HYDROLOGY AND MODEL OF THE OKOY GEOTHERMAL FIELD, NEGROS ORIENTAL, REPUBLIC OF THE PHILIPPINES

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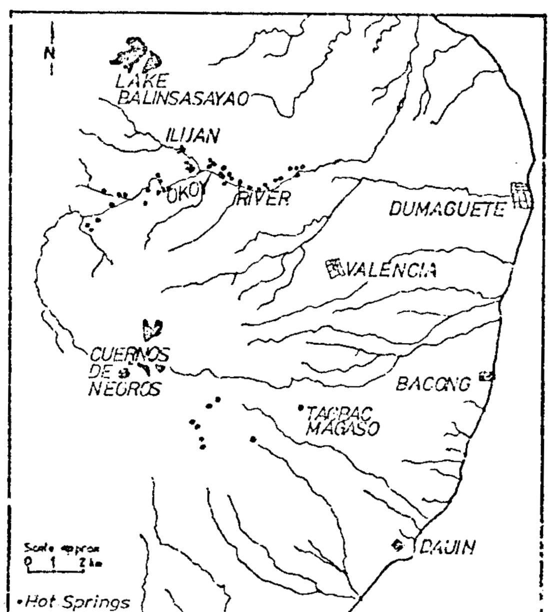
INTRODUCTION

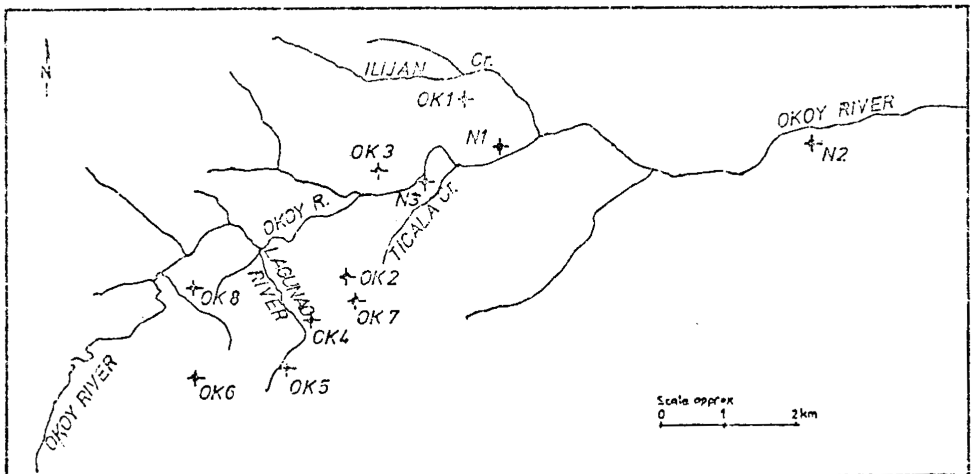
Ward (1980) described the exploration of the Okoy geothermal field. Resistivity surveying using Schlumberger traverses has covered an area of approximately 800 km^2 in the southern part of the Island of Negros. Hot springs and other thermal manifestations (Fig. 1) occur in the Okoy valley, Valencia and at Tabac Magaso, Dauin.



PROJECT LOCATION MAP Fig. 1

Initial shallow exploratory drilling indicated a possible sub-surface flow of hot water in the Okoy valley. Further deep exploratory drilling to the West has located two high temperature reservoirs.

Figure 2 shows the well locations within the Okoy geothermal field.



WELL LOCATIONS IN THE OKOY GEOTHERMAL FIELD Fig. 2

HYDROLOGY

Due to the complex nature of the Okoy geothermal field, wells drilled into the hydrothermal system generally balance well and reservoir pressures with internal flows. These internal flows cause difficulty in interpreting the downhole temperature and pressure measurements.

Most of the wells within the field penetrate a single phase reservoir and some have multiple permeable zones. Wells with multiple permeable zones generally have one zone with larger permeability and at this point the measured pressures equal the reservoir pressure. This point is known as the pressure control point. Elsewhere in the well the measured pressures do not equal the reservoir pressure.

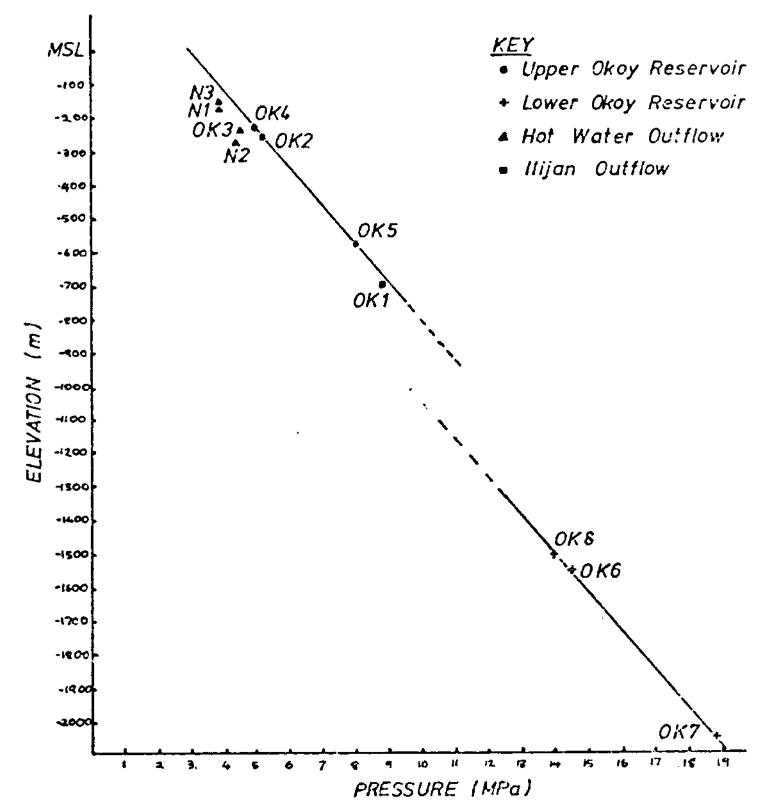
After examination of the well measurement data the pressure control point for each well was identified and listed in Table 1.

The pressure survey data was examined and rejected where the surveys showed transient effects, strong internal flows or obvious measurement errors. The remaining surveys were used to calculate the average pressures at the pressure control point for each well and listed in Table 1.

Table 1: Elevation - Pressure Data

Well	Pressure Control Point m MSL*	Average Pressure kPa
N1	- 169	3870
N2	- 268	4360
N3	- 152	3860
OK1	- 687	8810
OK2	- 246	5170
OK3	- 232	4500
OK4	- 223	4930
OK5	- 568	8020
OK6	- 1544	14540
OK7	- 2040	18810
OK8	- 1496	14000

The elevation - pressure data of Table 1 is graphed in Figure 3.



WELL PRESSURE Vs. ELEVATION IN OKOY FIELD Fig.3

* MSL = mean sea level

Examination of Figure 3 and a knowledge of the physical geography, geology and chemistry of the Okoy field suggests that the data can be grouped into four categories:-

(a)	Upper Okoy reservoir	(OK2, OK4, OK5)
(b)	Lower Okoy reservoir	(OK6, OK7, OK8)
(c)	Hot water outflow	(N3, OK3, N1, N2)
(d)	Ilijan outflow	(OK1)

UPPER OKOY RESERVOIR

The upper Okoy reservoir is a single phase system existing between +300m and -1000m MSL consisting of neutral chloride water with chloride concentrations of approximately 3600ppm. Deep drilling has encountered temperatures of up to 310°C and no re-charge system has yet been identified.

Some small two phase steam dominated zones overlie the reservoir.

Least square linear regression analysis gives an 'elevation - pressure relationship' for this category (a) data of Table 1 as $P = 2960 - 8.91\ z$. Where P is pressure (kPa) and z is elevation (m) relative to mean sea level. The co-efficient of determination for the analysis is 1.000 indicating an excellent fit.

The implications of the 'elevation-pressure relationship' are:-

(i) The piezometric water level of the reservoir is +330m MSL.

(ii) All Chloride springs which derive fluid from the reservoir will occur at elevations less than +330m MSL.

(iii) Surface thermal manifestations at elevations greater than +330m MSL which derive fluid from the reservoir are likely to be steam heated or discharge free steam.

(iv) The pressure gradient of 8.91 kPa/m corresponds to water of approximately 160°C. The average reservoir temperature is greater than 160°C thus the pressure gradient is super-hydrostatic.

LOWER OKOY RESERVOIR

The lower Okoy reservoir is a neutral chloride water system at elevations below -1000m MSL. Deep drilling so far has encountered temperatures ranging from 250 to 303°C and no recharge or outflow systems have been indicated.

Least squares linear regression analysis gives an 'elevation -pressure relationship' for the category (b) data of Table 1 as $P = 970 - 8.75\ Z$. The co-efficient of determination for the analysis is 0.999 indicating a reasonable fit.

The implications of the 'elevation-pressure relationship' are:-

(i) The piezometric water level of the reservoir is +110m MSL.

(ii) All chloride springs which derive fluid from the reservoir will occur at elevations less than +110m MSL.

(iii) The pressure gradient of 8.75 kPa/m corresponds to water of approximately 175°C. The average reservoir temperature is greater than 175°C thus the pressure gradient is super-hydrostatic.

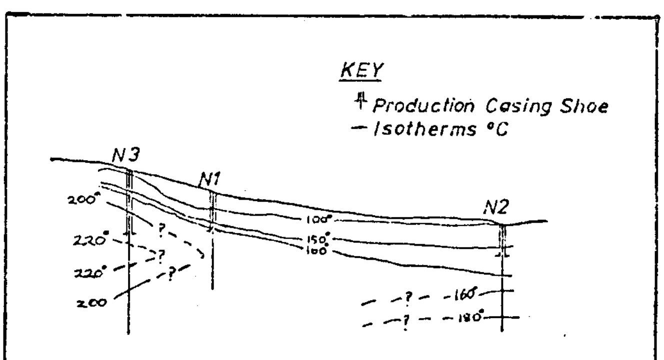
(iv) At an elevation of -1000m MSL the pressure difference between the upper and lower reservoirs is 2150 kPa. If permeability exists between these reservoirs, within the known field area, fluid will flow from the upper to the lower reservoir.

HOT WATER OUTFLOW

The shallow wells N1, N2 and N3 penetrate a hot water flow which supplies the Okoy valley springs.

Geochemical evaluation (Barnett, 1977) of the Okoy valley wells and springs indicated a general westerly direction as the source of the fluid.

Figure 4 shows isotherms drawn through wells N3, N1 and N2 also suggests a source to the west.



HOT WATER OUTFLOW - CROSS SECTION Fig. 4

The Okoy geothermal field cross sections (Smith, 1980 b) suggested wells N3, N1 and N2 are in an outflow from the Upper Okoy reservoir with OK3 in the outflow edge.

Comparison of the data from Table 1 for these category (c) wells with the derived 'elevation-pressure relationship' for the upper Okoy reservoir is given in Table 2. The pressure departures of Table 2 show a sequence of increasing pressure drop in the order: N3, OK3, N1, N2 indicating the flow direction.

Table 2: Pressure Comparison

Well	Pressure Control Point m MSL	Average Pressure kPa	$P=2960-8.91Z$ kPa	Pressure Departure
N3	- 152	3860	4314	- 450
OK3	- 232	4500	5030	- 530
N1	- 169	3870	4470	- 600
N2	- 268	4360	5350	- 990

ILIJAN OUTFLOW

The Okoy geothermal field cross sections (Smith, 1980 b) suggested OK1 is on the edge of a second hot water flow.

Comparison of the data from Table 1 for OK1 with the derived 'elevation-pressure relationship' for the upper Okoy reservoir is given in Table 3.

Table 3: OK1 Pressure Comparison

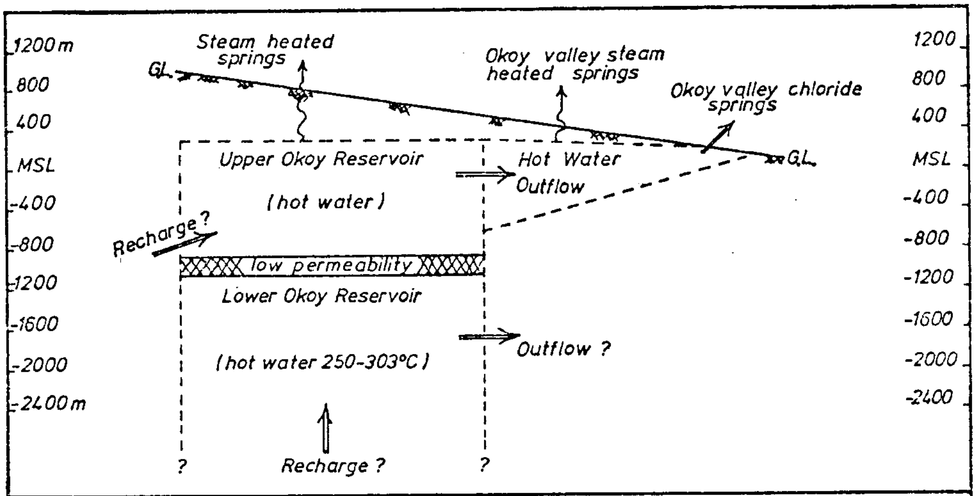
Pressure Control Point m MSL	Average Pressure kPa	$P=2960-8.91Z$ kPa	Pressure Departure
- 687	8810	9080	- 270

The pressure departure of Table 3 does not fit the sequence for the flow direction indicated by Table 2. It can be speculated that this second hot water flow may be from a geothermal system in the Balinsasayao area.

MODEL

A simple two dimensional conceptual model is given (Fig. 5) based on the descriptions of the upper and lower reservoirs and the hot water outflow.

Further exploration and delineation wells are being drilled in the Okoy geothermal field and it is hoped the information obtained will help clarify the complex nature of this field.



CONCEPTUAL MODEL OF THE OKOY GEOTHERMAL FIELD — Fig. 5

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