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GEOTHERMAL RESOURCES MAP AND GEOTHERMAL FEATURES OF THE KYUSHU REGION, SOUTHWEST JAPAN

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ABSTRACT

A geothermal resources map of the Kyushu Region, southwest Japan, was compiled at 1:500,000 scale for understanding an outline of geothermal resources areas and relation between the distribution of geothermal resources and regional geologic/tectonic settings. Hot springs, fumaroles, geothermal wells and geothermal resources areas are plotted on a simplified geologic map with Bouguer anomaly contour lines. The map is to be published in 2000. Geologic units were classified into 10 Neogene to Quaternary units and two units of pre-Neogene basement rocks. Active faults, active volcanoes and calderas younger than ca. 2 Ma and Bouguer anomalies were also indicated on the map. Hot springs were classified by water temperature, pH, total dissolved matter and major anion composition. Fumaroles were classified by maximum temperature, and geothermal exploration wells were classified by maximum well temperature and well condition. Geothermal resources areas were categorized into following three types. 1) Geothermal resources area related to Quaternary volcanoes, 2) Deep-seated hot water resources area, and 3) Geothermal resources area not related to Quaternary volcanoes, and the last was subdivided into 3A) type A and 3B) type B. Geothermal resources areas except type 2) areas are classified into 3 ranks (rank A, B and C) based on their geothermal potential. The map was digitally edited by GIS software. It allows us to maintain data easily and to distribute the map and data in digital publishing form such as CD-ROM. A rough comparison of the numbers of the geothermal resources area between Tohoku and Kyushu revealed the similarity of importance of young volcanism to the high temperature geothermal resources in both areas. The number of geothermal areas not related Quaternary volcanoes in Kyushu is less than that in Tohoku. This difference may be caused by the lack of Miocene volcanism and formation of sedimentary basins since Miocene in Kyushu.

1. INTRODUCTION

Geological Survey of Japan has been publishing “Geothermal Resources Map” series at 1 : 500,000 scale since 1993. The maps of this series display distribution and character of hot springs, fumaroles, geothermal wells and geothermal resources areas plotted on a simplified geologic map with Bouguer anomaly contour lines. Maps at 1 : 500,000 scale are suitable for understanding an outline of geothermal resources and relation between distribution of geothermal resources and regional geologic/tectonic settings such as young volcanism, active faults etc. Until now, two sheet maps with explanatory text, “Niigata” (Takahashi *et al.*, 1993) and “Akita” (Takahashi *et al.*, 1996), were published. Following them, the Geothermal Resources Map of the Kyushu region, southwest Japan, was compiled and to be published in 2000.

2. COMPILED DATA FOR GEOTHERMAL RESOURCES MAP

2.1 Data sets

Data sets compiled for geothermal resources map are as follows (Table 1): geology (including geologic boundaries, active faults, active volcanoes and calderas), Bouguer anomalies, hot springs and fumaroles, geothermal wells, geothermal resources areas, geothermal research areas.

Geology
Geological formations were classified into 12 units (10 Neogene-Quaternary units and two pre-Neogene units). Active volcanoes and calderas younger than ca. 2 Ma were plotted as indicators of heat source. Active faults, which indicate recent-present stress condition, were presented in different color from older faults. Geologic boundary data were compiled from the digitized Geological Map of Japan (1:1,000,000) (3rd. edition) (Geol. Surv. Japan, 1995).

Gravity
Bouguer anomalies were contoured at interval of 2.5 milligal. Gravity anomalies at 1:500,000 scale were mainly used to figure out the shape of the sedimentary basins in which deep-seated hot water resources exist.

Hot springs and fumaroles
Hot springs were classified by multiple indices such as water temperature, pH, total dissolved matter and major anion composition. Fumaroles and steam wells were classified by maximum temperature as compared with 100°C.

Geothermal wells
Geothermal wells were categorized into six types by combination of maximum temperature and well condition (producing steam and/or hot water, not producing).

Geothermal resources areas
Indicating geothermal resources areas is the most remarkable feature of the “Geothermal Resources Map”. This distinguishes “Geothermal Resources Map” from simple hot spring distribution map. Geothermal resources areas were extracted basically on the distribution of hot springs and other geothermal features. Detail criteria are described in 2.2. Yamaguchi *et al.* (1992) already extracted geothermal resources areas from nationwide resources map of 1 : 3,000,000 scale. We modified some areas for 1:500,000 scale map, and added some areas based on revised data.

Geothermal research areas
Geothermal research areas conducted by the Japanese government (Ministry of International Trade and Industry, and New Energy and Industrial Technology Development Organization) were compiled.

2.2 Classification of geothermal resources into types and ranks

Criteria of classification of geothermal resource types and ranks are shown in Fig. 1."Geothermal resources area" is defined as an area in which geothermal fluid of ≥ 42°C is obtained. Geothermal resource areas were categorized into following three types, and the last one was subdivided.

1) Geothermal resources area related to Quaternary volcanoes: Distributed area of Middle Pleistocene to Holocene volcanic rocks (excluding large-scale pyroclastic flow) and an area of 5 km surrounding it.

2) Deep-seated hot water resources area: Late Neogene to Quaternary sedimentary basin.

3) Geothermal resources area not related to Quaternary volcanoes: Geothermal area categorized in neither 1) nor 2). This type is subdivided into 3A) type A, and 3B) type B. Type A area is located back-arc side or within 20 km fore-arc side of the volcanic front. Type B area is located more than 20 km fore-arc side of the volcanic front. Geothermal resources area of this type is exceptional. Only two areas were identified in the Tohoku area and none in the Kyushu map.

Geothermal resources areas 1), 3A) and 3B) were classified into following three ranks based on measured temperature and geochemical thermometer values.

Rank A: Area with production of ≥ 90°C geothermal fluids, or with both of ≥ 70°C surface manifestation and >= 1 km^2 acidic alteration zone.

Rank B: Area with geochemical thermometer temperature of ≥ 150°C among non-Rank A areas.

Rank C: Others, including areas where no data are available.

2.3 Digitizing and editing data on Geographical Information System

Manually compiled data sets such as hot springs, geothermal wells etc. were digitized and edited on a Geographical Information System (GIS) together with other digital data. Digital editing was done with a computer software "ARC/INFO". Final data sets were made in ARC/INFO's standard and export file formats and also in DLG (Digital Line Graph) format. Digital editing on GIS allows us to add and correct data easily and to distribute the map and data in digital publishing form such as CD-ROM.

3. GEOTHERMAL FEATURES OF THE KYUSHU REGION

3.1 Distribution of geothermal resources areas

Geothermal resources areas of the Kyushu Region are shown in Fig. 2 together with representative Middle Pleistocene-Holocene volcanoes. Remarkable geothermal features of the Kyushu Region are as follows.

1) Geothermal resources areas and late Cenozoic volcanism in Kyushu are divided into north and south by the Kyushu Mountain which consists of a thick pile of Mesozoic accretionary prisms. An almost 100 km-long lack of geothermal resources along volcanic front is remarkable.

2) All of the rank A resources areas (i.e. high temperature geothermal resources) are related to Quaternary volcanoes.

3) Especially, several rank A volcano-related geothermal resources areas make a cluster in Hohi Volcanic Zone (HVZ in Fig. 2). HVZ, a kind of volcano-tectonic depression, started its activity ca. 5 Ma and effused vast amount of mainly andesitic lavas diminishing its active area and production rate (Kamata, 1989).

4) No geothermal resource area has been found on fore-arc side (Pacific Ocean-side) of the volcanic front.

5) Some geothermal resources areas not related to Quaternary volcanoes are located in/near Pliocene-Early Pleistocene volcanic provinces; e.g. areas north of HVZ. The heat sources of these geothermal resources may come from old volcanism.

6) There are still many geothermal resources areas not volcano-related, e.g. areas along the western coast and areas in northwestern part. All of them are in rank B or C and volcanism is not likely in these areas. Therefore these geothermal resources must be formed by deep circulation of meteoric water.

3.2 Comparison with the Tohoku volcanic arc

Geothermal activity in Kyushu is very high as shown in Fig. 2. The Tohoku arc is also has high geothermal potential (Tamanyu, 1996). Actually, five and eight commercial geothermal power plants are located in Kyushu and Tohoku respectively. Table 2 shows the numbers of the geothermal resources areas extracted in three geothermal resources maps, Kyushu, Niigata and Akita. The latter two are located on the Tohoku area.

The numbers of geothermal resources areas related Quaternary volcanoes are similar among three maps. And all or many rank A areas are Quaternary volcano-related in the all maps. This shows that young volcanism is the most important factor to the high temperature geothermal resources in both Kyushu and Tohoku areas, and that both areas have similar geothermal potential related young volcanism.

The number of geothermal areas not related Quaternary volcanoes of Niigata and Akita is larger than that of Kyushu. The Tohoku area was under intense submarine volcanism in the Miocene and thick formations cover entire Tohoku area. Many geothermal resources areas not Quaternary volcano-related occur in such Miocene formations. Thick Miocene formations possibly work as good geothermal reservoirs and/or circulation paths to the depth. Accumulation of heat since Miocene time may contribute to the occurrence of geothermal systems in Miocene formation areas. On the other hand Miocene volcanism and its products in the Kyushu area are restricted in narrow areas. Moreover, most part of the Kyushu area has been subaerial since Miocene age. Therefore, the Kyushu area contains less suitable reservoir formations and, maybe, less heat source than the Tohoku area.

4. CONCLUSIONS

Geothermal resources map of the Kyushu Region, southwest Japan, at 1:500,000 scale was compiled and digitally edited. The map displays distribution and character of hot springs, fumaroles, geothermal wells, geothermal resources areas and geothermal research areas plotted on a simplified geologic map with Bouguer anomaly contour lines. The map was designed to be suitable for understanding an outline of geothermal resources and relation between distribution of geothermal resources and regional geologic/tectonic settings. The map is to be published in 2000 by Geological Survey of Japan.

A rough comparison of the numbers of the geothermal resources area among three maps revealed the similarity of importance of young volcanism to the high temperature geothermal resources in both areas. The smaller number of geothermal areas not related Quaternary volcanoes in Kyushu compared to that in Tohoku may be caused by the lack of Miocene volcanism and formation of sedimentary basins since Miocene in Kyushu.

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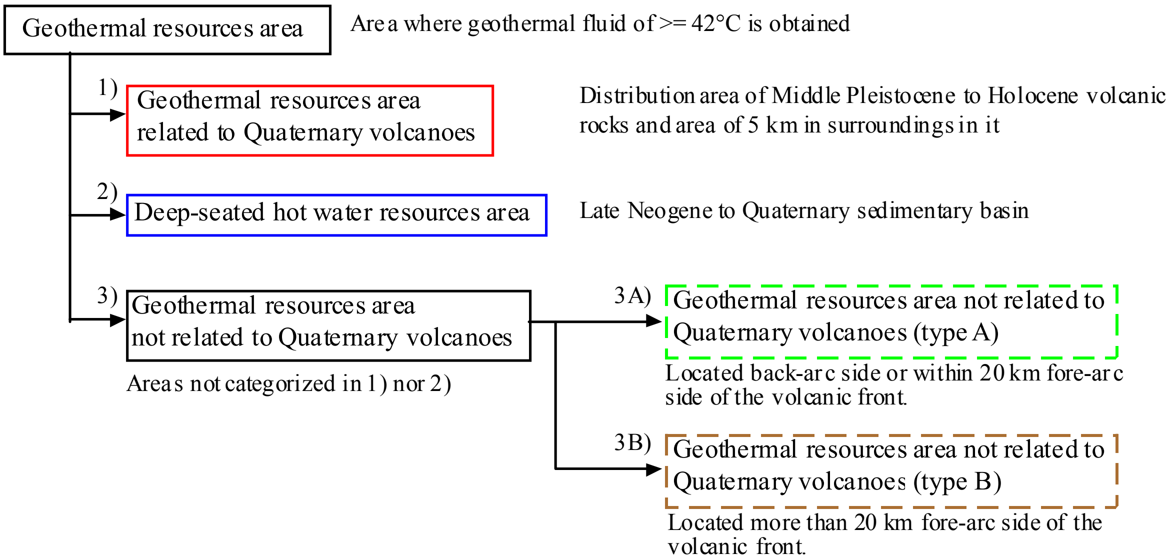
* in Japanese with English abstract

Table 1. Compiled and digitized data sets

Data name	Coverage name	Form	Remarks
Geologic boundary	geokyu	polygon	
Folding axis	-----	line	Not exists in the Kyushu map
Active fault	fltkyu	line	
Active volcano	volkyu	point	
Caldera younger than 2Ma	calkyu	line	
Hot spring	hotkyu	point	
Geothermal well	wellkyu	point	
Geothermal power plant	pwpkyu	point	
Geothermal resources area	ybokyup	polygon	Doughnut-like polygon
Geothermal resources area	ybokyul	line	Outer line
Geothermal research area	idxkyu	line	Conducted by the government

TYPE



RANK

Rank A = With pruduction of geothermal fluid of >= 90°C, or with both of surface manifestation of >= 70°C and acidic alteration zone larger than 1 km^2

Rank B = With geochemical thermometer temperature of >= 150°C among non-rank A areas

Rank C = Others (including areas where no data are available)

GEOGRAPHICAL RELATION

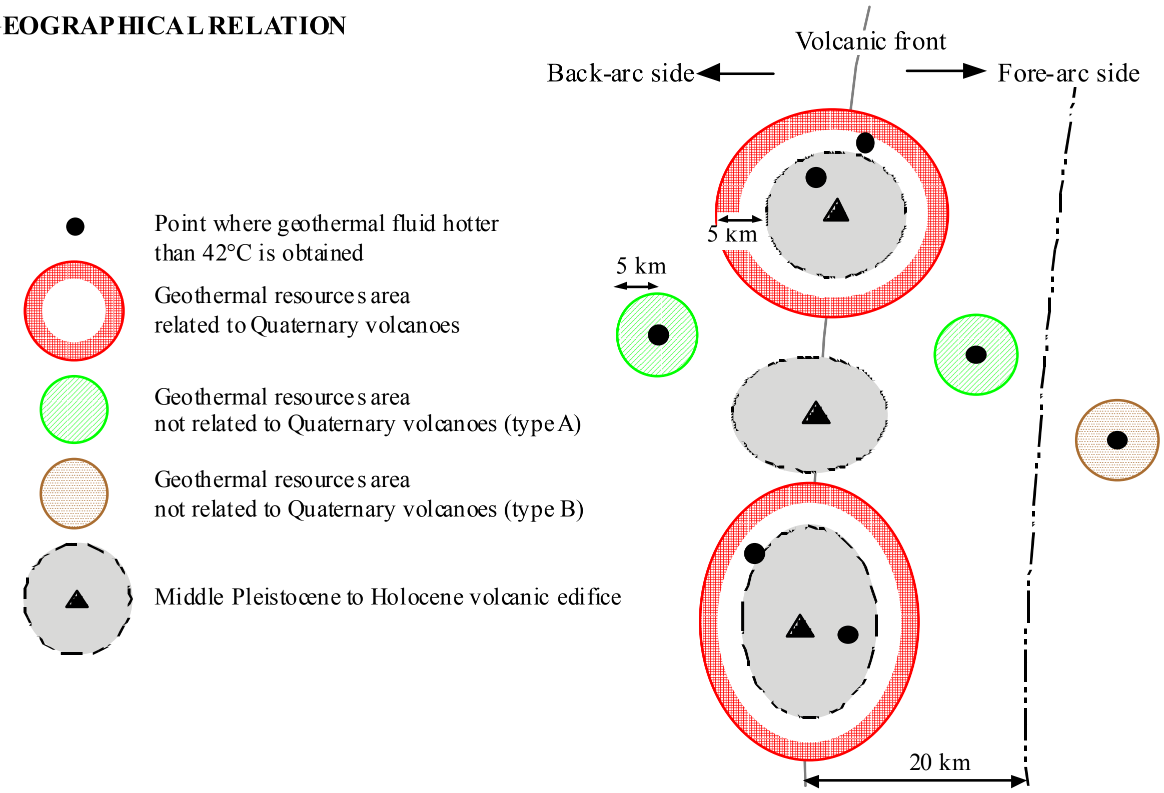


Fig. 1. Categories of type and rank of the geothermal resources areas, and their geographical relationship

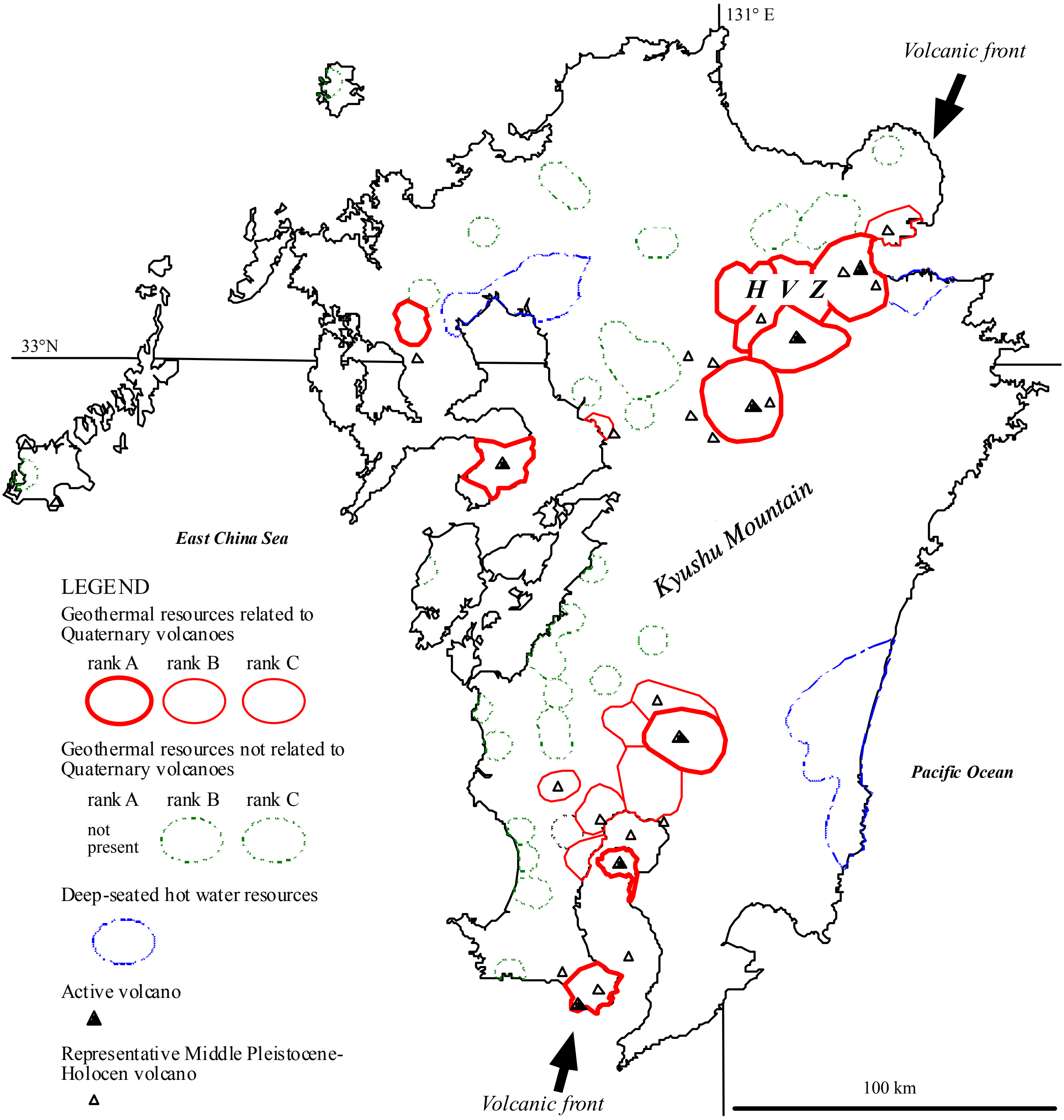


Fig. 2. Geothermal resources areas in the Kyushu region

Table 2. Comparison of the numbers of geothermal resources areas among Kyushu, Niigata and Akita maps

Map	Kyushu (this study)	Niigata (Takahashi *et al.*, 1993)	Akita (Takahashi *et al.*, 1996)
Quaternary volcano-related resources areas	19 (Rank A: 11, B:7, C:1)	16 (Rank A: 9, B:2, C:5)	19 (Rank A: 10, B:1, C:4)
Not Quaternary volcano-related resources areas	26 (Rank A: 0, B:7, C:19)	39 (Rank A: 5, B:9, C:25)	33 (Rank A: 3, B:6, C:24)
Deep-seated hot water resources areas	3	10	11