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Rock geochemistry related to mineralization processes in geothermal areas

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Abstract. Abundant geothermal systems in Indonesia suggest high heat and mass transfer associated with recent or paleovolcanic arcs. In the active geothermal system, the upflow of mixed fluid between late stage hydrothermal and meteoric water might contain mass of minerals associated with epithermal mineralisation process as exemplified at Lihir gold mine in Papua New Guinea. In Indonesia, there is a lack of study related to the precious metals occurrence within active geothermal area. Therefore, in this paper, we investigate the possibility of mineralization process in active geothermal area of Guci, Central Java by using geochemical analysis. There are a lot of conducted geochemical analysis of water, soil and gas by mapping the temperature, pH, Hg and CO_2 distribution, and estimating subsurface temperature based on geothermometry approach. Then we also apply rock geochemistry to find minerals that indicate the presence of mineralization. The result from selected geothermal area shows the presence of pyrite and chalcopyrite minerals on the laharic breccias at Kali Putih, Sudikampir. Mineralization is formed within host rock and the veins are associated with gold polymetallic mineralization.

1. Introduction
Geothermal energy is an attractive renewable energy which is becoming an important contributor to the energy mix. Geothermal energy is environmentally friendly when compared to other types of energy, especially those derived from fossil fuel combustion (fossil fuel), so that when developed, it will reduce the danger of greenhouse effect causing global warming.

Geothermal energy sources tend to not run out, because the process of its continuous formation during environmental conditions (geology and hydrology) can be maintained balanced. Given that this geothermal energy cannot be exported, the utilization is directed to meet the domestic energy needs, thereby geothermal energy will become a reliable and vital alternative energy because it can reduce Indonesia's dependency on fossil energy sources that are increasingly depleted and can provide added value in the framework of optimization Utilization of various energy sources in Indonesia.

Indonesia's geothermal potential is spread over two geological environments; volcanic and non-volcanic geological environments. In geothermal areas associated with volcanic environments, there are now many developed and producing electric energy that can be utilized, while in geothermal areas contained in non-volcanic environment is still not developed optimally. One of the obstacles is the lack of geosciences data and an understanding of the characteristics and formation of its geothermal system.

Besides that, contrary to other renewable energy sources such as solar or wind energy which show an increase in growth, Geothermal energy has only experienced linear growth in recent years [1,2].

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In recent years, many papers on various methods for exploration of non-volcanic geothermal in Indonesia have been published [3-7], both of them generally use water chemistry and geothermometry methods on their research. On the other hand, hundreds of researches on volcanic geothermal zone in Indonesia, which cannot mention here one by one, have been done.

2. Conceptual Model

Geothermal resources, understood as systems that store natural heat in rock and fluids within the Earth, can be divided into different types based on the temperature and the nature of the reservoir. A primary division of the geothermal systems can be made according to whether they are related to emplacement of magma or not. Magmatic geothermal systems include convective hydrothermal systems (water or steam dominated), hot dry rock and partial melt systems, while non-volcanic geothermal systems are usually associated with hot fluids in sedimentary or crystalline reservoirs, either with natural permeability (through faults and fractures) or needing additional stimulation of fluid pathways [8].

An ideal hydrothermal system consists, conceptually, of a heat source, some sort of groundwater system to transport and sometimes store the heat (reservoir), and a confining impermeable structure (cap). Conceptual models of geothermal systems provide an essential basis for the development of all reliable models of geothermal systems [9]. This applies to a varying degree to the different kinds of models, ranging from static volumetric models to dynamic models such as simple analytical models, lumped parameter models and detailed numerical reservoir models. This was emphasized as early as by [10] in their treatise on numerical modelling of geothermal systems [11,12].

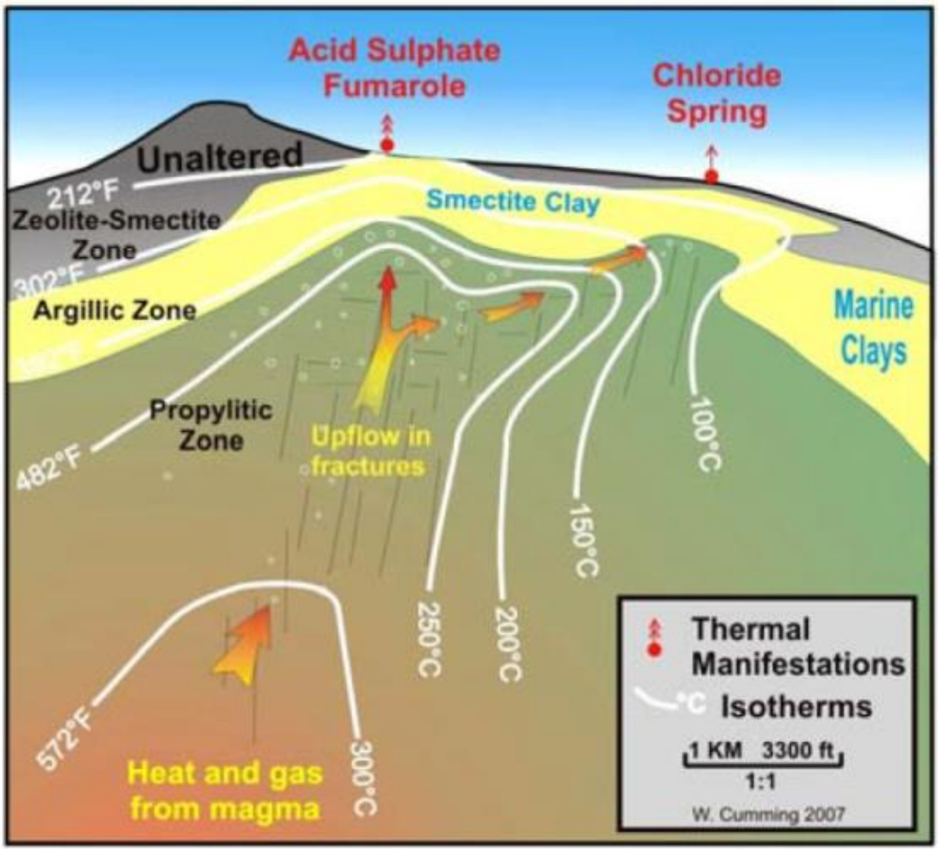

Figure 1. Conceptual model of a generalized geothermal system redrawn from [13].

Non-magmatic geothermal systems, on the other hand, exhibit a much greater variation in geometry, and it is generally not possible to construct a conceptual model encompassing the whole range of non-magmatic geothermal systems. The exact nature of conductive anomalies (if present) can vary greatly between different geothermal systems but, in general, it is related to electrolytic conduction in saline fluids. Geothermal fluids tend to have high concentrations of dissolved salts, and their conductivity increases with temperature [14]. For non-magmatic geothermal systems, imaging the electrical conductivity distribution helps locating deep aquifers that can act as reservoirs and fluid pathways.

3. Mineralisation in magmatic related hydrothermal system

It is now well accepted that hydrothermal ore deposits are formed in active hydrothermal system. The interaction between acid gases, metal elements, and heat emissions from magma with meteoric water in volcanic conduits forms a hydrothermal fluid which ultimately produces altered rocks and mineralization. Conduit or other term diatrema, vent and coral volcano are located under the crater and above the magma kitchen. This means that the mineralized deposits are present in the center faces of the volcano. Therefore, in order to search for new sources of mineralization, the first step is to find the facies of the ancient volcano center.

If we observed almost all gold and silver mining areas are located within the center of the volcano, from Grasberg in Papua, Totopo Barat in North Sulawesi, Kelian di Kalimantan and Pongkor in West Java. A common problem is that researchers are usually less interested in deepening volcanic geological environments in relation to the formation of gold deposits and other minerals.

Furthermore, based on radiometric analysis, volcanic rocks in an area have different ages. For example volcanic rocks in the Bayah area, Cikotok Formation is paleogenic, Tuf Citorek is Neogenic and the surroundings are volcanic rocks of Quaternary [15]. In the Cupunagara region volcanic rocks were found starting from ages of 1.4 million years to 59 million years old [16]. In the Kulon Progo Mountains, volcanic rocks are of ages between 12 million years to 76 million years old [17]. In Pacitan, volcanic rocks are of ages between 8.94 million years old to 42.7 million years old [17]. The data shows that magmatism and volcanism occur repeatedly, and it is possible that it is also followed by hydrothermal alteration and mineralization processes. If that is true then it is estimated that mineralization enrichment can occur in the area.

On non-volcanic geothermal zone, intrusive rocks show some sign of mineralization. The low sulphide quartz veins can be found in the sedimentary, metasedimentary, volcanic-sedimentary, massive sulphides and skarn deposits. The low content of sulphide minerals in these quartz veins is prominent because of the distance traveled. The volcanic layers are probably located at the distal end of hydrothermal veins, where most of hydrothermal fluids are relatively cool and less soluble for gold and other sulphide minerals. Thus, these types of quartz veins can only absorb small amounts of gold and some low temperature sulphide minerals such as galena and arsenopyrite. This type of quartz vein is normally low in sulphide content, and the gold is only associated with minor quantity of sulphide minerals.

Some of the hydrothermal veins are controlled by structure caused by granite intrusion. During the intrusive stage, low temperature contact metamorphism will form the shear zones around the intrusive bodies. The quartz veins, normally low in sulphides, infiltrate through these sheared zones and some cross cut the volcanic-sedimentary rocks. The quartz veins infill the fractures, cracks and bedding of the sedimentary rocks. Some of the hydrothermal veins probably originate from deeper levels. The hydrothermal solutions travel upwards along the granitoid shear zones to the surface. This type of hydrothermal veins is observed at the margins of granitoids.

4. Economic deposit

The question that needs an answer is why economic ore deposition are not common. One possible reason is that since very large amount of fluid flow are required to form ore deposits, it is the most permeable hydrothermal systems, where fluid flow is focused, that can form ore deposites, while a hydrothermal system may be viable as a source of power generation at much lower permeabilities. The degree of concentration required to lift mineralization to an economic grade also means that some special, usually hydrological combination of circumstance in time and space, is required.

A further factor is that an association between particular types of magmas and major economic ore deposits suggest that associated magmas must have particular compositions for a system to form a major ore deposit. As these are minor magma types, the majority of hydrothermal systems are associated with the wrong sort of magma to form major economic ore deposits [18].

5. Identification of volcanic Rocks Based on geochemistry

Elements that are used on identification of volcanic rocks by geochemistry method are:

5.1. Major Elements

Most igneous rocks and minerals, and the magmas from which they form, fall into the class of chemical compounds called silicates – consisting of metals combined with silicon and oxygen. The simplest way to visualize the chemical composition of complex silicate materials is as a mixture of oxides: silicon dioxide (SiO_2 – also known as 'silica') is usually the most abundant oxide in igneous rocks and minerals, and the oxides of titanium (TiO_2), aluminum (Al_2O_3), iron (Fe, both ferric Fe_2O_3 and ferrous FeO), manganese (MnO), magnesium (MgO), calcium (CaO), sodium (Na_2O), potassium (K2O) and phosphorus (P_2O_5) are usually present in significant amount as well. A typical silicate analysis, giving the percentage by mass of each of these oxides (traditionally referred to – inappropriately – as a 'weight percent' analysis). The advantage of reporting an analysis in terms of oxide percentages is that it neatly introduces the right amount of oxygen into the analysis without the need to analyze it directly. The elements listed, in which oxides are normally found at levels greater than 0.1% by mass, are collectively referred to as the major elements.

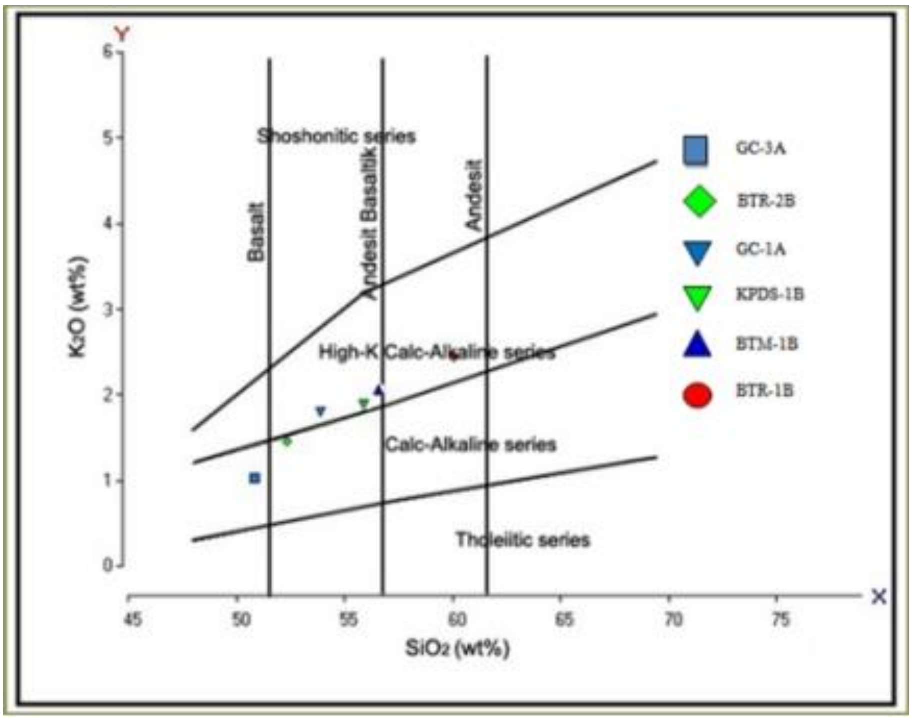

Figure 2. TAS grid of Guci Area showing common rocks types designated by the IUGS Sub commission on the Systematics of Igneous Rocks [19].

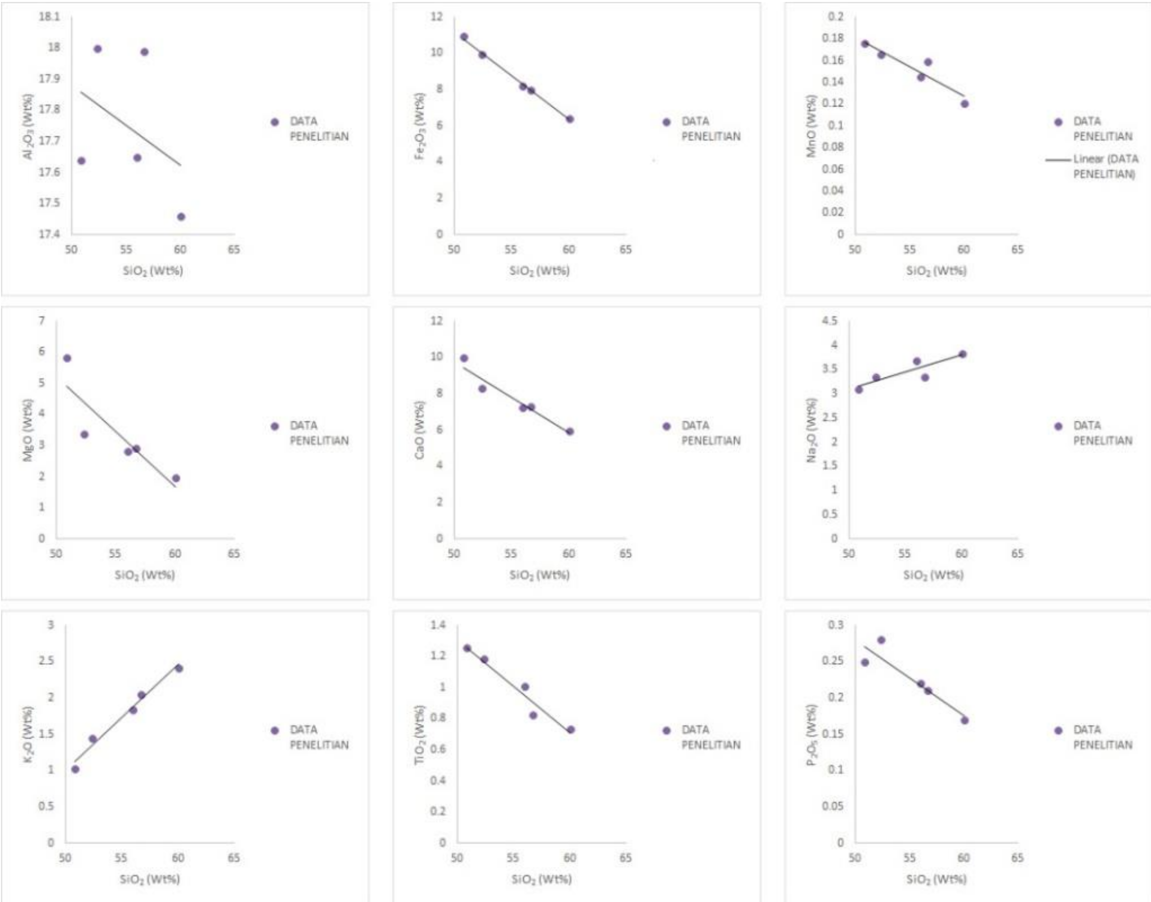

Figure 3. Harker Diagram of Major Elements on Guci area [20].

5.2. Trace elements

Numerous other chemical elements are present in magmas, rocks and minerals at concentrations below 0.1%. These less abundant constituents are known as trace elements, and their concentrations are expressed in parts per million by mass (‘ppm’=μgg−1=micrograms of element per gram of sample) or, in the case of the least abundant trace elements, in parts per billion (ppb=ngg−1=nanograms of element per gram of sample). In spite of their low concentrations, trace elements provide important information about magma sources and conditions of formation.

Analysis results from Guci Area show that the TiO2 content ranges between (0.734 – 1.254), Zr (98 – 218), Sr (265 – 363) and Y (23 – 31), shows the characteristics of Calc-Alkaline Basalt that formed on volcanic island arc and a back-arc side.

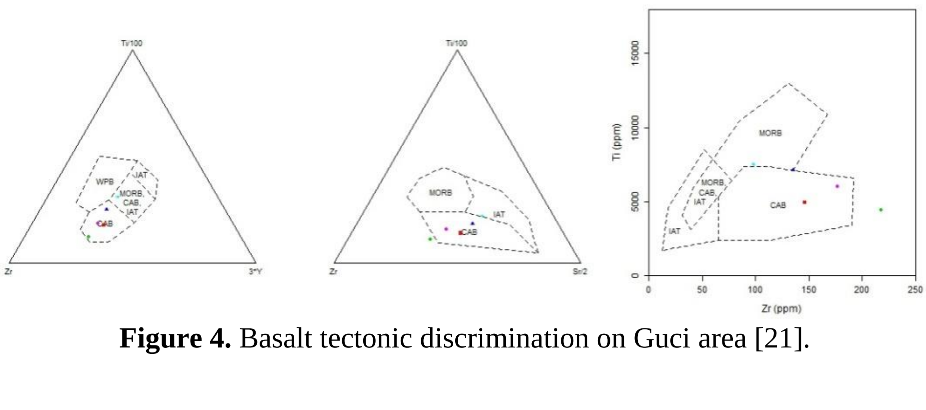

Figure 4. Basalt tectonic discrimination on Guci area [21].

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Table 1 A brief summary of some particularly useful trace elements in igneous petrology [22].

Element	Use as a petrogenetic indicator
Ni, Co, Cr	Highly compatible elements. Ni (and Co) are concentrated in olivine, and Cr in spinel and clinopyroxene. High concentrations indicate a mantle source.
V, Ti	Both show strong fractionation into Fe-Ti oxides (ilmenite or titanomagnetite). If they behave differently, Ti probably fractionates into an accessory phase, such as sphene or rutile.
Zr, Hf	Very incompatible elements that do not substitute into major silicate phases (although they may replace Ti in sphene or rutile).
Ba, Rb	Incompatible element that substitutes for K in K-feldspar, micas, or hornblende. Rb substitutes less readily in hornblende than K-spar and micas, such that the K/Ba ratio may distinguish these phases.
Sr	Substitutes for Ca in plagioclase (but not in pyroxene), and, to a lesser extent, for K in K-feldspar. Behaves as a compatible element at low pressure where plagioclase forms early, but as an incompatible at higher pressure where plagioclase is no longer stable.
REE	Garnet accommodates the HREE more than the LREE, and orthopyroxene and hornblende do so to a lesser degree. Sphene and plagioclase accommodates more LREE. Eu^{2+} is strongly partitioned into plagioclase.
Y	Commonly incompatible (like HREE). Strongly partitioned into garnet and amphibole. Sphene and apatite also concentrate Y, so the presence of these as accessories could have a significant effect.

5.3. Rare Earth Elements
Rare earth elements can be applied to:

- Eliminate Oddo-Harkins effect and make y-scale more functional by normalizing to a standard
- Estimates of primordial mantle
- Chondrite meteorite concentrations
- An extension of the normalized REE technique to a broader spectrum of elements

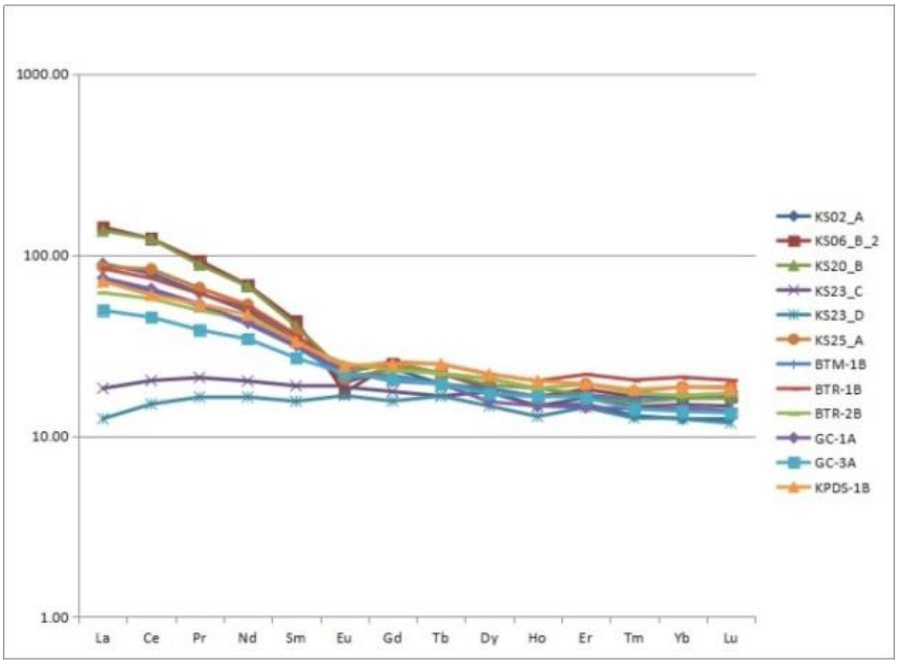

Figure 5. Spider Diagram of Guci area [22]

6. Conclusions

Analysis of rocks geochemical data from geothermal can reveal a lot about the source of the melt and the conditions (pressure, depth, extent of melting) where the melt is originally formed and also provides a number of qualifiers that allow us to subdivide those rock types that embrace magmas from a number of sources. From this paper, we can draw a conclusion that Guci Geothermal Area is formed on volcanic island arc and a back-arc side. Geochemical studies of primary mineral deposits can provide important insights to mineral systems as well as significant implications for mineral exploration.

Acknowledgments

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