A GEOSCIENTIFIC EVALUATION OF THE BASLAY-DANIN PROSPECT, NEGROS ORIENTAL, PHILIPPINES

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ABSTRACT

Recent geoscientific interpretation of the Baslay-Danin prospect reveals the need for exploration drilling as the next phase of evaluation.

Extensive near surface boiling occurs some 7 kms from the inferred reservoir source, with spring chemistry generally reflecting a mixture of steam condensate, shallow groundwater and in some cases small amounts of deep chleride water. Mixing models suggest four to five times dilution must occur to produce surface discharge composition in Baslay-Danin, using reservoir fluid chemistry from Palinpinon.

A vertical electrical sounding survey has proved an area of low-moderate resistivity (5-50 ohm-m) greater than 20 sq. km. This confirms a connection at depth beneath the original low apparent resistivity anomalies of Lipayo and Nagpantaw.

INTRODUCTION

The Baslay-Dawn prospect is situated in the south-eastern quadrant of the 1330 sq. km. Southern Negros Geothermal Reservation, approximately 6 kms SE of Palinpinon I, a geothermal power installation of 112.5 MWe, due for commissioning in 1983. It is separated from Palinpinon I by the summit crater of the dormant composite volcano, Cuernos de Negros.

There are 8 main thermal areas within the Baslay-Danin prospect (fig. 1). These are located over a surface area of greater than 50 sq. km. and extend NW over a distance of some 12 km from 50 m ASL in the SE, up to 1115 m ASL on the intermediate conal flank region of Cuernos de Negros. Hot and warm springs are found at San Miguel, Lipayo, Campocaw, Masaplod, Hagobaac, Maayong-Tubig and Nagpantaw. Steaming ground and minor fumarolic activity are located at Tagbac-Magaso. Altered ground occurs extensively throughout the prospect, with localized travertine deposits in Campocaw and Lipayo. Several areas of altered ground exist outside the Baslay-Danin and Palinpinon areas. These are located at high elevations (1400-1700 m) associated with substantial flows of cold, predominantly CO_2 gas. The most significant of these is in the Kaipohan area[1] (fig. 1).

Various geoscientific reconnaissance and exploratory surveys, both in the Palinpinon (Okoy) and Baslay-Danin areas were conducted from 1973-1977, to determine the most suitable areas for initial development. Relevant data and interpretation from these surveys are referred to in this evaluation. Regional schlumberger traversing defined low resistivity anomalies (<50 ohm-m) over a large area (refer Bromley, 1982), six of these situated with crude radial symmetry about Cuernos de Negros. This suggests a substantial hydrothermal system about a central igneous heat source. Geochemical interpretation (Glover, 1975) identified an extensive hot chloride aquifer within the Okoy Valley, which was supported by a strongly contrasting low apparent resistivity anomaly. Early exploration drilling (N-1, N-2, N-3, OK-1, OK-2, OK-3)[2] confirmed the lower Okoy valley as an outflow from a source further south to southwest. Exploration drilling therefore, progressed from areas characterised by chloride surface features (Wells N1, N2, N3, OK3; fig. 1) into areas at higher elevation to the SW which possessed acid sulphate spring chemistries (Well N3; fig. 1). This exploration strategy ultimately led to the development of Palinpinon I in the Puhagan sector (fig. 1).

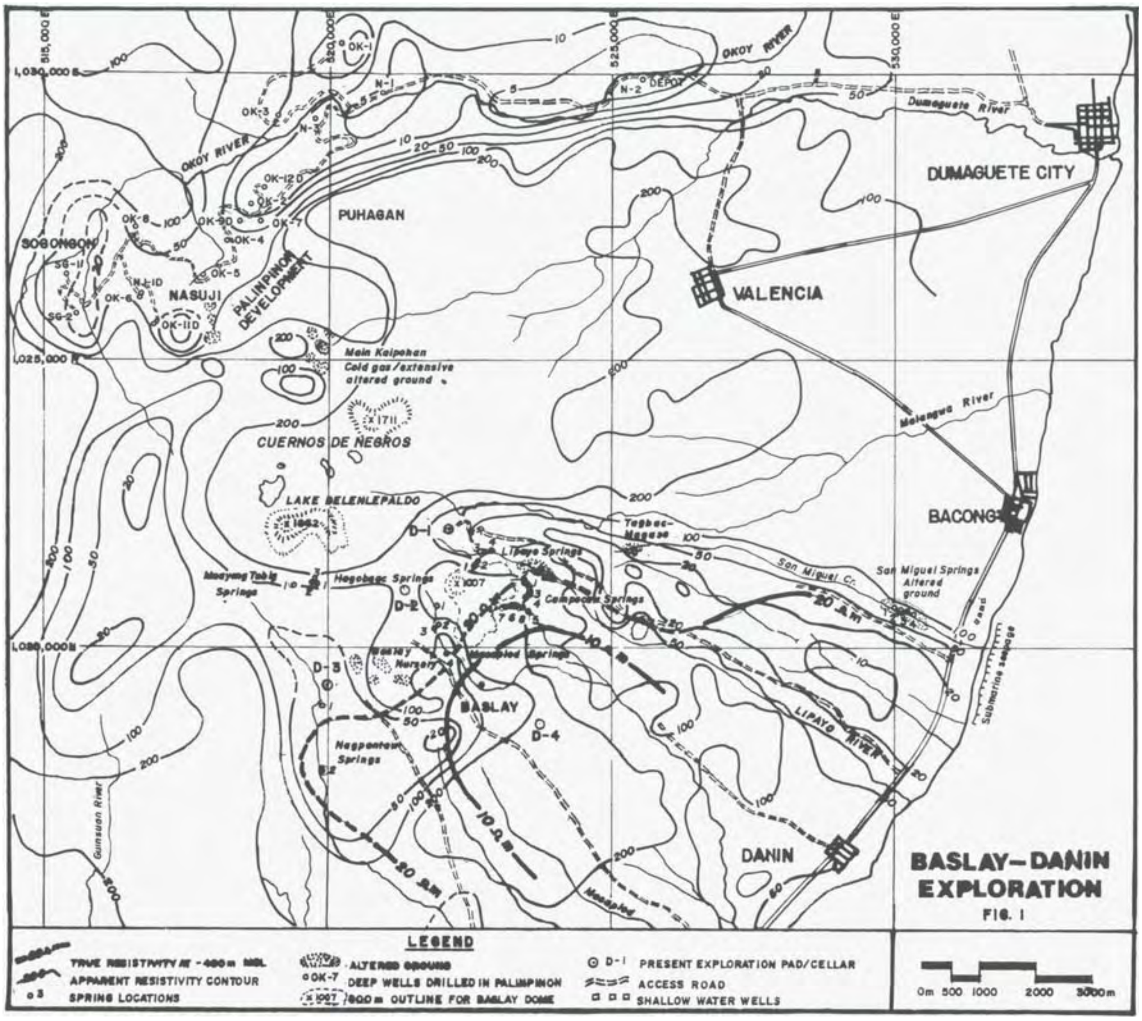
In a number of geothermal fields, e.g. Palinpinon, Tongonan, it has been recognized that natural discharge of dilute chloride water occurs some considerable distance from the higher temperature upflow portion of the parent source. With this background Baslay-Danin became a promising area for further geoscientific investigation.

GEOLOGY

Negros Island is dominated by 2 andesitic-dacitic volcanic complexes; Mts. Mandalagan-Silay-Canlaon (active) in the north and the coalescing volcanoes of Guintabon, Guinsayawan and Cuernos de Negros in the south. These complexes are aligned parallel to the NE-SW conjugate segment of the Philippine Fault.

[1]Kaipohan is used as a location name.

[2]From 1976-1978, 6 exploratory wells, Negros 1, 2, 3 and Okoy 1, 2, 3 were drilled (fig. 1).



STRATIGRAPHY

Cuernos de Negros, the largest cone in the southern volcanic complex is a dormant (14,000[1] years) composite volcano with a complex of craters around the summit region. At higher elevations pyroxene andesite and dacite lavas dominate while unconsolidated tephras form a volcanic ring plain around Cuernos de Negros. The plateau volcanics north of the summit region consists of pumiceous flow breccia, younger andesite flows and overlying dacitic lahars (fig. 2).

The hornblende andesite/dacite lavas in the Kaipohan area between Okoy valley and Baslay-Danin have been completely altered to opaline-silica (Wood, 1977). The cold acid altered areas typified by Kaipohan, appear to be due to the exsolution and migration of deep separated gases, the largest component being CO_2. Although cold, these may indicate the presence of a deep upwelling zone.

To the south and southeast of Cuernos de Negros, extensive lahars and ash fall deposits cover the region, disrupted only by the Baslay siliceous andesite dome. Thermal features are pronounced at the periphery of the dome, suggesting vertical permeability has been provided by its emplacement. The lava flows and lahars in the area extend for some kilometers without apparent loss of character (Tolentino; Loo, 1973).

The oldest rock unit mapped is the Cuernos Volcanics and is divided into three members (table 1). The older member, Talines andesite is composed of thick andesitic lavas, tuff breccias and tephra which make up Mt. Talines, SSW of Cuernos de Negros. Exposures of this rock are also found along the Guinsuan river and the headwaters of the Magaso stream. In thin section, the rock is porphyritic oxyhornblende clinopyroxene andesite.

The middle member of the Cuernos Volcanics is an oxyhornblende pyroxene andesite, more viscous and geomorphologically younger than the Talines andesite,

Overlying the andesites are dacitic lava flows and pyroclastics forming the Baslay-Danin volcanics. These are mapped over 80% of the prospect, together with the more recent deposits described in table 1.

[1] C^{14} date from D.S.I.R. (1982), and is a date of youngest datable activity.

BASLAY-DANIN STRATIGRAPHY TABLE I

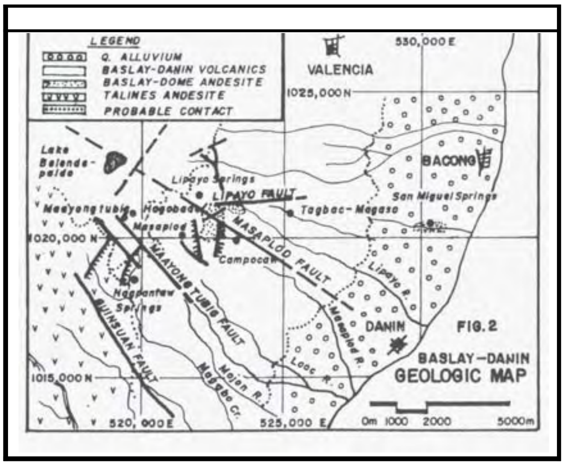
FORMATION	DESCRIPTION	AGE
QUATERNARY ALLUVIUM	LOOSE GRAVEL, TALUS AND PIEDMONT DEPOSITS; HOT SPRING PRECIPITATES.	RECENT
CUERNOS VOLCANICS A) YOUNGER MEMBER : BASLAY-DANIN VOLCANICS	DACITIC LAVA FLOWS, LAHARS, TUFF AND TUFF BRECCIA; 2-PYROXENE OXYHORNBLENDE DACITES	PLEISTOCENE TO RECENT
B) MIDDLE MEMBER: BASLAY DOME ANDESITE	OXYHORNBLENDE - BEARING CLINOPYROXENE ANDESITE	
C) OLDER MEMBER: TALINES ANDESITE	OXYHORNBLENDE - BEARING CLINOPYROXENE ANDESITE LAVAS AND PYROCLASTICS	

The Philippine Fault is a left lateral trans-current structure traversing the archipelago from north to south. Southern Negros is transected by a NE-SW trending conjugate of the Philippine Fault. The fault bound island margins of eastern and western Cebu define the lineament.

Structural mapping over southern Cuernos de Negros is complicated by a thick mantle of pyroclastics. The most significant field evidence for faulting are fault scarps, offset ridges, slickensides and sheared zones. Prior aerial photograph interpretation of structures was combined with field observation.

Faults transecting the Baslay-Danin prospect trend NW-SE. These are the Guinsuan, Maayong-Tubig, Lipayo and Masaplod faults (fig. 2). Localized faulting within the vicinity of the Baslay dome is apparent and these appear to serve as conduits for the migration of thermal fluids to the surface. The most prominent of these structures is the Masaplod fault which passes along the Masaplod headwaters and cuts across the Baslay dome (a fractured young intrusive).

The NW-SE trending Lagunao and Okoy faults (refer Seastres, 1982; Maunder, et al, 1982) appear to extend to Baslay-Danin. The lineaments are marked by offsets in rivers, and ridges; altered ground, a lake and hot springs.



GEOPHYSICS

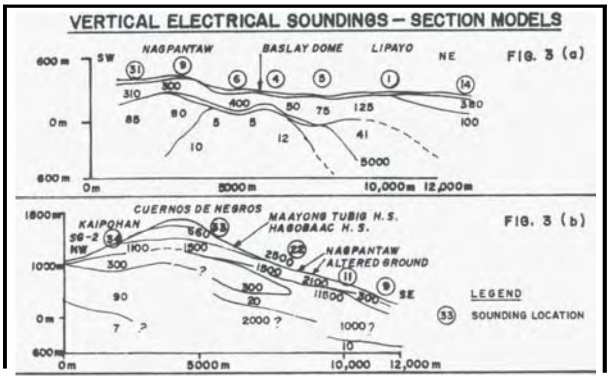
Several reconnaissance geophysical surveys dealing largely with heat flow from known thermal features were conducted from 1973-1975 (Aguilar, et al, 1973, 1974; Espaiiola, 1975). The assessed surface heat flow (Espafiola, 1975) was 31.5 MW (th) for Palinpinon and Baslay-Danin.

Schlumberger resistivity traversing in 1973 by the Commission on Volcanology covered parts of Baslay-Danin. An extensive d.c. resistivity survey by NPC[1]/KRTA[2] from 1975-1976 and PNOC-EDC/KRTA from late 1976-1977 covered most of the Southern Negros geothermal reservation (refer Bromley, 1982).

In Baslay-Danin two distinct low apparent resistivity anomalies were delineated. In Lipayo (fig. 1), a narrow fan-shaped anomaly implied fluid at depth flowing southeast, its presence more readily detected at shallower levels near the coast (broader anomaly). Another low anomaly was defined in Nagpantaw (fig. 1), separated from the Lipayo anomaly by a large area of 100-200 ohm-m resistivity.

During early 1982 vertical electrical soundings (VES) using the schlumberger array, were employed to investigate changes in resistivity with depth and to examine the possibility of a deep connection between various anomalies in Baslay-Danin (Bromley, 1982). Electrode spacings were limited to AB/2=1000 m in rugged terrain to the north and 1600-2000 m for most of the other soundings.

Two VES models are shown in fig. 3 (a, b), and indicate a deep connection between the Lipayo and Nagpantaw traversing anomalies (fig. 3a). The 10 ohm-m or lower resistivity layers are compatible with a chloride aquifer, substantiated by the appearance of mixed-chloride water at San Miguel spring to the SE of the section line at lower elevations. There also appears to be communication at moderate depths between the intermediate



1 NPC - National Power Corp., Philippines

2 KRTA - Kingston Reynold Thom and Allardice, New Zealand

resistivity values associated with the Kaipohan area and acid sulphate springs (e.g. Masaplod, Lipayo) as represented by the 20-90 ohm-m resistivity layer (fig. 2b).

Sounding 34 (fig. 2b) suggests a possible deep link between low resistivity anomalies identified in Sogongon (upper Okoy) extending beneath Cuernos itself and further south-east where a deep layer of low resistivity 10 ohm-m is modelled (refer Bromley, 1982; Seastres, 1982).

During 1975, dipole-dipole surveys by McPhar geoservices used 600 m dipoles in the more rugged areas and showed low apparent resistivities beneath a high resistivity cap between Puhagan and Baslay-Danin and extending east of Kaipohan. This resistive cap was apparently not penetrated by the other surveys. The dipole-dipole pseudo-sections then support hydrological connections at depth between Puhagan, Baslay-Da in and Kaipohan (Bromley, 1982).

SURFACE HYDROTHERMAL ALTERATION

A suite of minerals found as spring precipitates and sublimates from fumaroles are presented in table 2. Some of the minerals defined are not common to other Philippine geothermal areas where acid sulphate discharges exist e.g. Biliran. In most cases these sulphate minerals are not direct hydrothermal alteration products. In springs, these reflect the supersaturated nature of the fluid, resulting in the deposition of precipitates at spring edges and in outflow channels. At Tagbac-Magaso precipitates are formed from steam condensation on, and alteration of, andesite breccias surrounding the main fumarolic vents.

TABLE-2 BASLAY-DANIN SURFACE PRECIPITATES

LOCALITY	PRECIPITATES
Tagbac-Magaso	Alunogen, kieserite, tamarugite, alunite, gypsum, halotrichite, anhydrite, sulfur
San Miguel	Alunogen, tamarugite, jurbanite, cristobalite, gypsum
Maayong tubig	Iron hydroxide, sulfur, halotrichite, alunogen, jurbanite, gypsum, marcasite.
Hagobaac	Iron hydroxide, sulfur, halotrichite, alunogen
Giso	Halotrichite, alunogen, iron hydroxide, quartz, sulfur, cristobalite
Lipayo	Halotrichite, tamarugite, alunogen, jarosite, a- sulfur, gypsum, natrojarosite, cristobalite
Masaplod-Baslay	Gypsum, sulfur, calcite, cristobalite
Campocaw	Calcite, iron hydroxido
Nagpantaw	Halotrichite, alunogen

GEOCHEMISTRY

Chloride: Chloride concentrations in spring waters show a regular variation with elevation from 2.5 mg/kg at Kaipohan (highest elevation), increasing in a south-easterly direction towards the coast, where the highest chloride springs are found at San Miguel with 1000 mg/kg chloride.

pH and Sulphate: One of the most significant aspects of the spring chemistries is the generally acid nature of discharges, especially Masaplod, Lipayo and San Miguel. These springs also contain the highest chloride concentrations (table 3) and have the maximum discharge temperatures (also noted by Glover, 1975). Measured pH's range from 1.90 at Masaplod, to 8.08 at Campocaw. Sulphate values range range from. 87 mg/kg at Lipayo, to 1950 mg/kg at Masaplod and samples high in sulphate correlate with low pH's. Several processes can account for these high sulphate, acidic type discharges.

a.) Steam heating of near surface groundwater.
b.) Steam condensate mixing with small amounts of deep chloride water and further dilution by shallow level groundwater.
c.) Contact and leaching with sulphate minerals and/or precipitates.

One mechanism common to all of the above is boiling at depth, with steam separation and consequent condensation.

The highet pH's measured for the Compocaw springs (6.13-8.08) are due to the greater fresh water character of these springs i.e. dilute chloride-bicarbonate water.

CO_2, H_2S, NH_3: These constituents represent the main gaseous components likely to reflect the presence of free steam. Values of bicarbonate (total carbonate species reported as bicarbonate) range from 15-1100 mg/kg, with high concentrations supporting, steam heating and condensation. H_2S concentrations vary from 0.34 mg/kg at Hagobaac to 55 mg/kg at Kaipohan. Elemental sulphur deposition occurs in large quantities at spring vents and outflow channels. The concentration of NH_3 is 0.14 mg/kg at Hagobaac, to 2.44 mg/kg at San Miguel, with a general increase coinciding with decreasing elevation, to the east, similar to the chloride trend. This implies further contact of migrating condensate with a deep water component, in shallow springs, e.g. San Miguel or the enrichment due to boiling of the deeper water.

Boron: Due to the significant partition of boron into the steam phase at high temperatures (Koga & Noda, 1975), increasing concentrations in certain areas may qualitatively indicate where high temperature steam separation is occurring. Boron concentrations range from 0.06 mg/kg at Kaipohan, to 7.0 mg/kg at Masaplod. If the difference in absolute concentrations was due to a varying admixture of deep chloride water with meteoric, then Cl/B values for springs should be similar. This however is not the case and Cl/B values are lower in Masaplod and Lipayo compared with San Miguel i.e. 36-44 (Masaplod, Lipayo) c.f. 62 (San Miguel). The boron enrichment for the higher elevation springs supports a possible association with high temperature steam separation.

Alkali-metals: Lithium often serves as a qualitative indicator of high subsurface temperature and rock-water interaction. Significant concentrations of lithium may therefore indicate the presence of a deep water component in surface discharges. Lithium values range from 0.02 mg/kg at

(TYPICAL) BASLAY-DANIN WATER CHEMISTRY. HARPER/GALIA (1981-82) TABLE 3

SAMPLE CODE LOCATION	FLOW KG/S	ELEVATION m (a.s.l)	TEMP °C measured	TEMP °C Amer. SiO_2	DATE Sampling	(25°C) pH	Li	Na	K	Rb	Cs	Ca	Mg	F	Cl	SO_4	B	SiO_2	CO_2	HCO_3	NH_3	H_2S	
							MG/KG																
SAN MIGUEL WELL D	–	5	40.0	48.2	6-01-82	3.30	0.14	211	175	0.16	n.d.	478	132	0.02	698	1467	6.07	176	11	0	0.83	4.1	66.3
SAN MIGUEL SPRING #1	1.20	50	87.0	83.7	16-10-81	2.16	0.21	119	11.2	0.16	n.d.	235	54.7	3.47	993	220	4.89	296	217	0	2.70	n.a.	71.6
LIPAYO SPRING #1	3.24	730	62.0	61.0	18-11-81	2.69	0.07	71	19.4	0.08	n.d.	115	51.3	0.21	350	240	2.63	261	43	0	1.30	n.a.	2.13
LIPAYO SPRING #2	0.50	730	48.0	33.6	18-11-81	6.70	0.04	46	8.1	n.d.	n.d.	74	29.8	0.08	75	87	0.71	137	162	600	0.70	n.a.	0.71
CAMPOCAW SPRING #3	0.81	426	41.0	33.6	18-09-81	7.58	0.07	61	12.8	0.06	n.d.	93	56.0	0.08	192	196	1.64	137	12	329	0.81	9.8	n.a.
CAMPOCAW SPRING #8	1.17	438	38.5	30.4	24.09-81	6.13	0.09	62	12.8	n.d.	n.d.	79	57.0	0.08	194	179	1.42	128	359	341	0.46	1.2	n.a.
MASAPLOD SPRING #1	7.96	750	54.5	52.6	29.12.81	5.90	0.06	57	14.6	0.04	n.d.	89	36.3	0.24	162	155	1.69	189	356	239	1.00	1.0	0.55
MASAPLOD SPRING #2	5.56	610	61.8	57.5	29-12-81	1.90	0.06	92	30.9	0.11	n.d.	35	27.1	0.08	698	1651	6.99	204	265	0	1.46	2.1	17.3
MASAPLOD SPRING #3	12.1	620	60.1	53.7	29.12.81	2.01	0.06	92	29.9	0.10	n.d.	38	26.8	0.09	603	1659	3.66	194	176	0	0.63	7.5	24.5
NAGPANTAW SPRING #1	7.49	610	41.0	–	02-01-82	4.46	0.02	48	5.1	n.d.	n.d.	506	44	0.12	124	1559	0.51	63	471	10	0.12	31.5	0.20
NAGPANTAW SPRING #2	10.2	542	34.0	11.3	02.01.82	2.90	n.d.	29	4.1	n.d.	n.d.	330	28	0.08	57	1135	0.06	99	13	0	0.19	12.8	0.08
HAGOBAAC SPRING #3	0.22	1100	51.5	53.7	23.01.82	5.75	n.d.	44	12.5	n.d.	n.d.	58	23	0.21	45	247	0.56	192	171	3	0.16	0.3	4.37
MAAYONG TUBIG SPRING #1	6.91	1090	37.5	37.2	25.02.82	5.32	n.d.	22	6.0	n.d.	n.d.	32	11	0.23	10.6	66	0.65	146	422	58	0.67	3.6	8.55
KAIPOHAN POOL #1	–	1170	18.5	–	10.01.82	2.81	n.d.	94	4.0	n.d.	n.d.	9.5	3.0	0.28	21	173	0.06	82	107	0	2.8	35	n.a.

FOOTNOTE: n.d. – not detectable. Li/0.04; Rb 0.05; Cs 0.10 ppm. as detection limits
n.a. – not analyzed.

Campocaw, to 2.19 mg/kg at San Miguel. The fact that the highest concentration appears in the San Miguel springs is further evidence that these springs contain the largest fraction of a deep thermal fluid.

Rubidium concentrations range (where detected) from 0.03 mg/kg at Campocaw, to 0.17 mg/kg at San Miguel. The trend of increasing rubidium concentrations to the east at lower elevation may indicate a greater mixing fraction of a deep thermal water in this direction, although as explained later the chemical composition may still be largely affected by dilution.

Calcium/Magnesium: Calcium values range from 30 mg/kg at Masaplod, to 530 mg/kg at Nagpantaw and Magnesium values vary from 11 mg/kg at Maayong-Tubig to 57 mg/kg at San Miguel. With the general acid nature of discharges in Baslay-Danin, calcium and magnesium concentrations are high, (these elements being mobile under acidic, low temperature conditions).

Usual Na/K, Na-K-Ca geothermometry has limited or no use when applied to the acid sulphate waters found in Baslay-Danin.

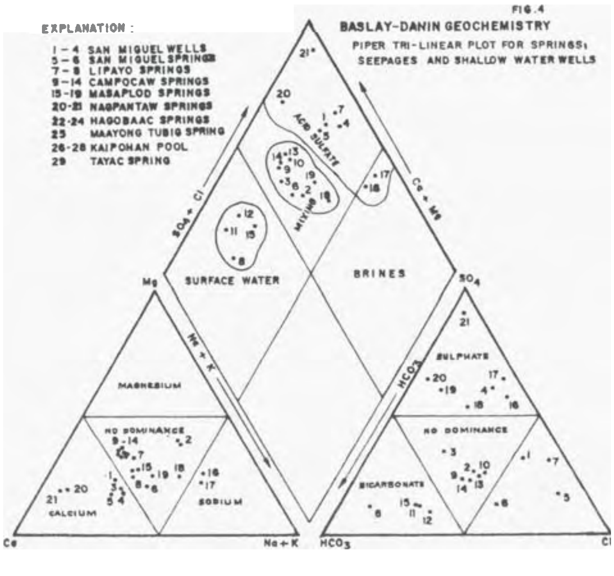


FIG.4
BASLAY-DANIN GEOCHEMISTRY
PIPER TRI-LINEAR PLOT FOR SPRINGS, SEEPAGES AND SHALLOW WATER WELLS

Discussion

The trilinear plot (fig. 4) demonstrates the chloride-sulphate, dilute chloride-bicarbonate nature of the waters in Baslay-Danin.

It appears that deep reservoir fluid (similar to fluid presently extracted in Puhagan, Nasuji-Sogongon) is only expressed at the surface having been severely affected by the admixture of steam condensate and meteoric water, It must also be recognized that moderate temperature leaching by laterally migrating fluids may contribute significantly to the higher mineralised fluids found in Baslay-Danin e.g. San Miguel.

The chemistry of Baslay-Danin waters should not be studied in isolation when reservoir chemistry from the present geothermal development in Palinpinon is available. To produce composition found in the higher chloride springs (e.g. San Miguel, Masaplod and Lipayo) from reservoir fluid similar to that presently tapped in Puhagan, would require a 5:1 minimum dilution assuming mixing with low temperature, zero chloride meteoric water. This dilution calculation considers mixing alone and ignores any mineralization attributable to acid leaching.

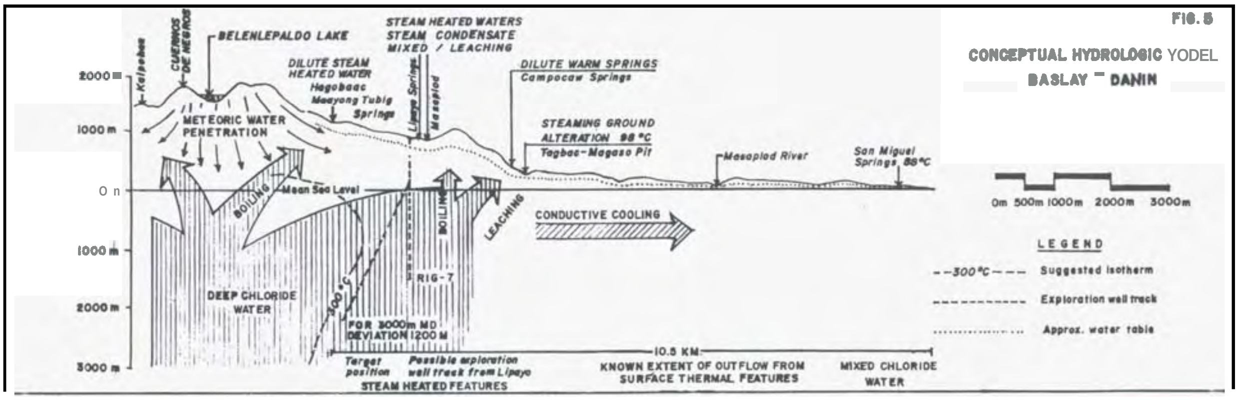
It is unlikely that any one process operates specifically to produce the spring compositions encountered. A more reasonable explanation is that a complex interaction of mixing, leaching, boiling and conductive cooling occurs.

Temperatures calculated from silica concentrations based on amorphous silica solubility match measured temperatures for springs (table 3). Spring chemistry therefore, is largely controlled by near surface processes.

Although various gas geothermometers were applied to fumaroles at Tagbac-Magaso, shallow surface effects on gas composition render results of doubtful significance.

CONCLUSIONS

A conceptual model that is consistent with both the field evidence from the Baslay-Danin area given above and the considerable amounts of reser-



voir data that have been obtained in the intensively drilled Puhagan and Nasuji-Sogongon field sectors (see Maunder et al, 1982), is shown in fig. 5.

It is considered that Baslay-Danin represents one sector of a large hydrothermal system associated with the late Quaternary, Cuernos de Negros volcanic complex. Indications from deeper penetrating resistivity methods are, that Baslay-Danin bears a direct relationship with the fluids currently produced in both the Puhagan and Nasuji-Sogongon sectors to the north, in the Okoy valley.

Any attempt at exploration drilling should then, take into consideration that the geoscientific appraisal here, marks the Baslay-Danin prospect as a low elevation outflow, from the Cuernos de Negros area.

The fact that Baslay-Danin represents a possible large, deep, broad outflow from a parent source some distance away, does not prevent it from possessing temperatures and permeabilities suitable for future power generation. The exact proximity this outflow has to the parent source is as yet unknown and can only be tested by drilling. However it should be noted that from considerations as to the symmetry of the Puhagan resource which shows isotherms unclosed and temperatures increasing to the SE i.e. towards Cuernos de Negros, it appears likely that exploration drilling from wellsites located in the high western and northern areas of Baslay-Danin, may succeed in encountering a resource just as attractive as Puhagan and Nasuji-Sogongon.

An exploration drilling strategy based on these views has been forwarded and four (4) sites are shown in fig. 1. A three (3) well. exploration drilling programme designed to start November, 1982 will test the model put forward here.

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