Exploration and comparison of geothermal areas in Indonesia by fluid-rock geochemistry

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ABSTRACT

Indonesia with its large, but partially unexplored geothermal potential is one of the most interesting and suitable places in the world to conduct geothermal exploration research.

This study focuses on geothermal exploration based on fluid-rock geochemistry/geomechanics and aims to compile an overview on geochemical data-rock properties from important geothermal fields in Indonesia. The work will be conducted over the next two years and this paper intends to present the methods and approaches we would like to use. The research carried out in the field and in the laboratory is performed in the framework of the GEOCAP cooperation (Geothermal Capacity Building program Indonesia- the Netherlands). Research along with capacity building will be combined in this Indonesian-Dutch project. The application of petrology and geochemistry accounts to a better understanding of areas where operating power plants exist but also helps in the initial exploration stage of green areas. Because of their relevance and geological setting representing geothermal fields in Java, Sulawesi and the sedimentary basin of central Sumatra have been chosen as areas will be the focus of the study. Operators, universities and governmental agencies will benefit from this approach as it will be applied also to new green-field regions and areas to be tendered.

INTRODUCTION

In a conventional approach, several methods need to be adopted and integrated to understand the geochemical and geophysical signatures of active geothermal systems (e.g., Rybach and Muffler 1981). These methods also apply for green-field studies and include: (a) geochemical investigations (e.g., using chemical geo-thermometers to infer the temperature of the geothermal reservoir and measurements of gas isotopes, such as $^3He/^4He$, to constrain the origin (mantle or crust) of fluids; (b) drilling of exploration wells; (c) gravity measurements to map any negative anomaly associated with the steam fraction in high-porosity reservoir rocks or to locate zones of lowered density provoked by thermal expansion in magmatic bodies; (d) application of electrical methods such as resistivity to search for zones of higher-salinity fluids; (e) use of seismic methods for the determination of shallow intrusions and their vertical extension.

Young volcanic zones along convergent plate margins are prime targets for the exploration of geothermal-energy sources as active magma chambers have an intrinsically geothermal potential (Bogie et al. 2005). Heath transfer in those areas is dominated by circulating fluids and, in the case of two-phase systems, also by steam. Therefore, surface manifestations like hot springs and steam vents are indicators for geothermal activity. Prior to any geophysical surveying of geothermal systems, a field-based geological and geochemical reconnaissance is required to develop a conceptual model of a geothermal field. The exploration phase predating drilling of the first well is commonly termed Greenfield exploration, referring to the juvenile non-exploited condition of a geothermal reservoir (Hochstein, 1988). However, superficial geothermal manifestations are not manifested in all volcanic fields. Geological formations serving as barriers or seals for fluids may prevent discharge of up-flowing waters.

Java, i.e., is geologically associated with the magmatic arc of the Sunda subduction zone (Simkin and Siebert 1994). Here, geothermal waters were subject of exploration and utilization over several decades (Hochstein et al., 2000; Hochstein and Sundarman 2008). However, the efforts to explore and exploit geothermal prospects changed over the years and also with respect to their location along the island chain. For example, activities for exploitation of geothermal energy centered on vapor-dominated system in western and central Java (in Salak or Cisolok) at the end of the 1970ies, where the infrastructure was sufficiently developed. Efforts increased in the mid 1990ies, when the Indonesian government encouraged foreign investors to take part in the exploration. Recently, the main activities are focused on existing power plants at Kamojang**,** Wyang Windu and Djeng.

Recent published works such as Deon et al. (2015) and Brehme et al. (2014, 2015, 2016) evidences the important of water and rock geochemistry when exploring tropical fields. Analyses on water and rocks deliver valuable information. An approach applied to a wider range of fields is still missing. By comparing the characteristic of the fluids, the alteration petrology and the rock we aim to contribute to compile an overview of the geochemistry in the important geothermal fields in Indonesia. The goal is not only to obtain scientific results but also to validate this method for universities and companies.

Because of their relevance and geological setting representing geothermal fields in Java, Sulawesi and the sedimentary basin of central Sumatra will be the focus areas of the study. The first phase of the fieldwork has been concentrated in Tanguban Perahu (Lembang) and Wayang Windu. (see Fig 1).

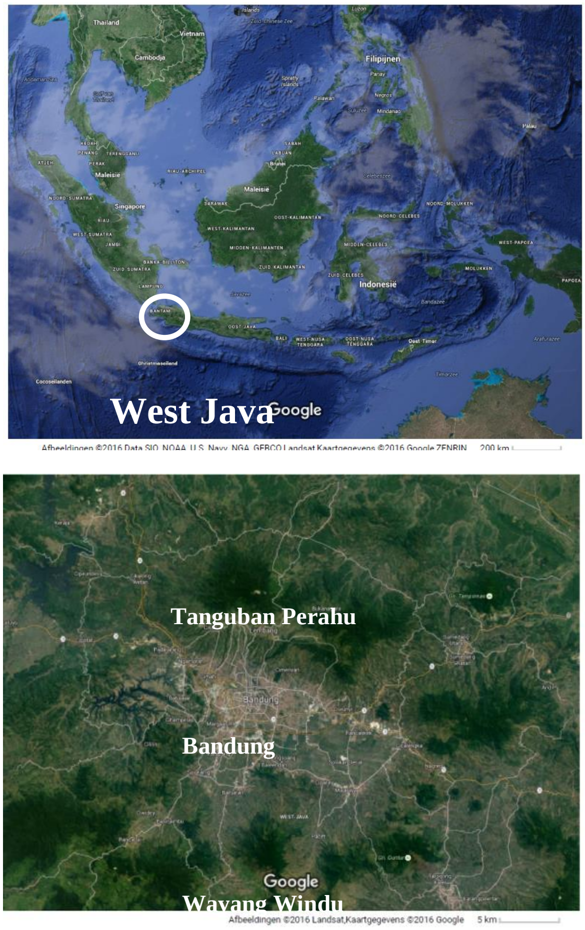


Fig. 1 Map of Indonesia with the highlighted research areas. Detailed map of the fieldwork area in West Java in the proximity of Bandung. (Source Google Earth)

METHODS

Water samples

Rock and water have been sampled in two locations as shown in Fig. 2. The water samples have been collected according to the procedure of Giggenbach & Gougel (1989) recommended for the quantitative analysis of the major ions. Water samples were filtrated using a 0.45 µm membrane filter to prevent the interaction of the fluid with suspended particles and algal growth. For the analysis of anions and isotopes, water samples were untreated, while for cation analysis, the water samples were acidified with HNO_3. The on-site measurements covered pH, temperature (T), electrical conductivity, and carbonate content (see Tab. 1a). The elements in the water samples were measured at the University of Twente, Netherlands (samples from Wayang Windu) and at Berlin Technical University Germany (samples from Tangunban Perahu). The analyses at ITC were performed by Perkin Elmer Optima 8300 DV (Dual View) ICP/OES. All elements were measured using a normal purge method, except, sulphur and phosphorus were measured using a high purge method. All elements were measured axially, except potassium and sodium they were measured radially, to avoid the underestimation of K, Na as a result of recombination of ions in the plasma. Calibration was performed by diluting a 1000 mg/L Merck ICP/MS standard solution. The measurements at Technical University Berlin were performed in the same conditions as described in Deon et al. (2015).

a)

Fig.2 a. Spring at Domas Crater with a view of Domas Crater (image by Francesco Pizzocolo TNO, Utrecht). b. spring at Kawah Wayang in Wayang Windu.

b)

Table 1a Field parameters. 1b Water chemistry.

Sample	T(˚C)	pH	Conductivity (mV)	GPS coordinates
DOM1	44	2.5	n.d.	-6.75844 107.6137
DOM2	88	1	n.d.	=DOM 1
KW1	68	1.8	370.6	-7.20648 107.6371
CIBL1	62.5	7.6	252	-7.23209 107.6168

Sample	Ca	Fe	K	Mg	Mn	Na	Cl-	SO_4^{2-}	HCO_{3-}
DOM1	60.1	29.6	10.6	10.5	1.5	23	50	1689	n.d.
DOM2	44	24.8	10.6	10.5	1.5	20.2	87	1773	n.d
KW1	22	44.6	10.6	9	-	12	n.d.	1073	0
CIBL1	83	-	23	52	-	65	n.d.	53	413

Rock samples

The first rock samples have been sampled both in Domas Crater in Tangunpan Perhau and in Kawah Wayang (Fig 3 and 4). The geomechanical experiments will be performed at TU Delft. The rock samples are currently being analyzed by means of Scanning Electron Microscope SEM and Electron Microprobe EMP at GFZ Potsdam. The acquiring and measurement conditions are described in Deon et al. (2015). X-ray powder diffraction XRD, X-ray fluorescence XRF are planned at ITC University of Twente, the Netherlands.

Secondary-electron (SE) images were collected with a JEOL JXA 8230 electron microprobe (15 kV accelerating voltage) Electron Microprobe Laboratory, Department of Inorganic and Isotope Geochemistry at the Helmholtz Centre Potsdam – German Research Centre for Geosciences (GFZ) in Potsdam, Germany.

RESULTS

Fluids

The results from the water samples show high sulphate concentration (˜ 1700 ppm) and the absence of bicarbonate in nearly all fluids except the sample CIBL. The amount of Cl – is moderate and compared to the sulfate not relevant in both the springs of Tangunban Perhau. A concentration of 1073 ppm could be detected in the fluid KW1 sampled in Kawah Wayang. KW1 contains no bicarbonate. On the samples (KW1 and CIBL) the Cl could not be determined. A second analysis will be performed in order to measure the Cl concentration in the samples where it is missing. With the exception of CIBL all the fluids contain no HCO3-. Na is basically identical for the samples from Tanguban Perhau (20 ppm) while CIBL shows a higher concentration (65 ppm) than the spring KW1 in Kawah Wayang. CIBL has also the highest concentration for Ca (83 ppm) and Na (65) but contains no Fe. The pH of the springs in Tangunban Perahu is quite acidic (1 and 2.5) as well as the spring KW1. The sample CIBL has a nearly neutral pH.

Rocks

The first analyses on two rock samples from the Wayang Windu area show a paragensis characterized mostly by plagioclase, quartz, and pyroxene. We plan to determine the mineralogical composition in the next months. Clay minerals have been detected at the EMP and occur as Kaolinite as shown in the EBS spectrum acquired directly on the crystal surface on one single mineral. Kaolinite $AlSi_2O_5(OH)_4$ constitutes approximately 5 wt. % of the sample.

DISCUSSION

The limited amount of samples presented in this work is meant to show which approach and techniques we would like to apply to get an overview of the geochemistry and petrology of the relevant geothermal fields in Indonesia. The major anions of water sample from Tangunban Perhau are plotted in Fig 4. According to the ratios of SO_4^{2-} - Cl^- and the absence of bicarbonate those water can be classified as steam heated waters. This is in good agreement with the sampling location which was directly in Domas Crater, the crater of the Tangunban Perahu volcano. The high concentration of SO_4^{2-} reflects the vicinity to the heat source, in our case the magma chamber. The other two samples from the area of Wayang Windu have respectively a different geochemical signature than in Domas crater. Sample KW1 has indeed a higher Fe content and a slightly lower SO_4^{2-}. Interesting is the difference in the concentration of SO_4^{2} for the CIBL which is significantly lower (only 53). CIBL is also the only sample with significant bicarbonate content. It is indeed located about 5 km from the crater of the Wayang Volcano. The concentration of bicarbonate corresponds as expected to almost neutral pH. Hypothetically CIBL can be considered as the only spring so far which would be one of the outflows of the geothermal system of the Wayang mountain. Comparing these first analysed samples they contain more sulfate than springs from Lamongan (see Deon et al. 2015), Lahendong (see Brehme et al. 2015) and Sipoholon (see Nukman et al. 2013). The gap in Fig. 4 indicate the necessity to conduct additional sampling campaigns for a complete overview but also to monitor over time the geochemical evolution of the Indonesian geothermal systems.

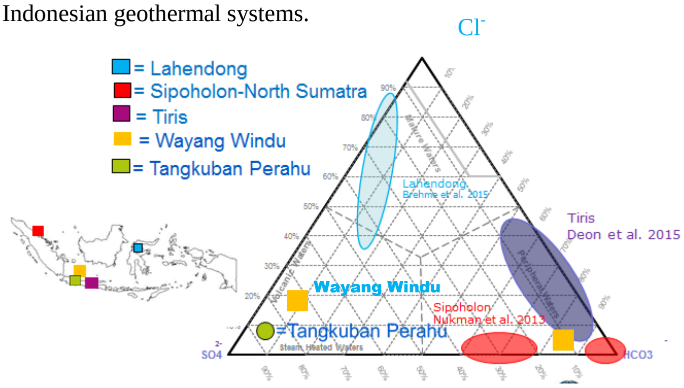
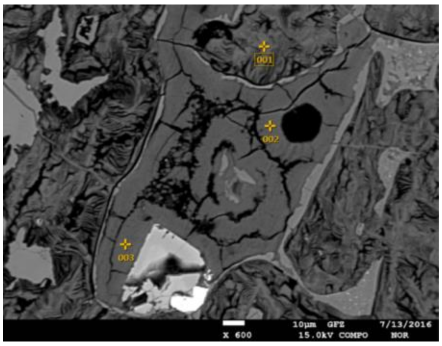


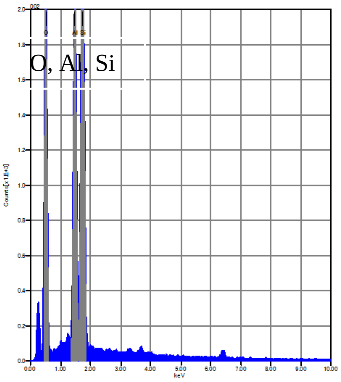
Fig. 4 Ternary diagram Ternary plot of the major anions Cl^-, SO_4^{2-}, HCO_3^-. Our samples plot in the field of heat steamed waters. Only one sample CIBL plots in the field of

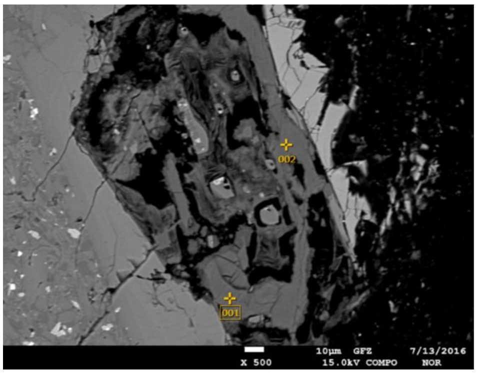
peripheral waters. Data from the literature show significant differences in the geochemistry from different fields.

The first analyses on one sample WW2a from Kawah Wayang have detected concentration of Kaolinite as shown in Fig. 5. The BSE (back scattered electron) image and the EBS spectrum reveal the alteration process on a plagioclase and its evolution in a clay mineral. The intensity of the peak corresponds to the concentration of the single element in the mineral. The occurrence of clay fraction is often hard to detect, especially if low concentrated like in our sample. Because of the low availability of clay minerals we have opted first to observe the sample at the EMP. It also saves time and costs in case the clay concentration is below the XRD detection limit. Knowing a priori if kaolinite or other clay minerals occur optimizes the analytical approach on rock samples. A relevant part of this research will be dedicated to the hydrothermal alteration once more fields will be visited.

The limited amount of samples and results presented in this paper is the beginning of a longer research plan, which will be developed within the GEOCAP cooperation. This includes not only research but also capacity building activities striving to improve the use of geothermal energy together with the Indonesian partners.







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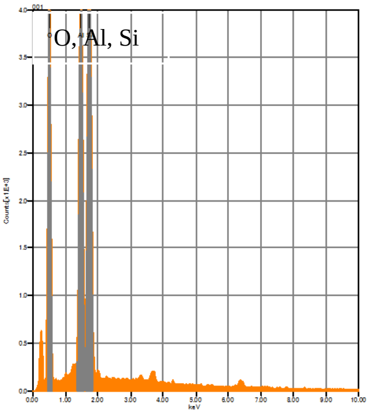

Fig.5 BSE (back scattered electron) images coupled with EBS spectra where Kaolinite can be observed as result of the alteration of the surrounding Plagioclase.

CONCUSION and OUTLOOK

Often water and fluid geochemistry couple with geology guarantee reliable results in the first exploration stage of “green fields” as well as areas where operating plants exist. This approach allows saving costs of sometime long and challenging geophysical and seismic campaigns, which nevertheless still have to be applied when appropriate. The geomechanical experiments will provide insides on the behaviour of typical Indonesian geothermal reservoir rocks under hydrofracturing and acidizing.

The content of this paper represents only the first step of our joint research work within the Indonesian-Dutch cooperation. A more detailed site selection and additional field campaigns are planned in the near future. They will deliver a best practice guide on how to explore fields with different geological backgrounds and provide an overview several geothermal areas. Operators, universities and governmental agencies will benefit from this approach, as it will be applied also to new green-field regions and areas to be tendered.

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