Geothermal and volcanism in West Java

I Setiawan¹, S Indarto¹, Sudarsono¹, A Fauzi I¹, A Yuliyanti¹, L Lintjewas¹, A Alkausar¹ and Jakah¹

¹Research Center for Geotechnology, Indonesia Institute of Sciences (LIPI), Bandung 40135
E-mail: bogalakon@gmail.com

Abstract. Indonesian active volcanoes extend from Sumatra, Jawa, Bali, Lombok, Flores, North Sulawesi, and Halmahera. The volcanic arc hosts 276 volcanoes with 29 GWe of geothermal resources. Considering a wide distribution of geothermal potency, geothermal research is very important to be carried out especially to tackle high energy demand in Indonesia as an alternative energy sources aside from fossil fuel. Geothermal potency associated with volcanoes-hosted in West Java can be found in the West Java segment of Sunda Arc that is parallel with the subduction. The subduction of Indo-Australian oceanic plate beneath the Eurasian continental plate results in various volcanic products in a wide range of geochemical and mineralogical characteristics. The geochemical and mineralogical characteristics of volcanic and magmatic rocks associated with geothermal systems are ill-defined. Comprehensive study of geochemical signatures, mineralogical properties, and isotopes analysis might lead to the understanding of how large geothermal fields are found in West Java compared to ones in Central and East Java. The result can also provoke some valuable impacts on Java tectonic evolution and can suggest the key information for geothermal exploration enhancement.

1. Tectonic and magmatism

The subduction of Indian-Australian oceanic plate to the Eurasian continental plate, which has started since Late Miocene until present with some paucities [1], produces magmatic activities along the Sunda-Banda arc [2]. In the Sunda-Banda subduction margin, some quaternary volcanic-magmatic rocks host geothermal system. The high cluster of geothermal localities is located in West Java [3], which is currently supply ~80 % of geothermal energy with almost 1034 Mwe installed capacity [4] from 4 high temperature geothermal fields i.e. Gn. Salak (Awibengkok), Wayang Windu, Darajat and Kamojang. As a segment within Sunda-Banda arc and a site of almost 22 geothermal fields (from brown to green fields) [5], West Java becomes an ideal place to analyse the relationship between the magmatic-associated subduction characteristic with the geothermal existences.

Magma compositions are modified by differentiation in the arc crust during its evolution, including their trace elements and isotope ratios. It is important to identify and remove post-modified magma due to magma mixing and crustal contamination prior to the discussion on the source compositions. Therefore, the parent magma can be effectively distinguished from those that have been modified at the magma source [6-11]. The basement of the western region of Java is continental crust and becomes progressively oceanic towards the east [12,13]. West Java is considered to be located in the transitional zone between oblique subduction in Sumatra and orthogonal subduction at the eastern part of West Java [1]. A combination of fractional crystallization, magma mixing, and crustal contamination will act to modify a mantle source from its primary composition (Figure 1).
This work is proposed to identify and to understand the temporal and spatial of geochemical, mineralogical, the isotopic variation of volcanoes and its associated geothermal fields in West Java across and along the subduction.

![Diagram of Subduction zone petrogenesis](image)

**Figure 1.** Some variables in subduction zone petrogenesis [3, 7, 17].

2. **The distribution of geothermal fields in West Java**

There are at least four volcanic complexes in West Java. They are Krakatau volcano and Danau complex in the westernmost of West Java separated about 60 km from each other. The Salak complex which consists of several single chain volcanoes (Salak, Kiarabere, Perbakti, and Gede) about 85 km apart (Figure 2), and Galunggung-Tangkuban Prahu complex.

Galunggung-Tangkuban Prahu are about 60 km apart from Salak complex. This zone is populated by many volcanoes that form a 90-km double volcanic chain along the arc [3]. Mount Galunggung and some other clustered volcanoes are located along the trench-side volcanic chain, while Mount Tangkuban Prahu, Mount Tampomas, and Mount Ceremai are located along the backarc-side volcanic chain [19].

There are different trends between surface structures from regional geology map and deep-seated structures from regional Bouguer anomalies [14]. Surface structures are dominated by N-S and NNE-SSW trending faults and lineaments, while the deep seated structures from Bouguer anomaly depict the major trend of NW-SE and WNW-ESE. The Riedel clay experiment is used as a model to explain the structural architectures in West Java [14]. The numbers of volcano-magmatic products (volcanoes and its associated geothermal fields) occur in rim structure: Gede, Patuha, Papandayan, Cikuray, Galunggung, Karaha, Tangkuban Parahu; while in middle part of the circle are Wayang Windu, Kamojang, Darajat and Guntur [14].
Figure 2. A. The active volcano-magmatic arc in Indonesia associated with geothermal locations [5].
B. The occurrence of geothermal field in Java, Based map is DEM of SRTM 30, geothermal field locations is adapted from [5].

There is a probable relationship between the existence of high potential geothermal prospects with the deep-seated structure in West Java which does not occur in the central and east of Java. The geothermal fields in West Java have never been associated with the crustal structure, unlike the one in Sumatra where the Sumatra Fault is highly associated with the geothermal localities [15]. A recent study suggests that there is a major arc parallel fault from regional gravity analysis in West Java, namely West Java Fault, which has 2 faults splaying trending at NW-SE [14]. The applied model proposes the major fault and its splay in dextral movement which are responsible for the formation of circular low Bouguer structure in Bandung-Garut Zone. Spatially, the zone hosts an anomalous cluster of abundant mass and
heat transfer as manifested by volcanoes and geothermal systems, including 5 globally rare vapor dominated systems [14].

The depth of the subducted slab underneath decreases from the Danau zone to Galungung zone. At Danau zone, the depth of slab is about 130 km beneath the volcanic front whose depth decreases into about 120 km at Salak zone and finally into 110 km underneath the volcanic front of Galunggung zone [19].

3. Type of geothermal systems
In West Java, geothermal has occurred in vapor and liquid dominated systems. The geothermal vapor dominated system includes Kamojang, Darajat, Wayang Windu, Patuha and Karaha-Talaga Bodas [19] while the other fields such as Awi Bengkok, Tangkuban Parahu etc. are the liquid dominated system. More detail classification of geothermal fields in West Java indicates 5 classes, which are vapour dominated system, vapour layer system, liquid dominated system, volcanic geothermal system, high temperature system [18,19].

The occurrence of vapor dominated systems in West Java is unusual; there are only 8 locations in the world which have been defined as vapor dominated systems, and 5 of them are located in West Java, especially clustered in the central part of West Java [19]. Vapor dominated systems require high potent and an intensive heat source [19].

4. Geochemical properties anomaly of magmatism in West Java
The structural architecture of West Java possibly has an important role in localising abundant heat and mass transfer along the segment. However, magmatic intrusion as a main parameter for heat properties in geothermal systems is also unique in West Java. Geochemical analysis suggests a stable magmatic supply in West Java for at least 10 Ma [20]. Crustal contamination also has a significant effect on the composition in the West Java areas [16]. The contamination with the terrigenous crustal materials was identified at Papandayan producing the medium to High-K rocks [16,17]. In West Java, volcanoes such as Papandayan and Patuha show significant enrichments in isotope ratios above mantle values (e.g. $^{87}\text{Sr}/^{86}\text{Sr} \sim 0.706$, $^{143}\text{Nd}/^{144}\text{Nd} \sim 0.5125$, $^{208}\text{Pb}/^{204}\text{Pb} \sim 18.91$ and $^{176}\text{Hf}/^{177}\text{Hf} \sim 0.2827$) which indicate a terrigenous crustal contaminant [16,17].

5. Concluding remarks
The anomalous geological condition, including large extension of Bandung Garut Zone (BGZ) due to deep seated structures of West Java Fault activation and prolonged magmatic supply from geochemical signatures, might only be a few factors among many unknown ones that are associated with the abundancy of high heat and mass transfer in West Java, as manifested by active volcanoes and geothermal systems within just ~300 km arc segment. Contamination with the terrigenous crustal materials from geochemical signature adds the uniqueness of West Java geological condition that is probably responsible for the anomalous high heat and transfer in West Java.

In terms of geochemical composition, magma sources of western Java are unique so that they can produce abundant geothermal and magmatic-hydrothermal related products i.e. hydrothermal mineralization. More detailed study of geochemical, mineralogical and isotopes analysis, from magmatic-hydrothermal related products, e.g. intrusive and volcanic rocks, hydrothermal mineralisation etc., in West Java, Central Java and East Java could explain many aspects, especially on what the main geochemical signatures are. They have been associated with abundant heat and mass transfer in West Java as manifested by active volcanoes and geothermal systems.

Acknowledgments
This work is written as a part of literature review of our future research work. We thank Research Center for Geotechnology, LIPI and to GCGE 2017 committee. We also thank the reviewer and the editor for their constructive suggestions.
References

[1] Hall R 2012 Late Jurassic–Cenozoic Reconstructions of the Indonesian Region and the Indian Ocean Tectonophysics 570-571 1-41

[2] Soeria-atmadja R et al 1994 Tertiary magmatic belts in Java, Journal of Southeast Asian Earth Sciences 9 13-27

[3] Setijadji L D 2010 Segmented Volcanic Arc and its Association with Geothermal Fields in Java Island Indonesia. Proc. World Geothermal Congress 2010 25–29

[4] Bertani R 2012 Geothermal power generation in the world 2005–2010 update report. Geothermics 41 1-29

[5] Hochstein M P and Crosetti M 2012 Ranking of Indonesia Geothermal Prospect (Known Reserves). New Zealand Geothermal Workshop 2012

[6] Thirlwall M F and Graham A. M 1984 Evolution of high-Ca, high-Sr C-series basalts from Grenada, Lesser Antilles: the effects of intra-crustal contamination. Journal of the Geological Society, (London), 141 427-445

[7] Davidson J P 1987 Crustal contamination versus subduction zone enrichment: Examples from the Lesser Antilles and implications for mantle source compositions of island arc volcanic rocks. Geochim. Cosmochim. Acta, 51 2185-2198

[8] Thirlwall M F et al 1996 Resolution of the effects of crustal assimilation, sediment subduction, and fluid transport in island arc magmas: Pb-Sr-Nd-O isotope geochemistry of Grenada, Lesser Antilles. Geochim. Cosmochim. Acta, 60 4785-4810

[9] Davidson J Pet al 2005 Crustal forensics in arc magmas. J. Volcanol. Geotherm. Res, 140, 157-170

[10] Handley H K et al 2008 Untangling differentiation in arc lavas: Constraints from unusual minor and trace element variations at Salak Volcano (Indonesia) Chem. Geol., 255, 360-376

[11] Davidson J and Wilson M. 2011 Differentiation and Source Processes at Mt Pelee and the Quill; Active Volcanoes in the Lesser Antilles Arc. Journal of Petrology, 52, 1493-1531

[12] Hamilton W 1979 Tectonics of the Indonesia region. US Geol. Surv. Prof. Paper, 1078 345

[13] Curray J R et al 1977 Seismic Refraction and Reflection Studies of Crustal Structure of the Eastern Sunda and Western Banda Arcs. Journal of Geophysical Research, 17 2479-2489

[14] Fauzi A et al 2015 Regional Structure Control on Geothermal Systems in West Java, Indonesia Proc. World Geothermal Congress 2015 (Melbourne, Australia)

[15] Hochstein M P and M Crosetti 2012 Ranking of Indonesia Geothermal Prospect (Known Reserves). Proceedings New Zealand Geothermal Workshop

[16] Dempsey SR 2013 Geochemistry of volcanic rocks from the Sunda Arc. Doctoral thesis Durham University

[17] Abdurrahman M and Yamamoto M 2012 Geochemical variation of Quaternary volcanic rocks in Papandayan area, West Java, Indonesia: Arole of crustal component, Journal of the Geological Society of Thailand, Geosea 2012 (Bangkok, Thailand)

[18] Hochstein M P and S Sudarman 2008 History of geothermal exploration in Indonesia from 1970 to 2000 Geothermics 3, 220-266

[19] Raharjo I B et al 2012 Why Are the Only Volcano-Hosted Vapor-Dominated Geothermal Systems in West Java, Indonesia? GRC Transactions 36

[20] Sendjaya Y A and Kimura J I 2010 Geochemical variation in Tertiary-Quaternary lavas of the West Java arc, Indonesia ; Steady-state subduction over the past 10 million years. Journal of Mineralogical and Petrological Sciences, 105 20–28