No. 38

REPUBLIC OF THE PHILIPPINES

REPORT ON ACUPAN-ITOGON GEOTHERMAL DEVELOPMENT

SECOND PHASE SURVEY

AUGUST 1984

JAPAN INTERNATIONAL COOPERATION AGENCY

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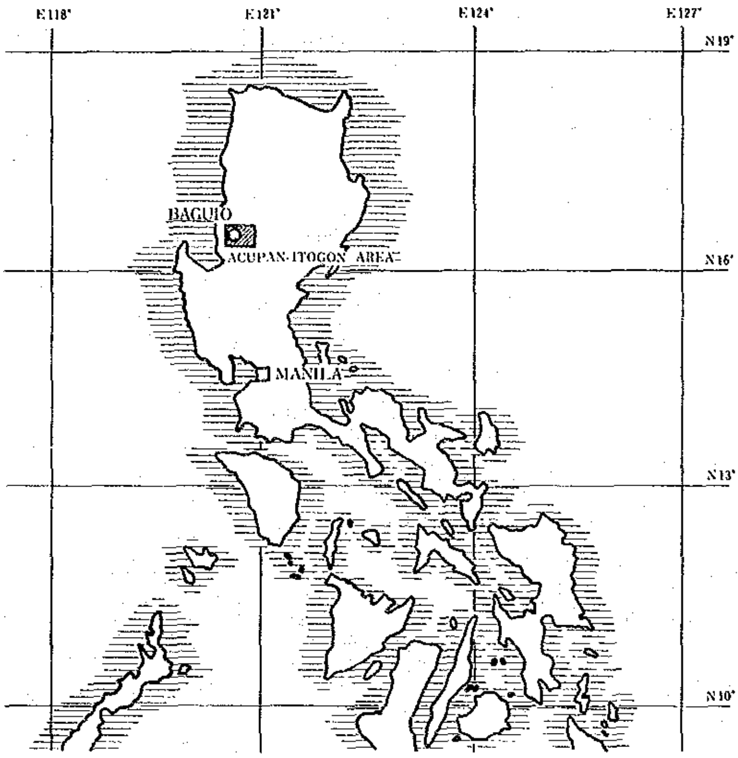

LOCATION MAP OF ACUPAN-ITOGON AREA

PROVINCE OF BENGUET
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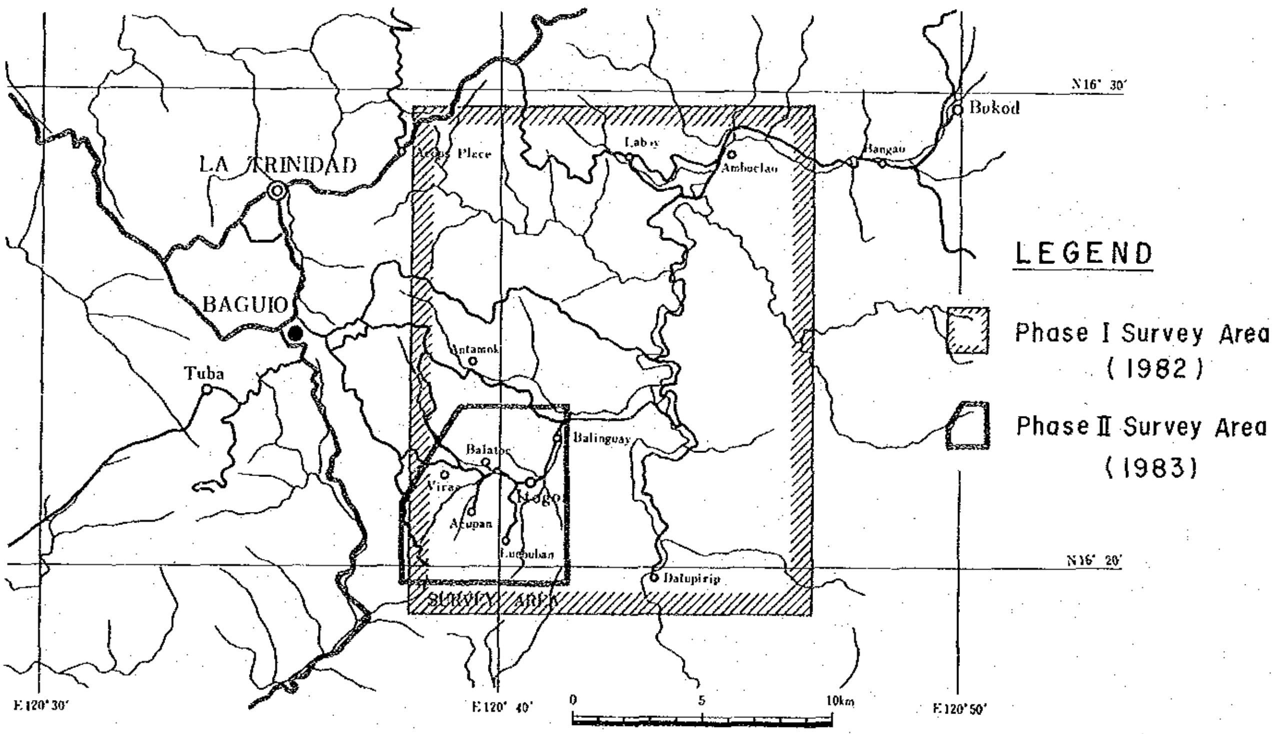

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CHAPTER I

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

I. SUMMARY

CHAPTER I SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1 SUMMARY

1.1 Results of Geoscientific Studies

The work program for the second phase of the BED-JICA Technical Arrangement for Acupan-Itogon geothermal project was successfully implemented through the joint efforts of BED-BISHIMETAL geothermal team. Detailed geoscientific studies undertaken in this phase activity has delineated a possible potential resource area of eight (8) square kilometers (4 kms x 2 kms) which warrants deep drilling exploration scheduled to be undertaken in the third phase of the Arrangement. The site of the first well (1,500 meters depth) has been identified by the survey team.

The geoscientific studies conducted in the prospect area are briefly discussed in the succeeding headings of this comprehensive report.

1.1.1 Geology and Structural Setting

The detailed geological survey was carried out over an area of 40 kilometer-square delineated by the Phase-I survey activity.

The Acupan-Itogon prospect area is a part of the southern extension of the Central Cordillera range which is generally underlain by Cretaceous-Paleogene metamorphosed rocks, thick sequence of volcano-sedimentary complex, various rock suites of siliceous plutons (commonly called the Agno batholith) and andesite-dacite volcanics (occurring as dikes, plugs, lava domes and pyroclasts).

The mappable rock units in the prospect area are classified as follows from oldest to youngest:

MESOZOIC	→ Late Cretaceous, DALUPIRIP SCHIST classified as low grade metamorphic rock equivalent to the greenschist facies.
PALEOGENE	→ Oligocene, ANTAMOK DIORITE Late Oligocene-Early Miocene, MIOCENE SEDIMENTARY ROCKS (thick sequence of interlayered sandstones, conglomerate, pyroclasts and lava flows)
NEOGENE	→ Early Miocene, ITOGON QUARTZ DIORITE AND TONALITE Early Pliocene, VIRAC GRANODIORITE Late Pliocene, ANDESITE COMPLEX (composed of lava flows, pyroclasts, dikes, breccia intrusives and plug)
QUATERNARY	Late Pleistocene, DACITE PLUGS (intrusive breccia with crystalline core of dacite porphyry)

The relationship of the two plugs (andesite and dacite) is distinctly defined in the "Balatoc plug" of Acupan mine area. Both surface and underground exposures revealed the later intrusion of the dacite into the andesite breccia plug. Both plugs apparently merged into a single tubular body steeply dipping to the southeast.

The nature of emplacement of the plugs in Acupan seems to be more of a hypabyssal intrusion, rather than an eruption center of volcanic activity as most of the previous investigators believed.

The cylindrical form assumed by the plug could be largely attributed to an intersection of two conjugate faults (northeast and northwest) which served as a passageway for the ascent of andesite and dacite lavas to the surface.

Hydrothermal Alteration. Intense argillization and silicification are distinctly recognized over the area covering Acupan mines and Itogon plug. X-ray diffraction analysis showed two types of alteration:

- acid-type characterized by kaolinite-jarosite; and
- neutral-type characterized by potash-feldspar-sericite-quartz secondary mineral assemblages.

Geologic Structure. The regional north-south structural lineaments which extend to several kilometers in the Central Cordillera range have influenced the development of conjugate system of northeasterly and northwesterly trending fractures and likewise could have induced the multiple stages of intrusion of the intra-Miocene siliceous pluton in the Central Cordillera.

The system of conjugate faults which dominantly dissect the transitional zone located between the east central uplift and the west downthrown sections could have influenced the regional distribution of emplacement of the andesite-dacite plugs and lava domes along the eastern fringe of the Central Cordillera. The northeast and northwest faults are well defined in the Acupan-Itogon and Antamok areas. However, the northeasterly trending faults are the dominant set of fractures in Acupan which controlled the localization of gold mineralization and intrusion of andesite-dacite plugs. In Antamok area, the mineralization is dominantly confined along the northwesterly trending fractures.

1.1.2 Geochemistry

The following surveys were conducted in the geochemical exploration for Phase-II:

- ground geochemical survey (199 stations)
- O/H isotope analysis of hot spring water (15 samples)

From the evaluation of results of geochemical exploration for the first year survey and the present investigation, conclusions on the estimated geothermal system for the Acupan-Itogon area are drawn. These are:

(a) Distribution of anomalous values in soil such as temperature, mercury content and radon gas concentrations trends in a northeast-southwest direction along a line connecting Acupan mine and the Itogon bridge.

(b) The said anomalies geologically correspond to the sites of the Balatoc plug and Itogon plug, and are distributed at the periphery of the plugs.

(c) Boiling springs, which have neutral pH, are discharging in Acupan mine and near the Itogon bridge. The underground temperatures, based on the silica and Na–K–Ca geothermometers, are estimated to be 147°–229°C and 193°–236°C, respectively.

(d) The source of the hot spring water could be precipitation. Some of the hot spring water show an oxygen shift probably due to the chemical interactions with the host rocks of the reservoir.

(e) Hot spring waters of Acupan may by classified into three main types: (a) Na/Cl; (b) Ca/SO_4; and Na/SO_4-HCO_3. The Na/Cl type generally exhibits an oxygen shift and its distribution is relatively limited to the lower levels of the Acupan mines.

(f) Occurrence of the Na/Cl type hot water is basically controlled by the Balatoc and Itogon plugs, and further influenced by the vein fracture systems. The aereal extent is estimated to be in the northeast-southwest direction.

(g) It is inferred that at the upper levels from Acupan mine to the Itogon bridge, calcite and other minerals fill the fissures and form self-sealed zones.

1.1.3 Microearthquake

Microearthquake occurrences were monitored in Acupan-Itogon area during the period October 14 to December 7, 1983, inclusive. The observation system consists of one (1) three-dimensional seismograph to measure the north-south, east-west and vertical ground movement and four (4) vertical seismographs which were installed 2–4 kilometers from each other.

A total of 973 earthquakes were recorded during the said period, of which 213 were observed to have S-P times of five (5) seconds or less. These were mainly of magnitudes 1 to 3, and are classified as microearthquakes. However, no microearthquake swarms were observed.

Results of data processing show that the estimated ratio of P- to S-wave velocity (Vp/Vs), Poisson's ratio and b-value in the vicinity of the area were 1.73, 0.25 and 0.88, respectively.

Hypocentral distribution proved the existence of three (3) active and three (3) blank zones of microearthquake occurrences as follows:

Active Zone I: The zone in which hypocenter distributions are located in the vicinity of the network, and the foci distributed discretely at depths.

Active Zone II: The zone in which hypocenter distributions are located 5 to 15 kilometers north of the network with focal depths ranging from 0 to 10 kilometers.

Active Zone III: The zone in which hypocenter distributions are located west of Zone II with foci distributed in a fan-shaped area to the west, dipping from depths of 10 kilometers.

Blank Zone A: The vertical cylinderlike zone surrounding Active Zone I.

Blank Zone B: The zone that covers the whole eastern part of the survey area.

Blank Zone C: The zone that corresponds to the southwestern part of the survey area.

From this results, in conjunction with those from previous geological, geophysical, geochemical and geothermal surveys, it can be assumed that the most interesting zones of possibly locating active structures that can be associated with geothermal systems are Active Zone I and Blank Zone A. Hypocentral distributions in Zone I show it can be related with plugs that may continue at depths since they are usually surrounded by hard and compact rocks of high heat conductivity.

1.1.4 Gradient Holes

The seven (7) shallow temperature gradient holes with a total length of 2,200 meters were drilled in Acupan prospect, purposely to define the lateral extent of the thermal flow in the selected area of interest through various activities performed in the hole:

- thermal and electrical logging;
- core logging and petrographic analysis; and
- core testing consisted of x-ray diffraction analysis, petro-chemical analysis and physical test.

The results of the gradient holes are as follows:

(a) All the seven (7) shallow holes drilled in the area generally encountered continuous stretches of quartz diorite and granodiorite suites which is interrupted by short stretches of andesitic breccia and dikes. The occurrence of dacitic breccia is limited along the contact of the dacite plug, as in the case of AGH-1 where it was drilled near the Itogon plug. On the other hand, the volcano-sedimentary complex was intersected in the first 190 meters stretch at AGH-3 in Virac, the westernmost site location of the seven (7) wells drilled in the prospect area. The sediments composed of intercalated layers of hematitic tuff-shale and greenish sandstone is correlated to the Zigzag Formation which outcrops along the upstream of Bued River. The subsurface geology showed by the drill hole data conform well with the surface mapping carried out over the 40 kilometer-square area.

(b) Hydrothermal alteration minerals such as chlorite, calcite, sericite, α-quartz with occasional occurrence of epidote are common to all gradient holes. The difference lies in the occurrence of gypsum-anhydrite as micro-veinlets and the clay minerals, kaolinite and montmorillonite. The area where AGH-1, -2 and -5 were spudded have the alteration mineral assemblage characterized by the presence of kaolinite and gypsum-anhydrite while AGH-3, -4 and -7 have montmorillonite and sericite.

(c) Chemical analyses of the samples showed that elements like Si, K, As and Rb are enriched with corresponding drop in Ca, Na, and Sr concentration near the highly fractured zone. Such depletion or gain in concentration of these chemical elements in rocks within a particular horizon could be explained by the interaction of the geothermal fluid with the country rock.

(d) Physical property test (resistivity and sonic velocity) conducted on the several core samples, generally showed that the rocks have low porosity and permeability. It is believed that the underground flow of geothermal fluid in Acupan-Itogon prospect area is more or less controlled by secondary permeability (fractures) which could bring significant physico-chemical changes in the rocks.

(e) Based on the significant temperature gradient obtained in the three (3) shallow holes, the projected underground temperature at various depths are shown below:

Estimated Underground Rock Temperature (°C)

Hole No.	500 Meters	1000 Meters	1500 Meters	2000 Meters
AGH-2	136°	206°	276°	346°
AGH-5	70°	110°	150°	190°
AGH-6	44°	64°	84°	104°

(f) Based on the soil temperature and shallow temperature gradient measurements, the outline of the near surface lateral thermal flow in the prospect area assumed an elongated flow trend to the northeast covering the site location of the AGH-1 and -2 and the two prominent dacite plugs (Balatoc and Itogon plugs) in the area. The temperature gradient is steeply dipping to the northwest as indicated by the measurements in AGH-5. The pattern of the thermal flow apparently follows the northeasterly trend of the dominant fault system in the area.

2. CONCLUSIONS

2 CONCLUSIONS

The various exploration techniques used during Phase-II survey have delineated an eight (8) square kilometer area of prime, deep drilling target centered around and between the Pleistocene Balatoc and Itogon plugs (Fig. I–2–1) The active geothermal system in the area is characterized by the following general salient features:

(a) It is structurally controlled as evidenced by the observed rapid lateral temperature decay away from the prime resource area (see gradient hole data);

(b) SiO_2 and Na–K–Ca geothermometries indicate a source temperature of 190–230°C; and

(c) Numerous thermal manifestations encountered in the deeper levels of the Acupan mine attest to the existence of an active, convective geothermal system in a medium of considerable structural density (that is, secondary permeability).

In addition to the above, the spatial distribution of thermal manifestations in and around the Balatoc and Itogon plugs and the apparent retrogressive nature of hydrothermal alteration in the area are worthwhile considering. The active geothermal system in the area can be presented in two ways, namely:

(a) the thermal springs in the vicinity of Itogon plug represent channeled, lateral outflow from the Balatoc plug; or

(b) the thermal manifestations in both localities are expressions of a larger system underneath the prime resource area.

Retrograde alteration in the form of amorphous silica deposition at upper mine levels (above 2300 L) where temperatures are relatively lower has produced a silica buffer zone which is observed to be widely distributed over the area.

The size of the geothermal system is therefore obscured by this cap rock and could probably explain why thermal manifestations are discretely concentrated in areas where topography or mine workings have intersected or penetrated the cap rock (e.g., Itogon and Balatoc plugs, respectively).

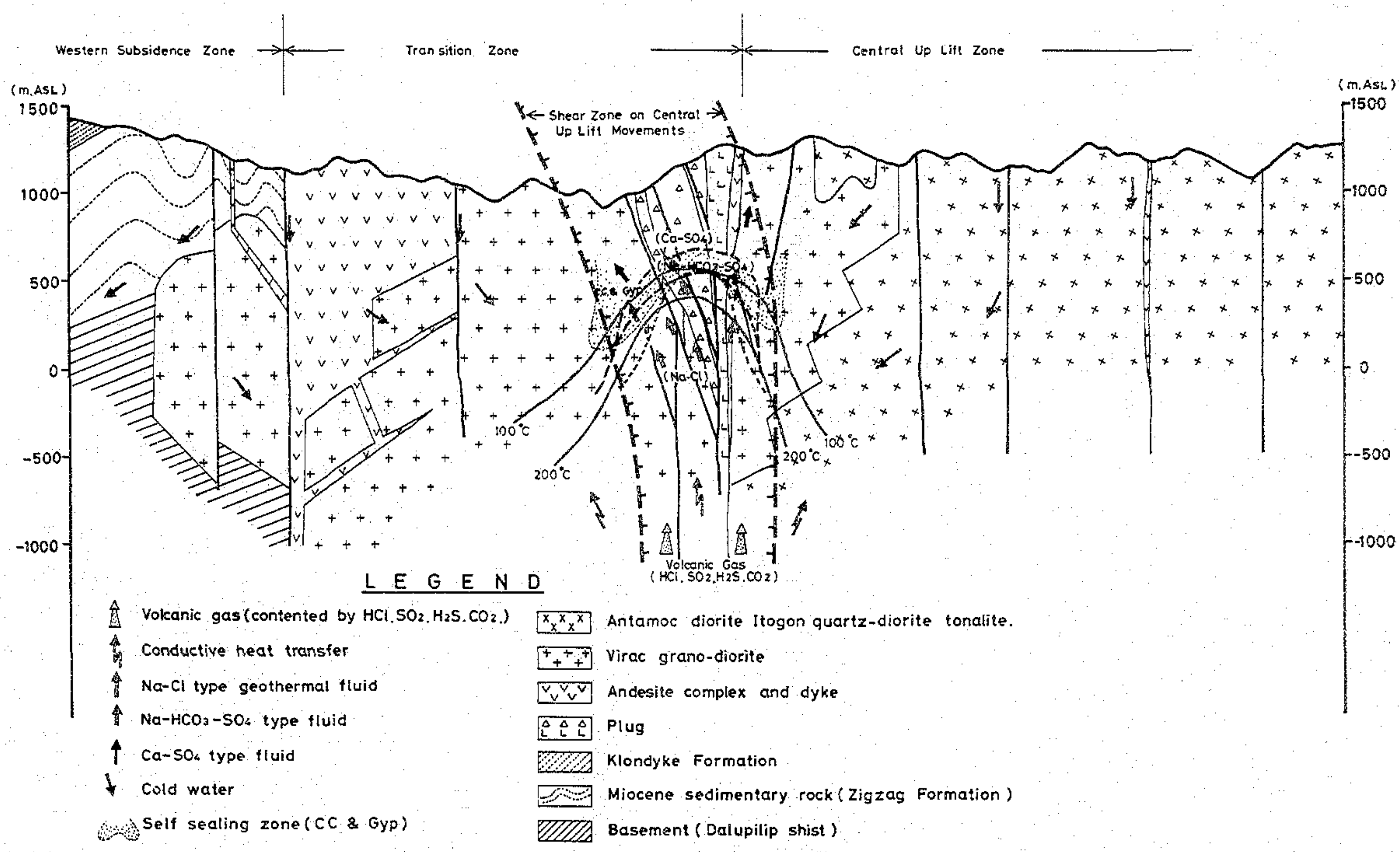


Fig. I-2-1 Conception Model of Geothermal at the Acupan Itogon Area

3. RECOMMENDATION

3 RECOMMENDATION

Based on the very encouraging results of the various geoscientific studies jointly undertaken by the BED and JICA teams under Phase-I and -II of the exploration program for the Acupan geothermal project, a conceptual model of the geothermal system of the prospect area was reconstructed. The model would be further tested by deep drilling program which is the main objective of the Phase-III activity under the Technical Arrangement for the said geothermal project. Drilling of deep exploratory wells would adequately test this model, namely target A and B shown in Fig. I–3–1.

However, for the first test well, the target A will generate subsurface geological and reservoir parameters like rock types and alteration, temperature, permeability, gas and water chemistry which are relevant information for the initial evaluation of the resource potential. Among the several sites chosen to achieve the above object the site-E, near the Balatoc plug is likely to be most favorable, considering the access road for heavy equipments of drilling machines. This program would ensure a relatively high success ratio of intersecting a promising potential productive zone.

3.1 Drilling Program

Well Nme	– ACUPAN-1
Site	– E (along Acupan creek, branch of Ambalanga River).
Location	– Acupan Mine, Itogon, Benguet
Ground Elevation	– 815 meters
Well Head Coordinates	– 5,168 meters, South
	– 360 meters, West
Measured Depth	– 1,500 meters
Measured Vertical Depth	– 1,350 meters
Kick-off Point	– 300 meters below surface
Drift Angle (maximum)	– 35°
Bearing	– S 20 E
Throw	– 515 meters

3.2 **Drilling Prognosis**

3.2.1 **Expected Structures and Lithology**

0–5 meters: Alluvium, terrance gravel and talus materials;

5–130 meters: Impermeable silica buffer zone;

130–1,100 meters: Massive Virac granodiorite;

1,100–1,200 meters: Fault zone: Star Fault; expected total loss circulation (TLC);

1,200–1,400 meters: Moderate to highly fractured Virac granodiorite;

1,400–1,500 meters: Highly brecciated contact zone of Virac granodiorite and Balatoc dacite plug.

3.2.2 **Bottom Temperature**

Based on the Na–K–Ca geothermometry which indicate a reservoir fluid temperature of 230°C and the temperature of 300°C based on projected temperature gradient at AGH-2, the well is expected to intersect a temperature of 250°C at 1,350 meters vertical depth.

3.2.3 **Overall Expectations**

It is anticipated that ACUPAN-1 geothermal well could be successfully discharged should the length of the well (1,500 meters) is sufficient enough to reach the targeted highly productive zone, i.e., the dacite breccia zone of the Balatoc plug.

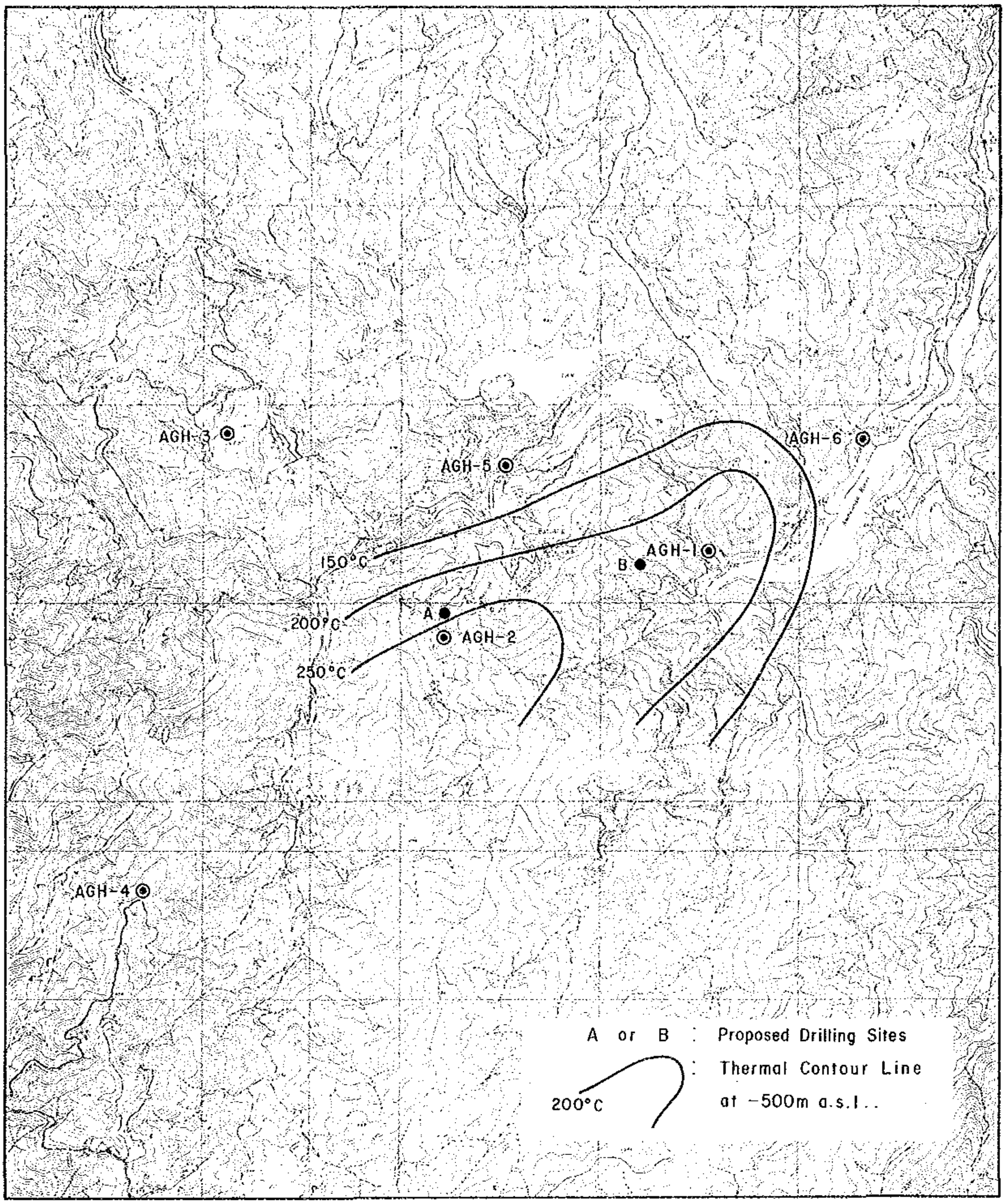


Fig. I-3-1 Location Map of Proposed Deep Well

CHAPTER Ⅱ
INTRODUCTION

I. ACUPAN-ITOGON GEOTHERMAL DEVELOPMENT PROJECT

CHAPTER II INTRODUCTION

1 ACUPAN-ITOGON GEOTHERMAL DEVELOPMENT PROJECT

1.1 Purpose of the Survey

The purpose of this survey is to make a comprehensive review and evaluation of the resource potential of Acupan-Itogon prospect area, located southeast of Baguio City in Benguet Province, Republic of the Philippines, through geological, geochemical and geophysical surveys and temperature gradient measurement of shallow holes. The survey is a result of the technical arrangement entered between the Energy Ministry's Bureau of Energy Development (BED) and the Japan International Cooperation Agency (JICA) upon the request of the Philippine government.

The second phase of the three-phase survey calls for the execution of the following activities:

- detailed geological and geochemical surveys;
- investigation of the micro-seismic activity over an area of 40-kilometer-square which had been delineated in the Phase-I survey activity as an area of interest with possible certainty of finding a potential geothermal resource; and
- drilling of seven (7) shallow holes for temperature gradient measurements and geological core logging.

Through these undertakings covered by the Phase-II activity of the Technical Arrangement, results of the survey will bring the exploration program to a decision whether or not to proceed to the drilling stage as envisioned in the Phase-III of the Arrangement. The implementation of the Phase-II work program is also aimed to zero-in the target site for the first test well (1,500 meters) based on the reconstructed conceptual model of the geothermal system of Acupan-Itogon prospect.

Arrow Graph of Survey

	1985					1984			
	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Geological Survey		28 ├──	────	14 ──┤					
Geochemical Survey		28 ├──	────	────	11 ──┤				
Geophysical Survey		28 ├──	────	────	21 ──┤				
Drilling Works for Gradient Holes				17 ├──	────	────	────	──┤	
Logging Works for Gradient Holes				17 ├──	────	────	────	────	──┤

1.2 Background of Technical Arrangement

The situation of power demand and supply of electricity for the Northern Luzon grid becomes critical considering the seasonal varaitions affecting the hydroelectrical dams such as the Binga and Ambuklao hydropower projects situated near Baguio City and the growing demands for electricity in Metro Manila.

From the view point of geothermal energy development, 24% of the power consumption in Luzon is being supplied by the geothermal power stations located at Tiwi (330 MWe) in Albay and Mak-Ban (220 MWe) in Laguna. The successful development of these two fields has prompted the Philippine government to accelerate the exploration/development of other known potential geothermal areas in Luzon to further augment the existing power supply of the island.

In the Northern Luzon, several potential resource areas were identified and underwent preliminary geoscientific investigations. Some of these are the Batong-Buhay in Kalinga-Apayao and Mainit-Bontoc in Mountain Province. However, the unstable political situation in the Northern Luzon has hampered the exploration of the geothermal resource in these areas. On the other hand, the preliminary exploration work undertaken by the joint BED-JICA geothermal team in Buguias, Benguet was also affected not by unstable political situation but by the non-acceptance of local residents against exploration activities. The survey in Buguias was carried out in January-March 1981 under the first BED-JICA Technical Arrangement and was discontinued due to the protest of the local residents of Buguias area.

For the Daklan prospect, also located in Benguet Province, the exploration work which was jointly undertaken by BED and Italian (Electroconsult) survey teams under a technical cooperation program had made progress in their activities to the point of drilling five (5) deep exploratory wells. The wells had confirmed the presence of significantly high temperature zone. However, the wells intersected poor permeability zones which did not warrant the continuation of the project activity toward possible development of Daklan.

To continue the search for potential geothermal resource in Northern Luzon, particularly in areas where there is a large demand for electricity such as Baguio City and the operating gold and copper mines, the BED made another request to JICA to undertake a geothermal investigation in Acupan-Itogon area.

In response to this request, JICA sent a second survey mission team in March, 1982 to determine the possibility of carrying out a geothermal exploration in the said prospect area. The scope of work of this survey project was drafted and the implementing arrangement was executed between BED and JICA in the same year.

During the four (4) months of the first year activity (i.e., from August 8 to December 5, 1982), reconnaissance geological, geochemical, gravity and geoelectrical resistivity surveys, etc., were conducted over the 300 kilometer-square prospect area. The survey results were reviewed by the Philippine BED geothermal staff during the period of March 9–16, 1983, and were consolidated in the first survey report.

The results of the Phase-I activity were very encouraging to warrant the implementation of Phase-II exploration program. The activities involved the conduct of detailed geoscientific studies and the drilling of shallow temperature gradient holes within the delineated 40-kilometer square area of interest in Acupan-Itogon prospect.

1.3 Members of Survey Team

Japanese Team (JICA Team)

Team Leader	Mr. Yasunori Sakai
	Mr. Kuniaki Nagata
Geological Survey	Mr. Keiji Nakano
	Mr. Takao Maeda
	Mr. Motomu Goto
Geochemical Survey	Mr. Kenji Wakita
	Mr. Minoru Saito
	Mr. Masahiro Nara
Geophysical Survey	Mr. Asahi Hattori
	Mr. Hiroshi Fukuda
	Mr. Manabu Kaku
Logging Engineer	Mr. Masashi Kurosawa

Philippine Team (Bureau of Energy Development)

Team Leader	Mr. Alfredo C. Troncales
Geophysical Survey	Mr. Edgardo S. Aguas
	Mr. Francisco A. Benito
	Mr. Rene A. Villarosa
	Mr. Leonardo U. Elemia

Geological Survey	Mr. Rene B. delos Santos
	Mr. Narciso V. Salvania
	Mr. Romeo R. Tena
	Ms. Helene G. Aniceto
Geochemical Survey	Mr. Zalzon C. Espino
	Ms. Evelyn Ray Reyes
	Ms. Mona Lisa V. Agoncillo
Sr. Electrical Engineer	Mr. Rodelio T. Palabasan
Sr. Mechanical Engineer	Mr. Josefino C. Adajar
Surveyer	Mr. Manuel R. Panagsagan
	Mr. Valentino Noble II
Cartographer	Mr. Ben P. Ignacio

2. HIGHLIGHTS OF GEOTHERMAL EXPLORATION

2 HIGHLIGHTS OF GEOTHERMAL EXPLORATION

2.1 Energy Affairs

The Philippines, a developing country in Asia, has been dependent so much on oil. The utilization of indigenous source of energy such as geothermal was only realized by the Philippine government at the start of oil embargo in 1973. It was then that the Tiwi geothermal field in Albay province was decided to undergo full exploitation for geothermal energy source of electricity. This was followed by other known potential resource areas like Mak-Ban in Laguna, Tongonan in Leyte and Palinpinon in Southern Negros. The total power generation coming from these four (4) fields is 781 megawatts of electricity as of 1983.

The per capita oil consumption has increased from 1.05 barrels with 36 million people in 1960 to 1.74 barrels with 49.5 million people in the early 1980s. According to some statistical data, the target national energy consumption is estimated to be 127.38 million barrels by 1987, which represents a per capita consumption of 2.23 barrels with 57 million people. On the other hand, the ratio of oil to the total energy consumption showed 92% for the period of 1973–1979. But the increase in supply of such non-oil energy as coal, geothermal and hydro-power generation caused the drop of said ratio to 82.7% in 1980 and 79.6% in 1981. It is expected that 13.9% of the energy supply shall be covered by the geothermal power generation so that dependency on oil shall be further lowered to 44%.

Among non-oil energy, the ratio of coal is estimated to continue increasing to over 18% (oil equivalent) while that of hydropower, 12% and geothermal power, 14%. It is expected that geothermal power generation will contribute about 1000 MWe in 1987 equivalent to 10% of the total power supply of the country.

2.2 Geothermal Energy Development

Geothermal exploitation in the Philippines made a remarkable progress in the '70s. In 1983, with the commissioning of the Palinpinon and Tongonan power plants, the total geothermal power generating capacity reached 781 MWe which raised its place as the second world's largest producer of geothermal energy for electric power generation next to Unites States.

The Six-year Energy Development Plan of the Philippines aims at accelerating the exploration/development of additional prospective potential areas to supplement the existing five (5) fields undergoing power development.

The developed fields and prospective areas are listed below:

Developed Fields	Province	Installed Power (1983)
Tiwi	Albay	330 MWe
Makiling-Banahaw	Laguna	220 MWe
Tongonan	Leyte	115.5 MWe
Palinpinon	Southern Negros	115.5 MWe
Manito	Albay-Sorsogon	(under exploitation)

Prospective Areas	Province
Batong-Buhay	Kalinga-Apayao
Daklan	Benguet
Acupan-Itogon	Benguet
Labo	Camarines Norte
Amacan	North Davao
Mandalagan	Northern Negros
Pinatubo	Zambales
Mount Apo	Davao-Cotabato

According to the plan, drilling work shall be carried out in these areas. By the end of 1987, a total of 566 geothermal wells shall have been drilled. Consequently, available geothermal steam is estimated to grow noticeably up to 2200 MW, which means an increase of 627 MW in four years from the current 1573 MW. Besides, the generating capacity is expected to reach 1000 MWe by the end of 1987.

Most of the generating geothermal fields in the Philippines have enough megawatt capacity under the wells and could always support additional power generating plants. The total installed power generating units in the four (4) developed field is 781 MWe and is breakdown as follows:

Areas			Total (MWe) (1983)
Tiwi	55.0 MWe x 6 units	=	300
Mak-Ban	55.0 MWe x 4 units	=	220
Tongonan	37.5 MWe x 3 units	=	112.5
	3.0 MWe x 1 unit	=	3.0
Southern Negros	37.5 MWe x 3 units	=	112.5
	1.5 MWe x 2 units	=	3.0
	Total Installed	=	781.0 MWe

CHAPTER III
DESCRIPTION OF SURVEY RESULTS

I. GEOLOGICAL SURVEY

CHAPTER III DESCRIPTION OF SURVEY RESULTS

1 GEOLOGICAL SURVEY

1.1 Purpose and Methodology

For the 40 kilometer-square area delineated by Phase-I survey as a highly prospective ground for a geothermal resource, a semi-detailed geological survey was carried out over the area covering a total length of 124 kilometers of survey routes (Fig. III–1–1). The geological field information were then plotted in a 1:10,000 scale map.

The purpose of the survey is to identify the type lithology, hydrothermal alteration and the structural system related to an active geothermal system.

Of the 630 samples collected, 87 were brought to Japan for petrographic analysis, radiochronological measurement, X-ray diffraction, etc. The results of these analyses were then correlated with other field data to pinpoint the potential target area for the first deep exploratory well and likewise to come-up a reconstructed model for the geothermal system of Acupan-Itogon prospect.

1.2 General Statement

The following is the stratigraphic sequence of rock units in the prospect area:

MESOZOIC —— Late Cretaceous, DALUPIRIP SCHIST;

PALEOGENE —
- Oligocene, ANTAMOK DIORITE;
- Late Oligocene-Early Miocene,

NEOGENE —
- MIOCENE-SEDIMENTARY ROCKS
- Early Miocene, ITOGON QUARTZ DIORITE and TONALITE
- Early Pliocene, VIRAC GRANODIORITE;

QUATERNARY —
- Late Pliocene, ANDESITE VOLCANICS; and
- Late Pleistocene, DACITE PLUGS.

The structural setting is characterized by three fracture system:

(a) North-south major lineament which harmonizes with the central uplift zone that has been active since Oligocene;

(b) Northeast-southwest; and

(c) Northwest-southeast conjugate faults.

The north-south structure is marked by the alignment of the multi-stage plutonic intrusion during Oligocene to early Miocene, while the northeast-southwest and northwest-southeast structures control the localization of the volcanic activities in the past as well as the directional intrusion of andesite/dacite dikes, plugs and breccia and of mineralized quartz veins. Dacite plugs are also observed at the cross points of the north-south, northeast-southwest and northwest-southeast trending fractures.

The heat source of the Acupan geothermal system seems to be related to the sub-volcanic activity of Pleistocene dacite plug (isotopic age of 1.28 – 0.49 Ma) and that the geothermal system of Acupan is structurally controlled by the northeasterly trending conjugate fault.

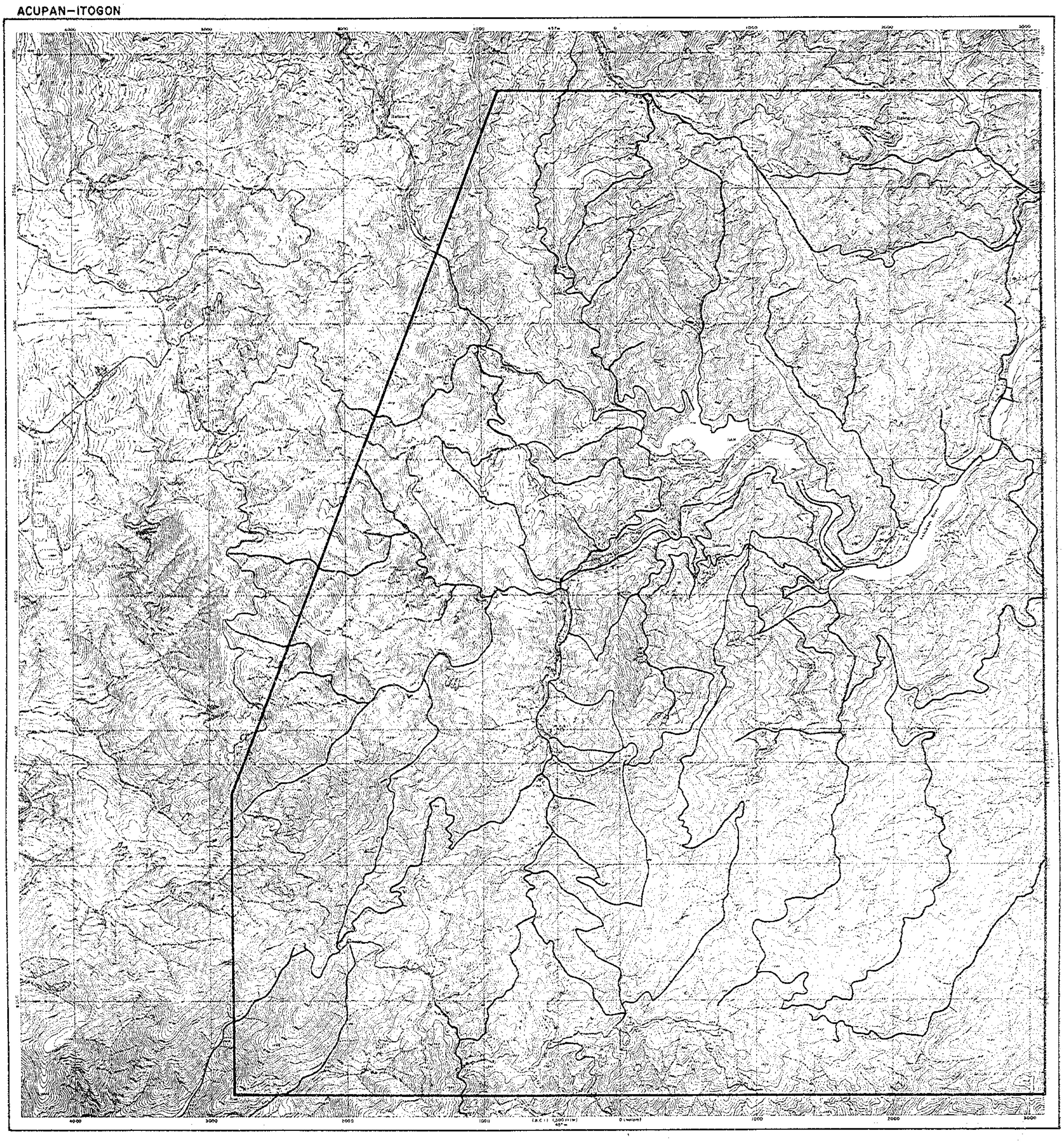


Fig. Ⅲ-1-1 Coverage of Geological Survey Route

1.3 Geology and Stratigraphy

The survey area (40 km^2) is underlain by Late Cretaceous Dalupirip schists; Late Oligocene to Early Miocene miocene-sedimentary rocks, Late Pliocene andesite complex and andesitic plug breccia; and Pleistocene Dacite plug (breccia with crystalline core) (Fig. III–1–2, III–1–3, and III–1–4).

1.3.1 Dalupirip Schist

Previous works: Smith (1970), Dickerson (1927), Leith (1938) relate the schist to a composite basement of Oligocene age which includes diorites, slates and cherts. Fernandez and Pulanco (1967), however, lumped it with an undifferentiated series of Cretaceous-Paleogene (kpg) rocks which have been locally metamorphozed by the so-called "composite diorite rocks". This view is shared by Oca (1951) and Balce, et al. (1980) who introduced the term "Dalupirip Schist" in reference to the "schistose Pugo (Formation)" exposed along the Dalupirip-Itogon Road.

Present work: The term "Dalupirip Schist" is used in this report. However, on the basis of K-Ar dating previously done by Metal Mining Agency of Japan (MMAJ)-JICA (1977) on this rock, it is considered to be older than Pugo Formation.

Distribution: Along the Ambalanga and Liang Rivers, on the northeastern corner of the survey area.

Thickness: Unknown

Lithology: Mainly composed of black and green schist where patches of muscovite and epidote are observed. Black schist alternates with strata of green and gray schists.

They are considerably mylonitized at the lower reaches of the Ambalanga River, west of Itogon town, and show some brecciated facies.

Aplitic and pegmatitic dikes intruded the Dalupirip schist.

Age: They are considered to be Late Cretaceous based on a K-Ar radiometric age of 80.6 ± 20.6 million year as reported by MMAJ-JICA (1977).

1.3.2 Igneous Rocks

Igneous rocks in the area are dominated by dioritic rock suites of the Agno Batholith which belong to multiple intrusive events occurring from Oligocene to Pliocene time. This process is occasionally interrupted by small scale andesitic effusions and intrusions of which the major volcanic activity occurred in Late Pliocene. The igneous activity in the area culminated with the intrusion of dacite plugs in Late Pleistocene time.

Agno Batholith

Previous works: Schafer (1954) recognized three (3) intermediate plutonic rocks of Eocene to middle Miocene age in the area, namely Antamok diorite (oldest), Itogon quartz diorite and Virac granodiorite (youngest). This rock sequence was interpreted by Worley (1967) as a product of normal magmatic differentiation process and collectively called them "Agno batholith". On the basis of K-Ar dating data, Wolfe (1981) was able to separate two distinct episodes of intrusion: one occurring during Oligocene which he called "Cordilleran batholith" and another during intra-Miocene time, he called "Agno batholith". He also recognized the latter as the ore-bearer or mineralization stage in the Baguio district.

Present work: In this report, "Agno batholith" is composed of the Antamok diorite, Itogon quartz diorite and tonalite (17.9 ± 0.9 Ma) and Virac granodiorite (5.2 Ma). They are regarded as co-magmatic intrusives.

(a) Antamok Diorite

Distribution: Distributed on the middle North-South section of the

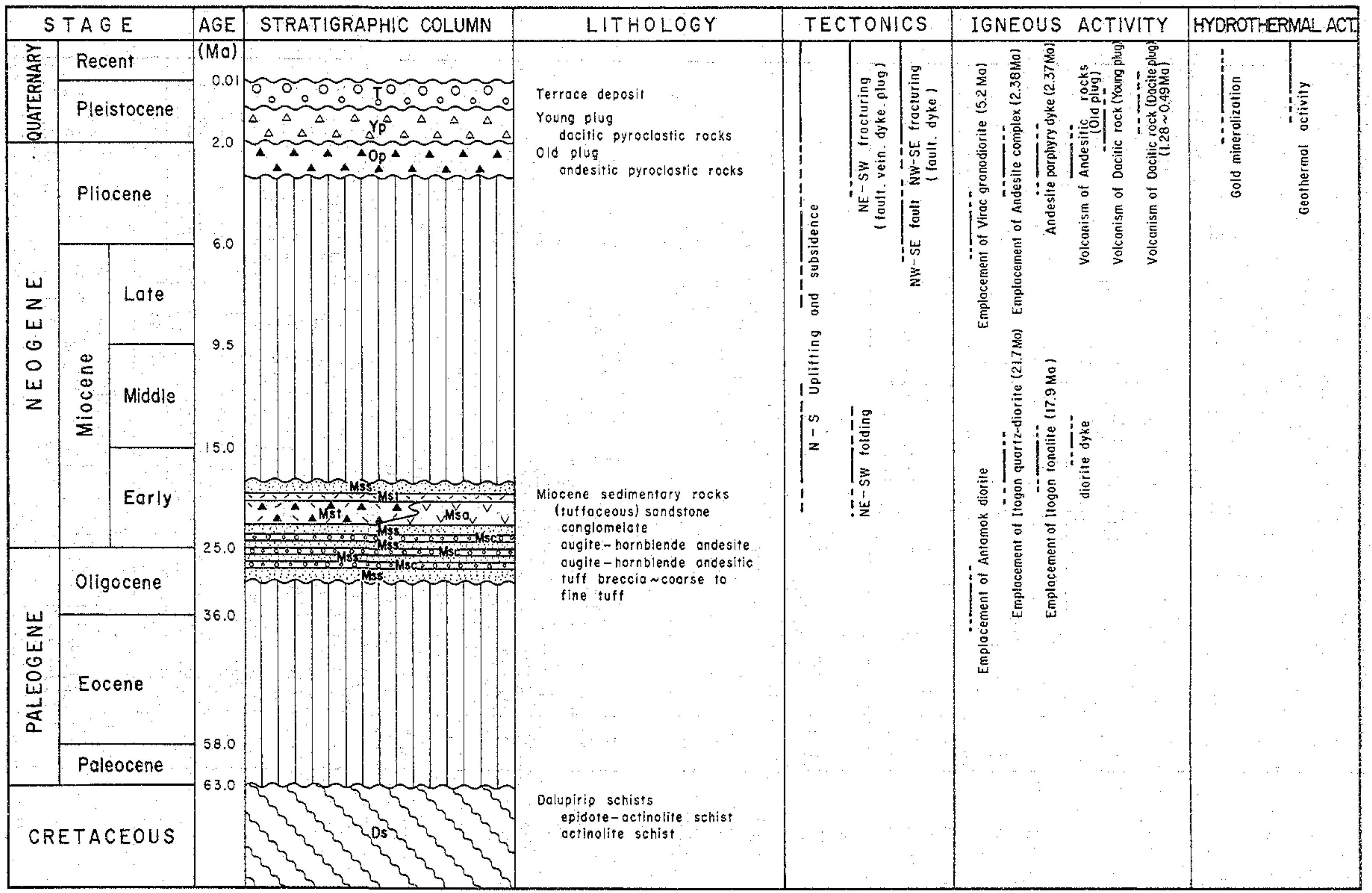
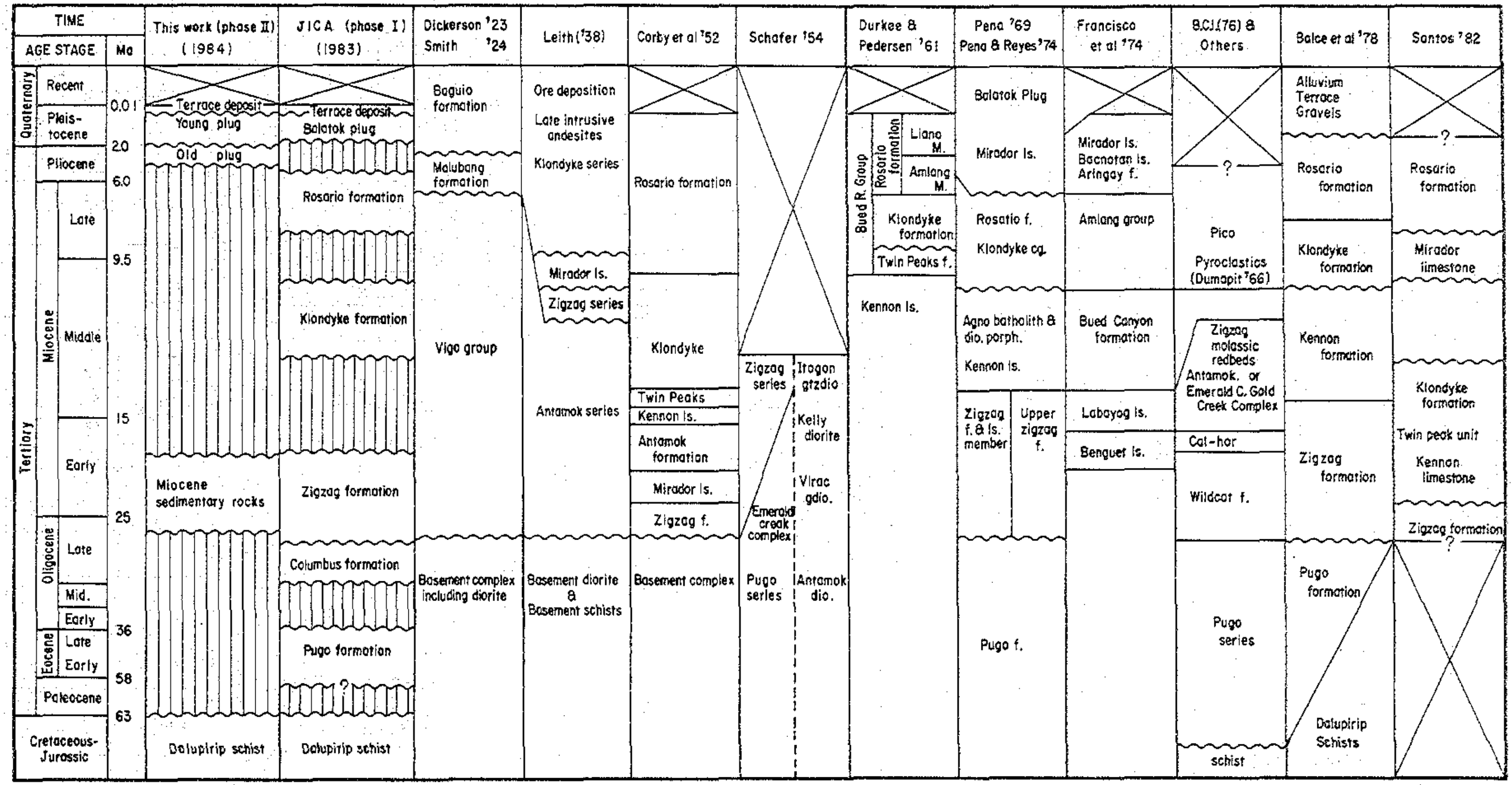
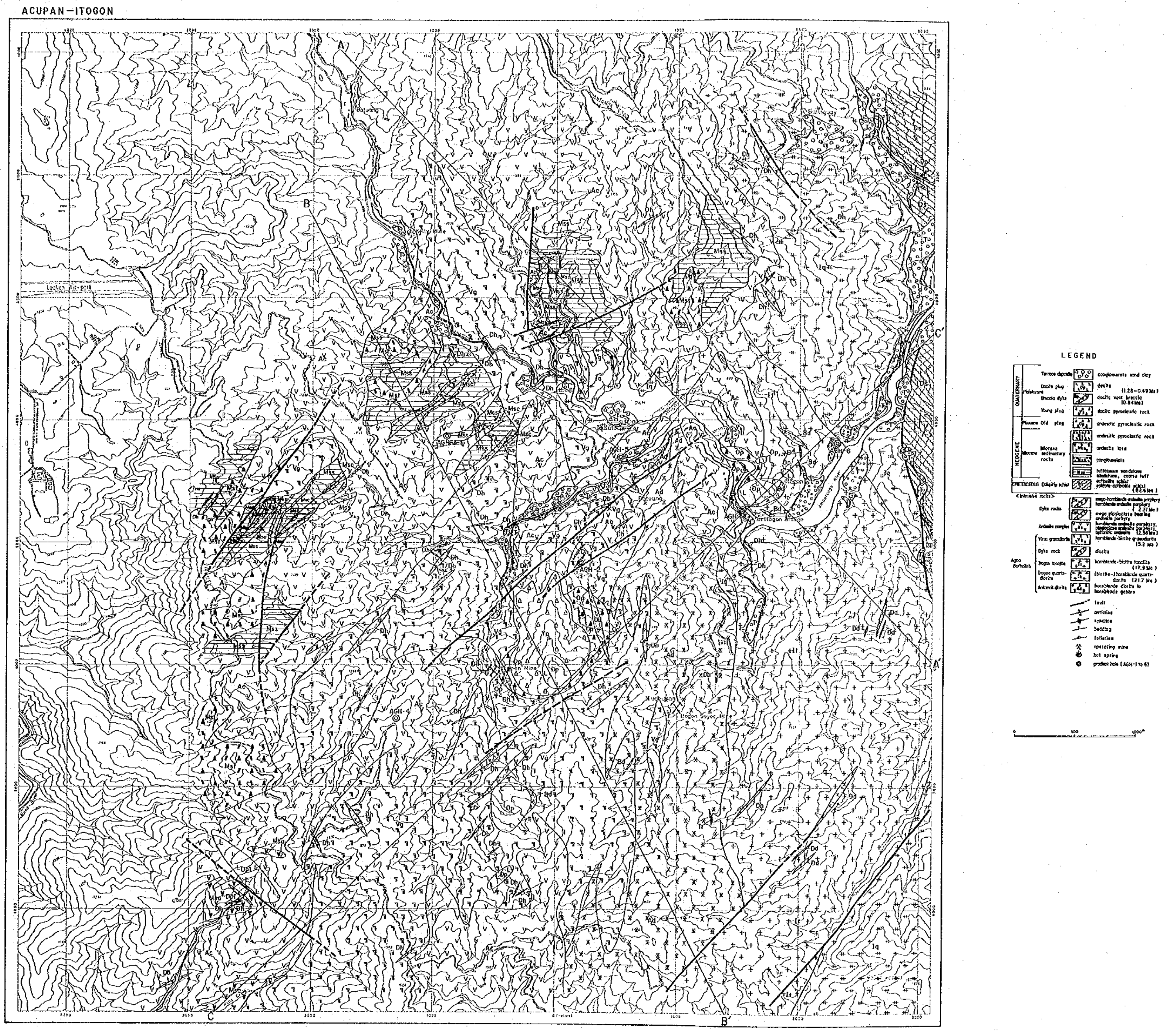


Fig. Ⅲ-1-2 Generalized Stratigrafic Column

Table Ⅲ-1-1 Corrlation of Rock and Stratigraphic Names





Fig, Ⅲ-1-3 Geological Map

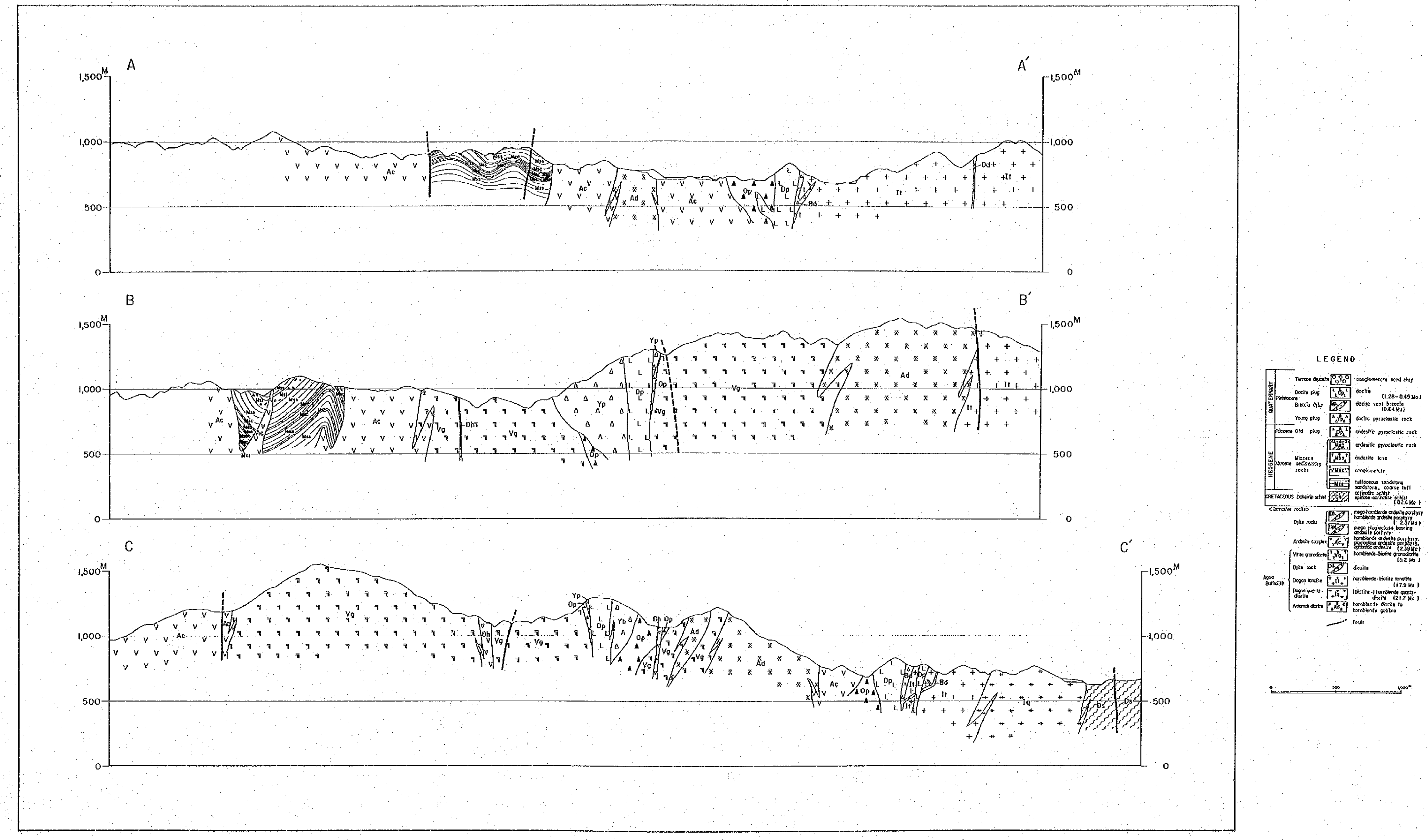


Fig. Ⅲ-1-4 Geological Profiles

survey area, from Batuang through Itogon-Suyoc Mine and down the south of the mine area.

Lithology: It is mainly composed of hornblende diorite. Facies change within the rock unit is common. In places, gabbro cumulates have been observed. Alteration is mainly slight (refer to Annex: Petrographic Description).

Stratigraphic relations: This is intruded by the Virac granodiorite. Its relationship with the Itogon quartz diorite is not very distinct in the field because of their similarity, composition and texture.

Age: Fragments of the Antamok diorite are embedded in the Miocene sediments. It is believed that the intrusion occurred during Early Tertiary.

(b) Itogon quartz diorite and tonalite

Distribution: The occurrence is along the northeast and southeast portions of the survey area.

Lithology: The major component is biotite-hornblende quartz diorite. Like the Antamok diorite, facies change are common.

Stratigraphic relations: It is intruded by the young dacite plug and Virac granodiorite.

Age: On the sample collected around Itogon town, the K-Ar radiometric age of 17.9 to 21.7 Ma was obtained (MMAJ and JICA, 1977). Thus, it is assumed that the time of intrusion was in the middle Miocene.

(c) Virac granodiorite

Distribution: It is distributed around the vicinity of Acupan mine.

Lithology: It is composed of leucocratic gray hornblende-biotite granodiorite.

Stratigraphic relations: It intrudes the Antamok-Itogon diorite and the Miocene sedimentary rocks.

Age: The result of the previous year's survey indicated a K-Ar radiometric age of 5.2 Ma equivalent to early Pliocene.

1.3.3 Miocene Sedimentary Rocks

Previous works: Smith (1907) and Dickerson (1927) referred to these rocks as part of the Vigo Group (Early to Late Miocene) which includes schists and diorites. Leith (1938), who recognized an unconformity between the Antamok Series and an overlying sequence of bedded sediments, called the latter Zigzag Series. It was later changed to Zigzag Formation with type locality at Bued River Canyon by Peña (1969) who established its age to be Early to Middle Miocene.

Present work: The term "Miocene Sedimentary Rocks" is adopted in this report.

Distribution: They are mainly distributed on the western part of the survey area, i.e., north of Balatoc, near Virac and southwest of Virac.

Thickness: Greater than 500 meter.

Lithology: They are mainly composed of tuffaceous sandstone, sandstone (Mss), conglomerate (Msc), andesitic pyroclastic rocks (Mst) and andesitic lava (Msa). The tuffaceous sandstone and sandstone are green to red-green in color and well-sorted.

Stratigraphic relations: It is intruded by the Itogon quartz diorite, Virac granodiorite and andesite volcanics. However, the relation with the lower strata is unknown.

Age: Considering that the formation is intruded by the Itogon quartz diorite (Early Miocene), it is assumed to be of the Oligocene to Early Miocene epochs.

Correlations: Lithologically, it is correlative to the Zigzag Formation distributed on the western part of the area (Table III–1–1).

1.3.4 Andesite Complex

Previous works: "Emerald Creek Complex" is a term used by Schafer (1954) for the "great composite sill or sheet" which separates the Pugo Formation from the Zigzag Formation. This has been erroneously correlated to the volcanic layers of the Zigzag and Pugo Formation. The local occurrence of the greenish andesite volcanics in the Acupan mine area is locally called Emerald Creek andesite.

Present work: To differentiate these rocks from older rock units, an arbitrary name of Andesite Complex is used in this report. This is a collective term referring to the major andesitic volcanic episode which occurred during the Late Pliocene. Products of this activity includes the old breccia plug with attendant andesitic pyroclasts and multiple dikes deposited on top and cutting into the Virac granodiorite, respectively.

Distribution: On the southern and western sectors of the survey area.

Lithology: The Andesite Complex are composed of andesitic breccia pipes, andesitic pyroclastics and dikes. Dike rocks are mainly porphyritic. Megahornblende bearing porphyries are observed along Philex Road cutting Virac granodiorite. In places, however, similar rock facies are observed as xenoliths in the latter. However, those belonging to this rock unit are very fresh in contrasts to older but similar rocks.

Stratigraphic relations: It intrudes the Miocene-Sedimentary Rocks, Antamok diorite, Itogon quartz diorite and Virac granodiorite.

Correlations: On the basis of the very restrictive age range (2.21 – 2.38 Ma) measured on a few andesite samples, all andesite rocks including those which occurred as breccia plug and dikes intruding the Virac granodiorite are classified under the same rock unit.

Age: The hornblende andesite sample collected at about one kilometer southeast of Balatoc, the K-Ar radiometric dating gave the age of rock at 2.38± 0.16 (Ma) (Table III–1–4), equivalent to Late Pliocene.

Table III–1–4 Isotopic Ages Determination of K–Ar Method

Sample No.	Rock Name	Mineral	K	Radiogenic ^{40}Ar	Air Contamination	Age	Remarks
J – 2	Andesite	Whole Rock	1.91%	STPcc/g 1.7666x10^{-7}	71.4%	m.y. 2.38±0.16	Andesite complex
J – 3	Andesite	"	1.11	1.0226x10^{-7}	72.9	2.37±0.17	This rock intruded in old plug.

$\lambda e = 0.581 \times 10^{-10}/Y$
$\lambda \beta = 4.962 \times 10^{-10}/Y$
$^{40}K/K = 0.01167$ atom%

Dike Rocks

They are composed of mega-plagioclase andesite porphyry and mega-hornblende andesite porphyry. In addition, numerous narrow dikes of andesite porphyry, lamprophyres and aplites are observed in the area. These dike rocks exhibit dominantly northeasterly trend at the southern part of the survey area and swerve to northwesterly direction in the northern sector of Acupan.

1.3.5 Plugs

Previous works: Most of the literature on these plugs come from Benguet Corporation. These include the works of Worley (1967) and Fernandez and Damasco (1980) among others. They are interpreted as diatremes and are classified as

Table Ⅲ-1-2 Results of Microscopic Observation of Thin Section

Formation Name or Egneous Body	Sample Name	Rock Name	Texture	Phenocryst and Grains							Groundmass and Matrix									Lithic fragments				Secondary minerals and Metamorphic minerals											Remarks
				Q	K-f	Pl	Bi	Ho	Au	Op	Q	Si	K-f	Pl	Bi	Ho	Cpx	Op	Gl	Gr.	An.	Da.	Tf	Q	Si	Cc	Ser	Sap	Chl	Act	Epi	Op	Ab	Tre	
Dacite plug	E-56	Biotite-dacite	porphyritic holocrystalline	○		◎	○			•	◎			○	•			•	•							○			○				•		
	E-95	Biotite-dacite	porphyritic holocrystalline	○		◎	○			•	◎			○	○			•							•	◎	○		○				•		
Breccia dyke	F-254	hornblende dacitic crystalline tuff	pyroclastic	◎		◎		○			○			○					○							•	•		○						
Young plug	G-31	dacitic lapilli tuff	pyroclastic	◎		◎	○				◎	•		○	•			•	○					○		○	○		○						
Old plug	F-133	hornblende andesite porphyry	porphyritic holocrystalline(subophitic)			◎		○		•				◎												•	○	•	◎		○	○			
	F-138	hornblende-andesite porphyry	porphyritic holocrystalline(subophitic)			◎		○						◎		○											○	•	◎		○	○			
Andesite complex	E-04	fine tuff	pyroclastic							•	◎			◎	•									•		•	•		○		◎				zenolith of Andesite complex
	E-05	andesite	porphyritic intersertal			◎				•				◎					○					•		○	•		◎		○				
	E-12	biotite-hornblende crystalline tuff	pyroclastic	•		◎	•	○		•	•			◎	•	•			○							•	○		○		◎				zenolith of Andesite complex
Virac granodiorite	F-24	biotite-hornblende granodiorite	hypidomorphic granular holocrystalline	○	○	◎	○	◎		•																	•		○		•	•			
Itogon tonalite	E-97	mylonite	sutured structure mortar (porphyroclastic)	◎	•	○	○																	•					•		•	•		•	intrud in Dalupirip schist.
	F-269	hornblende-biotite tonalite	hypidomorphic granular holocrystalline	◎		◎	○	○		•																		•	○		•				
	F-272	hornblende-biotite tonalite	hypidomorphic granular	◎		◎	○	•		•																		•	○		•				
	F-272	meta hornblende gabbro	equigranular (segregation)	•		◎	○	○		•														•		○	•	•	○	○	•	•			
Itogon quartz diorite	E-66	hornblend-dioritic gabbro	equigranular poikilitic(partly segregation)	•		◎		◎		•																○	•	○	○	○	•	•			accumulate rock
	E-68	biotite-hornblend gabbro	equigranular poikilitic(segregation)	•		◎	○	◎		•																	•		○	◎		•			accumulate rock
	F-104	biotite-hornblende gabbro	equigranular poikilitic			◎	•	◎																				•	○	○			○		accumulate rock
	F-143	biotite-hornblende quartz diorite	hypidomorphic granular poikilitic	◎	•	◎	◎	◎																		•	•	○	○						
Miocene sedimentary rocks	E-75	tuffaceous sand stone	clastic	◎			•				◎							•	◎					○	•				◎		○	•			
	E-77	tuffaceous sand stone	clastic	◎		○	•				◎			○				•	○										○		◎				
	E-87	tuffaceous conglomelate	clastic															•			◎	○	○	•	○				○		◎	•			
	E-108	hornblende andesite	porphyritic				◎											•								•	○		○	○	◎	•	◎		
	E-113	hornfels	granoblastic, mosaic												○			•						◎					○		○	•	○		near the contact of Virac granodiorite and Miocene sediments
	F-85	hornblende-augite andesite	porphyritic intersertal			◎		○	○					◎			•	○	•								○		○		○		○		zenolith of Virac granodiorite
	F-222	conglomelate	clastic																	○	◎	○	○						◎		◎				
	F-224	sand stone	clastic	◎	•	•	•		•	•																			•		•				
	F-291	hornblende-augite andesite	porphyritic holocrystalline			○	•	○	◎	•				◎	○											•	◎			○	•	•			andesite lava
Antamok diorite	E-25	hornblende-biotite granodiorite	hypidomorphic granular holocrystalline	•	○	◎	○	•		•														○	•	○	•	○	◎		○	•			
Dalupirip schist	E-98	epidote-actinolite schist	nematoblastic																					◎	•	•			•	◎	○	•	•		
	E-176	actinolite schist	nematoblastic																					◎					○	◎		•	○		
Dyke rocks	F-23	hornblende-andesite porphyry	porphyritic holocrystalline			◎		◎						◎		○											•		◎		○	○			
	F-28	hornblende-andesite porphyry	porphyritic hyalopilitic			○		○						◎					○					○	•	○	○		◎		•	•	○		
	F-295	doleritic andesite	subophytic(blastoophitic)			•					•			○	○											•	•		○	◎		•			
	F-296	hornblende dacitic andesite	porphyritic holocrystalline			◎	•	○			○			◎	○											•	○		○		•		○		so-called Bird's eye
	F-172	augite-hornblende andesite	porphyritic granophyric holocrystalline			◎		○	○		○	○		◎		○								○					◎		◎		•		porphyry intrud in Dalupirip schist
	E-100	biotite aplite	hypidomorphic granular	◎	•	○	○																				•		•						intrud in Itogon tonalite.

Q : quartz, K-f : potassium feldspar, Pl : plagioclase, Bi : biotite, Ho : hornblende, Au : augite, Op : opaqueminerals, Si : silica minerals, Cpx : crinopyroxene, Gl : grass, Gr : granitic rocks, An : andesite, Da : dacite, Tf : tuff, Cc : calcite, Ser : sericite, Sap : saponite, Chl : chlorite, Act : actinolite, Epi : epidote Ab : albite, Tre : tremolite.
(◎: abundant, ○: common, •: rare.)

Table Ⅲ-1-3 Isotopic Age Determination of Fission Track Method

Fisson Track Age datasheet

Sample NO. : J-1

Locality : (near the Itogon bridge)

Purpose : Rock Name(Formation) : Dacite plug

Seperated Mineral : Zircon
Etching Condition : Zircon ; KOH-NaOH binary eutectic 200°C-48hr
Mica ; 48% HF , 20°C-30min ,
Standard Glass ; 48% HF , 20°C-15sec ;
U-238 Decay Constant (1/year) : 6.85x10^(-17)
Formula calculated F.T. Age : T=6.12x10^(-8)·P·DS/Di
Thermal Neutron Flux : P=1.522x10^15 ; N= 717 ; D= 3.252x10^5

NO		Spontaneous Track			Induced Track			Ratio of Density (Ds/Di)	F.T.Age (m.y.)
		Count	Cell	Density	Count	Cell	Density		
1		2	200	3.628E+04	362	200	6.567E+06	5.525E-03	0.51
2		2	200	3.628E+04	422	200	7.656E+06	4.739E-03	0.44
3		2	200	3.628E+04	540	200	9.797E+06	3.704E-03	0.34
4		1	200	1.814E+04	318	200	5.769E+06	3.145E-03	0.29
5		4	200	7.257E+04	310	200	5.624E+06	1.290E-02	1.20
6		3	200	5.443E+04	406	200	7.366E+06	7.389E-03	0.69
7		1	200	1.814E+04	470	200	8.527E+06	2.128E-03	0.20
8		3	200	5.443E+04	388	200	7.039E+06	7.732E-03	0.72
9		2	200	3.628E+04	352	200	6.386E+06	5.682E-03	0.53
10		2	200	3.628E+04	356	200	6.459E+06	5.618E-03	0.52
11		2	200	3.628E+04	354	200	6.422E+06	5.650E-03	0.53
12		2	200	3.628E+04	292	200	5.298E+06	6.849E-03	0.64
13		1	200	1.814E+04	276	200	5.007E+06	3.623E-03	0.34
14		2	200	3.628E+04	368	200	6.676E+06	5.435E-03	0.51
15		2	200	3.628E+04	368	200	6.676E+06	5.435E-03	0.51
16		3	200	5.443E+04	518	200	9.398E+06	5.792E-03	0.54
17		1	200	1.814E+04	226	200	4.100E+06	4.425E-03	0.41
18		3	200	5.443E+04	530	200	9.615E+06	5.660E-03	0.53
19		3	200	5.443E+04	382	200	6.930E+06	7.853E-03	0.73
20		1	200	1.814E+04	292	200	5.298E+06	3.425E-03	0.32
21		2	200	3.628E+04	316	200	5.733E+06	6.329E-03	0.59
22		2	200	3.628E+04	494	200	8.962E+06	4.049E-03	0.38
23		1	200	1.814E+04	300	200	5.443E+06	3.333E-03	0.31
24		0	200	0.000E+00	344	200	6.241E+06	0.000E+00	0.00
1*								(0.51)	0.49
2	A	47	4600	3.707E+04	8640	4600	6.815E+06	5.440E-03	0.51
	B	47	4800	3.553E+04	8984	4800	6.791E+06	5.232E-03	0.49

Age 1* : Mean F.T.ages calculated from each grain age.
2 : F.T.ages calculated tracks and total observed ares.
A : Used only grains which spontaneous tracks were observed.
B : Used all grains.

"young" and "old" plugs (Balatoc) with contrasting bulk compositions. Both are considered to be Plio-Pleistocene. Balce, et al (1980), having found similar plugs in the Sto. Niño Mine, assigned a middle to late Miocene age for the Balatoc Plug.

Present work: Both "young" and "old" plugs are likewise treated separately in this report. While agreeing that the "old" plug in Acupan area could be a diatreme, the young "plug" is interpreted as an attendant breccia halo or pipe to a subvolcanic dacite intrusive (that is, has not reached the surface). This is further substantiated by the lack or total absence of an equivalent flow or pyroclastic member that can be related to an extrusive or explosive event during the emplacement of the dacite and its breccia halo. Moreover, the charge wood found in the Balatoc plug is believed to be part of an older strata that has been assimilated into the breccia together with other fragments of the country rock during emplacement of the crystalline dacite.

(a) Old Plug

Distribution: It is found in Acupan-Itogon area.

Thickness: Unknown

Lithology: It is made up of hornblende andesitic tuff breccia and lapilli tuff. The plug in Acupan mine is considered to be a diatreme.

The hornblende andesitic tuff breccia and lapilli tuff are dark to light gray and are highly compacted. Poorly sorted rock fragments, with average diameters of 5–6 cm. (maximum is 30 cm), are usually subangular to subrounded. These fragments consist of quartz diorite, diorite, granodiorite, hornblende-plagioclase andesite porphyry laid in a dark-gray andesitic tuff matrix.

Stratigraphic relations: It is intruded by the young dacite plug (of Late Pleistocene age). The andesite plug intruded the Virac granodiorite.

Correlation: It is correlated to the Late Pliocene Andesite Complex based on stratigraphic relations with older rocks.

Age: From its relation with other rock units in the area, it is presumed that it is of Late Pliocene age.

(b) Young Plug

Distribution: It is found in Acupan Mine where it is locally referred to as the Balatoc plug; in Itogon bridge area; and farther south of Acupan along a general northeast-southwest trend.

Lithology: The plug occurs as subvolcanics breccia pipes with crystalline dacite core. The dacitic breccia and the gray to pale greenish-gray lapilli dacite tuffs contained subangular to subrounded rock fragments (average diameter of 5–6 cm., with maximum of 20 cm) of aphanitic andesite, hornblende andesite porphyry and granodiorite. These fragments are laid on a dacitic tuffaceous matrix made up of plagioclases, quartz and biotite.

The crystalline core is composed of light gray biotite-hornblende dacite. Primary minerals include phenocrystal quartz (average size of 1–2 mm) making up to 20–30% of the rocks, hornblende and biotite (20%) and the rest are sodic plagioclases and orthoclase. Granodiorite also occurs as a xenolith.

Stratigraphic relations: It intrudes the old andesite breccia plug in and around Acupan mine and near Itogon bridge. Elsewhere, it intrudes Virac granodiorite and other older rock units outcropping in the area.

Age: Based on fission track and K-Ar datings of 0.49 to 1.28 Ma of the sample taken at the Itogon Bridge, the age of the dacite plug is placed at Late Pleistocene.

1.4 Igneous Activity

The igneous activity is represented by plutonic, subvolcanic and extrusive rocks with ages ranging from Oligocene to Pleistocene. Fig. III–1–5 presents the geochronological chart of igneous-volcanic activity based on the results of the radiometric date measurement. The geohistory of igneous activities can be summarized as follow:

(a) Intrusion of Antamok diorite along north-south direction during Oligocene. The type-section is at the eastern part of the survey area.

(b) Deposition of Miocene-Sedimentary Rocks in Late Oligocene to Early Miocene. Augite-hornblende andesite lavas and its pyroclastic equivalents which constitute part of the rock formation were dominantly deposited at the northwestern and southern sections of the survey area. The confinement of the andesite lavas in the southern part of the Acupan prospect area would suggest that the source of the volcanic materials was at the southern part of the area.

(c) The Itogon quartz diorite (21.7 Ma) was subsequently emplaced along a north-south direction.

(d) During Pliocene, emplacement of the Virac granodiorite (5.2 Ma) occurred. The trend of the intrusion is also north-south and swerve on a northwesterly direction at the northern part of the Acupan area.

(e) In Late Pliocene, the major upheaval of Andesite Volcanism which include the emplacement of Plug and dike intrusions (2.21 – 2.38 Ma) was centered at the northwestern part of Acupan mine area. The emplacement of andesitic dikes follow the northeasterly and northwesterly trending structures which likewise are the same structures controlling the ore-mineralization in the Baguio gold district area.

(f) During Pleistocene, intrusions of the Dacite Plug and breccia took place. The intrusion of the dacite materials were localized along the northeast-southwest fractures. Three known dacite plugs were mapped: one at Itogon bridge; second in Acupan mine (Balatoc plug); and the third is located a few hundred meters south of the Balatoc plug.