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SCALE VARIATION OF THE PRODUCTION WELLS FROM DEEP RESERVIOR IN KAKKONDA FIELD

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ABSTRACT

The scales precipitated in production well in production well of the Kakkonda geothermal area, North-eastern Japan, originated from the deep reservoir fluid that exists at the boundary between Quaternary Kakkonda granite and Pre-Tertiary formations. The scales of first production test are classified into two types based on sulfide mineralogy, Pb-Zn rich type and Cu rich type.

On progress of production the fluids from deep reservoir suffered by the fluid of shallow reservoir and meteoritic water. As changing chemical condition, mineral assemblage of scales of Well-13 changed from chalcocite (Cu_2S), loellingite ($FeAs_2$) and native antimony (Sb) to tetrahedrite ($Cu_{10}[Fe,Zn]_2[As,Sb]_4S_3$). But the ratio of the metal composition is almost constant. And the brine of WD-1a underlied Well-19 has the similar composition of the Well-19 scale. Therefore, deep reservoir of Kakkonda field evolves with mixing the fluid of shallow reservoir and the brine of occurred in the Quaternary Kakkonda granite.

INTRODUCTION

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.

The Kakkonda geothermal system consists of two major reservoir layers.

The shallow reservoirs exist around 1500 meters depth. Fluid from this reservoir is about pH 8, weakly alkaline NaCl type and has temperatures of 220-260C.

The deep reservoirs exist near the boundary between Pre-Tertiary formations and the Quaternary granite acts as a heat source of the present geothermal activity with a fracture system (Doi *et al.* (1995), Kato and Doi (1993) and Kato and Sato (1995)). The fluid from the deep reservoir is about pH 4, weakly acid NaCl type (under the atmospheric pressure, room temperature), and has higher vapor/liquid ratio and higher enthalpy than that of the shallow reservoir (Yanagiya *et al.*, 1996). This fluid is used for the second power generation unit of Kakkonda since 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 1991 to 1993 mainly consists of amorphous iron-silica and sulfide and has two extreme types of sulfide deposition based on sulfide mineralogy. One type is Pb-Zn rich scale found in Well-19; the margin part of the Kakkonda granite and another type is Cu rich scale found in Well-13, near the top of the Kakkonda granite (Yanagisawa et al., 2000)

By the way, after first production test, the reservoir condition and fluid composition changed on progress production. These changes influence the scale composition.

And more, NEDO conducted the deep-seated geothermal resources survey project at the Kakkonda geothermal field from 1992 to 1998. The target of this project is to clear the reservoir and thermal condition about 3000 to 4000 meters depth. In 1995, the drilling of deep exploration reached at 3729 meters depth and collected the hypersaline liquid in the Quaternary granite. The project obtained new information on the Kakkonda area for modeling the geothermal system: for example, the bottom of the hydrothermal convective zone was found at a depth of about 3,100m (NEDO (1999)).

In this paper, we investigated the chemical composition and mineral assemblage changes of scales of the ground pipe line near the separator of the several production wells from a deep reservoir in the Kakkonda geothermal system and discuss the relationship between the scales and the hydrothermal activity in the Kakkonda area.

GEOLOGY AND SAMPLING POINT OF THE SCALE

Figure 1 shows a schematic geological profile of the area along the Kakkonda River (Doi et al. (1995)). Among the rocks that have been reached by drilling in this area, pre-Tertiary sedimentary rocks intercalated with acidic tuff are the oldest. The rocks are unconformably covered by Miocene formations. These sedimentary rocks are intruded by the 4.9 Ma Torigoeno-taki dacite. A Quaternary-granite pluton intruded the sedimentary and dike rocks, metamorphosing the surrounding rocks. Radiogenic age is estimated to be about 0.2 Ma (Doi et al. (1995)).

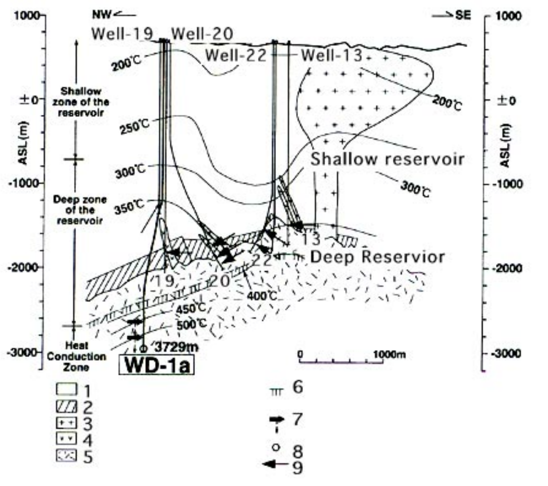

Figure.1 Schematic geothermal cross-section of the Kakkonda geothermal system along the Kakkonda river in a NE-SE direction (Modified from Kato et al., 1996). l: Tertiary formations; 2: Pre-Tertiary formations; 3: Torigoeno-taki dacite; 4: Old intrusives; 5: Kakkonda Granite: 6:Boundary of permeability between marginal granite and less permeable inner granite 7:depth interval of high gas 8: Brine in well WD-1a 9:Feed points near the upper margin of the kakkonda Granite: From left to right, Well-19, Well-20,Well-22 and Well-13

Rocks above -900 m ASL are intensively fractured, forming shallow geothermal reservoirs. Geothermal fluid in these reservoirs is weakly alkaline NaCl type and has temperatures of 220-260℃. Below -900 m ASL, productive fractures are found at and near the margin of the granitic pluton. Geothermal fluid in these deep reservoirs is slightly acid NaCl type and has temperatures of approximately 300-350℃. There are several wells by JMC and WD-1 well by NEDO that encounter the Quaternary granite.

Firstly, we collect the scale 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 1991 to 1993.

In 1995, to check the continuous of the metallic composition, we collect the scale of Well-22 between Well-13 and Well-19.

In 1999, we try to collect the same wells. But well-19 is partly damaged and pH rapidly changed. Therefore we compare the scale of Well-19 to the hypersaline fluid of WD-1a and fluid and scales of WD-1b by NEDO near Well-19. And more, instead of Well-22, we collected the scale of Well-20 between Well-13 and Well-19. Therefore, we can collect the same well only from Well-13. All scales were collected at production pipeline before separator on ground and after one-year precipitation.

SCALE SAMPLE ANALYSIS METHODS

Firstly, the textures and mineral assemblages in scales were observed with a reflection microscope and a scanning electron microscope (SEM).

After this, the bulk sample was powdered for X-ray diffraction and chemical analysis. The methods of the chemical analysis are as follows:

1) Major metal elements were analyzed by Inductively Coupled Plasma Emission Spectrometry (ICP-ES) method.

2) Na, K in the solution made by above method was analyzed by a compact ion.

3) As was analyzed by the Instrumental Neutron Activation Analysis (INAA) method.

4) S and C were analyzed by High-frequency burning infrared absorption method.

RESULTS

Scales of 1st production test

Mineral Assemblage

The scale at Well-13 contains chalcocite (CuS_2), bornite (Cu_5FeS_4) and loellingite ($FeAs_2$) as heavy metal minerals. These minerals are scattered in amorphous silica and considered detrital origin.

The scale at Well-19 is composed of amorphous silica layer and galena-sphalerite layer.

The scale at Well-22 mainly composed of amorphous silica, barite, galena. Small amounts of Cu-minerals are also present.

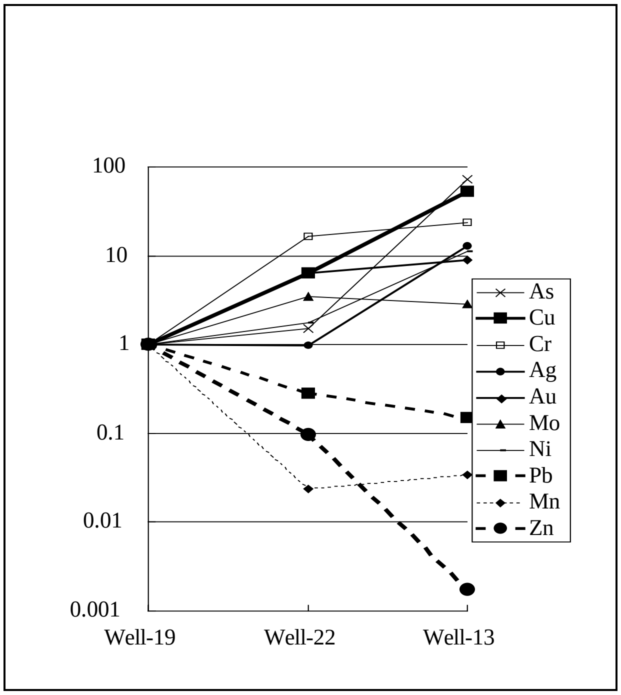

Figure 2: Chemical composition of the major metal elements standardized with the contents of Well-19

Chemical composition

The principle components of scales were amorphous silica and sulfide mineral. Total content of metal and sulfur occupied is 10-50%.

Figure 2 shows the relative concentrations of several metal elements normalized to Well-19. Metal elements were separated into two groups. Firstly, base metals such as Mn, Zn and Pb are rich in the scale of Well-19, especially the content of Zn is close to 20%. Secondly, Cu, Au, Ag, As, Cr, Ni and Mo are rich in the scale of Well-13, especially the content of Cu is close to 15%. Concentrations of Au and Ag in the scale of Well-13 are 19.4 and 550.0 ppm, respectively. The metal contents in the scale of Well-22 show the intermediate value between those of Well-13 and Well-19.

Chemical Change of fluids after 1st production test

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 form 600 to 1000 mg/kg after 1996. Si content gradually decreased. Temperature from geothermometry falled about 30 to 50 degrees in 8 years. These phenomena show the deep reservoir gradually suffered by the fluid of the shallow reservoir.

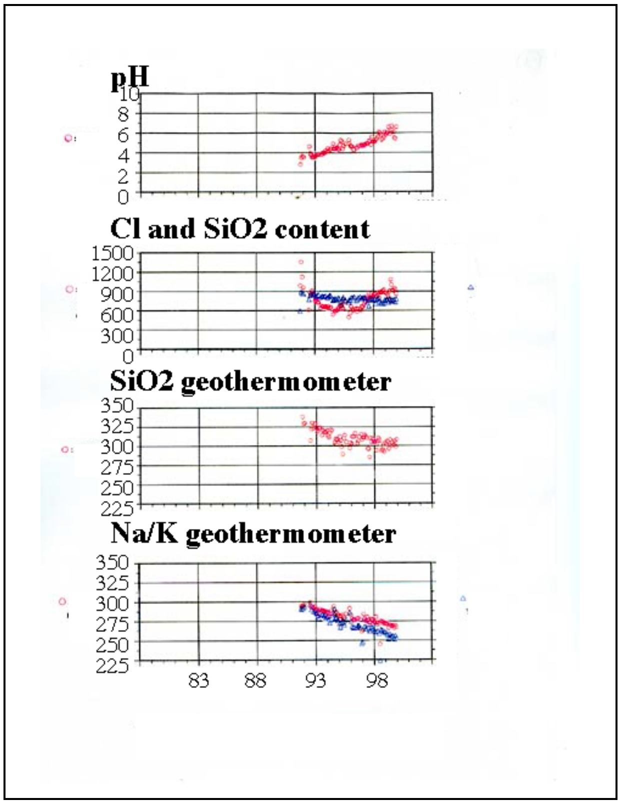

Figure 3: The change of pH, SiO2 and Cl content, SiO2 and Na/K geothermometry of Well-13 from 1991 to 1999

Scale of Well-13 at recently production (1999)

The scales of consist of mainly tetrahedrite with galena instead of chalcocite (Cu_2S), loellingite ($FeAs_2$) and native antimony (Sb). And sphlelite exists slightly in this scale. Figure 4. Shows the photo of the scale by SEM. In 1993, minerals are scattered in amorphous silica and considered detrital origin but in 1999, tetrahedrite shows dentritic growth spreaded. And as Table 1, Cu, Sb, Au, Ag and Zn are increased and especially sulfur is 6 times increased but As and Fe decreased from the first circular test in 1993.

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

	SiO2	Al2O3	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)

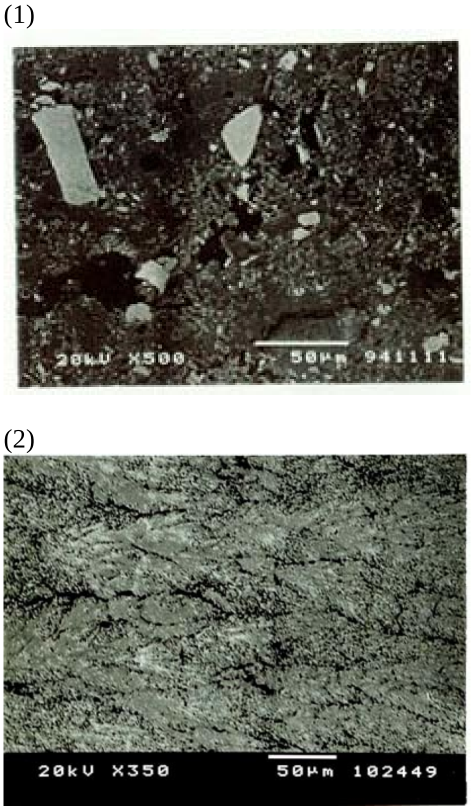

Figure 4. Photograph of the scale at Well-13 by SEM. (1) In 1993 (2) In 1999.

Sulfur content for scales at Well-13

When sulfur content is normalized as 13 for tetrahedrite, metal contents shown in Table 2. From this table, in 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 1999, sulfur exist enough for making tetrahedrite ($Cu_{10}[Fe,Zn]_2[As,Sb]_4S_3$).

Tale 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

Scale and fluid from WD-1

Hypersaline liquid of WD-1a (1995)

Hypersaline metal-rich liquid was obtained from a depth of 3,708m in the Kakkonda geothermal system (Kasai et al., 1996). Sampling of WD-1a 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.

Fluid and scale of WD-1b (1998)

NEDO monitored physical and chemical properties of fluid discharged from WD-1b (deeper than 2,625m depth) for 3 months. WD-1b pH descended from approximately 4.5 to 2.0 (pH at 20C), and its chloride concentration increased from approximately 2,000 to 10,000ppm with time, with large fluctuations, and halite scale (max. 10cm) precipitated in a surface flow line at the initial stage of the discharge test. Until the final stage, galena, sphalerite, magnetite, amorphous silica, smectite and anhydrite scale precipitated. These scales were reflected by fluid composition (Kasai et al., 2000).

Scale from middle point between well-19 and 13

.

Scales collected in 1999

The injection point of well-20 is near from that of well-22 between well-13 and well-19. The scale from well-20 consists of mainly magnetite and galena and Fe content is higher than 50%. Therefore, Pb and Cu content is lower than well-22, but the ratio of Pb, Cu and Zn is almost same as well-22 in 1995.

DISCUSSION

Compare with other geothermal field

Sulfide scales including Cu are reported at several geothermal areas for example, Salton Sea geothermal area (Skinner et al. (1967) and McKibben and Williams (1985)), Broadland geothermal area (Brown (1986)), Yamagawa geothermal area (Akaku (1988)) and Oku-Aizu geothermal area (Nitta et al. (1991) and Imai et al. (1988)).

Table 3 shows the mineral assemblage of Salton Sea, Broadland, Yamagawa, Oku-Aizu and Well-13 of Kakkonda. The mineral assemblage of kakkonda scale change to similar assemblage of Oku-Aizu scale. This suggests the deep reservoir has similar composition of fluid or similar geological condition.

The salinity of the deep reservoir fluids in the Kakkonda area is about 1,000 mg/kg (Yanagiya et al. (1996)) that is close to Broadland (Brown (1986) and lower than Oku-Aizu which exceeds 10,000mg/kg (Skinner et al. (1967), Akaku (1988) and Imai et al.

(1988)). This low salinity arises from the meteoric origin of the Kakkonda geothermal fluid.

Table. 3. Mineral assemblage of scale in several geothermal fields. This table shows the change of assemblage of Well-13 at Kakkonda.

Field	kakkonda		Oku-aizu	Yama gawa	SaltonSea	Broad land
	93	99				
Pyrite(FeS2)			○		○	○
pyrrhotite(FeS)				○		
shalerite(ZnS)		○	○	○		○
galena（PbS)	○	○	○	○		○
chalcopyrite（CuFeS2)			○		○	○
tetrahedrite（Cu10 (Fe, Zn)2(Pb,Sb)4S13）		○	○		○	
chalcociteCu2S)	○				○	
native antimony(Sb)	○					
loellingite（FeAs2)	○					

Origin of scales

From Figure 5, the relative concentration of Pb, Cu and Zn in Pb-Zn rich scale is similar to that of the liquid rich inclusion, brine of WD-1a with high salinity in kakkonda granite and fluid of WD-1b. 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 we think that 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)

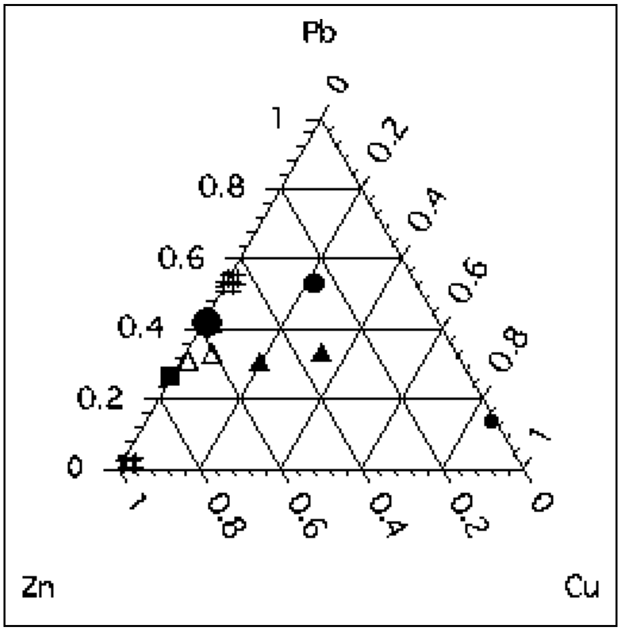

Figure 5: Pb-Zn-Cu ratio (ppm) of scale and fluid samples, Closed circle: scale samples at Well-19, 22 (20) and 13 from left to right, closed square: brine collected at the bottom of the well WD-1a (Kasai, 1996), closed triangle and open triangle: inclusion fluids inpolyphase and vapor-rich inclusions from quartz vein in a granitinc rock, respectively (Sasaki et al., 1998), sharp (#): Fluids from WD-1b (NEDO, 1999)

After several years’ production, in spite of the chemical change of fluid, 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

We characterized the change of scales from Kakkonda deep as progressing production.

(1) The fluids from deep reservoir became higher pH and lower temperature. The fluid is suffered by the fluid of shallow reservoir and meteoritic water.
(2) The mineral assemblage of scales of Well-13 changed from chalcocite (Cu_2S), loellingite ($FeAs_2$) and native antimony (Sb) to tetrahedrite ($Cu_{10}[Fe,Zn]_2[As,Sb]_4S_3$). But the ratio of the metal composition is almost constant.

(3) The relative concentration of Pb, Cu and Zn in the scale of Well-19 is similar to liquid rich inclusion and a brine of WD-1a in kakkonda granite.

(4) Deep reservoir of Kakkonda field evolves with mixing the fluid of shallow reservoir and the brine of occurred in the Quaternary Kakkonda granite.

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