THE PALIMPINON GEOTHERMAL RESOURCE NEGROS, REPUBLIC OF THE PHILIPPINES AN EXPLORATION CASE HISTORY

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ABSTRACT

Wells drilled into the Palimpinon geothermal field have intersected an extensive high temperature liquid reservoir in fractured rocks of Miocene age and younger. Production is typically from two or more feed zones and averages approximately 7 $MW_{(e)}$ per well.

The assessed amount of recoverable or potentially recoverable stored heat energy from the drilled area is equivalent to approximately 9000 $MW_{(e)}$ years of electrical energy but a large part of this resides in plutonic rocks, the exploitability of which has yet to be tested. Construction of a 112.5 $MW_{(e)}$ power station at Puhagan represents the first stage in field development. The extent of development beyond this figure will depend on several factors including the performance of Palimpinon I, further testing of the pluton and also the full extent of the resource.

RESULTS FOR SURFACE INVESTIGATIONS & EARLY DRILLING

The Palimpinon geothermal field is located on the island of Negros in the Central Visayan region of the tectonically active island arc which comprises the Philippine Republic. Interest was first aroused in the early 1970's by the presence of hot springs and hydrothermally altered ground in the Okoy Valley and Tagbac-Magaso geothermal areas. Analysis of spring samples by scientists of the Philippine Commission on Volcanology showed high concentrations of chloride ion, a finding confirmed by further geological and geochemical reconnaissance, which also located extensive hydrothermally altered country. These encouraging results provided the justification for a programne of Schlumberger resistivity traverses covering approximately 260 km . The regional pattern of resistivity is shown in Figure 1. This survey further supported the concept of a geothermal reservoir and in 1975 the Okoy Valley was selected as having most promise for development.

The major surface manifestations occur in the Okoy Valley which is located between two Quaternary volcanic centres, Balinsasayao to the north and Cuernos de Negros to the south, Figure 1. Several near-boiling springs with high concentrations of chloride ion occur at low elevations. Others having low chloride but high sulphate, characteristic of steam-heated meteoric water, occur in the higher country further west.

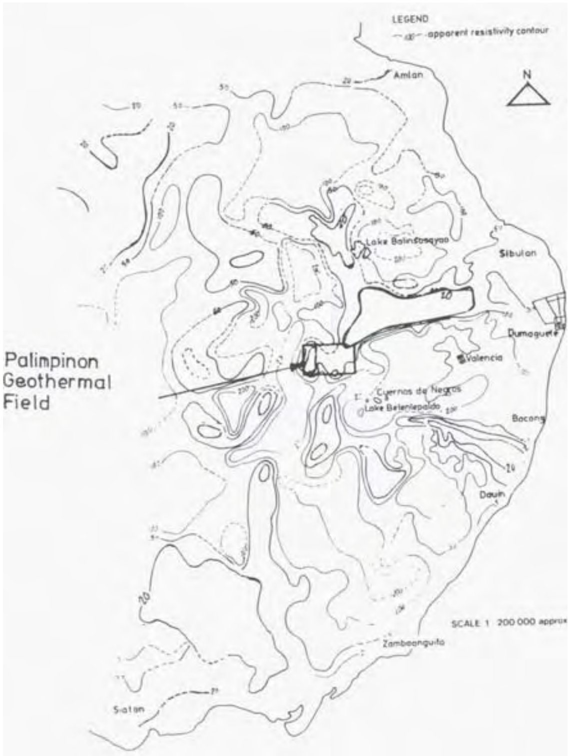


Figure 1:

Regional apparent resistivity, Southern Negros - Schlumberger array - AB/2 = 500 m.

These data together with the extensive hydrothermally altered ground, spring geothermometry, and resistivity findings provided strong evidence for a hot water reservoir, and in January 1976 drilling began with two shallow, 600 m exploration wells, Negros 1 and 2 (N1, N2) in the lower Okoy Valley, Figure 2. Although neither produced satisfactorily, both confirmed the existence of high temperatures at relatively shallow depths. Well data, including geochemistry, suggested that they had intersected an outflow from a 220°C or hotter liquid reservoir.

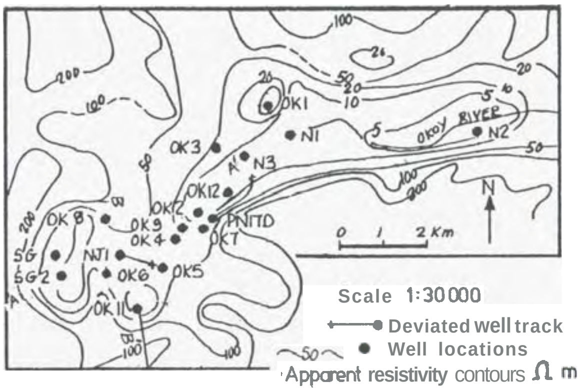


Figure 2: Schlumberger apparent resistivity, Palimpinon geothermal field - AB/2 = 500 m.

It was recognised that the closely confined 10-20 ohm-metre resistivity anomaly along the Okoy river was strongly influenced by topography and that the extension of the hot water beneath the higher country would be marked by higher apparent resistivities and less pronounced anomalies. Two such anomalies (20-30 ohm-metre) branched northwest and southwestwards from the Okoy Valley, and a series of exploratory wells encountered progressively higher temperatures to the southwest.

Two of the deep exploration wells, Okoy 4 and 5 (OK4, OK5) both have high measured temperatures - 299°C and 310°C respectively with no inversion - and OK5 produces an equivalent of approximately 8 $MW_{(e)}$. It is noteworthy that this well was the first in the Philippines to be stimulated into discharge by steam generated by a boiler.

Reappraisal of the resistivity data showed a large area of similar values in the upper Okoy catchment and it was postulated that this might represent an extension of the high temperature resource at OK4 and OK5. This was later confirmed by additional deep wells in the Nasuji/Sogongon area further west.

At this stage the decision to proceed with a 112.5 $MW_{(e)}$ geothermal power development, Palimpinon I, was taken by the Energy Development Corporation division of the Philippine National Oil Company. Construction of the power station and fluid transmission system at Puhagan are well advanced and commissioning is scheduled for mid 1983. The steep topography severely limited the number of suitable sites for vertical wells. This led to the adoption of directional drilling, all of the targets being reached from sites close to the location of the power station. Obvious advantages of this strategy are the use of shorter pipelines, easier access, common services, simpler well testing, easier well control and field management.

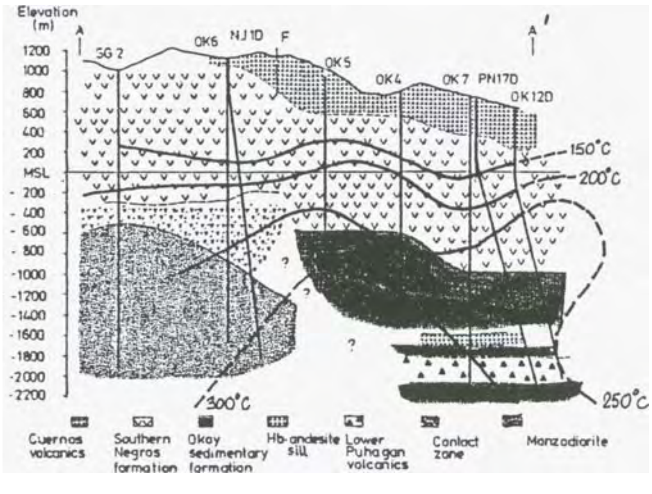
RESULTS OF DEEP DRILLING

At the time of writing a total of 15 deep exploration and development wells with an average depth of 2800 m had been drilled in the Palimpinon field. The bores discharge a two-phase mixture of steam and water from a single-phase liquid brine reservoir and usually from two or more zones. Permeability is derived from fractures fed from rocks of varying porosity; it is indicated in cuttings by drusy vein minerals, particularly quartz and adularia, and after completion by comparison of downhole temperature profiles. Enthalpy of the discharged fluid averages approximately 1230 J/g at a wellhead pressure of 0.8 MPa abs. and non-condensable gases approximately 2-2.5 weight percent of steam. Average electrical equivalent output of the producing wells at a separator pressure of 0.55 MPa abs. is about 7 $MW_{(e)}$. Wells in the eastern part of the field have provided steam for two 1.5 $MW_{(e)}$ demonstration turbogenerators since late 1980. The electricity from these units is used both by the project and the nearby city of Dumaguete.

A generalized stratigraphy of the Palimpinon Field has been given by Leach et al. (1982 this conference). Puhagan wells in the east penetrate andesites of the Southern Negros Formation and younger Cuernos volcanics which are underlain to drilled depths by rocks of the Okoy Sedimentary Formation. Although some of the highest temperatures occur in the sedimentaries, permeability is poor except where they have been interbedded with volcanics,

Further west, wells intersect an extensive body of monzodiorite which has been intruded into the overlying volcanics.

Subsurface geology based on the deep wells is shown in Figures 3 and 4; the temperature distribution is shown on the same sections. Collectively these data underscore the importance of the Nasuji monzodiorite to large scale exploitation in this area. In particular, the pluton has been intersected at depths as shallow as 500 m below mean sea level and accounts for the greater part of the resource with temperature in excess of 250°C. It thus accounts for a large proportion of the assessed thermal energy content in this part of the field.



Scale 1: 50 000

Figure 3: Section A-A'. Subsurface geology and isotherms.

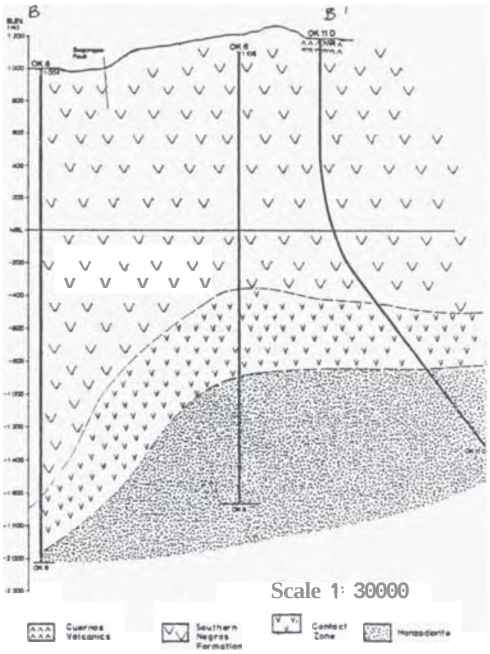


Figure 4: Section B-B'. Subsurface geology.

Results for completion and flow tests indicate that the monzodiorite accounts for a substantial proportion of the production from three wells located in the western part of the field. One, (SG-1) is cased into the pluton and therefore draws on it for its entire production of more than 5 MW(e). Characteristics of this and other bores located in the Nasuji/Sogongon sector of the field are given in Table 1 below.

Table 1: Characteristics of Nasuji/Sogongon Wells

Well No.	Depth Below Mean Sea Level (m)	Injectivity l/s MPa	Max. meas. temp °C	Output MW(e) at WHP of 0.8 MPa abs. and separator pressure of 0.55 MPa abs.
	1665	50+	288	10.7
	1978	10	291	3.5
OK-11	1270	10	265	
	1815	31	277	5.2
SG-2	1918	37	283	8.5
NJ-1	1743	15	247	?†

†Testing in progress

Production from plutonic rocks has also been observed in the Tongonan field. Wells drilled in the Malitbog sector intersect an average of 500 m of diorite which underlies approximately 1500m of andesite volcanics. Nevertheless natural systems developed in rock of this kind have yet to be commercially exploited and hence little is known about their long term energy yield. Clearly however, production from such reservoirs must rely more heavily on the fracture network than is the case for those developed in more porous rocks such as volcanics. Intrusive rocks which have been intensely and more or less homogeneously fractured could, under production conditons, be expected to behave in a manner similar to a porous reservoir. However, where this fracture network is confined to a few widely-spaced structures such as faults, reservoir capacity will be relatively small and heat transfer from rock to fluid less effective. Under these conditions the rate at which fluid is removed from the reservoir, and the nature and rate of fluid recharge are likely to be of critical importance.

Production from wells in the western part of the field is not confined to the monzodiorite. There is clear evidence from drilling circulation losses, well discharge, downhole measurements and petrology for permeability at the contact between the pluton and overlying volcanics particularly where the latter comprises a potpourri of intercalated andesites, porphyritic diorites and andesites, and micro-monzo and monzodiorites. However in other wells, Okoy 8, Okoy 11 and Nasuji 1 (OK8, OK11, NJ1) where the contact takes the form of a contact metamorphic hornfels, permeability is poor to absent.

The distribution of permeability within the Nasuji/Sogongon wells has been assessed largely on the basis of completion tests and data for flowing surveys and is shown in Figures 3 and 4. Although at present only 5 wells have been drilled into the pluton some observations are possible. Firstly there is no evidence from these data that permeability within the monzodiorite is other than random; nor is there any indication that production could not be expected from greater depths. Two of the five wells are only poorly permeable. One of these, Nasuji-1 has been successfully discharged but output to date has been small and unsustained. The other, Okoy-11 has the lowest injectivity of those shown but perhaps significantly penetrated the pluton to a depth of less than 500 m. The contact between the plutonics and overlying volcanics occurs as a hornfels in both these wells.

A petrological study of the nature and pattern of hydrothermal alteration has provided evidence for the origin of the fracture permeability that is found within the pluton. Details of this study are given by Leach et al. (1982 - this conference). The pattern is complex and to some extent resembles that commonly found in association with porphyry ore deposits; that is, a high temperature potassic zone at the contact of the pluton with rocks of the intruded Southern Negros Formation, a surrounding advanced argillic zone and beyond this, a zone of propylitic alteration. Alteration minerals present in the potassic and argillic zones were formed at higher temperatures than those measured at corresponding depths. They are therefore not in equilibrium with existing fluids but reflect higher temperatures of a past hydrothermal regime. This is also true of the propylitic alteration where it occurs in the uppermost parts of the Southern Negros Formation but, at greater depths minerals encountered in the Puhagan wells appear to be in equilibrium with existing fluids.

The relict alteration observed in the Southern Negros Formation does not appear to extend into the overlying Cuernos Volcanics and as such pre-dates their eruption. Furthermore, the persistence of high temperature minerals to the top of the Southern Negros Formation indicates that these volcanics were eroded to a considerable depth, perhaps in the order of 1000 m. A period of erosion is consistent with reports of a paleosol between the two formations.

There is some evidence from most Puhagan wells that the relict alteration has been succeeded in part by a lower temperature mineralogy which is in equilibrium with measured temperatures. The alteration is characterized variously by montmorillonite, interlayered illite-montmorillonite and zeolites, and although not pervasive this alteration appears to be widespread and extends into the overlying Cuernos Volcanics.

The point has been made that high temperature potassic alteration extends no further than 200-300 m into the pluton. Although some alteration persists below these depths within the monzodiorite, it is less intensive and was formed at temperatures similar to those now in existence.

It thus appears that there have been two episodes of hydrothermal alteration in the drilled part of the field; a phase of potassic, argillic and propylitic alteration and a later phase of alteration by more neutral fluids at close to present temperatures. This more recent episode is reflected in the alteration observed at greater depths within the pluton, the lower grade of alteration in the upper parts of the S.N.F. and lower members of Cuernos Volcanics, and possibly the deep alteration at Puhagan. It is believed that the first episode of alteration formed in response to the monzodiorite intrusion. This belief is based on the distribution of alteration with respect to the pluton, the similarity between the observed alteration pattern and that found in porphyry ore deposits which are commonly associated with intruded igneous rocks, and the probable magmatic origin of the acidic advanced argillic alteration,Leach et al. (1982).

Collectively the above observations imply that deep alteration present within the pluton post-dates intrusion of the monzodiorite. It follows that fracture permeability with which it is associated is not limited to joints formed during cooling of the pluton. Indeed, the nature and pattern of the more recent alteration is consistent with a period of renewed tectonism following a period of cooling. Such activity would likely have resulted in widespread fracturing of the rock including the pluton and as a consequence, a modified hydrology.

A definite relationship has yet to be established between the occurrence of faults and the incidence of permeability within the pluton although traces of several major faults lie only a short distance from producing wells OK6 and SG1 in the Nasuji/Sogongon area. Clearly, however these and associated shatter zones may be important upflow channels for geothermal fluid. Conceivably they may also access potential recharge aquifers both above and beyond the producing field.

Some knowledge of the existing field hydrology has been provided by a comparison of fluid chemistry and measured temperatures from Okoy wells.

Computation of the deep aquifer chemistries has been complicated by the fact that most of the wells produce from at least two feed zones, the contribution of each varying with wellhead pressure. Corresponding changes in the discharge chemistry have been observed for several of the wells and are most marked for those drilled at Puhagan. There is therefore a risk that apparent interwell variation may mask real trends across the field. In an effort to avoid such problems, the data used in the analysis were those obtained from samples discharged at high wellhead pressures. It was assumed that discharge under these conditions most closely approximates fluid derived from the deepest feed zone. Even so, some contribution from shallower aquifers cannot be ruled out. Therefore, observed field patterns are valid only in situations where variation across the field exceeds that obtainable from a given well.

A comparison of well chemistries on this basis has shown some interesting trends. In particular, the ratio of chloride to boron varies little across the field. Fluid supplying wells in the Nasuji/Sogongon and Puhagan areas is therefore likely to have a common origin, The small variation in reservoir pressure across the field is consistent with this inference. Furthermore, temperature sensitive parameters including the ratios Na/K, Na/K/Ca, Na/Li, Na/Rb and Na/Cs, suggest a progressive decline in temperature to the northeast, north and west from within the vicinity of OK5. These trends are generally consistent with those deduced from measured well temperatures. Cation geothermometry indicates a reservoir temperature of not less than 310°C which is in reasonable agreement with the maximum silica temperature of approximately 295°C and the maximum measured field temperature of 325°C in OK9.

Field chloride concentrations contoured in Figure 5 also show considerable variation. These reach a maximum of approximately 4200 ppm in the Puhagan area, (OK10) and decline progressively in the direction of SG1 and SG2. The range of approximately 1200 far exceeds that obtained for a given well (approximately 500 ppm) and is therefore taken to indicate a progressively less mineralized reservoir fluid from east to west.

The same general pattern is indicated by the isotherms at MSL-500 m and MSL-1500 m in Figure 5 and by the plot of aquifer chloride concentration versus supply water temperature, based on the concentrations of dissolved silica, Figure 6. The decline in chloride concentration from Puhagan to the Nasuji/Sogongon area is thus clearly related to a falling supply water temperature and cooling of the resource, and is considered to indicate progressive dilution of the reservoir fluid with a cooler less mineralized water.

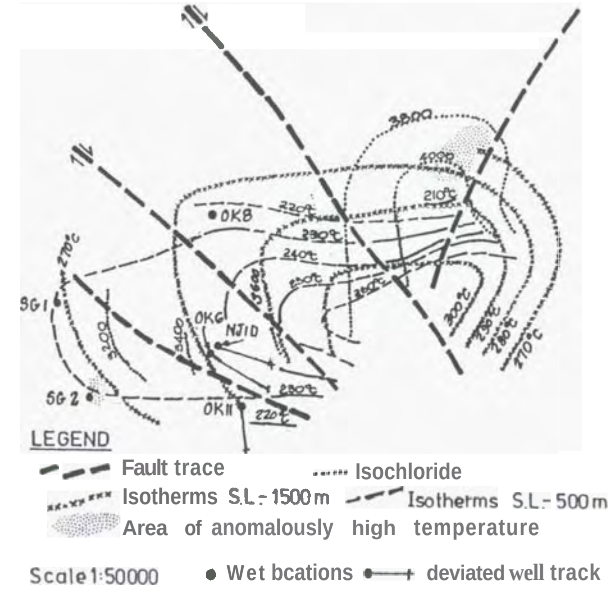


Figure 5: Isotherms, isochlorides, major structural features.

A different though equally well-defined trend is shown in Figure 6 by wells drilled in the Okoy Valley. Despite a progressive decline in supply

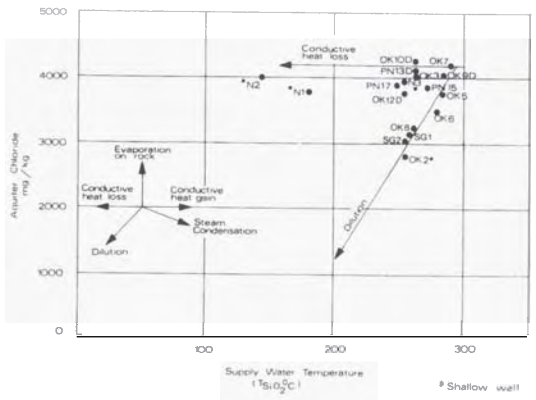


Figure 6: Plot of aquifer chloride concentration VS. Supply water temperature.

water temperature from OK7 towards the most easterly drilled well, N2, aquifer chloride concentrations vary little from an average of approximately 4000 ppm. Such a trend is consistent with the process of conductive cooling within the reservoir in an easterly direction and is supported by stable isotope analysis of the well fluids. However, it should be noted that it is possible to combine boiling with dilution to give the same result. Isotope analyses are consistent with the pattern of dilution indicated by the chemistry but more data are needed for confirmation.

The point has been made that the same general pattern is indicated by isotherms at depths of 500 m and 1500 m below mean sea level. There are however some interesting differences. The rate of cooling at the shallower plane is less uniform than that at S.L.-1500 m particularly to the west in the Nasuji/ Sogongon sector. The depth of these isotherms, 500 m below sea level, and the productive contact zone between the monzodiorite and overlying Southern Negros Formation are in general agreement in this area. These observations together with evidence for dilution of the reservoir fluid from east to west suggest a westerly flow across the Nasuji-Sogongon area at the contact between the pluton and volcanics. Flows of this kind have also been detected at the Tongonan geothermal field. Two pockets of anomalously high temperature are shown at the SL-500 m depth. One of these lies on the outflow to the northeast and may represent localized convective heat flow along a deep fracture, possibly the Ticala fault. Supporting evidence for this explanation is provided by the chemistry which indicates that fluids in the outflow path are cooled by conduction. The absence of dilution by meteoric water implies that the pressure drop along the outflow is small and as a consequence, that permeability is relatively high, a condition which could be satisfied by the presence of a fault. Fault control of fluid movement to the northeast may also account for the relatively steep thermal gradients indicated by the isotherms in this area.

The other zone of anomalously high temperature was intersected by SG2 at less than 100 m above the 500 m datum plane but still within the contact zone. Available evidence suggests that this too is a localized feature and as such the two areas may have a similar origin.

Total extractable or potentially extractable stored heat energy for the 11 km^2 drilled area of the Okoy field has been assessed at approximately 9000 $MW_{(e)}$ years. For a plant life of 25 years this figure corresponds to a maximum generating capacity of 360 megawatts, but as discussed elsewhere in this paper a large part of this resides in the pluton and exploitability has yet to be tested. The 112.5 $MW_{(e)}$ Palimpinon I power station under construction at Puhagan represents the first stage of the development of the Palimpinon field. The extent of future development beyond this figure will depend on several factors including the performance of Palimpinon I, further testing of the pluton and also the full extent of the geothermal resource. There is evidence that the hydrothermal system extends beyond the drilling area, particularly to the south where some of the highest subsurface temperatures have been recorded. Supporting evidence for the concept of a source in this direction, possibly underlying the Kaipohan area where there are numerous gas vents is provided by the regional (Figure 1) and deeper resistivity data. It thus appears likely that the Okoy, Baslay-Dauin, Dobdob, Calinawan and Siaton manifestations which radiate from Cuernos de Negros share a comn heat source.

Further drilling in Baslay-Dauin will test this thesis and confirm the full extent of the resource.

ACKNOWLEDGEMENTS

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REFERENCE

Leach, T.M. & Bogie, I. (1982)., Overprinting of hydrothermal regimes in the Palimpinon geothermal field, Southern Negros, Philippines.