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NATIONWIDE GEOTHERMAL ASSESSMENT IN JAPAN BY A VOLUME METHOD

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ABSTRACT

Geothermal resource assessment is the estimation of the amount of thermal energy that might be used economically at some reasonable future time. This resource assessment is of importance for providing a framework for long-term energy policy and strategy decisions by government.

Total Japanese geothermal resources of hydrothermal convection systems were assessed by a volume method in nation-wide scale. These systems were classified into three categories, High-temperature hydrothermal convection system(>150℃), Intermediate-temperature system(90℃-150℃), Low-temperature system(42℃-90℃). The resource calculation was performed with SIGMA (System for Interactive Geothermal Mapping and Assessment) computer systems at Geological Survey of Japan which is an integrated information system on geothermal resources. Data used for this assessment are nation-wide Bouguer gravity anomaly data and Curie isothermal depth data collected by NEDO (New Energy and Industrial Technology Development Organization), topographic data, and well-logging data which are archived on SIGMA system.

The methodology used in determining the accessible geothermal resource base for each hydrothermal convection system is essentially the same as a typical volume method presented in the paper of Brook et al.(1979), but which is slightly modified. Reservoir temperature is estimated by Curie isothermal depth data, and subsurface areas and thicknesses of reservoirs are estimated by gravity basement depth data assuming geothermal reservoirs are limited by impermeable basement rocks.

Thermal energy recoverable at the surface from high-temperature (>150C) hydrothermal convection systems is estimated to be 48.5×10^{18} J. This could contribute **20,540** megawatts of electricity for 30 years.

INTRODUCTION

The geothermal resource assessment in Japan has already been carried out several times starting from 1957. The methods used in these assessments are various such as surface thermal flux, volume method and magmatic heat budget. The estimation of geothermal potential becomes progressively more difficult as one proceeds from a local or regional scale to a nationwide scale.

NEDO started "Nationwide Geothermal Resources Exploration" project in 1980 with purpose to assess the geothermal resources in Japan and to locate systematically the distribution of high geothermal potential areas. Geological Survey of Japan is a co-partner with NEDO, and its role is to make a schematic plan and suggestions for NEDO. GSJ is also responsible for a calculation of geothermal resource assessment based upon data collected by NEDO. This project has been going on in three stages as follows.

1st stage (1980-1983)
NEDO conducted nationwide surveys with geological and geophysical techniques such as gravity survey, aeromagnetic survey, Landsat images and Radar image survey etc. to obtain precise geologic structures and crustal temperature distribution. By 1983, many prospective regions for high geothermal potential areas were identified.

2nd stage (1984-1986)
Four potential areas (Niseko, Hakkoda, Minami-Aizu, Kokubu) with each different type of geothermal structures were selected from the results of 1st stage survey, and various detail surveys were further conducted from 1984, like geologic surveys, fluid geochemical surveys, precise gravimetric surveys, resistivity surveys and heat discharge surveys.

3rd stage (1987-now)
Starting in 1987, comprehensive analytical techniques for geothermal resource evaluation has been undertaken. Another six model areas (Tokachi, Akitakoma, Bandai, Nasu, Aso, Yufu-dake) have been selected and surveyed.

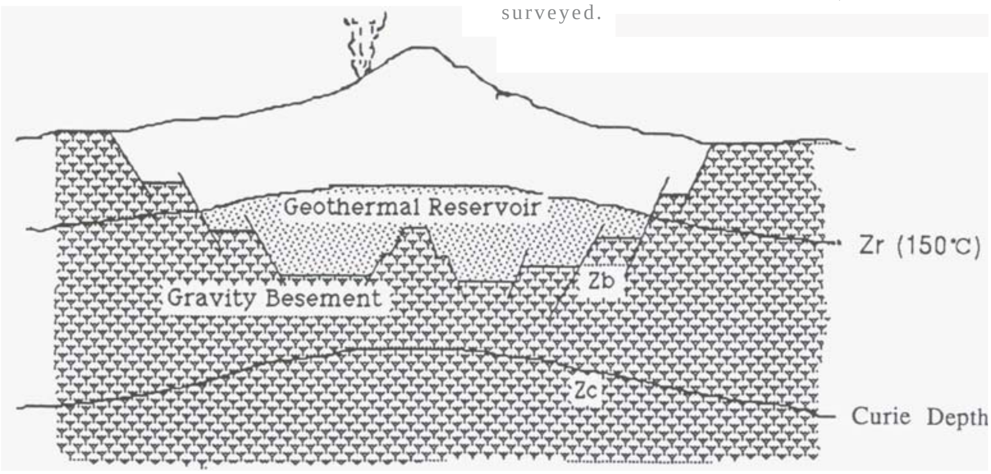

Figure 1. Schematic diagram of geothermal reservoir on which geothermal assessment is carried out by a volume method. Gravity basement depth and Curie isothermal depth are used for its calculation.

VOLUME METHOD

This method of estimation is probably most noted and most commonly used. Muffler and Cataldi(1978) concluded that the volume method is the most useful means of estimating geothermal resources and making comparisons among different areas and geological situations after a review of geothermal resource assessment methodology. White and Williams(1975). Renncr, White and Williams(1975), Brook et al.(1979) have followed the volume method for hydrothermal convection systems in the United States. Other numerous authors also have adopted this method for regional geothermal assessments.

The volume method we have used in this nationwide geothermal resource assessment in Japan is as follows. The geothermal energy originally in the reservoir Qr is calculated.(see Fig. 1)

$$Q_r = \rho c \int_{Z_b}^{Z_r} \int_S \{T(x,y,z) - T_{ref}\} \, ds \cdot dz$$

where

ρc : volumetric specific heat of rock plus water (2.7 J/cm³/ ℃)
$T(x,y,z)$: reservoir temperature at the point (x,y,z)
Tref : reference temperature (15℃)
S : reservoir area (x,y)
Zb : depth of gravity basement
Zr : reservoir depth at temperature 150℃

The volumetric specific heat ρc is calculated assuming the rock volumetric specific heat to be 2.5 J/cm³/ ℃ and the reservoir porosity to be 15 percent. The reservoir depth is bounded by a gravity basement depth and a depth corresponding to 150% temperature. The reservoir bottom is assumed to be a depth of impermeable gravity basement rocks, and thermal energy is calculated for high-temperature hot-water convection systems (greater than 150℃).

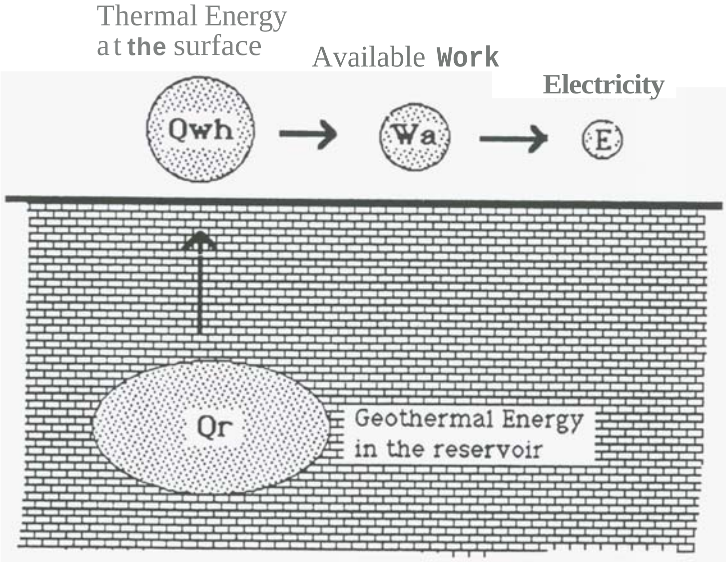

Figure 2. Conceptual flow of an algorithm of a volume method

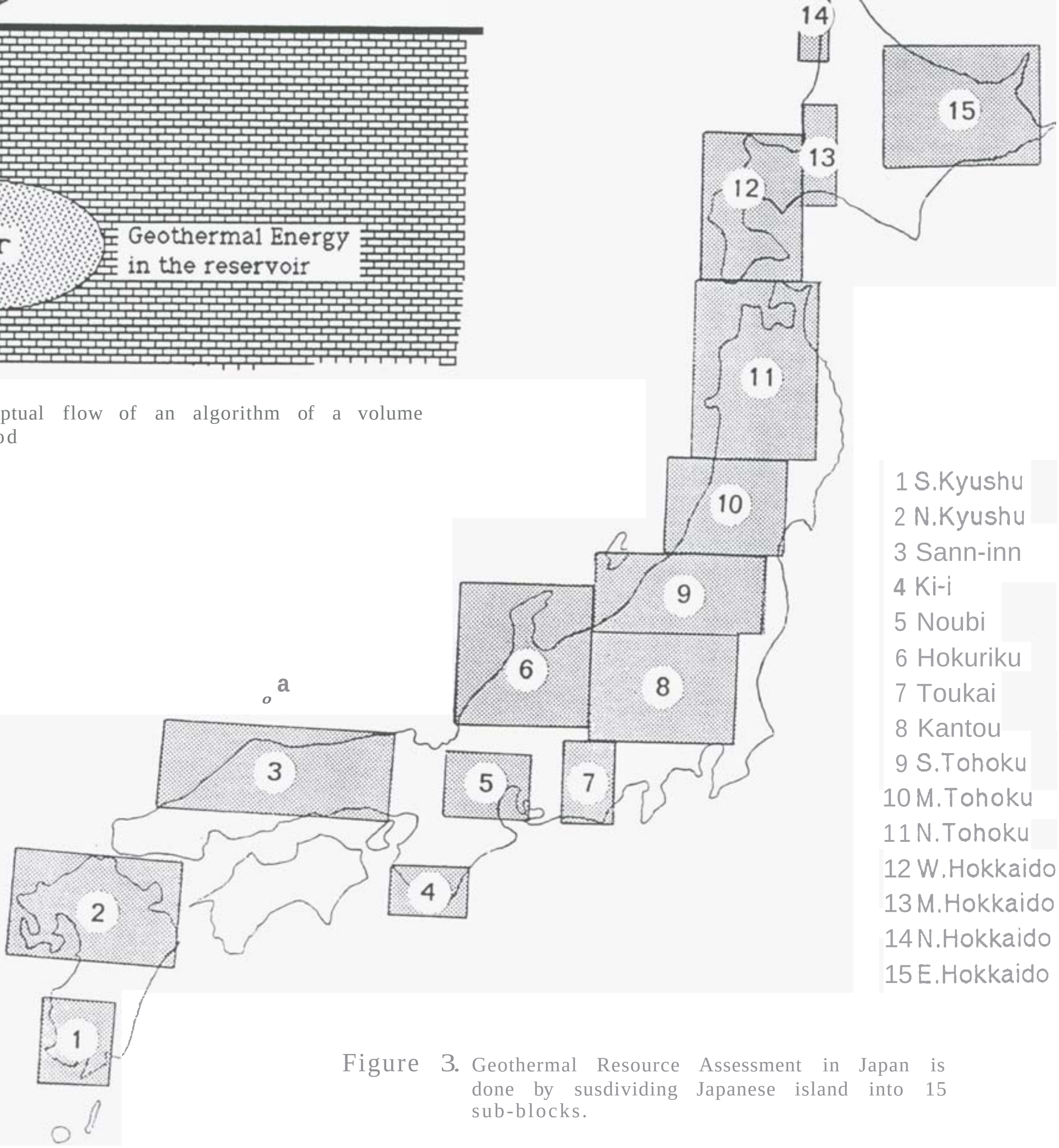

Figure 3. Geothermal Resource Assessment in Japan is done by susdividing Japanese island into 15 sub-blocks.

The methodology used in determining geothermal resource base is essentially the same as in Renner, White and Williams(1975). One significant modification to them is the usage of Curie isothermal depth and gravity basement depth. The reservoir temperature is calculated by Curie isothermal depth and a well-logging data-base system at GSJ. Although the exact Curie temperature of crustal rock at depth is still controversial (Wasilewski et al.(1979), Shuey et al.(1977). Haggerty(1978) etc.), 500°C temperature is usedfor this assessment which is reasonable temperature concluded from the point of thermal, magnetic and seismic velocity view(Byerly and Stolt(1977)) .

Surface ground is assumed to be 5 °C constant and vertical temperature is linearly increased to a 500°C Curie isothermal depth. Fig 1 is a schematic diagram of geothermal reservoir assessed by our volume method using gravity basement depth and Curie isothermal depth.

After the calculation of reservoir thermal energy Qr, geothermal energy recovered at the wellhead Qwh is derived.

$$Qwh = Rg * Qr$$

Rg is a geothermal recovery factor, and reflects the physical and technological constraints that prevent all the geothermal energy in the reservoir from being extracted. Nathenson(1975) estimates that 50 percent of the thermal energy is an ideal reservoir may be recovered in a sweep process. Following Brook et al.(1979), we assume that Rg equals 25 percent for a first approximation including the relatively small energy and friction losses that occur in the wellbore as the reservoir fluid rises to the surface.

Thermal energy at wellhead Qwh is then converted into mechanical energy (work) and electricity is finally produced. Available work Wa is given by

$$Wa = \Delta H - T \Delta S$$

$$= \frac{Q_{wh}}{(h_{wh} - h_{ref})} [h_{wh} - h_0 - t_0 (S_{wh} - S_0)]$$

where
- H : enthalpy
- S : entropy
- hwh : enthalpy per unit mass of fluid at the wellhead
- h0 : enthalpy per unit mass of fluid at the final state
- t0 : rejection temperature
- Swh : entropy per unit mass of fluid at the wellhead
- S0 : entropy per unit mass of fluid at the final state

The final electrical energy E is obtained by multiplying available work Wa by a utilization factor.

$$E = Wa * \eta_u$$

in which η_u is a utilization factor less than one to account for mechanical and other losses that occur in a real power cycle. A representative value of 0.4 was chosen for this utilization factor. Fig 2 shows a conceptual flow of an algorithm of a volume method.

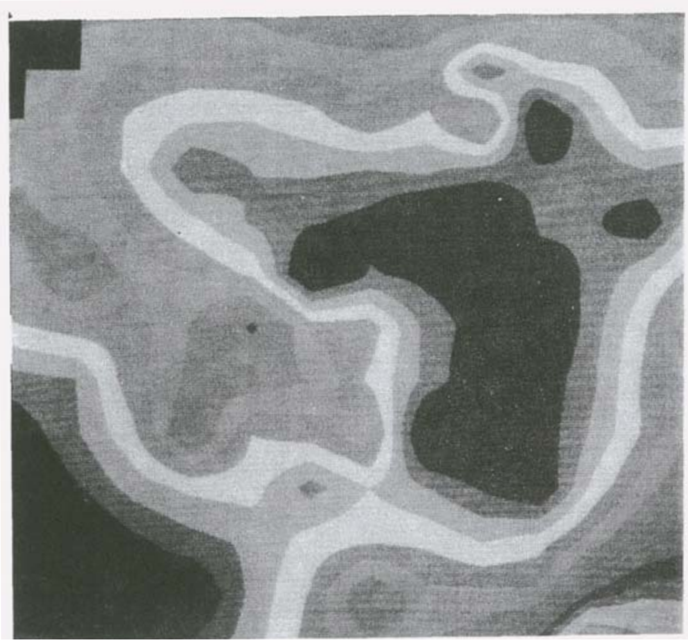

Figure 4. Curie isothermal depth map of Northern Kyushu (Block #2)

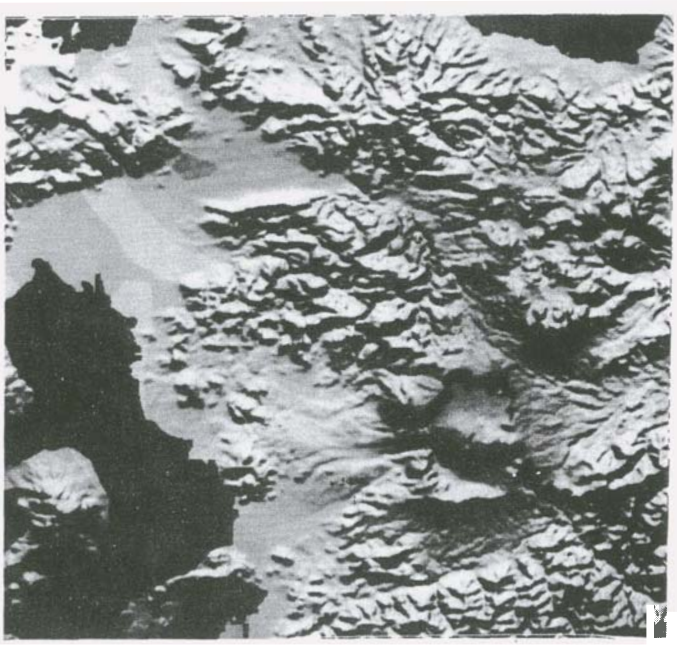

Figure 5. Color integrated map of Curie isothermal depth and computer-shaded relief map at Northern Kyushu

CALCULATION BY A VOLUME METHOD

Aeromagnetic data, Curie isothermal depth and digital elevation data cover all Japanese island. But gravity survey was only done at geothermal potential areas, and its coverage is restricted. Therefor Japanese island was subdivided into 15 small blocks as shown in Fig 3 , and three gridded data (Curie isothermal depth, gravity basement depth, topographic data) were created for each sub-block as a 500m grid data. Fig 4 is a Curie isothermal depth map (original map is color) of Northern Kyushu block(block #2). Fig 5 is an integrated map of Curie isothermal depth and computer-shaded relief map at same area.

Some block like #6 is high mountainous area and some part in this block lacks gravity data. The total area of 15 blocks is 186,079 km^2, and this area corresponds to about 50 % of total area of Japanese island. Although its coverage is half, it is carefully chosen for geothermal area. It can be considered, therefore, that geothermal resource assessment could be well carried out, and there is no extreme underestimate of geothermal potential in Japan. Table 1 shows a summary of geothermal assessment in Japan of high-temperature (>150 ℃) hot-water convection systems.

DISCUSSION

Table 1 summarizes, for each block, total area for assessment (km^2), a percentage of area for assessment (%), total reservoir volume (km^3), total reservoir thermal energy (Qr), available work (Wa) and electricity (Mwe:30years).

Total geothermal energy in the reservoir is 930 x 10^{18} J. Thermal energy recoverable at the surface from these reservoirs is estimated to be 48.5 x 10^{18} J. Total electrical energy producible from high-temperature(> 150 ℃) hot-water systems is estimated to be 20,540 megawatts for 30 years.

It can be found that the area for assessment corresponds to 2-4% of total land area. The block "East Hokkaido" indicates as high as 7.8%. and this is probably caused by the facts that gravity survey was carried out at mainly geothermal potential area and that shallow Curie isothermal depth was extrapolated eastward at the edge of gridded data.

Fig 6 is a bar chart and Fig 7 is a pie chart of electrical energy producible from high-temperature(>150 ℃) hot-water systems. Northern Tohoku block (northern main island) indicates a highest assessment as 4810 Mwe:30years, and total Tohoku region (N.Tohoku, M.Tohoku, S.Tohoku) corresponds to 35.1 % of total potential. Hokkaido(37%), Kanto:Koshin(11.5%) and Kyushu(15.2%) follow after this.

The electricity of total geothermal power plants under operation in Japan is about 250 Mwe at present moment, and it will increase up to 570 Mwe in next decade. Table 2 shows a depth range of production wells and its average depth at current operating geothermal power plants. Most production reservoirs are rather shallow region less than 1500 m except Mori. The depth of production wells is getting deeper and deeper at the newly developed geothermal areas like Hacchobaru-II, Kakkonda-II, Fushime and Sumikawa etc.

The geothermal resource assessment introduced in this paper is carried out assuming that the bottom of geothermal reservoir is the gravity basement which is impermeable. The average of its gravity basement is generally deeper than 1500 m. Therefor it can be said that the geothermal reservoir targeted by current production wells is generally shallow region while the reservoir for assessment by volume method extends much deeper region,

Block ID	Name	Land Area (km2)	Assessed Area (km2)	Ratio (%)	Reservoir Volume (km3)	Reservoir Energy (10**18J)	Available Work (10**18J)	Electricity (Mwe;30yrs)
1	S.Kyushu	7755	132	1.70	73	31.5	1.6	680
2	N.Kyushu	16220	460	2.84	246	110.1	5.8	2450
3	Sann-inn	8232	57	0.69	25	11.2	0.6	250
4	Ki-i	2948	0	0.00	0	0	0	0
5	Noubi	5861	0	0.00	0	0	0	0
6	Hokuriku	14463	0	0.00	0	0	0	0
7	Toukai	10803	0	0.00	0	0	0	0
8	Kantou	28559	752	2.63	271	112.9	5.6	2370
9	S.Tohoku	18800	518	2.76	147	58.8	2.8	1200
10	M.Tohoku	15910	233	1.46	123	53.9	2.8	1180
11	N.Tohoku	22427	668	2.98	479	216.1	11.4	4810
12	W.Hokkaido	14697	547	3.72	326	147.8	7.8	3320
13	M.Hokkaido	6831	0	0.00	0	0	0	0
14	N.Hokkaido	1481	0	0.00	0	0	0	0
15	E.Hokkaido	11092	868	7.83	412	187.8	10.1	4280
	(TOTAL	186079	4235	'2.28	2102	930.1)	48.5	20540

Table 1. Summary of Geothermal Resource Assessment in Japan

ACKNOWLEDGEMENT

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	Range of Production Well	Average depth
Matsukawa	945-1507 m	1251 m
Otake	350-1912 m	691 m
Onuma	1485-1767 m	1600 m
Okikoube	170-1500 m	415 m
Hacchoubaru	550-1971 m	1166 m
Kakkonda	887-1820 m	1197 m
Suginoi	247-778 m	429 m
Mori	655-2733 m	2077 m
Kirishima	70-250 m	160 m

Table 2. Depth of production wells at current operating geothermal power plants in Japan

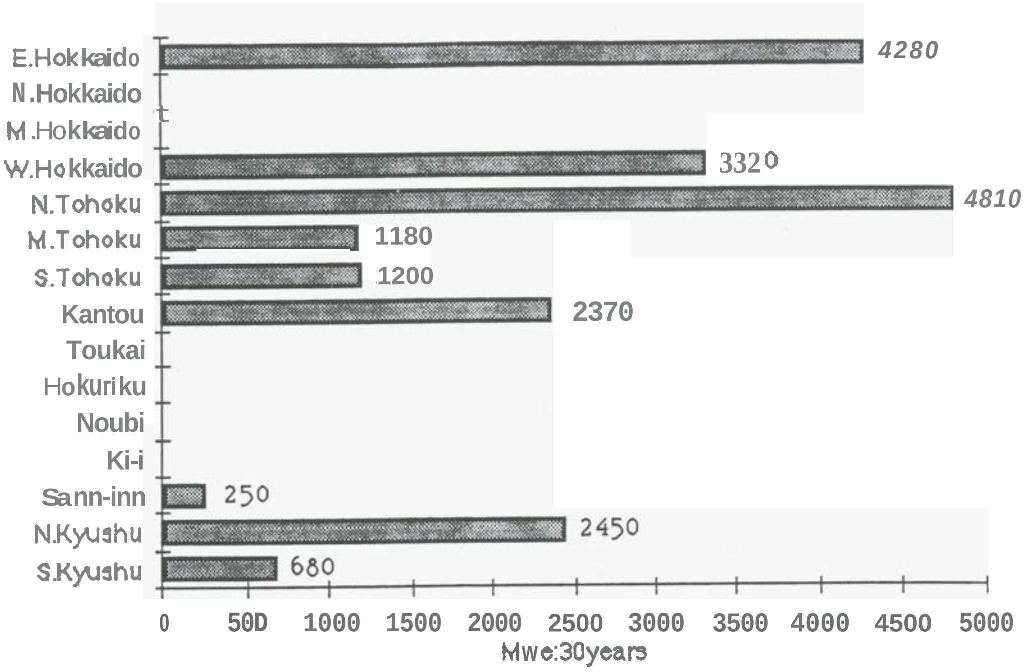

Figure 6. Bar-chart of the result of geothermal resource assessment in Japan by a volume method

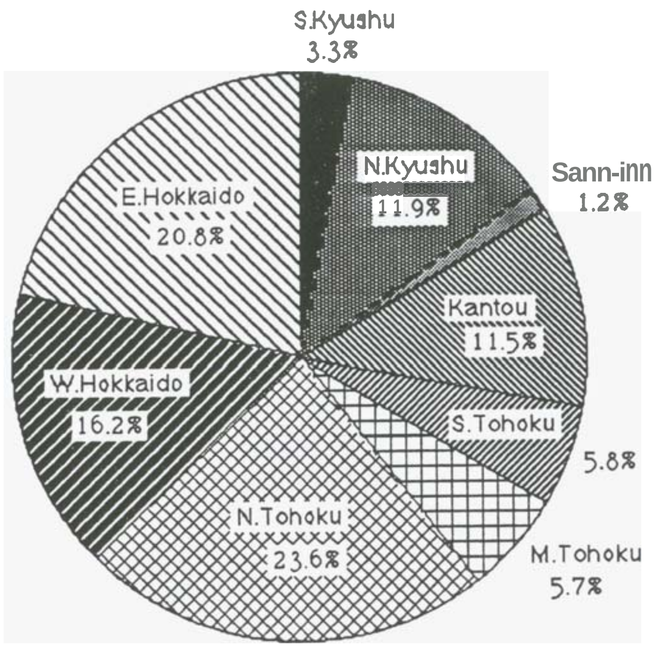

Figure 7. Pie-chart of the result of geothermal resource assessment in Japan by a volume method