PART－Ⅲ SUMMARY

CHAPTER 3

CONCLUSIONS AND RECOMMENDATIONS

Chapter 1
Summary of the Survey

1-1 Geological Exploration

(1) The geology of the survey area is classified into three (3) formations and intrusive rocks. These formations are the Buguias formation of Oligocene to lower Miocene, Loo formation of upper Miocene and Budo formation of Quaternary. The Buguias formation was formed under shallow sea water conditions with a maximum thickness of 3,500 m. The main components of the formation are basic rocks, and its pyroclastics and sedimentary rocks show complicated folding structure.

The Loo formation is mainly composed of terrestrial sediments and andesitic rocks with a maximum thickness of 800 m.

The Budo formation is composed of terrestrial acidic pyroclastics with dacite lava domes. It also intercalates lake sediments at several parts.

(2) The geological structure in the area is characterized by intense faulting, folding and block movement with apparent trends of N-S. The geological structure however is principally represented by a combination of graben and horst with trends of N-S and E-W. The folding structures show N-S trend axes and are classified into two (2) types, large-scale and small-scale folding. These folding structures are formed by box-folding in the sedimentation stage of Buguias formation due to fracturing of the basement rocks. The fracture system in the area was formed by the intrusion of plutonic rocks with N-S and E-W trends. Thereafter, NE-SW and NW-SE faulting followed which resulted to the horst and graben structures. In Quaternary, dacite lava domes, which are located at the eastern part of survey area, were formed at the intersection of the E-W and the N-S uplifted zone.

(3) Igneous activity in the area is as follows.

Submarine basaltic rocks occurred in late Oligocene to middle Miocene. Rhyolite is also locally observed.

In middle Miocene, plutonic rocks such as granodiorite and quartz diorite intruded.

Intermediate to acidic volcanics erupted in late Miocene and small-scale plutonic rocks were intruded.

In Diluvial age, hornblende andesite and biotite dacite activities occurred. Dacite lava domes were formed as a result of the latest volcanic activity in the area.

(4) The alteration in the area is classified into three (3) groups, regional burial metamorphism, mineral alteration and geothermal alteration. Geothermal alteration is distributed within a small area at the upper stream of Toking creek.

The altered zone extends with a N-S direction and is characterized by white colored argillization and silicification. The altered minerals detected by X-ray analysis are alunite, cristobarite and tridymite.

1–2 Geochemical Exploration

(1) The temperature measurements of one meter holes reveal that the high temperature anomalous zones are restricted or around geothermal manifestations in the area, reflecting hot water circulation near the surface.

(2) Four (4) distinct high temperature zones trending east to west were observed by bottom hole temperature measurement inferring probably the same direction of hot water flow. The high anomalous zones, however, tend to be parallel to the level contour line of 1,400 m A.S.L., that is, it indicates the water table in the area.

(3) All manifestations are distributed at the east and west bank of the Agno river around Buguias Central and are characterized by hot water flow and gas bubbling pools. Sinter deposits mainly composed of carbonates are also found around the areas of manifestations.

(4) All of the hotspring water samples except one, are of the Nacl Type, indicating water derived from deep geothermal fluids. Although hot water temperatures in the surface range from 40°C to 70°C, the geothermometry computed by chemical components of hot water suggests that the temperature of the geothermal reservoir in the depth would be over 200°C.

(5) From a consideration of the water table in the area, it is recommended to drill deep enough for the proposed thermal gradient boreholes in order to penetrate the aquifer, wherever drill sites are established above 1,400 m.

1–3 Gravity Survey

Topography of the survey area is characterized by steep mountains and the Agno river flowing through the area from south to north. Elevation of the survey points ranges from 1,100m downstream of Agno river to 2,340m on Mountain Lake.

In order to grasp the general trend of gravity structures, cross-shaped basic routes were planned along the road Abatan, north to Cabayan, south and curved point of Harshima road west of Sinepsip, west to upstream of Dalimona, east of Bodoan, Ifugao border.

Most of the other points were set within the area of 2 by 3 Km with a point interval of 500m as a general rule.

Gravity points :

With leveling survey by auto level	132
With traverse survey by transit	8
With microbarometers	101

Instruments :

La Coste G-236 Gravimeter	1
Paulin MDH-5 Microbarometer	2
Sokkisha B-2 Auto Level	1

After adopting several high precision corrections such as tide correction, drift correction, topographic correction and height correction, the Bouguer anomaly map with an apparent density of 2.60 appears to be the most consistent with underground structure. By means of this Bouguer anomaly map, some residual maps conducted by several band pass filters have been made and the geological structures corresponding with each wave length have been interpreted.

Results of interpretations are as follows:

(1) In the surrounding area of the gravity survey area eminent high gravity zones and several faults are confirmed.

(2) Surrounded by this high anomaly zone is a N-S trending syncline along the Pulibo ridge. Some small-scale low gravity structures were also detected.

(3) On the residual map of $\lambda = 0.25 - 1.8$ which well indicates the geological structure of shallower than 1,500m, the following structure are assumed; bending structure west of the Agno river, NW-SE trending fault from south of Abatan down to Dalimona and Bodo, *E-W trending fault south of Buguias Central and the distribution of dense intrusive rocks* seen between Dalimona and Buguias.

(4) On the high cut filter maps of $\lambda = 1.8 - 9.5$ and $\lambda = 9.5$ a basin structure with a diameter of 5–7 Km exists under the Buguias Central, which suggests that the survey area seem to show a good reservoir structure. The east plunging structure might also extend towards the Ifugao province.

(5) On the model calculation map of the E-W section from Sinepsip to Bodoan, block movement of deep gravity basement indicated as "Regional", step structure of several hundred depth indicated as "Residual" and shallow structure indicated as "Bouguer" are

shown. Based on those filtered waves a fault dipping to the east in the east of Sinepsip seems to be the western edge of a big scale rift valley. Among many block movements seen in the boundary of the first and the second layer, a fault dipping east running near Bodoan may control the comparatively shallow geothermal reservoir.

1–4 Magnetic Survey

A ground magnetic survey was conducted on the same points as the gravity stations and their intermediate points in order to study the correlation with the geology and demagnetization effect due to geothermal alteration.

A proton magnetometer used in this survey is one of the gifts of the Japanese Government to the Bureau of Energy Development in the Philippines.

To know the general trend of geomagnetic variations in this area magnetic deservations were carried out along the road between Abatan and Cabayan or Harshima road. However, no distinct anomalies were observed. The magnetic stations were planned as 3–4 points between each gravity station with point interval at around 150m.

Magnetic Station : 1,000 points A base station is in Buguias Central

Instrument : Observation : Barringer Research GH-122

Base Station : Geometrics G-816

As observed the magnetic intensity is affected by diurnal change which is especially strong in tropical regions. Time alloted diurnal correction based on the recorded change at the base station was applied and then the total average of the corrected value 40961 was subtracted.

As this corrected residual magnetic anomaly still contains noise due to the surface topography and shallow geology, a filtering by running average method has been adopted and a filtered equigamma map for the interpretation was made.

The inclination of the geomagnetic field is low (20°) in this area. Magnetic anomalies are normally observed above high susceptibility rocks which are of significant interest in the case of a geothermal region in relation to demagnetization phenomena.

Consequently the following conclusions were arrived at:

(1) A significant low magnetic anomaly detected along Toking creek and its northern side is considered to be due to the combined effect of small dykes intruded along E-W trend weak zones.

(2) A high magnetic anomaly extending eastwards from Buguias Central is assumed to be

due to the comparatively low magnetized Buguias formation on which demagnetization due to thermal alteration is affected.

This weak but wide anomaly extending to Bodoan and Ifugao side tends to extend to the region of interest where the heat source of this survey area is assumed to come up.

According to the results of the magnetic susceptibility measurements for the collected rock samples, andesite has comparatively high susceptibility of $10^{-3} \sim 10^{-2}$ e.m.u.. but no significant difference has been obtained.

More samples should be collected for comparison purposes in the future.

CHAPTER 2

CONSIDERATION OF GEOTHERMAL SYSTEM

Chapter 2

Consideration of Geothermal System

2–1 Geological Structure and Geothermal Fluid

The objective of geothermal exploration is to clarify the relationship between geologic structures having the favorable aquifer condition and the source of geothermal heat. Most of the geothermal resources in the world exist in grabens with favorable conditions for the water reservoir that could transfer geothermal heat. If a young volcano is somewhere around the graben structure, the place could be considered a promising area for geothermal development.

In general, the aquifer basin structure is controlled by the distribution of permeable and non-permeable layers, but since high temperature water has very low viscosity coefficients, it is believed that perfect non-permeable beds do not exist, unless the beds are without fractures. The structures that control the geothermal reservoir, therefore, are not the characteristics of the individual geological formation itself, but rather the combination of large scale geological structures.

The effects of drainage of the geothermal effluent from the production well is generally considered to affect several kilometers. The subsurface water stream flow is not controlled by the porosity in a narrow sense, but controlled by the porosity in a broad sense, including the fine structures. When considering the flow of low viscosity coefficient of the high temperature boiling water, even small cracks can not be disregarded.

Many surface geothermal manifestations do not necessarily mean that favorable high temperature fluid reservoir exist at depth.

Furthermore, the surface manifestations of the deep geothermal fluid may not necessarily be connected directly to the center of the high temperature geothermal reservoir.

In examining and analyzing the results of the survey, therefore, it is necessary to keep the above mentioned facts in mind in the interpretation of the survey results.

2–2 Survey Result and Geothermal Activity

(1) The geological structures in the area are characterized by intense folding and block movement that continued from sedimentation time of the Buguias formation in upper Oligocene ~ lower Miocene to the dacite lava dome forming activity in Quaternary. The geothermal manifestations observed on the surface have close relationships with the

geological structures, that is, geothermal activity located at or around Buguias Central along the Agno river is situated inside the low gravity anomaly as shown in the gravity map, wherein low Bouguer anomaly extends from dacite lava domes in the eastern part of the survey area to the west and is also geologically sited along the northern rim of the E-W trend uplifted zone.

(2) The post magmatic action of the dacite lava eruption, the latest volcanic activity (Fig. III–1–1) in the area is considered as the source of geothermal heat. It is evident from the fact that the geothermal manifestations are located on both sides of the lava dome, Buguias in the west and Ifugao in the east. The Ifugao manifestation is reportedly the most impressive one. However, the area has not been detailedly surveyed yet. Therefore, it is necessary to investigate the relation between geological strucrure and geothermal activity in order to clarify the total geothermal system in the area.

(3) *The results of the gravity survey reveals favorable conditions for a geothermal reservoir.* Presuming that over 52 mgal is a high gravity zone and below 48 mgal is low gravity zone, the basin structure with a 5–7 Km diameter surrounding Buguias Central, the location of the center of geothermal field is observed.

On the other hand, high gravity areas in the north, west and southward surrounding depressed zone have been shown as upliftment of basement rocks. It shows that the geological structures in the Buguias geothermal field have the same gravity anomaly like most of the geothermal fields in the world associated with graben structures.

(4) The location of hotsprings is restricted below 1,400m A.S.L. around Buguias Central, indicating the present water table. However, sinter deposits composed mainly of carbonate minerals have been recognized to spread widely in the area of hotspring activity. A geothermal alteration zone also exists at the upper stream of Toking creek, about 1,900m A.S.L. It means that the geothermal activity in the area would have occurred covering a wide area, before erosion took place.

(5) The temperature of hotspring water prevailing in the Buguias Central ranges from 40°C to 70°C and the nature of the water is of the NaCl type which would have been derived from the geothermal reservoir. The chemical components of hot water contain much Ca and Mg than the normal geothermal fluid. It suggests that Ca and Mg were extracted from the surrounding rocks due to the interaction between rocks and geothermal fluid in the course of migration of hot water from the geothermal reservoir to the surface.

Silica geothermometer shows the lowest temperature among computed temperatures due to the dilution of surface ground water. However, the other thermometers such as Na-K and Na-K-Ca show over 200°C. It is therefore, inferred that the actual reservoir temperature would have a high potential that can be used for geothermal power generation.

(6) Influence of demagnetization due to geothermal alteration is expected to be observed as high magnetic anomalies. In the Buguias area, a weak but high magnetic anomalous belt which is due to the broad low susceptibility rocks coincide well with the low gravity anomaly extending eastwards from Buguias manifestations, representing an extension of demagnetization effect of geothermal alteration and flow of geothermal fluid.

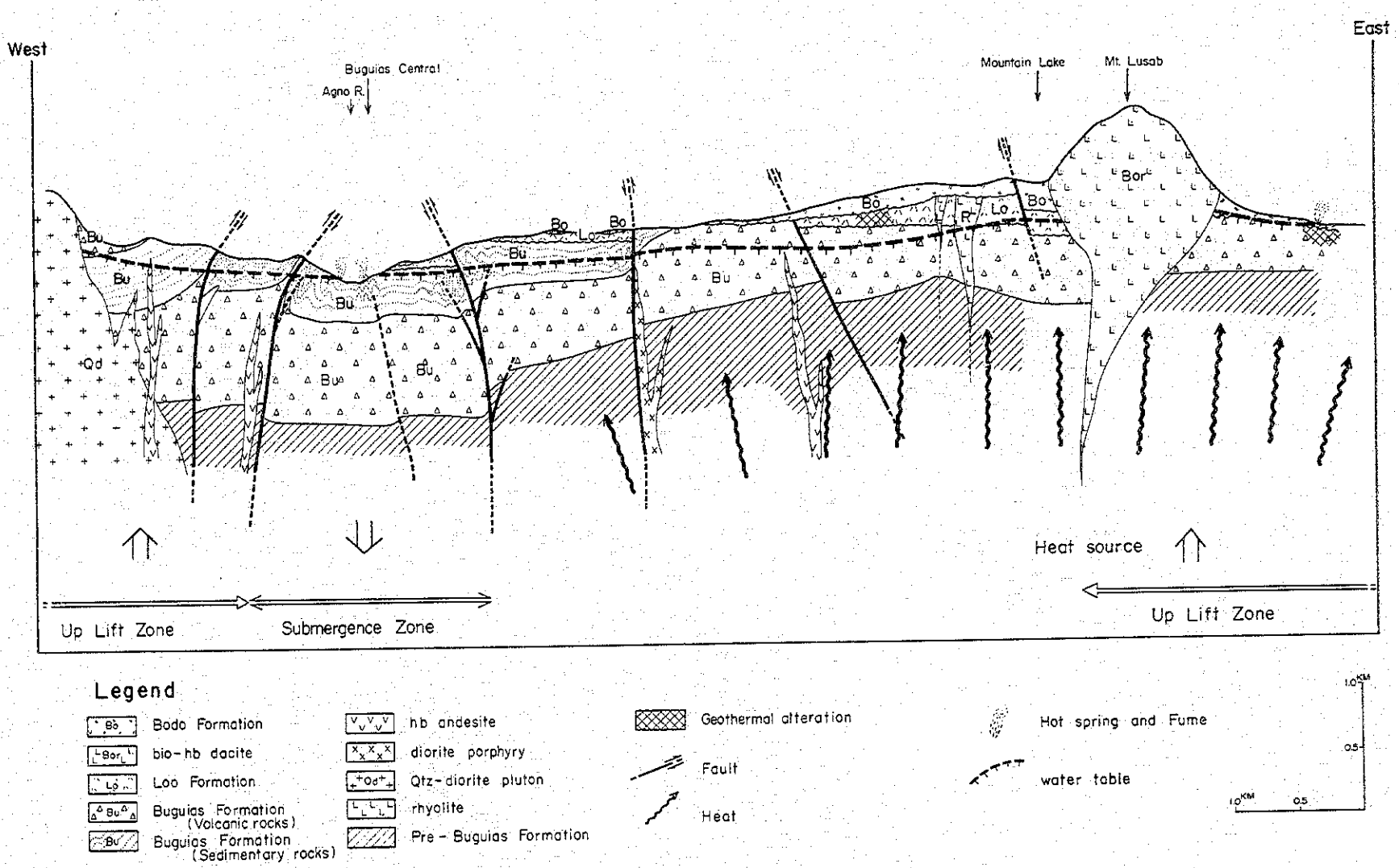

Fig. III–1–2 Structural Schema of Geothermal System in Buguias Area

CHAPTER 3

CONCLUSION AND RECOMMENDATIONS

Chapter 3

Conclusions and Recommendations

3–1 *Conclusions*

Impressive geothermal manifestations are not found in the Buguias area. However, the first phase of the geothermal survey has revealed some promising geothermal resources at depths in the eastern part of the survey area, where further detailed explorations are worthwhile conducting in the future.

1. According to the results of the geological and geophysical surveys, the geological structure of the area is characterized by uplifted zones in both the east and the west of the survey area, a N-S trend graben near Buguias Central, and their combined block movements. A semi-basin structure plunging towards the east, with its center around Buguias Central is believed to exist at depth and maybe indicative of a structure for a geothermal reservoir.
2. Based on the analysis of the geochemical survey, hot springs belong to the NaCl type, and the assumed temperature calculated from the chemical analysis is more than 200°C, which shows a good potential of high temperature geothermal fluid that can be used for geothermal electric generation.

   The magnetic survey conducted with the purpose of detecting demagnetizing effect caused by geothermal alteration indicates a weak, low magnetized zone stretching from Buguias Central to Bodoan towards the boundary of Ifugao province. This may suggest the flow of geothermal fluids from the East.
3. The heat source in this area is inferred to come from the magma chamber under the Quaternary dacite lava dome in the eastern side of this area. This lava dome seems to be related to the most recent volcanic activity (16,870 year B.C.), which has been confirmed from exploration results of the Daklan project, located about 25 Km south of this area.
4. The survey area of this phase is confined within the western side of the above mentioned dacite lava dome, which is considered to be the heat source of this area. A low gravity anomaly, however, tends to extend to the eastern side of the area. Furthermore, prominent geothermal manifestations are confined within the eastern side of this dacite lava dome. It is important in the future to determine the total extent of the geothermal system within this area.

In view of the above-mentioned conclusions, it is recommended that bore-holes be drilled to measure the thermal gradient at the following locations in order to conceptualized the geothermal fluid movement.

Proposed Sites of Thermal Gradient Bore-Holes

(1) Near the border of Ifugao Province east of Bodoan with an elevation of 2,050m (near gravity survey point 108).

(2) Two kilometers Southeast of Bodoan with an elevation of 2,150m (near gravity survey point 120).

(3) South of Bodo with an elevation of 1,800m (near gravity survey point 112).

(4) Downstream of Toking creek with an elevation of 1,500m (near gravity survey point 137).

(5) In Buguias Central with an elevation of 1,400m (near gravity survey point 1).

(6) Upstream of Toking creek with an elevation of 1,900m (near gravity survey point 109).

In order to confirm the deep thermal gradient, the drilling depths must be deep enough to penetrate the geothermal aquifer. The above mentioned locations have been selected because of the following reasons:

1. The locations are distributed between a heat source which is considered to be under the Quaternary dacite lava dome and the manifestations in Buguias Central.
2. Around Bodo nearer to the heat source, a graben structure with a NNE-SSE trend has been detected, which could be a good reservoir based on geological and geophysical surveys.

3–2 Recommendations

Based on the results of the recent survey of this phase, the most interesting areas for exploration have been selected.

(1) In order to delineate the geothermal reservoir of this area, resistivity surveys should be conducted, mainly in the eastern part of this survey area as shown in the following map. The low resistivity zones, faults, cap-rock, and so on which have deep relations with the reservoir must also be studied. There should be at least three (3) survey lines with a total length of more than 16 Km, and with a 250 m station interval, based on the Shlumberger configuration, expanding half electrode spacing from 10 to 1500 m.

(2) During the drilling of the thermal gradient bore-holes, all of the drill cores should be recovered as a general rule, and a systematic study should be made on them by microscopic study, X-ray diffraction analysis, and other physical properties.

After drilling, temperature and electrical loggings (Resistivity and Self Potential) should be conducted to study the geological structures and the geothermal system.

(3) In the Ifugao side, where prominent geothermal manifestations were found, it is recommended that geological, geochemical, gravity and resistivity surveys should be conducted. This survey, covering 80 Km^2 would correlate its findings with those from the Buguias area, which would enhance the image of the geothermal system, so that a comparison of the structure on both sides of the Quarternary dacite lava dome can be made.

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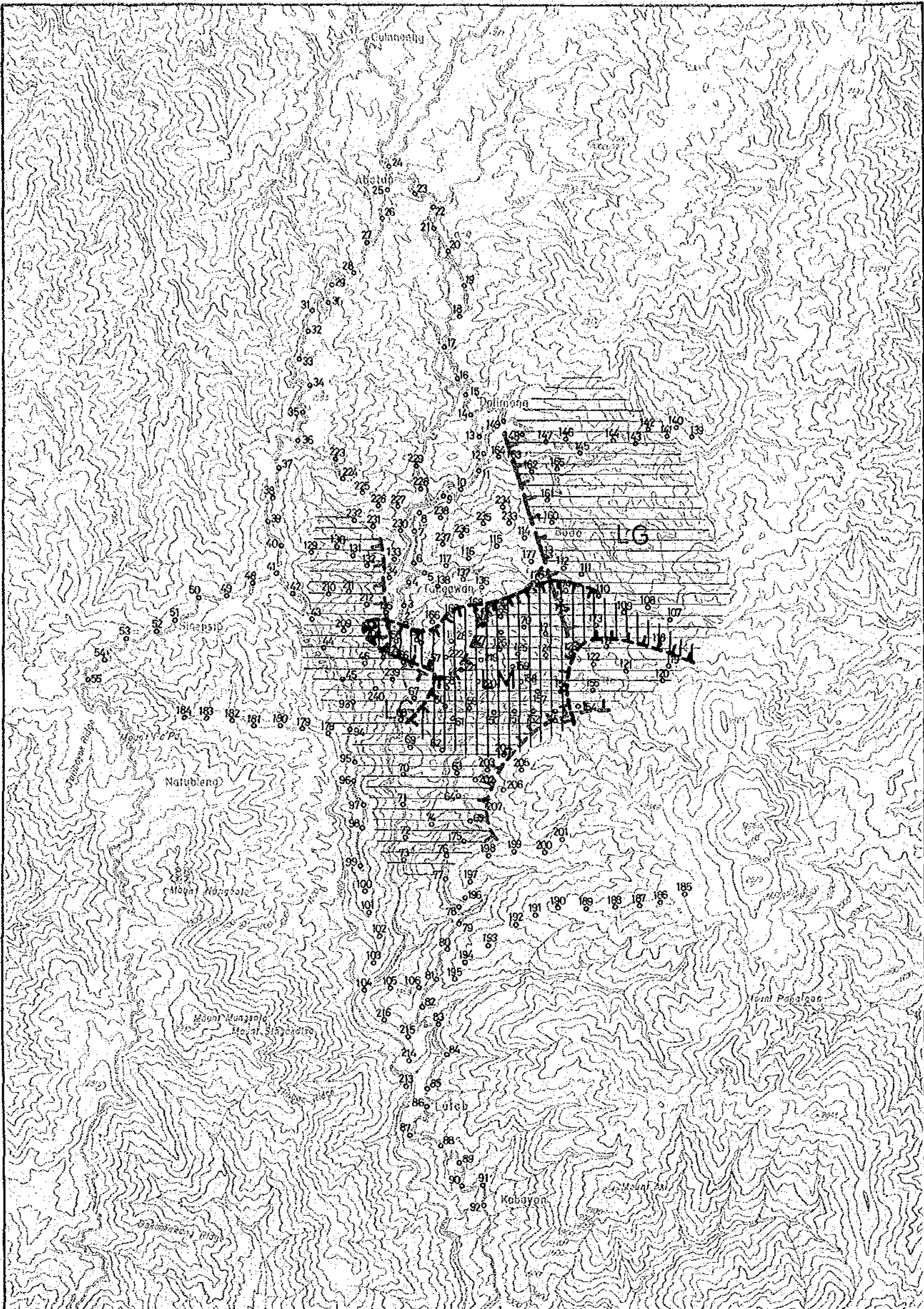


Gulnnoong
Abetun
Dolimang
Bade
LG
Tangewan
Sinepsip
Natublend
Mount Nangsala
Mount Pangalgan
Lutab
Kabayan
Mount Polag

Buguias Geothermal Development Survey

the Republic of the Philippines

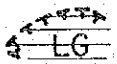
CONSOLIDATED GEOPHYSICAL ANOMALY

0 1000 6000 m

Jan ~ Feb, 1981

Fig. III-1-1

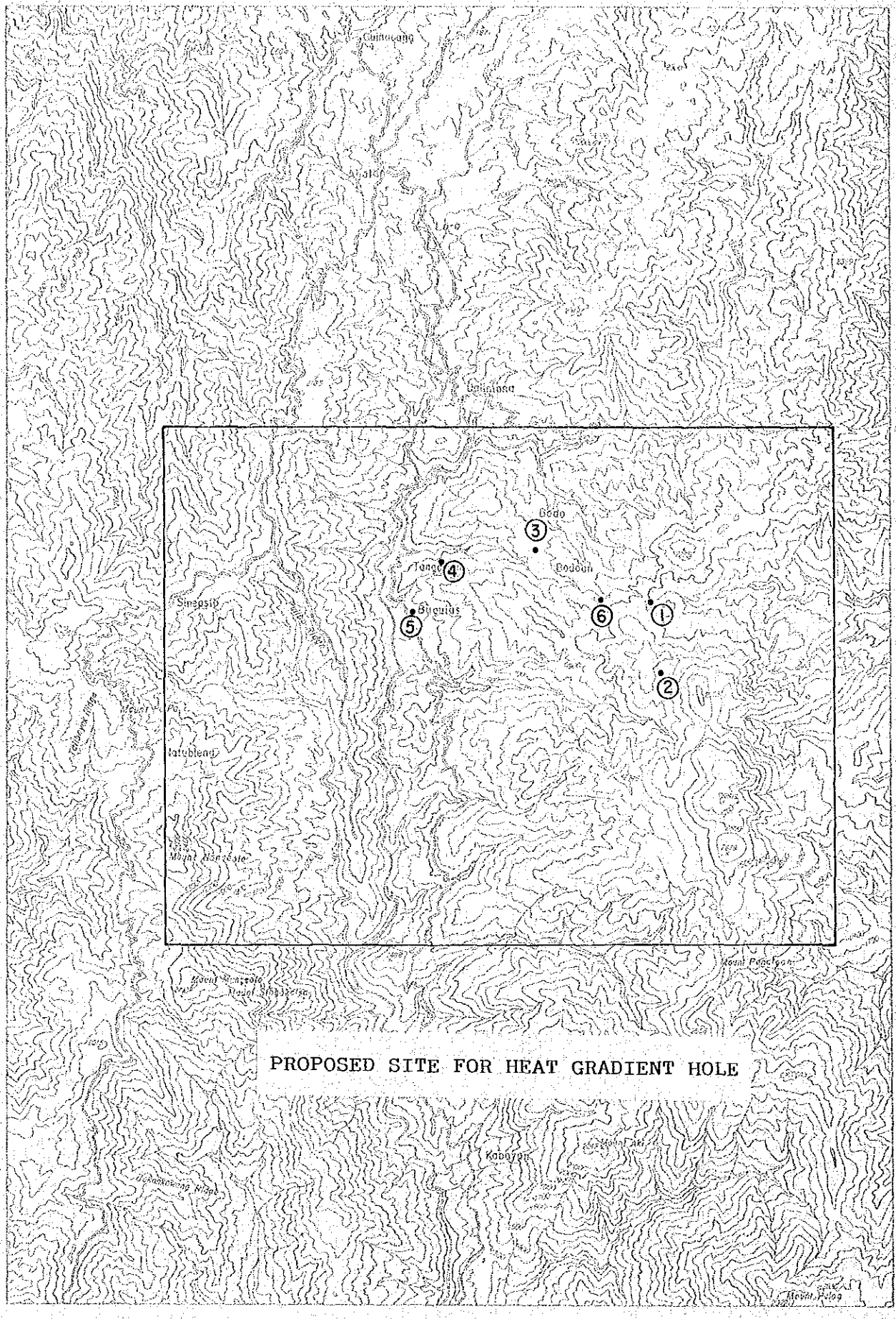
LEGEND



Low Gravity Zone

Fault Structure

Weak Magnetized Zone



PROPOSED SITE FOR HEAT GRADIENT HOLE