THE REPUBLIC OF THE PHILIPPINES

REPORT ON ACUPAN-ITOGON GEOTHERMAL DEVELOPMENT

SEPTEMBER 1985

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

It is with great pleasure that I present to the Government of the Republic of the Philippines this report on Feasibility Study of the Acupan-Itogon Geothermal Exploration Project.

This report is based on the result of surveys which was carried out from Aug. 1982 by the Japanese survey team following the request of the Government of the Philippines to the Government of Japan.

The survey team, headed by Mr. Y. Sakai, conducted a wide-ranging field survey in order to locate geothermal resources and sank a test well of 2,000 meter depth. The drilling was started at the end of 1984, and the discharge tests were made in May 1985. As a result of various tests, the geothermal structure of the subject area has become clear.

I hope that this report will be useful as a basic reference for implementation of the project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of the Republic of the Philippines and of the Philippine National Oil Company for their close cooperation extended to the Japanese team.

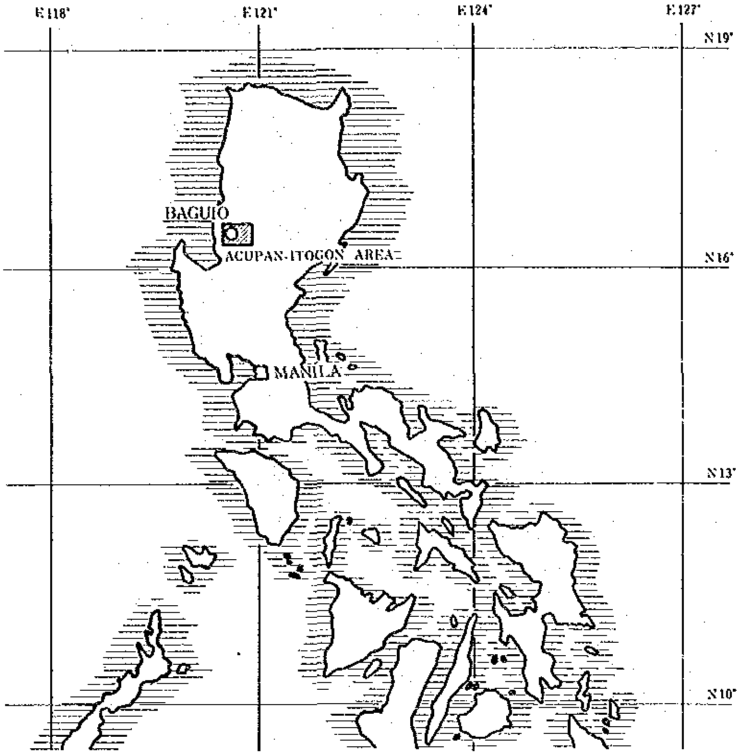
February, 1985

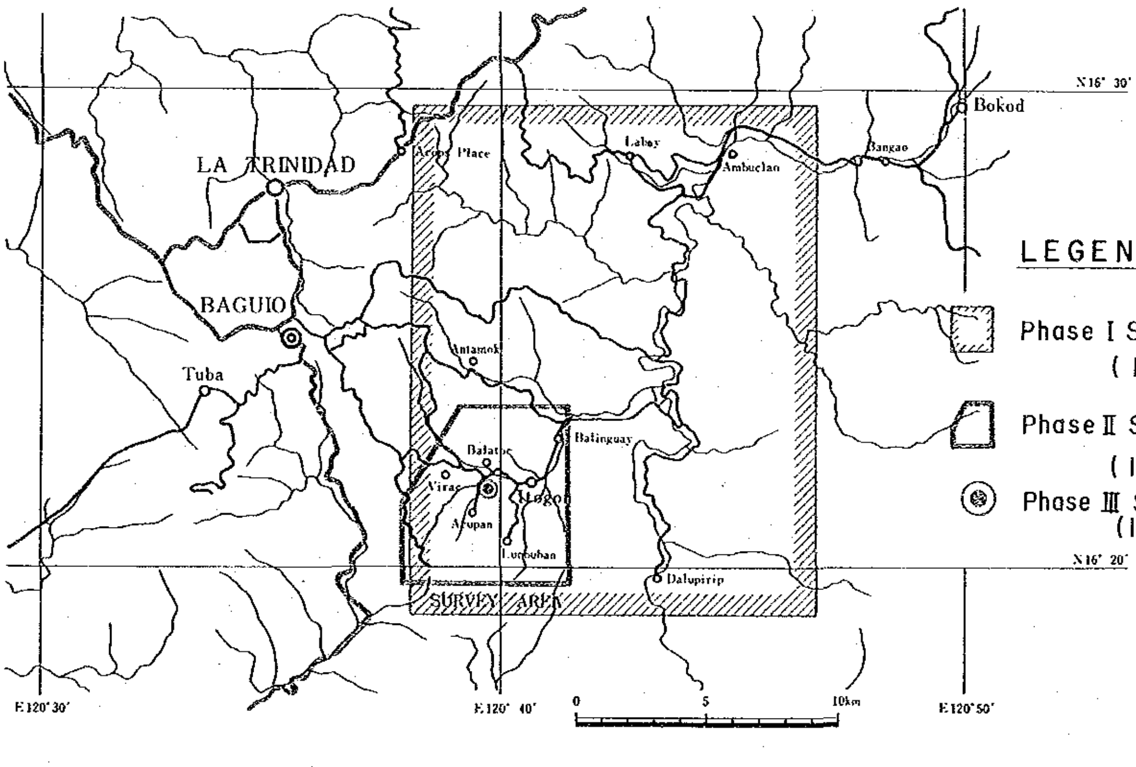
Keisuke Arita

Keisuke ARITA
President
Japan International Cooperation Agency

LOCATION MAP
OF
ACUPAN-ITOGON AREA

PROVINCE OF BENGUET
REPUBLIC OF THE PHILIPPINES





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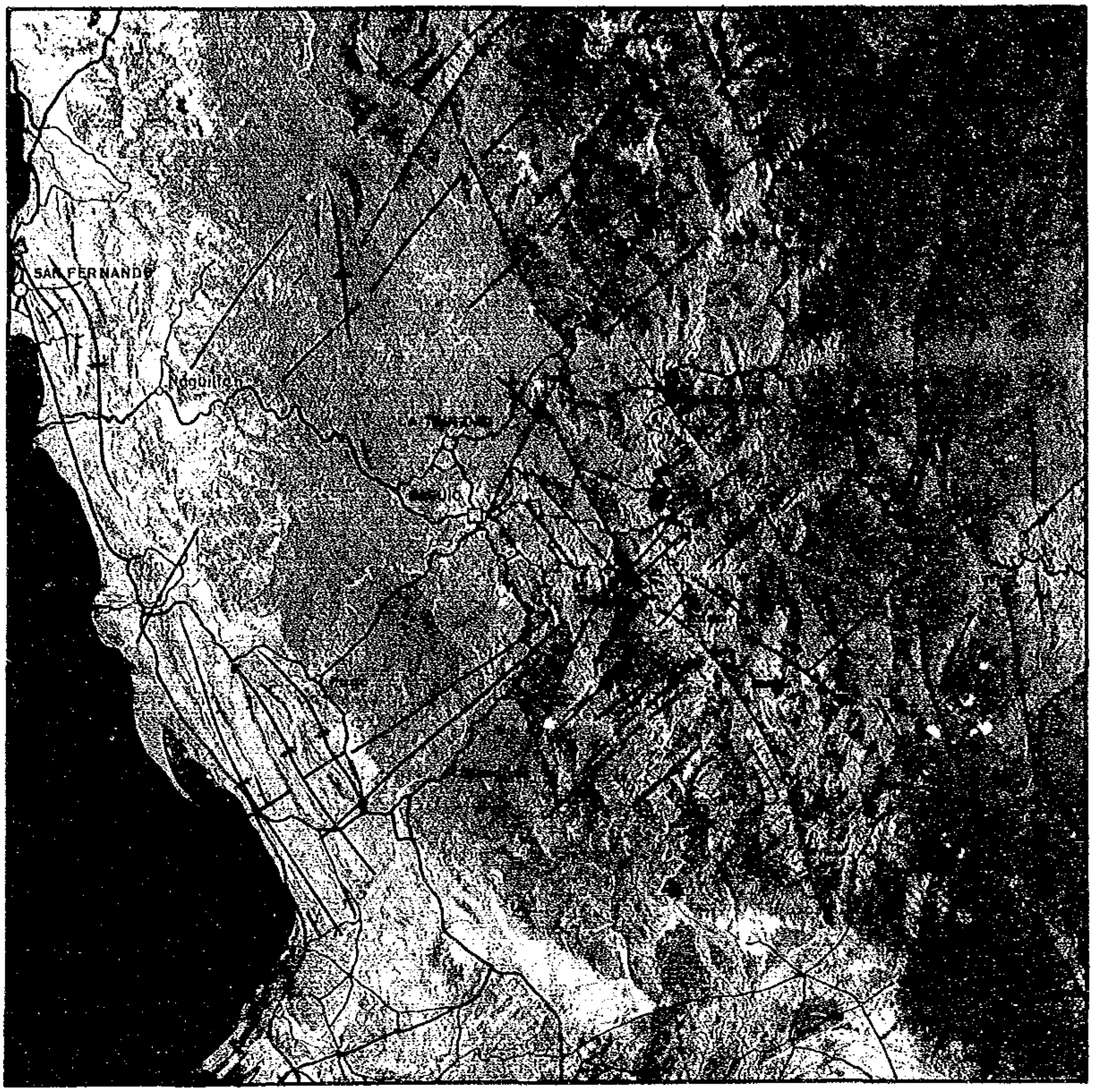
Phase I Survey Area (1982)

Phase II Survey Area (1983)

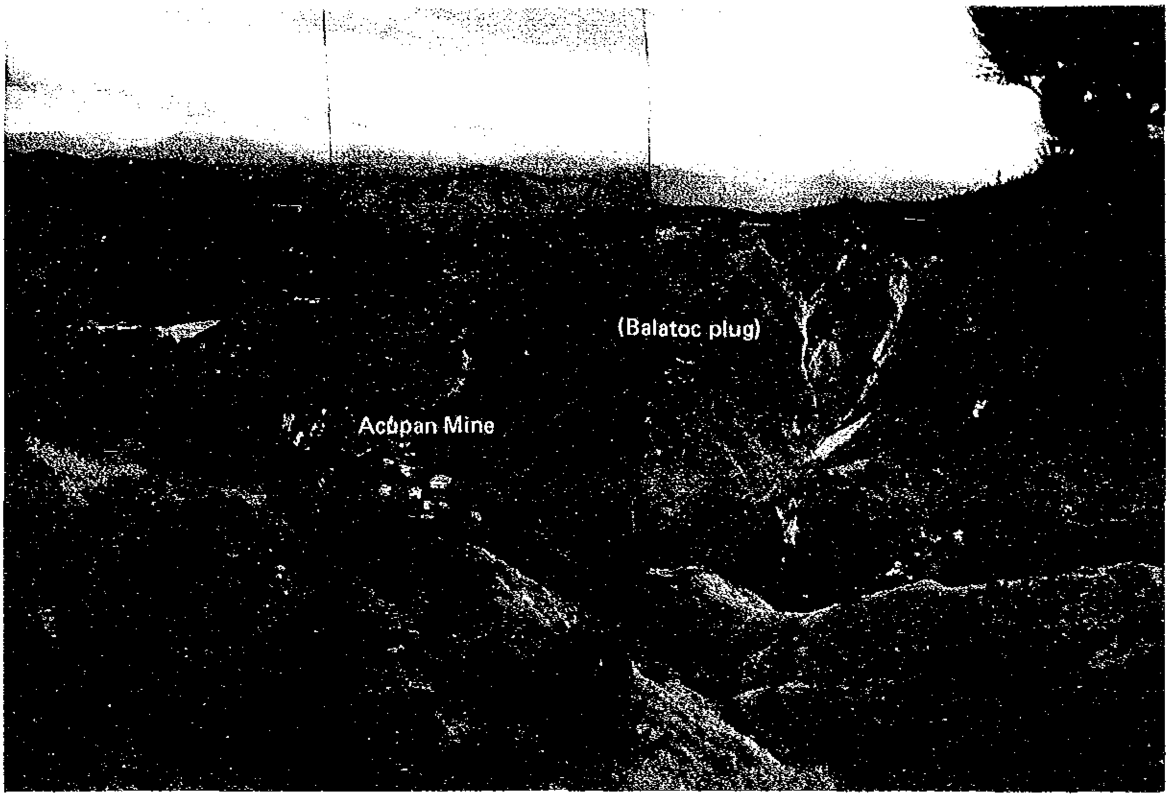
Phase III Survey Area (1984)



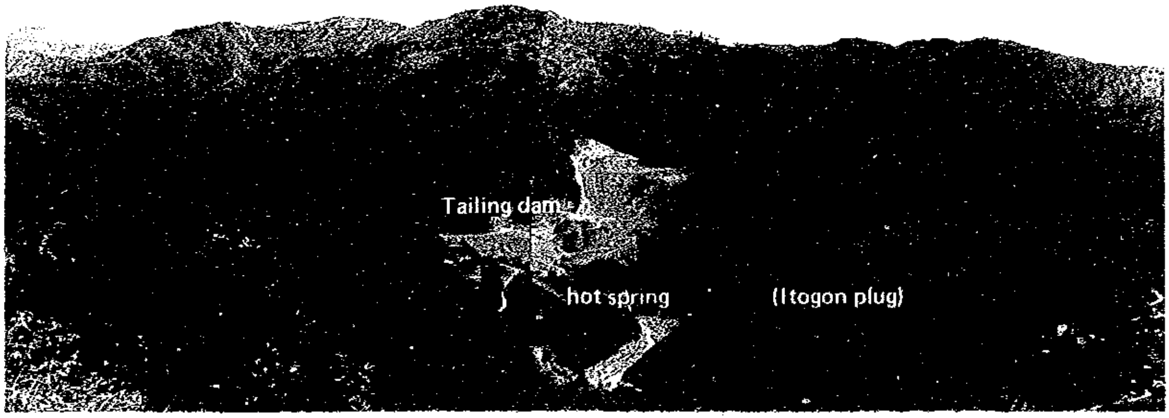
Legend

lineament
anticline
syncline
dip and strike

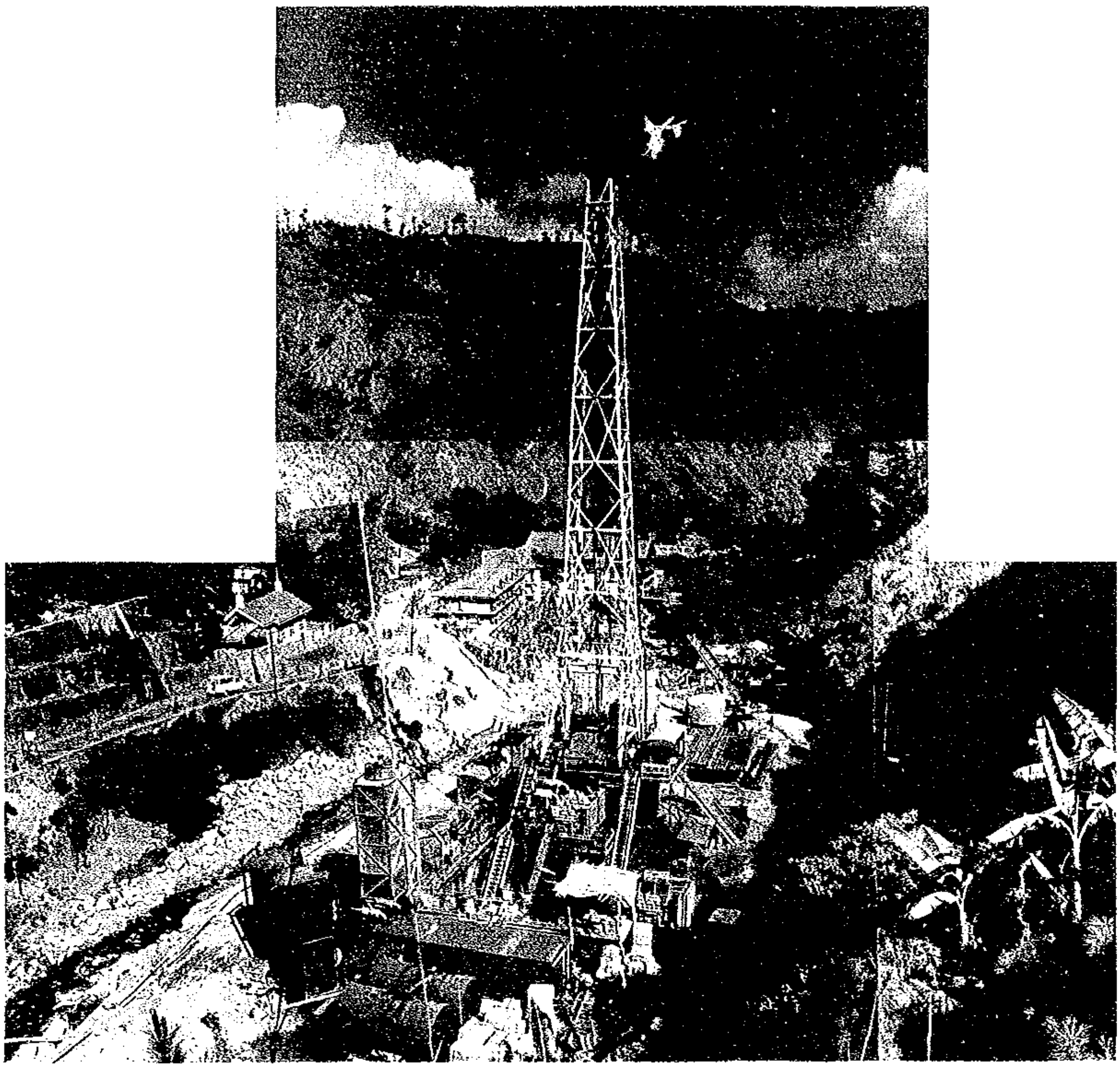
False Colour Imagery of the Land Sat



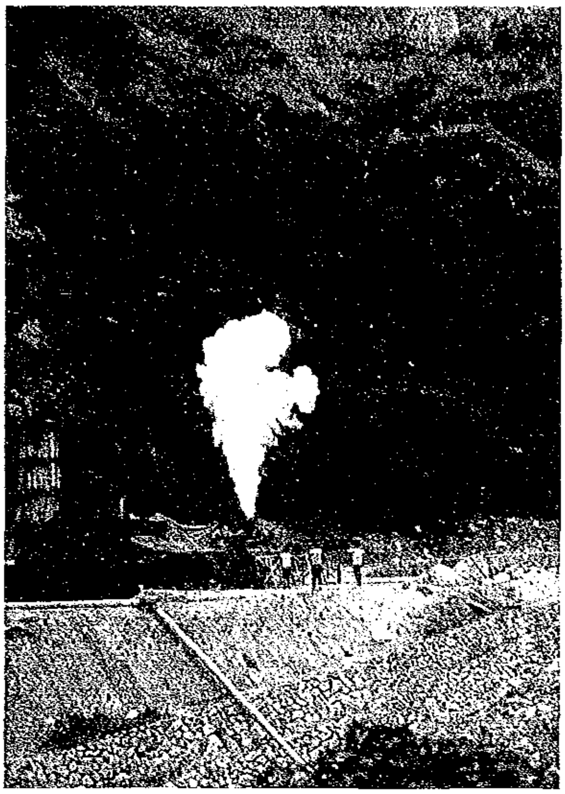
Perspective view of Acupan area



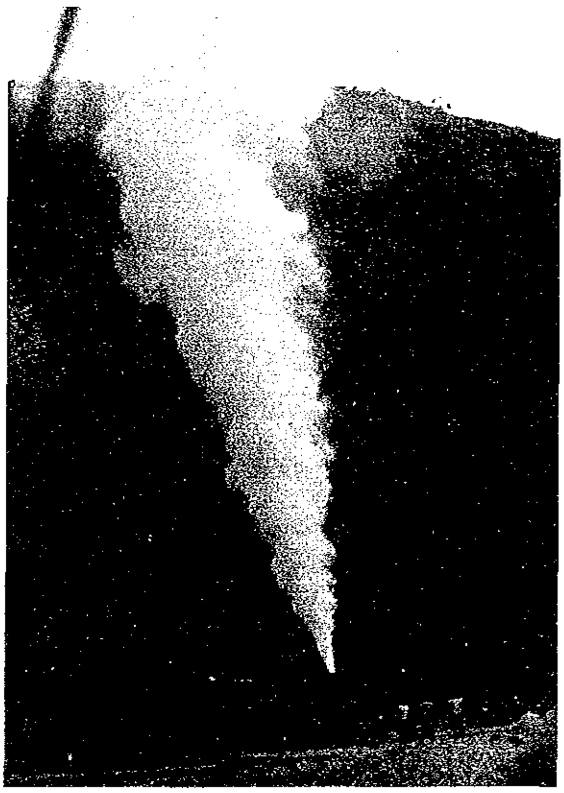
Perspective view of Itogon area

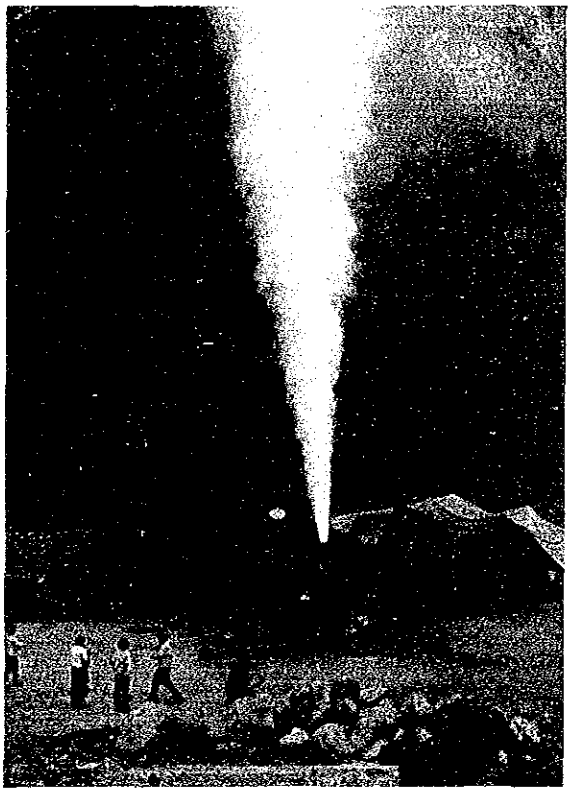


Drilling of the test well (AC – ID) (1)
Jan. / 1985



6:15 p.m.
Start of opening of wellhead valve.





Intensity of steam discharge lasted
for about 45 minutes.

Discharging of the test well (AC – ID)
May 14 / 1985

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ACUPAN-ITOGON GEOTHERMAL PROSPECT

UNDER BED-JICA TECHNICAL AGREEMENT ON GEOTHERMICS

EXECUTIVE SUMMARY

INTRODUCTION

Various geoscientific studies have been carried out in the Acupan-Itogon geothermal prospect in Benguet under the three-phase schedule of the Technical Arrangement on Geothermics jointly implemented by the Ministry of Energy's Bureau of Energy Development and the Japan International Cooperation Agency. Implementation of the work program of the Agreement started in August 1982.

The studies consisted of (a) reconnaissance to semidetailed geological, geochemical and geophysical surveys; (b) drilling of seven (7) shallow thermal gradient holes; and (c) drilling of a 2,000 meter-depth-exploratory well (Acupan-1D).

Geoscientific Findings

The geological setting of the Acupan-Itogon area is characterized by subvolcanic rocks which may be rendered relatively permeable at depth by the northeastern-southeastern structural features.

Thermal manifestations in the area consist of surface hot and cold springs and abundant discharges of hot water and steam in the underground workings of the Acupan mine.

Geochemical data from boiling springs suggest and estimated reservoir temperature in the range of 229°C and 236°C based on chemical geothermometers. Futhermore, the distribution and occurrence of the thermal features reflect a pronounced structural control.

From shallow gradient hole data, a NE-SW ellipsoidal area of

3.5 square kilometer, characterized by temperatures of over 200°C, was delineated at -1,000 meters s.l. This area is defined by (a) the Balatoc and Itogon plugs at the NE and SW trends, respectively; and (b) NE-SW trendings faults and structures at the middle sector.

Results of First Exploratory Well (AC-1D)

The drilling of AC-1D revealed that: (a) a temperature of 220°C was encountered by the borehole; (b) the rock units in the hole have interacted with neutral to weak alkali thermal fluids; and (c) semi-permeable zones were present but were insufficient to sustain continuous discharge.

These results seem to indicate the presence of an active heat source and a structurally-controlled potential reservoir in the prospect area.

Geothermal Model

The Acupan-Itogon thermal reservoir is interpreted to cover an area of 3.5 square kilometers stretching ellipsoidally NE-SW from the Balatoc Plug to the Itogon plug at -1,000 meters s.l. This area is defined by temperature of over 200°C and fracture-controlled secondary permeability which allows for the upflow of thermal fluids.

Based on the total water discharge at the Acupan mines, a heat flow of 33.6 megawatts has been estimated.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Interpretations of Phase-I to Phase-III surveys lead us to the following conclusions:

1. Geological Structure. The Acupan-Itogon area is located at the transitional zone between the Central Uplift Zone and the Western Subsidence Zone, in which fractures are developed quite well. These fractures not only generate secondary permeability for a geothermal reservoir but also act as loci for Late Pliocene to Pleistocene volcanic activities in the region. This means that the Acupan-Itogon prospect can be classified as a fracture-controlled type geothermal system.

2. Resevoir Temperature. Reservoir temperature estimated from silica contents and the alkali ratio of the thermal fluids are 229°C and 236°C, respectively. These estimates are further substantiated by AC-1D's bottom temperature of 220°C.

3. Shape and Size of Geothermal Reservoir. No information from deep zones could be obtained from geophysical surveys such as resistivity survey due to electrical noise caused by mine operation. However, based on data of the seven gradient holes and the test well, AC-1D, the size and shape of the geothermal reservoir above 220°C are assumed to be 3.5 km x 1.0 km, stretching ellipsoidally NE-SW at 1,000 meters b.s.l., respectively.

4. Origin of Hot Springs. The original water of hot springs could be traced to meteoric water recharged by precipitation. The hot spring waters in Acupan-Itogon area can be divided into three types, namely: Na/Cl, Ca/SO_4, and Na/SO_4-HCO_3 type of waters. The Na/Cl type is assumed to be a deep-seated brine of neutral pH. On the other hand, both the Ca/SO_4 and Na/CO_4-HCO_3 types could be steam heated ground water.

5. AC-1D:

A. Well Temperature: Formation temperature increase linearly at a rate of 11°C/100 meters showing a conductive heat flow. Bottom hole temperature of AC-1D is 220°C which is lower than that estimated from gradient holes. This temperature, indicates the presence of active heat source in the area which is a necessary condition of a geothermal reservoir.

B. Well Permeability: Two permeable zones were noted around 1,550 meters and 1,850 to 1,995 meters depths during hydrofracturing test. The injectivity index and the permeability thickness of these permeable zones are 1.79 l/min. MP and 0.259 x 10^{-12} m^3, respectively. The observed low permeability is due to the self-sealing effects of alteration minerals in the fractures. This has been indicated by the depletion of Na in the rocks and the abundance of silica, anhydrites, calcite and clay minerals associated with sulfide minerals.

C. Discharge test: Large volumes of steam discharge could not be expected due to the low permeability, but generally speaking, a certain amount of steam should be expected to flow out. However, the well could not discharge geothermal fluid continuously, even though the well was heaated and stimulated by the injection of compressed super heated steam inside the well. It would mean a shutdown of the channels, reopened by hydrofracturing, during the recovering the temperature for about three months.

6. Simulation of the Geothermal System. Based on the total water discharge in the Acupan mine, the estimated heat flow is 33.6 megawatts.

Two dimensional simulation of the geothermal system indicates that: (1) permeability of 10^{-15} -$10^{-6}m^2$ almost equals with the observed permeability of AC-1D. (2) the heat source widens at depth.

7. Potential of the Geothermal Resources. The Acupan-Itogon geothermal field is covered by a thick self-sealed zone. However, according to the two-dimensional simulation of thermal fluid, the high-temperature zone could spread widely in deep strata, although permeability of the reservoir should be low at its upper part. The reservoir temperature determined by the test well exceeds 200°C, and the thermal fluid of neutral brine is assumed to be appropriate for geothermal power generation. Considering the increase of the bore hole temperature of the test well, the temperature is assumed to become high in the reservoir at deep strata, where the self-sealed zone is no longer expected. The fractures trending N-S and NE-SW in direction would reach down to the deep strata, and would act as space and as channels for the thermal fluid.

Considering the economic viability of Acupan-Itogon prospect to the thriving population of Baguio City and mining industries in the area, the prospect warrants further exploration.

Recommendations

An additional survey is recommended to test the geothermal model obtained from the survey results of Phase-I to -III and confirm the geothermal resource potential of the area. This will include the following:

1. Fracture Analysis of the Area. This will facilitate interpretation of the distribution of potential fractures.

2. A study of the hydrology and heat flow.

3. To drill an additional test well under the following conditions:

a. The drilling site and depth of the test well shall be determined by: environmental effect of the area; acceptance of the local residents for the continuous well test; and, application of the previously obtained survey results and geothermal model.

b. The maintenance and examination of well logging equipment and so forth shall be satisfactorily performed upon execution of each logging job on the test well.

c. Stimulation method most appropriate to the well shall be applied, e.g., in the case of a well with low permeability, enhancement of permeability shall be made by swabbing or air lift.

4. Judging from the high geothermal potential and stringent conditions of the area from an energy view-point, the establishment of a development organization, including mining companies, are required to implement an effective additonal survey.

CHAPTER I SUMMARY

CHAPTER I SUMMARY

1-1 Reservoir Parameter

1-1-1 Geology

The geological structure of Northern Luzon is basically made up of the Central uplift zone and Subsidence zones of both its sides formed in the north-to-south direction. The majority of Quaternary volcanic rocks are localized in the Central uplift zone with a north-to-south trend. Geothermal manifestations are frequently found in the vicinity of the Quaternary volcanoes.

The investigated area is geologically situated at the transitional zone between the Central uplift zone and Western subsidence zone.

Quaternary dacite plugs, considered to be genetically related with the present geothermal activity of the area, are studded in the direction of northeast to southwest and north-to-south.

Geology of the Central uplift zone in the area is comprised of metamorphic rocks (Dulupirip schists), meta volcanics (Pugo formation) and quartz-diorite (Agno batholith). Likewise, that of the Western subsidence zone consists of Miocene andesite and pyroclastic sediments (Zigzag formation, Klondyke formation). At the boundary between the Central uplift and the Western subsidence zone are volcanic activities of early Pliocene Virac granodiorite, late pliocene andesite, and late Pleistocene dacitic plugs.

The geological setting in the transitional zone of the area is mainly characterized by north-south, northeast-southwest, and northwest-southeast faults and fold structures with trending north-south and northeast-southwest.

On the basis of strike frequencies of dykes and mineralized quartz veins prevailing in the area, it may be inferred that north-south, northeast-southwest, and northwest-southeast fracture systems are well developed.

These fracture systems are, however, not common in Antamok diorite and Itogon quartz diorite in the uplift zone.

Based on the analysis of fractures and vein systems in the area, development of a significant structural framework seems to be originally generated within the transitional zone located at the periphery of the uplift zone during the upheaval movement.

The heat source of the geothermal system in the area seems to be closely related to the subvolcanic activity of Pleistocene dacitic plugs which occurred near the Itogon Bridge and Acupan Mine, and the geothermal system is structurally controlled by north-south, northeast-southwest and northwest-southeast trending faults and fractures developed at the periphery of the Central uplift zone.

The Balatoc plug is located at the cross point of north-south and northeast-southwest fractures, while the Itogon plug is also situated at the intersection of northeast-southwest and north-south fractures.

Auriferous quartz veins and fault systems such as the Golden Gate and Star fault are well defined, trending northeast-southwest at the Acupan Mine and between the Balatoc and the Itogon plugs.

It may be said that upheavals of the Central uplift zone as well as associated structures have induced a hypabyssal intrusion of the Pleistocene dacitic plug, considered as the possible heat source of the geothermal system in the Acupan-Itogon prospect area.

1-1-2 Heat source

Auriferous mineralization prevailing in the investigated area is regarded as part of the geothermal indications in a broad sense. In fact, whitish argillized zones derived from mineralization are generally observed at many places, as well as geothermal manifestation. The heat source of the geothermal system in the prospected area seems to be related to subvolcanic activities from late Pliocene andesitic volcanics (Old plug) to late Pleistocene dacitic pyroclastics (Young plug) and its intrusive dacite.

In surrounding plugs, high-temperature hot water is discharging. This hot spring water suggests high subsurface temperature from readings of geothermometers.

Especially, significant geothermal indication are revealed underground at the Acupan Mine, which are related to the Balatoc plug, and hot springs discharging near the Itogon Bridge are related to the Itogon plug.

On the basis of geological and geochemical points of view, the detailed survey area was delineated to be the Acupan-Itogon area, where plugs existed. Distribution of surface soil temperature does not reveal any anomalous values, even though the area is considered to have a high-potential geothermal reservoir existing underneath it. The reason for no anomalous temperatures indication is not clear, but it may be inferred that there are:

- many geological fractures on the volcanic activity causing the heat source of the reservoir.
- self-sealing effect caused by mineral deposition from geothermal fluid.
- depression of the water level due to underground mining at Acupan.

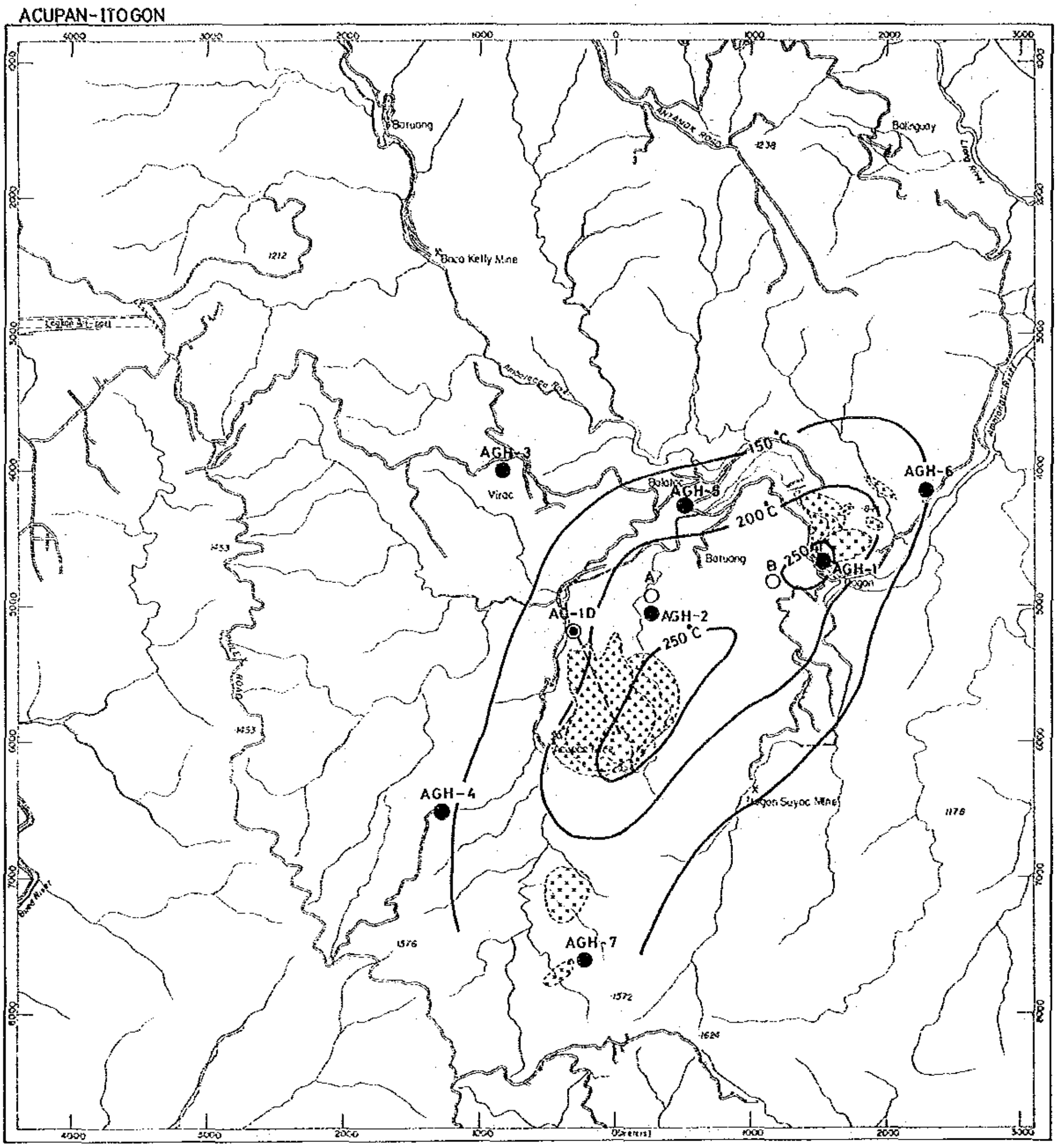
Relations, however, between location of the Balatoc plug and rock temperature distribution in the underground at Acupan shows a clear correspondence. In fact, the surrounding rock of the plug was brecciated along the periphery of the plug by its up-and-down piston movement. The brecciated zone played a role as is the passage of geothermal fluid, raising rock temperature along the brecciated zone.

On the other hand, rock temperature of the plug core is not very high due to having less permeability than its peripheral zone.

As shown on the soil temperature map and the Hg concentration map of the surface, their anomalous zones appear at the peripheries of the Balatoc and the Itogon plugs.

This map reveals hot thermal fluid ascending through permeable structures and reaching the surface along the peripheries of the plugs. The upflow of geothermal fluid, therefore, is assumed to be principally controlled by the location of the plugs.

Subsurface temperature contour lines at 1,000 m b.s.l. show the distribution of over 200°C extends in the NE-SW direction with the same arrangement as the Balatoc and the Itogon plugs (Fig. I-1-1). An area of a high potential zone of over 200°C spreads about 3.5 km x 1 km in an oval shape. The increasing rate of temperature by depth shows 10°C/100 m, however the reservoir boundary toward NE-SW is very sharp. The anisotropic characteristic of the temperature increase rate between reservoir's NE-SW and NW-SE direction is considered to result from the fact that the ascending fluid is not only controlled by brecciation of the plug movement, but also by the geological structure of NE-SW direction fracture system such as the North and Star faults (Fig. I-1-2).



0 200 1000 2000 m

LEGEND

- gradient hole
- test well
- proposed drilling site for test well
- isothermal line (-1000m a.s.l.)
- dacite plug
- young plug
- old plug
- isothermal line at -1000m a.s.l. (200°C)

Fig 6

Disposition map of gradient holes and test well

Fig. I-1-1 Disposition map of gradient holes and test well

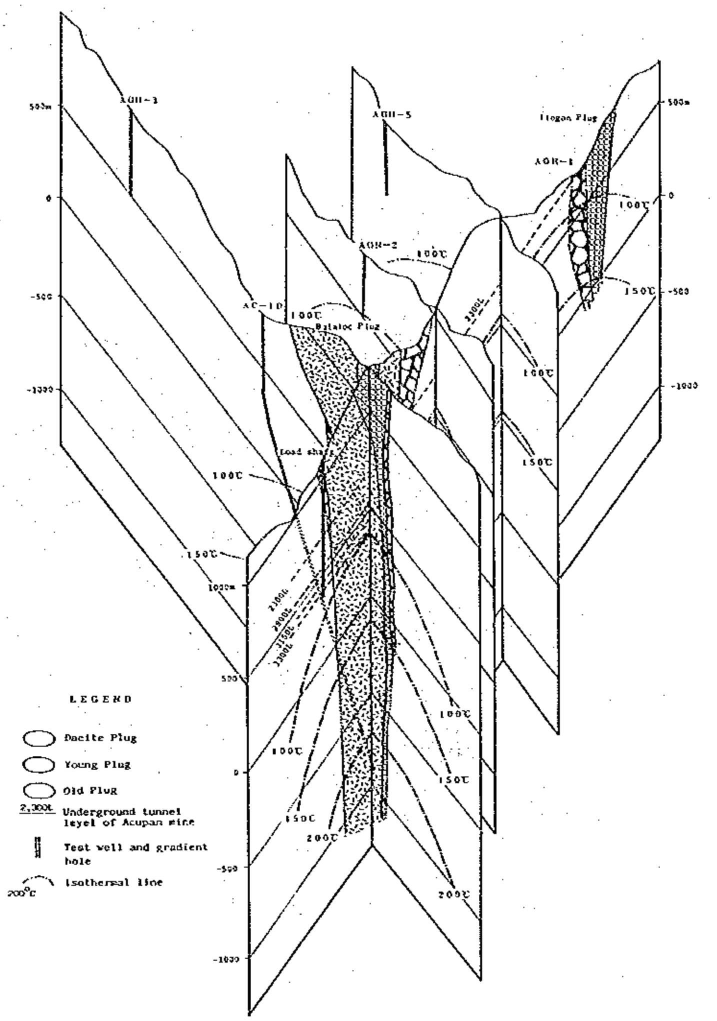


Fig. I−1−2 Block diagram of geology and isothermal profile

1-1-3 Hydrology

There are many discharging hot springs in investigated areas such as Dulupirip, Itogon, Klondyke, Asin, Pugo, Laboy, the Balatoc (underground of the Acupan Mine), Liang and Antamok. Most of these discharging hot springs are geologically controlled by the fracture system of the area, and are localized in the transitional zone between the Central uplift zone and the Western subsided zone. Especially, the high-temperature hot springs among them are situated near the dacitic plug, whose ages range from late Pleiocene to early Pleistocene.

On the basis of the soluble cation and anion content, the hot spring waters are classified into five types, namely; Na/Cl type (Acupan, Klondyke, Asin, Pugo), Ca/SO4 type (Acupan, Antamok, Laboy), CaSO4/HCO3 type (Antamok), Na/SO4-HCO3 type (Itogon, Antamok), and Na/SO4 type (Dalupilip).

Among them, the Na/Cl type is found localized in and around the peripheral boundary of the Balatoc plug while the Na/SO4-HCO3 type is observed near the Itogon plug, both types equally indicating high temperatures.

The O/H isotopic values of rain, river, and hot spring waters collected in the investigated area fall in a straight line of $\delta D = 8\delta^{18}O + 15$, which runs parallel to the model line formulated by Craig (1963) though with a slight shift to the left of the model line. On the basis of isotopic values of the samples, the origin of hot spring water could be attributed to meteoric water.

Discharging Na/Cl type, high-temperature water at the underground of the Acupan Mine has indicated some oxygen shift which points to possible chemical interaction between ascending thermal water and the country rock.

Considered from the isotopic point of view of D/H and O^{18}/O^{16}, the origin of the geothermal fluid may have originated from two different areas of meteoric water. That is, Ca/SO4-type spring water discharging at the underground of the Acupan Mine, which indicates a 10o/oo lower value of D compared with that of the Na/Cl type. It may be inferred that Ca/SO4 type water originates from a several hundred meters higher altitude than Na/Cl-type spring water. It is also considered that Na/Cl type spring water flows from somewhere far away from the site where it was collected.

As stated above, there are two types of discharging hot spring--the Na/Cl and the Ca/SO4 type. Each type of spring water has a different heating mechanism in the subsurface and also a different source of the water.

Another characteristic is that there is no transitional type between the two types, showing no mixing in the subsurface. This inferes that the two types of water are isolated from each other and bounded by an impermeable zone (Fig. I-1-3). From a geological point of view, an impermeable zone such as a shale bed does not exist in that area. The self-sealed zone, therefore, produced chemically by the deposition of soluble materials into the fractures, has occupied a part of the impermeable zone.

Existence of the so-called self-sealed zone is supported by an examination of cuttings and also by an injection test of AC-1D. In summarizing the foregoing statements, the heating mechanism of the hot spring waters prevailing underground at the Acupan and the Itogon areas is considered as follows.

The Na/Cl-type hot water comes from deep-seated water, its origin being underground water recharged from precipitation of low elevation. On the other hand, the Ca/SO4 type is thermal water heated at a shallow depth by H_2S and CO2 gases disassociated from the deep-seated hot water. And its origin is underground water derived from the surface around the Acupan-Itogon area.

This is the reason that two types of discharging hot water exist in the underground of the Acupan Mine. The Na/SO4-HCO3 type hot water discharging in the Itogon area is formed in the process of water-rock interaction dissolving Na of the rock during water ascent, which penetrated to the depth and was heated by H2S and CO2 (Fig. I-1-3).

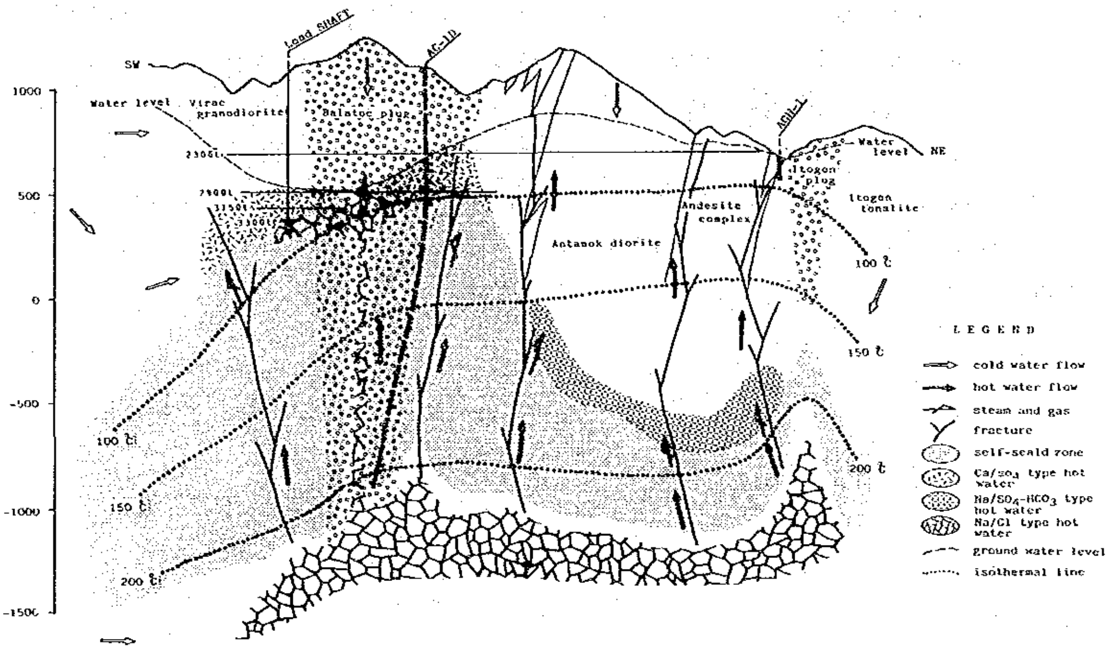


Fig. I–1–3 Conceptual model of geothermal system of the Acupan-Itogon area

1-2 Results of the First Emploratory Well (AC-1D)

1-2-1 Geology, geochemistry and injectivity test

The geology of Well AC-1D comprises granodiorite, andesite dyke and dacite pyroclastics (Young plug). The Young plug in the borehole appears almost at the location estimated from surface geology, decreasing its diameter in the depth. (Fig. I-1-4) The rocks sampled from the borehole generally suffer from hydrothermal alteration, suggesting that the thermal water may be from neutral to weak alkali. Bottomhole temperature in the past seems to have been higher than that of the present, since wairakite is detected near the bottomhole. Spectral analysis of the cuttings reveals that several passageways of thermal water existed in the past. In the course of temperature descending in the aquifer, leaking out of plagioclase and precipitation of quartz, clay, and sulfide minerals caused the cracks to choke. That is, so-called self-sealing.

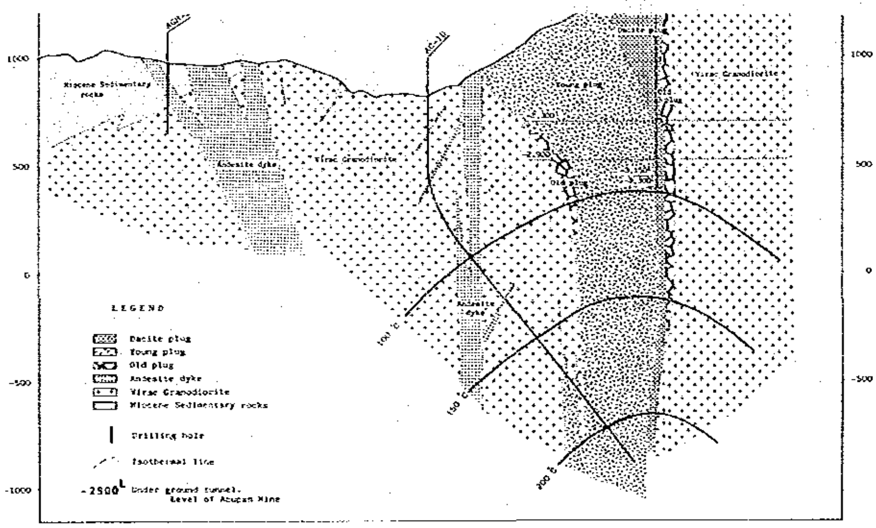


Fig. I-1-4 Geological profile of the test well

The static formation temperature of AC-1D (drilled length 2,000 m, vertical depth 1,677 m and bottomhole level 850 m b.s.l.)

was estimated to be 220°C. The temperature of the reservoir is high enough to enable discharging geothermal fluid. The rate of temperature increase with depth indicated almost a fixed rate of 11°C/100 m along the inclined borehole, suggesting heat conduction. This infers the existence of an impermeable formation, as stated above, the impermeable zone possibly formed due to the self-sealing effect. As a result of self-sealing, the present formation temperature might be around 60°C-100°C lower at about 1,600 m deep than that in the past, judging from a fluid inclusion temperature test of quartz collected from the borehole.

No circulation loss was observed while drilling of AC-1D, suggesting no permeable zone. On two occasions, hydrofracturing tests created a weak permeable zone, where the passageway of thermal water in the past was reopened. Values of the injectivity index and permeability thickness are 1.79 l/minMPa and 0.257×10^{-12} m^3 respectively. Those values are not enough high to enable enough discharging steam for power generation, although some flushing of steam is expected.

The permeable zone created by hydrofracturing was observed at two depths of 1,550 m and 1890-1990 m respectively. The upper permeable zone corresponds to the boundary of the Virac granodiorite and the Balatoc plug. On the basis of geochemical data, it is assumed that the boundary zone might have been a high permeable zone in the past. However, at present the zone is filled with quartz and clay minerals.

On the other hand, the permeable zone created near the bottom hole was not prominent in the past, although it indicates better permeability than the upper zone.

As previously stated, the Well AC-1D indicates that reservoir temperature in the area is high enough for geothermal power development, but offers poor permeability due to self sealing. In fact, the bottomhole of Well AC-1D is still located within the self-sealing zone, and has not yet reached the underlaying potential reservoir in the area.

1-2-2 Discharge test

After well completion, the temperature was monitored for 90 days to determine the stabilized reservoir temperature. A discharging test of the well was conducted on May 15, 1985.

Prior to the discharging test, a boiler was used for heating and supplying pressure to water in the well. Steam injection lasted consecutively for 27 hours. The steam temperature injected was 245.6^{o}C, and wellhead pressure during injection was 720 psi. The wellhead valve was opened at 5 p.m. on May 15.

When the valve opened, steam along with water gushed out for 40 minutes. As shown in the photograph, strong flushing lasted for the first 10 minutes, with mainly steam and less water. Dry steam flowed out for the last several minutes. After 40 minutes of powerful flushing, intermittent flow continued till the following day and after that.

Fig. I-1-5 is a temperature and pressure log chart before and after the discharging test. The water level of the well before the injection of steam with the boiler was 200 m from the wellhead, as shown at KP-6. By means of steam injection with the boiler, the water level was lowered to 600 m as estimated by temperature log chart (KT-13). This infers that the water level descended about 400 m.

After two days of discharge tests, the well temperature and the water level almost recovered to the same level before the test, as seen at KT-15 and KP-8. From these data, it is believed that geothermal fluid was moving in the borehole. After the discharge tests, however, the pH value and chemical components of the water collected from the well revealed contamination by condensed water of the injected heating steam.

The steam and hot water that gushed out from the well, therefore, may have been mainly injected heating steam and a small part of geothermal fluid that existed in the well. This implies that actual values of the injectivity index and permeability thickness were considerablly lower than those values calculated during the well test (1.79 l/m MPa and 0.257×10^{-12} m^3).

As to permeability, it may be considered that the big difference between the calculated and the actual value could have been caused by a time lag of 90 days. As previously stated, the permeable fracture was artificially made by the hydrofracture, and permeability thickness was calculated to be 0.257×10^{-12} m^3. Considering the discharge test of the well, however, the permeable zone made by hydro-fracturing was possibly choked no up again.

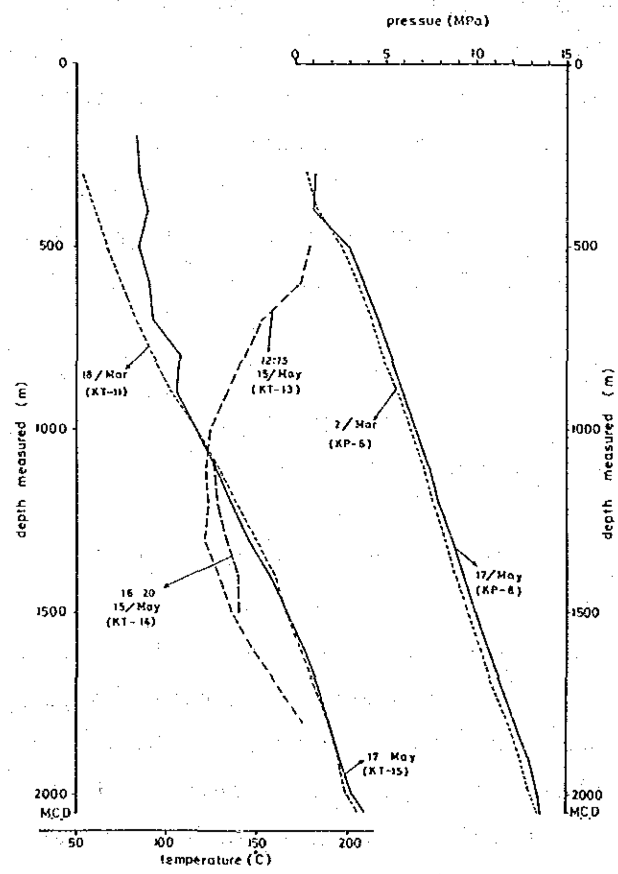


Fig. I–1–5 Thermal and pressure logging after and before the flashing test

1-3 Model of Acupan-Itogon Geothermal System

1-3-1 Geological and geochemical model

From the viewpoint of rock mechanics, it must be noted that geology of the the Acupan-Itogon area is composed of volcanic rocks whose porosities are quite low. And the geothermal system can be said to belong to a typical fracture-controlled type, considering that the fractures not only improve the very low porosity, but also allocate the fields for heat-source related recent volcanisms. The isothermal line of the 200°C extends in NE-SW direction, whose dimension is 3.5 kmx1.0 km at 1,000 m b.s.l., is occupied by heat-source related plugs at both ends and by fractures between the two plugs. The thermal fluid was able to flown up along the high-temperature zone, in which the average temperature gradient is about 10°C/100 m. However, to the northwest and southeast of this, the temperature gradients become very low, suggesting that the area is the down-flow zone of thermal fluid. As mentioned above, the model of the geothermal structure can be considered as a plate model when the fractures are viewed as the main point of study, and as the combination of two cylindrical models when the heat-source related plugs at Acupan and Itogon are studied as a key survey point.

The geothermal structure is summarized as follows from the viewpoints of balance of the underground water, energy, and chemical contents in thermal fluid.

Mining operation of the the Acupan Mine should affect the flow of underground water. The underground water level should be depressed broadly at and around the site of mining operation. For example, the actual area estimated for gathering precipitation to recharge water toward the mine site is about 15 km^2, although the topographical apparent recharge area is only about 9 km^2. The ellipsoid, with a long and short radius of 2.6 km and 1.9 km respectively, is equal to the actual area estimated and can cover the Itogon plug when the center is placed at the top of the

Balatoc plug. Ground water recharged at least within this area is believed to flow centripetally toward the Balatoc plug. Among the thermal springs around the the Acupan Mine and Itogon, fluids of the Ca/SO4 and Na/SO4-HCO3 type can be presumed to originate from the groundwater heated up at a depth.

Thermal springs of the Na/Cl type in the Acupan-Itogon area is judged to come from deep-seated thermal fluids. The original ground water assumed to be this type is not from precipitation at the Acupan-Itogon area, but from ground water recharged at an area of lower elevation. The ground water at a depth may solve chemical component of Na and Cl from country rocks while moving in a high-temperature condition. The lower contents of Cl in thermal fluids in the Acupan-Itogon area could mean that the geology is mainly composed of volcanic rocks but lacks marine sediments. The estimated Cl contents in thermal fluids at a reservoir would range from 2,000 to 4,000 mg/l, considering that the maximum Cl contents at the Acupan-Itogon area is about 1,700 mg/l, and also considering both the temperature of spring water samples and the dilution of fluid by surface ground water.

The most prominent seepages of hot springs are at the tunnel of the Acupan Mine. Fluids of the Na/Cl type ascend along the brecciated zone at the periphery of the Balatoc plug, rising through the self-sealed zone and pouring as boiling springs into the tunnel of the mine. Thermal water of the Ca/SO4 type also seeps outward from the Balatoc plug, although the temperatures of those springs are not so high. However, the total heat energy thrown off as drainage water is quite a lot, whose temperature and rate of discharge at the level of 2,900 are 43°C and 20 m^3/min respectively. Further, the estimated total amount of heat energy discharged of at the the Acupan-Itogon area is 33.7 MW, including other minor dischargings. This heat flow is common for geothermal fields.

1-3-2 Numerical model

The geothermal system of the the Acupan-Itogon area can be modeled as a plate joining both the Balatoc plug and the Itogon plug or as two cylinders at each plug. However, the following interpretations shall be based on the cylindrical model because the discharge of heat energy is prominent, and because detail data are located at the Balatoc plug.

Fig. I-1-6 shows a cross section of the cylindrical model joining the Balatoc plug and the test well (AC-1D). The pattern of a self-sealed zone, the ascent of Na/Cl type thermal fluid along the Balatoc plug, occurences of Ca/SO4 type thermal water genetically correlated with a flow of ground water, and underground isothermal lines are shown in the figure, details of which are as previously mentioned. This model was simulated by using a simulator SHAFT-K; an abstract of the results are as follows. Simulation was effected within the range of a model whose cylinder radius is 3 km and bearings are 15^{o}, and whose bottom is down to 1,500 m b.s.l. A nonstationary flow of the two phases of fluid and steam was assumed in this simulation range.

No geological and geochemical data can be used to derive information about a heat flow at a depth. However, the area of the source for heat supply is estimated to be not only restricted just beneath the Balatoc plug, but also to extend towards the outside of the plug, when the source is estimated at 1,500 m b.s.l. On the contrary, the temperature and the depth should be quite high and deep respectively when the extent of the source is restricted to only beneath the plug. Considering the seepages of hot spring water around the the Itogon plug, it points toward the former sources, although this is uncertain. The high temperature zone expands laterally at 1,500 m b.s.l.

According to simulation of the geothermal system, even the low permeability of a 10^{-15} to 10^{-16} m^2 order is sufficient to feed seepages of thermal fluid seen in the tunnel of the Acupan Mine. This low permeability implies a scarcity of tiny fractures and assures the presence of a self-sealed zone estimated from geological and geochemical data. The permeability of fractures artificially caused by hydro-fracturing of the test well (AC-1D) is also equal to that estimated from the above simulation. As mentioned above, the test well (AC-1D) could not discharge fluid continuously, although it is possible to discharge some amounts of fluid continuously even when permeability is as low as previously stated. This would mean that the test well does not cross the paths which feed thermal fluid from a depth into the tunnel, and that the fractures caused by hydrofracturing were already shut at the time of discharge test.

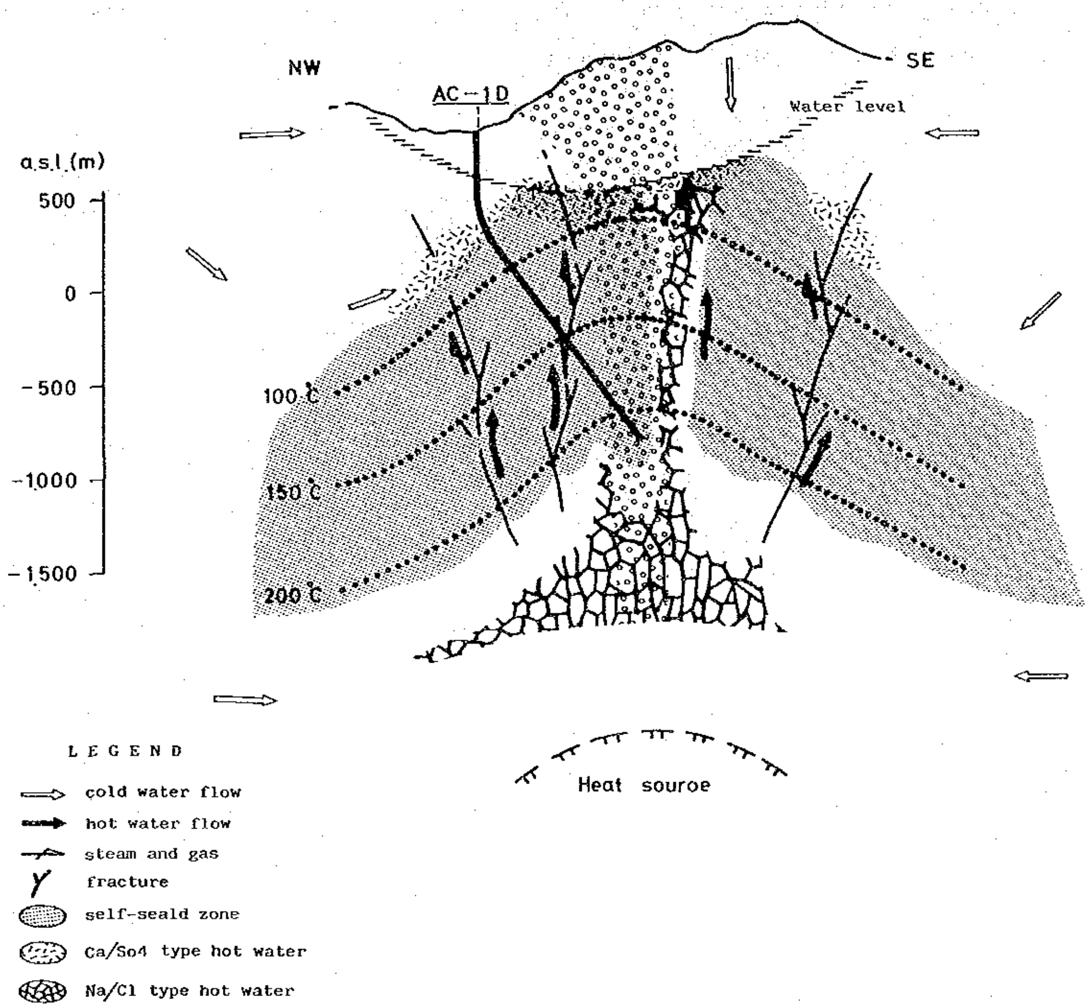


Fig. I-1-6 Conceptual model of geothermal system through the test well

A large quantity of thermal spring water with 33.6 MW equivalent of heat energy pours into the tunnel of the the Acupan Mine. A depression of the ground water level caused by mine operation would induce an upflow of deep seated thermal fluid which contributes genetically to thermal springs. If so, pressure reduction caused by depression of the ground water level and the ascent of deep-seated thermal fluid are assumed to be the cause and the effect. From the viewpoints of the cause and effect just mentioned, the potential of geothermal resources at Itogon is almost equal to that of the the Acupan Mine, although the amounts of energy disposed by thermal springs at Itogon is only equivalent to about 0.2 MW. In fact, the Hg content in soil and the intensity of hydrothermal alteration at the Itogon area are almost the same as those at the Acupan Mine.

VOLUME II INTRODUCTION

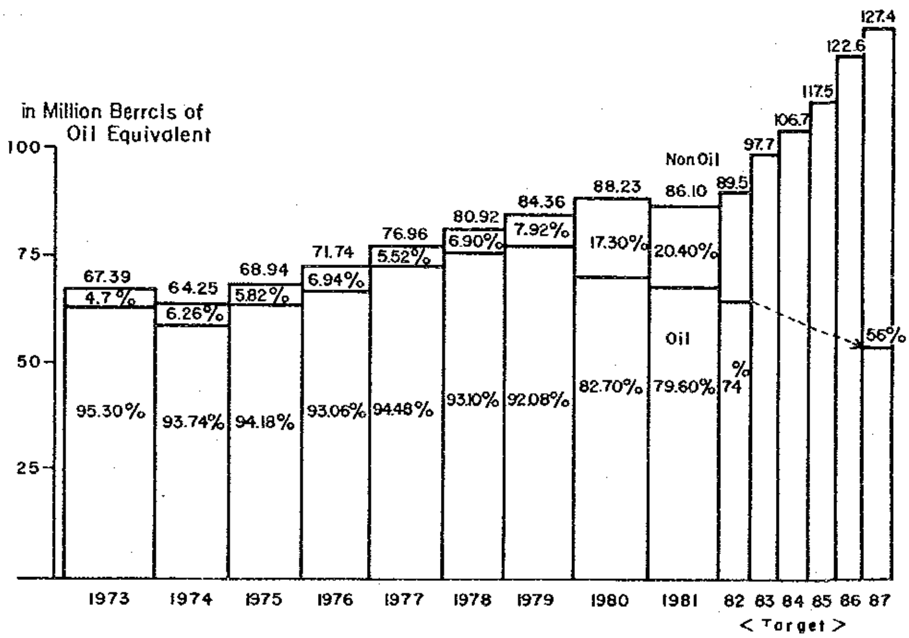
CHAPTER I GENERAL CONDITIONS IN THE REPUBLIC OF PHILIPPINES

CHAPTER I GENERAL CONDITIONS IN THE REPUBLIC OF PHILIPPINES

1-1 Energy Supply and Demand

While oil consumption by the Philippines is increasing year after year, the degree of dependency on oil is drastically decreasing, having been triggered by the so-called "oil shock" experienced by the nation in October 1973.

During the decade of the 1960's, 1.05 barrels of oil were consumed per capita by the population of 36 million in the Philippines. In the early part of the 1980's, this figure increased to 1.75 barrels per capita by the population of 49.5 millions. The statistics indicate that by 1987, oil is predicted to mark the consumption of 127.38 million barrels in total, or a per capita consumption of 2.24 barrels by the population of 57 million.



On the other hand, the rate occupied by oil in the total energy consumption, which registered a high level of 92% during 1973-1979 period, dropped to 82.7% in 1980 as a result of an increase of non-oil energy supplies such as coal and geothermal or hydraulic power generation. In 1981, this rate was further reduced to 79.6%. Plans by the nation are targeted to lower the oil dependency rate to 44% by 1987, supported by an increased supply of energy of 13.97% by geothermal power generation.

According to future programs, among non-oil energy, coal is being planned to further increase supplies to boost its dependency rate. When an oil equivalent conversion is made, coal is expected to exceed 18% in terms of the energy dependency rate, with hydraulic power generation reaching 12% and geothermal power generation sharing 14%. Particularly, geothermal power generation is planned to supply 1,554 MW by 1987, a level of 19% of all power supplies in the Philippines.

1-2 Trend of Geothermal Power Development

Geothermal power development in the Philippines displayed a remarkable growth during 1970's. In 1983, operation was commenced in the plants at Palimpinon and Tongonan, having caused a hike in the nations's geothermal power generation capacity to 781 MW. This high level has firmly established the Philippines as the second largest country of geothermal power generation, next only to the U.S.A.

Further, based on the 6-year Energy Development Plan up to 1987, geothermal power generation is to be developed in eight more areas by the end of 1987. With this addition, the number of geothermal power generating fields in the Philippines will increase to 14.

The six geothermal power generating fields presently under operation are as follows.

Tiwi	Albay	330 MW
Makiling-Banahaw	Laguna	220 MW
Tongonan	Legte	115.5 MW
Palimpinon	Southern Negros	115.5 MW
Manito	Albay	under exploration
Daklan	Benguet	under exploration

Eight more highly prospective fields are as follows.

Batong-Buhay
Acupan-Itogon
Batangas
Davao
Nothern Negros
Cagayan
Zambales
Cotabato

In these areas, earth surface investigation by drilling is presently under way. By the end of 1987, the cumulative number of test wells drilled for investigation purposes will reach as many as 556. As a result of such extensive survey work, the utilizable vaolume of geothermal steam is predicted to increase sizably, or to as much as 7,076 MW. Since present steam volume is 1,750 MW, this expansion means an increase of 880 MW in four years. As for power generator capacity, it is expected to reach 1,554 MW by the end of 1987.

The volume of geothermal steam already confirmed to exist in the Philippines continued to reveal a level in excess of the power generator capacities developed until now. In other words, the present situation in the country is that a shortage of power generators against steam availability is being covered by the continuous addition of power generators whenever budget allotment is possible.

In 1983, two new geothermal power generating stations were constructed by the Philippine National Oil Company (PNOC), one with a capacity of 112.5 MW at Tongonan and the other with that of 112.5 MW at Southern Negros (Palimpinon). These two plants increased the nation's total geothermal power generating capacity to 781 MW as per the following breakdown.

Tiwi	55.0 MW x 6 unit = 330
Mak-Ban	55.0 MW x 4 unit = 220
Tongonan	37.5 x 3 + 3.0 x 1 = 115.5
Southern negros	37.5 x 3 + 3.0 x 1 = 115.5

In the northern part of Luzon Island, highly prospective geothermal zones exist such as Batong-Buhey, Buguias, Daklan, and Acupan-Itogon, but none of these areas is yet developed for geothermal power generation. On the other hand, the capacity of hydraulic power generating dams near Baguio City, named Ambuklao and Binga, is rather decreasing while demand for power in that area continues to expand year after year. In other words, the power supply situation in the northern part of Luzon Island is being aggravated at a high pace. The two geothermal power generating stations Tiwi (330 MW) and Mak-Ban (220 MW), are presently supplying power that covers approximately 24% of the power demand on Luzon Island. Therefore, the Philippine Government wishes to proceed as soon as possible with geothermal power development, particularly in the northern part of Luzon Island, to improve the existing power supply situation.

Under such background circumstances, the BED (Bureau of Energy Development) of the Philippines again requested JICA to conduct surveys by selecting the above-mentioned areas, which are located close to power consumption sites such as Baguio City or the district where mining companies are situated. In response to this request, JICA dispatched a preliminary survey team in March 1982. Upon confirmation achieved by this team on potentialities of geothermal power development in the subject area, an S/W was prepared regarding final surveys, which then was followed by official mutual signing of the relevant Implementing Arrangement Agreement.

CHAPTER II OUTLINE OF SURVEYS

CHAPTER II OUTLINE OF SURVEYS

2-1 Objective of Surveys

The prime objective of surveys lied in achieving evaluation of geothermal potentialities in the Acupan-Itogon areas located in the southeast of Baguio City, Benguet Province, in response to a formal request by the Government of the Republic of Philippines. The surveys were composed of three stages. In the initial-year survey, geological, geochemical, and physical investigations were conducted in an area approximately 300 km^2, resulting in selecting areas of 40 km^2 that offer high potentialities for geothermal power development. As to the second-year survey, various actual in-the-field investigations were conducted, including drilling of temperature-measuring holes on the targeted survey areas. Also included in this phase of work were the preparation of conceptional geothermal structure models of the survey areas as well as preliminary studies on spots for drilling survey wells for the purpose of directly confirming the existence of geothermal fluid.

In the third-year survey, drilling of 1,500 m-deep survey wells was initially planned. However, the temperature rise was revealed to be slightly lower than originally estimated, probably on account of drop of underground water levels caused by mining excavation in the neighborhood. Consequently, the drilling depth was extended to 2,000 m. While details of the findings obtained by this actual drilling of survey wells are included in this paper, this report outlines the summary results of our analyses on geothermal potentialities in the target areas on the basis of the said details of survey findings.

2-2 Structure of Survey Team

Membership structure of the survey team is as follows.

JICA team

Project Manager	Mr. Yasunori Sakai (Bishimetal Exploration Co., Ltd.)
Organizer	Mr. Kuniaki Nagata (JICA)
"	Mr. Katsuhiko Ozawa (JICA)
Geologist	Mr. Eiyuu Matsunaga
"	Mr. Keiji Nakano
"	Mr. Takao Maeda
"	Mr. Motomu Goto
Geochemist	Mr. Kenji Wakita
"	Mr. Minoru Saito
"	Mr. Masahiro Nara
Geophysicist	Mr. Asahi Hattori
"	Mr. Hiroshi Fukuda
"	Mr. Manabu Kaku
"	Mr. Kazuto Matsukubo
"	Mr. Masashi Kurosawa
Drilling Engineer	Mr. Keiji Mitsutani
"	Mr. Kazuo Ooshima
Reservoir Engineer	Mr. Yasuhiro Kubota
"	Mr. Shuzo Kaku

BED team

Project Manager	Mr. Alfredo C. Troncales
Sr. Geophysicist	Mr. Edgardo S. Aguas
Geophysicist	Mr. Francisco A. Benito
Sr. Geologist	Mr. Rene B. de los Santos
Geologist	Mr. Narciso V. Salvaia
"	Mr. Romeo R. Tena
"	Miss Helene G. Aniceto
Geologic Aide	Mr. Leonardo U. Elemia
"	Mr. Velario D. Mata
Sr. Geochemist	Mr. Zalzon C. Espino
"	Mrs. Rosario D. Mosqueda
"	Mrs. Evelyn N. Reyes
Geochemist	Miss Mona Lisa V. Agoncillo
Mining Engineer	Mr. Rene A. Villarosa
Sr. Electrical Engineer	Mr. Rodelio T. Palabasan
Sr. Mechanical Engineer	Mr. Josefino C. Adajar
Monitoring Engineer	Mr. Manuel R. Panagsagan
Sr. Geodetic Engineer	Mr. Francisco Palabrica
Geodetic Engineer	Mr. Jose L. Cuaresma
"	Mr. Valentino Noble II
"	Mr. Allan O. Loleng
"	Mr. Cesar U. Dacanay
Cartographer	Mr. Ben P. Ignacio

2-3 Survey schedules

The survey schedules are as indicated in Table II-2-1.

Table II-2-1 Work Schedule

	Date	1982	1983	1984	1985
	Contents of Survey	A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	J F M A M J J A S
Phase I	Geological Survey	8 — 6			
	Geochemical Survey	6 — 6			
	Gravity Survey	27 — 5			
	Electric Survey	27 — 5			
	Report		*		
Phase II	Geological Survey		28 — 6		
	Geochemical Survey		28 — 11		
	Microearthquake Survey		28 — 21		
	Temperature Gradient hole Survey		18 —	— 27	
	Report			*	
Phase III	Drilling of Test well			22 —	— 16
	Logging and Completion Test				23 — 14
	Flaching Test				15
	Report				*

2-4 Organizations Visited by the Survey Team

The following organizations were visited by the survey team.

- Japanese Embassy, in Republic of Philippines
- Manila Office of International Cooperation Corporation
- Bureau of Energy, Philippines
- Philippine National Oil Company (PNOC)
- National Power Corporation (NPC)

CHAPTER III SUMMARY OF SURVEY

CHAPTER III SUMMARY OF SURVEY

The following represent the summaries of surveys through Phase I to Phase III.

3-1 Geological survey

Results from both the regional reconnaisance survey of Phase I and the semidetailed survey of Phase II reveal the following concerning the geology in this area (Fig. II-3-1).

(1) The regional geological structure of northern Luzon is characteriz-ed by a block structure stretching in the N-S direction, which consists of the Central uplifted zone and the Subsidence zones at both sides of the former. The survey area is located at a transitional zone between the uplifted zone and its west side subsidence. The Buguias area, where exploration work was conducted with JICA-BED technical cooperation in 1981, is on the east side opposite the uplifted zone, about 45 km to the north of the Acupan-Itogon area.

(2) The Central uplifted zone consists of Dalupirip metamorphic rocks of late Cretaceous and Aguno batholith of the late Oligocene to Pliocene. On the other hand, both the eastern and Western subsidence zones mainly consist of Miocene sedimentary rocks, for example the Klondyke formation. The youngest volcanisms of andesite complexes and dacitic plugs occurred at the Transitional zone during the late Pliocene to late Pleistocene.

(3) Fractures trending mainly NS, NE-SW and NW-SE in direction are dominant in the transitional zone, while they are not so well developed in both zones of the Central uplifted zone and the Western subsidence zone. Moreover, young volcanisms of

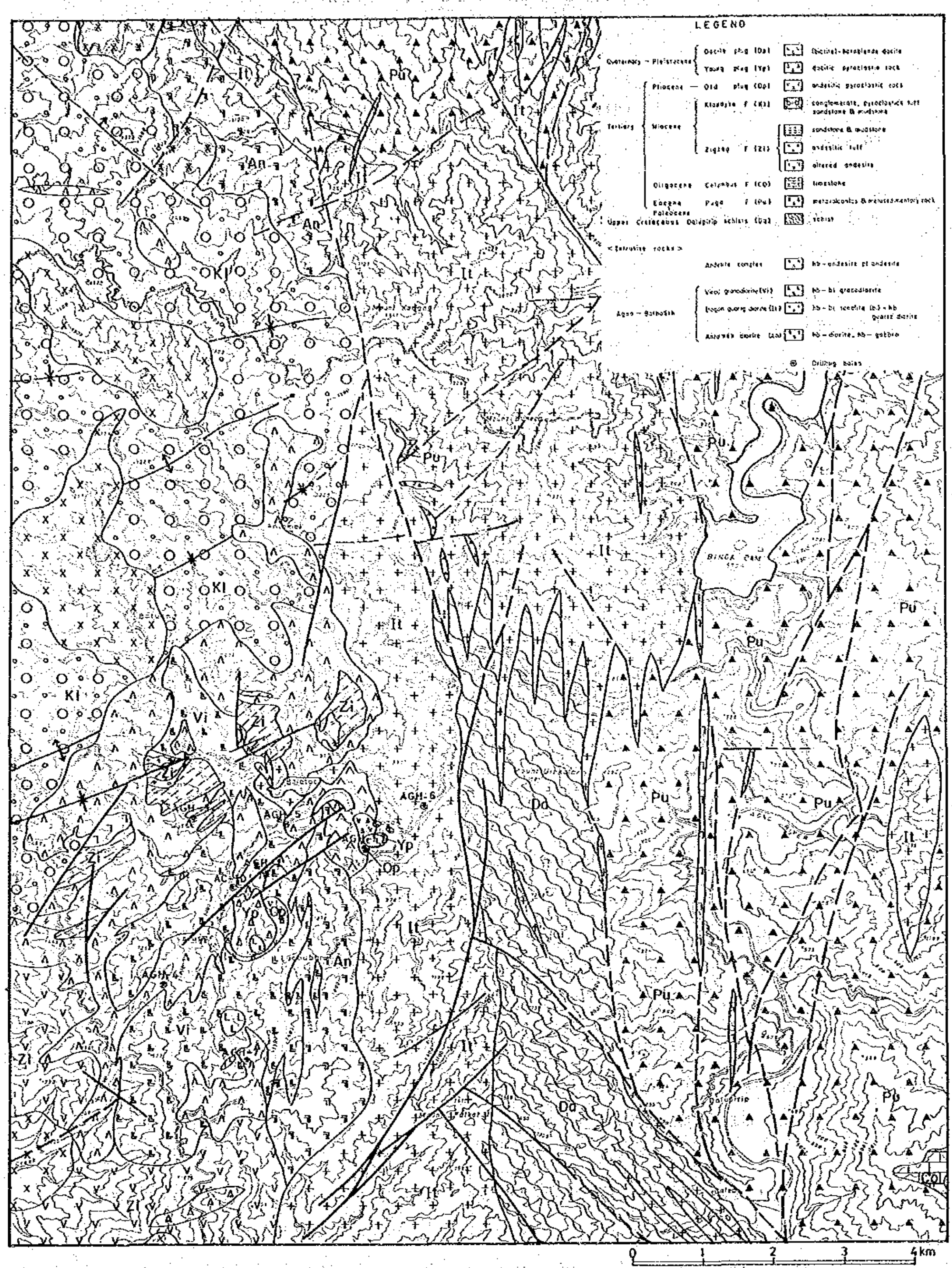


Fig. II–3–1 Geological map

Andesite complexes and plugs are assumed to be closely related with these fractures. Especially, the plugs occurring on the junctions of faults of the NS and NE-SW systems.

(4) Some seepage of hot spring water is observed in the survey area, all of these locations being closely related to the fractures mentioned above. Furthermore, the high-temperature hot water is flowing at Acupan and Itogon, in which the youngest volcanisms of plugs occurred. But in the Acpan Mine, in which gold mining is now under operation, hot springs are discharging water of very high temperature. Because of such reasons the target location for the deep test well on Phase-III survey was determined.

3-2 Geochemical Survey

The geochemical survey consists of ground surface temperature measurements, which includes the temperature analyses of mercury contents in soil and the radon gas concentration in soil air, as well as the chemical and isotopic analyses of spring water samples. The following is an abstract of the survey.

(1) Temperature at the 1 m depth reveals certain anomalies above 27.8°C from a standpoint of statistical procedures. However, it does not reflect the thermal structures at further depths, but only representing topographic influences.

(2) When the threshold value is set at 90 T/D statistically, the anomalies of radon gas concentration are observed mainly in the vicinity of the Acupan Gold Mine. However, rather than showing the underground geothermal structures, is shows only the width of open space between the ground surface and the water level, considering that most of the anomalies are located at ridges.

(3) Mercury content in soil is quite characteristic (Fig. II-3-2). That is, anomalies (above 478 ppb) are evident intermittently at the peripheries of the Balatoc plug and the Itogon plug, spreading and stretching in the NE-SW direction. While mercury anomalies seem to relate to gold mineralization of the Acupan Mine, at the same time, they are also assumed to respond to geothermal manifestations.

Table II-3-1 shows representative manifestations observed within and around the survey area. The pH values range between weak acid to weak alkali, and thermal seepage with high temperatures are seen at the tunnel of the Acupan Mine and Itogon. The following are revealed.

(4) The geochemical temperature estimated from T_{SiO_2} and $T_{Na-K-Ca}$ shows 147-229°C and 193-236°C respectively at Acupan and

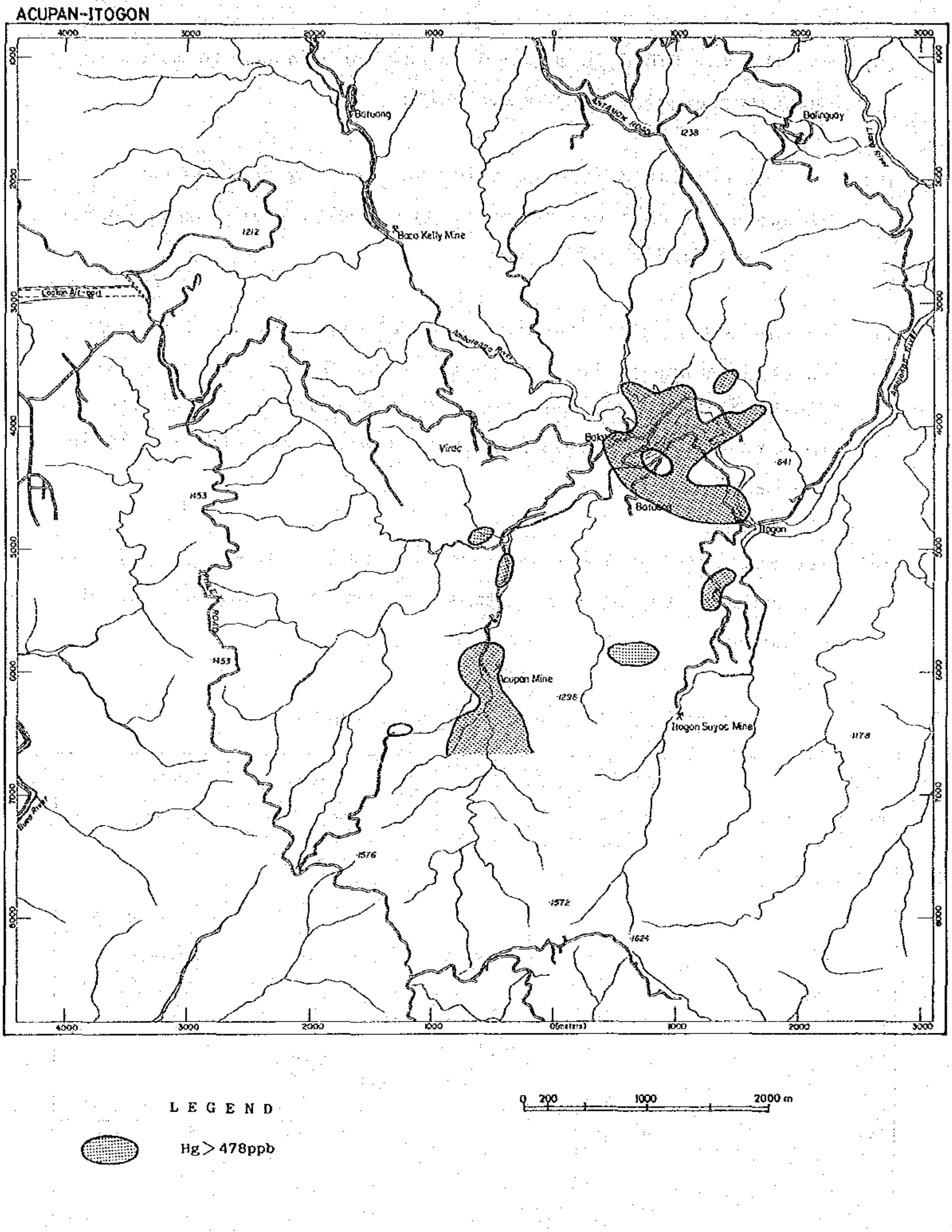


Fig. II–3–2 Hg anomaly map

Itogon. This temperature is high enough to expect a geothermal reservoir at depth.

(5) The thermal fluid is assumed to have originated in meteoric water recharged from precipitation.

(6) The thermal fluid is classified in three types from the viewpoint of chemical composition--namely, Na/Cl type, Ca/SO_4 type, and Na/SO_4 $-HCO_3$ type.

(7) In the Acupan Mine, seepage of Na/Cl type fluid are closely related in and at the periphery of the Balatoc plug, while fluid of the Ca/SO_4 type seeps from the outer zone of the former. An oxygen shift in thermal water is evident only in the Na/Cl type.

(8) Thermal fluid at Itogon belongs to the Na/SO_4-HCO_3 type, with Cl content ranging from 5 to 45 percent in total equivalents of anions.

Table II–3–1 List of spring water samples

Sample Code	Hot Spring Location	Elevation H.a.s.l.	Temperature (°C)	pH	Discharge Vol. (ℓ/min)	Acid gas V%		Deposit	Country Rock/Geology
						CO_2	H_2S		
DA	Dalupirip	420	42.5	5.5	>50	–	–	calcite & quartz vein $CaSO_4$ & $FeSO_4$ films	gravels on Pugo formation
IT-1	Itogon	680	89.5	7.5	5	99.94	0.66	calcite veinlet calcite sinter, gypsum-like	Balatoc Plug
IT-2			62.2	7.5	5	–	–	crystals, $FeSO_4$	along the contact between lower Balatoc plug and overlying detritus
KL	Klondyke	240	49.5	7.5	10	<0.05	<0.005	calcite veinlet	andesitic tuffaceous sand-stone (Rosario Formation)
AS	Asin	260	73.8	8.0	not sure	<0.05	<0.005	none	gravels
PU	Pugo	80	36.3	7.0	5–6	<0.05	<0.005	none	gravels on tuffaceous sand-stone (Rosario Formation)
LA-1	Laboy	660	47.5	7.0	10	–	–	calcite thin veinlet along jointing	hb. qtz diolite
LA-2		700	47.5	7.0	15	–	–	calcite epidote veinlet	granite
BA-1	Balatoc (Acupan Mine)	Acupan mine 3300 level (519 m)	81.0	7.5	25	–	–	gypsum and calcite vein	diorite
BA-2		3150 level (565 m)	62.1	8.0	60–80	?	?		andesite
103C	Liang	530	66.0	8.3	4	–	–		diorite
76-B-12	Antamok	Antamok 1850 level	51.7	?	?	?	?	?	?

3-3 Gravity Survey

Stations are set at 500 - 700-meter intervals along roads and ridges, and the average station density is 1.7 points/km^2. The Bouger anomaly map (ρ = 2.6), residual map (λ = 0.25-2.1), and second derivative map are shown in App. 2, App. 3 and Fig. II-2-3 respectively. The following is an abstract of interpretations on these results.

(1) The average density of rock samples collected from the surface is comparatively as high as approximately 2.7, showing only a little difference in each rock type. Accordingly, as for the Bouger anomaly, the difference is comparatively small, ranging from 49 mgal minimum to 77 mgal maximum.

(2) The Bouger anomaly map, corrected by using a density of 2.6, is assumed to be the best to reveal underground geology.

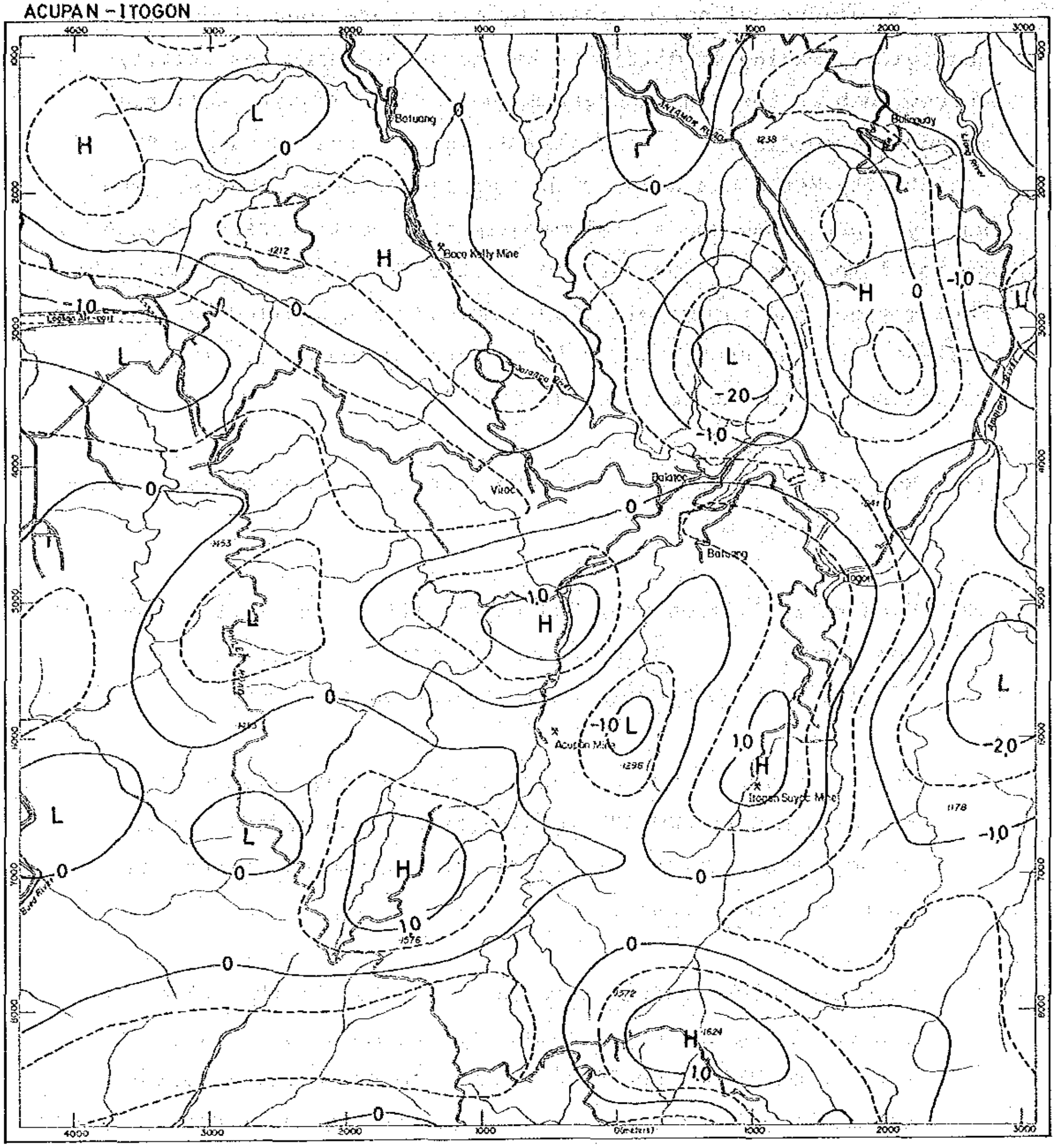
(3) The low Bouger anomaly running at the east side of the Itogon Bridge in the N-S direction seems to respond to occurences of acidic rocks of Itogon quartz-diorite and tonalite, whose silica contents are high. On the other hand, high anomaly at the western part of the survey area well reflects the distribution of basic rocks such as andesite lava.

(4) The average density of rock samples collected from the Balatoc plug is as low as 2.46. The minor low anomaly in the vicinity of the Acupan Mine is considered to reveal a plug which is characterized by acidic rocks of high silica content.

(5) Fractures comprising such a depression as basin structure are not evident in the survey area.

(6) The N-S direction low anomaly running at the east of the

Itogon Bridge, previously mentioned, could not be fully explained by density differences caused by rock type differences. There might be certain other factors that reduced density, such as fractures and alteration at deep strata.



unit : mgal

Fig. II–3–3 Second derivative map of gravity

3-4 Electrical Survey

The electrical noise caused by mine operations are not negligible, making it difficult to use an ordinary resistivity survey such as the Schlumberger method or the magneto telluric method. Accordingly, a specially designed Signal Enhanced DC Resistivity Meter was used, with 3 Hz square wave signals. The survey lines along roads are composed of nine traverses up to 69.6 km total in length. However, as for the Dalupirip area, both the Schlumberger and the Dipole-dipole method were applied because the distance is long enough to avoid noise from the mine. The followings is the abstract (Fig. II-3-4).

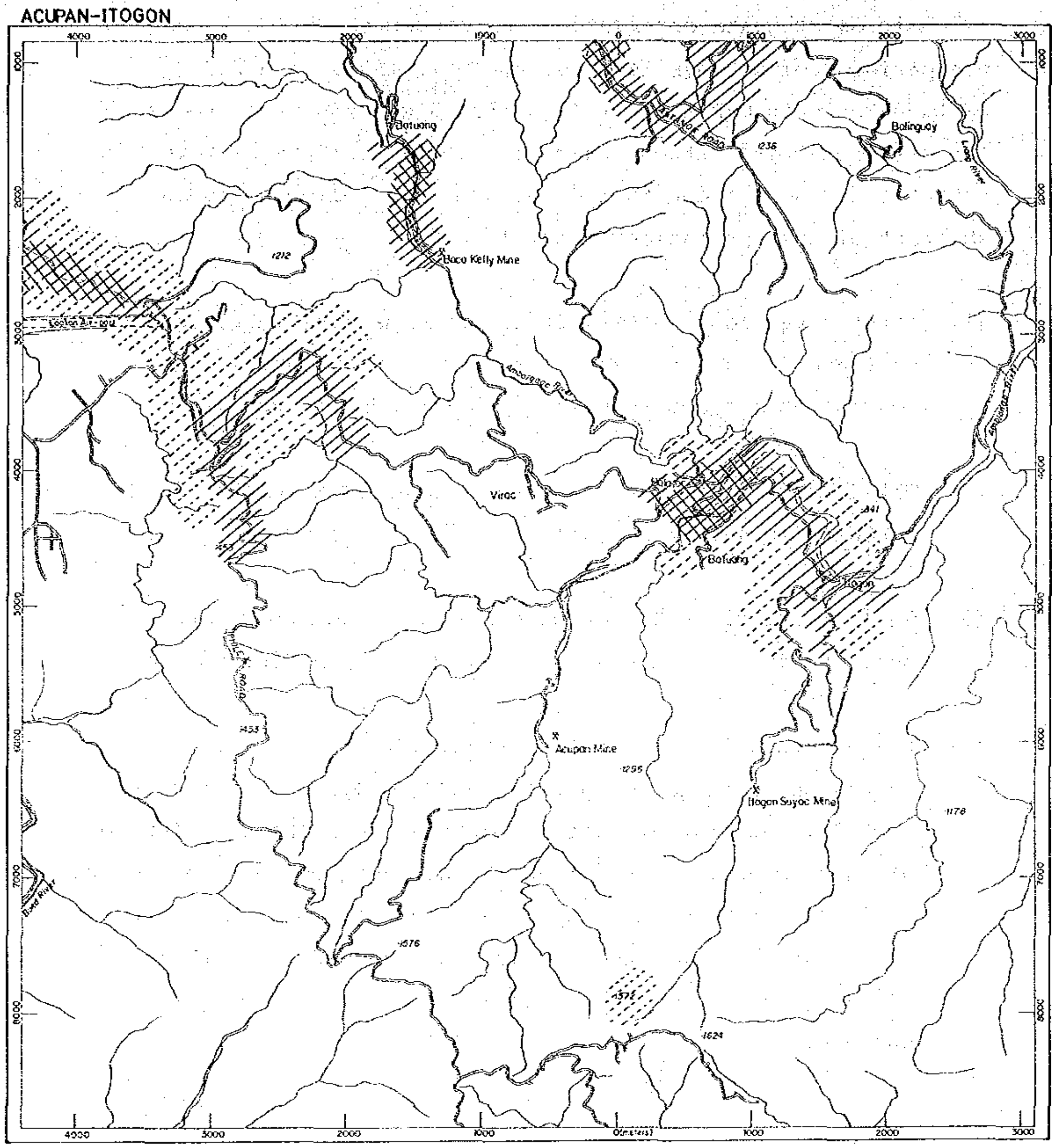
(1) Resistivities of the near-surface range is approximately from 50 to 1,000 Ωm.

(2) High resistivities over 500 Ωm prevail at the eastern part of the survey area, where Dalupirip schist and Itogon quartz diorite with no hydrothermal alteration crop out.

(3) In the Dalupirip hot spring area, a low resistivity zone trending N-S to NNW-SSE in direction is observed. It is assumed that geothermal fluids are restricted to near the surface along a fault.

(4) Some other low resistivities are detected in the following areas. Among those, anomalies in Antamok, Baco-Kelly, and the Itogon Bridge could be related to hydrothermal alteration caused by gold mineralization, considering their proximety to the mine. Low resistivities near the air strip and at the northwestern corner of the survey area are also assumed to be related to mineralization.

ACUPAN-ITOGON



LEGEND

low resistivity zone

100m depth (50Ω-m)

200m depth (100Ω-m)

300m depth (100Ω-m)

0 200 1000 2000 m

Fig. II–3–4 Resistivity map

3-5 Microearthquake Survey

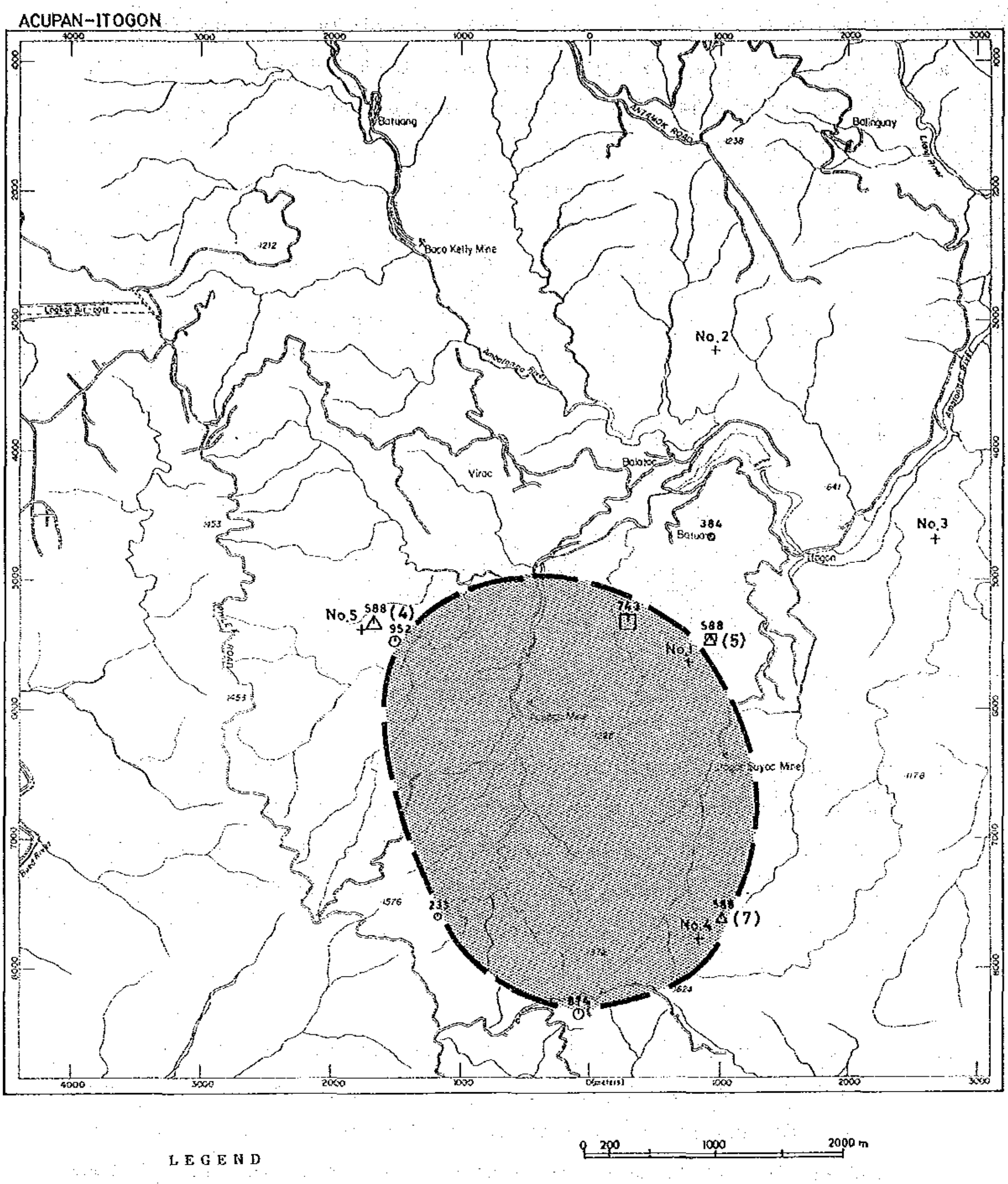
Microearthquake observation was conducted during 55 days of the period from October 14 to December 7, 1983. The 213 earthquakes with S-P time of less than 5 seconds were processed for data analysis, although a total of 973 earthquakes were detected during the monitoring period. The following is an abstract of interpretations (Fig. II-3-5).

(1) Three dimensional distribution of focused earthquakes are confined in the northern part of the survey area, with considerable occurrence in depth towards the west.

(2) The density of focuses of the earthquakes is higher in the northern survey area, while rare in the south.

(3) A pipe-like distribution of earthquake focuses can be observed in a small scale around the Acupan Mine to Itogon.

(4) The distribution patterns of focuses mentioned above correspond well to the geology and geological structures. That is, the plate structure, defined from the distribution of focuses, reveals the tranditional zone between the Central uplifted zone and the Western subsidence zone, while the pipe-like structure would reveal the Balatoc and the Itogon plugs, along which thermal fluid is assumed to ascend to the surface.



LEGEND

No 1

\+ Seismograph

Depth (Z)	Magnitude (M) 0≦M<1	1≦M<2	2≦M<3
0<Z≦10	∘	○	◯
10<Z≦20	▫	□	☐
20<Z	▵	△	△

Anomalous microearthquake activity zone

Fig. II–3–5 Epicentral distribution map of micro earthquakes

3-6 Gradient hole survey

Seven holes were drilled. Their locations and details are shown in Fig. I-1-1 and listed in Table II-3-2 respectively. The geological and thermal loggings are also shown in Fig. II-3-6. Fig. I-1-1 shows the isothermal line estimated at the 1,000 (m) b.s.l. The following is an abstract of the survey.

Table II—3—2 Temperature of gradient holes and test well

	Well. No.	Well Head a.s.l. (m)	Depth (m)	Water Level (m)	Bottom Temp. (S.F.T.°C)	Gradient (°C/100m)	(Estimated)-Actual Formation Temperature			
							500 m	1,000 m	1,500 m	2,000 m
Gradient Hole	AGH-1	690	112.85	0	90.7	?				
	AGH-2	905	357.50	190	115.0	28 (14)	(136)	(206)	(276)	
	AGH-3	977	322.50	0	24.0	?				
	AGH-4	1,350	538.0	185	24.0	?				
	AGH-5	755	400.0	30	62.0	8	(70)	(110)	(150)	(190)
	AGH-6	685	207.15		32.0	4	(44)	(64)	(84)	(104)
	AGH-7	1,451	301.5	55	29.4	?				
Test Well	AC-1D Vertical Conversion	821	2,000.0 1,677	230	221	11	55	125	195	

(1) Hydrothermal alteration, seen widely, is characterized mainly by montmorillonite, sericite, chlorite, α-quartz, and calcite. Kaolinite, epidote and anhydrite are also evident intermittently. However, it is difficult to effect zonation because of a lack of differences in the alteration mineral assemblage.

(2) The contents of Si, K, As, and Rb in country rocks are enriched at the paths of geothermal fluid, while the contents of Ca, Na and Sr are depleted. Well observed in the hole of AGH-2, this is assumed to be caused by the desolution of rock forming minerals such as plagioclasse, and also to be caused by the deposition of secondary minerals such as sericite.

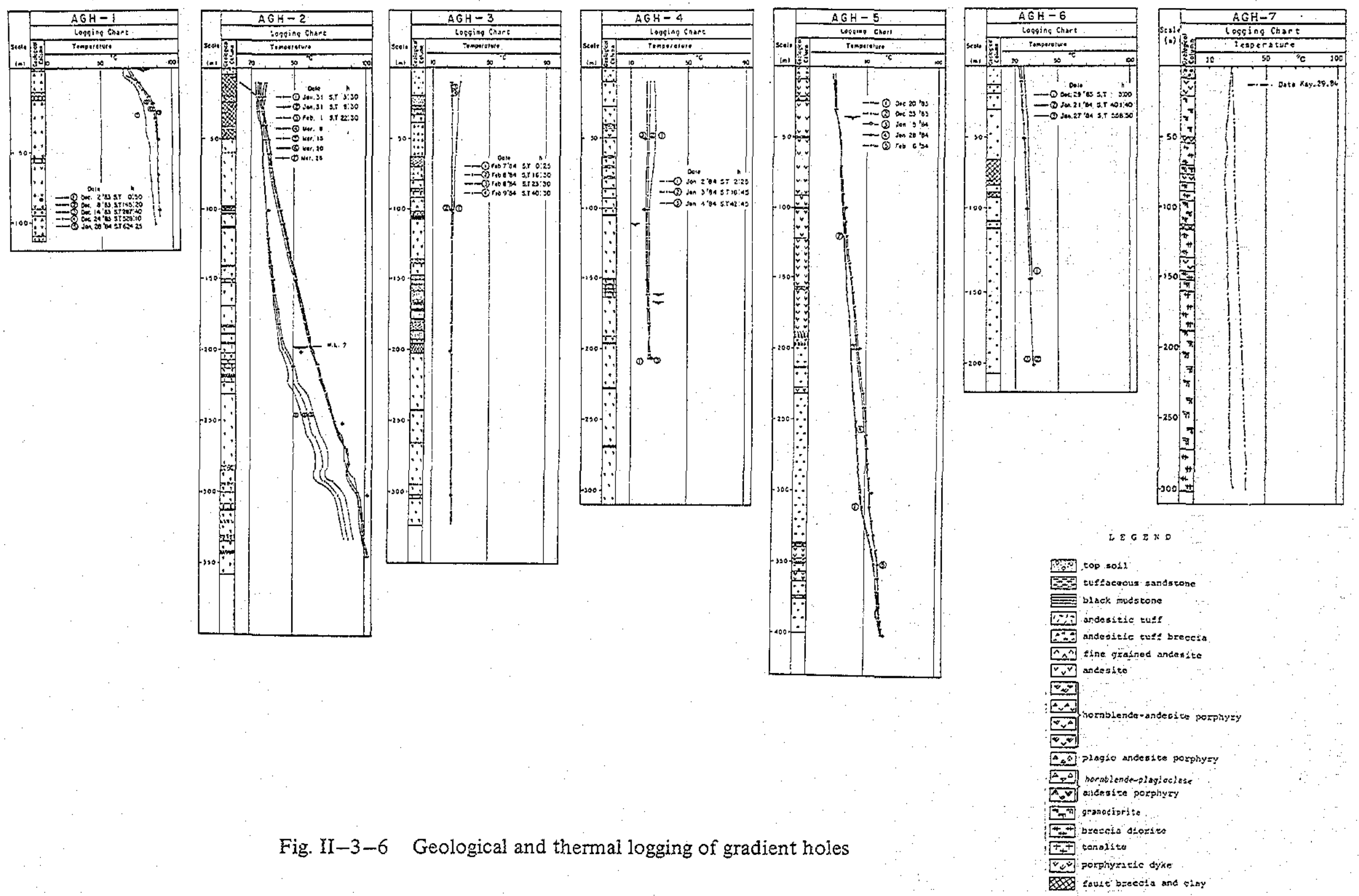


Fig. II–3–6 Geological and thermal logging of gradient holes

(3) Physical properties of core samples are as listed in the Table II-3-3.

Table II—3—3 List of rock mechanical properties

Formation or Body	Sonic velocity (km/sec)	Thermal conductivity ($\times 10^3$ cal/cm·sec·°C)	Density (g/cm^2)			Porosity (%)	Permeability (darcy)	Specific electric resistance (Ω·cm)	Specific heat (g/cal)
			natural condition	wet	dry				
Old plug	3.63	6.245	2.66	2.68	2.63	4.96		9.25×10^5	0.230
Andesite porphyry dykes	5.07	6.828	2.77	2.77	2.76	0.83		4.06×10^6	0.219
Andesite complex	5.29	6.103	2.79	2.79	2.79	0.18		2.68×10^5	0.208
Virac granodiorite body	5.42	5.880	2.78	2.78	2.78	0.40		1.59×10^6	0.214
Itogon quartz diorite body	5.45	6.663	2.71	2.72	2.71	1.41		8.98×10^5	0.212
Miocene sedimentary rocks	4.34	6.623	2.67	2.71	2.66	4.71		1.98×10^5	0.222