INITIAL ASSESSMENT OF THE TINOC GEOTHERMAL PROSPECT, IFUGAO, PHILIPPINES

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ABSTRACT

Initial assessment of the Tinoc Geothermal Prospect in Ifugao suggests the existence of a geothermal resource in the area. This is based on the results of geological and geochemical surveys earlier done in the area and the recently conducted Schlumberger Resistiviy Traversing (SRT). The prospect area exhibits impressive thermal manifestations, in the forms of warm to hot springs, boiling pools, solfatara, gas seeps and altered ground.

Four lithologic units were identified in Tinoc, i.e. dacitic lava flows, pyroclastic rocks, diorite and meta-sedimentary rocks. Major structural features dominating the area are the NE-SW and N-S trending faults. The NE trending faults traversed along areas of hot springs and solfatara. The probable heat source of an intermediate temperature geothermal system at Tinoc could be associated with the Quaternary dacite lava dome of Mt. Tebeyo.

A neutral pH Na-Cl water type with high chloride content characterizes the hot springs in Tinoc. Chemistry of the waters however does not indicate the presence of a mature geothermal system. Geothermometry indicates a subsurface temperature of around 160°C. There are evidences to suggest on the presence of a more saline parent water possibly at higher temperatures but tends to be rich in sulfate at depth.

Results of resistivity traversing at AB/2=500 m delineated an anomaly that is possibly related to the occurrence of a geothermal system. Although this seems to be localized and confined along the thermal manifestations in Tukucan and its vicinities, there is a possibility that this anomaly could widen at depth. Deeper probing geophysical methods are recommended to determine the extent of the resource and resistivity distribution at depth.

1.0 INTRODUCTION

The Geothermal Division of the Department of Energy conducted geological and geochemical surveys in Tinoc, Ifugao from 1994 to 1995 to determine the geothermal potential of the area. Schlumberger Resistiviy Traversing (SRT) survey was conducted in 2003 to complement the earlier surveys. This report presents an initial assessment of the geothermal potential of the area based on the results of the surveys done in the area.

Mention of the Buguias Geothermal Prospect is made during the latter part of the report as geochemical evaluation suggests that the thermal fluids found in the two prospects belong to a single system. The Buguias Geothermal Prospect was the subject of geological and geochemical surveys made in 1980 through the Republic of the Philippines-Japan International Cooperation Agency – Buguias Geotthermal Development, First Phase Survey.

The Tinoc Geothermal Prospect is located some 60 km north-northeast of Baguio City. The area lies close to the western boundary between Ifugao and Benguet Provinces and east of the Buguias Geothermal Prospect as shown in Figure 1. It is accessible either from Baguio City to Abatan via the Halsema Highway or by air travel from Bagabag, Nueva Vizcaya. It is accessible by bus or jeepney, which ply Abatan to Kabayan route. From Toking junction is two-three-hour drive to Mansuyusoy via Catlubong-Mansuyusoy dirt road. Thence, from Mansuyusoy is another one-hour drive going to Barangay Tukucan. Poblacion Tinoc, which is the site of the municipal government, is a half-hour drive from Mansuyusoy via the Mansuyusoy-Tinoc road.

Barangay Tukucan is located in an area of relatively youthful topography characterized by rugged prominences towering from 1000 to

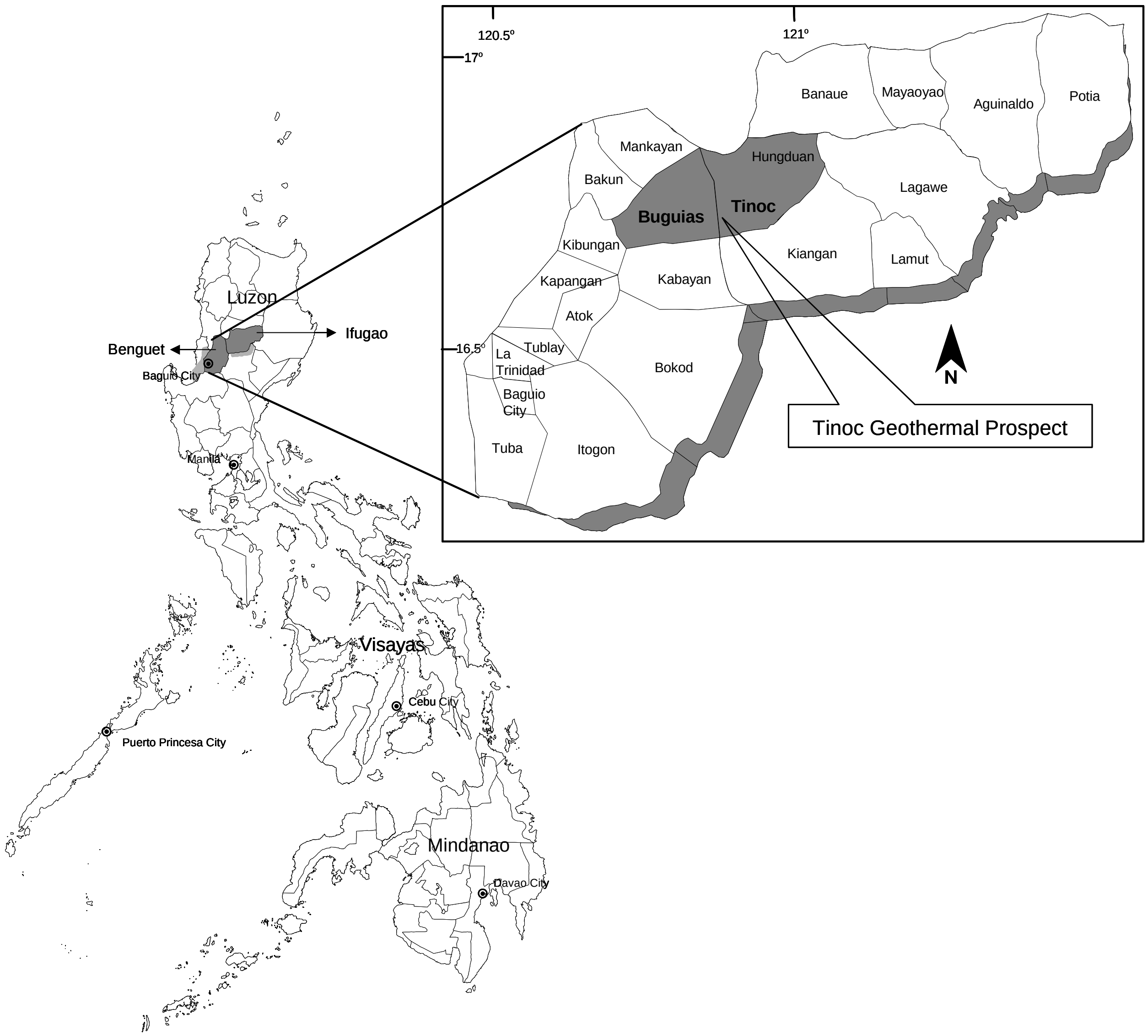

Figure 1. Location map of Tinoc geothermal prospect.

2800 meters high and by deeply incised valleys. Prominent peaks are Mt. Tebeyo in the southwest and Mt. Guibul in the northeast (Fig. 2). All the streams in the area are still in their youthful stage of development as characterized by the presence of deep V-shaped valley and waterfalls. The drainage patterns are dendritic and annular suggesting presence of huge intrusive body. The barangay site in the municipality of Tinoc is a remnant of an ancient landslide as interpreted from aerial photographs.

The province of Ifugao is blessed with a temperate climate. The short dry season starts from early January to late April. Wet season starts from May to late December. The hottest months are March and April while the coolest are from November to February. Banaue, Tinoc, Hungduan and the southern part of Kiangan are the coolest place in the province (Fig. 1).

Pine trees grow abundantly along river embankments while second growth and shrubs thrive well along mountain slopes. Cogonal grasses cover the barren mountain slopes and ridges. Patches of flattened slopes and banks of the drainage system are converted into rice paddies. Other gentle slopes are converted to kaingin for root crops.

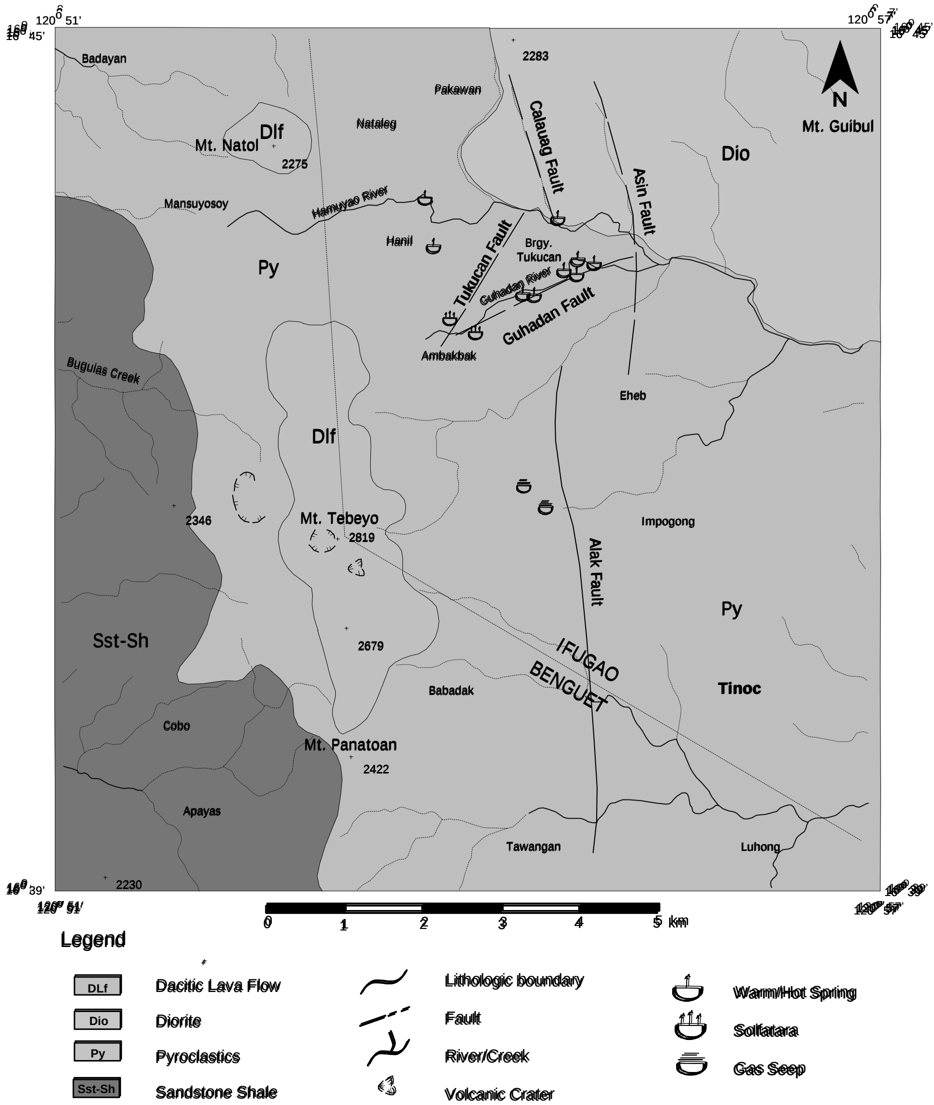

Figure 2. Simplified geologic map

2.0 REGIONAL SETTING

The prospect area is in Northern Luzon, which is bounded by the Philippine Sea on the East and the South China Sea on the West. It lies between the elongated northern part of the Philippine Trench and the Manila Trench, wherein deep earthquakes and volcanism were generated by subduction of crustal slabs.

The general geology of Tinoc geothermal prospect is genetically related to Luzon Central Cordillera. Luzon Central Cordillera is a 300 km long, 50-80 km wide and 1500-3000 m high range (Sevillo, 1996), of major north-south controlled geanticline, formed largely from Miocene Orogeny continuing unto the Quaternary time.

The geology of Cordillera Central is composed of Late Cretaceous crystalline rocks, Lower Paleogene basic volcanics with normal sediments, Uppermost Paleogene to Lower Miocene basic to acidic volcanics accompanied by limestone and Quaternary acidic volcanics.

The Tinoc prospect area lies along the fringes of this Cordillera. Other known geothermal prospect areas are in Kalinga, Bontoc, Daklan and the Acupan-Itogon areas. The Cordillera is a multi-stage volcano-plutonic arc cored by synorogenic batholithic masses of diorite, intruded along pre-existing structural zones near the end of Middle Miocene (Fernandez and Pulanco, 1967).

3.0 LOCAL GEOLOGY AND STRUCTURES

A simplified geologic map of the prospect area is shown in Figure 2. The tentative stratigraphy of the Tinoc prospect is as follows:

Dacitic lava flows	-	Quaternary
Pyroclastic rocks	-	Quaternary
Diorite	-	Miocene (?)
Metasedimentary rocks	-	Eocene (?)

Metasedimentary rocks. This formation is wholly composed of metamorphosed sandstone and shale. Good exposures along the Abatan-Kabayan area, especially in Toking, show clear bedding that strikes N40°E and dips 35° SE. They are light to dark green, dense and well indurated. Intense chloritization and epidotization are responsible for the green tone of the altered matrix and of the metasedimentary rocks as a whole. Pyritization is also common in outcrops along Toking-Catlubong road.

Diorite. Intruding the metasedimentary rocks are the diorite stocks occurring in a wide range of tones and texture. It is commonly gray in hand specimen, but lighter and darker varieties are also common. It is medium- to coarse-grained and generally massive. The rock is locally silicified, chloritized, epidotized and pyritized mostly along veins and fractures. Typical rock exposure of the rock is located at the slopes of Mt. Guibul.

Petrographically, the rock exhibits a hypabyssal porphyritic to medium-grained, hypidiomorphic-granular texture, primarily consisting of plagioclase, ferromagnesians and invariably, quartz. The ferromagnesian content varies from hornblende to biotite. Alteration of the rock is generally propylitic with calcite and epidote both affecting the primary minerals except quartz. Illite is an associated replacement of the feldspars and chlorite is that of the ferromagnesians.

Dacitic Tuff and Pyroclastic rocks. These rocks are topographically expressed as localized plateaus, mesas and ridges. These unconformably overlie the metasedimentary rocks and diorite in the area. They are composed of tuff and tuffaceous sediments of dacitic composition. The rocks exhibit various shades of gray, are massive, porous and could easily be eroded.

Dacitic lava flows. This rock is well exposed along the slopes of Mt. Tebeyo, especially in Eheb area. It is fine to medium-grain and is composed of bipyramidal quartz phenocrysts (forming about 5% of the rock), ferromagnesian and sodic feldspar phenocrysts set in a quartzofeldspathic matrix. The ferromagnesians of the rock are oxyhornblende, pyroxene and biotite in the order of decreasing amount. The ferromagnesians of the dacite at Sitio Calauag are indiscernible due to complete alteration to chlorite ± calcite ± epidote ± opaques. The matrix of these dacites also varies from micrographic to spherulitic whereas matrix of the dacites in Sitio Hanil and at Guhadan River is hyalopilitic.

The side looking airborne radar image (SAR) shows many lineaments of different orientations but from the aerial photo interpretation, much of these lineaments are only deeply incised valleys that are almost vertical. Two steeply dipping NE trending faults intersect the warm/hot springs and the solfatara. The first is termed as Guhadan Fault, which extends from the upstream side of Guhadan River and is characterized by high and vertical wallrock of pyroclastics. This fault traverses several warm/hot spring and solfatara in Guhadan River. The other is termed as Tukucan Fault, which appears at the southernmost portion of Tukucan and traverses the other solfatara in the area.

4.0 SURFACE HYDROTHERMAL ALTERATION

Interaction between geothermal fluids and the rocks in the prospect area has invariably altered the primary mineralogy generally by replacement and deposition of secondary minerals. Alteration in the prospect is predominantly in the form of clay alteration and silicification.

Replacement observed is either complete or partial. Oxidation was observed only within the immediate vicinity of the spring/pool area. Diorite outcrop in Hamuyao River also shows strong to total alteration of ferromagnesian minerals to chlorite + calcite + epidote +

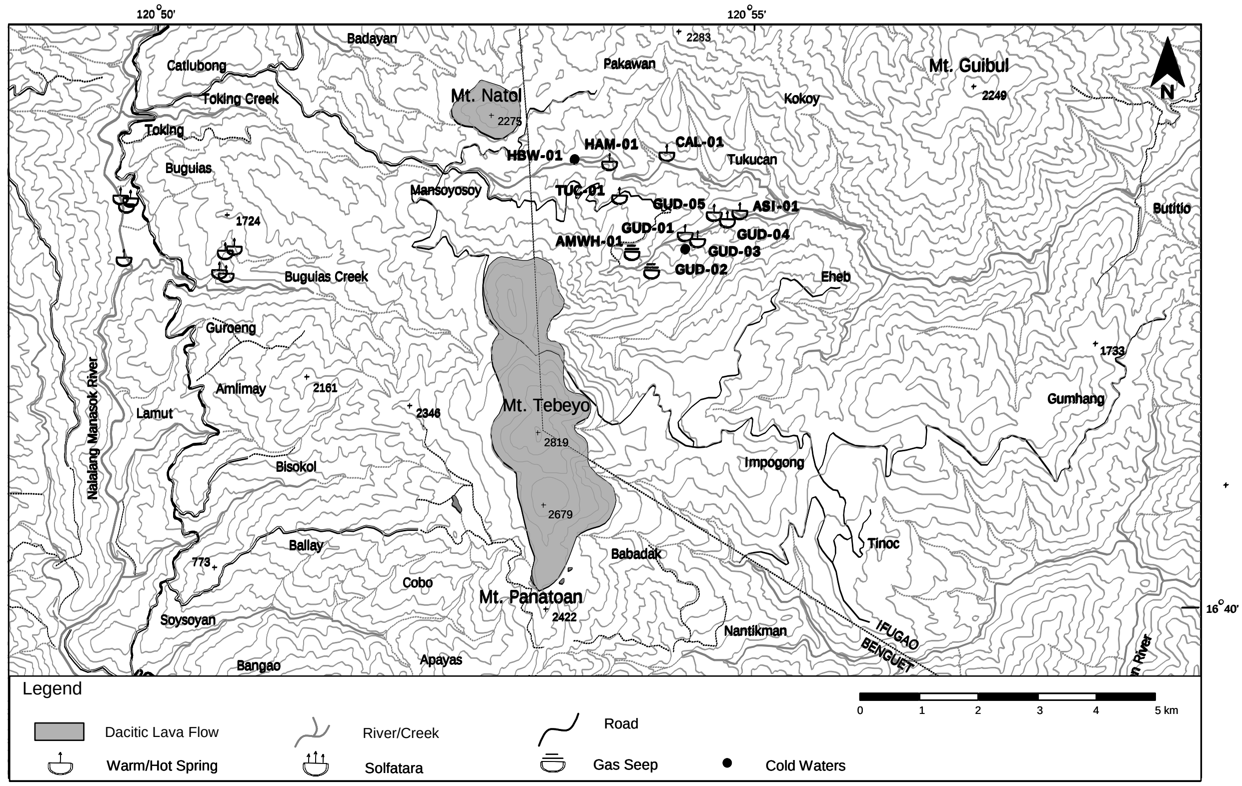

Figure 3. Location map of thermal manifestations.

opaques. Plagioclases are also replaced by clay/illite + calcite + chlorite + epidote. Minute fractures are also filled-up with calcite + chlorite + epidote. Weak to moderate silicification is localized on the immediate vicinity of the hot spring area. The intensely altered rocks scattered within the solfatara area of Sitio Ambakbak is bleached white and vuggy and coated with native sulfur.

5.0 THERMAL MANIFESTATIONS

Hot springs, boiling pools, solfatara, and cold gas seeps and altered ground manifest in Barangay Tukucan. These are shown in Figure 3 together with the warm/hot springs of Buguias, Benguet. The solfatara is located in Sitio Ambakbak of Barangay Tukucan. It is characterized by strong sulfur odor, steaming and altered ground, boiling mud pools, and native sulfur deposits. Warm to hot springs are located in Sitio Hanil and along the banks of Guhadan and Hamuyao Rivers and their tributaries. Field temperatures range from 32-60 °C and pH range from 6-7.

6.0 WATER CHEMISTRY

Chemical compositions of thermal and non-thermal waters are given in Table 1. The quality of which is relatively good with <10% deviation.

Based on their chemical composition, the thermal waters are grouped as follows:

a. Neutral pH Na-Cl water type characterized by high chloride content
b. Neutral pH $Ca\text{-}HCO_3$ water type characterized by low ionic content
c. Acid sulfate water type characterized by low pH and high SO_4

Chloride rich waters are present in Hamuyao labeled as CAL-01 and HAM-01 and Guhadan Rivers labeled as GUD-01, GUD-03, GUD-04, GUD-05, ALA-01 and ASI-01. On the $Cl\text{-}SO_4\text{-}HCO_3$ plot shown in Figure 4, they show up near the Cl corner, on the mature region similar to Buguias thermal waters. The fluid composition is predominantly Cl with high Na and K and significant concentrations of boron, lithium, cesium and rubidium. This is typical of waters in high temperature geothermal systems.

Table 1. Chemical analysis of water sample in Tinoc.

Sample Label	TUC-01	CAL-01	HAM-01	AMWH-01	GUD-01	GUD-02	GUD-03	GUD-04	GUD-05	ALA-01	ASI-01	HBW-01
Field Temp., ^{o}C	35	64	42	88	39	21	42	60	42	47	61	25
pH	6.1	6.54	6.77	2.04	7.7	7.28	6.91	7.1	7.59	7.52	7.3	6.95
Na	17.5	1070	1560	11.8	760	68	851	2041	1139	1320	2600	18.8
K	3.42	195	263	6.8	126	36.2	217	495	302	254	426	2.62
Ca	38.4	158	312	7.15	139	13.3	134	296	161	134	238	13.8
Mg	14.9	18.8	49.6	2.09	13.3	4.24	12.4	38	17.6	23	64.4	3.9
Li	0.04	3	4.5	ND	2.25	0.13	2.04	4.2	2.43	4	7	ND
Rb	ND	1.1	1.44	0.07	0.73	0.09	0.71	1.43	0.82	1.28	2.24	0.03
Cs	ND	0.44	0.51	ND	0.20	ND	0.11	0.64	0.13	0.62	1.06	0.23
B	0.26	19.7	28.6	153	15.2	1.17	17.4	40.7	20.4	25.6	49.2	0.32
SiO_2	132	123	122	194	72.6	48	90.2	154	108	119	166	29
SO_4	44.2	105	558	1077	34.7	21.7	25.8	62	32.2	39.4	176	26
Cl	9.93	2090	2700	22.7	1630	106	1594	3874	1895	2610	4750	11.7
HCO_3	185	3.18	836	ND	285	76.1	292	717	470	507	1090	55.9

Bicarbonate water is found in Sitio Hanil labeled as TUC-01 while sulfate steam heated water is present in Sitio Ambacbac labeled as AMWH-01. On the Cl-SO_4-HCO_3 plot shown in Figure 4, these waters appear in the HCO_3 and SO_4 corner, respectively. Cold surface water samples were also taken from Hamuyao and Guhadan Rivers to be used as background values.

7.0 ORIGIN OF WATERS

A plot of chloride and boron as conservative species is shown in Figure 5 both for the Tinoc and Buguias thermal waters. The figure shows a linear trend indicating that these waters likely originated from the same source. Likewise, the trend suggests that the waters are products of mixing of non-thermal, dilute water with a hot fluid from a deep source. The Tinoc waters are shown as the more dilute counterpart of Buguias waters.

The increase of Ca and Mg with Cl however suggests that it is not derived from mixing alone, otherwise they would be more richer in the more dilute waters. It seems that these elements are rich in the parent water. Likewise, in that SO_4 tends to increase with Cl, there is evidence to suggest that the parent water is also sulfate rich.

8.0 GEOTHERMOMETRY

Geothermometry is used for the determination of subsurface temperature by assuming equilibrium between specific minerals and the geothermal fluids at depth. Calculation of subsurface temperature using silica and the various cation geothermometers for the Tinoc thermal waters yield a wide range of estimate.

Silica geothermometer yields a value of 129-167°C which correlate well with $K/\sqrt{Mg}$ geothermometer, but lower compared to values obtained using Na/K and Na-K-Ca. Balmes (2000) used mineral equilibrium diagrams using a speciation program WATCH to estimate the subsurface temperature. Results show a number of minerals equilibrating at a temperature range of 100-150°C.

Giggenbach (1988) suggested that a triangular diagram with Na/1000, K/100 and Mg at the apices can be used to classify waters as fully equilibrated with rocks at given temperatures, partially equilibrated and immature. From Figure 4, which shows the waters as mature, it was expected that the waters would plot on the full equilibrium region in the Na-K-Mg diagram. However, as shown in Figure 6, the thermal waters of Tinoc are slightly scattered and similar with that of Buguias which fall within the immature region. Disagreement between the geothermometers, results of mineral equilibrium diagrams and Na-K-Mg diagram suggest that deep equilibration was not achieved.

9.0 GEOPHYSICS

A reconnaissance D. C. Schlumberger Resistivity Traversing (SRT) survey was conducted to delineate low resistivity anomalies in the prospect area worthy of follow-up

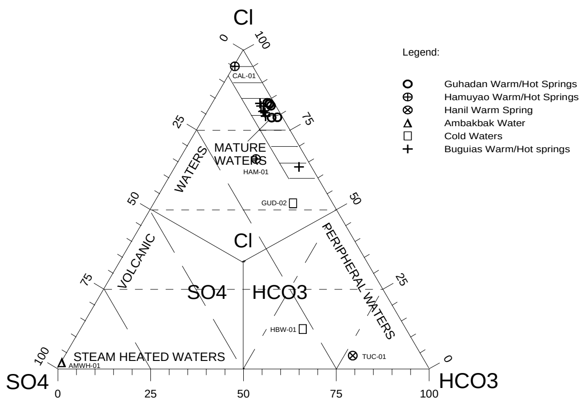

Figure 4. Relative Cl, SO_4, HCO_3 content of Tinoc waters.

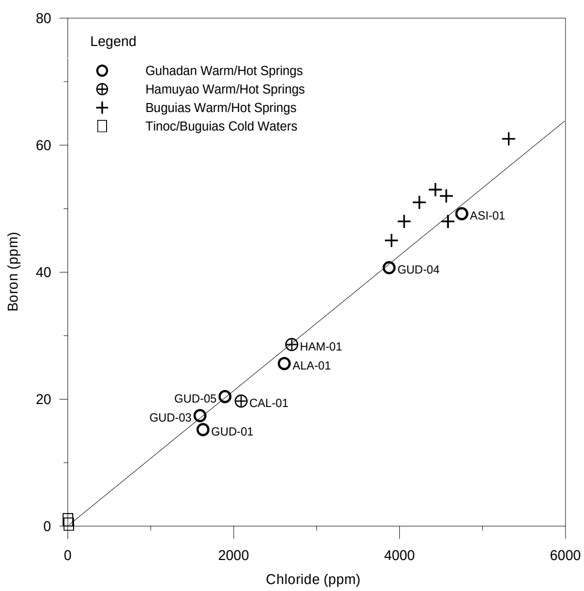

Figure 5. Chloride-Boron cross plot.

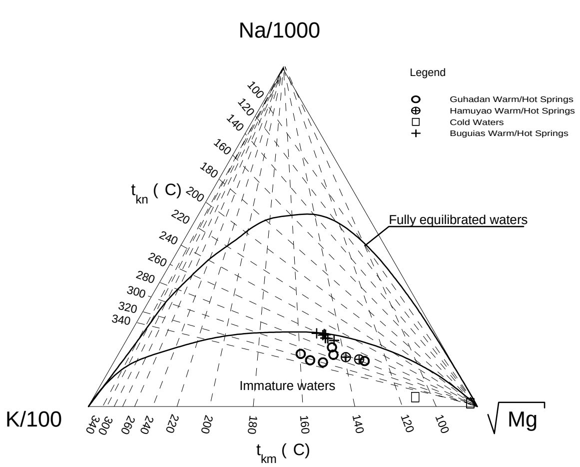

Figure 6. Relative Na, K and Mg contents of Tinoc water.

geoscientific studies. The most important application of SRT is mapping the extent of near surface (≤ 100 m depth) hydrothermal alteration associated with (located above or along outflow paths) the geothermal system/resource.

A total of 23 SRT stations were occupied and tested in the Tinoc geothermal prospect. These stations covered an area of about 126 km^2. The resistivity traversing used two fixed half-current electrode (AB/2) spacings of 250 and 500 m. Potential electrode spacing (MN) was constant at 25 m. Iso-resistivity maps at AB/2=250 and AB/2=500 m were prepared to determine the lateral variation in resistivity at shallow depth. These contour maps are based on the apparent resistivity values obtained from the survey and will serve as one of basis of interpretation of the geothermal system in the area.

From a relatively small NE trending anomaly (≤ 100-ohmm) bounded by high resistive body coincident with the direction of Guhadan and Tukucan faults at AB/2=250 m, the Nataleg-Pakawan anomaly increased and widened at AB/2=500 m as shown in Figure 7. On the contrary, the Impogong-Tinoc anomaly at AB/2=250 m decreased at AB/2=500 m and is now confined within the vicinity of Tinoc. These two anomalies are now connected by resistivity contour at 200-ohmm and include the Tukucan area where the thermal manifestations occur.

Correspondingly, the high apparent resistivity values of about 1000-ohmm have shifted to the west and are now centered at Mt. Tebeyo.

In summary, a low apparent resistivity (≤ 100-ohmm) anomaly that is possibly related to the occurrence of a geothermal system beneath Mt. Tebeyo was mapped and could be the subject of a much deeper exploration studies. Although, this seems to be localized and confined within the immediate vicinities of thermal manifestations at AB/2=500 m., there is probability that this anomaly could widen at depth based on the decrease of apparent resistivity values from AB/2=250 to AB/2=500 within the Tukucan area.

10.0 CONCEPTUAL MODEL

The post magmatic action of the dacite lava eruption, the latest volcanic activity in the area

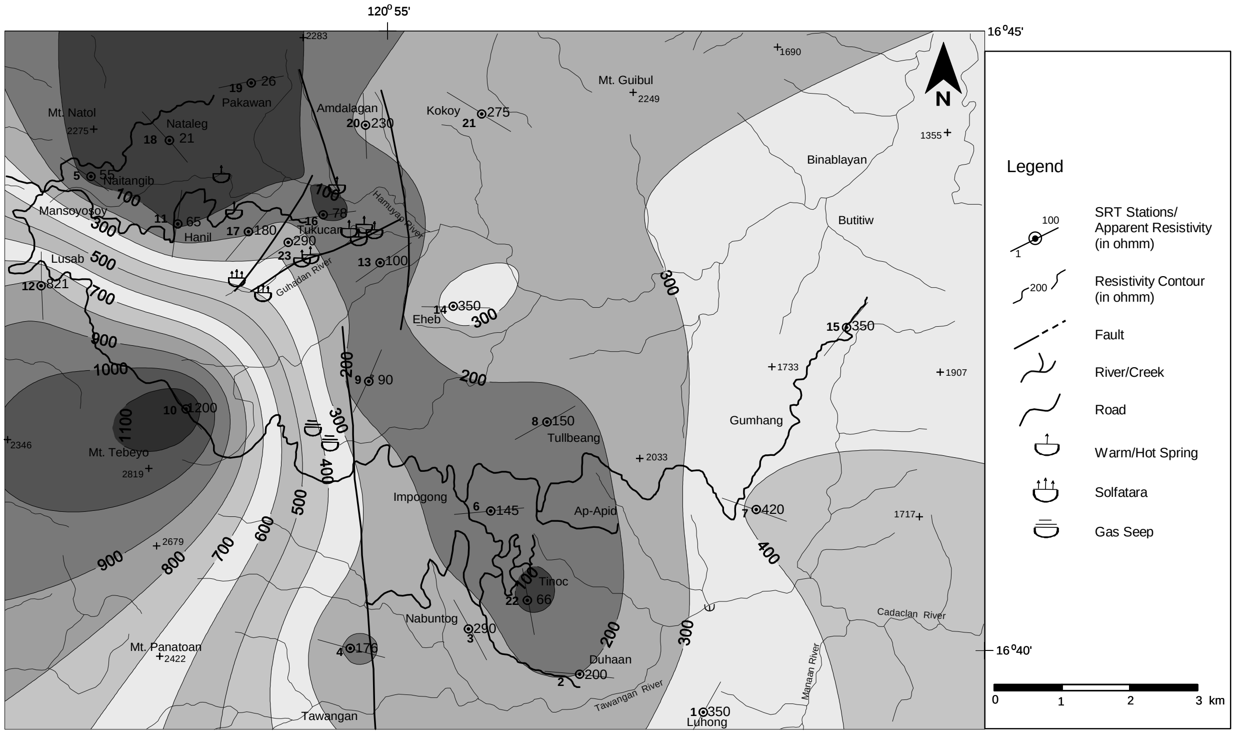

Figure 7. Isoresistivity map at AB/2 = 500 m.

(RP-JICA, 1981) is considered as the source of geothermal heat in the Tinoc prospect area.

It is generally postulated that a deep Cl rich reservoir is present beneath this Quaternary dacite lava dome. The fluid rises to near surface levels through geologic faults and fractures. The outflow is manifested by the presence of near neutral chloride springs at lower elevations in Hamuyao and Guhadan Rivers. These waters that reached the surface are products of neutralization reactions between water and rock as the waters ascend to the surface. A more saline parent water possibly at higher temperatures exists at depth though tends to be sulfate rich.

11.0 CONCLUSION AND RECOMMENDATION

Tinoc Geothermal Prospect possess the characteristics of a promising geothermal potential as shown by occurrences of young dacitic domes, solfataras, cold gas seeps, altered grounds and warm to hot springs.

Results of geoscientific studies suggest the existence of a geothermal resource in the area. Chemistry of the waters however does not indicate the presence of a mature geothermal system. Evaluation of the Tinoc waters together with those sampled in Buguias during the RP-JICA First Phase Survey in 1980 revealed that these waters likely originated from the same source. The heat source could be related to the Quaternary dacite lava dome (Mt. Tebeyo). Geothermometers indicate an intermediate subsurface temperature of about 160°C. A more saline parent water possibly at higher temperatures exists at depth though tends to be sulfate rich.

A ≤100-ohmm resistivity anomaly that includes the thermal manifestations in Tukucan was delineated. This is possibly related to the occurrence of a geothermal system beneath Mt. Tebeyo. Based on the decreasing apparent resistivity values surrounding the thermal areas, this anomaly could widen at depth. This could be the subject of a much deeper geophysical exploration studies to determine the extent of the resource and resistivity distribution at depth. Additional geologic mapping and geochemical sampling of other thermal manifestations is also recommended to complement the geophysical survey.

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