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Some Examples of Structural Control on the Occurrence of Hot Springs in Northeast Japan

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Abstract

Some of hot springs distributed in the southwestern part of Miyagi Prefecture have a close genetic relation with faults trending NNE-SSW. The hot springs have been issued along the fissures of these faults. In the Obara-Kamasaki spa area, the fault shear zone consists of many reverse strands with clockwise *en échelon* arrangement caused by left-lateral transcurrent movement. In the Akiyu spa area, the fault extends beneath the hot spring swarm, though its plane may be consealed. Seismic activity along the faults have occurred recently in both areas. Therefore, these faults are considered to be reactivized preexisting ones.

1. Introduction

It has been pointed out by many workers that the issue of thermal water is closely related to the geologic structures. However, only a few of this type of research have been published to date. According to NAKAMURA (1962), in the northern Izu Peninsula, the hot springs have a tendency to be issued from the NNE-SSW trending fissures. These "fissures" presumably belong to one of a conjugate set of active faults. TANI (1969) remarked that the distribution of hot springs in Northeast Japan is related to the major tectonic lines, the Morioka-Shirakawa line, the Akita-Sakata line, and so forth. In a recent paper, SUGIYAMA (1980) suggested that many hot springs in Japan exist at the point of intersection of two or more anticlines.

Northeast Japan which is a part of the so-called "Green tuff" region is typified by a dominance of volcanic rocks in an intensively deformed environment. A large number of hot springs are distributed in that region. Most of them can be explained as the results of the volcanism during Quaternary, or rather late Neogene. In addition, the occurrence of these hot springs seems to be closely related to the Quaternary crustal movement.

The study has revealed that the hot springs distributed in the southwestern part of Miyagi Prefecture have a close association with the fault system of a specified direction, that is a group of NNE-SSW trending faults which are considered as preexisting faults to be reactivized during Quaternary. The faults which exist in two hot spring areas, Obara-Kamasaki and Akiyu, were studied on the basis of field analysis. The Obara-Kamasaki area is located in the southern Miyagi Prefecture, several kilometers north of the Miyagi-Fukushima prefectural border. The Akiyu area is located about 15 kilometers west of Sendai. In this paper, the

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author discusses a few points about the relationship between the geologic structures and the hot springs. For further details of the stratigraphic works in those areas, the reader should refer to KITAMURA and FUKUDOME (1979) and KITAMURA, FUKUDONE and KUROMARU (1979).

2. Outline of geology

2.1 Obara-Kamasaki spa area

The geologic sketch map of this area is shown in Fig. 1. The Neogene and Pleistocene deposits in this area are divided into five strata which are the Hachimoriyama Andesites, the Akaihata Formation, the Aketo Formation, the Ezokura Formation and the Zao Volcanic Products in ascending order.

The Hachimoriyama Andesites consist of lava and pyroclastic rocks of pyroxene andesite and hornblende andesite. The total thickness exceeds 700 meters. Volcanic breccia of pyroxene andesite is dominant. Lava occurs as block or clinker-like lava flow. The thickness of each flow unit is less than 10 meters. A groundmass of the andesite shows glassy or hyalopilitic texture. In the southern part of this area the rocks are relatively fresh, while, in the northern part they have been undergone a moderate alteration. To the west of the Kamasaki Spa, the bed contains some pebbles of granitic rocks derived from the pre-Tertiary basement. Volcanic and sedimentary environment of this formation, at least the upper part, may be regarded as of submarine.

The Akaihata Formation, conformably overlying or interfingering with the Hachimoriyama Andesites, is a marine deposit. It is composed of siltstone, andesitic lapilli tuff and medium to coarse grained sandstone. The formation has a maximum thickness of 450 meters. Siltstone is massive as a whole, but partly becomes well-bedded and shaly. Lapilli tuff alternating with siltstone is lithologically similar to that of the Hachimoriyama Andesites. Sandstone is made up of well-rounded clastic material derived from the Hachimoriyama Andesites. The sandstone is dominant in the southern part of this area, and yields abundant invertebrate fossils indicating a shore reef condition. Composition of the molluscan fauna is correlative with that of the Moniwa fauna in the Sendai region. From the siltstone, *Globorotalia fohshi barisanensis* LeRoy which indicates the middle Miocene age was reported.

The Aketo Formation conformably overlies the Akaihata Formation, and partially interfingers with the Hachimoriyama Andesites. The estimated thickness is 400 meters. The formation consists mostly of acidic pyroclastic rocks as pumice tuff and alternation of fine tuff and crystal tuff, and is accompanied with a small quantity of rhyolite lava. Molluscan fossils obtained from the lower part of this formation show affinity to the Tsukinoki fauna in the Sendai region. Distinguished white pumice tuff, which is stratigraphically situated at about 50 meter above the base of the formation, is traceable as a key bed all over the area. After sedimentation of the Aketo Formation, a tectonic movement occurred on a remarkable scale and elevated this area, which is shown by a clinounconformity underneath the Ezokura Formation.

The Ezokura Formation consists mainly of dacitic fine tuff, pumice tuff and dacite lava, but contains thick volcanic mud flows and gravels in the northern exposures. The maximum

thickness is 250 meters. In general the rocks of this formation is loosely consolidated. The depositional environment seems to be of lacustrine and locally fluvial. The sedimentological features bear a close resemblance to that of the Shirasawa Formation west of Sendai.

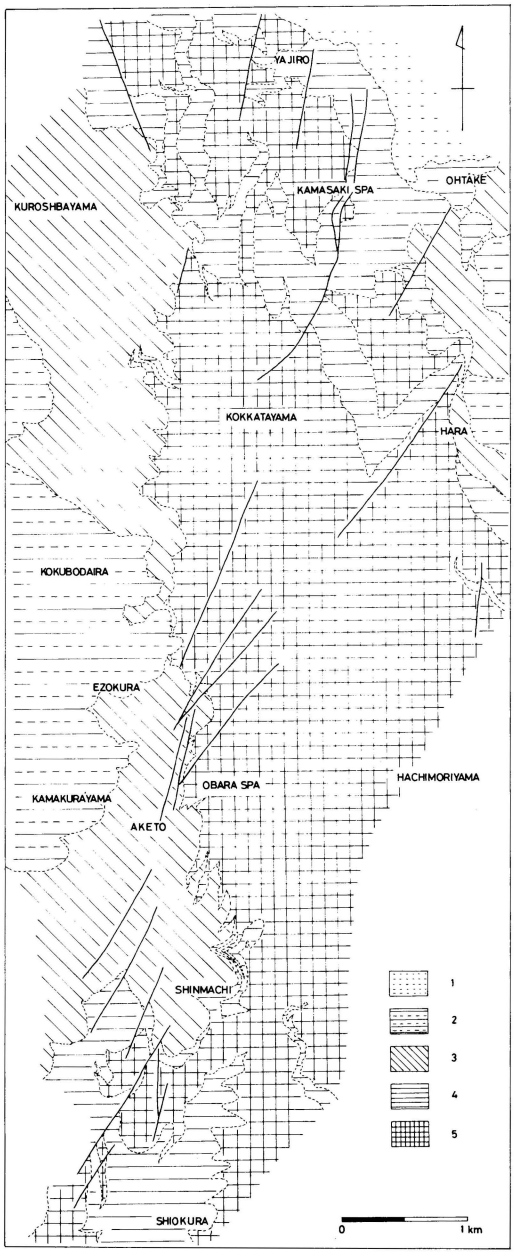

Fig. 1 Geologic sketch map of the Obara-Kamasaki spa area.
1. Zao Volcanic Products, 2. Ezokura Formation, 3. Aketo Formation, 4. Akaihata Formation, 5. Hachimoriyama Andesites.

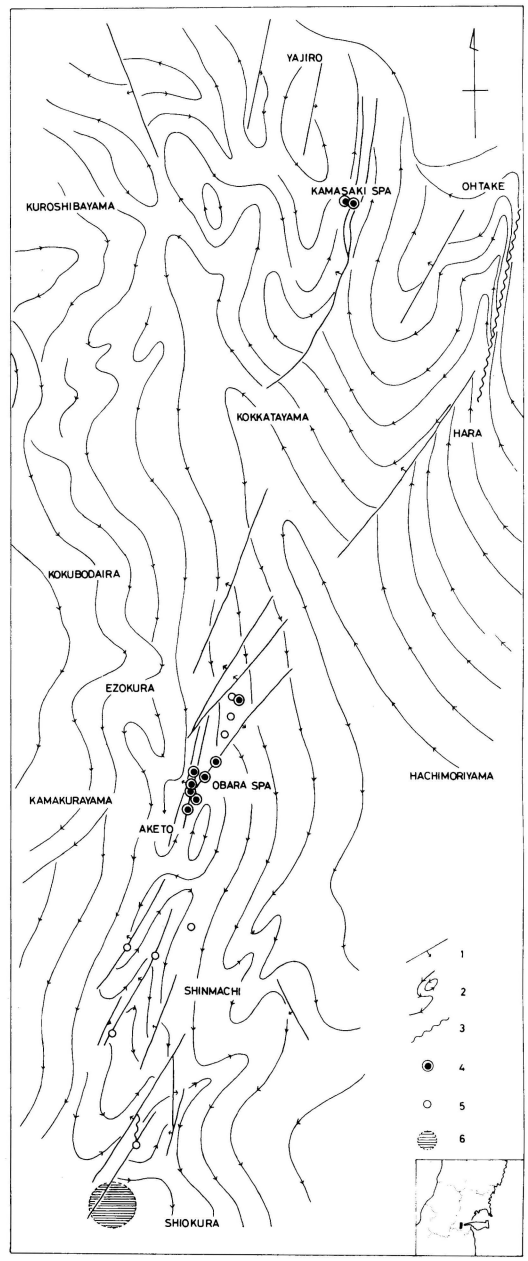

Fig. 2 Structural map of the Obara-Kamasaki spa area.
1. fault, 2. strike line, 3. axis of flexure, 4. hot spring, 5. point of thermal identification, 6. epicenter of earthquake in 1956.

The Zao Volcanic Products, widely distributed to the north, are composed of volcanic ash and mud flows, and form a nearly level slope.

2.2 Akiyu Spa area

The succession of the Neogene rocks in this area is established with several revisions as follows, in ascending stratigraphic order (see Fig. 3).

The Takadate Volcanics range in composition from rhyolite to basalt as a whole. In this area, they are composed chiefly of pyroxene andesite and its pyroclastic rocks, and rhyolite in lesser amount. The total thickness exceeds 300 meters. In the northwestern part of the area, the rocks have been undergone silicification and chloritization to varying degrees. Many drillings have also shown the existence of the andesites about 200 meters below the surface of the Akiyu Spa.

The Goishi Formation probably correlative with the Moniwa plus Hatatate Formations rests unconformably upon the Takadate Volcanics with a basal conglomerate. The estimated thickness is 120 meters. The lowest part of this formation consists of granule-bearing coarse to medium grained sandstone derived principally from the underlying andesite. The sandstones yield large quantities of molluscan faunas which indicate a neritic sea condition. The lower to middle part of the formation is made up of medium to fine grained quartzose sandstone, thus decreasing in grain size upward. The upper part is tuffaceous to some extent and contains some layers of pumice tuff. Both of the litho- and biofacies of this formation suggest a change in sedimentary environment from shallow to relatively deeper waters.

The Ozawa Formation which is mapped at the west edge of this area is composed of homogeneous, poorly stratified tuffaceous mudstone. The formation probably unconformably covers the underlying unit.

The Kamafusayama Dacite is composed mostly of hypersthene-hornblende dacite and its volcanic breccia. This dacite characteristically contains large phenocrysts of quartz, and locally becomes porphyritic. The formation unconformably lies on the Goishi Formation across a general trend of the Goishi Formation.

A typical facies of the Yumoto Tuff is light-brown, weakly welded dacitic pumice tuff, which is commonly called "Akiyu-ishi". The formation is as much as 170 meters in maximum thickness. The basal bed contains a great amount of exotic pebbles. In the lowest part, the deposits are well-stratified and cross-laminated, and contain some pisolites and irregular blocks of tuffaceous mudstone lithologically similar to the Ozawa Formation. The upper part becomes loosely consolidated and lighter colored. The formation interfingers with the Kamafusayama Dacite. The stratigraphic relation with the Takadate and Goishi Formations is in distinct clinounconformity. However, the relation with the Ozawa Formation is unsettled.

The Saikachinuma Formation, which is in a clinounconformable relation with the underlying formations, consists mainly of fine tuff and pumice tuff. The formation exceeds 100 meters in maximum thiekness. The fine tuff is well-stratified and yields well-preserved plant fossils indicating a cold-climatic condition. The lower part of the pumice tuff exhibits cross-lamination and slumping structures, and contains intruded clastic dykes of the fine tuff in some places. In appearance the pumice tuff resembles that of the upper part of the Yumoto Tuff. However, it is more poorly consolidated, and the essential blocks in this formation are

rhyolite in contrast with dacite in the Yumoto Tuff.

3. Geologic structures and their relation with the hot springs

3.1 Obara-Kamasaki Spa area

Major structure in this area is a northward plunging broad anticline with a NNW-SSE trend. Locally, wavy folding structures with short wave-length and small amplitude are formed as the result of the disturbance owing to the faulting. Especially, the western wing of

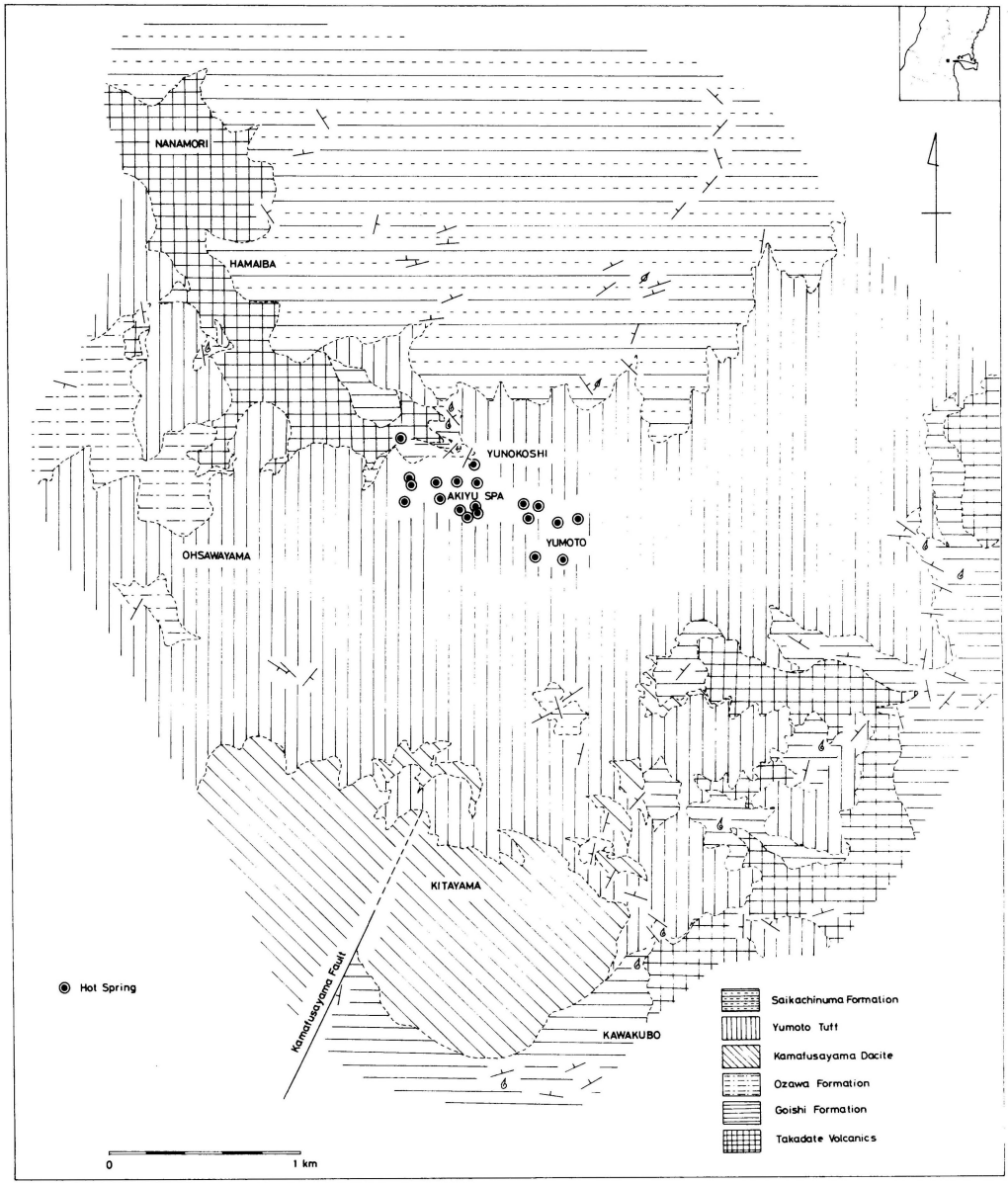

Fig. 3 Geologic sketch map of the Akiyu Spa area.

the broad anticline is modified to complicate forms by the second order folds and a shear zone with a NNE-SSW trend in later stage. It seems that this shear zone plays an important role in location of the orthogonal bend in the middle course of the Shiroishi River. As Fig. 2 shows, the shear zone extends over 10 kilometers and consists of ten and more strands, 1 or 2 kilometers in length, with a clockwise *en échelon* arrangement. Although for all the strands the sense of movement can not be determined in the field, some of them have reverse component. The anticlinal structure trending NE-SW which is genetically related to the formation of thrust fault is recognized on the hanging side of the fault. Therefore, it is interpreted that each strand is related to thrust shear caused by left-lateral transcurrent movement. Fig. 2 shows the relationship between the geologic structures and the distribution of hot springs in this area. The figure clearly shows that the hot springs are distributed along the strands of the shear zone. This is a typical example that the disposition of hot springs is controled by geologic structures. At the present day, it is impossible to see the evidence that the hot springs directly gush out from the fracture zone of the strands at the resort area of the Obara and Kamasaki Spas, because of ill-exposure by capping or buildings. However, at another two places the evidence that the hot water has been issued from the fracture zone of the strands can be observed. One is at the point of 300 meters lower reaches of the Shiroishi River from the water inlet of the Zao Power Station; the other is at the point of about 700 meters north of Shiokura. In the later outcrop, the thermal identification is still recognized. The warm water extrudes from the fissures in the lapilli tuff of the Hachimori-yama Andesites and forms a muddy precipitate in the river. Thus, the hot springs in this area well out along the strands with a NE-SW trend. In the northeast edge of this area, a flexure structure trending NNE-SSW has been formed. It seems to show the same character of movement as the shear zone described above.

In 1956, an earthquake of M 6.1 was took place in this region. The epicenter was estimated in the vicinity of Shiokura (Fig. 2), which corresponds to a extension of the shear zone. Therefore, it is possible that the shear zone is still "active".

The spots of high density of Hg and CO_2 which indicate a possibility of the reservoir of the thermal water are observed by WATANABE *et al.* (1979) to the south of the Obara Spa where we also expect its occurrence from the afore mentioned point of view.

As illustrated in Fig. 4, all the hot springs of the Obara, the Kamasaki, the Tokkata and the Sakunami spas distributed in the southwestern part of Miyagi Prefecture lines up in a straight line with a nearly N-S trend. The Sakunami Spa occurs along a reverse fault trending NNE-SSW, *i.e.* the Sakunami fault, as well as the Obara and Kamasaki Spas. The Sakunami fault has been activated during late Quaternary (AMANO, 1980). I can presume the existence of a major tectonic line here, and each fault is regarded possibly as the secondary fault of this tectonic line. The major tectonic line might be formed by upheaval of the Backbone Ranges during Quaternary. Incidentally, the Aone and Joge Spas are also situated at the extension of the Sakunami Fault.

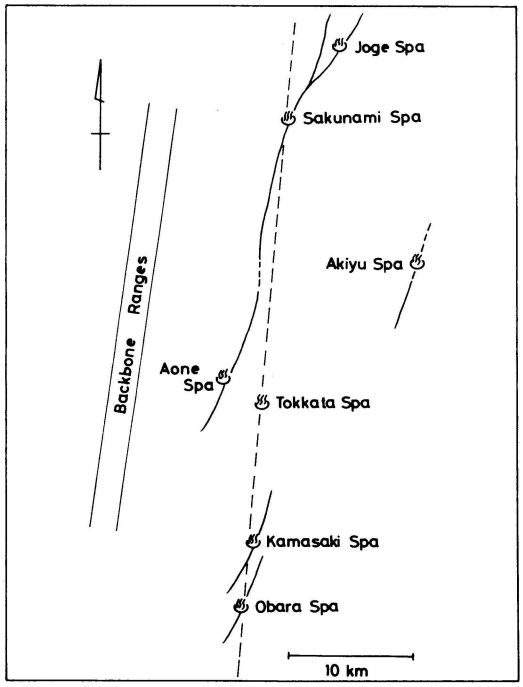

Fig. 4 Distribution of hot springs and fault system in the southwestern part of Miyagi Prefecture.

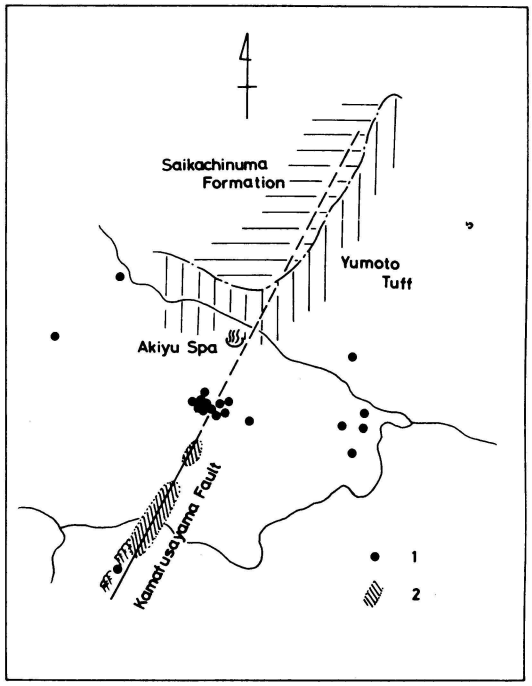

Fig. 5 Structure and seismic activity along the Kamafusayama fault.
1. epicenter of small earthquakes, after TAKAGI *et al.* (1970) and SASAKI (1975).
2. hydrothermal alteration zone.

3.2 Akiyu Spa area

Geologic structure of this area is very gentle and the Neogene formations generally lie in nearly flat, though several unconformable relations have been observed with uneven surfaces. Only the Kamafusayama fault trending NNE-SSW disturbs this gentle structure. The Takadate Volcanics and the Goishi Formation have the NE-SW trending synclinal structure with low dips. A remarkable structural gap exists between the Yumoto Tuff and the underlying units. The Saikachinuma Formation is situated in the southern margin of the volcano-tectonic-depression, called "Paleo-Sendai lake".

The Kamafusayama fault well-exposed between the Kamafusayama Dacite on the west and the Goishi Formation on the east at the western corner of this area indicates relative uplift of the east block. The fault plane is vertical with fault clay of 1 meter wide, but can not be traced as far as the Akiyu Spa. However. a number of joints and clastic dykes with a N-S or NE-SW trend were observed in the Yumoto Tuff. The boundary between the Yumoto Tuff and the Saikachinuma Formation changes abruptly its direction from WNW-ESE to NNE-SSW and becomes rectilinear along a presumed extension of the Kamafusayama fault, as seen in Fig. 5. It is assumed that the east block have been elevated against the west block to form this structure, and the sense of displacement is in agreement with the outcrop observation mentioned above. In addition, the results of geophysical survey by

YOKOYAMA (1979) suggest the existence of a fault with the direction of NNE-SSW through the Akiyu Spa area. Consequently, it can be considered that the Kamafusayama fault extends beneath the Akiyu hot spring swarm, though the fault plane itself may be concealed under the Yumoto Tuff. The distribution of the hydrothermally altered white clay, almost composed of montomorillonite-sericite mixed-layer minerals, is well coincided with the presumed extension of the fault. This fact also indicates the presence of the concealed fault under the Yumoto Tuff.

Recent seismic activity along this fault supports the above-mentioned interpretation. Since 1970, the Akiyu Spa and its vicinity have been shaked in several times by small earthquakes (TAKAGI, *et al.*, 1970; SASAKI, 1975MS). Some of them took place just below the presumed extension of the Kamafusayama fault as is evident from Fig. 5. In the eastern margin of the Backbone Ranges, the well-known active fault (*e.g.* the Nagamachi-Rifu and Sanbongi faults, the Western marginal fault of the Fukushima Basin, etc.) are thrust and have a NE-SW strike. Therefore, it is possible that the Kamafusayama fault is also "active" and the hot water plays the important role in the generation of the earthquake in such a place. As another example of the earthquake at the hot spa area, the Narugo Earthquake in 1976 is noted.

It is concluded that the underground geothermal water which supplies the hot springs on the surface may be preserved along the Kamafusayama fault and its accompanied joints or fissures which are mainly formed in the formations below the Yumoto Tuff.

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References

AMANO, K. (1980): Geology of the Ou Backbone Ranges in Miyagi and Yamagata Prefectures, Northeast Honshu, Japan. *Tohoku Univ., Inst. Geol. Pal., Contr.*, no. 81, p. 1-56.**

KITAMURA, N. ahd FUKUDOME, T. (1979): Geology of the area around the Obara and Kamasaki spa, Miyagi Prefecture, Japan. *In* Hot Springs of Shiroishi City, Miyagi Prefecture, p. 50-64.**

————, ———— and KUROMARU, T. (1979): Geological studies on hot springs of Akiyu district, Miyagi Prefecture. *In* Hot Springs Akiyu-machi, Miyagi Prefecture, p. 85-127.**

NAKAMURA, H. (1962): Report on the geological studies of hot springs in Japan. *Rept. Geol. Surv. Jap.*, no. 192, p. 1-128.**

SASAKI, S. (1975MS): Development of long-range and small sized observation system of small earthquakes: an example in the southwest of Sendai. Tohoku Univ., Inst. Geophys., Master Thesis.*

SUGIYAMA, R. (1980): Hot spring geology: structural control of thermal springs (abstract). *Geol. Soc. Jap.*, p. 5-8.*

TAKAGI, A., MINENAGA, O., MISHIMA, M., YASUMURA, M. and MATSUZAKI, K. (1970): The extremely small earthquakes in Kamafusa, Miyagi Prefecture (abstract). *Seismol. Soc. Jap.*, no. 2, p. 9.*

TANI, M (1969): On the relation between the distribution of hot springs and geostructures in Northeast Japan. *Chinetsu*, no. 19, p. 8-16.**

WATANABE, A., SUZUKI, K. and HACHIYA, E. (1979): Geochemical stdies on hot springs Obara and Kamasaki, Miyagi Prefecture. *In* Hot Springs of Shiroishi City, Miyagi Prefecture, p. 1-18.**
YOKOYAMA, H. (1979): Geophysical studies on hot springs of Akiyu, Akiyu-machi, Miyagi Prefecture. *In* Hot Springs of Akiyu-machi, Miyagi Prefecture, p. 36-84.**

* *in* Japanese
** *in* Japanese with English abstract

東北日本における温泉の構造規制の二・三の例

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要旨

宮城県西南部に分布する温泉のうちいくつかは，成因的にＮＮＥ－ＳＳＷ系の断層と密接な関係をもっている。温泉はこれらの断層に沿って湧出しているものと思われる。小原一鎌先温泉地域では，断層剪断帯は左横ズレ運動によって生じた時計回りの雁行状配列をなす10数条の逆断層性 strand から構成されている。秋保温泉地域では，断層は伏在しつつも，その延長は温泉群の直下を通る。両地域では最近地震活動が起こっている。従って，これらの断層群は古キズが再発した活断層の可能性がある。

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