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論　　文　　要　　旨

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論文題名　GEOCHEMICAL AND NUMERICAL MODELING STUDIES OF THE KOTAMOBAGU GEOTHERMAL FIELD, INDONESIA
（インドネシア国コタモバグ地熱地域の地球化学および数値モデリングに関する研究）

論　文　内　容　の　要　旨

Geothermal energy is one of the clean and renewable energy resources and plays an important role in alternative energy resources. The geothermal resources in Indonesia are estimated to be about 27,000 MW and are distributed in the islands of Java, Sumatra, Bali, Nusatenggara, Sulawesi and Halmahera. Indonesian geothermal systems occur in areas with Quaternary volcanism and active volcanoes along well-defined volcanic arcs. In the eastern part of Indonesia, the island of Sulawesi has been shaped and deformed as a result of collision with the Sula platform, and the promising geothermal fields are locatedat Lahendong, Tompaso and Kotamobagu in Northern Sulawesi.

The Kotamobagu geothermal field is associated with thermal manifestations such as hot spring over an area of 300 km^2, with an inferred high temperature source beneath Ambang Mountain, an active strato-volcano with last eruption in 1850.

Geothermal exploration in Kotamobagu was started by a private company in Indonesia in the 1980s, but no scientific and engineering studies has been systematically conducted nor reported in public. In order to understand the geothermal system and its potential of Kotamobagu the author conducted field and laboratory studies on soil air gas, waters of hot spring, river, shallow well and rain. These data were carefully interpreted for developing a conceptual model of Kotamobagu. Then, a three dimensional grid model of geothermal system was developed for numerical simulation of the field.

This dissertation is composed of seven chapters that are summarized as follows.

Chapter 1 introduces the geothermal potential in Indonesia, geothermal fields in North Sulawesi including Kotamobagu, and objectives of the study.

Chapter 2 discusses soil air gas survey conducted on the southern slope of Mt. Muayat mainly in Liberia village using soil gas of mercury and carbon dioxide, and soil mercury. Soil air gas was measured at 33 points with intervals from 50 to 200 m in an area of 4 km E-W and 2 km N-S. Concentrations were divided into groups on the basis of the cumulative frequency curves. Anomalies of high CO_2 concentration (>1 %) generally overlapped with those of soil air Hg (>4 ng) in the center and eastern part of the area. This result implies a presence of flow path of high temperature fluid below this area.

Chapter 3 presents the geochemical analysis of water samples at thirty locations from hot spring and shallow well in the area with 30 km E-W and 20 km N-S of Kotamobagu. Elevation of sampling site ranges from 144 m up to 1,438 m above sea level (a.s.l.). The water type was characterized using the ternary plot of Cl, HCO_3 and SO_4 into five groups of SO_4, Cl-SO_4, HCO_3, Cl, and hybrid waters. Hot spring waters collected near Mt.Muayat were acidic and of SO_4 type, indicating steam heated water. As the distance from the summit of Mt.Muayat increases, the water type changed from Cl-SO_4 to HCO_3 type. Hot spring water collected at Lobong in the western edge of the field has relatively high concentration of Li (2.3 ppm) and Cl (700 ppm) compared to other samples. Temperatures of geothermal fluid at depth were estimated with geochemical geothermometers as 88-190°C by quartz geothermometer, 180-230°C by Na-K-Ca-Mg and maximum temperature of 230-320°C with Na-K geothermometer. Based on the geochemical analysis of water samples, the presences of two geothermal systems were proposed: a geothermal system related to Mt. Muayat of active volcano and another one in the sedimentary formation in the Lobong area.

Chapter 4 discusses stable isotope of water for water samples collected from hot spring, shallow well, river and rainwater. To estimate the origin of hot spring water and the recharge area of water, flow path of fluid and isotope exchange between the water and the rocks were identified on the basis of the results of chemical characteristics of hot spring waters and stable isotope ratios, $\delta^{18}O$ and $\delta^{2}H$, of hot spring, river and rainwater. The hot spring waters have oxygen shift by less than 2‰ from the local meteoric water line (LMWL), which implies the hot spring water is mainly meteoric water origin. The recharge elevation range of hot spring water in the southern slope of Mt. Muayat was determined to be from 993 m to 1,127 m a.s.l. by evaluating the stable isotope ratio of local meteoric water and hot spring water. On the basis of these results, a conceptual model of the Kotamobagu geothermal field was developed. This conceptual model describes the characteristics of thermal water, the origin of hot spring water, the flow pattern of thermal water and the estimated water temperature below Mt. Muayat.

Chapter 5 discusses the numerical model of the Kotamobagu geothermal system. A grid system was developed on the basis of the geological and structural data and the conceptual model developed in Chapter 4. A numerical simulation of the natural state was conducted with the TOUGH2 simulator for temperature profiles of the system. Results were verified for the temperature of the natural discharge in this field, specifically that of hot springs. The effects of the presence of fault systems on the formation of hot springs located in the southern part of Kotamobagu were investigated with the model. High temperature mass recharge of the total flow rate at 51 kg/s of 260°C was assigned at eight blocks NW to SE below the center of Mt. Muayat. The natural state of Kotamobagu was obtained by simulating this numerical model for 13,000 years. The results show that high temperature fluid ascends from the bottom layer of Mt. Muayat, then flows out to the surface through horizontal and vertical flow paths. A dominant mass flows through the grids corresponding to Faults FLT11 and FLT33 to the northeast and to the southwest. Mass and heat discharges at the Bakan hot spring located on the southern edge of the field seem to be not directly derived from the source below Mt. Muayat.

Chapter 6 is composed of the summary of this study, new findings on characteristics of the Kotamobagu geothermal system, and recommendations for the future study.