New Diagram Showing Potential of Geothermal Wells Drilled in a Geothermal Area

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Key Words : geothermal prospecting, geothermal well, geothermal alteration mineral, rate of temperature decline, quadrangle diagram, Yuzawa-Okachi area.

Abstract

It is difficult to clarify potential of some geothermal wells drilled in the geothermal prospect area. Various geothermal alteration minerals are observed in the geothermal area. Comparing the formation temperature of alteration minerals, estimated from the various known data, with the measured temperature of wells, temperature decline and rate of temperature decline were gained for the first time. A new diagram showing geothermal potential was proposed as a quadrangle diagram, composed of Maximum temperature (T), Index containing temperature decline (DI), Activity index (AI) and Heat flow (HF) and was proven to be very effective as an indicator of potential of geothermal wells drilled in the geothermal prospect area.

1. Introduction

Geothermal resources are an important domestic energy source which are abundantly distributed in Japan. Geothermal energy is low cost, produces low pollution and moreover gives a lot of benefits to the community including multi-purpose uses.

The most important factor for geothermal prospecting is to grasp the characteristics of geothermal activity and the geothermal reservoir.

The characteristics of geothermal activity are considered not only in the present state but also in the progress of geothermal phenomena from the past to the present, that is, the thermal history.

The author proposes a new diagram showing potential of geothermal wells drilled in three typical geothermal areas in Japan, and shows this diagram to be very effective for other geothermal area.

2. The Present State of Geothermal Resource Development in Japan

The location of geothermal power plants and main geothermal development sites in Japan is shown in Figure 1.

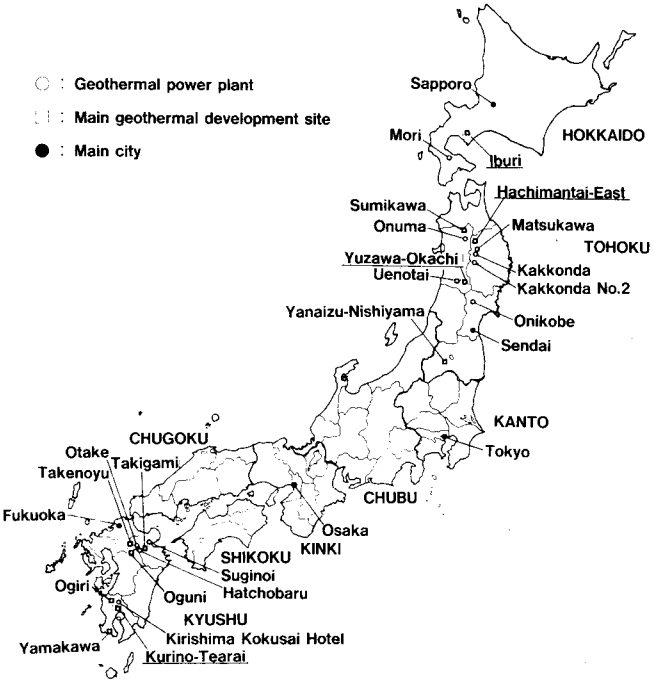

Figure 1 Location of geothermal power plants and main geothermal development sites

3. Study on Geothermal Prospecting using Geothermal Alteration Minerals

In Japan, the main geothermal areas are distributed in three districts, Hokkaido, Tohoku and Kyushu. In three typical geothermal areas, Iburi in Hokkaido, Hachimantai-East in Tohoku and Kurino-Tearai in Kyushu (Figure 1), many geological investiagations were carried out. Each of these areas has different geothermal conditions.

Geothermal alteration zones are widely spread on the surface and underground in the geothermal area. The various alteration minerals provide a fossil record of the geothermal history.

The author clarified that the species, occurrences and cogenetic relations of geothermal alteration minerals (clay minerals, zeolite minerals) have close relations with geothermal characteristics and show alteration zonations characteristic of many geothermal areas (Tanaka, 1992).

The formation temperature of geothermal alteration minerals can be estimated from the various data on mineral synthesis experiments (Figure 2, Figure 3), drilling core analyses of deep petroleum and geothermal wells (Figure 4), formation temperature of fluid inclusions, etc. Comparing the formation temperature of alteration minerals with the measured temperature of wells, temperature decline can be gained (0° ~228℃), and rate of temperature decline can also be calculated (0° ~54℃/10,000years), using the descended temperature and the age of volcanic host rocks of heat source. This is the first numerical data of this type gathered in Japan.

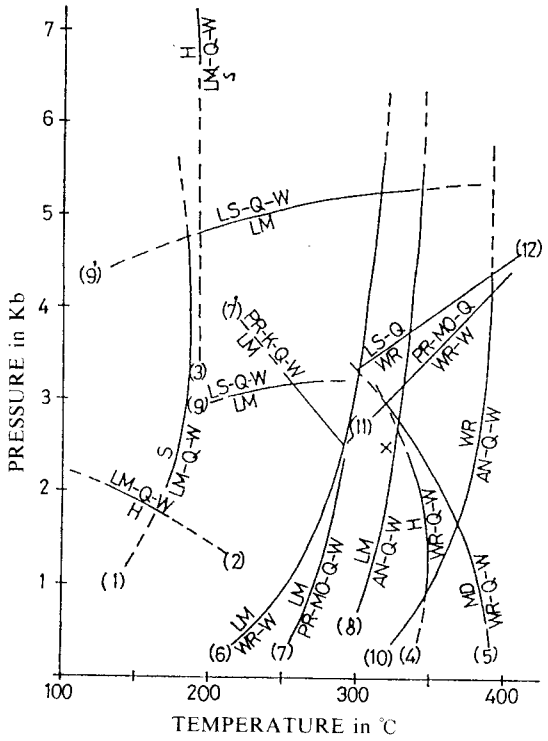

Figure 2 Reaction curves of Ca-Zeolites (Nakajima, 1977)

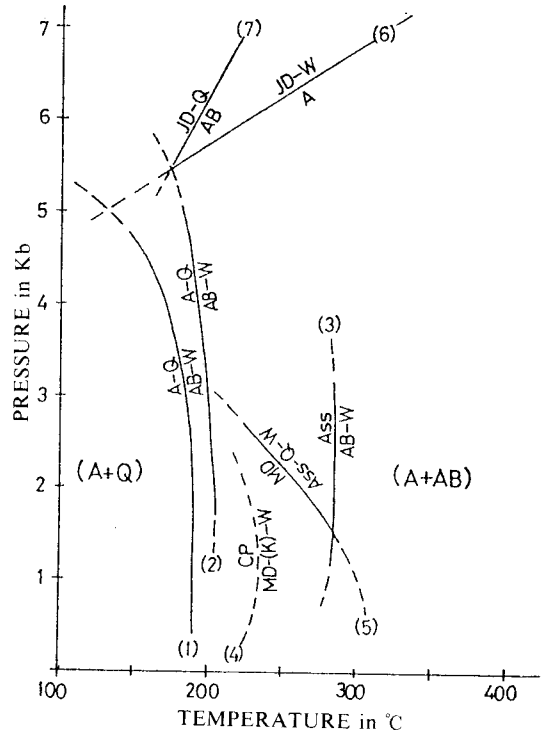

Figure 3 Reaction curves of Na-Zeolites (Nakajima, 1977)

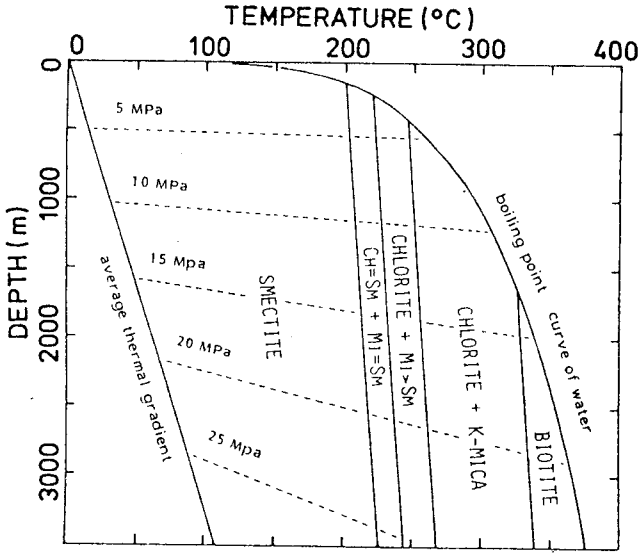

Figure 4 Stable relations of clay minerals in active geothermal fields (Hayashi, 1986)

4. New Diagram Showing Potential of Geothermal Wells

The potential diagram can be drawn as a quadrangle diagram (Figure 5) as follows.

Maximum temperature of geothermal well (T)

X-axis : T=Tm

Tm : Maximum temperature of the well (℃)

Index containing temperature decline (DI)

$$\text{X'-axis : } DI=\left[1-\frac{\Delta T}{T+\Delta T}\right]\times 100$$

△T : Temperature decline (℃), △T=Tf-Tl

Tf : Formation temperature of alteration minerals (℃)

Tl : Measured temperature of the well (℃)

Activity index (AI) (Hayashi et al. 1981, Hayashi, 1982)

$$\text{Y-axis : } AI=\left[1-\frac{Tb-Tm}{Tb-Tg}\right]\times 100$$

Tb : Boiling temperature of water at the depth (℃)

Tg : Imaginary temperature by average geothermal gradient (3℃/100m) at the depth (℃)

Heat flow (HF)

$$\text{Y'-axis : } HF=K\ \frac{\triangle\theta}{\triangle z}$$

K : Thermal conductivity ($\times 10^{-3}$ cal/cm·sec℃)

$\frac{\triangle\theta}{\triangle z}$: Geothermal grandient (℃/cm)

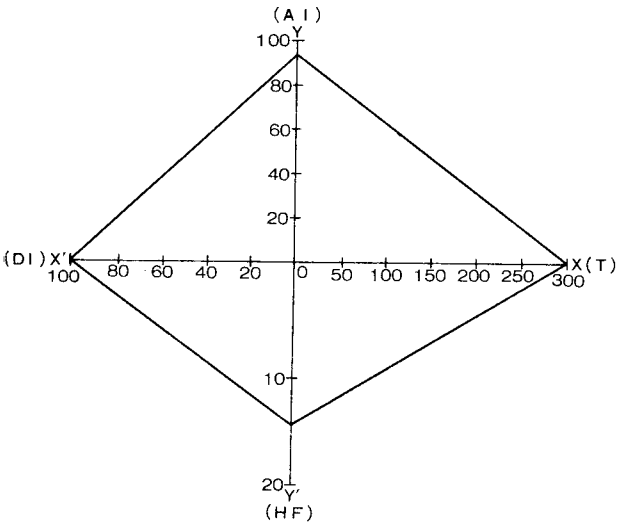

Figure 5 Quadrangle diagram

Measured and calcurated data for drawing each quadrangle diagram of some geothermal wells in three geothermal areas, are shown in Table 1.

Table 1 Measured and calculated data of geothermal wells in three geothermal areas.

Area	Well No.	Maximum Temperature (T) (℃)	Temperature Decline (△T) (℃)	Index eg. △T (DI)	Activity Index (AI)	Heat Flow (HF) (HFU)
Iburi	IB-1	130.8	171	43	28	5.25
	IB-2	120.9	171	41	28	2.87
	IB-3	136.9	169	45	33	2.39
	IB-4	106.4	189	36	22	2.89
	IB-5	271.1	24	92	91	12.9
	IB-6	111.9	123	48	41	3.69
	IB-7	93.6	167	36	24	5.36
Hachimantai-East	HT-1	185.6	116	62	63	14.4
	HT-2	213.0	29	88	66	4.44
	HT-3	218.0	77	74	63	7.82
	HT-4	152.3	138	52	41	5.12
	HT-5	92.5	146	39	32	9.50
	HT-6	135.3	107	56	40	5.38
	HT-7	95.5	153	38	37	0
	HT-9	143.7	147	49	43	6.08
Kurino-Tearai	KT-1	191.4	63	75	53	2.58
	KT-2	87.5	228	28	19	7.92
	KT-3	87.4	—	—	19	—
	KT-4	184.6	24	88	53	3.86
	KT-5	281.9	0	100	95	5.99
	KT-7	216.7	28	89	58	4.01
	KT-8	298.4	29	91	88	7.51

The new Index containing temperature decline (DI) has a close relation to Activity index (AI).

The larger is the area of quadrangle diagram of geothermal well, the more promising is the potential of the well. Well IB-5 in Iburi area, Well HT-2 in Hachimantai-East area, Wells KT-5 and KT-8 in Kurino-Tearai area are the most promising wells in each geothermal area. In fact, Well KT-5 produced vapour dominated fluid (7.8t/h, V:W=1:0.3), and Well KT-8 water dominated fluid (51t/h, V:W=1:1.9), in 1982.

5. Results Using New Diagram for Other Geothermal Area

The writer applied the prospecting method using this quadrangle diagram for Yuzawa-Okachi geothermal area in Akita Prefecture, Japan.

Measured and calculated data for drawing each quadrangle diagram of five geothermal wells in Yuzawa-Okachi geothermal area, are shown in Table 2.

Table 2 Measured and calculated data of geothermal wells in Yuzawa-Okachi geothermal area.

Well No.	Maximum Temperature (T) (℃)	Temperature Decline (△T) (℃)	Index eg. △T (DI)	Activity Index (AI)	Heat Flow (HF) (HFU)
YO−1	92.2	171	35	23	2.00
YO−2	228.2	70	77	66	8.04
YO−3	241.9	84	74	76	9.07
YO−4	195.9	125	61	63	11.1
YO−5	194.0	107	64	62	6.09

Using these data, a geothermal potential map in Yuzawa-Okachi geothermal area was generated (Figure 6). Well YO-3 has the largest quadrangle diagram area and should therefore be the most promising well in this area. In fact, vapour dominated fluid (16.5t/h, V:W= 1:0.6) has been produced.

6. Discussion

The author proposed a new diagram showing potential of geothermal wells drilled in three typical geothermal areas in Japan, and demonstrated that this diagram is very effective for other geothermal areas.

Much more to develop the result of this study, more precise work will be necessary to further develop this method, i. e., collection of various data on other mineral synthesis experiments, drilling core analyses of deep petroleum and other geothermal wells, formation temperature of fluid inclusions, for other geothermal areas.

7. Conclusions

Assessment of the characteristics of geothermal activity is an important part of geothermal exploration. The characteristics of geothermal activity must be determined not only for the present state but also for the progress of geothermal phenomena from the past to the present, that is, the thermal history.

Various geothermal alteration minerals are observed on the surface and underground in geothermal areas, forming geothermal alteration zones. The formation temperature of these geothermal alteration minerals was estimated from the various known data. Comparing the formation temperature of alteration minerals with the measured temperature of wells, temperature decline (△ T) was determined (0° ～228℃). The rate of temperature decline was also calculated (0° ～54℃ /10,000years) using the temperature decline and the age of volcanic host rocks of heat souce.

A new diagram was proposed in the form of a quadrangle, composed of Maximum temperature (T) , Index containing temperature decline (DI), Activity index (AI) and Heat flow (HF).

This diagram was shown to be effective as an indicator of potential of geothermal wells drilled in three typical geothermal areas in Japan, as well as in other geothermal areas, where promising steam production has been encountered.

Acknowledgements

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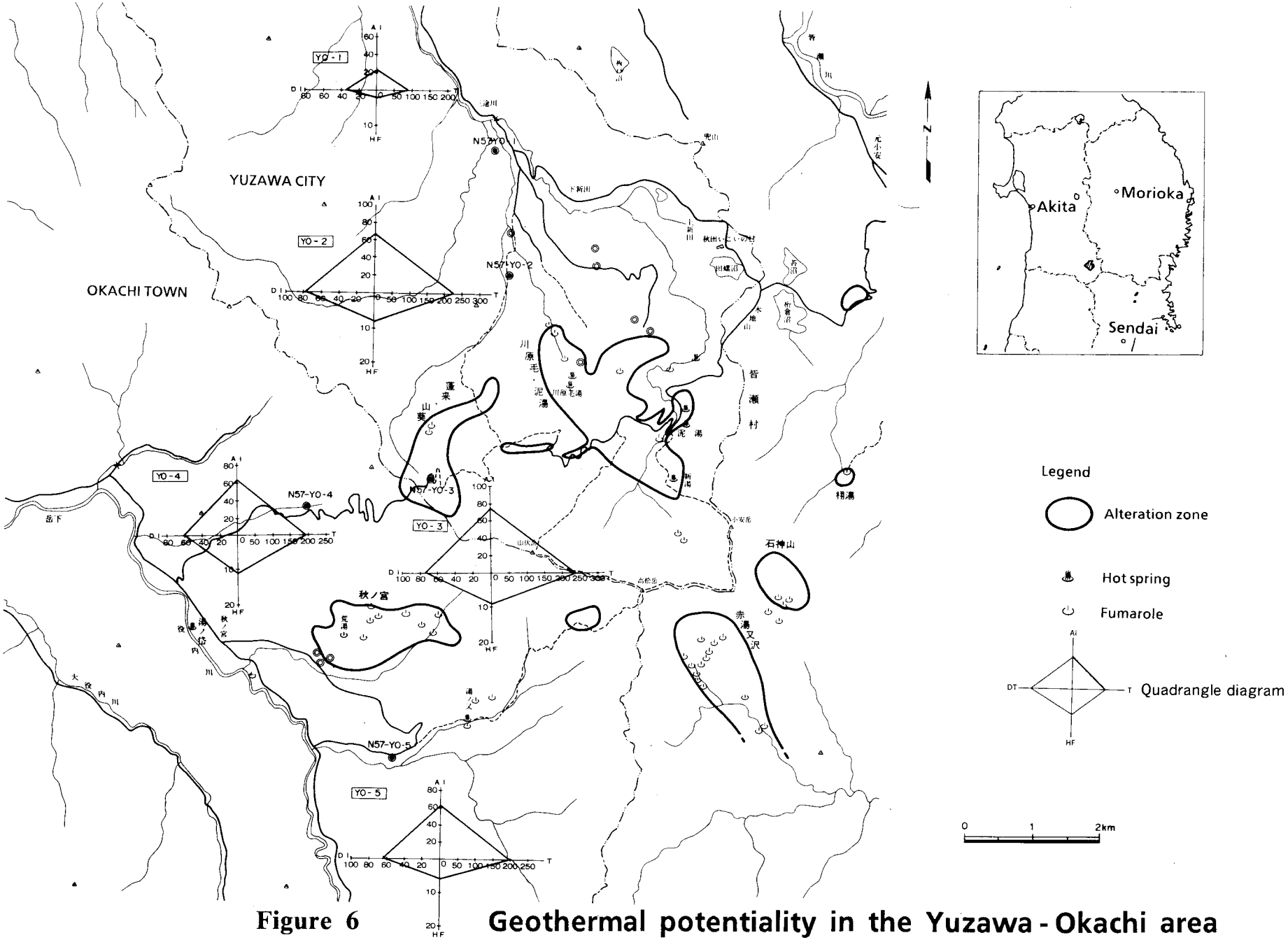

Figure 6 **Geothermal potentiality in the Yuzawa - Okachi area**

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