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Characteristics of Geothermal Anomaly in South Korea

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ABSTRACT

The heat flow anomaly in South Korea was analyzed with Geographic Information System (GIS) using spatial overlay analysis technique in the aspects of lithology, geologic time and Mohorovicic (Moho) depth. A total of 247 heat flow data over South Korea were constructed to the spatial database (D/B) and digital geologic map including lithology, geologic time, and Moho depth was also made. The average of heat flow is 64 ± 14 mW/m^2 in South Korea. In the aspect of lithology, the area of sedimentary rock contains high heat flow of 74 mW/m^2, sedimentary/volcanic rock area 62 mW/m^2, plutonic rock area 63 mW/m^2, and metamorphic rocks area 61 mW/m^2. In the geologic time sequence, the Cenozoic strata has 91 mW/m^2, the Mesozoic and Paleozoic strata 65 mW/m^2, the Proterozoic strata 55 mW/m^2, and the Archean strata has 61 mW/m^2. In Moho depth aspect, the shallow depth area has higher heat flow than the area of thick crust. As a result of the tabulate analysis, the southeastern part of Korean Peninsula appeared to be the highest heat flow anomaly.

1. INTRODUCTION

As to the history of the geothermal study in South Korea, both Chang et al. (1970) and Mizutani et al. (1970) who led the " Korea-Japan cooperation reaearch for Columbo Plan" began to work on this field. In this time, 18 heat flow data were collected mainly mine deposit areas. And there were added 17 heat flow data by Suh (1976) to make total 35 heat flow data. Han and Chapman (1985) suggested that the distribution of the heat flow in South Korea was related to the subduction zone through the West Pacific Ocean-Japan-East Sea-Korea from the viewpoint of the plate tectonics. Lim et al. (1989; 1996; 1997) and Yum et al. (1997) published a study on the regional pattern of heat flow in the Korean Peninsula and added heat flow data. Korea Institute of Geoscience and Mineral Resources (KIGAM) has measured 217 heat flow data from 1989 until 1997 to make total 252 data. Although we have no the active volcanic areas, there are some places for low-enthalpy geothermal potential. A clear evidence of geothermal is the distribution of hot springs over the Korean Peninsula. Furthermore, the drilling technique for deep well is continuously improving. Then, where is the suitable place to develop the economically feasible geothermal energy? In order to select the promising site in some quantitative way, we adopted GIS based analysis technique using existing heat flow data and geologic and geophysical information.

This study is to analyze the relationship between heat flow and geological data of South Korea using GIS. For the analysis, a total 247 heat flow data in-land and 1:1,000,000 scale geological map of South Korea (Figure 1) were constructed to spatial D/B. Then spatial relationship between heat flow spatial D/B and geological D/B was analyzed using spatial tabulate analysis technique in the aspect of lithology and geologic time by ArcView Software. The distribution map of Moho depth from the spectral analysis of Bouguer anomaly map (Cho et al., 1996; Kim et al., 2003; Figure 3) was also constructed into spatial D/B and we analyzed it and heat flow D/B with overlap method. In this study, the heat flow data acquired during the period of 1970-1997 were used to analyze the relationship between the items such as lithology, geologic time and Moho depths. Although the heat flow data is total 252, the data from offshore and Jeju Island were excluded to analyze the in-land Korean Peninsula to result in a total of 247.

2. GEOLOGIC SETTING

Figure 1 shows digital geologic map of South Korea (KIGAM, 1995). The geology of Korea is composed of relatively old rocks that age from Precambrian to Quaternary. The Precambrian metamorphic rocks (PR and AR groups in Figure 1) crop out extensively in the Korean Peninsula from the north to south covering almost a half of the territory. Especially in South Korea, Archean groups mainly consist of gneiss and schist complexes and exposed in the Gyeonggi Massif, central Korea and in the mountainous area over southern part of the Peninsula. The Paleozoic sediments (PT, O, and og group) are distributed mainly in central-eastern part of South Korea forming high mountains. It is very difficult to find some hot spring or evidence of geothermal phenomena in those areas composed of Precambrian and Paleozoic (PAL group) rocks.

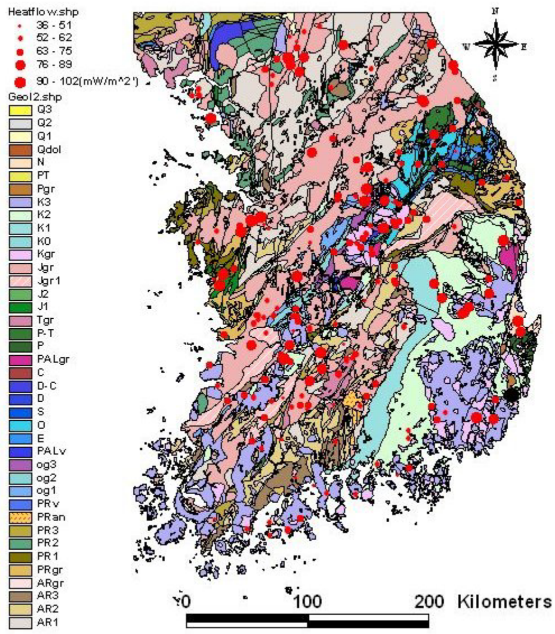

Figure 1: Digital Geology Map and Heat Flow Data of South Korea (KIGAM, 1995). Measurement Locations of Heat Flow are Superimposed as Red Dots Size of Which Corresponds to Measured Values.

The major outcrop of the Jurassic granite (J group) occurs as batholith stretching along NE direction in the middle part of the Peninsula across the country from the east to the west. Cretaceous granite is mainly limited in the south-eastern part. Following the granite intrusion and tectonic movement in the south-eastern part during the Cretaceous (K group) and the early Tertiary (P group), several linear structures has formed with direction of NEE, parallel to the eastern coast line (Figure 1).

Quaternary volcanic rocks (Q group) are exposed in some islands in the South and East Sea, and in some areas in the main land of Korea. There is no geothermal phenomenon such as hot springs or high subsurface temperatures in those volcanic areas.

3. CONSTRUCTION OF SPATIAL D/B

For the analysis of relationship between heat flow data and geology, collected geothermal data was constructed to spatial D/B using GIS. The heat flow spatial D/B consists of identification number (ID), name (SN), Longitude (Long.), Latitude (Lat.), thermal gradient (Gr.), thermal conductivity (Cond.), heat flow (HF) and reference (Ref.) (Table 1). The spatial D/B is of ArcView shape format with point attribute.

Table 1. Database Structure of Heat Flow D/B

Name	Data type	Length	Description
ID	Integer	8	Identification number
SN	Text	20	Sample name
Long.	Float	8	Longitude
Lat.	Float	8	Latitude
Gr.	Float	8	Thermal gradient
Cond.	Float	8	Thermal conductivity
HF	Float	8	Heat flow
Ref.	Integer	4	Reference number

The 1:1,000,000 scale geological map of Korea (KIGAM, 1995) was constructed to spatial D/B. The geological spatial D/B consists of area, perimeter, ID and geologic code (Table 2).

Table 2. Database Structure of Geologic D/B

Name	Data type	Length	Description
Area	Float	12	Area
Perimeter	Float	12	Perimeter
ID	Integer	5	Identification number
Code	Text	8	Geologic code

The geological map is of ArcView shape format with polygon attribute. The heat flow data distribution with geological map was made to thematic map using ArcView as shown in Figure 1.

The Moho depth map of Korea was published by Kim et al. (2003) using Bouguer gravity of Korea. It was constructed to spatial D/B also. It consists of ID, Moho value, etc. as Table 3. Thematic map of Moho depth was also made using ArcView as shown in Figure 2.

Table 3. Database structure of Moho depth D/B

Name	Data type	Length	Description
F-node#	Float	5	From node number
T-node#	Float	5	To node number
L-poly#	Float	5	Left polygon number
R-poly#	Float	5	Right polygon number
Length#	Float	12	Length
Moho#	Float	5	Identification number
Moho-ID	Float	5	Identification number
Elevation	Float	5	Moho value

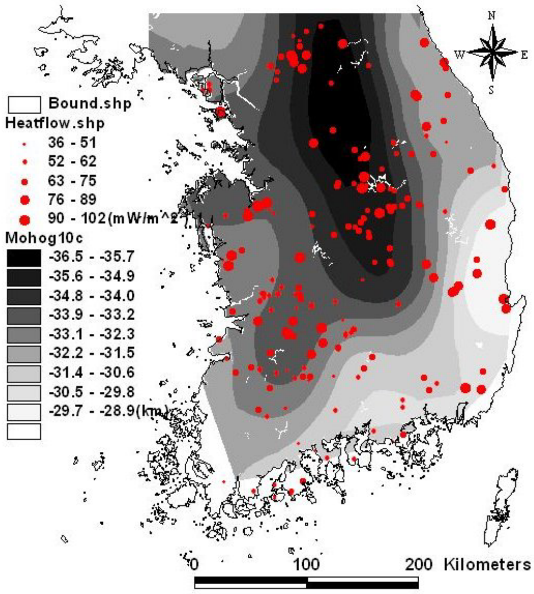

Figure 2: Thematic Map of Moho Depth of South Korea using ArcView (Kim et al., 2003).

4. DISTRIBUTION OF HEAT FLOW

The low-temperature geothermal phenomena in Korea are closely related to granite distribution, especially of Jurassic and Cretaceous periods, and localized through deeply connected fracture system as geothermal water conduit. In the point of geothermal gradient or heat flow, however, high geothermal anomaly does not always coincide with granite region but sometimes with areas covered with sedimentary rocks. This resulted from that the thermally low conductive sedimentary formation preserves the heat contained in the granite basement and thus showing high geothermal gradient.

Figure 3 shows the distribution of heat flows in South Korea. Total 248 heat flow data has been measured although not of even distribution. Average heat flow is 64±14 mW/m^2. Southeastern part of Korea that is covered with Tertiary sediments shows the highest heat flow more than 90 mW/m^2. Geothermal gradient measured along the boreholes in this area also shows as high as 40 °C/km. Considering average geothermal gradient in Korea is 25.7 °C/km, this high anomaly along with high heat flow value indicates a high geothermal potential for low-temperature utilization.

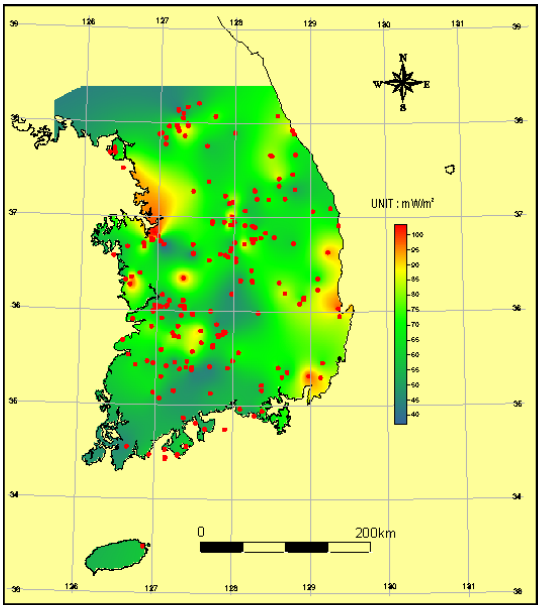

Figure 3: Heat flow distribution map of South Korea (Kim, 2004).

5. SPATIAL RELATIONSHIP BETWEEN HEAT FLOW AND GEOLOGIC DATA.

For analysis of relationship between heat flow and geologic data, a tabulate analysis is carried out using ArcView S/W and the result is shown in Table 4.

5.1 Relationship between Heat Flow and Rock Types

In the aspect of rock type, the area of sedimentary rock shows high heat flow of 74 mW/m^2, sedimentary/volcanic rock area 62 mW/m^2, plutonic rock area 63 mW/m^2, and metamorphic rocks area 61 mW/m^2 as shown in Figure 4. The reason why sedimentary rock area shows the high heat flow is that the sedimentary rock covers the plutonic; the residual heat from igneous activity remains being covered with sedimentary rocks of low thermal conductivity.

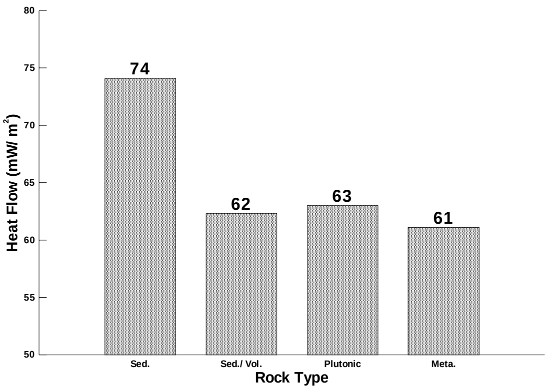

Figure 4: Average Value of Heat Flow vs. Rock Types (Sedimentary, Sedimentary/Volcanic, Plutonic, and Metamorphic rock).

5.2 Relationship between Heat Flow and Geologic Time

In the geologic time sequence as shown in Figure 5, the Cenozoic strata has 91 mW/m^2, the Mesozoic and Paleozoic strata 65 mW/m^2, the Proterozoic strata 55 mW/m^2, and the Archean strata 61 mW/m^2. It is already known that the younger geologic strata show higher values than the older ones (Stein, 1993; Han, 1992).

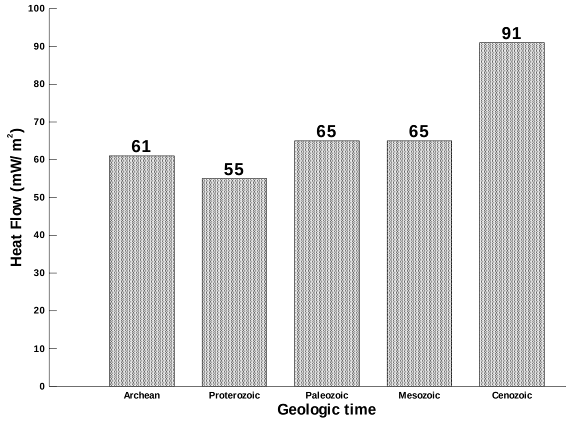

Figure 5: Average Value of Heat Flow vs. Geologic Time.

It may be unreasonable that only two heat flow data in Cenozoic area apply to the analysis in statistics. However, there are 11 boreholes and measured geothermal gradient over the Cenozoic areas (Pohang Basin) in southeastern part of Korea. Although the thermal conductivities of the rock samples along the borehole were not measured, and thus the heat flow data are not available for all of the wells, high geothermal gradients more than 40 °C/km over the area make the high heat flow acceptable.

5.3 Relationship between Heat Flow and Moho Depth

In the aspect of Moho depth (Figure 6), the shallow depth area has higher heat flow than the one of thick crust, which is also the same result as published by Han (1992) for the study on geothermal model.

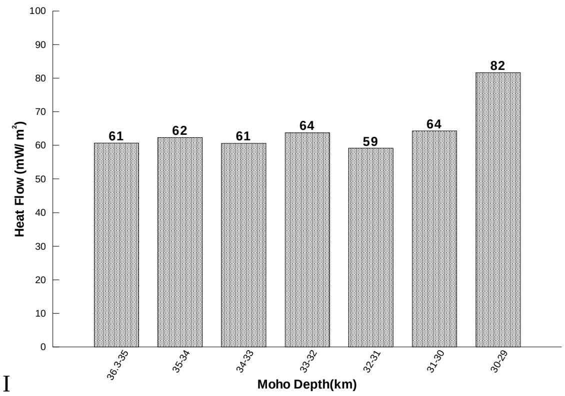

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Figure 6: Average Value of Heat Flow vs. Moho Depth

6. DISCUSSION AND CONCLUSIONS

A total of 247 heat flow data were analyzed to construct the spatial database and digital geologic map including lithology, geologic time. The relationship between heat flow and geologic data were elucidated using the tabulate analysis with each item by ArcView S/W. The average of heat flow is 64 ± 14 mW/m^2 in South Korea.

In the aspect of rock types, the area of sedimentary rock shows high heat flow of 74 mW/m^2, sedimentary/volcanic rock area 62 mW/m^2, plutonic rock area 63 mW/m^2, and metamorphic rock area 61 mW/m^2. In the geologic time sequence, the Cenozoic stratum has 91 mW/m^2, the Mesozoic and Paleozoic strata 65 mW/m^2, the Proterozoic strata 55 mW/m^2, and the Archean strata 61 mW/m^2. In the Moho depth aspect, the shallow depth area shows higher heat flow than the area of thick crust.

Figure 7 shows a heat flow anomaly map in terms of correlation between measured heat flow and geologic characteristics such as lithology, geologic time and Moho depth. The Pohang and Ulsan in the southeastern part of Korean Peninsula appear to be the regions of average highest heat flow anomaly. The next are Ulsan-Pohang-Uljin, Jinju-Haman-Changnyeong, Pocheon-Yeoncheon and Samcheok.

Of course, it should be noted that the measurement stations of heat flow are neither of even distribution nor covering whole territory. Therefore, this result can be regarded as just starting step on the quantitative analysis of geothermal characteristics of South Korea. Furthermore, geothermal potential in terms of low-temperature geothermal water development should be considered along with lineament distribution that is closely related with deeply extended fracture. Therefore, measuring larger number of heat flow data all over the Peninsula and also further analysis of these data with geologic and structural information should be made in the future.

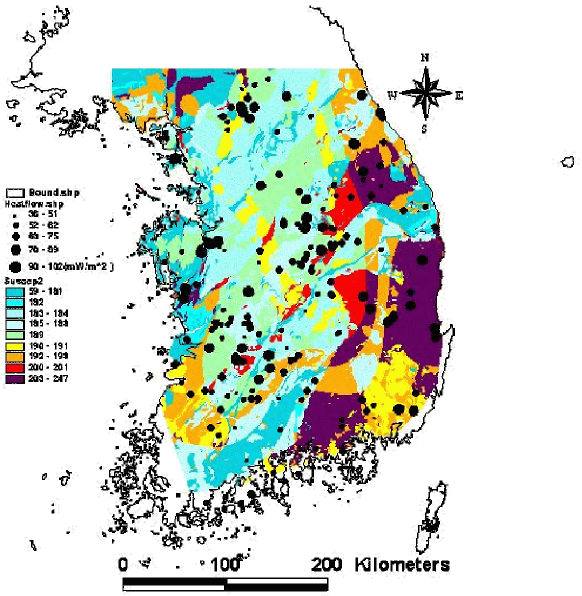

Figure: 7 Heat Flow Anomaly Map as a Result of Overlay Analysis on the Correlation between Heat Flow and Rock Types, Geologic Sequence and Moho Depth.

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Table 4. Average Heat Flow corresponding to Geology

No.	Geologic symbol	No.s	H.F. avg. (mW/m^2)	STD	Geologic time	Rock type	Stratigraphic Units
1	Q3	-	-	-	Cenozoic	Sed./Vol.	Pumice, Marine Sediments
2	Q2	-	-	-	Cenozoic	Volcanic	Basalt, Volcanic rocks, Trachytes
3	Q1	-	-	-	Cenozoic	Volcanic	Basalt, Trachytes
4	N	2	91	10	Cenozoic	Sedimentary	Yeonil Gp.
5	P(T)	-	-	-	Cenozoic	Sed./Vol.	Janggi Gp.
6	Pgr	-	-	-	Cenozoic	Plutonic	Namsan Granite
7	K3	23	62	14	Mesozoic	Sed./Vol.	Yucheon Gp.
8	K2	17	75	11	Mesozoic	Sedimentary	Hayang Gp., Neungju Gp., Jinan Gp.
9	K1	1	77	-	Mesozoic	Sedimentary	Sindong Gp.
10	K0	-	-	-	Mesozoic	Sedimentary	Myogog Fm.
11	Kgr	18	64	8	Mesozoic	Plutonic	Bulgugsa granite
12	Jgr	101	64	14	Mesozoic	Plutonic	Daebo Granite
13	Jgr1	10	60	5	Mesozoic	Plutonic	Foliated Granite
14	J1	4	87	20	Mesozoic	Sedimentary	Daedong Gp.
15	Tgr	6	54	9	Mesozoic	Plutonic	Hesan Comp.
16	P-T	2	67	3	Paleozoic	Sedimentary	Pyeongan Gp.
17	C	3	67	7	Paleozoic	Sedimentary	Pyeongan Gp.
18	D	1	59	-	Paleozoic	Sedimentary	Rimjin Gp.
19	S	1	87	-	Paleozoic	Sedimentary	Hoedongri Fm.
20	O	3	65	14	Paleozoic	Sedimentary	Great Limestone Gp.
21	E	4	63	9	Paleozoic	Sedimentary	Yangdug Gp.
22	PALv	-	-	-	Paleozoic	Volcanic	Paleozoic Basic Volcanic Rocks
23	Og3	1	60	-	Paleozoic	Metamorphic	Ogcheon Gp.
24	Og2	8	62	18	Paleozoic	Metamorphic	Ogcheon Gp.
25	Og1	4	68	23	Paleozoic	Metamorphic	Ogcheon Gp.
26	PR3	-	-	-	Proterozoic	Metamorphic	Taen Fm.
27	PR2	-	-	-	Proterozoic	Metamorphic	Yeoncheon Gp., Jangrag-Euiam Gp.
28	PR1	2	50	2	Proterozoic	Metamorphic	Seosan Gp., Yuli Gp.
29	PRgr	1	65	-	Proterozoic	Plutonic	Buncheon Granite, Hongjesa Granite,Sancheong Anorthosite(PRan), Seosan granitic gn.
30	AR3	5	62	12	Archean	Metamorphic	Porphyroblastic Gneiss
31	AR2	5	61	12	Archean	Metamorphic	Granitic Gneiss
32	AR1	25	60	15	Archean	Metamorphic	Gneiss, Migmatitic Gneiss