Journal of Volcanology and Geothermal Research 358 (2018) 77–86

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

# Structure of the acid hydrothermal system of Papandayan volcano, Indonesia, investigated by geophysical methods

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ARTICLE INFO

*Article history:*
Received 6 April 2018
Received in revised form 7 June 2018
Accepted 10 June 2018
Available online 30 June 2018

*Keywords:*
Hydrothermal system
ERT
Acid-sulfate
pH and conductivity
Papandayan

ABSTRACT

Papandayan (2665 m asl) is an Indonesian stratovolcano located at 50 km from Bandung in west Java and characterized by an intense hydrothermal activity. An advanced alteration takes place where acid fluids interact with rocks, weakening the edifice, so that even minor explosive eruptions threaten the stability of its flanks. The purpose of the current study is to delineate the geometry of the acid hydrothermal plume using Electrical Resistivity Tomography (ERT). We used self-potential, pH measurements in water (*in situ*) and of soil samples, $SO_2$ and $CO_2$ soil concentration mappings to better understand the resistivity structure. Measurements have been performed inside the 1772 crater with a maximal depth of investigation of about 250 m for electrical resistivity tomography.

At low pH, the mobility of $H^+$ (or $H_3O^+$) ions represents a dominant contribution to the electrical conductivity leading to an unusually high conductivity of pore water. For Papandayan spring water, the theoretical electrical conductivity calculated for chemical composition and pH yield indeed exceptionally high values in the range $20-25\text{Sm}^{-1}$. The surface conductivity of the altered unconsolidated samples determined from a recent study ($< 0.04\text{Sm}^{-1}$) is negligible in comparison with the conductivity of the pore water. The theoretical conductivity values are then compared with the results of our geophysical survey. Our 3-D inversion of electrical resistivity data identifies the entire crater of Papandayan volcano as a relatively conductive medium ($>0.005\text{Sm}^{-1}$) with an extremely high bulk conductivity within the central part of the crater ($\sim 2\text{Sm}^{-1}$). The main degassing zones in the crater, Kawah Emas, Manuk and Kawah Baru, are all connected by conduits to this common reservoir at a depth of 100 m. Because the location of this good conductor coincides with elevated ground temperature, main fumaroles, and with detectable $SO_2$ degassing, we interpret it as an acid hydrothermal plume. Low pH impacts also the self-potential distribution: a clear correlation is observed between the pH values measured in soil samples and the self-potential. The main degassing area is associated with a negative anomaly of self-potential likely produced by the electro-kinetic effect due to upwelling fluid flow in acid conditions.

It follows from our results that the assessment of the pH conditions is necessary for the interpretation of electrical resistivity structures and self-potential distribution on hydrothermal systems where acid conditions and acidity variations can be expected due to chemical reactions between volcanic gases and groundwater.



## 1. Introduction

The Papandayan stratovolcano in Western Java (Indonesia) is related to the subduction of the Indian oceanic plate beneath the Java arc (Hamilton, 1979), see Fig. 1a. According to the overview of its historical activity given by Abidin et al. (2003), the magmatic eruption in 1772 created a crater of about 1.6 km in diameter, caused the collapse of the northeast flank, and produced a debris avalanche that destroyed about 40 villages, killing nearly 3000 people (Abidin et al., 2003). More recent and less destructive eruptions occurred in 1882, 1923–1927, 1942, 1993 and 2002 (Abidin et al., 2003) as well

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https://doi.org/10.1016/j.jvolgeores.2018.06.008
0377-0273/

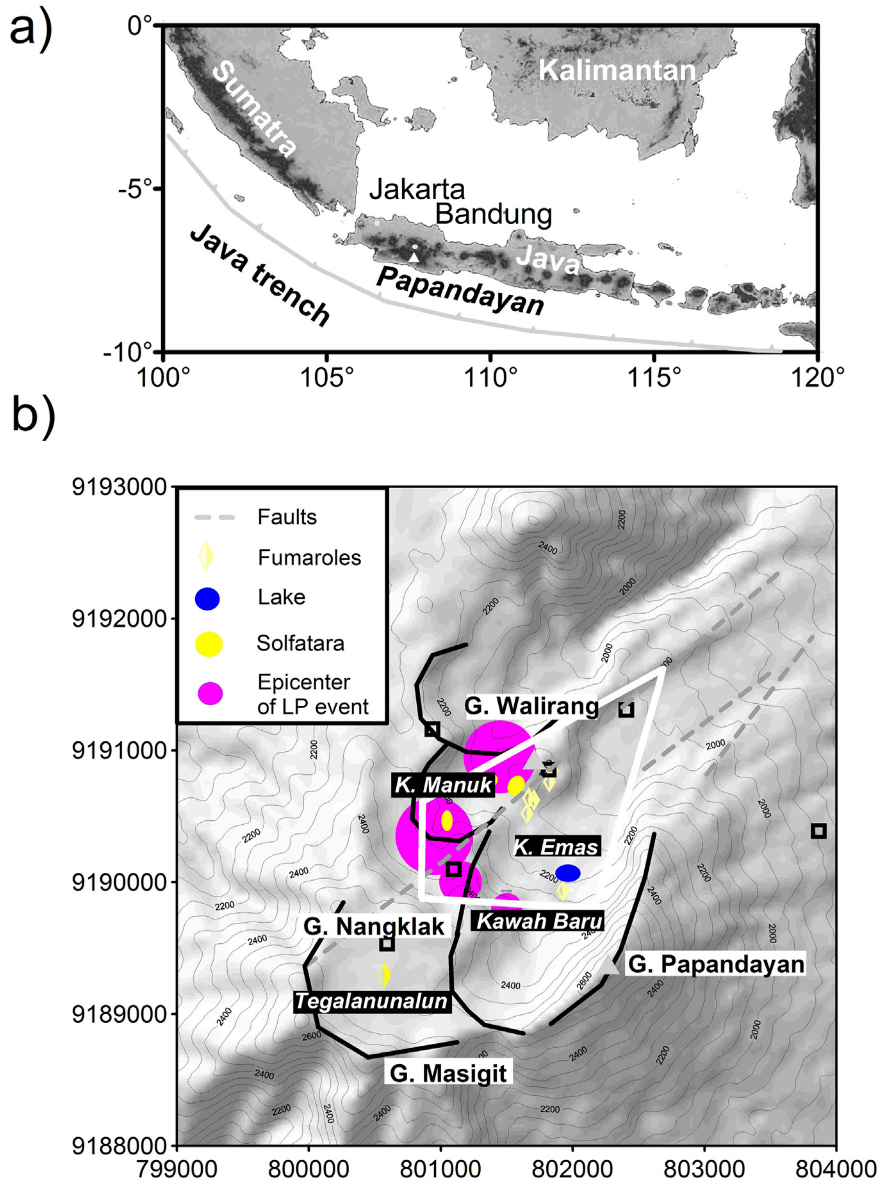


**Fig. 1.** Location of Papandayan volcano (a) with locations of inferred faults, main fumaroles, and study area (b) (simplified after Mazot et al., 2008). Main geological structures including faults, crater-rims, fumarole fields are shown in UTM coordinates in meters. The area of the 3-D ERT model is marked with a white polygon, the localization of seismic stations used by Syahbana et al. (2014) as well as epicenters of the long period (LP) events likely related to the hydrothermal activity are shown with squares and purple ellipses.

as a hydrothermal unrest in 2011 (Syahbana et al., 2014). The recent activity is hydrothermal and consists mainly of gas emanations from fumaroles, sulfur-mud pools, hot springs at main craters Nangklak, Emas, Manuk, and Kawah Baru, all sitting in the 1772 crater. The 2002 eruption created the Kawah Baru (Kawah Baru means “new crater”) and triggered landslides on the Western slope of the volcano.

Papandayan is a modest $SO_2$ emitter: Bani et al. (2013) estimated the total $SO_2$ flux as $\sim$ 1.4 tons per day during the inter-eruptive period against 7000 tons per day during the 2002 eruption (Mazot et al., 2008). The geochemistry of the hot springs and fumarole gases, as well as mineralogy of eruptive deposits has been studied by Mazot et al. (2008) after the 2002 eruption.

The chemical composition of gases and/or hot springs reflects interactions between the deep fluids and the superficial aquifer. In general, upwelling volcanic fluids containing the acid gases sulfur dioxide ($SO_2$), hydrochloric acid (HCl), hydrofluoric acid (HF) across the hydrothermal zone beneath the crater produce low pH solutions (Giggenbach, 1987). $SO_2$ reacts with water to form sulfuric acid ($H_2SO_4$) plus native sulfur ($S^0$) according to reactions (Giggenbach, 1987):

$$3\,SO_2 + 3\,H_2O \Longleftrightarrow 2\,H_2SO_4 + H_2O + S^0, \tag{1}$$

or sulfuric acid and hydrogen sulfide:

$$4\,SO_2 + 4\,H_2O \Longleftrightarrow 3\,H_2SO_4 + H_2S, \tag{2}$$

The acidity of waters originates from the proton release due to dissociation of HCl and $H_2SO_4$ at temperatures below 400 °C (e.g., Nicholson, 1993). These conditions are met at Papandayan volcano where the temperature of Kawah Emas fumarole is close to 300 °C, the most abundant gas components being $H_2O$, $CO_2$, $H_2S$ and HCl (Mazot et al., 2008). Close to the surface, the oxidation of the $H_2S$