Geothermal Resources Map Aided by Remote Sensing Data

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ABSTRACT

Numerous survey data for geothermal energy resources are being accumulated in Japan and they are compiled as a "Geothermal Geology Map". The compilation is made on the geological map at present. Among survey data, such remote sensing data as satellite image, airborne SAR, or aerial thermal infrared image are recognized to be useful and have actively been used for regional geothermal surveys.

In this paper we first discuss on the thermal historical meaning of the ratio of abnormally high geothermal surface to geothermally altered bareground whose information are obtained from remote sensing data.

Secondly we discuss on an approach to compile geothermal data onto remote sensing image data for further exploration or resources assessment purpose.

1. Introduction

In a series of geothermal resources surveys, remote sensing data occupy an important role at the early phase of the survey and the image data seem also useful as a base map of the compilation of various survey result at the summary stage of the survey.

There is good reason that remote sensing data are actively used for geothermal surveys because the resources heavily depend of the existence upon the area of young volcanism in Japan and are controlled by the development of young open fractures as fluids paths, whose surface traces are well shown on remote sensing image data. The unique data on the distribution of anomalously high geothermal surface obtained by aerial thermal infrared images are also valuable.

In the beginning, we briefly review on the use of remote sensing data for geothermal survey purpose and in the next, a focus is put on the discussion on the thermal historical meaning of geothermal manifestation observed at the Hachimantai area, the model area in this paper.

The survey data are compiled onto maps and presently the compilation is made on geological maps. Taking into account of the recent improvement on resolution of satellite remote sensing data and importance of topographic information in geothermal surveys, we propose the computer aided extraction of geothermal information and their compilation.

2. Remote Sensing Applied for Geothermal Survey

Applications of remote sensing and data analysis thus far made for geothermal surveys are briefly described in the next.

(1)thermal infrared image(airborne, helicopter-borne)

Geothermal surveys by aerial thermal infrared image were done during 1973-1975 selecting five areas in our country for the mapping of abnormally high geothermal spots and possible near shore hotsprings(Hase et al., 1975), and in 1979 and 1980 for the mapping of surface temperature (Kawamura and Yamaguchi, 1982, Kawamura, 1984). The method on the measurement of heat flux from geothermally anomalous surface by applying a helicopter-borne scanner was proposed(Sekioka, 1985) and this method was used in recent measurement surveys in four volcanic and geothermal areas in Kyushu(Yuhara et al., 1987). Other than these, number of applications are reported for monitoring volcanic activity.

(2)Airborne SAR

An airborne synthetic aperture radar(SAR) technique was introduced from the United States in a part of the Nationwide Survey for Geothermal Resources by the New Energy Development Organization(NEDO) and the imaging flight of our country was conducted in 1981(Suyama et al., 1982). As a product, radar mosaic maps of 1:200,000 scale were prepared in the manner fitted to topographic map series of the same scale by the Geographical Survey Institute(GSI). The images are used for the refinement of existing geological maps and specifically the result of lineament analysis was re-arranged as the lineament density map, and was used as the data of first-order assumption of the "fracture density" map in the nation-wide extraction of geothermally potential areas by the NEDO. Some examinations in use of the data for the purpose are made(e.g. Yamaguchi, 1985).

(3)Space data (Landsat MSS,TM, and SPOT data)

Some of large topographic features which were first observed by Landsat images and had not been noticed by other existing data attracted interest. Particularly large circular or semi-circular features develop in volcanic terrains were remarked from geothermal resources point of view. For example, in three of regional volcano-geothermal areas in northern Honshu, the Hakkoda, Hachimantai,and Kurikoma area, from north to south, above stated features develop and these of the Hachimantai and Hakkoda were first remarked by Landsat image observation(Hase, 1976; Muraoka and Hase, 1981). This information paid important role in the succeeding geothermal projects in the both areas. The Hachimantai and surrounding area, where is put the regional name the "Sengan" area, is selected as the example and the discussion area in this paper(Fig. 1).

Computer aided synthetic use of space and digital terrain data provided by the GSI, with geophysical data are being examined for geothermal resources exploration and assessment purpose(Miyazaki, 1986) and the method is thought most preferable in compiling data and applied in this paper.

3.Thermal Historical Evaluation of Geothermal Manifestation

Many geothermal manifestations are well preserved in natural condition in the studied area, especially they are easily observed at Goshogake, one of the attracting locations in the Hachimantai National Park area(Fig.2). Among manifestations, "drifting" or "shifting" of hot spots is noteworthy. It is noted that many of geothermally anomalous locations in the Sengan area are seen in areas of landslide developed at the peripheral slope of comparatively young(Plio-Pleistocene) volcanoes(Hase et al., 1983; Sumi et al., 1986)(Fig.3). The surface soil and rock should have encountered disturbance at such areas and have high porosity. This is also shown by the nighttime aerial thermal infrared image in which many of cold springs are found to flow out from landslide locations as the case of hotsprings. In suchgeothermal locations, the change of fluid paths to a surface will be frequent due to the sealing of them by the bearing of hydrothermally altered minerals. The drifting of geothermal manifestation at locations of landslide can be well explained and it causes rapid expansion of geothermally altered bareground. It is schematically illustrated(Fig.4).

The figure indicates that a thermal historical process can be evaluated by knowing the ratio of degree of the "live" geothermal manifestation to that of the geothermally altered bareground as the "dead" geothermal phenomenon. The simple method measuring both areas will serve in assessing the extent of geothermal activity at such locations and it is easily performed by applying remote sensing techniques.

In this case the definition on the boundary which defines the live geothermal surface from the background is necessary. Several empirical results made to know the detectable boundary of effective outgoing radiation from geothermal surface in terms of heat flow by one of the authors(Hase, 1974) can be used. The abnormally high geothermal surface distinguished from the surrounding background surface temperature will be said in a practical sense to be about 200 times stronger than the average conductive heat flow of the earth(heat flow unit; HFU) or 13.4 W/m^2).

Let us put the ratio of surface distribution of the live geothermal manifestation to the dead geothermal surface to be E.

$$E = G_l / G_d$$

where G_l ; an area of geothermally live surface(m^2)
G_d ; an area of geothermally dead or altered bareground(m^2)

E is thought to be large when geothermal activity is comparatively young and vice versa.

The result of the measurement of E in the Sengan area ranges from 0.09 to 0.37(Table 1). and it is plotted onto a logarithmic graph(Fig.5). The measurement of the live geothermal area was done using nighttime aerial thermal infrared images and that of geothermally altered bareground was done by using conventional aerial photographs. They were measured by the Color Data System 1200 developed by the Nac Co. It is an opto-electronic image analysis system having planimeter function. The result may have an error but it is neglected for this purpose. Goshogake and Fukenoyu is located close to each other and thought to have same thermal history. The iso-E line of the Fig. 5 seems to show an exponential relation. Supposing the iso-E line to suggest the iso-chronal line indicating thermal historical process in the area, the relationship among other locations seems reasonable.

4. Data Selection for Resources Image Map

Important surface information for the exploration and assessment of geothermal resources is listed below.

* geothermal manifestation; geothermally anomalous spots (hotsprings, fumarole, high temperature ground, hotpool, mudpot), geothermally altered bareground, geothermally retarded vegetaion
* geothermally related landforms; landslide (horse-shaped scarp, crack, slid mass), abnormal gully shape, mudflow deposits
* volcanic feature; eruption center, caldera, crater, rift or fissure, young intrusive rock, lava and pyroclastic flow unit
* specific geologic unit related to control or to tap geothermal fluids; slab of lava flow and welded tuff or fine grained sediments as heat insulator(cap rock), etc.
* geologic structure; fault, lineament, sheared zone, plastic deformations(foldings, dome or basin structure), strike trends

These surface characteristics are well detected and mapped by remote sensing data. For deeper geothermal resources, contribution of these information is limited and the assumption on the regional geologic setting becomes inevitable. Other informations valuable for the purpose are;

* geophysical data to give information on subsurface structure, the existence of fluids, or temperature; gravity, aeromagnetics, resistivity, seismic, spontaneous potential, natural seismicity
* temperature(measured, estimated from thermometry), heat discharge, heat flow
* geochemical or hydrochemical data; chemical composition of fluids(hotsprings, fumarole, coldsprings, soil gas, thermal water, etc.), hydrothermal mineral assemblages, stable isotope
* hydrothermal ores(gold, silver, copper, zinc, sulphur, sulphide, etc.), volcanogenic iron ores(limonite, etc.), clay minerals(pyrophyrite, etc.)

These informations and other information such as drilling (temperature hole, exploration well, etc.) location, geothermal power plant, access road, etc., have thus far been compiled onto geologic maps. Taking into account of the fact that geothermal resources are strongly controlled by young volcanism and young tectonic movement in our country, surface information indicated by topographic feature or geothermal manifestation itself is important. For example, the meaning of geologic boundary in assessing geothermal resources is not necessarily conspicuous.

This leads us the idea that the base map for the compilation is better to have as detailed topographic information as possible and remote sensing data can fulfill this requirement.

The mappable information onto a single compile map is limited, and the combination of useful information can be different from one area to the other, it is desirable for the compilation to have flexibility to cope with above stated requirement.

5. Compilation onto Remote Sensing Data

Among all useful information listed above for the geothermal exprolation and assessment, we have chosen alteration area, eruption center, Quaternary andesitic volcanic area and land slide, which are mappable well by using remote sensing data for compilation to make a geothermal resources map at the Hachimantai area. The base map for this compilation may be topographic data(Digital Terrain Model) or satellite image. The above information were originally plotted on 1:50,000 scale map and this scale requires the smaller spatial resolution(20-30m) for a base map. Topographic information provided by the Geographical Survey Institute is 250m spatial resolution, and this is too large for retaining the original geothermal information to be compiled. Therefore we decided to use Landsat TM data band 4(0.76-0.90 μm) with 30m spatial resolution as a base map. This TM data was taken in autumn, Oct. 22, 1985, and is suitable for compilation in the sense that sun elevation angle is low enough and topographic information is quite enhanced.

Original information plotted on the 1:50,000 scale map are first digitized with the support of ARC/INFO program loaded on Microvax II. ARC program can help to generate polygon data with DLG(Digital Line Graphs) format at the end. The polygon data are checked after digitizing operation by plotting them on Tektronix 4115 display. The final data are then geometrically corrected to register with TM data base map(Fig. 6).

6. Discussion

Thermal historical evaluation at geothermal locations described in this paper is based upon the field observation at Goshogake, the Hachimantai area. We need more data in order to say whether this type of evaluation can be applied to other geothermal areas. This is a simple and macroscopic evaluation. We neglected surface recovery factor by vegetation activity in this paper, however, the consideration will be necessary for geothermal locations develop in vegetated areas. More detailed evaluation can be possible by highly applying the capability of remote sensing data. That is, remote sensing data are providing for us capability on; 1) the measurement of heat flux from geothermally anomalous surfaces, 2) the detailed zonation of geothermally altered bareground by discriminating hydrothermal minerals, and 3) the detailed zonation of geothermally retarded vegetation by spectral characteristics.

A method for estimating heat flux from a geothermal surface applicable to thermal infrared remote sensing has thus far been proposed(Sekioka and Yuhara, 1974) and the method was used for the helicopter-borne remote sensing(Sekioka, 1985). It might be applied to aerial thermal infrared survey if geometrical rectification of the image is made and sufficient local climatological data are obtained for the radiation correction.

However without these, the estimation of heat flux from an airborne altitude becomes too theoretical and erroneous. There are limited number of reports mentioned on the accuracy of the result. A cross check survey between the snowfall calorimetry and the heat balance method showed the difference to be within an order of magnitude(Sekioka and Yuhara, 1975). The result of comparison of heat flux measurement made on the data obtained by the helicopter-borne thermocamera over same locations in different time(Yuhara et al., 1987) seems to have roughly same order of difference. In case of estimation by aerial thermal infrared survey, the difference may be much greater. A simple method in use of thermal infrared image data proposed in this paper seems more practical.

Concerning the space image as the base map in this study, we used Landsat TM data(band 4) for the compilation. In utilizing remote sensing image data for the extraction of geothermally related feature, ground resolution of the image should be considered.

It is discussed that the most appropriate image for the surface feature analysis in terms of the resolution-scale relationship may be expressed as $RS = 0.01(cm)$ (Yamaguchi, 1985), where R is the resolution of data and S is the scale of the image used.

In our present geothermal surveys, the result of surveys is compiled into 1:100,000 scale maps. When we extract geothermal information from remote sensing data to cope with the 1:100,000 scale compile map, the original data should have spatial resolution of at least 10 meter according to the above equation. This suggests that the SPOT image is more appropriate to use in this study if good scene is obtained. The airborne SAR image applicable for our purpose has stated ground resolution of about 15 meter, but the data obtained under low impinging angle of microwave have preferred orientation of topographic enhancement by shadow effect and can not be discussed equally.

For geothermal exploration and assessment purpose, we want to compile as much information as possible on an image map, however, it lessens the usefulness of the map if too many informations are displayed on a single image map. We need the best selection of useful data onto a compile map of the area concerned and thus compilation needs the flexibility on the selection of data.

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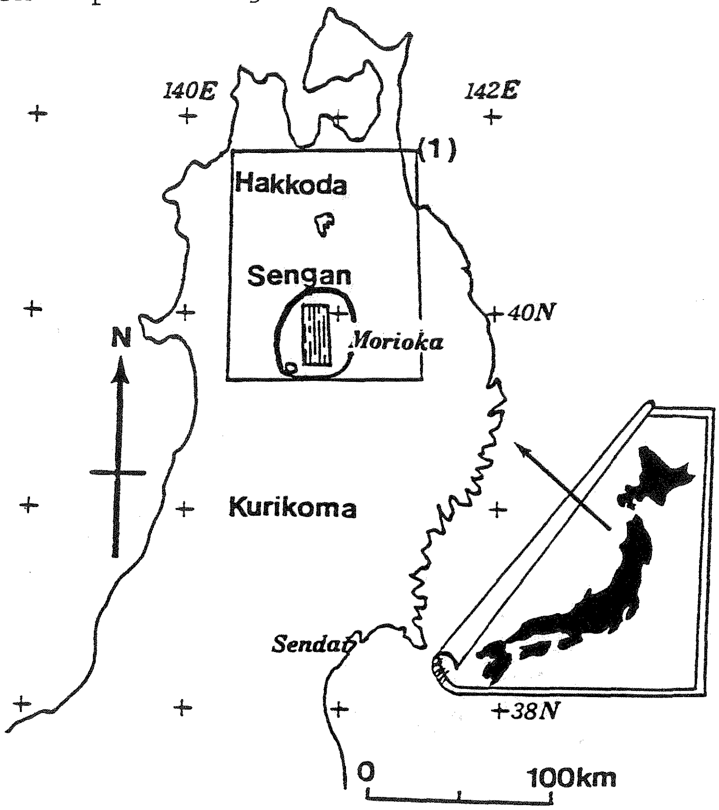
Fig. 1 Index map showing the studied area, the Sengan area



(1) N-look airborne SAR image

(2) nighttime thermal IR image

Table 1 Extent of geothermally altered bareground and <u>anomalously high geothermal surface</u>*

No.	Name of Geothermal Location	Elevation Above Sea Level (m)	Mean Altitude to Scanner (m)	Geothermal Bareground (m²) [Gd]	Thermally "live" Area (m²) [Gl]	Ratio $E = \frac{[Gl]}{[Gd]}$
1	Sumikawa	820 - 860	1,230	14,100	1,700 - 1,900	0.12-0.13
2	Goshogake	970-1,000	1,085	151,000	47,000-56,000	0.31-0.37
3	Fukenoyu	1,080-1,160	950	54,400	14,700	0.27
4	Obuka	1,120-1,140	940	15,800	1,300	0.08
5	Tamagawa	750 800	1,250	57,300	20,000	0.35
6	Denzaemon	1,290-1,400	730	34,000	3,000 - 3,300	0.09-0.10
7	Toshichi	1,370-1,400	690	68,600	5,600	0.08
8	Up. Stream Tama-gawa	670 - 730	1,370	27,000	2,800 - 3,300	0.10-0.12
9	Nyuto	780 - 960	1,205	63,000	9,300	0.15
10	Kakkonda Matsu-zawa	670 - 900	1,330	18,000	1,700	0.09

* geothermal surface whose thermal intensity is stronger about 200 times than average heat flow unit(HFU) of the earth

Fig. 2 Goshogake geothermal location and thermal IR image

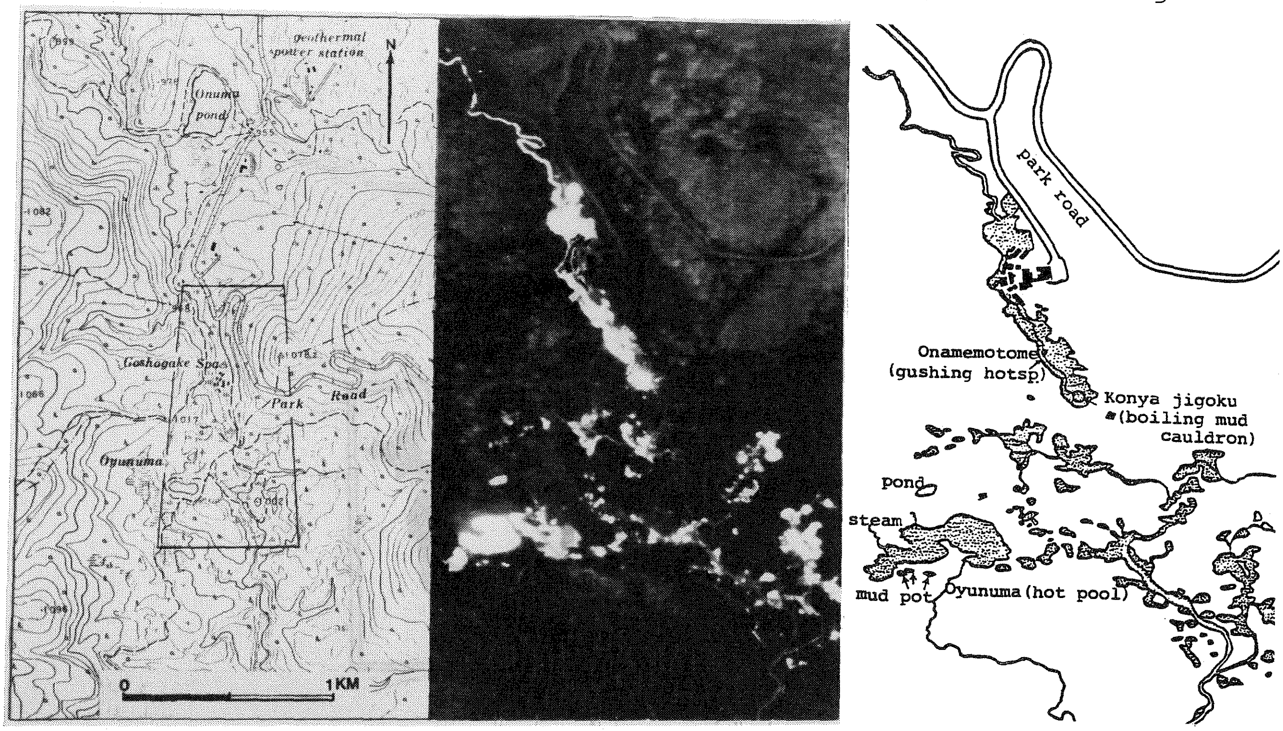
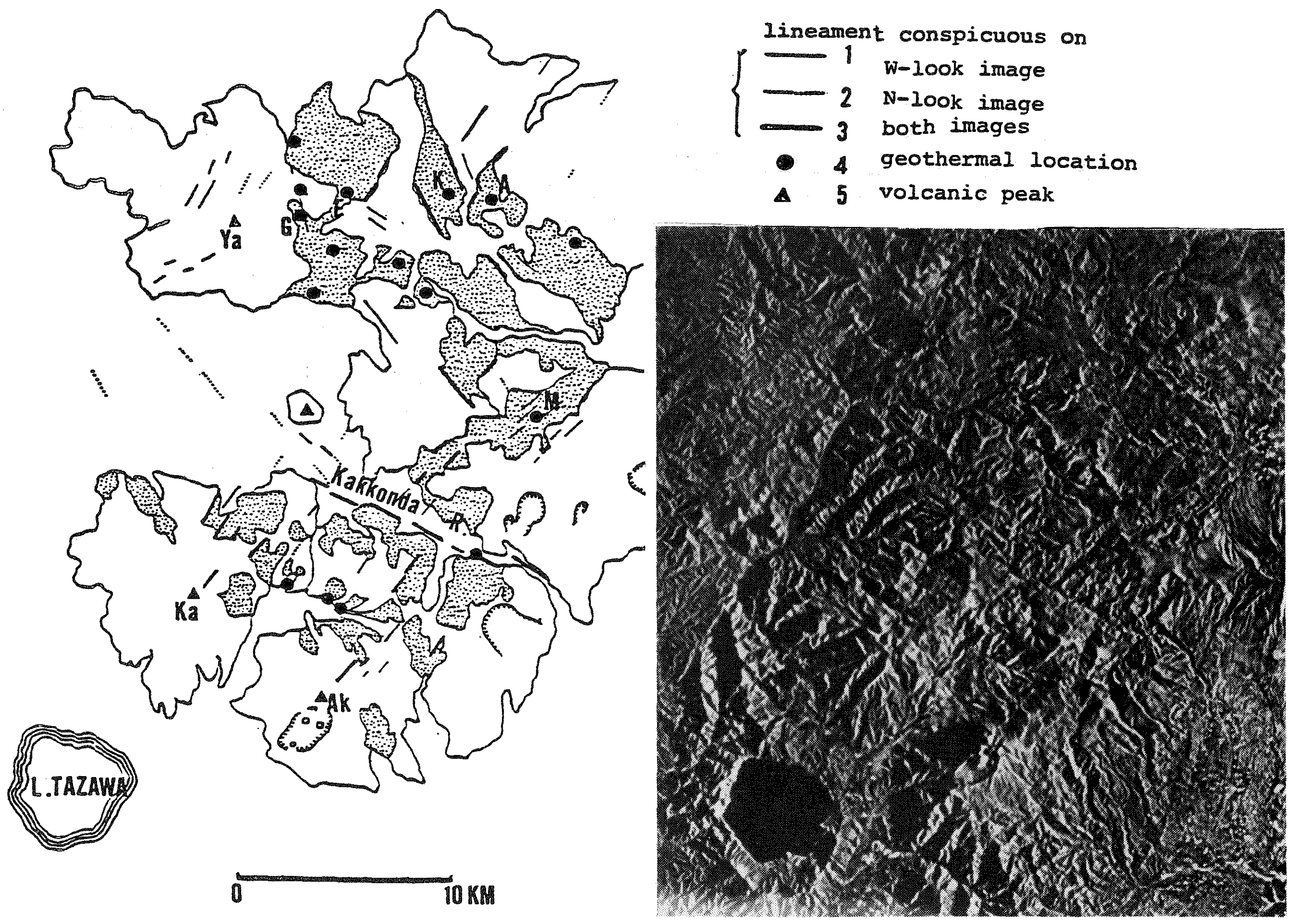


Fig. 3 Development of semi-circular topographic feature and land slides in the studied area
West look airborne SAR image (right) shows these feature well



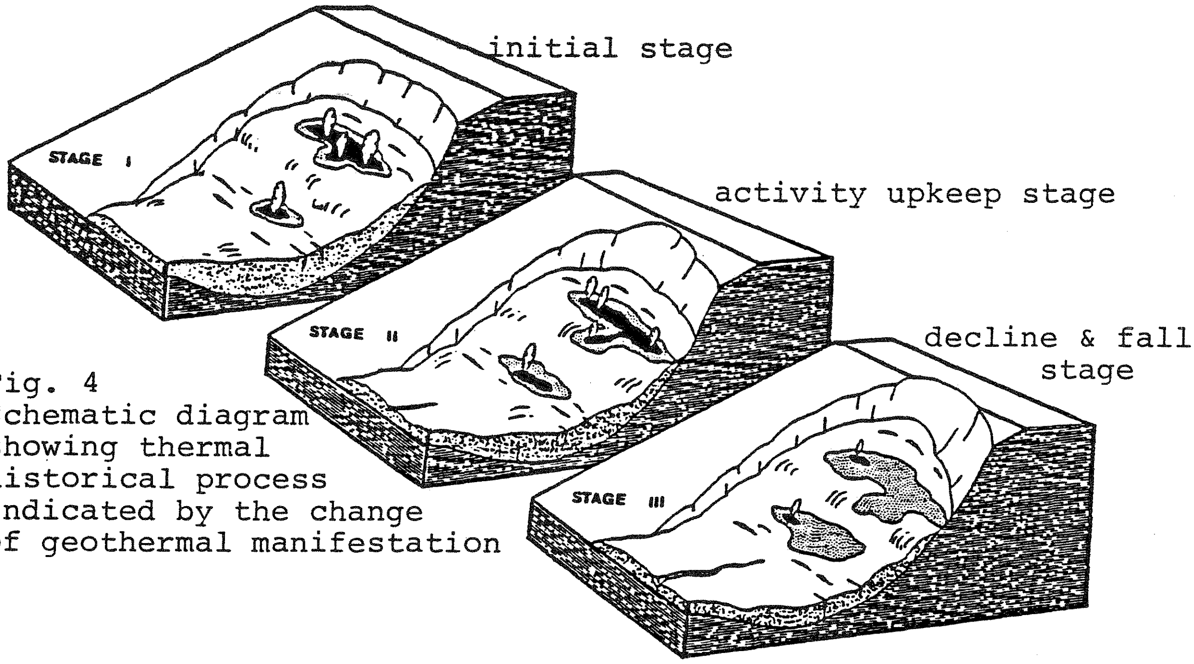


Fig. 4
Schematic diagram showing thermal historical process indicated by the change of geothermal manifestation

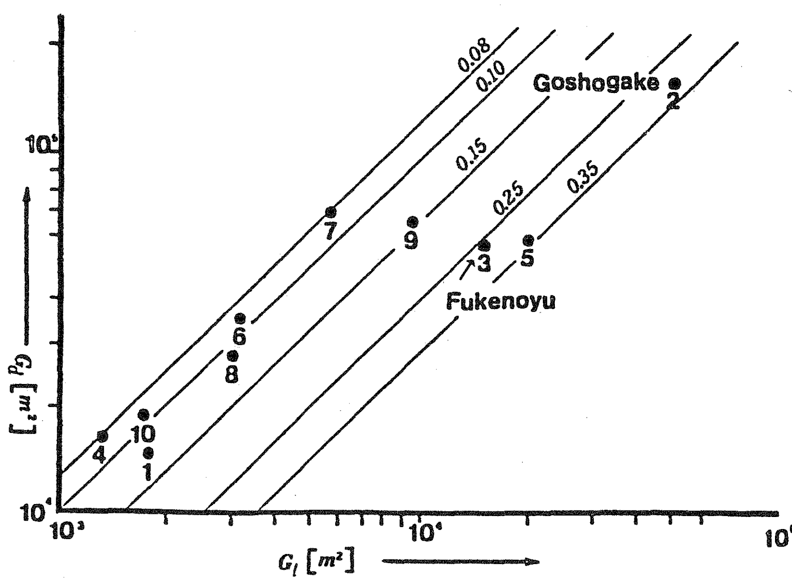


Fig. 5
Iso-chronal relation of geothermal locations in the studied area
(for location name refer Table 1)

G_l ; geothermally live surface

G_d ; geothermally altered bareground

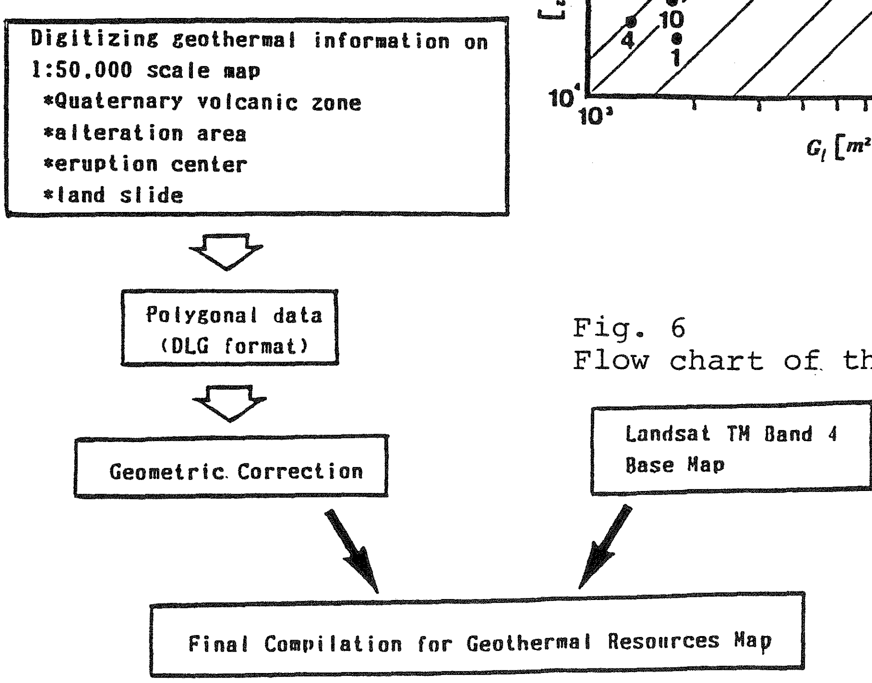


Fig. 6
Flow chart of the compilation