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AN UPDATED GEOTHERMAL RESOURCES MAP OF THE TOHOKU VOLCANIC ARC, JAPAN

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ABSTRACT

A geothermal resources map of the Tohoku volcanic arc was compiled at 1:1,000,000 scale to allow a better understanding of the geothermal resources and geothermal heat sources of the area, from geology and hot spring geochemistry. The map was created using "ARC/INFO". Some interesting features in the distribution pattern of the geothermal resources are indicated. Most high temperature resource areas (hot spring temperature > 90°C) are in and around Quaternary volcanic terrains with few exceptions. The volcanic front is delineated by the N-S trending eastern margin volcanoes. High potential geothermal resources are related to Quaternary volcanoes and/or concealed intrusive bodies, the most likely resource for geothermal electric generation. However, medium temperature resources areas (hot spring temperature; 42-90°C, geochemical temperature > 150°C) occur outside of Quaternary volcanic terrains, and are roughly arranged on NW-SE trending zones extending west from the volcanic front. This implies that these areas are heated by deep circulation of meteoric water along deep fracture zones from conductive heat transfer through highly conductive rock units. These areas could be regarded as identified potential fields for further geothermal exploration. However, geothermal exploration has already proved that most of these areas contain only medium enthalpy hydrothermal water (around 200°C), which is not enough for electricity generation. Medium to low temperature resources areas occur in late Neogene to Quaternary sedimentary basins, and are categorized as deep-seated hot water resources in sedimentary basins of non-volcanic terrain. This resources map is correlated with the distribution maps of heat discharge by hot springs, and depths to basement from gravity. Developed high temperature resources areas correspond to high heat discharging areas of hot springs and shallow basement. This suggests that these areas are heated actively by fluid circulation in Tertiary and Quaternary formations, and also heated by conductive heat transfer in pre-Tertiary basement.

1. INTRODUCTION

The Tohoku volcanic arc on the Japanese islands of Honshu and southwestern Hokkaido, is generated by subduction of an oceanic plate (Pacific plate) beneath a continental plate (North American plate or Okhotsk microplate). This arc displays much greater volcanic and geothermal activity in comparison with other Quaternary volcanic areas, such as the Cascade arc, USA (Muffler and Tamanyu, 1995). A geothermal resources map of the Tohoku volcanic arc was compiled at 1:1,000,000 scale to illustrate the known & hypothesized geothermal resources and geothermal heat source of the area, based on geology and geochemistry. The map was digitally synthesized by computer software "ARC/INFO (version 6)" from the 1:500,000 scaled geothermal resources maps of "Niigata" (Takahashi et al., 1993), "Akita" (Takahashi et al., 1996), "Aomori" (in preparation) and "Sapporo" (in preparation). These geothermal resources areas have been already discussed, but in less detail on the nationwide geothermal resources map of 1:3,000,000 scale (Yamaguchi, et al., 1992). However, some previously documented geothermal resource areas have been revised by the more detailed mapping done here.

2. DIGITIZED DATA FOR GEOTHERMAL RESOURCES MAP

2.1 Digitized data

The data included in this map are as follows; geologic boundaries, anticline and syncline axes, faults, geothermal resource areas, hot springs, geothermal research areas, calderas, active volcanoes, and acidic hydrothermal alteration areas. These are shown on the legend of the geothermal resources map together with the geology derived from 1: 500,000 scaled neotectonic maps published by Geological Survey of Japan (Fig. 1).

Geological formations were classified into 10 units of Neogene to Quaternary rocks, and 2 units of pre-Neogene basement rocks. Active volcanoes and calderas younger than 2 Ma and acid hydrothermal alteration zones were also described. Hot and mineral springs were classified by water temperature, pH, chemical concentration and anion composition. Fumarolic areas are listed by maximum fumarole temperature, and geothermal exploration wells by maximum well temperature and well condition (single or two phase).

2.2 Classification of geothermal resources

Geothermal resources are classified into 3 types according to the distribution of Quaternary volcanoes, high-temperature (>42°C) hot springs and Quaternary sedimentary basins as follows: type I, geothermal resource area related to Quaternary volcanoes: type II, geothermal resource area not related to Quaternary volcanoes; and type III, deep-seated hot water resource area in late Neogene to Quaternary sedimentary basin. The Type II geothermal resource area is further subdivided into 2 sub-type (sub-type A and sub-type B) by west or east of the volcanic front.

Type I and type II (sub-type A & B) are subdivided into 3 ranks according to measured and calculated geochemical temperatures of hot springs (Rank A, B and C). The field discriminated as Rank A includes high-temperature hot springs (>90°C). Rank B includes medium-temperature hot springs (>42°C) and high geochemical temperatures (>150°C). Rank C includes medium-temperature hot springs (>42°C), low geochemical temperatures (<150°C).

3. GEOTHERMAL FEATURES IN THE TOHOKU VOLCANIC ARC, JAPAN

The compiled map suggests some trends in the distribution pattern of geothermal resources: (Figs. 2 and 3).

- Geothermal resource areas related to Quaternary volcanoes occur mainly along the volcanic front, and disperse partly westwards from some parts of volcanic front.
- Geothermal resource areas not related to Quaternary volcanoes (sub-type A) cluster around the volcanic front, and disperse west of the volcanic front.
- Geothermal resource areas not related to Quaternary volcanoes (sub-type B) occur exceptionally east from the volcanic front in the southern part of the map.
- Deep-seated hot water resources in late Neogene to Quaternary sedimentary basins occur along the coastal plains near the Japan Sea and Pacific Ocean, and in inland basins.
- Geothermal resource areas not related to Quaternary volcanoes (type II, subtype A) seem to be located along NW-SE trending belts. These features comprise the six High Temperature Zones (HTZ) west of the volcanic front. Some of them are related to the geologic tectonic belts and/or Pliocene volcanic terrains.

The geothermal resource areas related to Quaternary volcanoes have the highest temperatures and higher "topographic areas". This heat source is assumed to be the heat generated by Quaternary volcanism and plutonism (case: Hachimantai). Therefore, these areas are regarded as high potential geothermal fields and the most promising areas for future exploration. However, most areas are in National parks where geothermal exploration is severely restricted.

The heat sources of geothermal resource areas not related to Quaternary volcanoes, must be assumed. Type A and B are artificially divided according to their position west or east of the volcanic front respectively. Type A includes some rank A areas (the high temperature area), but type B never includes rank A area. This is consistent with the thermal contrast between west and east of the volcanic front, as indicated by heat flow values and estimated subsurface temperatures (e.g. Okubo, 1993). High temperature areas in type A may be related to young intrusive rocks which do not outcrop at the surface. Medium temperature areas in area type B may be related to deep circulation of meteoric water along fault systems because concealed Quaternary magma chambers are not expected east of the volcanic front.

Some of the Type A high temperature areas might be regarded as potential geothermal fields. They seem to be located along NW-SE trending zones, and the high temperature and wide geothermal resource areas generally occur close to the volcanic front, whereas the medium to low temperature and narrow geothermal areas occur far from the volcanic front. Six NW-SE trending zones are recognized. Two of them are the Noboribetsu - Niseko High Temperature Zone (HTZ) and the Minamikayabe - Nigorikawa - Yakumo HTZ in southwestern Hokkaido. (Wakahama, et al., 1993, Tamanyu et al., 1994, Wakahama, et al., 1995). The other four are: The Hachimantai - Iwakisan HTZ, Yakeishidake - Akita HTZ, Zao - Hijiori - Chokaisan HTZ, and Shiobara - Okuaidu - Murakami HTZ in Northern Honshu. This last zone includes the Okuaidu geothermal field. These HTZs seem to be related to the geologic tectonic belts and Pliocene volcanic terrains. The identification of these zones is tentative, and more detailed investigation is necessary.

The western parts of the above-mentioned zones have been eagerly expected to be suitable for geothermal exploitation because they are outside national parks. However, the areal geothermal exploration surveys carried out by NEDO, have shown that these areas contain only medium enthalpy hydrothermal waters (< 200°C) in the fields of Okushiri, Yakumo and Kaminoyu-Santai in Hokkaido, and Eastern Obanazawa and Akakura in Northern Honshu. The only known exception to this is the Okuaidu area, which has a maximum temperature over 300°C and is exploited as a 65 MW power station (Yanaizu-Nishiyama) since May 1995. The Okuaidu field is regarded as a Quaternary caldera with large pyroclastic flow deposits despite its location 40 km west from the volcanic front.

4. CORRELATION OF THE HIGH TEMPERATURE RESOURCES AREAS WITH OTHER DATA

4.1 Correlation between high temperature resources areas and hot spring heat discharge

The convective heat flux from hot springs in Japan were calculated and summed in discrete blocks (7’30” in longitude and 5’ in latitude), and published as the 1: 2,000,000 scaled map of heat discharge by hot springs in Japan (Sumi, 1980). The value of the heat flux is greatly affected by the volume of discharging hot water rather than the temperature of hot springs. This map shows which areas have more potential and the average heat convectively discharged from hot springs in each block. The high temperature resource areas are selected by the temperature of existing hot springs in and around Quaternary volcanoes. The selected high temperature resources areas are correlated with the distribution map of heat discharge by hot springs. The selected areas are consistent with high heat discharging areas on the map. This means that the volume of discharging hot water from hot spring is controlled by the recharge area of meteoritic water, as it were, the Quaternary volcanic terrain in this case. The average temperature of hot spring is also controlled by the distance from Quaternary volcanic terrain.

4.2 Correlation between geothermal resources areas and depth of gravity basement

The depths of basement calculated from gravity in northern Honshu were obtained by three-dimensional analysis of gravity data. Two layers of variant density (2.0-2.2 g/cm^3 for upper layer, and 2.5-2.7 g/cm^3 for lower layer) were used in the inversion (Komazawa, in preparation). The basement obtained from gravity, so called gravity basement is generally regarded as lower Tertiary and pre-Tertiary according to the correlation between gravity data and geologic data from drill holes. The selected high temperature resources areas were correlated with the distribution map of depths of gravity basement. All of the high temperature resources areas related to Quaternary volcanoes (rank A) are generally located in zones with the gravity-inferred basement (> sea level) on the backbone range. On the other hand, the high temperature resources areas not related to Quaternary volcanoes (rank A) are mostly located at the deep zones of gravity basement (< sea level) on and west the backbone range. These are related to the caldera features and inland basins that have a deeper basement and enhance this heat supply by assumed magmatic intrusion accomapanied with tectonic depression.

5. CONCLUSION

The geothermal resources are classified into three categories: resources related to Quaternary volcanoes, resources not related to Quaternary volcanoes, and deep-seated hot water resources in sedimentary basins. The first two resources are subdivided into three ranks: A, B and C according to the physical and geochemical temperatures of hot springs.

The resources areas of rank A (high temperature) are mostly located on the backbone range (on and just west the volcanic front), with few exceptions. These high temperature resources also correspond to the high heat discharging areas of hot springs and shallow gravity basements. It means that these are heated actively by fluid convection in Tertiary and Quaternary formations, and conductive heat transfer in pre-Tertiary basement. Previous geothermal exploration surveys have already shown that most of these areas contain high enthalpy hydrothermal water (> 200°C).

The medium temperature resources areas (rank B) occur outside of Quaternary volcanic terrain, roughly arranged on NW-SE trending zones extending west from the volcanic front. This implies that these areas are either heated by deep circulation of meteoric water along deep fracture zones or conductive heat transfer through conductive rock units such as pre-Tertiary basement. Some of these could be regarded as potential geothermal fields for further geothermal exploration. However, geothermal exploration surveys have already suggested that most of these areas contain only medium enthalpy hydrothermal water (around 200°C), and relatively low potential for geothermal electric generation.

Medium to low temperature resources areas occur in late Neogene to Quaternary non-volcanic sedimentary basins, and are identified as deep-seated hot water resources in sedimentary basin of non-volcanic terrain. These are expected to be utilized for direct use of hot water in future.

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* written in Japanese with English abstract
**written in Japanese without English abstract

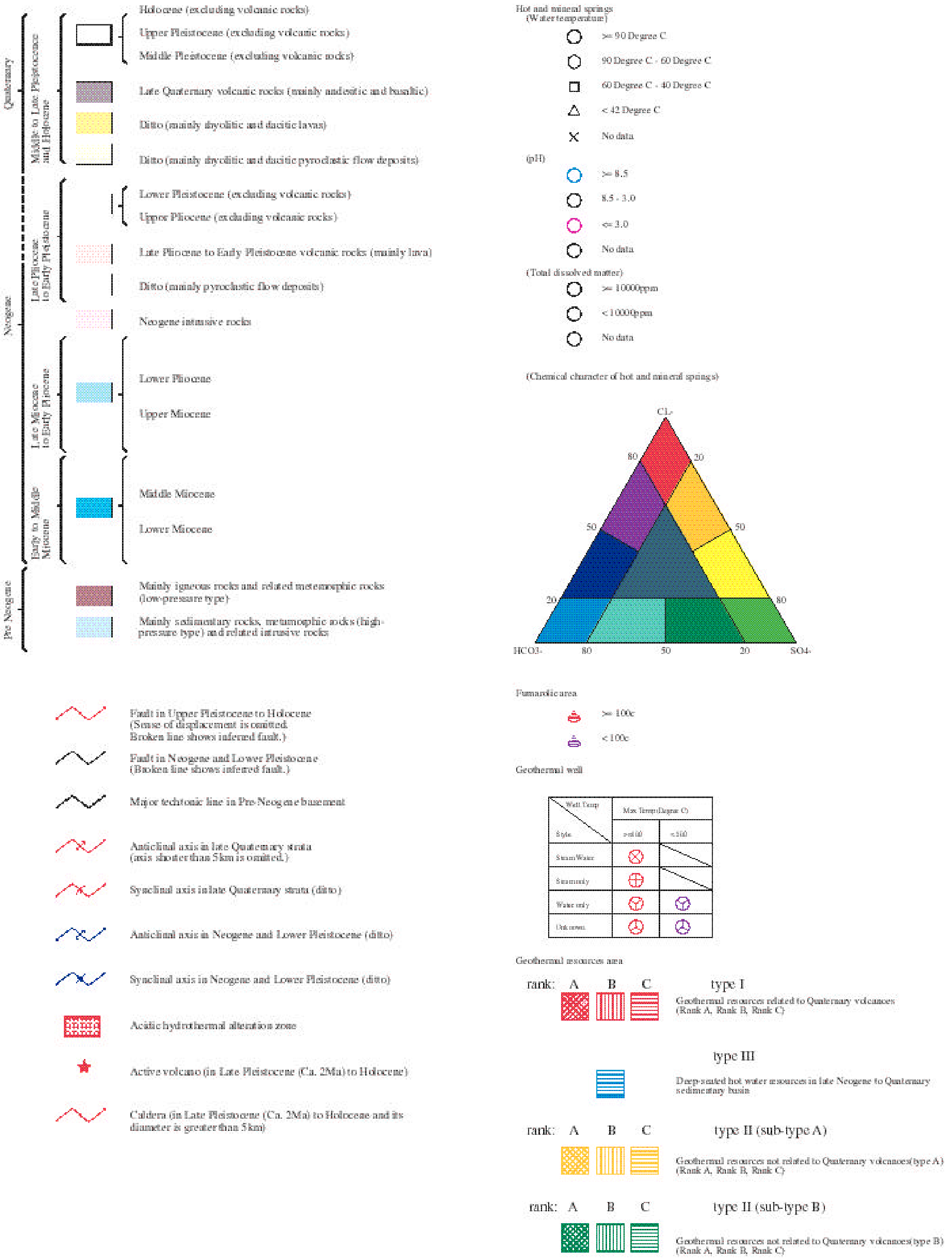

Figure 1. Legend of the geothermal resources map

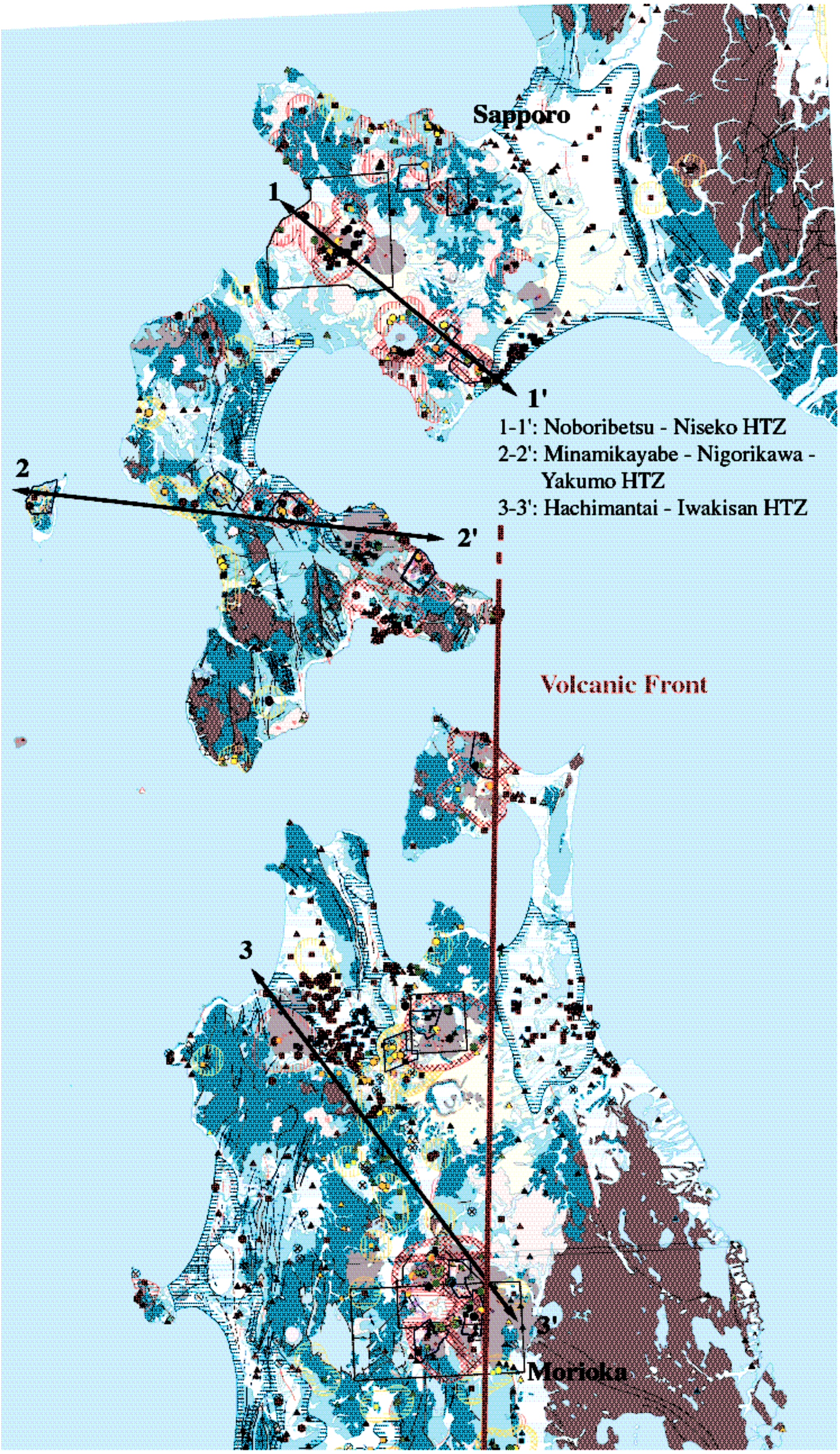

Figure 2. Geothermal resources map of northern part of Tohoku volcanic arc

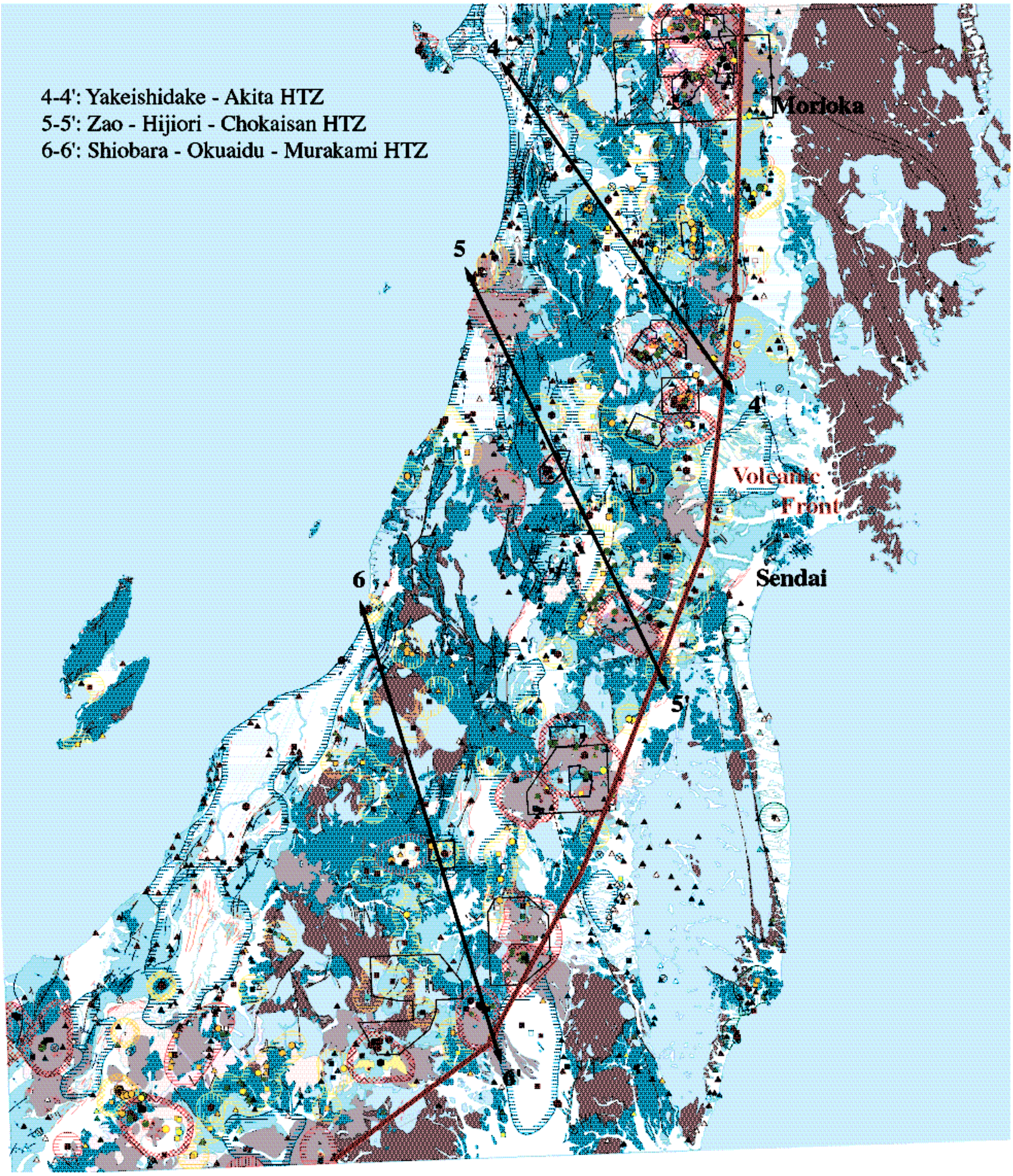

Figure 3. Geothermal resources map of southern part of Tohoku volcanic arc