. The well does not discharge.

Okoy 2 drilled within the south west trending arm of the resistivity anomaly penetrated andesitic rocks which had undergone hydrothermal alteration to a generally higher degree than those seen in previously drilled wells. The Occurrence of illite in the bottomhole core suggested temperatures of 230°C to 250°C, which was confirmed by measurement data (Table 2). Output tests indicated that permeability is poor within the interval drilled, It was concluded that economic temperatures existed but that future wells would need to be drilled to

Internal flows in the wells have resulted from a differential pressure between the permeable horizons and have created difficulties in initiating discharges. This problem has recently been overcome by the use of steam stimulation.

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