Conceptual model for non-volcanic geothermal resources - examples from Tohoku Japan –

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Abstract

Non-volcanic geothermal areas are geographically classified into two types. One is the geothermal areas occurred in mountain and hilly countries far from Quaternary volcanic terrains, and the other the deep-seated hot water resources in late Neogene to Quaternary sedimentary basins. Some hot springs of the former are closely related with active faults, geologic faults, topographic margin of basins, buried old calderas, intrusive bodies and so on, and some of the latter with topographic margin of basins and active faults. In general, basin margins play the role of aqueducts for diluted hot springs, and active faults for chemically mixed hot springs to flow up. While, some intrusive rocks originate high-temperature hot springs. However, there are some exceptions of above mentioned distribution characteristics. A number of diluted hot springs occur broadly in the Hirosaki and Kamikita plains, and these waters seem to be derived from infiltrated meteoric water of surrounding mountains, and warmed up by relatively high heat flow at the bottom of the basin. Some hot springs are characterized by low concentrated hot springs in spite of their high temperature. These features are recognized at the hot springs discovered in old time. The examples are as follows: Yuze, Tsunagi, Hanamaki, Dai, Obara, Dake, Kinugawa, Yunokoya and so on. The formation mechanism of these exceptions should be further investigated from the viewpoint of heat and water sources.

Keywords: geothermal resources area, non-volcanic area, hot spring, Tohoku volcanic arc, conceptual model

1. Introduction

Thermal features of the Tohoku volcanic arc were summarized based on 1:500,000 scaled compiled geothermal resources map [1, 2]. These data were standardized and edited together with Kyushu area, and published as CD-ROM version [3]. Non-volcanic geothermal activities are recognized broadly west and near east of the volcanic front of the Tohoku arc. These non-volcanic geothermal areas are geographically classified into two types. One is the geothermal areas occurred in mountain and hilly countries far from Quaternary volcanic terrains, and the other the deep-seated hot water resources in late Neogene to Quaternary sedimentary basins.

The hot springs with the largest production rate or the highest temperature are selected from each geothermal area as the representative hot springs, and compared each other in terms of chemical characteristics, temperatures, dissolved chemical concentrations and production rates of hot springs. Most hot springs are classified into three types: diluted hot springs, chemically mixed hot springs, and chloride-rich concentrated hot springs [4, 5].

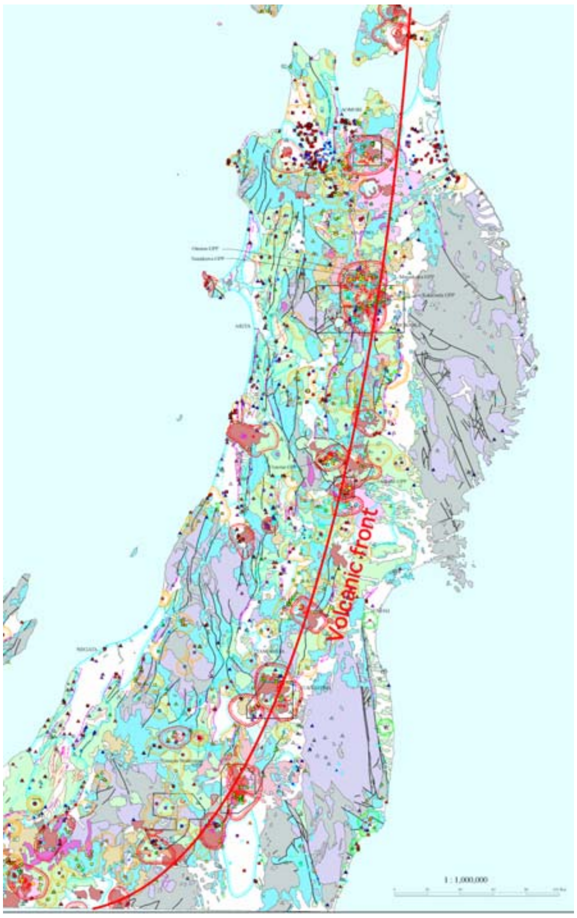


Fig. 1 Digitized geothermal resources map

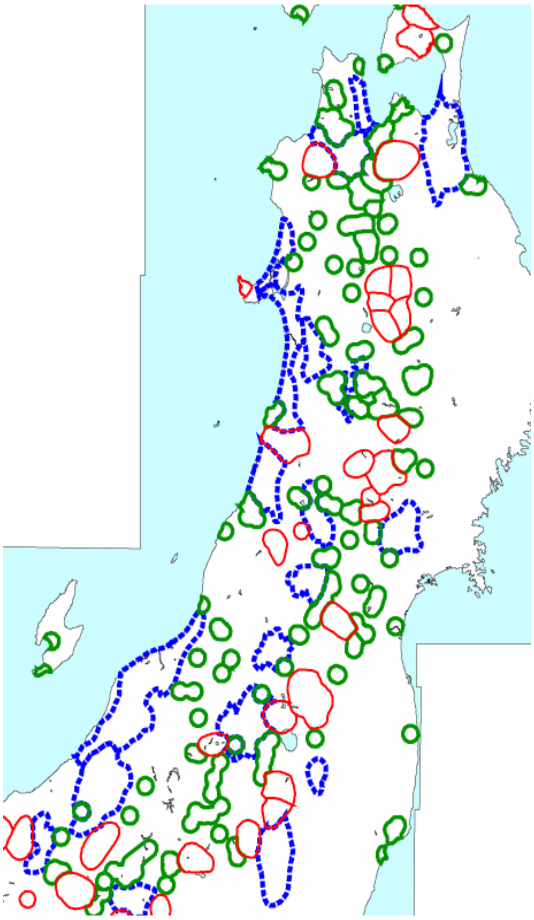


Fig. 2 Selected potential fields

In order to investigate the distribution pattern and the origin of non-volcanic geothermal areas, the locations of hot spring are compared to geographical features and geological setting in terms of hot spring types. The studied geothermal areas are referred from the resources areas delineated by 1:500,000 scaled geothermal resources maps of Niigata area [6], Akita area [7], Aomori area [8] and the digitized map published as the CD-ROM version of the geothermal resources map of Tohoku and Kyushu [3]. Digitized geothermal resources map for Northeast Japan, and selected potential fields are shown in Fig. 1 and Fig. 2.

2. Geographical and geological setting of non-volcanic geothermal resources

2.1 Geothermal areas not related to Quaternary volcanoes

Geothermal resources areas not related to Quaternary volcanoes occur generally at mountain and hilly countries where are composed of pre-Quaternary formations. The heat sources are assumed as consolidated magma chambers and conductive heat flow instead of molten magma of Quaternary volcanoes. Half of them are unknown on control parameters. The other half of them are structurally controlled by active faults (active in late Quaternary age), geologic faults (active in pre-Quaternary age), topographic margin of basins, buried old caldera, intrusive rocks and so on [4].

Tsukioka fault and Yamagata eastern fault are typical examples in which hot springs are closely related to active faults, and these hot springs should be categorized as active fault related geothermal resources areas (Fig. 3, 4). Sukagawa zone is recognized as high gradient zone on the iso-gal contour map, and geologic fault is inferred along Sukagawa zone (Fig. 5). Senami and Matsunoyama (Fig. 6, 7) are typical examples in which isolated high-temperature hot spring occur with high-chloride component. In general, diluted hot springs defined as low concentration of the total dissolved matter (<1000mg/l) tend to be controlled by topographic margin of basins and buried old calderas. While, chemically mixed hot springs (sulfate or mixture of sulfate, carbonate and chloride components) tend to be controlled by active faults, and chloride rich hot springs by inferred intrusive rocks. These indicate that basin margins play the role of aqueducts for diluted hot springs, and active faults for mixed hot springs. While, intrusive rocks seem to originate chloride rich hot springs. Some hot springs are characterized by low concentrated hot springs in spite of their high temperature. Examples are as follows: Tsunagi, Dai, Hanamaki, Obara, Dake, Kinugawa, Yunokoya and so on. Hot rocks that have high thermal conductivities may heat these hot springs conductively. It is worth to note that Joban-Yumoto (Fig. 8) and Izura hot springs locate 75 km far east from the volcanic front in spite of its high temperature. The heat sources of these hot springs have not yet identified. These might be originated by deep water circulation along faults.

2.2 Deep-seated hot water resources in young sedimentary basins

Deep-seated hot water resource areas occur generally in late Neogene to Quaternary sedimentary basin, and delineated by gravity low anomalies. Plenty of hot water has been expected in these areas because the younger formations are generally more porous in late Neogene to Quaternary sedimentary basins. In actual, a number of diluted hot springs occur broadly in the Hirosaki (Fig. 7) and Kamikita (Fig. 8) plains, and waters seem to be supported by infiltrated meteoric water from surrounding mountains. However, these are only exceptions. In other most Quaternary basins, hot springs do not occur broadly in the basins but regionally at the margins of basins and/or along the active faults (active in Quaternary age). For examples, many hot springs in Niigata and Tokamachi basins occur densely at the margins of basins related to active faults and shoreline. Tsukioka-Ideyu hot springs are excluded from the Niigata geothermal areas, and Muikamachi hot springs are also excluded from the Tokamachi geothermal areas because these are located towards mountain beyond the boundary of plain. Muramatsu hot spring regarded as the representative hot spring of the Niigata area is produced by deep drill holes and characterized by its extremely high flow rate (53,680 l/m) and total dissolved matters (41,483 mg/l). This spring is used not only for production of natural gas and iodine dissolved in water, but also for direct use of hot water.

3. Relationship between hot spring types and geological settings

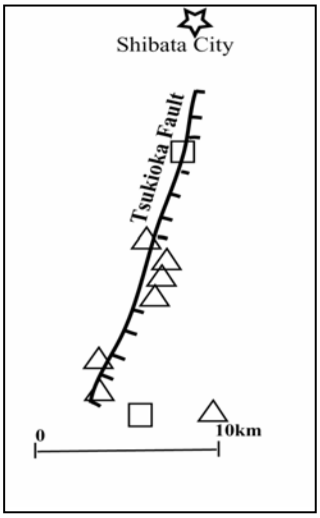
3.1 Active and geologic faults

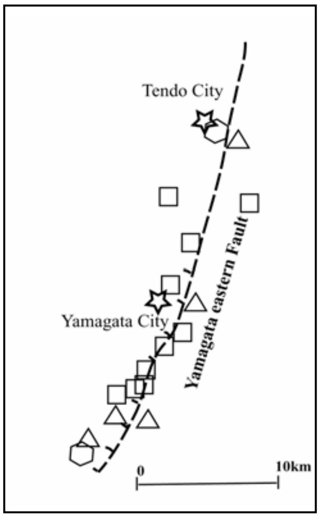
(Tsukioka fault) (Fig. 3)

There are 7 hot springs along the Tsukioka active fault that is 18 km in length. The fault is identified as westward dipping reverse fault of Quaternary age on the surface, however, the fault plain seems to be transformed into normal fault in depth based on the gravity Bouguer anomalies. The fault is located at the boundary between Quaternary plain and Tertiary mountain, and expected to play the role of fluids path from deep infiltrated meteoric water under the mountain to shallow aquifers under Quaternary plain. Four of seven hot springs are characterized chemically by predominance of sulfate anion.

(Yamagata eastern fault)(provisional name) (Fig. 4)

There are 17 hot springs along the Yamagata eastern fault that is composed of southern half inferred active faults (17 km length) and northern half inferred geologic fault (17 km length). The fault is located at the boundary between Tertiary mountain and Quaternary basin. 13 of 17 hot springs are characterized chemically by predominance of sulfate anion.





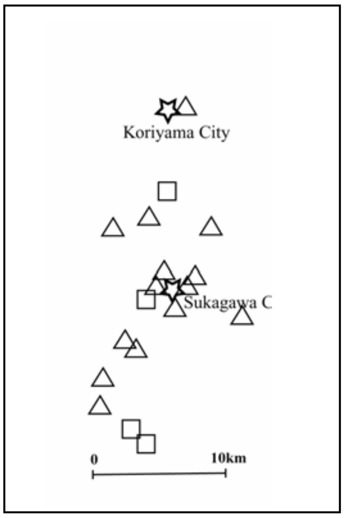
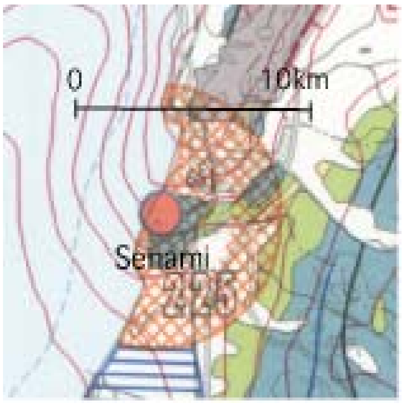
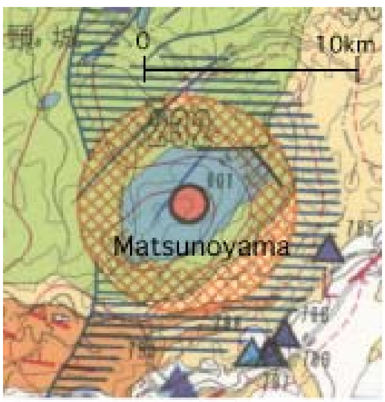


Fig. 3 Tsukioka fault *Fig. 4 Yamagata eastern fault* *Fig.5 Sukagawa belt*

(Sukagawa zone) (provisional name) (Fig. 5)

There are 18 hot springs along NNE-SSW trending belt from Koriyama to Kagamiishi through Sukagawa. There is no identified fault there, but gravity Bouguer anomalies show the steep gradient and suggest conceived fault. Chemical analysis data are available for 10 hot springs, and 7 of them are characterized by predominance of carbonate anion.





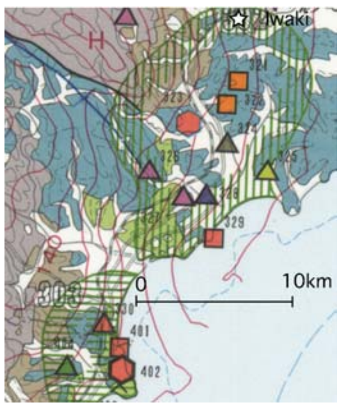


Fig. 6 Senami hot spring *Fig. 7 Matsunoyama hot spring* *Fig. Joban-Yumoto hot spring*

3.2 Inferred intrusive rocks

(Senami hot spring) (Fig. 6)

The Senami hot spring is isolated and its temperature exceeds 90 deg C. The heat source of this spring seems to be related to the high-level intrusive rock [9].

(Matsunoyama hot spring) (Fig. 7)

The Matsunoyama hot spring is isolated and its temperature exceeds 90 deg C. The heat source of this spring seems to be related to the high-level intrusive rock based on the distribution pattern of subsurface temperature [9].

3.3 Deep circulation

(Joban-Yumoto and Izura hot springs) (Fig. 8)

The Joban-Yumoto and Izura hot springs are located 80 km far east from the volcanic front. The hot spring temperature exceeds 60 deg C. The water production rate of Shiratori hot spring in the Joban-Yumoto hot spring is as much as 42,000 l/min. The heat source of these spring is not clear, but might be related to deep circulation of infiltrated water.

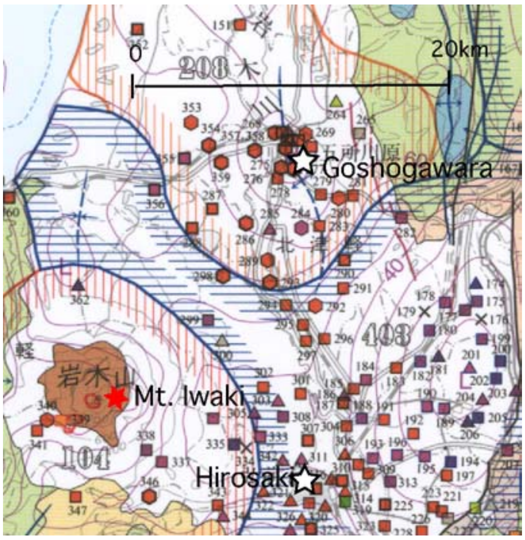


Fig. 9 Hot springs in Hirosaki plain

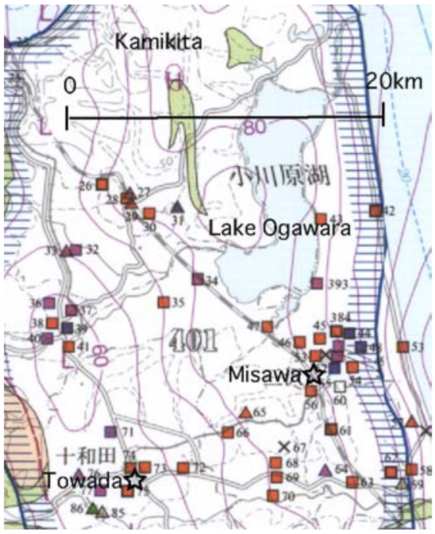


Fig. 10 Hot springs in Kamikita plain

3.4 High heat flow

(Hirosaki plain) (Fig. 9)

The Hirosaki plain is the inland basin located westward from the volcanic front. The 80s hot springs have been exploited, and produce hot water ranging from 40 to 60 deg C. Most springs produce the amount of hot water ranging from 200 to 500 l/min. The production reservoir seems to be about 800 m in depth. Assuming that it is 10 deg C at surface and 60 deg C at 800 in depth, it can be calculated as 60 deg C/ km as average thermal gradient.

(Kamikita plain) (Fig. 10)

The Kamikita plain is the coastal basin located eastward from the volcanic front. The 50s hot springs have been exploited, and produce hot water ranging from 40 to 50 deg C. Most springs produce the amount of hot water ranging from 200 to 1200 l/min. The production reservoir seems to be about 1,000 m in depth. Assuming that it is 10 deg C at surface and 50 deg C at 1,000 in depth, it can be calculated as 40 deg C/ km as average thermal gradient.

4. Conceptual model for the origin of non-volcanic geothermal resources

The conceptual model for the origin of non-volcanic geothermal resources is shown in Fig. 11. In general, Neogene can be regarded as permeable horizon and then convection regime. On the other hand, pre-Tertiary basement can be regarded as impermeable horizon except fault zones and then conductive regime. Therefore, the depths of pre-Tertiary basement and fault systems are important to interpret the fluid circulation.

Light blue arrows indicate the ground water movement, red solid arrows the hot water movement through permeable fault zones, and red dotted arrows effective heat transfer in Tertiary and Quaternary formations with supporting by high heat flow in pre-Tertiary basement. Hot water seems to be derived from solidified magmas or well conductive intrusive bodies. Therefore, the interaction between groundwater and deep-seated hot water should be investigated in detail from the viewpoint of resource assessment and environmental assessment.

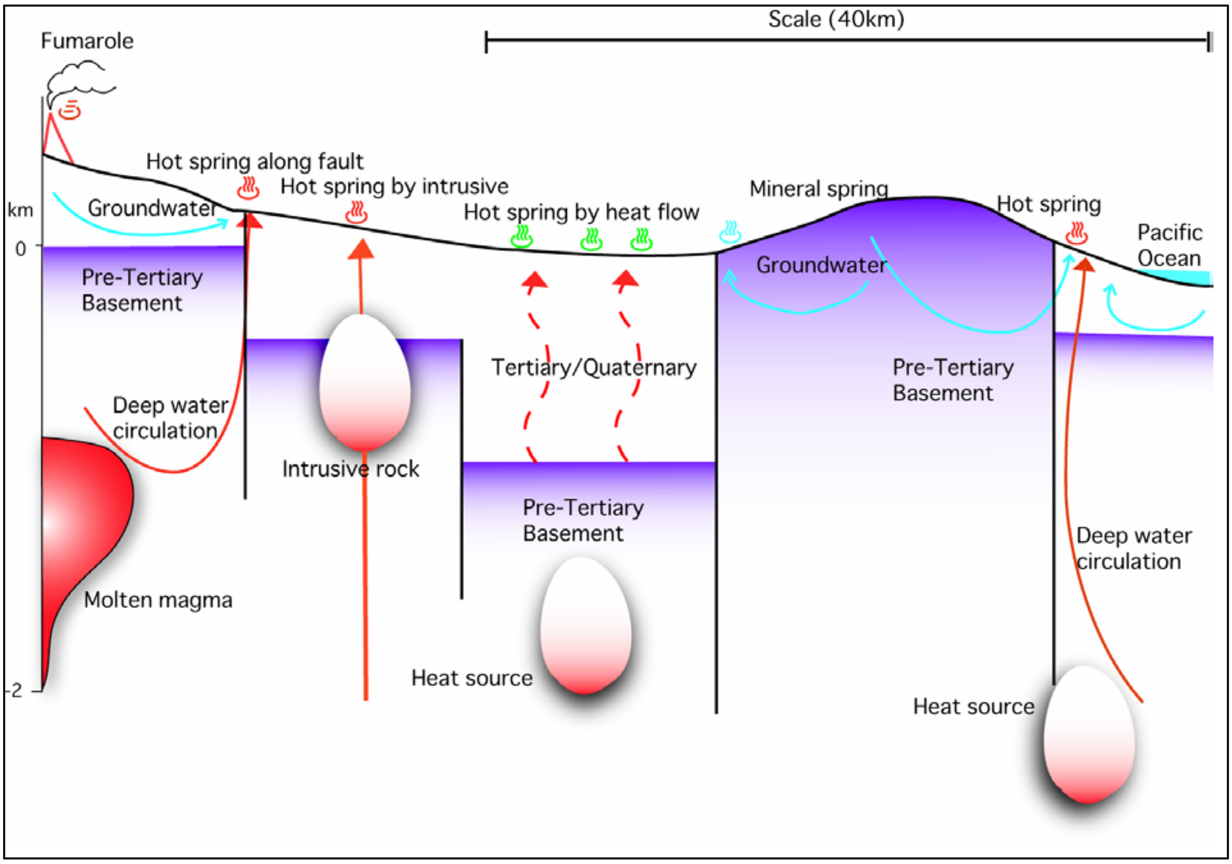


Fig. 11 Conceptual model for the origin of non-volcanic geothermal resources

References

1. Tamanyu, S. Takahashi, M., Murata, Y., Kimbara, K., Kawamura, M. and Yamaguchi, H. Geothermal resources map of the Tohoku volcanic arc, northeast Japan. *Geothermal Resources Council Transactions*, 20, 401-405 (1996).
2. Tamanyu, S., Takahashi, M., Murata, Y., Kimbara, K., Kawamura, M., Matsunami, T. and

Yamaguchi, H. An updated geothermal resources map of the Tohoku volcanic arc, Japan. *Proceedings of the World Geothermal Congress 2000,* 1817-1822 (2000).
3. Sakaguchi, K. and Takahashi, M. *Geothermal resources map of Tohoku and Kyushu (CD-ROM Version).* Digital Geoscience Map GT-1, Geological Survey of Japan, AIST (2002).*
4. Tamanyu, S., and Sakaguchi, K. Distribution and characteristics of non-volcanic geothermal resources in the southern part of Tohoku arc, Japan. *Proceedings of 2002 Beijing International Geothermal symposium*, 204-210 (2002).
5. Tamanyu, S., and Sakaguchi, K. Distribution and characteristics of non-volcanic geothermal resources areas –examples from the northern part of Tohoku Japan. *Abstract of 2002 annual meeting Geothermal Research Society of Japan*, B19 (2002).
6. Takahashi, M., Yamaguchi, Y., Noda, T., Komazawa, M., Murata, Y. and Tamanyu, S. *Geothermal resources map of Niigata area*. 1:500,000-scaled map and its text. Miscellaneous maps series (31-1), Geol. Surv. Japan. 116p (1993).*
7. Takahashi, M., Murata, Y., Komazawa, M. and Tamanyu, S. *Geothermal resources map of Akita area.* 1:500,000-scaled map and its text. Miscellaneous maps series (31-2), Geol. Surv. Japan, 162p (1996).*
8. Takahashi, M., Komazawa, M. and Tamanyu, S. *Geothermal resources map of Aomori area, scale 1:500,000.* Maps series (31-5), Geol. Surv. Japan, 126p (2001).*
9. Shimazu, M. *Records of hot springs in Niigata prefecture*. Nojima Publisher, 140p. (2001)**

*Written in Japanese with English abstract
**Written in Japanese without English abstract