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MULTIPLE HYDROTHERMAL ACTIVITIES IN THE OKUAIZU GEOTHERMAL SYSTEM, JAPAN

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SUMMARY

Hydrothermal alteration around the Okuaizu geothermal system was studied in the field and by microscope observation, X-ray diffraction and the calculation of saturation conditions for the alteration minerals based on previously reported analytical data of the geothermal fluid. Three stages of hydrothermal alteration were recognized : 1) middle Miocene submarine hydrothermal alteration, 2) late Miocene caldera-related hydrothermal alteration, and 3) hydrothermal alteration by the present Okuaizu geothermal system.

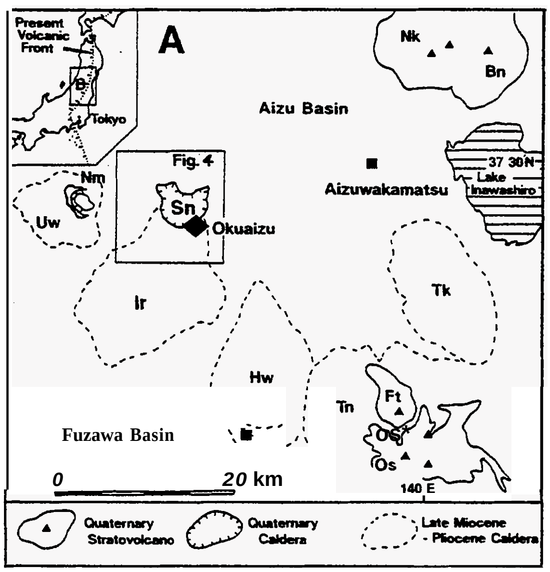

Figure 1. Regional location map. Sn : Sunagohara caldera (Pleistocene), Ir : Iriyamazawa caldera (late Miocene) and Nm : Numazawa volcano (active 5000 ago) (after Yamamoto, 1992)

1. INTRODUCTION

Okuaizu geothermal system, located in Fukushima prefecture, northeast of Honshu island, has been explored from 1974 by New Energy Development Organization (NEDO) and the Okuaizu Geothermal Co. Ltd. (OAG) (Fig. 1) . After drilling 43 wells including exploration, production and re-injection, the OAG installed 65 MW power station and started commercial operation in May, 1995 (Nitta et al., 1995). During exploration of this system, no complete explanation of the alteration has been done. Nitta et al. (1987) recognized that two stages of hydrothermal alteration, one which is related to Miocene submarine hydrothermal activity and the other which is related to present day geothermal activity. This paper presents the results a mineralogical study of surface and subsurface alteration of this area, and reveals that multiple hydrothermal activities took place in this area from the middle Miocene to recent age.

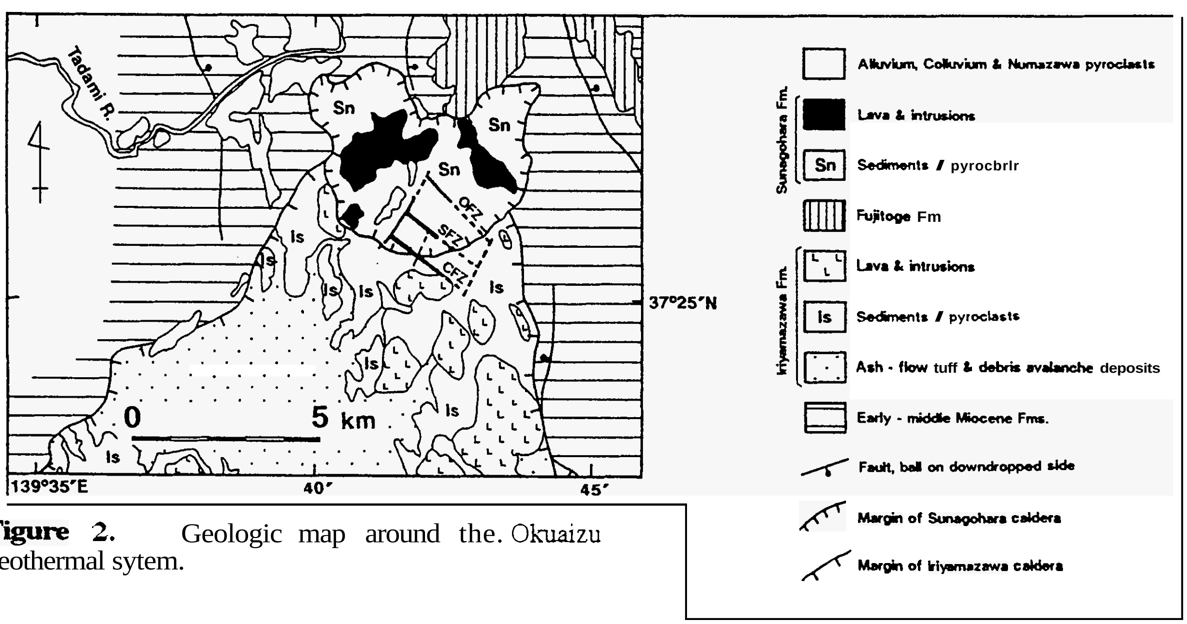

Figure 2. Geologic map around the Okuaizu geothermal sytem.

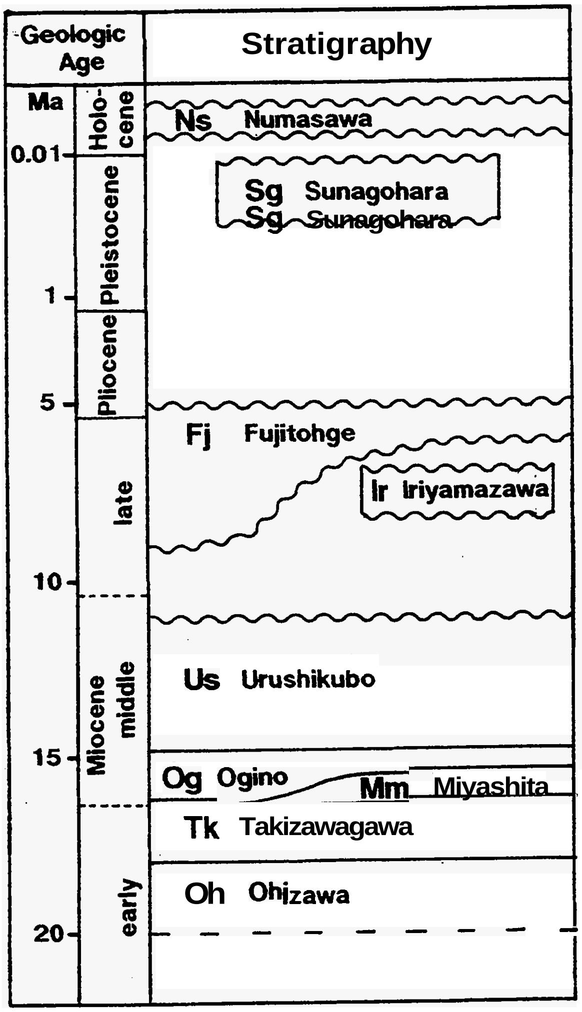

Figure 3. Stratigraphy of the **Okuaizu** area.

2. GEOLOGY

2.1 GENERAL GEOLOGY

The Okuaizu area is located in the "Green Tuff region" which is characterized by intense Neogene submarine volcanic activity, and is about 50 km back-arc side of the present volcanic front parallel to Japan trench (Fig. 1). The nearest Quaternary volcano, Numazawa-kazan is about 10 km west and was active about 5000 years ago (Kato et al., 1984 ; Fig. 2). The basement is thought to be pre-Tertiary granodiorite and/or sedimentary rocks. Early to middle Miocene formations (O-hizawa, Takizawagawa, Ogino and Urushikubo Formation) consisting mainly of rhyolitic to dacitic lavas, pyroclastic rocks intercalated with clastic rocks, and minor basaltic rocks, are considered to unconformably overlie the basement (NEDO, 1985 ; Nitta et al., 1987 ; Fig. 3). The late Miocene caldera related Iriyamazawa Formation which consists of dacitic ash flow tuffs, debris avalanche deposits and lake sediment, unconformably overlies the early to middle Miocene formations (Yamamoto, 1992). Pleistocene lacustrine sediments (Sunagohara Formation) and rhyolite lava domes (Yunotake Rhyolite), which formed in a caldera environment, unconformably cover Miocene formations (Komuro, 1978 ; Mizugaki, 1993 ; Figs. 2 & 3).

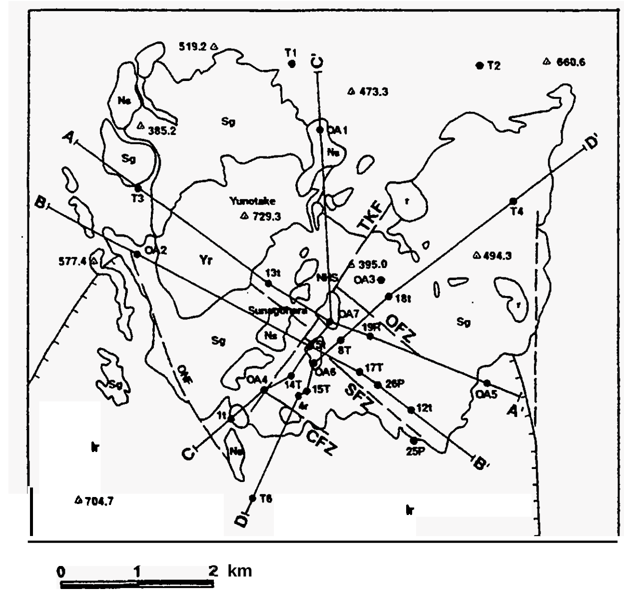

Figure 4. Map showing location of geothermal wells (including exploration, production and re-injection), major fracture zones and cross-secton lines, and distribution of the Sunagohara Formation (Sg and Yr). CFZ : Chinoikezawa fracture zone, SFZ : Sarukurazawa fracture zone, and OFZ : Oizawa fracture zone in the Okuaizu geothermal system.

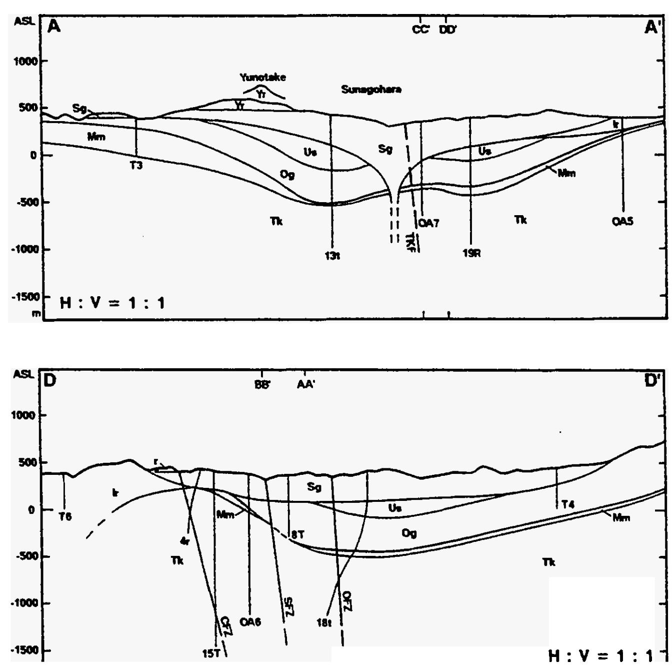

Figure 5. Geologic cross sections along the lines showed in Fig. **4.** Ns : Numazawa ash flow tuff, Sg : Sunagohara Formation (Yr : Yunotake Rhyolite),

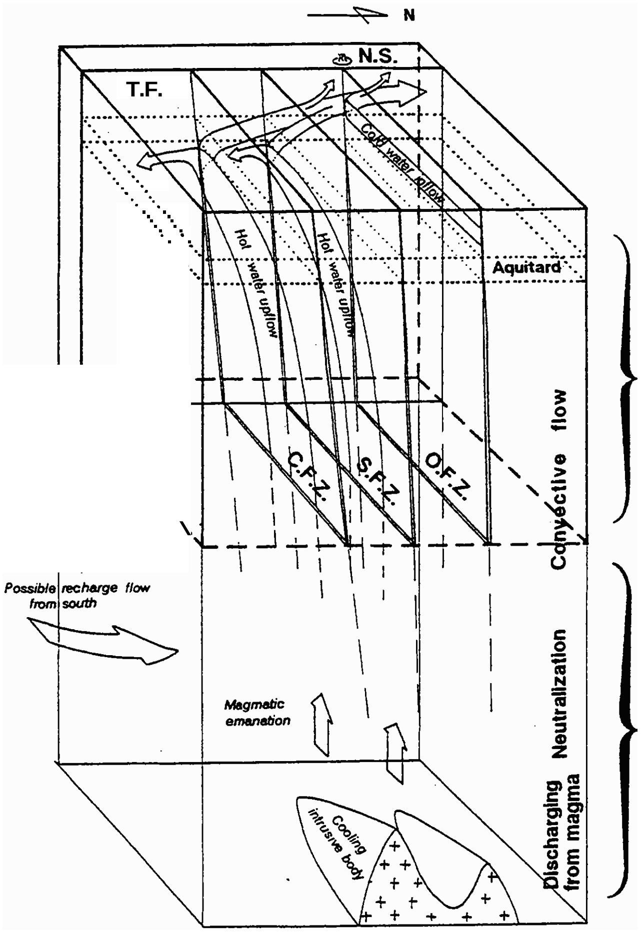

Figure 6. Structural and fluid flow model of the Okuaizu geothermal system. Abbreviations are the same as in Fig. 4 (Seki, 1991).

2.2 GEOLOGY AND HYDROLOGY OF THE OKUAIZU GEOTHERMAL SYSTEM

The uppermost portion of the geothermal system lies in the Quaternary caldera structure which is 5 km in diameter (Sunagohara caldera ; Figs. 4&5). The age of this caldera was estimated at 0.5 to 0.2 Ma (NEDO, 1985). The rest of the system is within the Takizawagawa and other Miocene formations (Nitta et al., 1987).

The hydrology of the system is strongly controlled by the steeply dipping open-space fracture system (Fig. 6). The production area is composed of two major parallel fracture zones called the Chinoikezawa and Sarukurazawa fracture zones, which strike NW, and dip 76 and 83 NE, respectively (Nitta et al., 1987 ; Figs. 4&5). The temperature of the production zones ranges between 280 and 340 C (Ohga, 1992). Another major fracture zone called the Oizawa fracture zone is located about 1 km NE of the Sarukurazawa fracture zone and strikes NW and dips 87 NE (Figs. 4&5). Because the temperature of this zone is more than 100 C lower than that of production zones, the Oizawa zone is used for reinjection (Nitta et al., 1995).

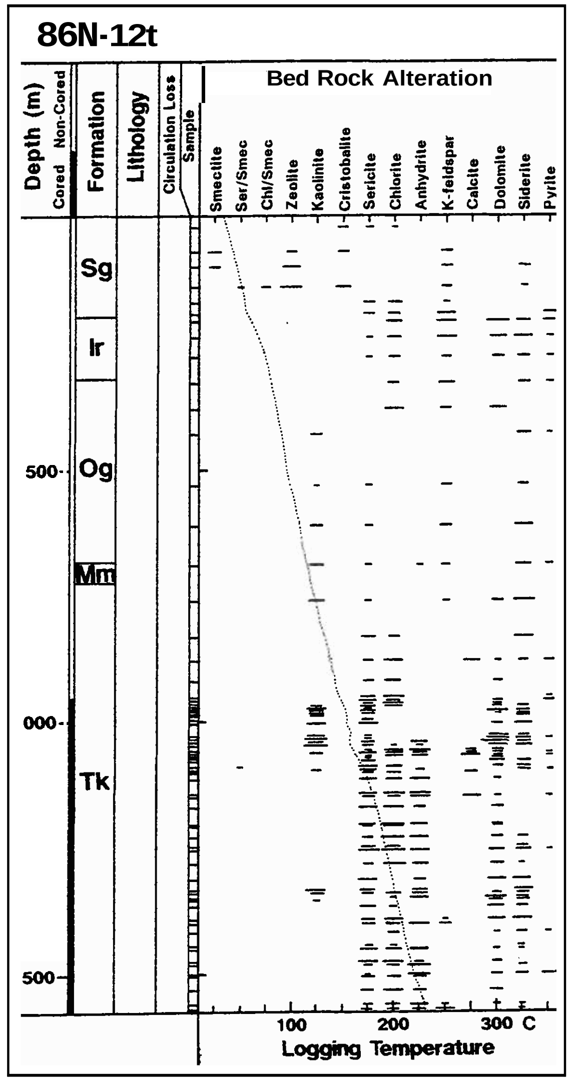

Figure 7, Alteration mineralogy of exploration well 86N-12t.

3. HYDROTHERMAL ALTERATION

3.1 GENERAL DISTRIBUTION PATTERN OF ALTERATION MINERALS

Argillic to advanced argillic alteration occurs at shallow levels of the geothermal system. The alteration minerals of the argillic zone comprise of smectite, interlayered sericite-smectite, kaolinite, zeolite and K-feldspar. Advanced argillic alteration, composed mainly of smectite and mordenite, with minor sericite, kaolinite and alunite appears locally near the Sarukurazawa fracture zone. Anhydrite is widespread in the deeper part of the system, where temperatures are greater than 100 to 200 C. Although chlorite-sericite alteration has affected the greater part of the bedrock in the middle to deeper portion of the geothermal system, it occurs only in the Takizawagawa Formation, a distance from the geothermal system. Carbonate minerals observed around the geothermal system include calcite, dolomite, siderite, kutnahorite, ankerite and rhodocrosite. Well 86N-12t shows a typical distribution pattern of the alteration minerals in this system (Fig. 7).

3.2 ALTERATION MINERALS RELATED TO PARTICULAR FORMATIONS

Several alteration mineral assemblages are recognized in the Takizawagawa and the Iriyamazawa Formations.

Takizawagawa Formation : Chlorite-sericite alteration is ubiquitous within and outside the present geothermal system, except for the sporadic appearance of kaolinite in place of chlorite at various levels inside the geothermal system. The other Miocene formations except the Iriyamazawa Formation do not have chlorite-sericite alteration outside the geothermal system.

Iriyamazawa Formation : Chlorite and sericite, or interlayered chlorite-smectite and sericite commonly occur in the dacitic ash flow tuff of the Iriyamazawa Formation. Mordenite +/- smectite appears in the lake sediments in the shallower portion of this formation.

3.3 ALTERATION MINERALS OBSERVED IN THE PRESENT GEOTHERMAL SYSTEM

Rock alteration : Chlorite-sericite alteration is quite common in the deeper portion of the system. Anhydrite is also a common pervasive alteration mineral in the deeper portion around the reservoir. Kaolinite-sericite alteration sporadically appears in various levels. Mordenite, K-feldspar +/- smectite +/- cristobarite assemblage is common in the shallower portion of the geothermal system where rhyolitic tuff and tuffaceous siltstone of the Sunagohara Formation are distributed.

Veins : *An* assemblage of quartz, anhydrite +/- sericite +/- rhodocrosite +/- sulfide minerals such as pyrite, sphalerite, galena and chalcopyrite is common in the reservoir depth. Some form within ordinal fracture filling veins, and others are present as euhedral to subhedral mineral aggregates in open-space fractures. Early quartz-sericite veins with ambiguous selvages are common in deeper portions within and outside the geothermal system. A small amount of carbonate +/- zeolite veins occur at shallower portion of the geothermal-system.

4. MULTIPLE HYDROTHERMAL ACTIVITIES

Alteration at the Okuaizu geothermal district is of three main types : middle Miocene submarine hydrothermal alteration, late Miocene caldera-related hydrothermal alteration, and hydrothermal alteration occurred in the present geothermal system.

4.1 MIDDLE MIOCENE SUBMARINE HYDROTHERMAL ALTERATION

Middle Miocene submarine hydrothermal alteration is widespread in dacitic to rhyolitic volcanic and pyroclastic rocks in the Aizu district, which include the Okuaizu geothermal system (Hayakawa et al., 1977). Alteration minerals produced in this stage are mainly chlorite and sericite, which are almost ubiquitous in the Takizawagawa Formation within and outside the present geothermal system.

4.2 LATE MIOCENE CALDERA-RELATED HYDROTHERMAL ALTERATION

Hydrothermal alteration is recognized in the Iriyamazawa Formation which was deposited in the Iriyamazawa caldera, 20 x 15km in diameter. This caldera is filled by dacitic ash flow tuff, debris avalanche deposits and post-caldera lacustrine sediments, and its estimated age is 7.1 +/- 1.0 Ma (Yamamoto, 1992). Chlorite-sericite or interlayered chlorite-smectite and sericite alteration occurs in the Iriyamazawa Formation, spatially isolated from the zones of similar alteration in the Takizawagawa Formation and the deeper portion of the present geothermal system. This alteration in the Iriyamazawa Formation is thought to be the product of a hydrothermal system driven by heat source under the Iriyamazawa caldera which erupted voluminous ash flow tuff. Mordenite +/- smectite also occurs in the lake sediment in the upper part of the caldera, even in a distance from the Okuaizu geothermal area.

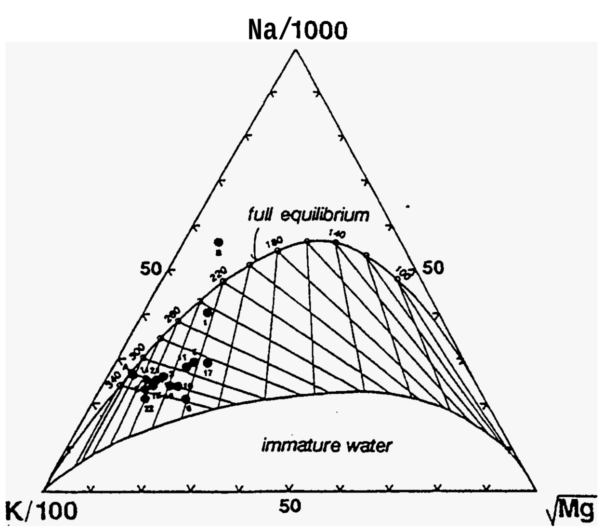

Figure 8. Na-K-Mg diagram of separeted water from prodction wells (Seki, in press).

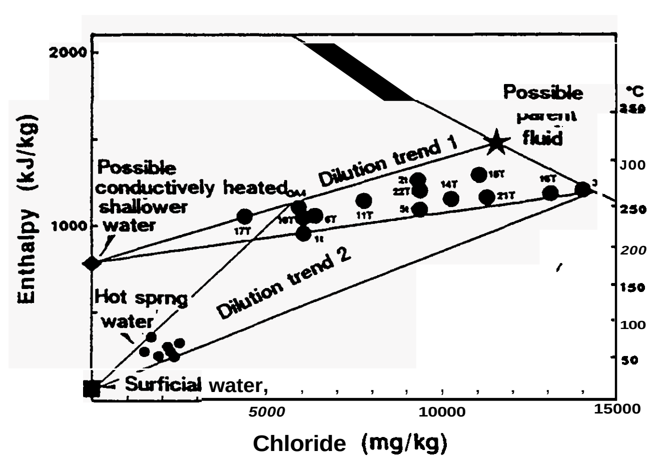

Figure 9. Chloride-enthalpy diagram for calculated reservoir fluid (Seki, 1991).

4.3 RECENT HYDROTHERMAL ALTERATION AND MINERALIZATION

Argillic to advanced argillic alteration at shallow levels, chlorite-sericite alteration in the middle to the deeper levels and anhydrite at deeper levels, sporadic appearance of kaolinite-sericite alteration, and several types of carbonate minerals occurring in places in various levels of the Okuaizu area are all thought to be products of the recent geothermal activity.

The chemical compositions of the geothermal wells plotted on Na-K-Mg triangular diagram (Giggenbach, 1988) show that the Okuaizu geothermal fluids are close to the full equilibrium line, which means almost full equilibrium is attained between geothermal fluids and alteration minerals such as feldspars and clays (Fig. 8).

Calculated mineral-fluid saturation conditions for the present reservoir fluids are : saturated with quartz, K-feldspar, plagioclase and anhydrite for all the production wells, sericite for most wells, undersaturated to oversaturated (saturation indices : -2 to 2) with kaolinite, slightly undersaturated (-1) with calcite for most wells, undersaturated to slightly oversaturated (-2 to 1) with siderite, undersaturated to oversaturated (-10 to 2) with chlorite, oversaturated (1 to 6) with pyrite (Seki, in press). The results of the calculations, together with the fact that quartz, anhydrite, sericite and pyrite exist in euhedral to subhedral form in the open-space fractures in the reservoir depth, indicate that those minerals are precipitated from the present geothermal fluid.

Sulfide scale deposition such as pyrrhotite, pyrite, sphalerite, galena, chalcopyrite and tetrahedrite in the exploration well 84N-2t (Imai et al., 1988), and gold and silver deposition with several base metal sulfides in the surface pipeline in the production well 87N-15T (Nitta et al., 1991) also indicate that the geothermal fluid is almost saturated with those heavy metal sulfides and precious metals.

Argillic alteration and advanced argillic alteration are formed in the shallower zones by steam heated waters of the present geothermal system. Sporadic appearance of kaolinite-sericite is probably formed in the zones of local boiling. Calcite existing immediately below the level of kaolinite appearance (1000 m depth) in the well 86N-12t may indicate local boiling bad occurred in the deeper level. Chlorite-sericite alteration is formed in the zones of neutral-pH, high chloride geothermal fluid in the deeper levels of the present system (Fig. 9).

5. CONCLUSIONS

Three stages of alteration have been documented at the Okuaizu geothermal district : 1) middle Miocene submarine hydrothermal alteration, 2) late Miocene caldera-related hydrothermal alteration, and 3) hydrothermal alteration under the present geothermal system. Spatial distribution of the three stages of alteration around the Okuaizu geothermal system is shown in Figure 10.

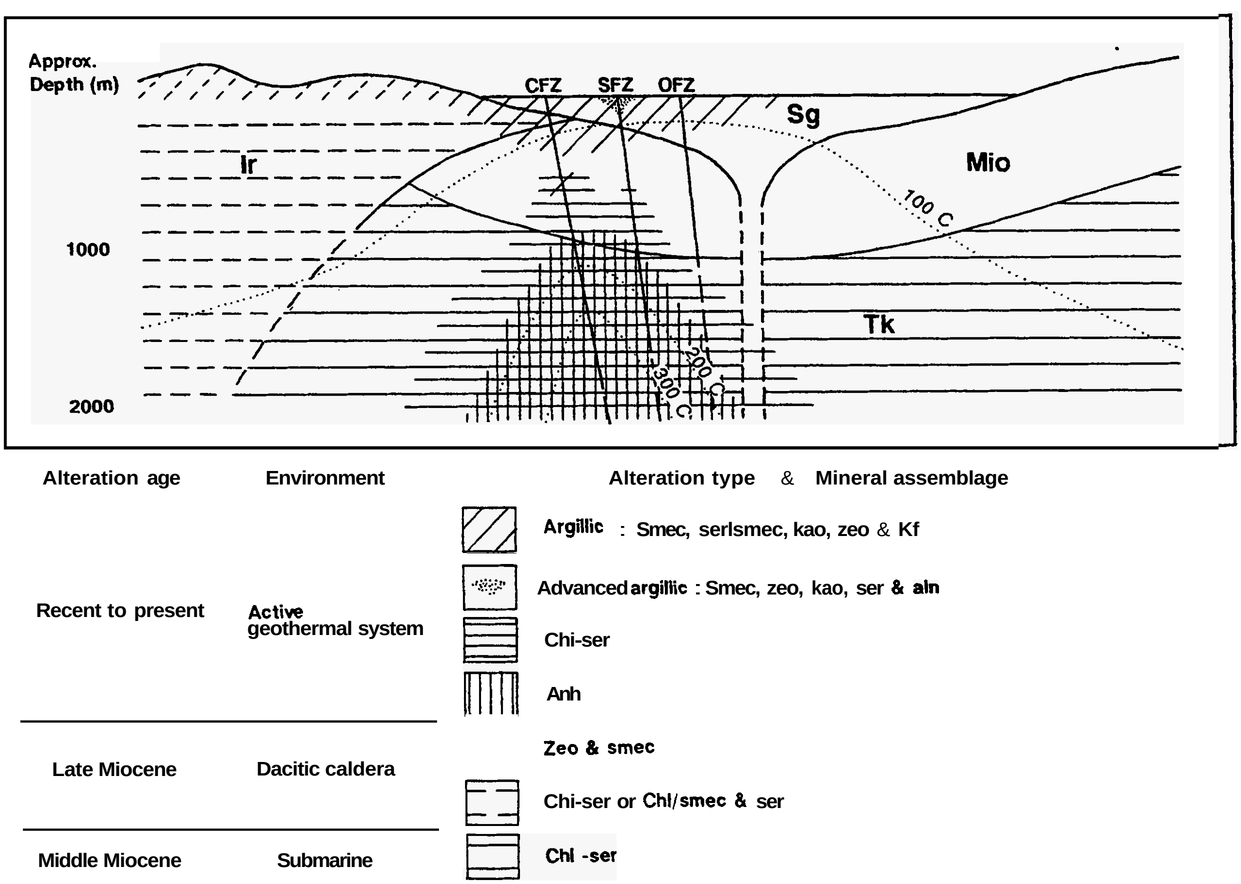

Figure 10. Generalized cross section showing the alteration ages, types and mineral assemblages.

Alteration 1) is characterized by a widespread chlorite-sericite assemblage in middle Miocene silicic volcanic and pyroclastic rocks within and outside the Okuaizu geothermal system. Alteration 2) is limited to the Iriyamazawa Formation formed at 7 Ma. The alteration assemblage consists of chlorite-sericite or interlayered chlorite-smectite and sericite in the dacitic ash flow tuff in the lower part, and zeolite +/- smectite in the lake sediment in the upper part of the caldera. Alteration 3) occurs in the present Okuaizu geothermal system. Argillic alteration consisting of smectite, interlayered sericite-smectite, kaolinite, zeolite and K-feldspar, and advanced argillic alteration consisting mainly of smectite and mordenite, with minor sericite, kaolinite and alunite occur in the zones of steam heated shallower groundwater. Anhydrite alteration occurs at the deeper levels with higher temperature. Chlorite-sericite alteration appears in the middle to the deeper levels with neutral-pH, higher temperature geothermal fluids. Kaolinite-sericite alteration sporadically appears in the zones of probable local boiling, and several types of carbonate minerals occur in places in various levels of the Okuaizu geothermal system.

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REFERENCES

Giggenbach, W. F. **(1988).** Geothermal solute equilibria : Derivation of Na-K-Mg-Ca geoindicators. ***Geochim. Cosmochim. Acta,*** Vol. **48, 2693-2711.**

Hayakawa, N., Suzuki, S. and Oda, Y. **(1977).** Diagenesis and hydrothermal alteration of the Neogene rocks in the Aizu district, Japan. ***Mining Geol.,*** Vol. **27,367-378** (in Japanese with English abst.).

Imai, H., Adachi, M. Takahashi, M. Yamaguchi, M. and Yashiro, K. **(1988).** Sulfide mineralization in Oku-aizu geothermal field, with the genetical relation to the epithermal gold deposits. ***Mining Geol..*** Vol. ***38,*** **291-301** (in Japanese with English abst.).

Kato, H., Awata, Y. and Shimokawa, K. (1984). ***Geol. Survey Japan 1 : 500,000 Neotectonic Map Sheet 7, Niigata***

Komuro, H. **(1978).** The formation of the late Miocene collapse basin at the Yanaizu district, Fukushima prefecture, Japan. ***Chikyuu Kagaku,*** Vol. **32, 68-83** (in Japanese with English abst.).

Mizugaki, K. **(1993).** Geologic structure and volcanic history of Sunagohara caldera volcano, Fuhushima, Japan. ***Jour. Geol. Soc. Japan,*** Vol. **99, 721-737** (in Japanese with English abst.).

New Energy Development Organization **(1985).** ***Geothermal development research report, no.8, Okuaizu region,*** **811p** (in Japanese).

Nitta, T., Adachi, M., Takahashi, M., Inoue, K. and Abe, Y. **(1991).** Heavy metal precipitation from geothermal fluids of 87N-15T production well in the Okuaizu geothermal field, Tohoku district, Japan. ***Mining Geol.,*** Vol. **41, 231-242** (in Japanese with English abst.).

Nitta, T., Suga, S., Tsukagoshi, S. and Adachi, M. **(1987).** Geothermal resources in the Okuaizu, Tohoku district, Japan. ***Chinetsu,*** Vol. **24, 26-56** (in Japanese with English abst.).

Nitta, T., Tsukagoshi, S., Adachi, M. and Seo, K. **(1995).** Exploration and development in the Okuaizu geothermal field, Japan. ***Resource Geol.,*** Vol. **45, 201-212** (in Japanese with English abst.).

Ohga, H. **(1992).** Drilling activities in the Okuaizu geothermal field. ***Chinetsu,*** Vol. **29, 203-221** (in Japanese with English abst.).

Seki, Y. **(1990).** Gas concentration in aquifer fluid prior to boiling in the Ohu-aizu geothermal system, Fukushima, Japan. ***Geochem. Jour..,*** Vol. 24, 105-121.

Seki, Y. **(1991).** The physical and chemical structure of the **Oku-aizu** geothermal system, Japan. ***Geochem. Jour.,*** Vol. **25, 245-265**.

Seki, Y. (in press). Geochemical characteristics of the Okuaizu geothermal system, Fukushima, Japan. ***Bull. Geol. Surv. Japan.,*** Vol. **47.**

Takeno, N. **(1988).** Manual of pH estimation and chemical speciation code (PECS) for geothermal fluid. ***Geol. Surv. Japan Open File Rep.,*** 49, 26p.

Yamamoto, T. **(1992).** Chronology of the Late Miocene - Pleistocene caldera volcanoes in the Aizu district, Northeast Japan. ***Jour. Geol. Soc. Japan,*** Vol. **98, 21-38** (in Japanese with English abst.).