Acid Zone Delineation In Tangkuban Parahu Geothermal Working Area

Arsyi Hadyan[1,2], and Suryantini[1]

[1] Geothermal Engineering Master's Program – Faculty of Mining and Petroleum Engineering (FTTM), Institut Teknologi Bandung (ITB), Jl. Ganesha 10, Bandung 40132, Indonesia
[2] PT PLN (Persero), Jalan Trunojoyo Blok M-1 No. 135, Jakarta, Indonesia
Email: arsyi.hadyan@pln.co.id

Abstract. The Tangkuban Parahu Geothermal Working Area is located in West Java, Indonesia, and is dominated by volcanic products from Mt. Sunda and Mt. Tangkuban Parahu. Mt. Tangkuban Parahu was generated after Mt. Sunda eruption which produced large caldera. Acid zone in Tangkuban Parahu GWA becomes important to be studied regarding its origin which associated with intensive volcanic activity up to present days. The study applying the magnetotelluric data to determine the total conductance numbers for identifying anomalies corresponding acid zones. Total conductance with specific amount tied with acid manifestations in some locations to acquire approximate number of acid zones. The acid zone map delivered from total conductance data further calibrated with aleration zones and comprimising structure data. From preceding processes, the study has obtained the 2D distribution map of acid zone in Tangkuban Parahu GWA. The acid zone spread from the Kawah Ratu and Kawah Domas northward to Cijalu, northeastward to Ciater, and southward to Kancah. While Cikole and Amblongan estimated to be area which consist more benign fluids with near-neutral pH.

Keywords: *Tangkuban Parahu, geothermal, acid zones, magnetotelluric, total conductance.*

1 Introduction

The Tangkuban Parahu Geothermal Working Area is located in West Java, Indonesia**,** approximately 20 km north of Bandung. Geothermal system in this area associated with volcanic products from Mt. Sunda and Mt. Tangkuban Parahu. Mt. Tangkuban Parahu was generated after Mt. Sunda eruption which produced large caldera.

According to Pusat Vulkanologi dan Mitigasi Bencana Geologi (PVMBG) in press release on 28th February 2024, the latest eruption Mt. Tangkuban Parahu occurred in 2019 and based on this fact may be categorised as Type A volcano (Pratomo, 2006 in [1]). Intense volcanic activity in this area results in high acid content that potentially capable of causing problems during geothermal

Received ________, Revised _________, Accepted for publication __________

exploration, exploitation and utilisation. Moreover, the fact that the acid alteration zone is exposed in the Domas area with an area of more than 20,000 m^2 further strengthens the idea (Nasution et al., 2004 in [2]). Acidic compounds can be corrosive substances in geothermal well drilling activities, to this extent the distribution of acidic zones may be used to mitigate geothermal drilling plans in Tangkuban Parahu. Based on previous research that has been done, until now there has been no discussion specifically and in detail to determine the delineation of acid zones in WKP Tangkuban Parahu. Understanding the distribution of acid zone important to prevent problems that may arise.

Previously, a slim hole exploration drilling of K-3 well was conducted in this area with a depth of 612 m. Nevertheless, there is no additional drilling conducted in the area causing lack of well-preserved and factual subsurface data to provide better understanding of acid zone in Tangkuban Parahu.

In a study at the Dieng geothermal field conducted by Boedihardi et al., the acidic zone with pH <4 in Sikidang fumarole is associated with alunite mineral. The mineral at a depth of 400 m was recorded to show a total conductance value of >1000 Mhos (Boedihardi et al., 1991 in [3]). In principle, the relationship between these two phenomenon may be explained by Ohm's Law of Electrical Conductivity[1] (1827) in [4]. In summary, if the reservoir fluid is an acidic fluid with strong electrolytes, it would resulting a low resistivity value, thus meaning it has a high conductivity value and will produce a high conductance value as well. This principle can be used as an approach in delineating acidic zones in a geothermal field area, of course by integrating other data such as geochemistry and geology.

2 Regional Geology Setting

According to Nasution et al., 2004 [2], volcanic activity in the Tangkuban Parahu complex is divided into 3 main episodes: Pre-Caldera, Sunda Volcano, Tangkuban Parahu Volcano (Sunda Caldera).

2.1 Pre-Caldera

The Pre-Caldera products occupy the eastern and northeastern parts of the Tangkuban Parahu complex area consisting andesite lava and pyroclasts. The age of this unit is estimated to be lower Quaternary. Furthermore, Sunardi and Kimura conduct K-Ar dating resulting 1,105 Ma on andesit lava in Batunyusun.

---

[1] The Ohm's law of electrical conductivity states that voltage is a function of current and electrical resistivity that occurs due to a potential difference in a conductor field (Ohm, 1827).

2.2 Sunda Volcano

The Sunda volcano consists of three bodies: Sunda, Burangrang and Tangkuban Parahu which are formed on a basement of Neogene sedimentary rocks. Sunda volcanoes can be divided into Sunda Andesite (QSI) and Sunda Pyroclastics (QSp). Sunda Andesite is exposed on Mount Sunda and Mount Kukusan (Figure 1). K-Ar dating of the Sunda Andesite indicates an age of 0,560-0,205 Ma (Sunardi and Kimura, 1998 in [5]).

2.3 Tangkuban Parahu Volcano

Volcanic activity in this episode is represented by an active volcano, referred to Tangkuban Parahu Volcano and located on the northern rim of the Sunda caldera. The mountain has three large craters, namely Kw. Ratu, Kw. Upas and Kw. Baru, which produces lava and pyroclastic material constructing good stratovolcano morphology. The product consisting two main units: Tangkuban Parahu Andesite (QTl), and Tangkuban Parahu Pyroclast (QTp). K-Ar dating of the Tangkuban Parahu Andesite from the northern (Kasomalang and Sagalaherang) and southern (Dago and Cisarua) areas ranges from 0,041-0,051 Ma and 0,048-0,062 Ma, respectively.

Table 1 K-Ar ages and characteristics of the analysed rock samples (Sunardi and Kimura, 1998 in [5])

No	Episode	Unit(s)	Age (Ma)
1	Pre-Caldera	Andesite lava	1.1
2	Sunda Volcano	Sunda Pyroclastics	0.205 - 0.180
		Sunda Andesite	0.56-0.205
3	Tangkuban Parahu Volcano	Tangkuban Parahu Andesite	0.062- 0.041
		Tangkuban Parahu Pyroclast	0.040-0.022

The main alignment and circular features identified from the aerial photographs and confirmed in the field indicate the geological structure of the Sunda and Tangkuban Parahu volcanic complexes. These structures are distributed in the south, southeast and north, which probably control most of the thermal manifestations in this area. The morphology of the caldera is clearly shown by the slopes of the caldera wall. The caldera is about 5 km in diameter with a northeast-southwest direction, and is known as the Sunda caldera. This caldera may be associated with a large eruption of pyroclastic products, covering a large area. The Lembang Fault to the south of Mt. Tangkuban Parahu extends about 20 km from Mount Pulosari in the east and Cisarua in the west, where it is covered by Quaternary volcanic deposits.

The Ciater normal fault is northeast-southwest trending, characterised by alignments in river valleys, slopes and thermal manifestations. Several small normal faults or the Ciasem and Batukapur faults lie to the north of Tangkuban Parahu and strike east-west, characterised by a line of small hills and a scattering of warm springs (Figure 1).

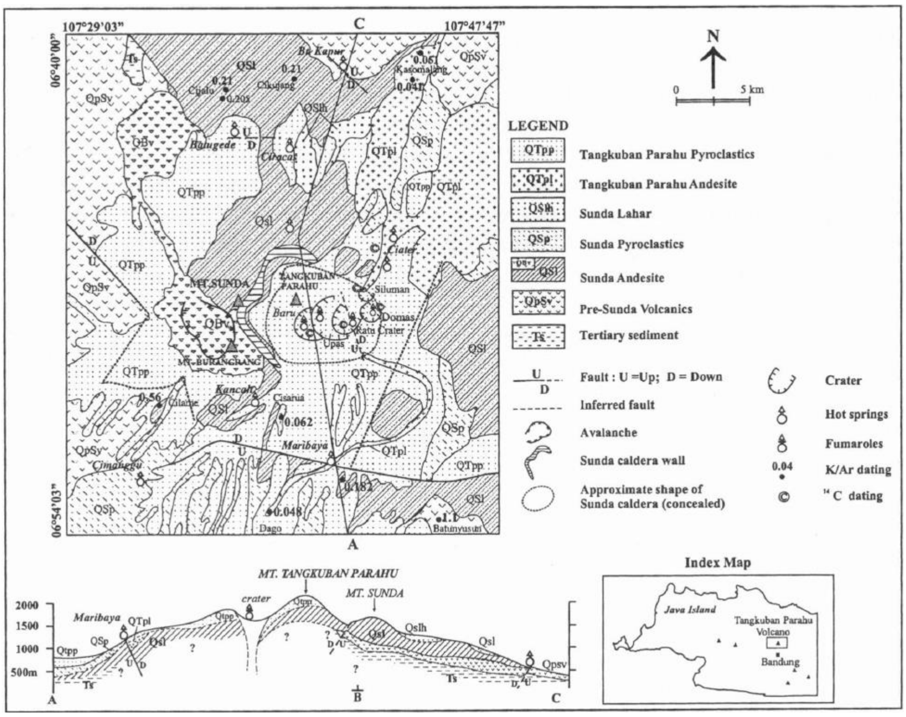

Figure 1 The geology of Sunda and Tangkuban Parahu volcanic complex, West Java (Sutoyo and Hadisantono,1992 in [6])

3 Data and Analysis

Field survey were conducted to collect geological data (rock lithology, structure, samples); geochemical fluids from manifestations, and geophysical data acquisition.

3.1 Hydrothermal alteration and structure

From geological mapping observed some area covered by altered rock in Tangkuban Parahu summit (Kw. Ratu, Kw. Baru, and Kw. Domas) and in Ciater. The alteration zones in Tangkuban Parahu divided into 3 types alteration which are advanced argillic zone, argillic zone, and iron bearing sulfate zone (Figure 2).

The advanced argillic zone is commonly characterized by silicate minerals and alunite, as well as topaz, zunyite, tourmaline and other aluminosilicates which formed under acidic pH. The advanced argillic zone develops in the three main craters of Tangkuban Parahu, namely Kw. Upas, Kw. Ratu, and Kw. Domas. Alunite forms together with the silica minerals over a wide temperature range at a slightly higher than 2 fluid pH (Stoffregen, 1987 in [7]) and indicating very acid environment.

The argillic zone is commonly characterized by kaoline (halloysite, kaolinite, and dickite) and illite group minerals (smectite, illite-smectite, and illite). Argillic zone is formed under pH between 4-5 with relatively low temperature <220-250ºC. The argillic zone that developed in Tangkuban Parahu was identified from rock outcrops around the Paguyangan Badak Crater, Jayagiri, and Ciater.

This zone is indicated by the presence of jarosite mineral from the XRD analysis. This mineral is commonly associated with acid sulfate soil environments which form due to the acid water discharged by a hot spring. XRD analysis also found the presence of actinolite mineral along with jarosite and other minerals. Actinolite is commonly found in the inner propylitic alteration zone with temperature conditions >300 °C, rich in chloride, and near neutral pH. However, it still unclear whether actinolite found in this zone is produced in propylitic alteration or not considering the associate minerals have not been found.

Most of geological structure observed and analysed in this area generally open. The structure then classified into two categories; 7 certain faults and 5 inferred faults (Figure 2). Crucial structures that may affect the distribution of fluids in this area such as Ciater Fault, Cimandiri Fault, and Tilu Leuwi Opat Fault, show openings which are unlikely to impede fluid flow.

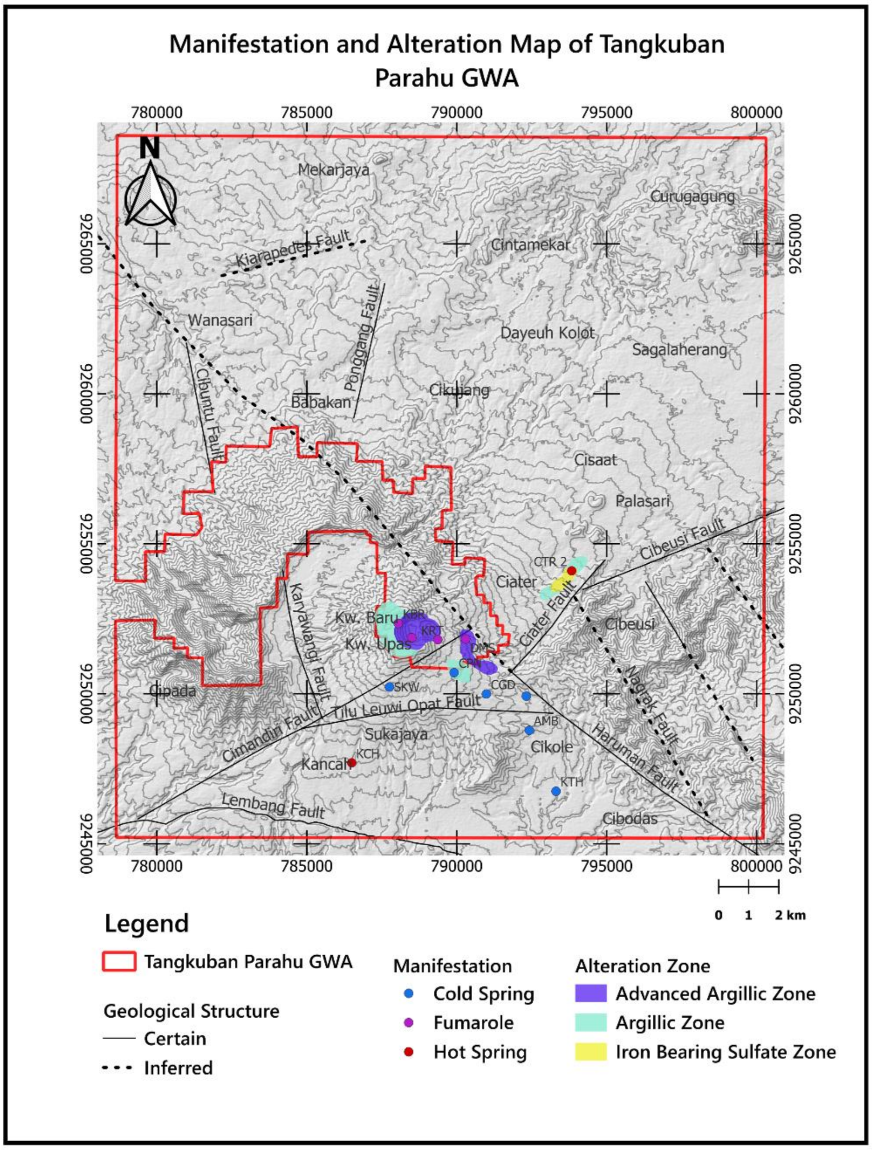

Figure 2 Hydrothermal alteration and manifestation distribution map of Tangkuban Parahu GWA

3.2 Acid zones and geochemical data from manifestations

Acid zones in a geothermal condition refer to areas in the subsurface that contains geothermal fluids with a low pH (acidic). These zones are often identified by the presence of acidic gas such as hydrogen sulfide (H_2S), as well as high sulfur content, which may come from mineral alteration processes or interactions with surrounding rocks. Nasution and Nasution in [8] disclosed that the boundary of acid fluid in volcanic setting to the neutral chloride brine is approximately 0,75 to 1 km in diameter from the volcanic vents. In Tangkuban Parahu, the acid zone is associated with its geologic setting as an active volcano and the acidic fluids distributed following the permeable zone, which is probably spread in reservoir.

Geothermal manifestations of Tangkuban Parahu consist of several fumaroles located in the collapse creater of Mt. Tangkuban Parahu, while hot springs are distributed around the slopes of the mountain. Figure 2**Error! Reference source not found.** illustrates the distributions of manifestations in Tangkuban Parahu GWA. Physical properties of manifestations in Tangkuban Parahu GWA have shown in Table 2. Hot springs in Kancah and Ciater measured to have acid pH respectively 2,4 and 2,2. This locations might be used as benchmark for the parameters calculated in determining acid zones distribution in Tangkuban Parahu GWA. While, manifestations in Maribaya, Karang Tengah, Cikole Gede, and Amblongan resulting near-neutral pH and may be identified as non-acid zone.

Table 2. Physical and Field data of Tangkuban Parahu GWA manifestation

No	Location	Type	Sample Code	X	Y	Temperature (ºC)	pH
1	Kawah Domas	Fumarole	DMS	790297	9251828	90	-
2	Kawah Ratu	Fumarole	KRT	789370	9251805	93,8	-
3	Kawah Upas	Fumarole	KUS	788496	9251870	88	-
4	Kawah Baru	Fumarole	KBR	788048	9252348	90	-
5	Ciater	Hot Spring	CTR 2	793831	9254100	37,3	2,2
6	Kancah	Hot Spring	KCH	786499	9247699	34,5	2,4
7	Maribaya	Hot Spring	MRB	793427	9244205	39,7	6,7
8	Sukawana	Cold Spring	SKW	787757	9250227	-	-
9	Karang Tengah	Cold Spring	KTH	793308	9246753	23	6,6
10	Cipanguluan	Cold Spring	CPN	789911	9250707	17	5,4
11	Cikole Gede	Cold Spring	CGD	790986	9249994	18	6,2
12	Pal 16	Cold Spring	P16	792319	9249921	19	6,8
13	Amblongan	Cold Spring	AMB	792420	9248783	21	6,6

3.3 Magnetotelluric data

As the distribution of acidic fluids is quite dependent on the distribution of permeable zones, which are most likely through geothermal reservoirs, MT data may be playing crucial role. From the aspect of resistivity, acidic fluids shall produce low resistivity because acidic fluids generally contain dissolved ions, such as hydrogen ions (H^+) and certain anions (e.g., Cl^- in hydrochloric acid or SO_4^{2-} in sulfuric acid), which may transmitted conveniently in solution. The ions in an acidic causing the solution to be more conductive. If more ions contained in solution, electric current shall conduct more fluent through the solution. The low resistivity value directly indicates the high conductivity value of the acidic fluid solution, and linearly increases its conductance value.

MT data, both the existing and new data, have been processed. The MT data have good to excellent data quality. Distribution of MT stations may be seen in Figure 3. The main subject of this study is calculation of total conductance from MT data. Chave & Jones in [9] states that in a homogeneous medium, the scale of electromagnetic induction is scaled by the skin depth value from equation below:

$$\delta = 503\sqrt{\rho T} \tag{1}$$

δ = skin depth value (m)
ρ = resistivity
T = period

After obtaining the skin depth value, the total conductance value is calculated by subtracting the thickness by the resistivity.

$$S = \delta / \rho \tag{2}$$

δ = skin depth value (m)
ρ = resistivity
S = total conductance (mhos)

3.4 Analysis

From the data displayed above, processing is carried out to obtain an acidity contour map. Firstly, manifestations which shows acidic pH are tied with nearest MT station. The total conductance value at the station then used as a benchmark in making the classification of acidity levels at the research site, as may be seen in Table 3.

Table 3. Table of acidity classification derived from total conductance value and manifestation

No	Manifestation	pH	S value (mhos)	Remarks (class)
1	Ciater	2,2	> 350	Strong acid (1)
2	-	-	200 – 350	Slightly acid – acid (2)
3	Cikole Gede	6,8	< 200	Neutral (3)

The classification is then used in drawing contour lines to determine the distribution of each classification unit (Figure 4). Contour map of acid classification then combined with alteration and structural data to produce more integrated map with higher confidence level, as may be seen in process shown in Figure 5.

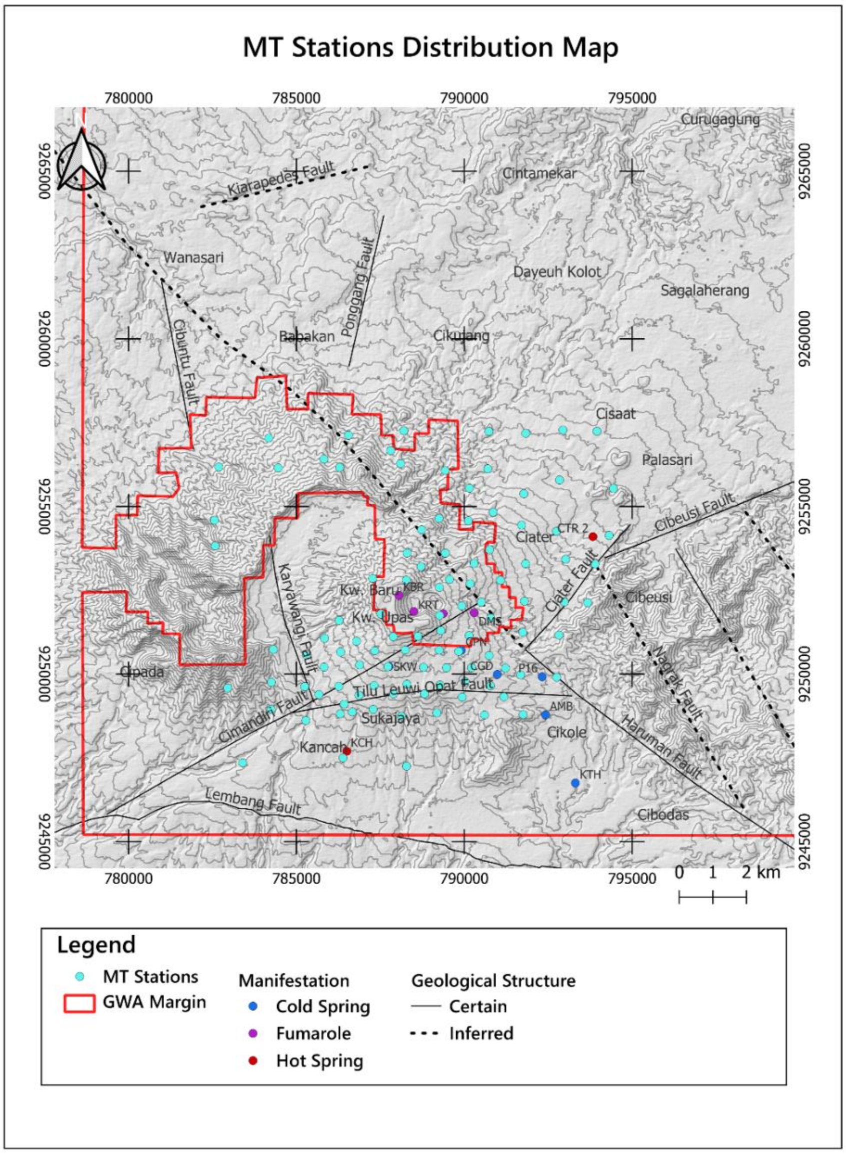

Figure 3. MT stations distribution map

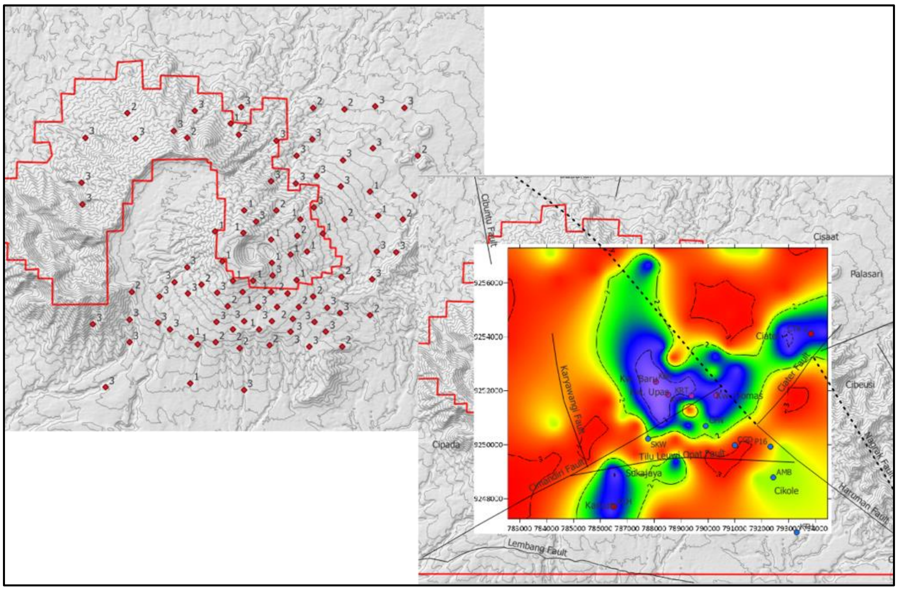

Figure 4. Contour map generated from acid classification. This figure then further processed by combining alteration and structural data for more integrated map

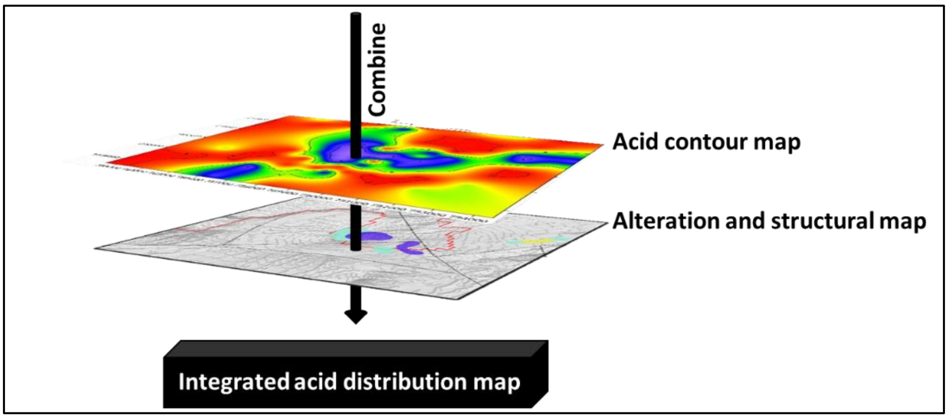

Figure 5. Illustration of processing maps into an integrated acid distribution map in Tangkuban Parahu GWA

4 Results

From stages of process previously disclosed, the acid distribution map at Tangkuban Parahu GWA contrived. As may seen in Figure 6 the acid zone[2] extend from Tangkuban Parahu summit to the north toward Cikujang, approximately 2 km north of Tangkuban Parahu caldera rim. On the other part acid advanced from the summit to southern part of the region past Kancah, and eastward trough Ciater.

While the Cikole and Amblongan area are estimated to have non-acidic fluids, and western part in Situ Lembang predicted to have benign fluids as well.

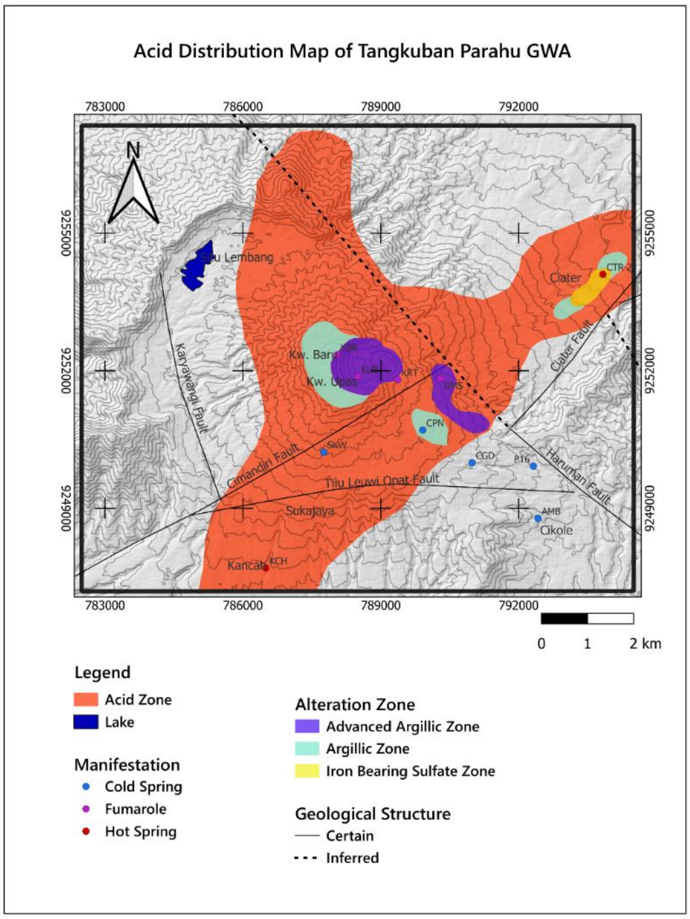

Figure 6. Acid distribution map of Tangkuban Parahu GWA

[2] Acid zone in this figure refers to strong acid zone – slightly acid zone.

5 References

[1] Pratomo, I. (2006). *Klasifikasi Gunung Api Aktif Indonesia,Studi Kasus Dari Beberapa Letusan Gunung Api Dalam Sejarah*. Jurnal Geologi Indonesia.

[2] Nasution, A., Kartadinata, M. N., Kobayashi, T., Siregar, D., Sutaningsih, E., Hadisantono, R., & Kadarstia, E. (2004). *Geology, Age Dating and Geochemistry of the Tangkuban Parahu Geothermal Area, West Java, Indonesia*. J. Geothermal Resource Soc. Japan.

[3] Boedihardi, M., Suranto, & Sudarman, S. (1991). *Evaluation Of The Dieng Geothermal Held; Review Of Development Strategy*. IPA 20th Annual Convention Proceedings.

[4] Ohm, G. S. (1827). *The Galvanic Circuit Investigated Mathematically* (T. D. Lockwood (trans.)). Kraus Reprint Co.

[5] Sunardi, E. and Kimura, J. (1998) *Temporal chemical variation in Late Cenozoic volcanic rocks around the Bandung Basin, West Java, Indonesia*. J. Min. Petr. Econ. Geol.,vol. 93, 103-128.

[6] Sutoyo and Hadisantono, R. (1992) *Geological map of Tangkuban Parahu volcano, West Java. Bandung, Indonesia*.

[7] Stoffregen, R. (1987). *Genesis of acid-sulfate alteration and Au-Cu-Ag mineralisation at Summitville, Colorado*. Economic Geology, vol. 82, 1575-1591.

[8] Nasution, A., and Nasution M. P. (2021). *Geochemical Modeling of Acid Fluid from Volcanic Geothermal Areas, Case Study of Indonesian Geothermal Prospects.* Proceedings World Geothermal Congress 2020+1.

[9] Chave, A. D., & Jones, A. G. (2012). *The Magnetotelluric Method: Theory and Practice*. Cambridge University Press.