NOTICE CONCERNING COPYRIGHT RESTRICTIONS

Geothermal Resources Council, TRANSACTIONS Vol. 6, October 1982

CLASSIFICATION OF SCHLUMBERGER RESISTIVITY SOUNDING CURVES IN GEOTHERMAL FIELD

Seibe ONODERA

Department of Mining
Faculty of Engineering
Kyushu University

ABSTRACT

The classification of Schlumberger resistivity sounding curves in various geothermal fields is treated in the application of a multiple-layer resistivity problem. In comparison of the result of interpretation of resistivity sounding curves with near exploratory or production wells, it is demonstrated that only some type curves, which are satisfied by geothermal requirement, indicate the existence of geothermal reservoir. As a result, the distribution map of type curves in Kirishima geothermal field is presented as a basic data to determine the drilling target. Finally the result of interpretation of Schlumberger resistivity sounding curve observed at the station of I-23 is correlated with the drilling logs of the exploratory well KT-4.

TYPE CURVES IN GEOTHERMAL FIELD

If we classify a total of 597 Schlumberger RS (resistivity sounding) curves obtained in such geothermal fields as Otake, Hatchobaru, Sensui, Kirishima, Onikobe, Dieng in Central Java, and El Tatio in Chile by use of 2- to 6-layer type symbols, and if we sum up the number of similar types, then we have Table 1, according to the classification of RS curves in a multiple-layer resistivity problem (Onodera, 1961).

Table 1. The type of resistivity sounding curves in geothermal areas

2 layer		3 layer		4 layer		5 layer		6 layer	
Type	No.	Type	No.	Type	No.	Type	No.	Type	No.
1(1)	0	1(11)	0	1(111)	0	1(1111)	0	1(11111)	0
2(2)	5	2(12)	15	2(112)	2	2(1112)	0	2(11112)	0
		3(21)	29	3(121)	68	3(1121)	0	3(11121)	0
		4(22)	27	4(122)	97	4(1122)	1	4(11122)	0
				5(211)	10	5(1211)	1	5(11211)	0
				6(212)	22	6(1212)	23	6(11212)	0
				7(221)	69	7(1221)	64	7(11221)	0
				8(222)	13	8(1222)	16	8(11222)	0
						9(2111)	1	9(12111)	0
						10(2112)	1	10(12112)	0
						11(2121)	37	11(12121)	7
						12(2122)	8	12(12122)	1
						13(2211)	7	13(12211)	0
						14(2212)	1	14(12212)	0
						15(2221)	26	15(12221)	13
						16(2222)	0	16(12222)	0
								17(21111)	0
								18(21112)	0
								19(21121)	0
								20(21122)	0
								21(21211)	0
								22(21212)	4
								23(21221)	10
								24(21222)	0
								25(22111)	1
								26(22112)	0
								27(22121)	1
								28(22122)	0
								29(22211)	0
								30(22212)	0
								31(22221)	0
								32(22222)	0

Table 2.
The distribution of wells for various type curves

No. of wells	Layer	Type curves
1	3	2(12)
2		3(21)
1		4(22)
5	4	3(121)
2		5(211)
11		7(221)
4	5	7(1221)
2		11(2121)
1		15(2221)
29		

In practice, the classification of these curves extends to several categories of 2- to 8-layer types.

Of these, only Schlumberger RS curves, which are satisfied by the geothermal requirement (Onodera, 1980), indicate the existence of fracture type geothermal reservoir, which are proved by exploratory and producing wells, as listed in Table 2. It is known from the Table that particularly such types of 7(221) for the four-layer curve, 3(121) for the for the four-layer curve, and 7(1221) for the five-layer curve demonstrate possible existence of the fracture type geothermal reservoir.

This statistical data teaches us the fact that, in selecting the site of geothermal drilling based on the geothermal requirement for Schlumberger RS curves, at first, observed RS curves should be classified into the type of curve groups, and the zoning map of type curves should be drawn.

THE GEOTHERMAL REQUIREMENT

The geothermal requirement is defined as the combination of resistivity values of sequence layers, which are correlated to an altered formation and a fracture type geothermal reservoir, respectively, and a depth of their interface from the surface, whose value must be greater than 350 m.

Table 3 shows some numerical values for the geothermal requriement, and also is called necessary condition for the Schlumberger RS curve indicating the existence of the fracture type geothermal reservoir.

Fig. 1 shows the solution for the iterative least-squares interpretation of Schlumberger RS curve observed near the production well H-7 in Hatchobaru geothermal field, and Fig. 2 illustrates the correlation of the interpreted result of the same curve with the temperature log in well H-7.

Table 3. Some numerical values for Geothermal Requirement

Well	Station	Type curves	A in ohm-m	B in meters	C in ohm-m
O-15	LOS13	3(21)	20	480	100
H-16	LOS24	3(121)	77	1,000	270
H-12	LOS23	3(121)	40	700	250
O-6	LOS12	3(121)	7.4	430	140
O-7	LOS14	7(221)	10	550	300
H-1	C-13	7(221)	8	996.8	106
H-7	A-10	7(1221)	3.6	702	198.7
H-12	B-12	7(1221)	2	694.3	198.7
U-1	ES-17	11(2121)	12	750	200
7	7-EW	13(2211)	4.6	478.3	207.3

A: Resistivity of altered formation; B: Depth of interface; C: Resistivity of fracture type geothermal reservoir; O: Otake; H:Hatchobaru; U: Onikobe; 7: El Tatio.

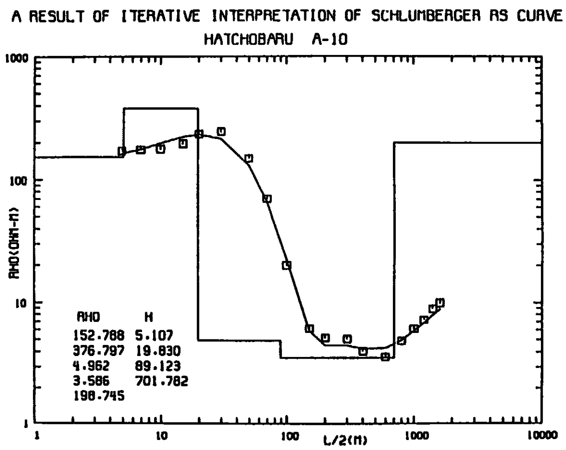

Fig. 1.

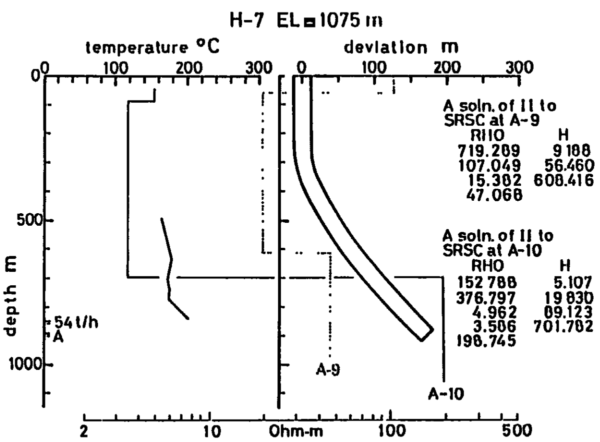

Fig. 2. Correlation of the result of iterative interpretation of RS curves observed at stations A-10 and A-9 with the temperature log in well H-7

In the solution of RS curve for A-10, the fourth resistivity layer (resistivity of 3.6 ohm-m) corresponds to an altered formation, say Hohi volcanic complex, and the fifth resistivity layer is correlated to the fracture type geothermal reservoir, called Usa formation. And the depth of their interface is given by 702 m. These values show a typical geothermal requirement. The flow rate of steam from H-7 was 21.8 t/h dated March 3, 1980. Geothermal fluid was ejected from cracks at a depth of

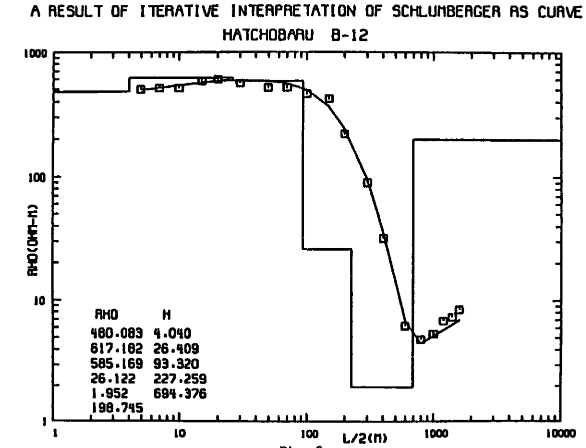

Fig 3

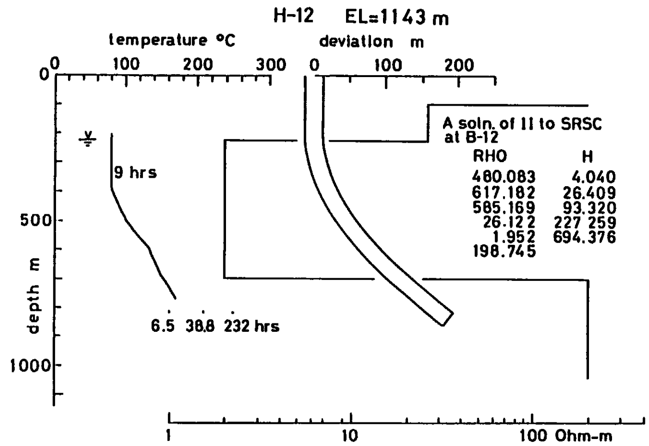

Fig. 4 Correlation of the result of iterative interpretation of RS curve observed at the station B-12 with the temperature log in well H-12

850 m, which is formed in the fifth resistivity layer of 198.7 ohm-m in resistivity.

Similar example is also shown in Figs. 3 and 4. The well H-12 produced the steam flow rate of 45.7 t/h under pressure of 6 atg. dated March 4, 1980.

APPLICATION

Fig. 5 shows the distribution map of type curves for the resistivity sounding curves observed in Kirishima geothermal field now under geothermal development by the Geothermal Section of Thermal Power Department in the Kyushu Electric Power Co., Inc. This zoning map shows an area, which is occupied by the type curves at the resistivity sounding stations given by color visions.

A total number of 85 belong to the four-layer type 4(122) of the Schlumberger RS curves, which do not indicate the existence of the fracture type geothermal reservoir, are observed in Kirishima geothermal field. Painting out these areas by making use of pink, the residual area corresponds to a promising geothermal development area, which is supported by such substantial statistical data as the four-layer type 7(221)

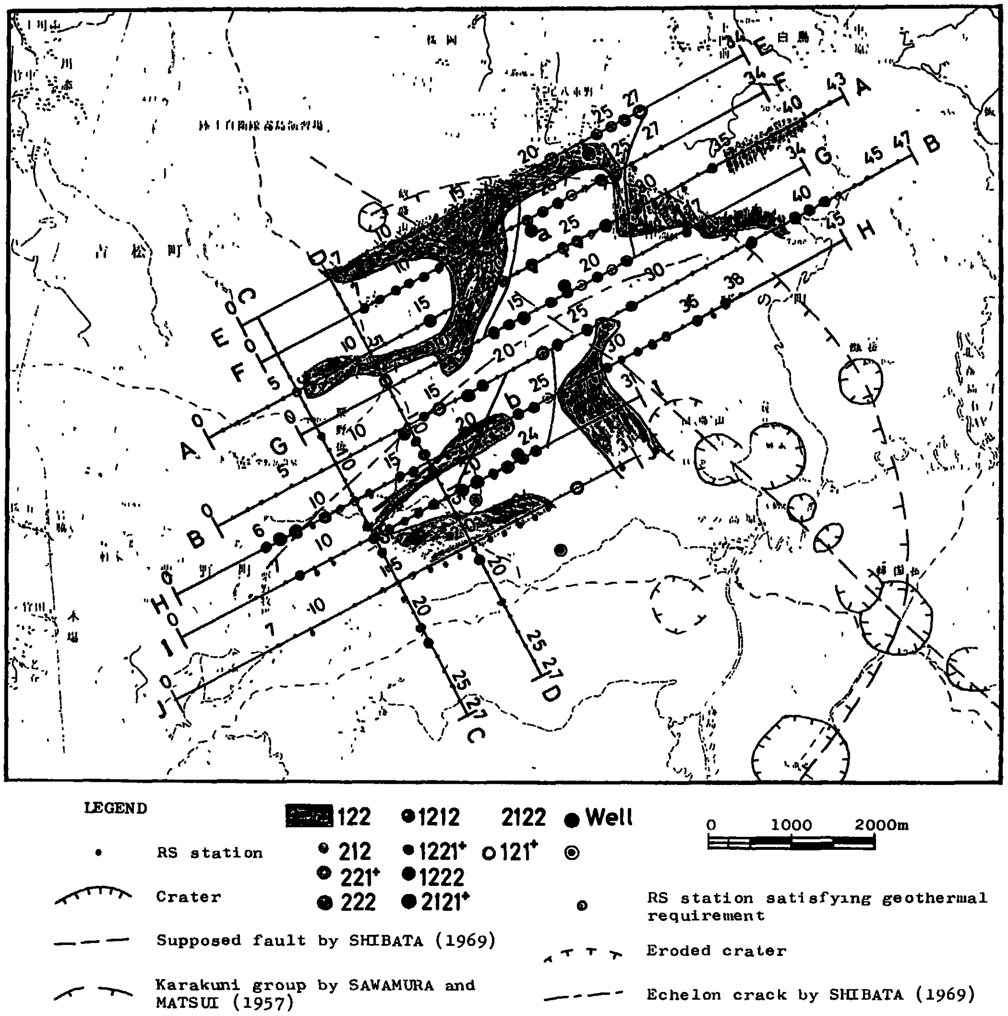

Fig. 5. Map showing the distribution of types of resistivity sounding curves in Kirishima geothermal field

and 3(121) and the five-layer type 7(1221) and 11(2121).

These can be divided into three areas, namely (1) West area of Mt. Shiratoriyama-Shiratori spa., (2) area of Kurino spa.-Kurinodake-Shiratori spa., and (3) central part of the area investigated by resistivity sounding exploration.

As for the types of RS curves indicating statistically the existence of the fracture type geothermal reservoir, the numbers of type curves are 7 for the type 3(121) and 7 for the type 7(221) of the four-layer RS curves, and are 26 for the type 7(1221), including the RS curve at the station of I-23 near the exploratory well of KT-4, and 13 for the 11(2121) of the five-layer RS curves. Consequently, from a view point of the classification of RS curves, it is naturally concluded that the areas numbered by (1), (2), and (3) are fully expected to develop Kirishima geothermal resources.

CORRLATION OF THE RESULT OF INTERPRETATION OF RS CURVES OBSERVED AT THE STATION, I-23 WITH THE DRILLING LOG OF KT-4

Fig. 6 shows the correlation of the result of interpretation of Schlumberger RS curve observed at the station, I-23 with the drilling log of the exploratory well, KT-4.

From the RS curve, geothermal requirement is given by the combination of the resistivity values of 20 ohm-m for the fourth resistivity layer, which corresponds to the altered formation, called the Sagariyama lava, the resistivity value of 180 ohm-m for the fifth resistivity layer, which is correlated to the fracture type geothermal reservoir, called the Makizono lava, and the depth of these interface of 780 m. Especially, the resistivity sudden fall for the half electrode spacing of 900 m indicates the existence of a hydrothermal system.

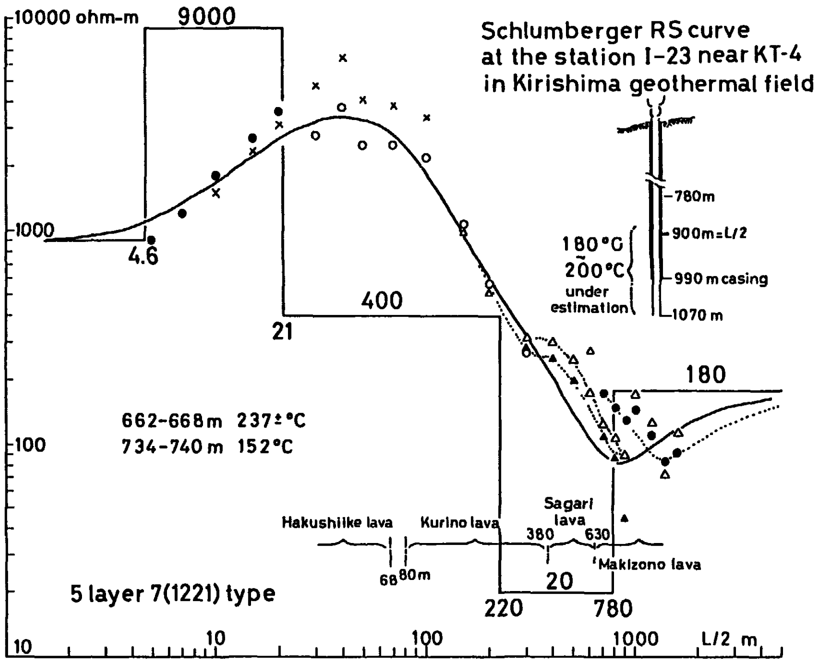

Fig. 6. Five layer 7(1221) type of the Schlumberger resistivity sounding curve indicating the existence of fracture type geothermal reservoir, which was proved by the exploratory well KT-4 in Kirishima geothermal field.

On the other hand, as shown in the right upper corner of Fig. 6, the casing with 7 inches in diameter was inserted at a depth of 990 m. The bottom temperature distribution in the well gives approximately 180 ^{o}C to 200 ^{o}C at a depth range from 900 m to 1,070 m. Such temperature distribution satisfies a condition of swabbing. Within the interval from 990 m to 1,070 m with 6 inches in diameter, the portion of escaping the drilling mud is existent at a depth of 990 m, and the escaping rate was observed by 60 t/h over. From here, the flow rate of steam of 15 t/h approximately was observed under the well pressure of 1.5 atg. Although this exploratory well does not correspond to an ordinary geothermal producing well, it is worth while to prove the existence of geothermal resources at a depth of 1,000 m, approximately.

As a result, the error of the interpreted result by making use of the ordinary curve matching method is given by 22 per cent, which is too large compared with another cases.

In addition, two temperature data, that is, 237 ^{o}C$^{\pm}$ for depths from 662 m to 668 m and 152 ^{o}C for 734 m to 740 m, which are shown in the left middle part of Fig. 6, are obtained by the estimation from the fluid filling temperature of core samples at laboratory after Assistant Prof. M. Hayashi, Division of Geothermal Geology, Research Institute of Industrial Science, Kyushu University.

DRILLING TARGET IN FUTURE

It is suggested from geoelectrical point of view that the most promising area as drilling target should be pointed out to the ridge of Mt.Shiratoriyama.

CONCLUSION

The research on the classification of resistivity sounding curves goes back to the academic year of 1961. In its application, it was presented here that the zoning map of the type for Schlumberger RS curves should be treated and discussed before writting the report of resistivity exploration for geothermal field. At present, the statistical probability of resistivity sounding curves, which were proved by the production wells,is of few magnitude. However, this distribution map not only presents and delineates an area of geothermal development, but also ought to have a close relation to a geological map in geothermal field.

ACKNOWLEDGEMENT

The author would like to express his sincere appreciation to the Kyushu Electric Power Co., Inc. for the offer of the drilling logs of KT-4 in Kirishima geothermal field.

REFERENCES

Onodera, S., 1961, A contribution of the theory of a multiple-layer resistivity problem, BUTSURI-TANKO (GEOPHYSICAL EXPLORATION), vol. 14, no. 4, 165-175.

Onodera, S., 1980, Geothermal indicators of resistivity and self-potential explorations, BUTSURI-TANKO (GEOPHYSICAL EXPLORATION), vol. 33, no. 5, 255-262.