

Case Study of the Change of Scale With Production

Norio Yanagisawa

Institute for Geo-Resources and Environment, Higashi, Tsukuba, Ibaraki, Japan
n-yanagisawa@aist.go.jp

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ABSTRACT

In geothermal field, the fluid geochemistry of several production well changed with operation of geothermal power plant. The change of fluid geochemistry affects to scale properties.

For example, the Kakkonda geothermal field, North-eastern Japan, several deep reservoir is developed until the boundary between Quaternary Kakkonda granite and Pre-Tertiary formations.

On progress of production the fluids from deep reservoir suffered by the fluid of shallow reservoir and meteoritic water. With temperature of production well decreasing and chemical composition changed, silica precipitation decreased and the metal sulfide mineral assemblage of scales of Well-13 changed from chalcocite (Cu_2S), loellingite (FeAs_2) and native antimony (Sb) to tetrahedrite ($\text{Cu}_{10}[\text{Fe,Zn}]_2[\text{As,Sb}]_4\text{S}_3$).

Introduction

Recently, several geothermal survey are progressing in Japan supported by JOGMEC and new geothermal development will start in the near future. According to new geothermal development, estimation of possibility of the scale precipitation is one of important issue. And in existing geothermal power plant, the situation of scale and corrosion at pipeline and wells change during operation due to the change of the reservoir condition and fluid geochemistry. This situation change is related to the operation cost, for example selection of inhibitor, pH adjust method and cleaning program of pipeline and plant.

If the estimation system of scale change exists, the system will supply cost saving to the operation. The development of estimation system is need for future geothermal development. And we start to review the change of scale at existing geothermal field.

In this paper, we show the case of scale change at Kakkonda geothermal field, Japan.

Kakkonda Geothermal Field

The Kakkonda geothermal field is located in the northern part of Honshu Island, where a liquid-dominated geothermal system has been utilized for power generation totaling 80 MW. And the Kakkonda geothermal system consists of two major reservoir layers.

The shallow reservoirs exist around 1,500 meters depth with weakly alkaline NaCl type and temperatures of 220 degree C.

Figure 1 show the geological section of Kakkonda geothermal field. The deep reservoirs exist about 2,800 meter depth near the boundary between Pre-Tertiary formations and the Quaternary granite acts as a heat source of the present

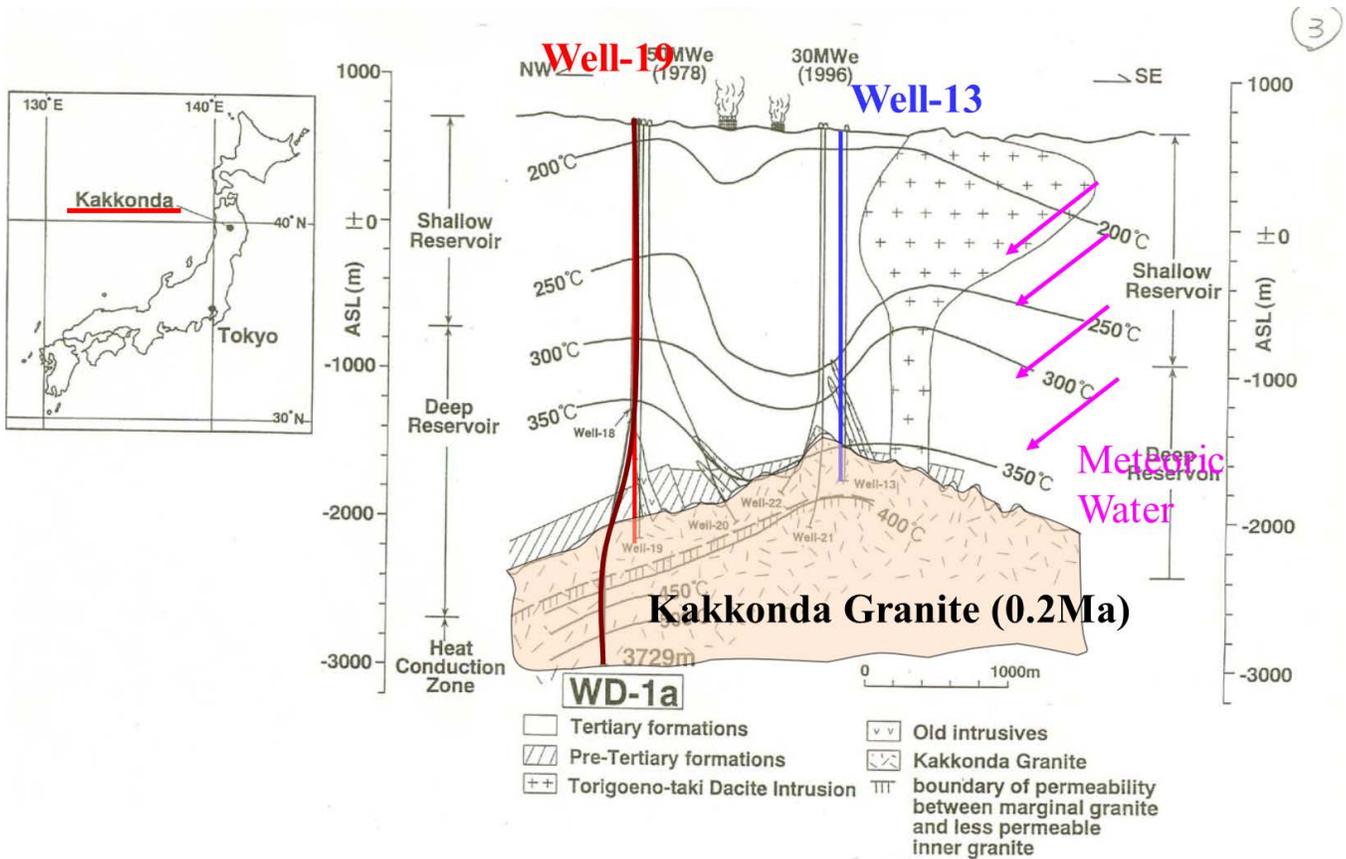


Figure 1. Schematic geothermal cross-section of the Kakkonda geothermal system along the Kakkonda river in a NE-SE direction (Modified from Kato et al., 1995).

geothermal activity with a fracture system (Doi et al. (1995)). The fluid from the deep reservoir is about pH 4, weakly acid NaCl type and has higher vapor/liquid ratio and higher enthalpy than that of the shallow reservoir (Yanagiya et al., 1996).

The higher enthalpy fluid with much dissolved silica causes the deposition of the scale in the pipeline. The scale deposited at first production test in 1993 mainly consists of amorphous iron-silica and sulfide (Yanagisawa et al., 2000).

NEDO conducted the deep-seated geothermal resources survey project at the Kakkonda geothermal field and the drilling of deep exploration reached at 3,729 meters depth and collected the hypersaline liquid in the Quaternary granite in 1995.

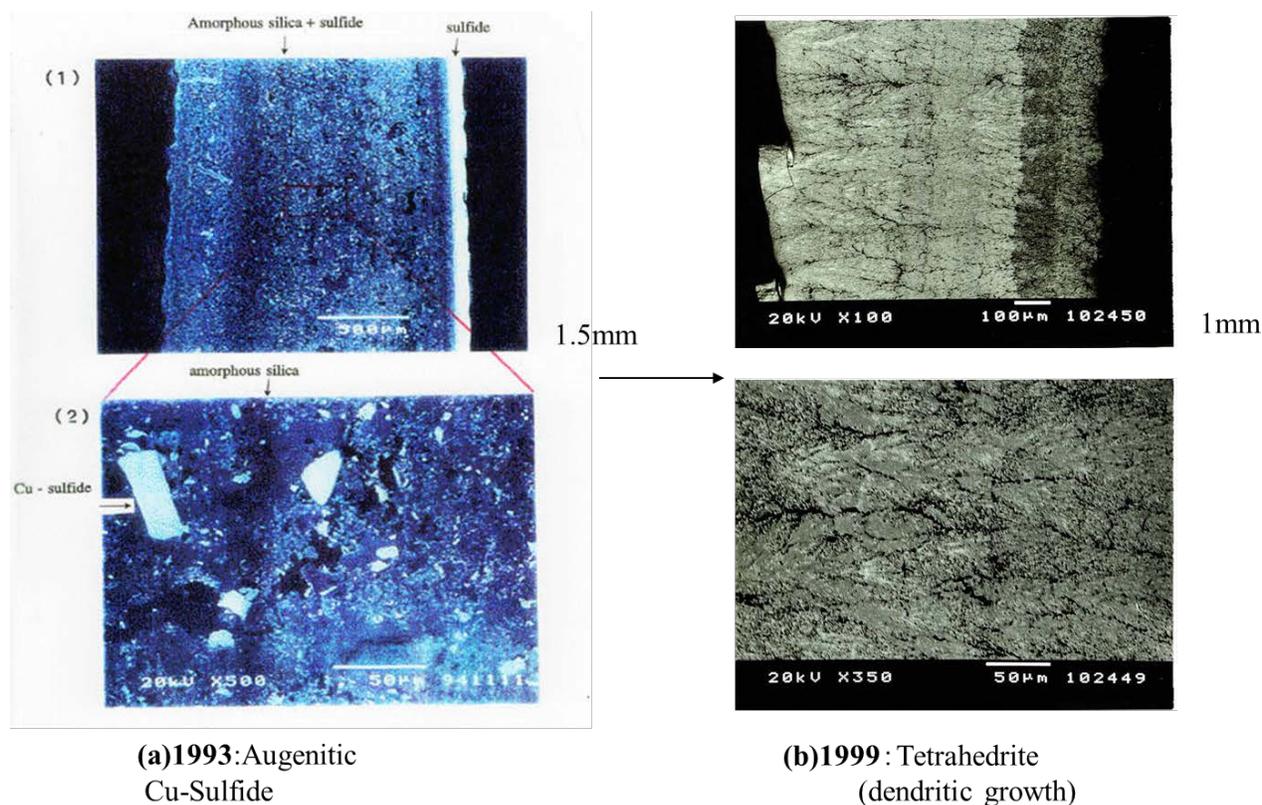
Firstly, the scale samples were collected for analysis at two production wells: Well-13 is at the central part of the Kakkonda granite; Well-19 is the marginal part of the Kakkonda granite at first production test in 1993. But in 1999, well-19 is partly damaged and pH rapidly changed. Then, the scale sample was collected from well-13, only. All scales were collected at production pipeline before separator.

The textures and mineral assemblages in scale samples were observed by a scanning electron microscope (SEM). And mineral species were detected by X-ray diffraction and chemical analysis was carried out by Inductively Coupled Plasma Emission Spectrometry (ICP-ES) method, ion chromatography and High-frequency burning infrared absorption method.

Scale Change at Well-13

Figure 2 show the photograph by SEM composite image of scales sampled at well-13 in 1993 and 1999. The blight area show the existence of metal sulfide and the dark area show the amorphous silica. The scale at Well-13 contains chalcocite (Cu_2S), bornite (Cu_5FeS_4) and loellingite (FeAs_2) as heavy metal minerals shown in blight area. Several minerals have 50 micron meter size and about 100 micron meter layer of sulfide on surface of scale. But the scales sampled in 1999, tetrahedrite ($\text{Cu}_{10}[\text{Fe,Zn}]_2[\text{As,Sb}]_4\text{S}_3$) exists as dendritic growth mineral and metal sulfide layer disappear. And scale thickness is about 1mm per year and slightly slower growth.

Table 1 shows the chemical composition change of the scale at Well-13 in 1993 and 1999. The Cu, Sb, Au, Ag and Zn are increased and especially sulfur is 6 times increased from 1993 to 1999 but As and Fe decreased from the first circular test in 1993. And silica composition of 1999 sample decreased about half of 1993 sample and the ration sulfide mineral increased from about 23 percent to 70 percent with production, and when sulfur content is normalized as 13 for



(a)1993:Augenitic
Cu-Sulfide

(b)1999: Tetrahedrite
(dendritic growth)

Figure 2. The photograph by SEM composite image of scales sampled at well-13 in 1993 and 1999.

Table 1. Chemical composition change of the scale at Well-13. These values are in percentage but from Au to Mn in ppm.

	SiO ₂	Al ₂ O ₃	FeO*	Cu	Pb
1st Prod.('93)	47.00	2.47	18.21	14.30	2.23
('99)	23.00	2.25	1.76	29.42	1.67
	Zn	S	As	Sb	
1st Prod.('93)	0.04	2.70	4.50	0.50	
('99)	6.28	18.00	2.51	16.40	(%)
	Au	Ag	Mo	Ba	Mn
1st Prod.('93)	19.4	550	490	46	780
('99)	2342	4950	41	28	13 (ppm)

Table 2. Metal contents of scales normalized as 13 for Sulfur

	Cu	Fe+Zn	As+Sb	S
Well-13(93)	34.7	35.1	9.9	13
Well-13(99)	11.4	2.4	4.2	13
Tetrahedrite	10	2	4	13

Table 3. Fluid composition of well-13 and shallow reservoir at 1991.

	pH	SiO ₂	Na	Cl
Well-13	3.7	920	946	1340
Shallow Reservoir	8.3	660	804	1260
		mg/l	mg/l	mg/l

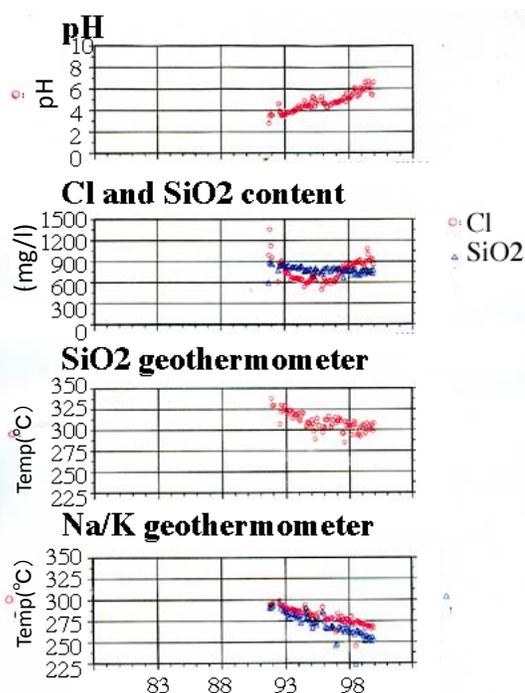


Figure 3. The change of pH, SiO₂ and Cl content, SiO₂ and Na/K geothermometry of Well-13 from 1991 to 1999.

tetrahedrite, metal contents shown in Table 2. From this table, in the scale sampled at 1993, sulfur is much smaller than the calculated one assuming all Cu and Pb are included in not only tetrahedrite but also chalcocite and galena both of which are detected by XRD. Such as native antimony and loellingite, not sulfide but metal element or metal composite of Cu or Pb may exist in this scale. Therefore in the scale sampled at 1999, sulfur exist enough for making tetrahedrite (Cu₁₀[Fe,Zn]₂[As,Sb]₄S₃).

Fluid Chemical Change at Well-13

Figure 3 shows the change of pH, SiO₂ and Cl content, SiO₂ geothermometry and Na/K geothermometry of well-13 from 1991 at first production test to 1999. From this figure, pH gradually increased from about 4 to 6. Cl content firstly decreased until 1996, but it increased from 600 to 1000 mg/kg after 1996. Si content gradually decreased. Temperature from geothermometry decreased about 30 to 50 degrees C in 6 years. Table 3 shows the fluid composition of well-13 and well from shallow reservoir at 1991. The shallow reservoir shows high pH about 8.3 and low SiO₂ concentration. Then, the trend in the Figure 3 show the deep reservoir gradually suffered by the fluid of the shallow reservoir. And this change influence to scale precipitation especially the decreasing of silica precipitation.

Relationship Metal Sulfide Scale With Deep Reservoir

During the deep-seated reservoir survey by NEDO, the hypersaline metal-rich liquid was obtained from a depth of 3,708m in WD-1a well of the Kakkonda geothermal system (Kasai et al., 1996). Sampling from WD-1a well was conducted by reverse circulation after a standing time of about 196 hours with temperature recovering to >500C. This original hypersaline liquid has a salinity of ca. 55 wt % NaCl eq., consisting of Na-Fe-K-Mn-Ca chloride, rich in Zn and Pb but poor in Cu, Au and Ag.

The scale of well-19 is Pb-Zn rich and similar to that of the liquid rich inclusion, brine of WD-1a with high salinity in Kakkonda granite. This observation suggests that the meteoritic water diluted the brine in the Kakkonda granite and deposits the Pb-Zn rich scale.

On the contrary, the origin of the Cu in Cu rich scale is not clear as the base metal contents of the geothermal fluid from Well-13 has not been analyzed. But the Cu rich brine might exist around Well-13 and it may be the source of Cu. Sasaki et al. (1998) mentioned that the vapor rich inclusion is slightly rich in Cu relative to polyphase inclusion in the granite in WD-1a. Considering that the geothermal fluid from Well-13 is originated from vapor rich environment. This idea is supported by the fact that the ratio of B/Cl and As of fluid of Well-13 is much higher than the other well fluids. (Yanagiya et al., 1996)

After several years' production, with the chemical change of fluid, the ratio silica is decreased due to lower temperature of production and the species of metal sulfide changed. But the ratio of the metal composition of scales of Well-13 is almost constant. Therefore, the deep reservoir of Kakkonda field evolve with mixing the fluid of shallow reservoir and the brine of occurred in the Quaternary Kakkonda granite suggested to have similar zoning to that found in Porphyry Copper deposit.

Conclusion

The Kakkonda geothermal field, North-eastern Japan, several deep reservoir is developed until the boundary between Quaternary Kakkonda granite and Pre-Tertiary formations.

On progress of production the fluids from deep reservoir suffered by the fluid of shallow reservoir and meteoritic water. With lower temperature, silica scale decreased. And with changing chemical condition, mineral assemblage of scales of Well-13 changed from chalcocite (Cu₂S), loellingite (FeAs₂) and native antimony (Sb) to tetrahedrite (Cu₁₀[Fe,Zn]₂[As,Sb]₄S₃). But the ratio of the metal composition is almost constant.

References

- Doi, N., Kato, O., Kanisawa, S. and Ishikawa, K. (1995). "Neo-tectonic fracturing after emplacement of Quaternary granitic pluton in the Kakkonda geothermal field, Japan.", *Geothermal Resources Council Transaction* 19, 297-303
- Kasai, K., Sakagawa, Y., Miyazaki, S., Sasaki, M. and Uchida, T. (1996). "Supersaline brine obtained from quaternary Kakkonda granite by the NEDO's deep geothermal well WD-1a in the Kakkonda geothermal field, Japan.", *Geothermal Resources Council Transactions*, 20, 623-629.
- Kato, O. and Sato, K. (1995). "Development of deep-seated geothermal reservoir bringing the Quaternary granite into focus in the Kakkonda geothermal field, northeast Japan.", *Resource Geology* 45, 131-144 (in Japanese).
- Sasaki M., Fujimoto K., Sawaki T., Tsukamoto H., Muraoka H., Sasada M., Ohtani T., Yagi M., Kurosawa M., Doi N., Kato O., Kasai K., Komatsu R. and Muramatsu Y. (1998). "Characterization of magmatic/meteoritic transition zone at the Kakkonda geothermal system, northeast Japan." *Proceedings of the 9th international symposium on Water-Rock Interaction*, 483-486
- Yanagisawa, N., Fujimoto, K. and Hishi, Y. (2000) "Sulfide scaling of deep-geothermal well at Kakkonda geothermal field in Japan", *Proceedings of World Geothermal Congress 2000*, 1969-1974
- Yanagiya, S., Kasai, K., Brown, K. L. and Giggenbach, W. F. (1996). "Chemical characteristics of deep geothermal fluid in the Kakkonda geothermal system, Iwate Prefecture, Japan", *Journal Japan Geothermal Energy Association*, 33, 1-18 (in Japanese with English abstract).