

# 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. On the other hand, DN-1 encountered temperature of at least 240 °C, neutral-pH fluid with reservoir chloride of 3000 mg/kg. In particular, the presence of sulphur in the DN-1 discharge provoked debates and much speculations 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 prospect within the Negros Island from an economic point of view and the success of modular plant development at Pal II and other areas in the Philippines; 2) Reinterpretation of the genesis of sulphur contained in DN-1 discharge fluid; 3) Encouraging temperature, permeability and neutral-pH alterations at depth and that of DN-1 discharge fluid; and 4) Reinterpretation of the hydrological model from geochemical and geological point of view.

The study indicates good potential for modular power development. Two approaches are examined to further characterise the area and address concerns pertaining to future development

## 1.0 Introduction

The Dauin geothermal prospect (previously called Baslay- Dauin geothermal prospect) is located about 5 km. southeast of the 192.5 MWe Palinpinon Geothermal Project (Fig. 1). Between 1973 to 1977 surface exploration works in Palinpinon and the Baslay-Dauin prospects have been 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 based on high subsurface temperature (>250°C) and more coherent hydrological model compared with Baslay-Dauin. The ensuing phases of exploration activities were thus focused in Palinpinon. Renewed interest in the prospect began in 1981 to complete the geoscientific appraisal not only to evaluate it in

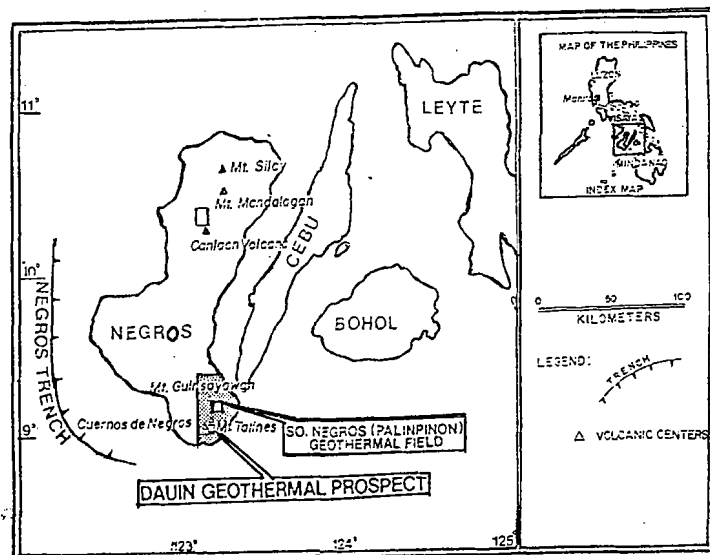


Fig. 1. Location map of the Dauin geothermal prospect showing its relative location with respect to the Palinpinon geothermal field in the north, the distribution of Quaternary centres from north to south and the Negros Trench to the west.

isolation but also to establish its regional potential. Thus, additional follow-through investigations were initiated comprising of tandem geochemical-geological studies and regional Schlumberger and vertical electrical soundings to complement and validate earlier data.

Harper and Arevalo (1982) presented an exploration model which considers the area as a low-elevation-outflow of a large hydrothermal system associated with the Late 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.

This paper presents the drilling results and a reevaluation made in 1994 and 1996 for the following reasons: 1) renewed interest on other geothermal prospect within Negros island from an economic point of view and the success of modular power development at Palinpinon 2 and other parts of the Philippines; 2) re-interpretation of the genesis of sulphur contained in the discharge of well DN-1; 3) encouraging temperature, permeability, and neutral-pH alteration at depth and its initial Qscharge; and 4) refinements of the hydrological model in the light of new geological and geochemical surveys and interpretations in 1996.

### 2.0 Tectonic Setting

The Palinpinon geothermal field and the Baslay-Dauin geothermal prospect form 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 volcanoes (Figs. 1 and 2). The system is associated with the east-northeast facing subducting 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 suggests that the east-northeast subducting slab has penetrated to 150 km underneath the Negros arc (Acharya and Aggarwal, 1980).

### 3.0 Surface Geology, Stratigraphy and Structures

The prospect is 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). It is comprised of clinopyroxene-hornblende andesite lava flows, pyroclastics, and volcanic breccias with minor dacite lava flows. This unit was encountered in DN-1 from the surface to 635m while it was present in DN-2 down to 336m. This unit was deposited sub-areally as attested by the presence of intercalated paleosols (Reyes, 1983; Gonzales, 1983; Hermoso, 1983). Underlying the CV is the Plio-Pleistocene Upper member of the Baslay Volcano-Sedimentary Formation (BVSF).

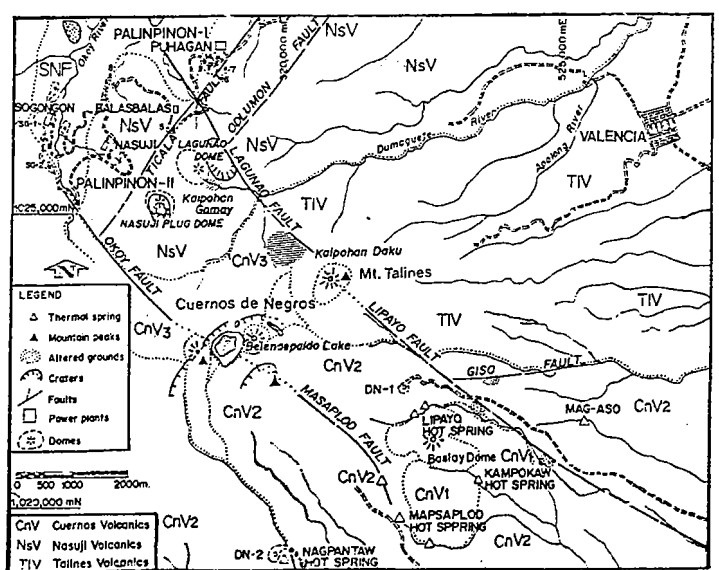


Fig. 2. Surface geology, volcanic features and major structures. Palinpinon 1 and 2 are shown at the north east quadrant. Wells DN-1 and DN-2 of the Dauin geothermal prospect are found south of the area including the major thermal springs.

It is made up of fresh to weakly altered andesitic to dacitic crystal tuff, volcanoclastic breccias, and hornblende-clinopyroxene andesite lava flows. This sub-unit was deposited in a submarine environment. The formation has been encountered in DN-1 from 635 to 1455m while in DN-2, from 336 to 1576m. 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 (Fig. 3).

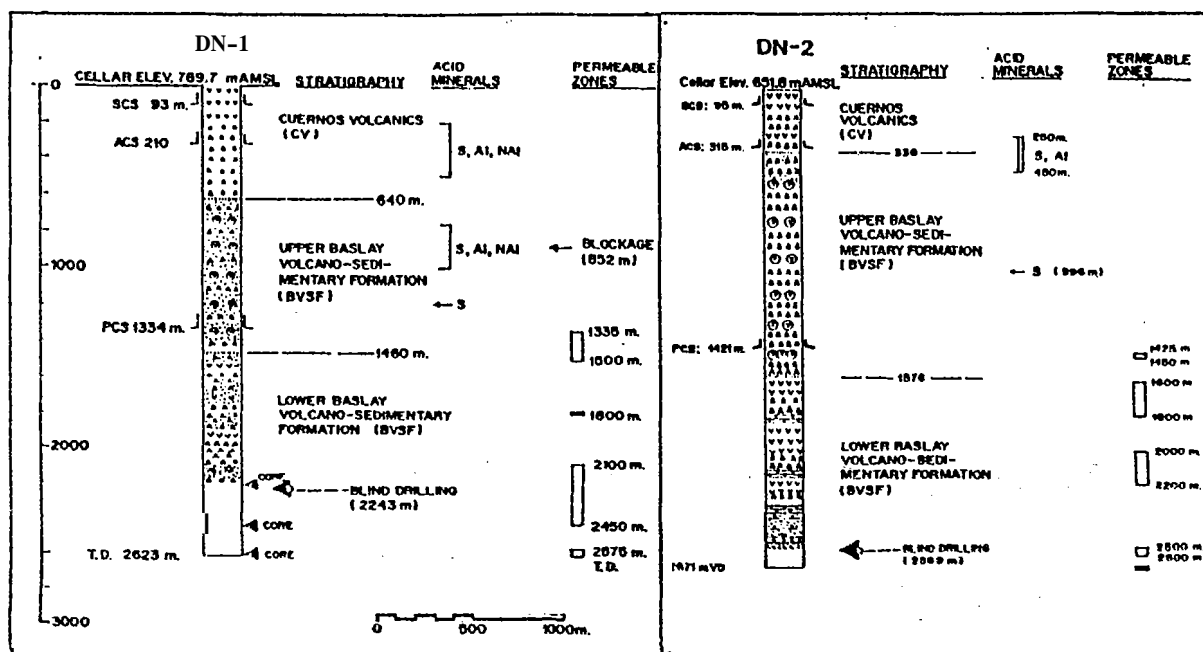


Fig. 3. Stratigraphy, location of acid alteration mineralogy and permeable zones in wells DN-1 and DN-2 (Petrology after Reyes, 1983)

The underlying Lower member of the BVSF, having an older age of Lower Pliocene, is also composed of andesitic to dacitic crystal tuff, volcanic breccias, and 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 1455m until its total depth of 2618m. Likewise, it is present in DN-2 from 1576m down to its total depth of 2671m.

Based on the general 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 Pliocene-Pleistocene member of the BVSF can be similarly correlated with the Late Pliocene to Early Pleistocene Southern Negros Formation (SNF). The Lower Pliocene lower member of the BVSF can thus be correlated with the Early Pliocene Okoy Sedimentary Formation, OSF, (Pamatian, 1992). The formations equivalent to the Miocene Puhagan Volcanoclastic 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 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 contact 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 major 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, called Lipayo and Masaplod Faults, and their branches are thought to control the distribution of **most** thermal features. (Fig. 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 Laguna Fault in Palipinon (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).

#### 4.0 Geochemistry

The water chemistry of the selected thermal features have been reviewed by Harper and Arevalo (1982). Table 1 summarises the water chemistry. It includes the previous and the new data collected in 1996.

**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 <sub>4</sub>	HCO <sub>3</sub>	tCO <sub>2</sub>	H <sub>2</sub> S	B	SiO <sub>2</sub>	NH <sub>3</sub>
					Concentration units 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	4x	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	nd
	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	273	0.68	0.49	152	0.19
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	21.4	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	144C	na	na	na	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	113	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			7.88	13	4.8	0.0	22	11.0	28	60	1.89	36	nd	0.38	90	0.03

\*nd-no data; na-no analysis

*N. E. Data were after Glover, 1975; Harper and Arevalo, 1982; and Mejorada, 1996)*

The surface chemistry of the Baslay-Dauin thermal springs consists of chloride-sulphate **and** dilute chloride-bicarbonate waters with pH of **1.9** (e.g., Masaplod) to **7.8** (e.g., Campocaw). The chemistry of the **springs** indicates that they were controlled by near-surface processes. Hence, geothermometric estimates using solute geothermometers are meaningless. The ternary plot of the springs is given on Fig. 4. The spring flowrates range from **.22 kg/s** to **12.1 kg/s** (e.g., Masaplod); surface temperatures ranged from **18** to **87° C**.

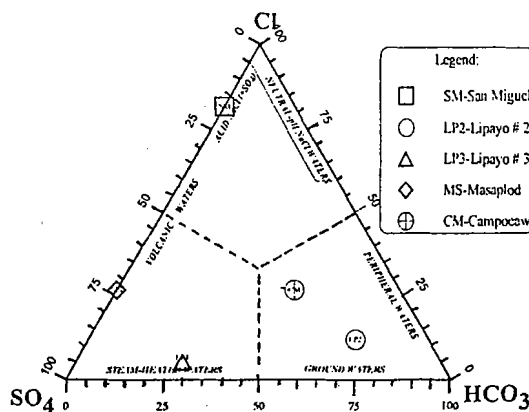
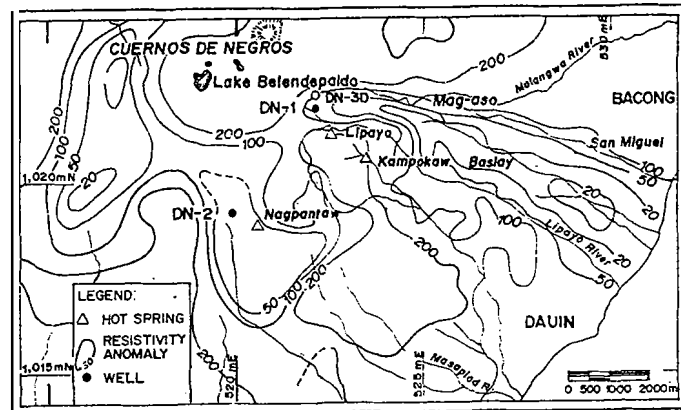


Fig. 4. Ternary plot of Dauin springs.

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).

## 5.0 Geophysics

The most recent geophysical works on the southern Negros island have encompassed the Palinpinon field and the Baslay-Dauin prospect (Layugan and Maneja, 1992). These included 35 new vertical electrical sounding stations north and 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).



**Fig. 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.

The latest survey have confirmed the results of earlier works in terms of the regional distribution of shallow resistivity anomalies both at Palinpinon and Baslay-Dauin (Fig. 5).

In addition, it refined the interpretations at Baslay-Dauin with the better delineation of the Lipayo anomaly, a narrow anomaly (9 km by .9 to 3 km) which is defined by DN-1 in 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 characterise the northern part of the Lipayo anomaly.

## 6.0 Drilling And Discharge Testing Results

DN-1 the first exploratory vertical well was drilled in 1982 down to 2623.6 m to test the hypothesis that the geothermal source is located close to Cuernos de Negros and the Lipayo resistivity anomaly.

The well subsequently discharged by boiler stimulation in May 1983. Table 2 summarises the well data and other discharge information. Table 3 summarises the available gas chemistry of same well.

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

**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 <sub>4</sub>	tCO <sub>2</sub>	H <sub>2</sub> S	B	SiO <sub>2</sub>	NH <sub>3</sub>
				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	

\*nd -no data (not analyzed)

PERMEABLE ZONES (m VD)	FLUID TYPE	TEMP. (°C)	WHP (MPag)	H° (kJ/kg)	MF (kg/s)	PowerPot. (MWe)
1335-1500	2 phase	220				
1800	2 phase	228	0.41	806	45.8	0.9
2100-2450	water	238				
2575 -BOTTOM	water	240				

**Table 3.** DN-1 Gas Chemistry

SAMPLE CODE	SAMPLING DATE	CO <sub>2</sub>	H <sub>2</sub> S	NH <sub>3</sub>	R	H <sub>2</sub>	O <sub>2</sub>	N <sub>2</sub>	CH <sub>4</sub>	CO <sub>2</sub> /H <sub>2</sub> S
		Concentration units in mmoles/100 mole 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

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 unbearable H<sub>2</sub>S 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<sub>4</sub><sup>-2</sup>) concentration 250 to 300 mg/kg; 3) H<sub>2</sub>S concentration of 50 mg/kg (weirbox); 4) presence of elemental sulphur in the discharge fluid; 5) calculated temperature 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<sub>2</sub> and H<sub>2</sub>S were the main component of the discharge and occurred in almost same proportion; 2) CO<sub>2</sub> and H<sub>2</sub>S levels in the well were much higher than wells in Palinpinon 2; 3) H<sub>2</sub>S concentrations is 200 to 300 times higher than the neutral-chloride wells in Palinpinon 1 and 10 times higher than the acid wells in Palinpinon 2 (e.g., NJ-1D, NJ-2D and BL-ID )

DN-2, the second vertical **exploratory** well was **drilled** in 1983 **down** to a depth of 2670 m at a distance of about 4 km. of DN-1 and approximately **400** m north of the acid-sulphate Nagpantaw hot spring. **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 in the area was due to the result of DN-1 and concerns on possible acidity in the area.

No discharge data is available for well DN-2 since the well was never discharged due to low bottom hole temperature (about 180°C) and poor permeability (injectivity = 18l/s-MPa with positive well head pressure).

## 7.0 The Sulphur Enigma

The presence of native sulphur in the discharge of DN-1 have provoked much speculations and debates about its depth of origin and genesis. The issue was made more interesting **by** the fact that the accompanying discharge fluid remained neutral (pH= 6.40 to 7.20) throughout the initial discharge since fluid in contact with native sulphur will ~~turn~~ acidic at **equilibrium** conditions.

Two views on the possible source location of sulphur at DN-1 are reviewed in **this** paper: 1) from the blind-drilled section, 2230 to 2623 m , Reyes, 1983 ; and 2) from a possible casing break between 850 to 930 m (Hermoso, 1996).

The speculation that sulphur could have originated from the **blind-drilled** section between 2230 and 2623 is premised on the following:

- 1) the absence of sample from **blind-drilled** section (2230 to 2623m);
- 2) the highest H<sub>2</sub>S levels detected at 2450m during downhole sampling and;
- 3) the “**H<sub>2</sub>S-reeking**” core 7 taken from 2217m, about 23m from the total loss zone where **blind-drilling** began.

The second speculation on the **depth** of origin implies a possible casing **break** between 850 to 930m (Hermoso, 1996). The strong evidences for this speculation are:

- 1) the presence of discrete acid alteration minerals between the postulated **depth** which included alunite and natroalunite, sulphur, **quartz**, pyrite and rutile (Reyes, 1983 and Villarosa, 1994).
- 2) the preponderance of acid alteration between 200 to 1200m pointing to the most likely source as the cased-off and cemented section.
- 3) all samples from 1307 to 2623m including cores 8 and 9 are devoid of acid alteration indicators and the predominant alteration suite including smectite, illite, chlorite, **quartz**, epidote, calcite and zeolite **suggest** the passage of neutral-pH within the said section.
- 4) sulphur when present in abundance is highly corrosive to casing and cement as was experienced in Rotokawa, New Zealand (Truesdell, **pers. comm.**, 1996).
- 5) the presence of blockage at 851m and the composition of the blockage (mainly cement and alunitized chips, Villarosa, 1994) interpreted to be a possible casing **break**.

The **first** argument on the source depth of sulphur appeared to be based on negative evidence rather than the physical presence of sulphur. The sample which reeked of hydrogen sulphide, however confirmed the **high** H<sub>2</sub>S level within the well but does not pinpoint specific depth location since **this** can be assimilated **by** the sample

during sample retrieval. The presence of high H<sub>2</sub>S level at 2450m from the downhole sample suggests that sulphur is present at depth in the form of sulphur species H<sub>2</sub>S but in no way identify any definitive depth of origin since downhole samples from newly drilled wells do not necessarily reflect stable well condition and is prone to subjective speculations.

The second argument and facts appear to provide better explanation for the source depth of sulphur and give tangible evidence compared with the former. This argument is corroborated by petrologic evidences and recent downhole surveys. It is argued here that the blockage at 850m is due to a casing break caused by the corrosive fluid at such depth. The presence of alunitized cement chips strongly argued for the casing break. Alunite, (K, Na)Al<sub>3</sub>(SO<sub>4</sub>)<sub>2</sub>(OH)<sub>6</sub>, when found as fresh euhedral crystals together with pyrite, quartz and sulphur has been used as positive indicator for the presence of acid fluids in Philippine geothermal wells (Reyes, 1990). Since no alunite mineral was found in the well except from 850 to 930m would support the casing break theory and that sulphur entered the well either as a result of corrosion or from casing implosion.

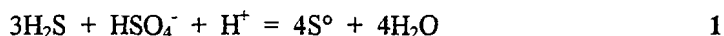
There are some doubts, however, on when the break occurred due to the absence of evidence for a casing break prior to the discharge and even a day prior to the shutting of the well. In fact, on May 30, 1983 the downhole survey tool reached 2600m (Harper and Clotworthy, 1983). The apparent difficulty in the initial attempt to conduct downhole survey were interpreted to be due to high mass flow conditions (>25 kg/s rather than due to blockage in the well. Thus, this would imply a depth source behind the casing with entry through the 1350 which is immediately below the production casing. Conversely, the fact that the survey tool is only 32 mm in diameter would similarly indicate that the blockage could not have been detected during the lowering of the instrument and only the 60 mm diameter "Go-devil" survey can detect it. The fact that alunitized cement chips were recovered from the 40 mm impression block would suggest the source being mainly from the cased-off section. The fact that the amount of sulphur discharge in the well never diminished would suggest a continuous replenishment within the well which is accompanied by notable change in colour of the weirbox fluid from dark green to dark grey at throttled conditions.

Thus, based on the DN-1 limited discharge the presence of discrete sulphur feed entering the well is proved. This feed mixes with the neutral fluid. However, it seems the contact time was insufficient to produce an acid fluid.

## 8.0 Genesis Of Sulphur at DN-1

The other question in the prospect area is the possible genesis of sulphur abundantly discharged at the weirbox. The sulphur can be coming from depth (as molten sulphur) or generated at the surface.

Several mechanisms for the formation of elemental sulphur have been invoked. Harper and Clotworthy (1983) suggested that the sulphur could form from the reservoir fluid from the following reaction:

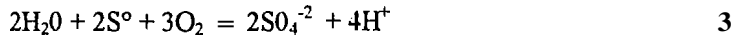


This is unlikely as the well discharged neutral waters, belying the presence of acidic reservoir fluids sufficient to generate the high amounts of sulphur at the weirbox.

However, the discharge fluids have very high H<sub>2</sub>S levels (200 times the neutral wells in Palinpinon). In this case, elemental S can easily be generated at the weirbox from the surface oxidation:

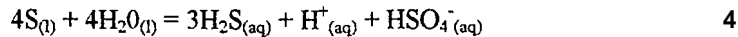


The complete sulphide oxidation process from equation 2 can be described **by**:



Although reaction 3 is thermodynamically favoured at the weirbox, it is kinetically inhibited and **needs** to be catalyzed **by** sulphur-oxidizing bacterium. It is for this reason that sulphide oxidation is not completed **to** produce the acid sulphate waters but is arrested until S formation only.

The other possibility forwarded is that the **S** is entering the well in its molten phase (melting point = 115°C) at depth (e.g., **from** the casing break at 850m and below or flowing behind the casing and entering at 1350m) and solidifies **upon** cooling at the weirbox. Sulphur hydrolysis is expected to **occur once** molten sulphur is in contact with water at high temperature as expressed **by** the reaction:



Thus, acidic sulphate -sulphide waters are expected at the surface discharge. **This** equation is favoured at high temperatures producing very high H<sub>2</sub>S gas output.

The neutral discharge of DN-1 suggests that active S hydrolysis is not occurring during the discharge testing. The very high H<sub>2</sub>S levels in the discharge would suggest reaction 4 occurring at some discrete points of the reservoir (e.g., presence of buried S bodies at shallow depths), with the acidic waters produced already effectively neutralised **by** the reservoir rocks (Truesdell, pers. comm., 1996). Thus, only the neutral high H<sub>2</sub>S waters **reach** the surface where **partial** H<sub>2</sub>S oxidation (reaction 2) produces the elemental S at the weirbox

From the above **discussions**, debates were similarly focused on whether sulphur produced the H<sub>2</sub>S by hydrolysis (shallow, non-magmatic source) or whether H<sub>2</sub>S at depth **as** suggested above, **produced** the sulphur (magmatic source).

The only available data on the isotopic composition of the elemental sulphur **from** DN-1 indicate  $\delta^{34}\text{S}$  value of -4 ‰ indicative of the kinetic fractionation during formation by oxidation of H<sub>2</sub>S with  $\delta^{34}\text{S}$  of around zero ‰ (Robinson, et al., 1987). **This** favours the formation of sulphur at shallow depth and the kinetic fractionation explains the neutral-pH of DN-1 discharge.

## 9.0 The Dauin Potential and Future Strategy

From the foregoing discussions we have examined the options for further works at Baslay-Dauin . Two options are identified: 1.) work-over of DN-I and 2) drill a new well, DN-3D (Candelaria, 1994), Bayrante (1996).

The former option involves the assessment and verification of the casings and liners including the repair of any casing breaks below 850m. Downhole surveys and sampling at shut and **open** conditions are envisioned to better characterise the feeds zones following the work-over. The data from these activities are intended to verify and locate the extent of the sulphur intersected **by** the well which contribute directly to the discharge. The data will also be **useful** in assessing future drilling targets.

The latter option, on the other **hand**, requires the drilling of a third well in the prospect either from the same pad **as** DN-I or distant from it. The proposed well, DN-3D, is intended to gather more **information** at the northeast sector and at the same time address outstanding issues constrained **by** the present paucity of data.

Between the two options, it is recommended here that drilling of the third well, DN-3D be pursued first using a new pad (Fig. 5) . **Likewise**, we recommend the subsequent mechanical work-over of DN-I. **This** exploration tack is intended not only to better characterise the **prospect** but also to address any environmental

issues attendant to future testing since DN-1 can be initially used as injection well. No further work is recommended at present until after the exhaustive testing and evaluation of Baslay-Dauin after the proposed drilling.

### 10.0 Conclusions

The result of the 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 (Fig. 6).

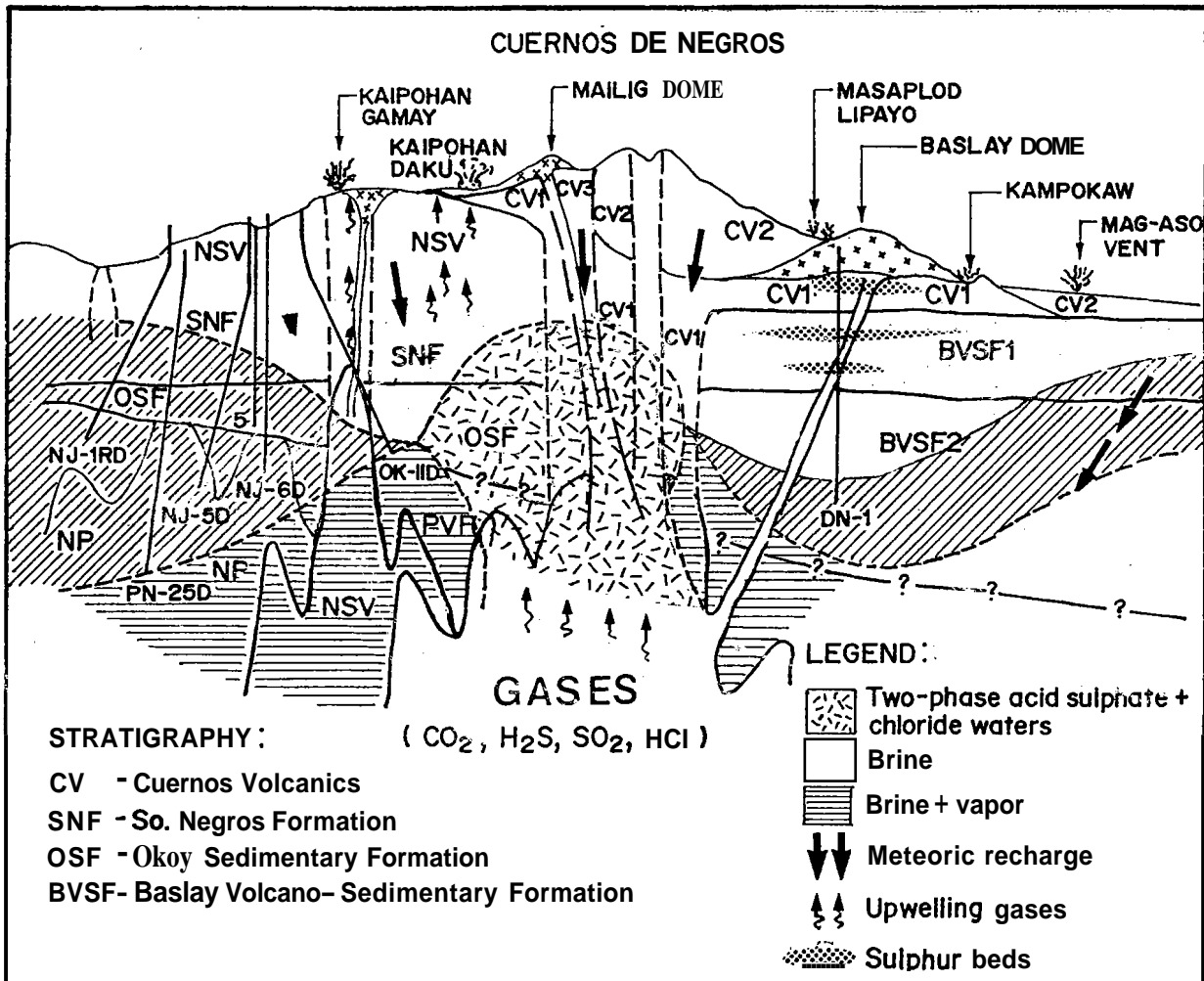


Fig. 6. A north-south section of the Palinpinon geothermal field and the Dauin geothermal prospect illustrating a hypothetical model of the resources.

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<sub>2</sub>S 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 1200m) tapped 200 to 250°C, neutral pH, dilute alkali-Cl waters, with the rising geothermal waters encountering sulphur beds at shallow depths produced the acidic (pH = 2.1 to 2.5),

high sulphate (500-1000 mg/kg) spring waters associated with high H<sub>2</sub>S output (Ellis and Giggenbach, 1971; Krupp and Seaward, 1987).

The available data, similarly 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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