GEOTHERMAL GEOLOGY AND REVIEW OF EXPLORATION BILIRAN ISLAND

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ABSTRACT

Biliran Island has been the subject of a geoscientific exploration programme, and the most promising area is currently being drilled. The first exploratory well has confirmed high temperatures at depth, although it did not encounter significant permeability. The major thermal features of Biliran are located close to a fault, and their chemistry (acid-sulphate-chloride) indicates an input of magmatic volatiles. It is conjectured that magmatic volatiles are rising on the fault, but that away from this zone a more typical convective hydrothermal system exists. There are similarities to the Krafla Geothermal Field in Iceland.

INTRODUCTION

Biliran Island is located immediately to the north of the Island of Leyte, Republic of the Philippines. Following the successful exploration and development of the Tongonan geothermal field on Leyte, Biliran has been the subject of a continuing geoscientific exploration programme since 1979, culminating in a 3-well deep drilling exploration programme which commenced March 1982. Exploration and drilling has been carried out by the Philippine National Oil Company, with geoscientific and drilling consultative assistance provided by Kingston, Reynolds, Thom and Allardice Ltd., as part of the New Zealand Government Energy Co-operation Programme.

Geoscientific techniques suggest the existence of a substantial geothermal reservoir. A commercial resource has not yet been proven by drilling, but preliminary indications are favourable. Of particular interest is the fact that the more prominent surface manifestations are predominantly solfataric, and yet alteration mineralogy from the first drillhole and some of the surface samples points to a neutral-chloride fluid as the alteration medium (A.G. Reyes? pers. comm.). If delineation drilling suceeds in proving the existence of an exploitable neutral-chloride reservoir, this raises the exploration potential of other solfataric areas,

GEOLOGIC SETTING

The tectonic history of Biliran is dominated by its position on the Philippine Fault Zone, which as been the locus of active volcanism and tectonism since the Miocene (Alcaraz 1947). The Philippine Fault is mapped as passing to the west of Biliran, along the coast of the Calubian Peninsula of Leyte. The developed geothermal field of Tongonan, and other prospective areas at Gaas, Burauen and Anahawan, also lie along this zone.

STRATIGRAPHY

Apart from localised thin deposits of reef limestones and marine sediments, the surface geology of Biliran is wholly made up of volcanic rocks and associated volcaniclastic deposits (Table 1). Biliran-1 drillhole has revealed, however, underlying non-volcanic formations. The stratigraphically lowest unit, only encountered in the last 10m of BN-1, consists of sediments and volcanic breccia, intensely sheared and then subjected to low-grade metamorphism (upper zeolite facies). It may be correlative to metamorphosed sediments and volcanics of Cretaceous age, exposed in Cebu and Samar (Bureau of Mines 1962). Overlying this is a sequence of fossiliferous clastic and crystalline limestones with intercalated pyritic calcareous shales, Paleontological dating gives an age of Late Miocene to Basal Pliocene and an outer neritic environment. Depositional basins existed both to the east (Samar Basin) and west (Visayan Basin) of Biliran during Miocene-Pliocene times and similar sediments to those encountered in Biliran-1 are now exposed on the adjacent islands of Leyte and Samar.

A thick sequence of volcaniclastic sediments (the Pulang Yuta Formation) occurs above the limestones in BN-1. It is tentatively correlated with similar material (the Panlahuban Formation) exposed in river valleys on the western side of Biliran, but differs in the degree of alteration.

The younger volcanic rocks of Biliran have been divided into a number of units based mainly on geomorphic grounds, but with some petrologic distinctions (Espiritu 1980). The volcanic formations of Biliran are predominantly andesitic, with minor quantities of basalt and dacite. They are therefore similar to the volcanic rocks of mainland Leyte.

Table 1. Stratigraphy of Biliran Island

Age	Unit	Description	min. thickness m
Quaternary	Recent Alluvium	Slope-wash, alluvium and beach deposits graded to present sea-level.	50
Quaternary	Quaternary Terraces	Raised alluvial terraces and debris fans *not* graded to present sea-level.	200
Pleistocene	Sayao Volcanics	Upper member: biotite-bearing hornblende, forming thick, steep-sides flows. Pumiceous in part. Lower member: hornblende andesite lavas and pyroclastics.	500
Pleistocene	Villavicenta Limestone	Back-reef corraline limestone containing andesite clastics.	5
Pleistocene	Biliran Volcanics	Lava flows of porphyritic pyroxene basalts, pyroxene and hornblende andesites and agglomerates.	1200
Pleistocene	Tamburok Basaltic Andesite	Basaltic pyroxene andesite lavas and pyroclastics. Hornblende rare.	400
Pliocene (relative ages not distinguished)	Busalis Andesite	Fine-grained hornblende-bearing pyroxene andesites.	100
Pliocene (relative ages not distinguished)	Panamao Volcanics	Sub-aerially deposited hornblende bearing pyroxene andesites.	800
Pliocene (relative ages not distinguished)	Kandako Basalt	Porphyritic augite basalt.	500
Pliocene (relative ages not distinguished)	Asluman Volcanics	Pyroxene andesite lavas.	1000
Pliocene (relative ages not distinguished)	Naliwatan Andesite	Fine-grained pyroxene andesite flows, lahars and agglomerates. Typically in thin (10m) layers.	1200
Pliocene (relative ages not distinguished)	Panamao Volcanics	Hornblende-bearing pyroxene andesites and associated pyroclastics. Marine in part. Typically in thin (<10m) flows.	100
Pliocene (relative ages not distinguished)	Catmon Volcanics	Hornblende-bearing pyroxene andesites and pyroclastics. Includes silicified breccias and hydrothermally altered tuff in upper section.	900
		- - - conformable contact - - -	
Pliocene	Panlahuban Formation	Volcanic breccia, unsorted or bedded. Heterogenous clasts, but predominantly pyroxene andesite tuff.	50
	↕ Correlatives?		
Pliocene	Pulang Yuta Formation	Volcano-sedimentary breccia. Predominant clast pyroxene andesite, but also contains hornblende andesite, andesitic tuffs, hornblende dacite, calcitic siltstone. Clasts altered to varying degrees, but bulk of rock and matrix typically altered to chlorite, calcite, smectite (± quartz, gypsum, hematite, pyrite, epidote).	1690
Miocene ?	Caibiran Sedimentary Unit	Intercalated pyritic calcareous shales and fossiliferous limestone.	345
		- - - unconformity - - -	
Cretaceous	Metamorphic Basement	Phyllonite of sediments and volcanic breccia, subjected to low-rank regional metamorphism.	15

STRUCTURES

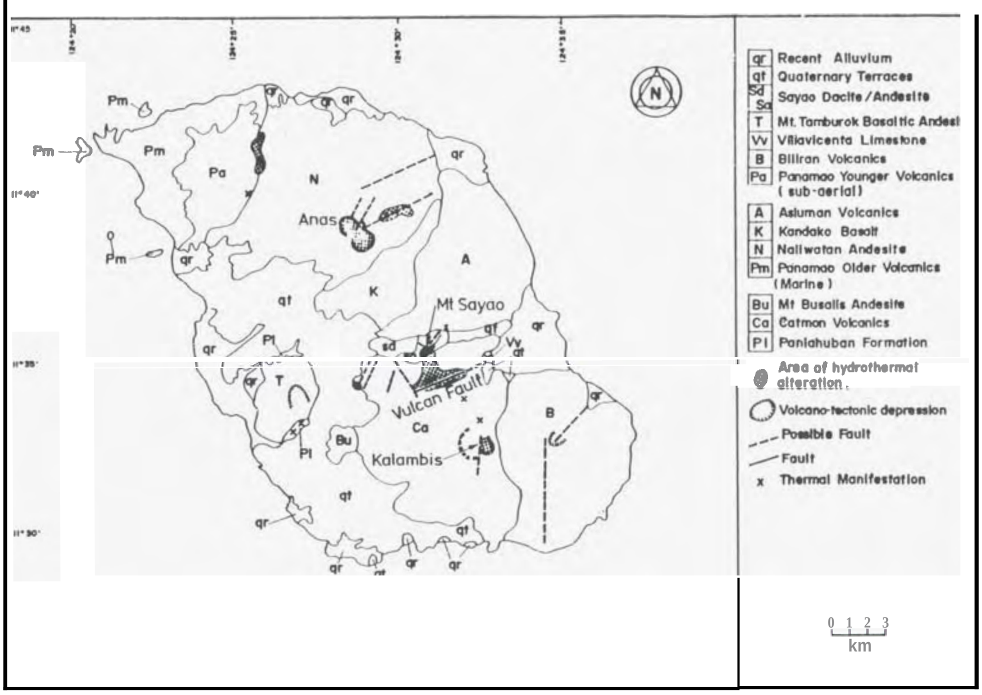
The present-day topography of Biliran is made up of a series of coalescing volcanic piles and associated volcaniclastic debris. The degree of erosion of the volcanoes varies, indicating a range of ages, from the deeply dissected composite volcanic massif of Kalambis Ridge to the youthful dacite dome of Mt. Sayao, reputed by local inhabitants to have been historically active (1938).

The general trend of the volcanic centres of Biliran is NW, parallel to the regional Philippine Fault Zone (and the Philippine Trench to the east). This volcanic alignment can be traced northward into Luzon, and southwards into Leyte. Similar NW elongation of the low-resistivity-anomaly between Vulcan and Kalambis (Figure 2) is noteworthy and may be indirectly caused by a some deep-seated structure - perhaps a buried branch of the Philippine Fault.

A major fault (the Vulcan Fault) running NE across Biliran can be recognised, based on topographic lineation and field evidence such as intensely sheared rocks, localised hydrothermal alteration, and alignment of thermal features. Other smaller faults have also been mapped. The most intense thermal activity is located close to the line of the Vulcan Fault, and it is likely that it is acting as a channel for the upflow of hydrothermal fluid. (Figure 1).

Altered ground in the Kalambis and Anas areas is contained within two large (~1 km^2 and 3 km^2) roughly circular depressions, which are interpreted as volcano-tectonic collapse structures. They are not the focus of present-day hydrothermal activity, although weakly-flowing, dilute acid-sulphate springs occur in their vicinities.

Figure 1. Geology of Biliran Island



GEOCHEMISTRY

Analysis of surface thermal waters and gases divides the Biliran thermal features into 3 geochemical types (Tables 2, 3).

(i) Hot acid-chloride-sulphate fluids
(ii) Hot or warm acid-sulphate fluids, chloride less than 250 ppm
(iii) Warm neutral-bicarbonate-chloride waters.

The acid-chloride-sulphate features are considered to be those closest to the most actively-upflowing zones. The acid-sulphate waters are interpreted as steam-heated surface waters, typical of the higher elevation of geothermal systems. Waters of the third type occur at lower elevations and represent outflow from the geothermal system, diluted with meteoric water and either derived from a neutral-chloride reservoir or neutralised by interaction with country rock. Both the spatial distribution of the thermal features and measured gas ratios are consistent with this interpretation (Figure 2).

Acid-chloride-sulphate fluids are not common features of hydrothermal systems, and their existence here indicates a direct input of magmatic volatiles to the system. This is confirmed by the presence of HCl, HF and SO_2 in gas samples, not only from Vulcan and Tenego but also at Libtong and Vulcan Gamay. Additional evidence lies in high He/Ar ratios (Cope 1982; Glover 1981).

The chemistry of Biliran thermal features means that conventional solute geothermometers cannot be usefully applied. Gas geothermometers give a wide range of results, probably indicating natural variations as well as sampling and analytical error. (Table 3).

THERMAL MANIFESTATIONS

The most impressive thermal features on Biliran are in the Vulcan thermal area, consisting of boiling pools, mudpools and mildly superheated steam vents (Figure 2). There is a large flow of gas, and much sulphur has been deposited around the vents. An unusual feature is a "mudpool" which emits material containing 75% sulphur with natroalunite and traces of gypsum and opaline silica, forming lava-like flows up to 500 m long and 1-2 m thick.

There are smaller areas of boiling springs and steam vents at Libtong and Vulcan Gamay. The most active thermal features of Biliran lie in a broad NE belt approximately paralleling the Vulcan Fault. Warm (<60°) springs occur at several locations, in addition to a number of cold but mineralised seepages, some of which emit small quantities of gas.

Table 2. Chemistry of Biliran Thermal Waters

AREA	TEMP. °C	pH	CONCENTRATIONS EXPRESSED IN mg/kg: Na	K	Ca	Mg	Li	B	Cl	SO_4	SiO_2	HCO_3	MOLECULAR RATIOS: Na/K	Na/Li	Cl/B	Cl/SO_4	OURCE OF DATA
Panlahuban	42	7.4	125	28	52.4	38.7	0.13	2.8	121	160	163	464	7.6	290	13.3	2.05	a
Bunot	65	7.1	158	38	72.9	47.0	0.14	3.7	177	221	175	340	7.1	341	14.8	2.17	a
Vulcan	90	2.1	9.4	15	53.6	23.6	0.01	6.2	375	2700	257		1.1	> 285	18.4	0.4	a
Vulcan Gamay	89	2.2	8.9	4	32.5	17.4	0.01	3.6	7	1600	257		3.5	> 270	0.6	0.01	a
Vulcan Gamy	85	2							301	924							b
Tenego	75	1.7	50.5	21	79.4	34.9	0.2	6.3	1152	1200	231		5.0	> 913	56.0	2.6	a
Libtong	63	2.8	4.9	3	5.4	2.4	0.01	1.0	9	185	60		2.9		2.7	0.13	a
Villavicenta	50	7.9	133	26	243	88.2	0.06	2.0	248	500	165	530	8.6	> 669	38.8	1.34	a
Mohon	46	7.1	134	9	315	49.0	0.01	4.7	101	960	116	238	25.3	>4045	6.5	0.29	a
Panamo	451	3.0	15	8	42.7	6.1	0.02	0.2	9	184	94		3.2			0.26	a
Anas	351	6							213	624							
Vulcan	95	1.2'							9480								b

Sources of Data:
a = Galia and Clemente (1980)
b = D.M. Cope, pers.comm. (1982)

Footnote:
Well discharged after steam stimulation 31/7/82.

Table 3. Chemistry of Gases, Biliran Thermal Features

AREA	H_2O+	CONCENTRATIONS, MOLE % CO_2	H_2S	N_2	H_2	CH_4	NH3	HCl	HF	S_2	SO_2	GAS RATIOS CO_2/H_2S	CO_2/H_2	H_2/CH_4	CO_2/CH_4	MEAS. TEMP °C	CALCU-LATED TEMP. °C*	SOURCE OF DATA
Libtong	93.7	84.1	3.3	0.56	0.007	0.56	0.01	0.05	0.035	9.05	1.43	25	1200	0.013	150	96	191	a
Libtong	88.9	91.6	6.9	0.38	0.004	0.22		0.27		0.80		13	2200	0.020	420	95	192	b
Vulcan	76.1	91.1	6.1	0.53	0.12	0.16		0.07		1.81		15	759	0.750	570	64	286	b
Tenego	97.1	83.0	3.7				0.06	2.61	0.029	8.44	2.20	23				115		a
Tenego	96.0	96.5	2.5	0.54	0.002	0.01				0.46		39	48000	54.0	9600	105	186	b
Vulcan	96.8	92.3	2.8	1.79	0.11	0.02						33	840	5.5	4600		292	a
Vulcan	91.7	92.6	1.5	0.49	0.005	0.001	0.05	0.04	0.025	4.63	0.63	62	18000	3.8	67000	102	220	a
Vulcan	96.6	88.8	9.9	0.63	0.01	0.02		0.09		0.49		9	9000	31.5	4000	100	240	b
Mohon		99.4	0.2	0.27	0.007	0.19						552	130000	0.004	500	30	123(PCO_2=1MPa) 83(PCO_2=0.1")	
Villavicenta		93.5	0.02	6.37	0.0005	0.11						4670	200000	0.004	850	49	102	b
Panlahuban		63.2	0.12	36.3	0.34							300			190	46	53(PCO_2=0.1")	b

+ H_2O = mol % in total sample

* Temperatures calculated by D'Amore and Panichi (1980) geothermometer, using PCO_2=1 MPa except for Mohon and Panlahuban samples.

Sources of data:
a = Glover (1981)
b = Cope (1982)

HYDROTHERMAL ALTERATION

Areas of intense acid alteration surround the active thermal areas. Typical assemblages are cristobalite-gypsum-sulphur-kaolinite-hematite-pyrite, + natroalunite, quartz, leucoxene and sulphate?. In addition, there are large areas of altered ground not related to present-day thermal activity, with generally similar mineral assemblages. Occasional surface samples, however, have mineralogy more typical of neutral-chloride alteration (for example illite-montmorillonite from the Vulcan area - T.M. Leach pers.comm). In part alteration must be relict, as shown by the presence of high temperature phases (e.g. pyrophyllite, epidote) now occurring on the surface.

In contrast, cores and cuttings from the first deep drillhole (BN-1, with a total depth 2425 m), reveal that acid alteration is minor and restricted to the upper portion (down to 114 m). Below this level clasts within the Pulang Yuta Formation have varying degrees and ranks of alteration, but examination of the groundmass and fine-grained material shows that the latest phase of alteration to produce an assemblage of chlorite-illite-montmorillonite-vermiculite, and interlayered clays, plus calcite-quartz, with minor gypsum, hematite and pyrite and traces of epidote. This assemblage is more typical of medium temperature (120-200°C) alteration by a neutral-chloride fluid. However, temperatures predicted on the basis of alteration mineralogy have proved to be lower than measured downhole temperatures, and so may not be a reliable indicator of present conditions in the reservoir.

GEOPHYSICS

Biliran has been surveyed using a combination of Schlumberger traversing, dipole-dipole, and vertical electrical sounding resistivity techniques. Results of Schlumberger traverses with AB/2 spacing of 500 m are shown in Figure 3 as isoresistivity contours. In general the more-deeply-penetrating techniques have tended to support the Schlumberger results, but have added significant information by revealing that low-resistivity anomalies are connected at depth beneath the fresh, unaltered young volcanics of Mts. Sayao and Tamburok (Figure 2).

The resistivity pattern is interpreted as indicating a geothermal reservoir centered approximately on the Vulcan Gamay area, and with outflow to the east and west. The low-resistivity anomaly between Vulcan and Kalambis may also be an outflow, or it may be a separate zone of upwelling.

Figure 2. Interpreted Resistivity Section, Based On Combination of VES and Dipole-Dipole Data. Figures are Resistivity In Ω m.

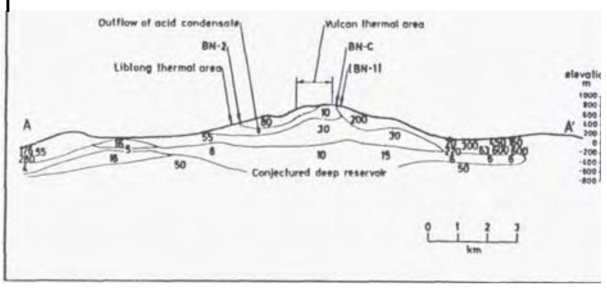
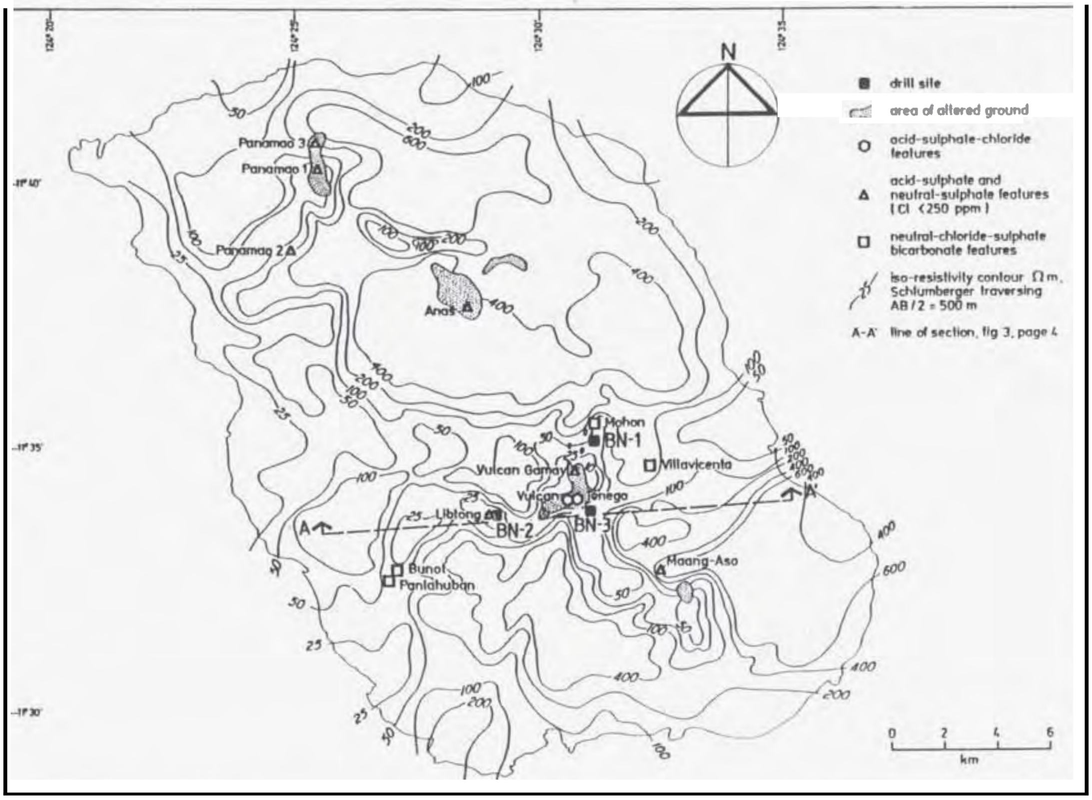


Figure 3. Resistivity Map of Biliran and Geochemistry of Thermal Manifestations



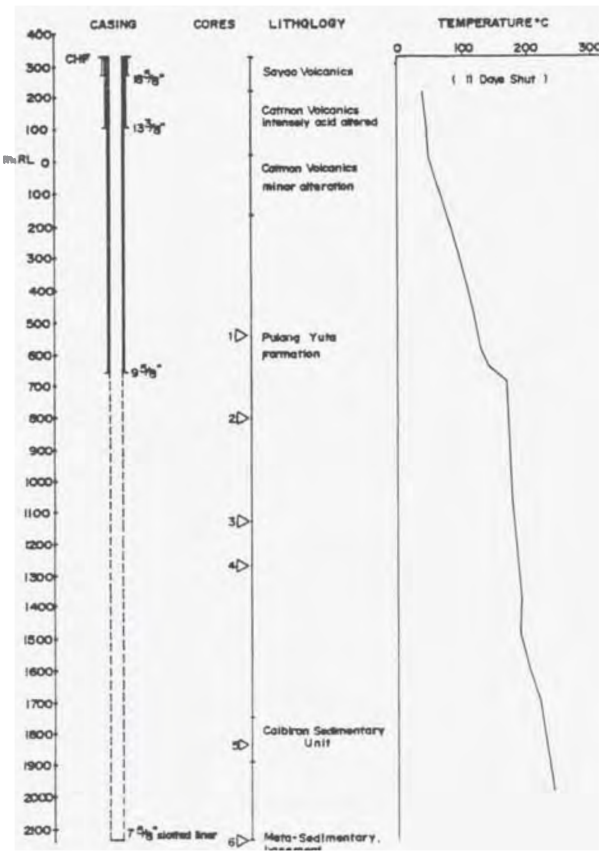
RESULTS OF EXPLORATION DRILLING

At the time of writing, June 1982, the first of 3 planned deep exploration wells, BN-1 had recently been completed to a depth of 2425 m.(Fig.4).

This well is located to the north of the Vulcan surface manifestations and, although hot, appears to have limited permeability. Nevertheless it has provided useful geological information, in particular, evidence for neutral-chloride alteration. The major part of the well passed through a thick volcano-sedimentary unit (the Pulang Yuta Formation). This unit was not recognized on the surface and its thickness was unexpected. After penetrating the Pulang Yuta Formation, a gas kick was experienced within the underlying sediments indicating high formation pressures and that the relatively impermeable Pulang Yuta Formation was acting as a cap. Gas (predominantly CO_2 with no distinctive magmatic component) was successfully circulated out and the well now stands with zero wellhead pressure.

The limited permeability suggested by the lack of circulation losses during drilling is consistent with results obtained during injectivity testing at low flowrates. However, at higher flowrates the injectivity improved, possibly indicating formation breakdown. The well is still heating (maximum bottomhole temperature = 254°C, as of 3/7/82 and an attempt will be made to discharge it in the near future).

Figure 4. BN-1 Well Data



CONCEPTUAL MODELS OF THE BILIRAN SYSTEM

Two alternative models have been developed to described the Biliran geothermal system. They can be sumnarised as follows:

1) Thermal features in Biliran are the result of the direct upflow of magmatic volatiles, mixing with groundwater to produce a hot, acid fluid. The centre of upflow is near the Vulcan thermal area. Outflow of mixed fluid and condensate, and hydrothermal alteration by the outflowing fluid, produce the observed low-resistivity anomaly.

2) A magma chamber or intrusive at depth conductively heats meteoric water, giving rise to a convective hydrothermal system. Within this system, high-permeability channels along faults permit the local upflow of magmatic volatiles, producing restricted zones of acid fluid, However, the bulk of the system consists of neutral chloride fluid, as is connnonly encountered in other convective hydrothermal systems, and this is responsible for the observed low resistivity.

If the first of these hypotheses is correct, then the area may be underlain by an acid, corrosive fluid, a similar situation to that encountered at Tatun geothermal field, Taiwan (Chen 1970). In this case the area could not be exploited using conventional geothermal technology.

If the second model applies, then there is a much better chance of developing an exploitable resource. There may be acid zones within the field which will have to be avoided, but the rest of the reservoir can be drawn upon. A similar situation exists in Krafla field, Iceland (Armansson et al 1981), where magmatic volatiles arise along a linear structural feature producing acid conditions, but are surrounded by a neutral-chloride reservoir,

On balance, the second model of Biliran is favoured for the following reasons:

- evidence of neutral-chloride alteration in some surface samples.
- evidence of neutral chloride alteration throughout most of BN-1.
- an indication on interpreted VES/dipole sections of 2 separate low-resistivity layers: a shallow one presumably corresponding to acid condensate, and a deeper one which may represent the neutral reservoir (Figure 3).
- restriction of acid-chloride water in surface features to those along the line of the Vulcan fault.

CONCLUSIONS

Geoscientific exploration and drilling has not yet proven the existence of an exploitable geothermal resource on Biliran but indications are promising. The presence of a magmatic component in outflow from surface thermal features is a cause for concern, as it may indicate the existence of acid conditions at depth. However, by analogy with other explored geothermal systems, it is probable that acid conditions are restricted to localised upflow zones. Investigation of the area is continuing.

ACKNOWLEDGEMENTS

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