GEOTHERMAL EXPLORATION AND MONITORING BASED ON HEAT FLOW AND HYDROTHERMAL ALTERATION USING SATELLITE REMOTE SENSING TECHNIQUES

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（別紙様式２）

論　文　要　旨

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論文題名	GEOTHERMAL EXPLORATION AND MONITORING BASED ON HEAT FLOW AND HYDROTHERMAL ALTERATION USING SATELLITE REMOTE SENSING TECHNIQUES （衛星リモートセンシング技術を用いた，放熱量と熱水変質に基づく地熱探査とモニタリング）		

論　文　内　容　の　要　旨

A new world energy economy is emerging as the great energy transition from fossil fuels to renewable sources of energy in progress due to rise of fossil fuel price, oil insecurity, pollution and climate instability with burning coal for energy. And additionally recent nuclear accident influences other sources of renewable energy. Consequently, geothermal energy could provide one of such important alternatives because it is renewable and clean. Hence, it is required to explore and develop geothermal energy to increase its contribution to the world energy needs. As most of the geothermal resources are near the active volcanoes, ground-based explorations are sometimes difficult due to unstable ground, national park areas around the volcanoes as well as expensive and time consuming. Therefore, remote sensing data could be a solution for the geothermal exploration with less time and cost-effectiveness by proper techniques. This thesis examines the application of satellite remote sensing techniques to the investigation and monitoring of some geothermal areas in New Zealand and Japan. The research and development of methods for heat flow studies using satellite thermal infrared data (Landsat TM/ETM+) and associated satellite image processing techniques constitute the major portion of this study. A new method has been formulated based on existing laws of its parameters to estimate radiative heat flux (RHF) using satellite thermal infrared data from a geothermal area. The significant finding is about the use of satellite thermal infrared data for the first time using the newly developed method for RHF estimation and monitoring from geothermal areas of this study. In addition, hydrothermal alteration mapping using the conventional methods for satellite imagery was evaluated in and around an active volcanic area in Japan to explore the geothermal indicator minerals.

This dissertation consists of six chapters to illustrate researches carried on satellite remote sensing based heat flow studies and mapping of hydrothermal alteration from active thermal areas in New Zealand and Japan.

Chapter 1: This chapter describes the background information of geothermal scenery in New Zealand and Japan. New Zealand is producing about 11% of total energy supply from geothermal resources from the North Island only, although they have some potentialities in South Island too. In Japan, 21 electric power units at 18 geothermal sites are in operation with a total capacity of 537 MWe, which amounts to only about 2.3% of its potential geothermal power. This chapter addresses the necessity of exploration for geothermal resources with satellite remote measurement techniques for development of geothermal energy in these countries. Additionally, the purposes of this thesis are described here.

Chapter 2: This chapter describes the basic principles of remote sensing and their applications for

geothermal studies i.e., geological, heat flow and alteration mapping. The methods of both airborne and satellite remote sensing for this type of studies were described here. Additionally, thermal infrared remote sensing techniques were illustrated here for geothermal heat flow studies separately.

Chapter 3: This chapter demonstrates briefly about satellite images used for this study, software and programs, and the methodologies that were used in this thesis work. The Stefan-Boltzmann equation for radiative heat flux (RHF), the normalized differential vegetation index (NDVI) method for spectral emissivity estimation, and the mono-window algorithm for land surface temperature (LST) were utilized in the developed method of RHF estimation. The basic principles and working flow of each method were explained in this chapter.

Chapter 4: In this chapter, heat flow studies of all the study areas in New Zealand and Japan using the developed method for satellite image are described as separate four case studies. The initial study of RHF was conducted in the Karapiti thermal area in New Zealand using Landsat TM/ETM+ thermal infrared data for the first time, supported by ground measurements, to investigate the RHF changes between 1990 and 2011. The geothermal radiative heat flux (net RHF), of subsurface origin, was then assessed by subtracting the re-radiated heat flux that was of solar origin, as determined using coincident satellite imagery at two external non-geothermal sites. The total net RHF decreased by about 7 MW from 1990 to 2011. After development the RHF estimation method using satellite thermal infrared data in the Karapiti thermal area, the techniques were applied to monitor heat flow from three active thermal areas in Japan, i.e., Unzen Geothermal Field, Kuju Fumaroles and Aso Volcanic Area. And the fact that the estimated RHF was about 15.6% of heat discharge rate (HDR) from the geothermal area was also discovered in the Karapiti thermal area. Therefore, this percentage was applied to estimate HDR in the three active thermal areas. In Unzen Geothermal Field, the highest total RHF was obtained about 39.1 MW in 2005 and lowest was about 12 MW in 2001. The monitoring results showed a single fold trend of HDR from 2000 to 2009 with highest about 252 MW in 2005 and lowest about 78 MW in 2001. Next, Kuju Fumaroles were selected to monitor heat losses using Landsat 7 thermal infrared data from 2002 to 2010. The results showed that the highest total RHF was found about 57.7 MW in 2002 and lowest about 21.1 MW in 2010. And the highest HDR about 372.7 MW in 2002 and the lowest about 136.3 MW in 2010 were estimated. In the final case study for heat flow, thermal activity at Aso Volcanic Area was monitored by using Landsat ETM+ images. The total RHF was obtained about 607 MW in 2002 and the lowest about 354 MW in 2008.

Chapter 5: In this chapter, to evaluate the conventional method for mapping of hydrothermal altered deposits in Kuju Volcano using Landsat 7 ETM+ image, the color composite, band ratio, principal component analysis, the least squares fitting and reference spectra analysis methods were used. All methods showed high efficiency for mapping of hydrothermal altered hydroxyl and iron-oxide minerals, especially alunite, illite, kaolinite, chlorite, orthoclase, quartz, goethite, hematite and jarosite. So, these alteration mapping techniques could be used for exploration of geothermal indicator minerals.

Chapter 6: This is the last chapter and consists of the summary and conclusion as well as future recommendations for advancement of the methodology of geothermal studies using satellite imagery. It is concluded that the satellite remote sensing data is a useful and efficient option for geothermal heat flow exploration and monitoring using the method developed in this study as well as exploring geothermal indicator minerals for identifying new area of interest using the conventional alteration mapping methods.