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Development Potential of the Dauin Geothermal Prospect, Negros Oriental, Philippines

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ABSTRACT

The Dauin geothermal prospect, situated 5 km southeast of the Palinpinon I and II sectors, was drilled between 1982 and 1983 to test its viability for development. Drilling results indicated that DN-1 was drilled closer to the source region than DN-2 where permeability, temperature, and alteration mineralogy were generally unpromising. DN-1 encountered temperatures of at least 240°C and a neutral-pH fluid with reservoir chloride of 3000 mg/kg. In particular, the presence of sulphur in the DN-1 discharge provoked debates and many speculation on the nature of the fluid in the area. The area was re-evaluated in 1996 for the following reasons: 1) Renewed interests on other geothermal prospects within Negros Island from an economic point of view and the success of modular plant developments are Pal II and other areas in the Philippines; 2) Reinterpretation of the genesis of sulphur contained in the DN-1 discharge fluid; 3) Encouraging temperature, permeability and neutral-pH alterations at depth and the neutral character of DN-1 discharge fluid; and 4) Reinterpretation of the hydrological model from a geochemical and geological point of view. The study indicates good potential for modular power development.

Introduction

The Dauin geothermal prospect (previously called Baslay-Dauin geothermal prospect is located about 5 km southeast of the 192.5 Mwe Palipinon Geothermal Project (Figure 1). Between 1973 to 1977 surface exploration works in the Palinpinon and the Baslay-Dauin prospects were undertaken to establish the potential of the two areas for advanced geothermal exploration study. Although the thermal features within the Baslay-Dauin area appear more extensive and attractive, the Palinpinon geothermal field was chosen for advanced exploration because of indications for high subsurface temperature (>250°C) and a more coherent hydrological model than Baslay-Dauin. The ensuing phases of exploration activities were thus focused in the Palinpinon area. Interest in the prospect was renewed in 1981, to complete the geoscientific appraisal and to establish the hydrological relationship of Baslay-Dauin to the Palipinon field. Thus, additional investigations were initiated comprising tandem geochemical-geological studies and regional Schlumberger and vertical electrical soundings to complement and validate earlier data.

Harper and Arevado (1982) presented and exploration model, which considered the area as a low-elevation-outflow from a large hydrothermal system, associated with the Late

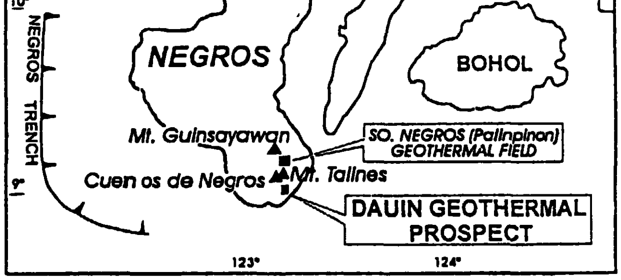

Figure 1. Location map of the Dauin geothermal prospect showing its relative location with respect to the Palinpinon geothermal field in the north, the distribution of Quaternary volcanic centres from north to south and the Negros Trench to the west.

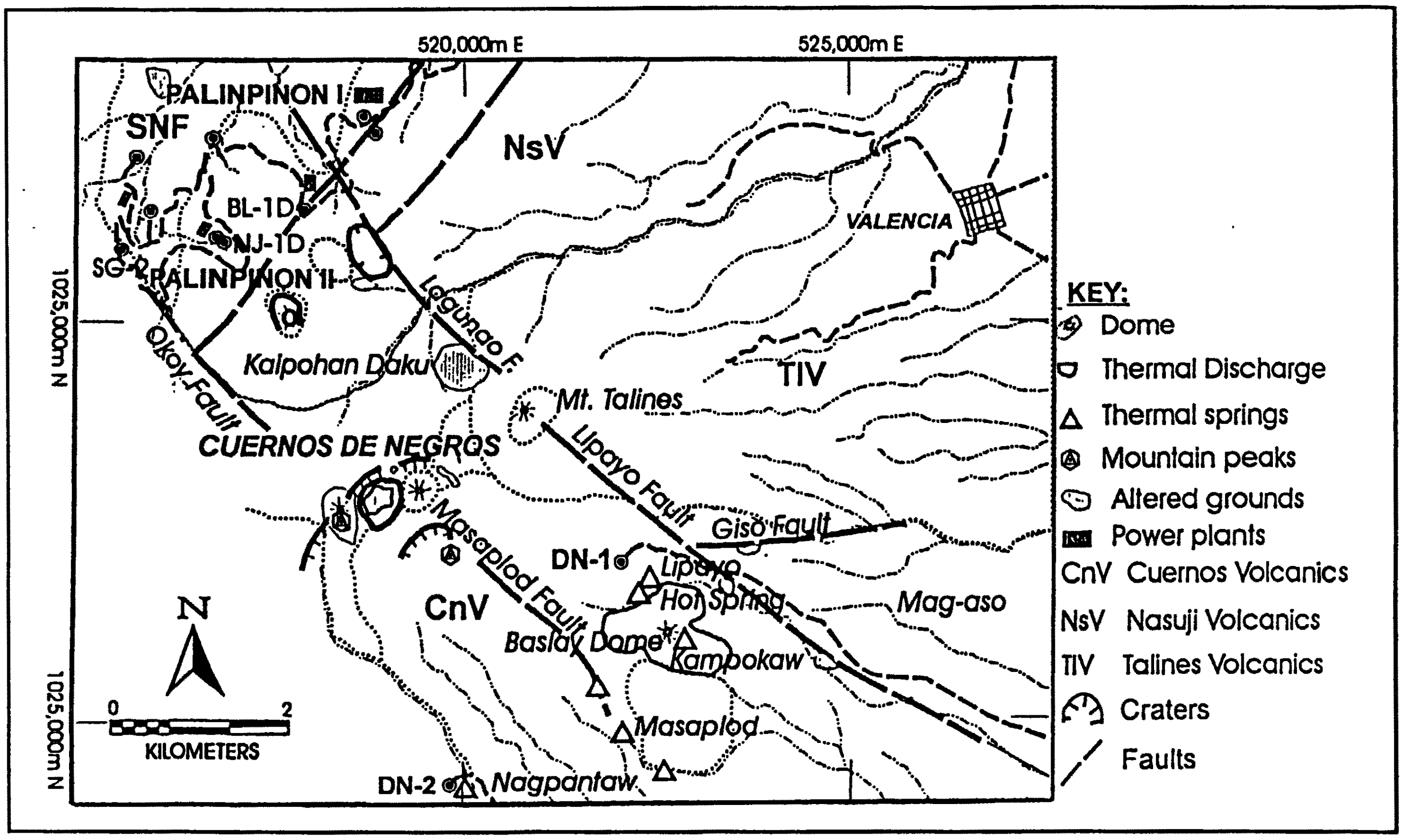

Figure 2. Surface geology, volcanic features and major structures. Palpinpinon I and II are shown at the northeast quadrant. Wells DN-1 and DN-2 of the Dauin geothermal prospect are found south of the area including the major thermal springs and thermal discharges.

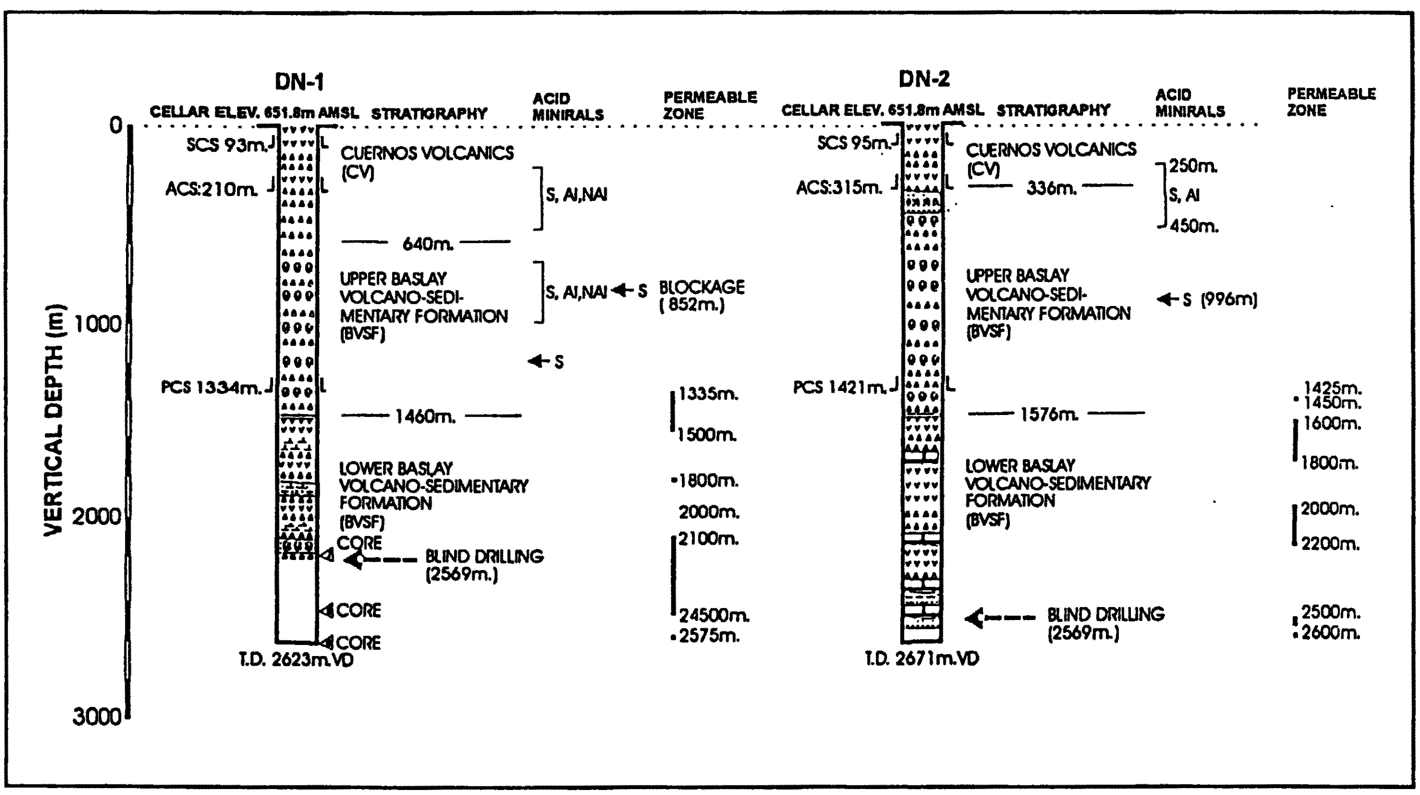

Figure 3. Stratigraphy, location of acid ateration mineralogy and permeable zones in wells DN-1 and DN-2 *(Petrology after Reyes, 1983).*

Table 1. Water Chemistry of Dauin Thermal Areas.

Sample Code	Sampling Date	Flow (kg/s)	Temp. (°C)	pH	Na	K	Li	Ca	Mg	Cl	SO_4	HCO_3	tCO_2	H_2S	B	SiO_2	NH_3
					Concentration in mg/L												
San Miguel	10/16/81	1.2	87.0	2.16	119	11.2	0.2	235	54.7	993	220	0	217	0	4.9	296	2.7
Lipayo #2	12/29/81	0.50	48.0	6.70	48	8.1	0.04	74	29.8	75	87	na	nd	nd	0.71	137	0.70
	05/18/82	0.76	46.5	6.18	50	8.6	0.04	82	30.6	11	90	na	561	0.65	2.24	150	0.22
	12/12/82	1.06	46.0	6.48	51	7.9	0.04	84	30.0	nd	97	na	nd	nd	1.78	162	0.14
	07/04/89	nd	42.0	6.07	47	9.0	0.04	88	31.2	56	89	329	621	0.17	0.56	141	0.23
	10/12/94	0.70	45.0	7.67	45	11.4	nd	64	85.0	111	208	308	229	nd	1.94	170	0.19
	05/25/96	0.94	47.0	3.51	51	10.2	nd	76	28.0	113	860	nd	178	nd	0.10	154	0.10
	10/27/96	0.94	44.0	6.16	nd	15.5	nd	73	27.8	70	160	84	279	0.68	0.49	152	0.04
Lipayo #3	05/25/96	nd	32.0	3.21	16	5.4	nd	32	9.0	28	100	0.00	321	0.00	0.32	111	0.04
	10/27/96	nd	30.0	5.57	nd	6.0	nd	34.5	8.4	14	180	73.69	297	0.68	0.43	113	0.24
Masaplod #3	12/29/81	8.82	61.1	2.01	93	29.9	0.1	38	26.8	603	1659	na	176	7.49	6.99	190	0.63
	05/18/82	12.50	59.5	1.61	93	30.5	0.1	35	30.5	656	1817	na	229	6.07	0.27	181	0.54
	12/12/82	15.80	60.0	2.07	96	30.7	0.1	82	31.1	646	1761	na	na	nd	7.12	204	0.66
	07/26/89	nd	60.0	1.97	94	27.4	0.1	110	31.8	402	851	na	15	0.34	4.75	204	na
	10/27/94	4.50	61.0	2.47	100	36.4	nd	98	84.6	515	1440	na	na	nd	5.94	214	na
	05/26/96	4.50	62.0	1.97	101	28.9	nd	82	30.5	599	300	na	na	nd	5.84	192	0.18
	10/27/96	4.70	60.0	1.96	96	25.0	nd	76	31.0	561	1460	na	na	0.68	5.16	193	1.88
Campocaw-3	09/18/81	0.81	33.6	7.58	61	12.8	0.1	93	56.0	192	196	329	12	9.80	1.64	137	0.81
	06/01/96	nd		7.88	13	4.8	0.0	22	11.0	28	60	1.89	86	nd	0.38	90	0.03

N.B. Data were after Glover, 1975; Harper and Arevalo, 1982; and Mejorada, 1996 nd - no data; na – no analysis

Quaternary Cuernos de Negros volcanic complex. The study proposed a three-well exploration-drilling program to test the model, which was thought to be similar to that of Palinpinon in the north which is also associated with Cuernos de Negros.

This paper presents the results of subsequent drilling, and re-evaluations made in 1994 and 1996 for the following reasons: 1) renewed interest in other geothermal prospects within Negros island from an economic point of view and the success of modular power developments at Palinpinon II and in other parts of the Philippines; 2) re-interpretation of the genesis of sulphur contained in the DN-1 discharge fluid; 3) encouraging temperature, permeability, and neutral-pH alterations at depth and neutral character of DN-1 discharge fluid, and 4) reinterpretation of the hydrological model from a geochemical and geological point of view.

Tectonic Setting

The Palinpinon geothermal field and the Baslay-Dauin geothermal prospect from the part of the west-facing Negros Island - arc system defined from north to south by the Mts. Silay, Mandalagan, Canlaon and Cuernos de Negros - a belt of Quaternary volcanos (Figures 1 and 2) produced by subduction of the Sulu Sea basin along the Negros trench since Miocene time (Hamilton, 1979).

The Negros trench extends regionally northward to the west of Panay island to the Mindoro -Tablas collision zone (Rangin et al., 1991) and connects to the east subducting Manila trench. The southward extension of the Negros trench appears to be contiguous with the subduction along the Cotabato trench (Sajona, 1992).

The presence of shallow - to intermediate-depth earthquake hypocenters suggested that the east-northwest subducting slab has penetrated to 150 km underneath the Negros arc (Archarya and Aggarwal, 1980).

Surface Geology, Stratigraphy and Structures

The prospect in underlain by at least two formations as encountered in wells DN-1 and DN-2. The youngest rock unit exposed at the surface is the Pleistocene to Recent Cuernos Volcanics (CV), (Figures 2 and 3). It is comprised of clinopyroxene hornblende andesite lava flows, Pyroclastics, and volcanic breccias with minor dacite lava flows. 365 m thickness of the CV was encountered in well DN-1 and 336 m in well DN-2. This unit was deposited sub-areally as attested by the presence of intercalated paleosols (Reyes, 1983a, 1983b; Gonzales, 1983a; Hermoso, 1983).

Underlying the CV is the Plio-Pleistocene Upper member of the Baslay Volcano-Sedimentary Formation (BVSF). It is made up of fresh to weakly altered andesitic to dacitic crystal tuff, volcaniclastic breccias, and hornblende-clinopyroxene andesite lava flows intercalated with thin lenses of fossiliferous calcarenite and cacisilitie. This sub-unit was deposited in a submarine environment. The formation has been encountered in DN-1 from 635 to 1455 m (820 m thick) while DN-2, from 336 to 1576 m (~1240 thick). This unit is separated from the younger CV by the presence of a 30 m paleosol layer in DN-1 while a paleosol and an intensely altered volcanic breccia mark the formational boundary in DN-2 (Figure 3).

The underlying Lower member of the BVSF, having an older of lower Pliocene, is also composed of andesite lava flows but can be distinguished from the upper member by the presence of intercalated fossiliferous calcarenites, calcisiltites, and limestones. This sub-unit has not been bottomed-out by both DN-1 and DN-2. It has been encountered in DN-1 from 1455 m until its total depth of 2618 m (~1163 m thick). Like-

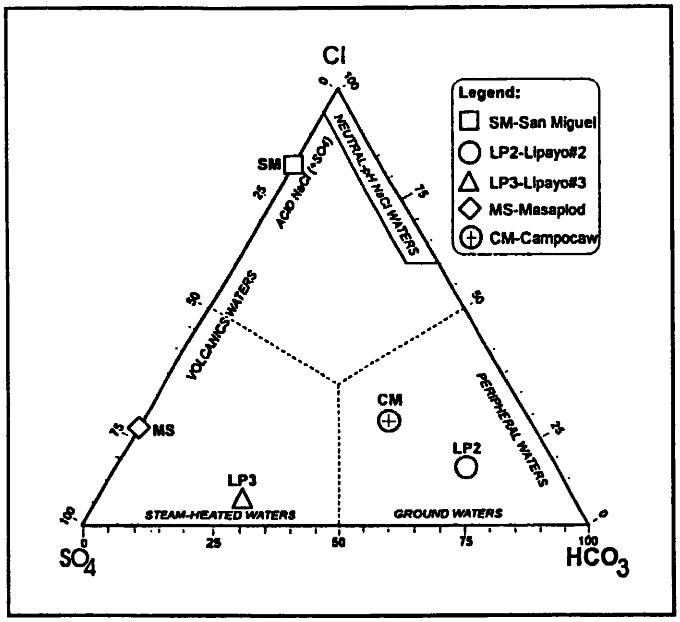

Figure 4. Terary plot of Baslay-Dauin springs.

wise, it is present in DN-2 from 1576 m down to its total depth of 2671 m (~1095 m thick).

Bases on the geothermal lithologic characteristics and age data, the three units encountered in DN-1 and DN-2 can be correlated with the formations encountered in the Puhagan and Nasuji-Sogongon sectors of the Palinpinon geothermal field. The CV is also the youngest volcanics exposed in the field. The underlying Plio-Pleistcene member of the BVSF can similarly correlated with the Late Pliocene to Early Pleistocene lower member of the BVSF can thus be correlated with the Early Pliocene Okoy Sedimentary Formation, ISF, (Pamatian, 1992). The formations equivalent to the Miocene Puhagan Volcaniclastic Formation (PVF) and the Late Miocene Nasuji Pluton (NP) encountered at deeper levels of Nasuji sector were not encountered so far by the two wells in the Dauin Geothermal prospect. Units equivalent to NP and the PVF are likely present

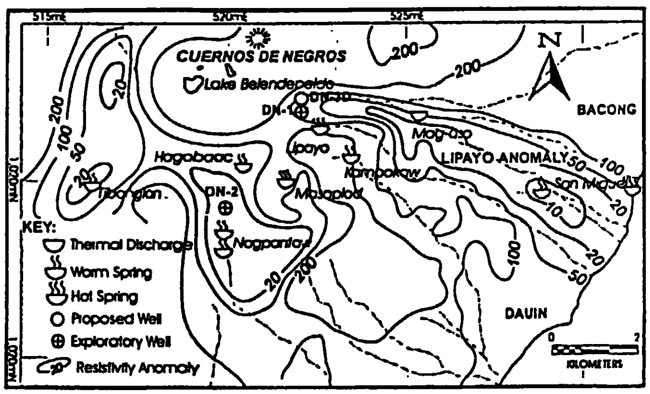

Figure 5. Lipayo iso-resistivity anomaly, Dauin geothermal prospect (After Layugan and Maneja, 1992). Also shown are the location of wells DN-1, DN-2 and the proposed well DN-3D. Note the location of Lipayo, Mag-aso and San Miguel springs.

at deeper levels in the prospect and are beyond the drilled depths.

Permeability in the prospect is mainly due to faulting and secondary fracturing. Intra- and inter-formational contract permeability have been noted during the drilling but only as minor channels. In contrast to the Palinpinon field, the Dauin prospect is not extensively transected by minor fault structures. The younger volcanic deposits consisting of extensive lahar deposits, flow breccias and pyroclastic flows may have obscured the fault structures since the presence of impressive hotsprings and steaming grounds attest to subsurface permeability and fluid flow.

Among the faults mapped in the Dauin prospect, two faults, the Lipayo and Masaplod Faults, and their branches are thought to control the distribution of most thermal features. (Figure 2). The Lipayo Fault channels and visibly controls the Lipayo, Campocaw, Mag-aso, and the San Miguel springs. This fault is considered the southern extension of the Lagunao Fault in Palinpinon (Tebar and Pamatian, 1990). The Masaplod Fault southwest of the area invariably controls the Masaplod springs. This structure possibly extends northwest and was correlated with the Okoy Fault by Pamatian (1992).

Geochemistry

The water chemistry of the thermal features was reviewed by Harper and Arevalo (1982) and is summarized here in Table 1 together with new data collected in 1996.

The surface chemistry of the Baslay-Dauin thermal springs consists of acidic chloride-sulphate and dilute neutral chloride-bicarbonate waters with pH of 1.6 (e.g., Masaplod) to 7.8 (e.g, Campokw). The chemistry of the springs indicates that they are controlled by near-surface processes. Hence, geothermometric estimates using solute geothermometers are meaningless. A ternary plot of anionic constituents of the sprongs is given in Figure 4. The spring flowrates range from .50 kg/s to 15.8 kg/s (e.g., Masaplod); surface temperatures ranged from 30 to 87°C. Masaplod, Lipayo, and San Miguel springs exhibit the highest chloride and temperature but are acid and typically contain native sulphur in their discharge path (Glover, 1975).

Geophysics

The most recent geophysical studies in Southern Negros have encompassed the Palinpinon field and Baslay-Dauin prospect (Layugan and Maneja, 1992). Thee include 35 new vertical electrical sounding stations completed in the north, northeast, and southern quadrant of Cuernos de Negros, and covered much of Baslay-Dauin and Valencia. The work likewise reviewed and integrated all earlier Schlumberger resistivity traverses (Bromley, 1982) and those completed between 1974 to 1979 by the Commission on Volcanology (now called Philippine Institute of Volcanology and Seismology or PHIVOLCS).

The latest surveys have confirmed earlier results in terms of the regional distribution of shallow resistivity anomalies both at Palinpinon and Baslay-Dauin (Figure5).

Table 2. Well DN-1 Data and Other Discharge Information.

Sample Code	Sampling Date	Depth (m VD)	pH	Na	K	Li	Ca	Mg	Cl	SO_4	tCO_2	H_2S	B	SiO_2	NH_3
					Concentration units in mg/L										
(weirbox)	05/28/83	-	6.78	2809	270	2.27	18	11.5	4006	1073	12	77.6	56.9	192	10.40
-do-	05/29/83	-	6.69	2809	270	2.65	18	11.5	4042	310	18	47.6	77.6	565	12.80
-do-	05/30/83	-	7.01	2859	274	2.65	15	11.8	4538	215	10	56.6	80.4	576	12.60
(downhole)	02/26/83	1900	7.85	1066	83	5.70	107	5.9	1375	413	356	10.9	20.6	392	7.70
-do-	02/26/83	2450	4.16	1045	84	2.35	38	6.6	1429	863	76	40.6	25.2	503	10.80
-do-	03/23/83	2600	6.20	1148	84	2.37	nd	1.6	1525	75	856	479	9.8	435	6.40
-do-	03/26/83	2200	5.48	1377	102	1.25	nd	7.7	1964	135	260	390	33.2	470	
-do-	04/16/83	1450	4.60	1236	131	1.00	81	42.9	1786	774	682	2.4	31.1	67	
-do-	04/16/83	1900	2.38	1267	131	.1.05	11	21.1	1786	613	580	3.4	31.9	110	
-do-	04/16/83	2200	4.70	1387	137	1.10	75	35.3	1914	555	8141	-	32.7	79	

WHP (Mpaa)	H° (kg/kj)	MF (kg/s)	Power Pot. (Mwe)	Permeable Zone (m VD)	Fluid Type	Temp. (°C)
0.41	806	45.8	0.9	1335-1500 1800 2100-2450 2575- Bottom	2 phase 2 phase water water	220 228 238 240

In addition, the interpretations at Baslay-Dauin have been refined with the better delineation of the Lipayo anomaly, a narrow anomaly (9 km by .9 to 3 km) which is defined by DN-1 n the west and by the San Miguel springs to the southeast. This 10-30 ohm-meter anomaly coincides with the Lipayo, Nagpantaw, Campokaw, Mag-aso and San Miguel thermal springs.

The Baslay dome exhibits high resistivity values (80 to 200 ohm-meter) and separates the Lipayo and Nagpantaw anomalies previously reported by Harper and Arevalo (1982).

Finally, northeast-southwest oriented high resistive body (<100 to 300 ohm-m) within Tibanglan, Cuernos de Negros, Mt. Talines and Valencia characterize the northern part of the Lipayo anomaly.

Drilling and Discharge Testing Results

Well DN-1

DN-1 the first exploratory vertical well was drilled in 1982 down to 2624 m to test the hypothesis that the geothermal source is located close to Cuernos de Negros and the Lipayo resistivity anomaly (Hermoso et al., 1989).

The well was subsequently discharged by boiler stimulation in May 1983. Table 2 summarizes the available gas chemistry of same well.

The most unusual aspect of the well discharge was the presence of significant mount of amorphous elemental sulfur accompanying the darkish-greenish to dark-grey (at throttled condition) near neutral discharge fluid (pH=6.40 to 7.20).

During the second day of continuous well discharge through the silencer, minor leaks appeared in the discharge lines to the silencer. Attempts to repair the line had been made by bleeding the well to no avail. Thus, the well was placed on vertical discharge while welding was being made. However, these were constrained by the sulphur fall-out and the H_2S concentration which caused eye irritations to the crews. As a result the well was again by-passed to the silencer during attempts to install a second tee. Unfortunately, the well was shut three days after its discharge when leaks in the well head tee aggravated by May 31, 1983. It developed gas pressure of 1.2 MPag upon shut condition. This declined to .34 MPag on the second day and ultimately fell to zero after three days.

The water chemistry for DN-1 discharge and downhole sample data revealed the following: 1) presence of near-neutral pH (i.e., 6.40 to 7.20); 2) high sulphate (SO_4^{-2})concentration 250 to 300 mg/kg; 3) H_2S concentration of 50 mg/kg (wierbox); 4) presence of elemental sulphur in the discharge fluid; 5) calculated geothermometer temperatures of 238 to 241°C; 6) Cl/B ratio of 16 to 17 and; 7) reservoir chloride of about 3300 mg/kg.

The gas chemistry of DN-1 indicates: 1) CO_2 and H_2S were the main component of the discharge and occurred in almost same proportion; 2) CO_2 and H_2S levels in the well were much higher than wells in Palinpinon 2; 3) H_2S concentrations is 200

Table 3. DN-1 Gas Chemistry.

Sample Code	Sample Date	CO_2	H_2S	NH_3	R	H_2	O_2	N_2	CH_4	CO_2/H_2S
		Concentration units in mmoles/100 moles steam								
DN-1	05/24/83	2651	2250	nd	85.10	nd	nd	nd	nd	1.18
	05/28/83	2490	2165	nd	77.70	nd	nd	nd	nd	1.15
	05/29/83	2629	1349	5.90	15.70	0.25	0.02	3.30	12.10	1.95

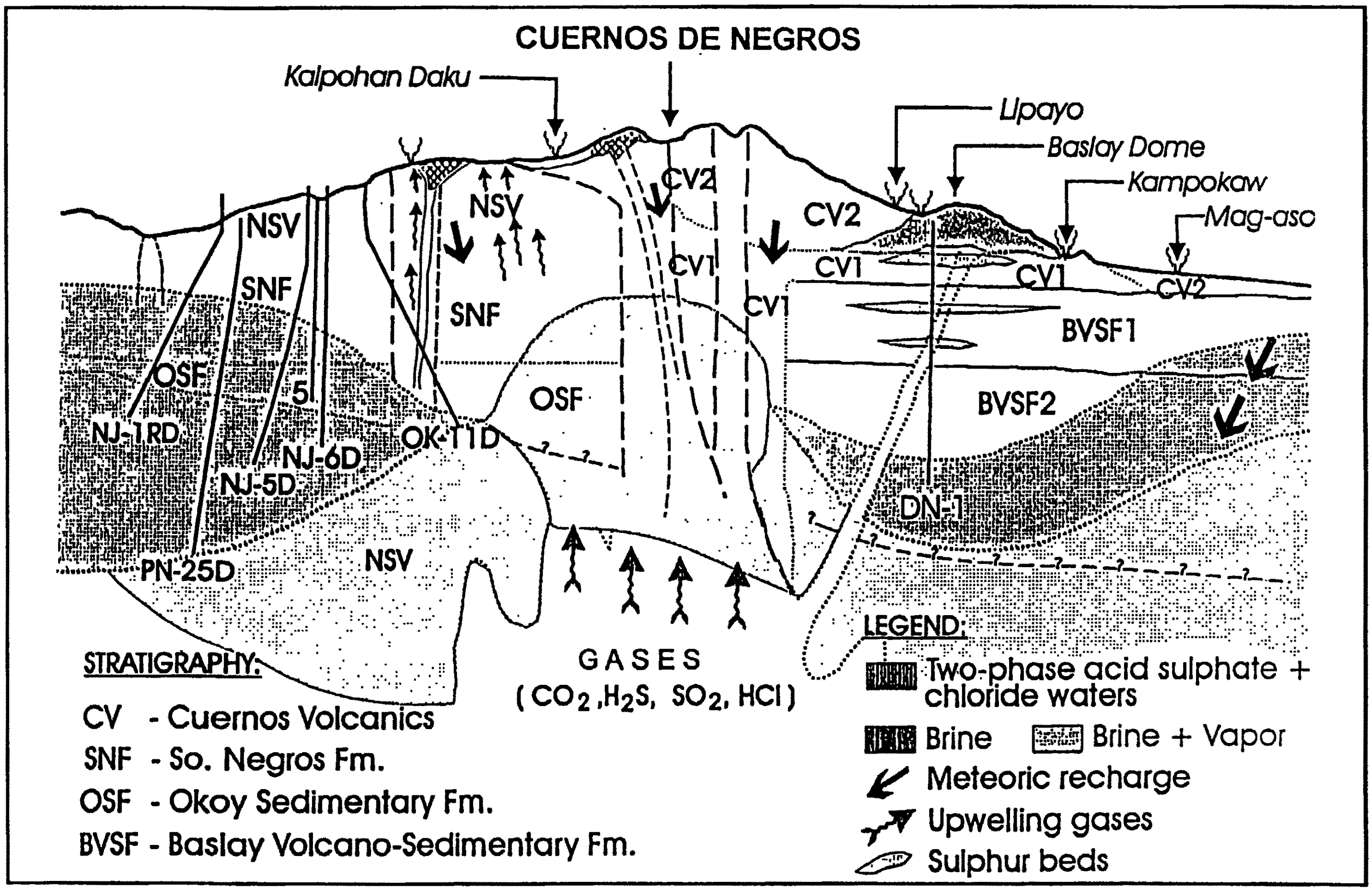

Figure 6. A north-south section of the Palinpinon geothermal field and the Dauin geothermal prospect illustrating a hypothetical model of the resource.

to 300 times higher than the neutral-chloride wells in Palinpinon 1 and 10 times higher than the acidic wells in Palinpinon 2 (e.g., NJ-1D, NJ-2D and BL-1D).

Well DN-2

DN-2, the second vertical exploratory well was drilled in 1983 to a depth of 2670 m at a distance of about 4 km. From well DN-1 and approximately 400 m north of the acid-sulphate Nagpantaw hotspring (Hermoso et al., 1989). This well was sited in the area to test the southernmost extension of the postulated resource manifested by the Nagpantaw low-resistivity anomaly. Furthermore, the decision to locate the well distant from its original location was due to the result of DN-1 and concerns on possible acidity in the area.

No discharge data is available for well was never discharged due to low bottom hole temperature (about 180° C) and poor permeability (injectively = 18 l/s-MPa with positive well head pressure). Downhole samples from DN-2 showed chloride of 656 mg/kg, low CO_2 and H_2S but high sulphate values (450 mg/kg). The downhole pH ranged from 6.3 to 7.20 at 25°C. The data, however, reflect typical chemical values in newly drilled wells. For example, the high sulphate normally results from the oxidation of H_2S with completion test fluid and in no way characterize the true chemistry of the well.

Conclusions

The results of initial two-well exploratory drilling and the geochemistry of the surface thermal discharges clearly demonstrate the unique characteristics of the Dauin geothermal prospect. This study argues for the presence of a neutral-pH exploitable resource close to the area drilled by DN-1 (Figure 6).

The abundance of acid sulphate thermal discharges show the area where outflowing geothermal brine has come in contact with discrete zones of elemental sulphur. Deep drilling of DN-1 shows the presence of a 240°C, near neutral pH waters with high H_2S in the steam phase.

Two geothermal areas similar to Dauin are the Rotokawa, New Zealand and the Tatun, N. Taiwan which are in the advanced stage of deep drilling. At Rotokawa, sulphur containing beds occur at depths of about 100 meters. Deep drill holes (300 to 1200 m) tapped 200 to 250°C, neutral pH, dilute alkali-Cl waters, with the rising geothermal waters encountering sulphur beds at shallow depths producing the acidic (pH = 2.1 to 2.5), high sulphate (500-1000 mg/kg) spring waters associated with high H_2S output (Ellis and Giggenbach, 1971; Krupp and Seaward, 1987).

The available data, thus strongly indicate the development potential of Dauin geothermal prospect. Although the present resource estimate on size of the resource was placed at 20

MWe, this is considered here as conservative. The present information from the two wells needs to be supplemented and the best direction requires the drilling of a new well, DN-3D and the subsequent work-over of DN-1.

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