GEOTHERMAL SURVEY USING THERMAL INFRARED REMOTE SENSING IN JAPAN

by

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ABSTRACT

Geothermal energy is thought to be an important domestic energy source in Japan. In the national survey of geothermal resources, aerial thermal infrared remote sensing has been applied and five areas were selected as the survey area. The merits of the survey are rapid mapping of thermally anomalous spots and visual effect. Particularly an alignment of thermally anomalous spots characterized by fumaroles is closely related to fracture pattern and thus this method is useful to understand shallow underground geothermal phenomena.

1. INTRODUCTION

Concentration of geothermal energy in the Japanese Islands is remarkably high reflecting active tectonism along the Circum-Pacific Orogenic Belt in part of which the Japanese Islands Arc is located. Yearly energy discharge by volcanic activity in the Japanese Islands is estimated to be 7 x 10^{23} erg, which is 10% of the total yearly global discharge. The total of continual heat discharge from all hot springs in Japan is calculated to be 2 x 10^{22} erg allowing some analogy. The geothermal energy, therefore, is thought to be the important domestic energy source in Japan.

Current geothermal production wells are dug into a depth not deeper than 2,000m from the surface. Exploration of this "comparatively shallow" geothermal reservoir, which is the current object of exploitation, depends its clue upon the surface manifestation such as hotsprings, fumaroles, or alteration zone.

Mapping of the distribution of thermally anomalous spots by the application of thermal infrared remote sensing technique is expected to provide a direct information for the purpose.

The study of thermal infrared imagery for geologic and geothermal purposes was commenced in 1965 in Japan and the result is being comprised to the current nationwide geothermal surver program.

2. OBJECTIVE OF AERIAL THERMAL INFRARED SURVEY IN THE NATIONAL SURVEY OF GEOTHERMAL RESOURCES

The national gerothermal resources survey program in Japan was started in FY'73 (April 1, 1973 - March 31, 1974), selecting thirty potential geothermal areas characterized by conspicouus geothermal anomaly, especially with fumarole and hotsprings of boiling temperature(Fig. 1). The program is included in a long-term new energy research and developmnet program named "Sunshine Project".

Geological Survey of Japan takes charge of the summarization of the geothermal survey and most of field surveys are being carried on by contract base with private companies under the supervision of the Geological Survey. Principal survey items are ground heat discharge survey and alteration survey. The both survey items cover thirty areas.

Thermal infrared airborne survey, electric survey, seismic survey, and gravity survey are applied to the sreas where useful information is anticipated.

The merits of the aerial thermal infrared survey are rapid mapping of the distribution of thermally anomalous spots and visual effect. The mapping of thermally anomalous spots in an inaccessible volcanic area or in a near shore area where an exact location of shallow subaqueous hotspring is hard to be found, the use of aerial thermal infrared remote sensing method gives the greatest merit. At the same time, visual understanding of a surface geothermal distribution makes possible the interrelation between the surface temperature anomaly and fractures as a heat transfer path. Particularly, in the area where geothermal anomaly is characterized by fumaroles, good correlation is observed between them.

Finally five areas were selected for the aerial thermal infrared survey and they partly cover seven areas among the thirty areas of the national geothermal resources survey area (Table 1,refer to Fig.1).

Table 1. Aerial thermal infrared survey area

No.	Name of area	Location	Latitude	Geology	Objective of survey
1.	Souther part of Shirane	Central Japan	36 30'N	Quaternary volcanic area	Understanding of structural interrelation, correlation of seasonal change of imagery with previously obtained
2.	Satsunan	Southern Kyushu	31 15'N	Quaternary volcanic area	understanding of structural interrelation
3.	Izu	Central Japan	34 30'N	Tertiary to Quaternary volcanic area	Shoreline spring, thermal appraisal of Quaternary lava dome
4.	Hachimantai	Northeast Japan	40 N	Tertiary to Quaternary Volcanic area	Understanding of structural interrelation, new finding of geothermal spot
5.	Hakusan	Central Japan	36 N	Quaternary volcanic area	New findnng of geothermal spot

The quantitative measurement of surface heat discharge is not tried in the survey. As mentioned before, the detailed ground heat discharge survey is being made digging bore holes up to 10m deep as one of other items of the survey. Major heat discharge is made by outflow of high temperature hotspring, which is underratedly shown on the imagery. Image distortion caused by topographic effect to the scan direction, unappropriate V/H ratio, and rolling, the pitching and yawing of the airplane gives innegligible effect for the quantitative measurement (Fig. 2a, b, c).

3. BACKGROUND OF THERMAL INFRARED REMOTE SENSING FOR GEOTHERMAL PURPOSE

After the encourageous result of thermal infrared surveys of Hawaiian volcanoes (Fischer and others, 1964), the Geological Survey of Japan started the study on the application of thermal infrared technique and under the joint research contract with the Geological Survey, the Nippon Electric Company constructed the first thermal infrared airborne sensor named "Infravision III" for geologic and other general purposes in 1967 (Matsuno and others, 1969/70). However, after comparatively smooth research progress that time, there was a little time gap to commercial uses of the remote sensor mainly because of lack of social concerns and needs.

Environmental problems resulted from the Japanese abrupt economic expansion became strong incentive to the progress and utilization of remote sensing techniques. The first commercial application of the thermal infrared airborne sensor is the mapping of thermally polluted water discharged from the industrial area along the seashore area.

In the summer of 1972, the summer course of the Japan Society of Photogrammetry was held in the Manza Hotsprings, Gunma Prefecture, aiming at the effective use of thermal infrared remote sensing techniques for geothermal and volcanologic purposes. The Nakanihon Koku aerial survey company and the Fujitsu Co. cooperated with us in the summer course, and the Nakanihon Koku Co. made a demonstration flight over the Kusatsu-Manza area prior to the opening of the summer course. The flight was done in the moonlight by single-engined Cesna-206 airplane. The scanner used is named "JIRCO" scanner which is one of basically the thermal mapper of the AGA Co. and modified by the Nakanihon Koku Co. The imagery obtained was exhibited to the attendants and was convinced the applicability for the purpose. During the same course an imaging test of a selected thermally anomalous spot in the area by a land-use thermal infrared imaging instrument constructed and named "Infra-Eye 501" by the company, attracted the interest of volcanologists attended the meeting.

The launching of the Earth Resources Technology Satellite (LANDSAT-1) and the release of the MSS data by NASA made a new epoch in the remote sensing.

By the outbreak of energy crisis, the exploration and exploitation of domestic energy source-geothermal resource, is accerelated and the thermal infrared remote sensing has been applied to the survey of geothermal energy reserves.

4. POTENCY AND LIMITATION IN THE USE OF AERIAL THERMAL INFRARED IMAGERY

The arrangement of geothermally anomalous spots characterized by fumaroles without/with a little hotwater well relfects shallow underground geothermal structures. Geothermal energy is transferred to the surface through vertical fracture system and due to self sealing effect of such geothermal energy path by educed minerals dissolved in thermal water, or secondary alteration minerals formed by high temperature geothermal fluids, fractures grdually tend to be sealed off, and only fractures with wide openings, or fractrures whose openings are being maintained, are effective as a heat trasfer path. Such open fracture is mostly fault and sometimes is an active fault systematically formed under stress field of the area concerned.

The recognition of precise locations of thermally anomalous spots therefore gives clue for the understanding of structurally controlled geothermal manifestation. Aerial thermal infrared imagery makes it possible to understand the distribution of thermally anomalous spots not only "spots" but also as "spots with geological significance."

The authors consider that the greatest potency of aerial thermal infrared imagery for geothermal purpose is in the pictorial interpretation of areal thermal pattern including thermally anomalous spots. Basic methodology of photogeologic interpretation is applied to the interpretation of aerial thermal infrared imagery.

Photogeology has been recognized one of the most effective geothermal survey methods particularly in Quaternary volcanic areas. Informations in relation to fracture pattern, distribution of alteration zone, and mapping and sequences of lave flow units, are efficiently understood by use of aerial photographs. The aerial thermal infrared imagery has the same potency as aerial photograph in view of rapidness and areal understanding of thermal information of the area concerned. Besides it provides also geologic information on thermal property. The information is unique and cannot be replaced by other remote sensing data.

Tonal difference appeared on the aerial thermal infrared imagery is:

1) anomalously high geothermal pattern

2) open water

3) vegetation pattern due to the difference of emittance and the difference of the formation of dew film between broad leaf and needle leaf

4) residual effect of differential solar insolation on the sunny side surface and shaded surface during daytime

5) difference of thermal property (thermal inertia) of rocks and soils caused mainly by the difference of moisture content within the pores

6) adiabatic temperature change effect caused by the difference of elevation

7) temperature inversion

From our experience, it is said that the smallest thermally anomalous spot detected by the imagery obtained from the air about 1,000m high above the ground surface shows conspicuous manifestation at the site and it may not be overlooked by geologists who had a chance to visit that site.

On the other hand, large scale imagery obtained from the air about 600m high above the ground surface detects inconspecuous geothermal anomaly diffecult to depict by the field survey.

In the Japanese geothermal field, vegetation is generally quite rich and verge on geothermal bareground. A concentrically circular arrangement is observed on the vegetation growth pattern. The typical case is seen at Gosho-gake of the Hachimantai geothermal area.

The center of a geothermal spot is hot pool, fumarole vents, mud pot, or mud volcano, and to the outside it changes from convection dominated hot ground, convective and conductive zone, and to conductive zone. First vegetation nearby the center is short grass zone consisting of retarded tall grass and plant of resistive against geothermal environment represented by high acidity and high rate of heat flow. The outside is tall grass zone such as miscanthus or bamboo grass then replaced by shrubby zone which merges into forest tree zone (Fig. 3).

The development of vegetation at a geothermal ground is affected by:

1) abnormally high rate of heat flow preventing the development of root

2) groundwater containing volcanic gas constituent

3) volcanic gas from fumarole and other sources

It is known that relatively high percentages of sulfur are accumulated within leaves of plants growing in geothermal area (Minohara, personal communication).

The concentrically circular distribution of vegetation may be elongated to leeward of a local prevailing wind and also downward direction of groundwater movement.

Detectable geothermal anomaly by thermal infrared imagery from surrounding thermal pattern is limited to that of heat discharge of more than one hundred times greater than the average crustal conductive heat flow (calculated to be 1.5×10^{-6} cal $cm^{-2}sec^{-1}$), according to the experimental measurement thus far made (Hase, 1974).

5. PROCEDURE OF SURVEY

Aerial thermal infrared survey consists of three parts. They are, 1) preliminary survey, 2) concurrent-with-flight survey, and 3) check survey (Fig. 4). Private aerial survey companies take charge of imaging flight under the contract with the Geological Survey of Japan. The airplane used for the survey is single-or twin-engined airplanes. The flight is made before lacal sunrise and an airplane takes off an airport nearby the survey area which has nighttime take-off facility in midnight. The navigation and imaging flight are done by eye-sight navigation in the moonlight. Therefore the date of the survey is limited to about a week around full moon in a month.

The flight course determination, confirmation of tele-communication network in order to promptly follow up the abrupt change of local weather condition, nighttime light target set up, and the determination of temperature measurement point are important and have to be fixed prior to the flight. These preparations are done in the preliminary field survey.

In the aerial thermal infrared survey, imaging flight in the southern part of Shirane, Satsunan, Izu, and Hakusan areas was done by the Nakanihon Koku Co. and that in the Hachimantai area was done by the Japan Weather Association jointly with the Toho Koku Co. Temperature measurement at the positions previously set up and recording of weather condition are made in parallel with the concurrent-with-flight survey.

The source data are converted into image form from magnetic tape within a week. This is a rough imagery for field check survey. It is necessary to do the field check as soon as possible after the flight. Particularly in Japan, many of geothermal areas are included in National Parks and in some case, with hotspring resorts. For example, all of five the areas selected for the aerial thermal infrared survey are included in the National Parks respectively.

The distinguishment of "natural" geothermal anomaly from artificial heat source has firstly to be done.

Thermal spot such as a municipal incinerator located at the remote place from residential area and a bonfire coinstantaneously made at the time of imaging flight have been misinterpreted to be natural geothermal anomaly and corrected by the check survey.

In the imagery obtained from mountainous geothermal area, the resolution along the valley bottom is inferior to that of the mountain top and sometimes become insufficient so as to distinguish hotwater discharge pattern from the "normal" river water pattern. A quasi temperature difference pattern resulted in partial cover of tree canopy over the river water surface makes difficult the judgement without field check survey.

6. EXAMPLE OF THE SATSUNAN AREA

The area is located in the southernmost part of Kyushu. The area occupies the western part of the Quaternary Ata caldera that is more than 10km in diameter. The outer rim of the caldera borders the area. The Kaimon-dake stratovolcano, which is the highest peak in the area(922m), lava domes, caldera lake, and geothermal anomaly in the area, characterize volcanic topography.

The basement rock of the area is Jurassic to Paleogene rocks crop out in the northern to northeastern part of Lake Ikeda. The rocks consist of sedimentary rock and andesitic volcanic rock, which encountered hydrothermal alteration. Thick Quaternary volcanic products unconformably cover the underlying rocks. (Ota, 1966).

Geothermal anomaly develops in the area is, fumarole dominated geothermal anomaly in the mountain side, hotsprings in the Alluvial low land, and subaqueous hotsprings along a part of beach line (Fig. 5). The sandy beach of Ibusuki is well known by the spot of natural sauna baths using heated sand by geothermal energy.

Seven flight courses of total of 71km were flown, among which six courses had the same NE - SW direction and the other course was perpendicular to these courses, in the NW - SE direction (Fig. 6). Flight altitude is 1,100m above the sea level except one course which was flown with the altitude of 2,000m since the Kaimon-dake volcano was lying along the swath. The flight was done during 0550 - 0630 JST on Oct. 16, 1973. The local sunrise of the area (31 16'N) was 0622, but there was no direct solar insolation by the end of flight because of 90% could cover concealing the horizon.

The scanner used was the remodeled thermal mapper of the AGA Co. Total F.O.V. of 80 degree was imaged using wavelength region from 4.7 - 5.1 um (since the next imaging flight on, HgCdTe detector mounted scanner has being used).

Geothermal anomaly characterized by fumarole

According to the result of aerial photo-interpretation of the area, many linear features and circular features are depicted. Particularly typical volcanic depressional topography represented by Lake Ikeda, Unagi, and Yamakawa aligns having NW - SE trend. Fractures predominantly develop on the mountain slope of NE side of this alignment. On the other hand, fumarole dominated geothermal spots develop in the northern part of Unagi and they are observed in topographic lows interpreted as linear and circular features delineated by aerial photo interpretation.

After the result of aerial thermal infrared survey, four geothermal spots which are known only by limited local people were "newly found".

Geothermal anomaly by hotspring

Abundant hotwater gushes out from many spots and it is found in the Allubial flat land. Temperature of hotwater ranges in 80 to 30 C and it is used efficiently for bath water of hotels and inns, fish (eel) breeding, or forcing cultivation of plants. Some amount of excessive howwater is discharged into the river unused.

The broadest areal distribution of anomalously high temperature pattern in imagery is observed along the river water surface and fish breeding pond.

Shoreline and subaqueous hotspring

Shoreline hotspring at the sand beach of Ibusuki is clearly shown on the thermal infrared imagery. Also shoreline hotspring gushing out from a part of inner wall of crater rim at Yamakawa is caught in the imagery. However nearshore subaqueous hotspring anticipated at the sea off Yamakawa could not be detected.

Geothermal anomaly in the area seems to be limited within the outer rim of the Ata caldera. Coldspring along the shoreline of Uomi may support the fact.

7. SUMMARY

The national survey of geothermal resource program was started in FY 1972. Among several survey items, aerial thermal infrared survey was applied and five geothermal areas that cover partly seven areas of total thirty areas in the program were selected.

The flight is conducted by private aerial survey companies under contract with the Geological Survey of Japan. The time of imaging flight is limited to be done before sunrise and the flight is done by eyesight navigation in the moonlight.

The merit of aerial thermal infrared remote sensing is rapid and visual effects. The imagery is obtained from the air of 600 to 1,000m hight above the ground surface. Inconspicuous geothermal anomaly difficult to depict by the field survey is detected by the large scale imagery obtained from the air 600m high above the ground surface.

Surface geothermal anomaly represented by fumarole dominated one reflects shallow underground geothermal system. In fact, in the survey of the Satsunan area, southernmost part of Kyushu, good correlation was obtained between the fracture trace pattern interpreted from aerial photograph and alignment of geothermal anomaly displayed on aerial thermal infrared imagery.

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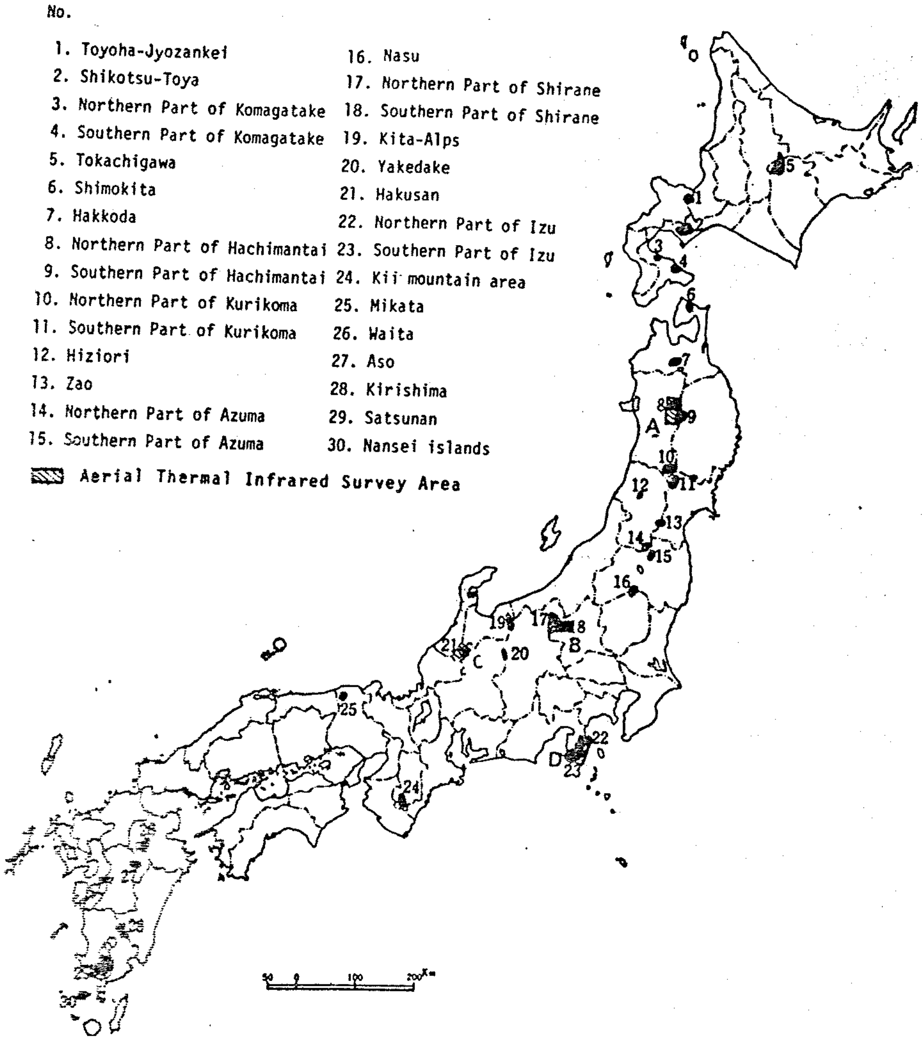

FIGURE 1. Distribution map of the area of the national geothermal resources survey

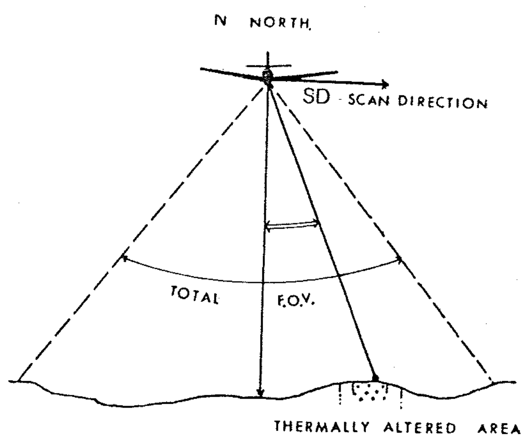

FIGURE 2-a. Index

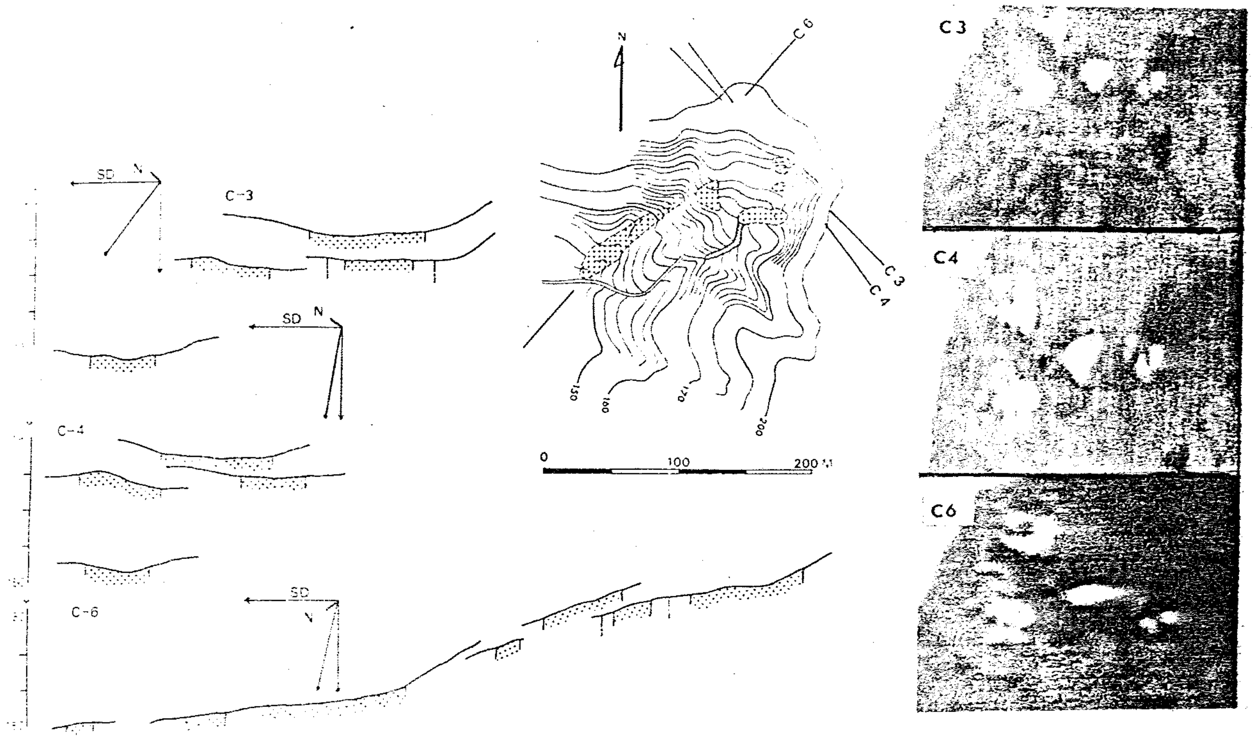

FIGURE 2-c. The same thermally anomalous spots at Unagi, imaged by courses 3, 4, and 6. Spots righthand side to the black spot correspond to dotted area shown

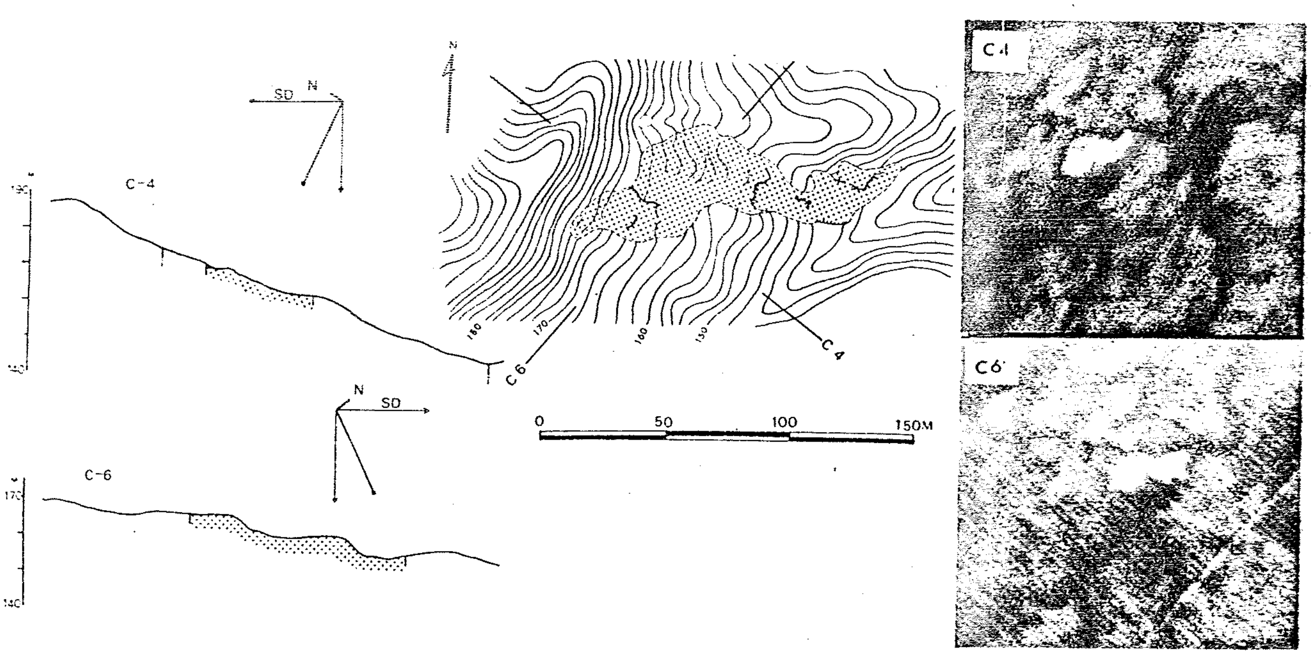

FIGURE 2-c. The same thermally anomalous spot at northeast of Unagi imaged by courses 4 and 6

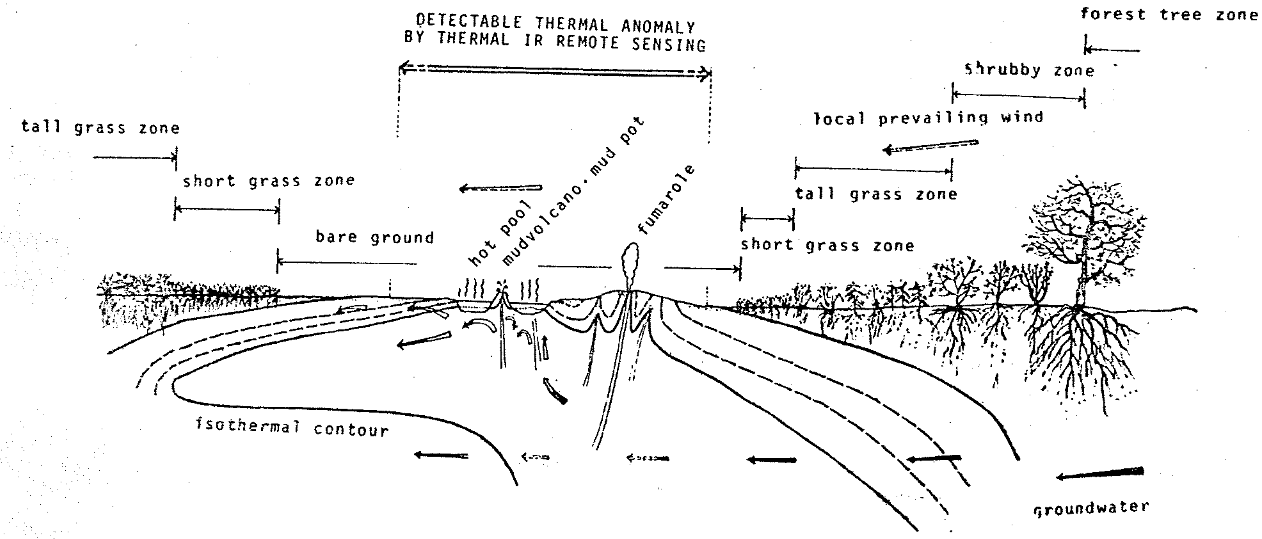

FIGURE 3. Conceptual diagram showing geothermal ground and surrounding vegetation pattern

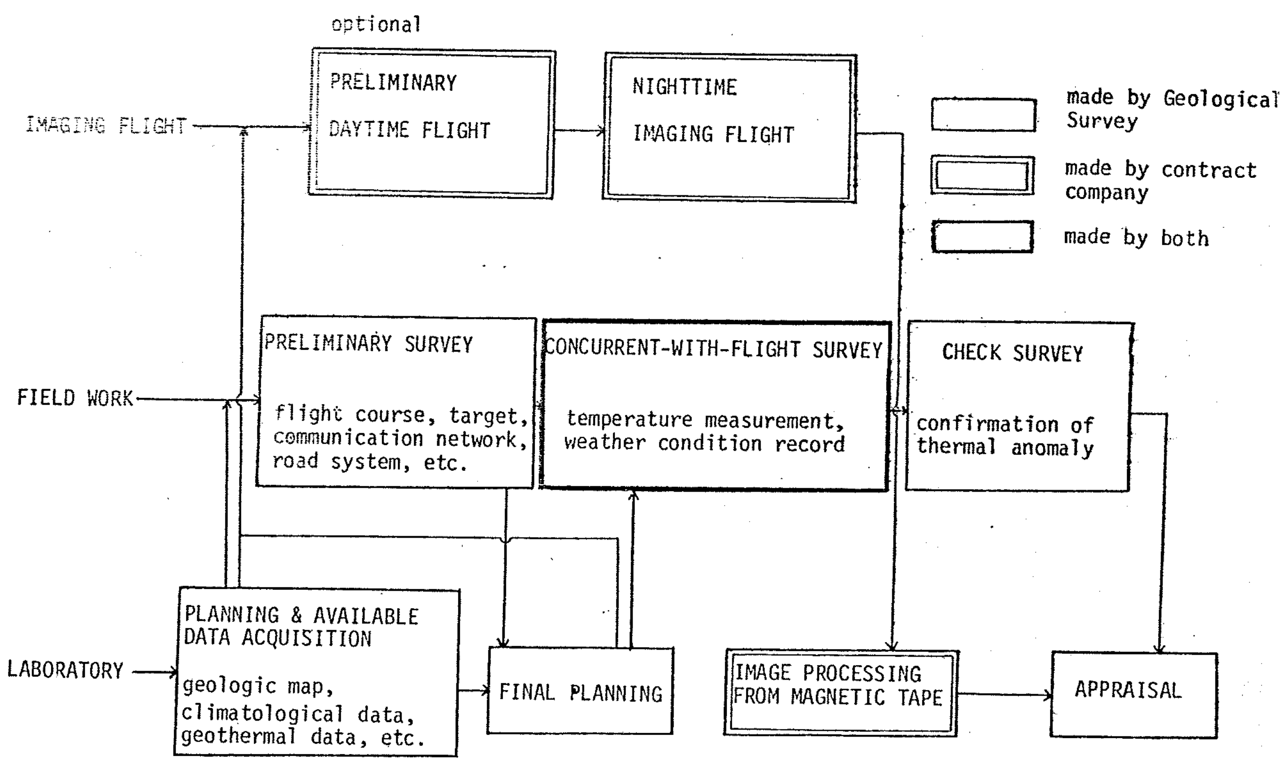

FIGURE 4. Flow chart of aerial thermal infrared survey

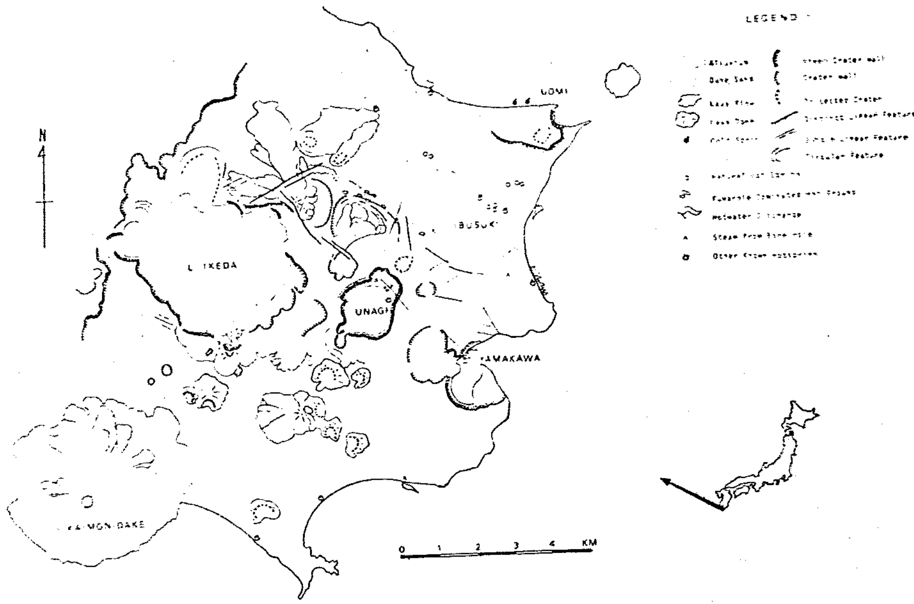

FIGURE 5. Explanation map of the Satsunan geothermal area, Kyushu

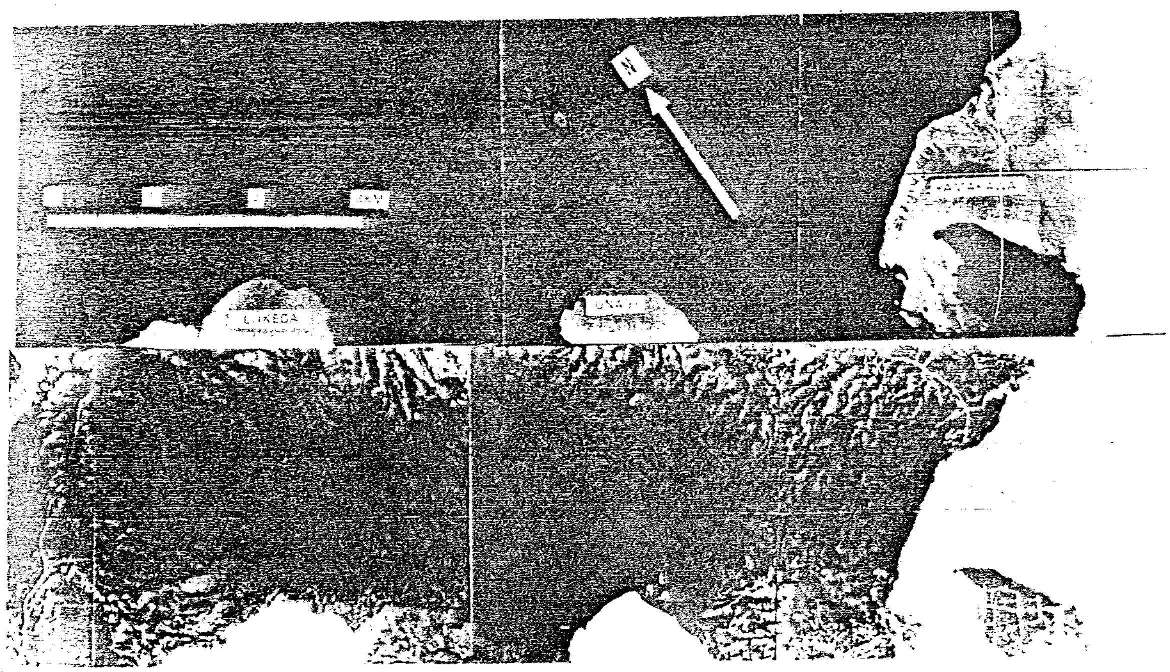

FIGURE 6. Aerial thermal infrared imagery along the course of SE-NW direction