4. TEMPERATURE-GRADIENT HOLES

4 TEMPERATURE-GRADIENT HOLES

4.1 Purpose and Methodology

The objective of temperature-gradient hole drilling is two-fold:

(a) to delineate the possible thermal anomalies in the area by measuring the thermal gradient; and

(b) to acquire subsurface information on stratigraphy, structures and near surface hydrothermal alteration.

The results of the undertaking were correlated with previous information derived from geological, geophysical and geochemical surveys in the area.

On the basis of results of Phase-I exploration work, the initial program finalized by JICA and BED was to drill five (5) temperature gradient holes with depths ranging from 300 to 800 meters. However, seven gradient wells were actually drilled to acquire a broader information with a total aggregate depth of 2,200 meters. The holes are located around Balatoc plug and spaced at 800 to 1,500 meters covering an area of eight (8) square kilometers.

Three rigs were used simultaneously to facilitate the drilling of seven (7) holes and continuous coring was carried out on all the gradient holes with BQ-size core in the lower sections. Water or hi-seal bentonite depending on the permeability conditions were used as drilling fluid. The completed holes were permanently cased with schedule 40 G.I. pipes with inside diameter of 76.2 mm (1 1/2") for temperature monitoring (Fig. III–4–1).

Activities carried out in the field included:

(a) core logging;

(b) temperature logging;

(c) resistivity logging;

(d) preparation of composite logging charts and maps;

(e) X-ray diffraction analyses of 59 core samples;

(f) chemical analyses for 20 elements of 36 core samples (the 20 elements are: Si, Al, Mg, Ca, Na, K, Mn, As, Hg, B, Cu, Pb, Zn, Sb, Li, Rb, Sr, Be, Ba, and Co);

(g) thermal conductivity and sonic velocity tests for 59 core samples;

(h) physical test for density permeability, specific resistance and specific heat on 15 core samples.

4.2 Borehole Geology

4.2.1 Megascopic Description of Rock Units

The various rock types encountered in each gradient hole will be discussed in this section. For the microscopic descriptions of these rocks, refer to Section III–4.5.1 and Appendix "A".

(a) AGH-1: As illustrated in Fig. III–4–2, the geology of this borehole comprises of the following, from top to bottom: river bed sediments (0–2.20 m); andesitic tuff breccia (2.20–54.10 m); fine-grained andesite dikes (17.70–19.90 m) which intrude into the hornblende andesite porphyry; hornblende-plagioclase andesite (54.10–57.70 m); hornblende andesite porphyry (57.70–67.50 m) and mega-hornblende-bearing andesite porphyry (90.00–94.50 m).

Angular to sub-angular fragments in the andesitic tuff breccia are about 2–10 cm in size. The fragments are composed of tonalite and normal diorite.

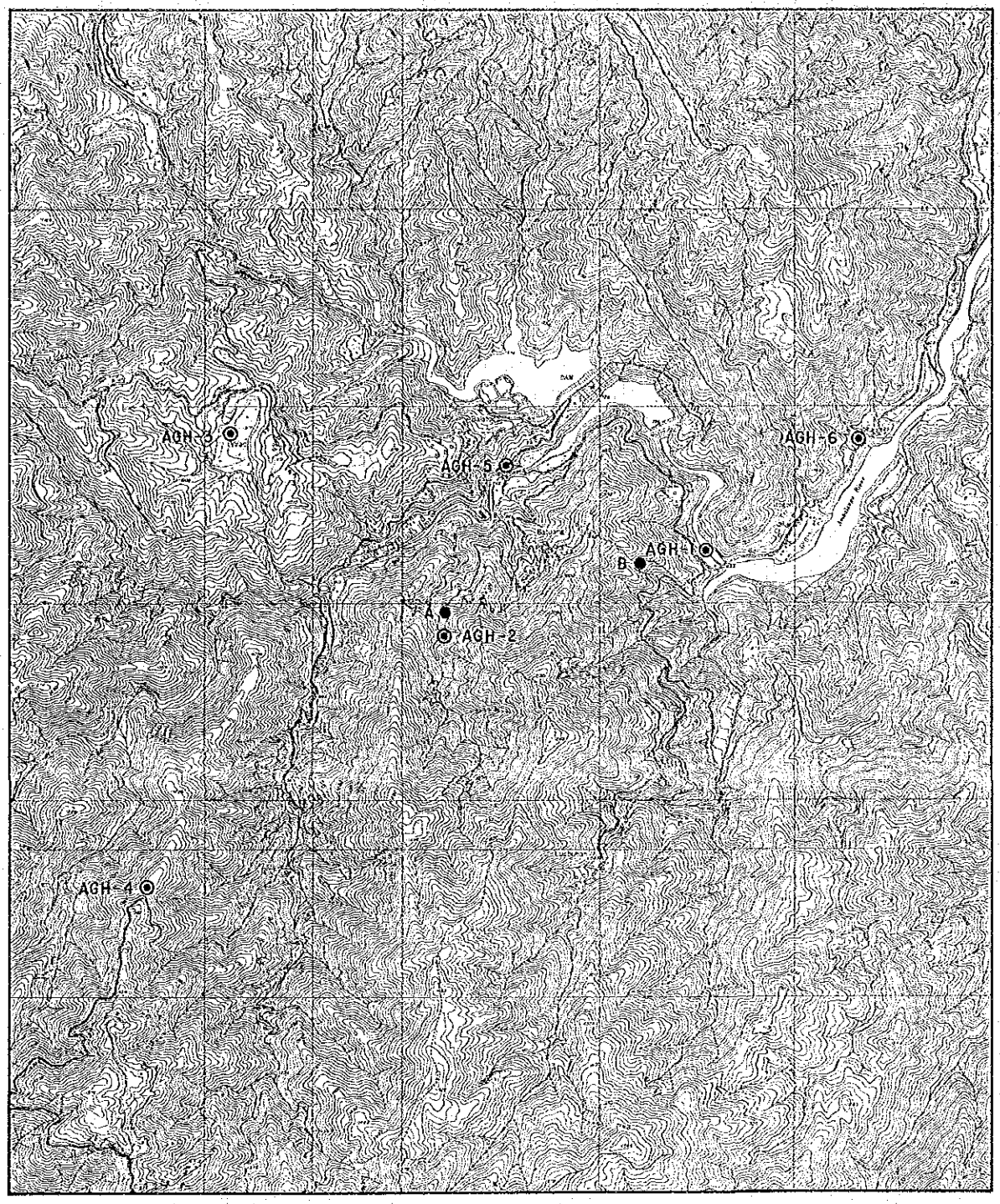


Fig. Ⅲ-4-1 Location Map of Gradient Hole (AGH-1 to 6)

Argillization is seen along with filmlike network of calcite veins. Some spots of epidote are recognized occasionally.

This rock is considered to be equivalent to the andesitic pyroclastic rock of the old plugs in Acupan.

The lithic-fragments bearing hornblende andesite porphyry is dark green. The fragments consist of hornblende andesite porphyry and diorite. These fragments are angular-subangular with 2–3 cm in diameter. This rock belongs to the mappable andesite volcanics.

The fine-grained andesite dikes which intrude the various suites of andesitic rocks such as hornblende andesite porphyry (HbA), mega-hornblende bearing andesite porphyry and andesitic tuff breccia dip at a low angle of 15° while the HbA which grades into hornblende-plagioclase andesite porphyry dips at a steep angle of 80°.

(b) AGH-2: As illustrated in Fig. III–4–3, the geology of this borehole from top to bottom is as follows: talus deposits (0–4.0 m); granodiorite (4.0–334.2 m); dikes of hornblende-plagioclase andesite porphyry (140.5–168.8 m); and hornblende andesite porphyry (202.1–212.6 m ; 285.0–300.0 m ; 308.3–313.0 m and 334.2–357.5 m).

The granodiorite is generally gray in color and the hornblende as its chief mafic mineral. The hornblende is 1–2 mm in crystal length and constitutes 20% of the total mineral volume. Sometimes this rock contains fine-grained andesite fragments. This rock is classified as the Virac granodiorite.

The hornblende-plagioclase porphyry, which intrudes the granodiorite, is light green in color and contains fragments of the intruded rock. The hornblende and the plagioclase phenocrysts are about 5% and 20–30%, respectively.

The hornblende andesite porphyry is dark green in color. Phenocrysts of hornblende are 1–4 mm in length and is about 20% volume.

The rocks generally suffered argillization and silicification, associated with calcite, gypsum-anhydrite and quartz veinlets. The argillization and silicification are developed along fractures. A network of calcite, gypsum-anhydrite and quartz veins is observed. Such conditions, while widespread in general, apparently increases at depth.

(c) AGH-3: As illustrated in Fig. III–4–4, the lithology of this borehole from top to bottom is: surface soil (0–19.8 m); andesitic pyroclastic rock and siltstone-sandstone (19.8–194.8 m); granodiorite (194.8–322.5 m); and andesite dike which intrudes the granodiorite (33.0–38.3 m; 79.0–85.3 m; 87.0–102.9 m; 107.0–135.6 m; 139.0–147.2 m).

The light green colored andesitic pyroclastic rock is a hornblende-bearing tuff (19.8–26.6 m), lapilli tuff (29.0–33.0 m) and breccia (38.3–62.3 m; 69.7–79.0 m). The lapilli tuff is green in color and has subangular-rounded clastics of old rocks. The breccia is massive and compact.

The siltstone and the sandstone are reddish-brown, massive and tuffaceous. These sediments tend to grade into andesitic pyroclastic rocks at the top and to siltstone at the bottom. They are comparable with the Miocene sedimentary rocks.

The above rock units apparently belongs to the upper Zigzag Formation that is well exposed along the Bued River.

The granodiorite is light pale green in color. Some of the hornblende and plagioclase are partially altered to epidote. This rock is correlated to the Virac granodiorite.

The andesite dikes vary from plagioclase andesite to hornblende andesite porphyry (33.0–38.3 m, 87.0–91.5 m); mega-hornblende bearing andesite porphyry (79.0–85.3 m and 101.5–102.9 m); and hornblende andesite porphyry (107.0–135.6 m and 139.0–147.2 m). The dikes intrude the Miocene sedimentary rocks.

Argillization in the sedimentary rocks is distinctive with minor occurrence of chlorite and epidote. On the other hand, alteration in the granodiorite is very weak. Some pyrite, epidote and chlorite veinlets are observed along fractures. Calcite fillings in fractures are recognized to be more prominent at depth of 100–230 meters.

(d) AGH-4: The geology of this borehole comprises mainly of granodiorite being intruded by andesite dikes. The granodiorite contains phenocrysts of Hb and plug. The hornblende is generally fresh, except for some crystals that show partial alteration to chlorite. The plagioclase is likewise partially altered to chlorite and weakly impregnated with pyrite (Fig. III–4–5).

The dikes are made up of mega-hornblende bearing andesite porphyry (9.5–27.0 m, 29.5–40.5 m, and 85.0–92.1 m); plagioclase andesite porphyry (69.0–70.0 m, 76.8–78.0 m, 99.0–104.5 m, 149.6–150.0 m and 153.4–156.7 m); and fine-grained andesite (190.0–194.5 and 226.0–226.6 m). Gradational change of the mega-hornblende bearing andesite porphyry to plagioclase andesite porphyry is sometime observed in the section.

Occurrence of clays, calcite, chlorite, epidote as fissure fillings are noted throughout the length of the drill cores. Calcite veinlets in particular are abundant at the bottom of the hole.

(e) AGH-5: The geology of this borehole is: andesite porphyry (0–212.2 m); breccia (212.2–400.0 m); and andesite dikes which intrude both the andesite porphyry and the brecciated diorite (Fig. III–4–6).

The andesite porphyry varies in composition, i.e., hornblende-plagioclase andesite porphyry (0–8.70 m); hornblende andesite porphyry (8.70–20.8 m, 39.75–90.80 m, 121.0–173.1 m, 178.0–187.95 m and 196.90–212.10 m); and plagioclase andesite porphyry (20.8–22.4 m). The hornblende-plagioclase andesite porphyry contains a large quantity of hornblende (2–3 mm) of about 20% and plagioclase (1–2 mm) of 30–40% volumes.

The hornblende andesite porphyry contains fine grain of hornblende phenocrysts that are in minor amounts. These rocks belong to the andesite volcanics mapped in the survey area.

The breccia is observed below 213.0 meters. The dioritic fragments vary in size embedded in a matrix of hornblende andesite. Considering the similarity of the matrix to that sample at 213.0 m, it is inferred to be also part of the andesite volcanics.

Dikes are composed of plagioclase andesite porphyry (20.8–22.4 m); hornblende-plagioclase andesite porphyry (59.0–59.55 m, 99.0–99.50 m, and 337.2–346.2); and hornblende andesite porphyry (349.5–349.8 m, 355.8–362.8 m). Lithologically, it is difficult to differentiate these andesite dikes from other members of the andesite volcanics.

Green colored alteration (epidote-chlorite) together with argillization and silicification is noticeable occurring along fissures throughout the section. Calcite and gypsum-anhydrite are also present in the fissures.

(f) AGH-6: As illustrated in Fig. III–4–7, the geology of this borehole from top to bottom is: talus deposits (0–12.85 m); quartz diorite (tonalite) (12.85–19.15 m, 30.6–207.15 m); and hornblende-plagioclase andesite porphyry.

The quartz diorite (tonalite) is greenish gray in color and contains phenocrysts of quartz and hornblende. Hornblende is 2–3 mm in crystal length and is about 30–40% by volume. Quartz phenocrysts range from 1 to 5 mm in crystal length. Large crystals of quartz of more than 5 mm are frequently present in the section. This rock is part of the Itogon tonalite.

The hornblende andesite porphyry is light gray in color, and intrudes the quartz diorite. It contains a large quantity of the hornblende and plagioclase phenocrysts. Hornblende (2–3 mm in crystal length) accounts for 30–40% by volume of the total mineral composition.

The hydrothermal alteration is comparatively weak and fractures are poorly developed. Some portions are brecciated (i.e., 66.1–115.0 m). Veinlets of calcite and pyrite are sparse.

(g) AGH-7: Borehole lithology of AGH-7 is as follows: mega-hornblende andesite; breccia; and granodiorite. It is intruded by hornblende andesite, aphanitic andesite, mega-hornblende andesite, microdiorite, hornblende andesite porphyry and aplitic dikes.

From 0–9.5 meters, top soil is encountered. From 9.5 to 22.85 meters, the mega-hornblende bearing andesite is intensely brecciated, silicified, argillized and pyritized. At 116.5 meters, a mega-hornblende andesite intrudes the contact of mega-hornblende bearing andesite and the breccia. This signifies that there are two stages of andesite volcanism.

The granodiorite encountered throughout hole was generally intensely brecciated and pyritized. The granodiorite drilled in the upper section were argillized and pyritized with occasional silicification. At the depth of 195–271.1 meters, pyrite is associated with chlorite and calcite.

The breccias encountered are well cemented with angular fragments of diorites and andesites in an andesitic (?) matrix (to be confirmed by petrography). they are generally argillized, fractured and pyritized. Occasional silicification and quartz and calcite stringers are observed from 84.0 m depth and below.

Fault gouges of not less than 20 cm were identified at the following depths: 79.80 to 80.25 m, 100.33 to 100.55 m, and 180.05 to 180.35 m. Several other gouge zone with thickness of 10 cm or less were also note.

4.2.2 Analysis of Results

Fig. III–4–8 shows the geological profile of the area, on the basis of the borehole geology of the six gradient holes (AGH-1 to AGH-6).

Geologically, the area is composed of Itogon tonalite, Miocene sedimentary rocks, Virac granodiorite, andesite volcanics, andesite dikes and old plugs.

The Itogon tonalite outcrops extensively around AGH-6. At the border contact, andesite dikes are noted cutting into the quartz diorite. Furthermore, Miocene sediments occur around borehole AGH-3, and is intruded by the Virac granodiorite and andesite volcanics. The Virac granodiorite is distributed in the western part of the Itogon quartz diorite (tonalite) while the andesite dikes intrude these rocks at various places. The andesite dikes and plugs (old and young) are localized along the border contact of the Itogon quartz diorite (tonalite) and andesite volcanics, and across the fractured zone in the Virac granodiorite.

The survey area is underlain mainly by dioritic plutons and volcanic intrusive rocks with poor exposures of Miocene sediments.

4.3 Temperature Measurement

4.3.1 Method of Measurement

Downhole temperature logging were ran at regular intervals after the completion of the hole until the thermal gradient has been determined. A logging unit equipped with a motor drive logging winch, 500 meter winding cable connected to a cable head and temperature probe was used for the purpose. However, gradient holes AGH-2, AGH-4 and AGH-7 have to be measured with a pocket type Digi-Multi thermistor due to failure to utilize the logging unit in the galvanized casing. Flowline and bottom hole temperatures were also monitored during the course of the drilling using the pocket type Digi-Multi thermister and dial thermometer. The stabilized formation temperatures were estimated for all the boreholes using the Lachenbruch and Brewer's graphical analysis.

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH- 1 (0 m - 150 m)

Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature
2.20	top soil		Old Plug	
	andesitic tuff breccia, breccia composed by plagioclase andesite porphyry, hornblende andesite porphyry, tonalite, diorite and aphanitic andesite. shape; subangular to subrounded, ø = 1 to 2cm.	3.40, spots of epidote seen. 6.80, θ=90, calcite veinlet. 7.90, θ=90, calcite film. 14.85 to 17.70, strongly argillized, mega hornblende altered to chlorite, montmorillonite seen. 1 to 3 mm calcite film to calcite veinlet developed.		
17.70	θ=15, fine grained andesite.	19.50 to 19.90, strongly crushed and argillized (montmorillonite).		
19.90	very strongly argilized brecciated rock with occidental fragments of tonalite (ø=10cm)			
22.40	very strongly argillized, brecciated rock, with occidental fragments of tonalite (size 10 cm).	22.40, strongly argillized. 23.70, strongly argillized.		
	33.50 to.. very strongly argilized brecciated rock. undistinglish original rock,	33.50 to 43.00, strongly argillized and crushed core.		
		43.00 to 50.60, strongly argillized and calcite film to network developed.		
		49.20, θ=70, crack.		
54.10	θ=80. changing to hornblende-plagioclase andesite porphyry. hornblende altered to chlorite epidote and clay minerals.	55.20, θ=85, calcite film to veinlet. 56.00, θ=45, argillized along the crack.		73°C
57.70	changing to massive, hard, compact hornblende andesite porphyry. hornblende; 1 to 2 mm, 15%. pyrite and epidote seen.	56.70 to 57.70, strongly argillized, chlorite and epidote.		
		65.10, θ=20, argillized along the crack. 66.30, θ=80, calcite clay, width 1 to 2 mm. 67.70, θ=80, calcite clay, width 1 to 2 mm. 67.80 to 67.90, calcite network. 69.00 to 70.00, calcite film and veinlet along the crack, width 1 to 3 mm, θ=30 and 80 to 90.		
67.60	gradually change to include xenolith and brecciated facies (andesitic lapilli tuff). matrix; hornblende andesite porphyry, greenish grey color, hard, compact. breccia (or xenolith); hornblende andesite and quartz diorite. shape; angular to subangular. ø= 2 to 3 cm.	76.00, θ=60 to 80, crack with argillization. 76.80, θ=50, calcite clay.		81°C
		83.45 to 83.65, θ=60, argillized along the crack. 86.70 to 86.85, θ=60, argillized zone.		81°C
90.00	changing to hornblende andesite porphyry to mega hornblende andesite porphyry.	90.00 to 90.10, strongly argillized with fault breccia.		76°C
94.60	gradually changing to andesitic lapilli tuff with lithic fragments of tonalite and andesite.	94.40, θ=80, calcite film.		
109.60	quartzdiorite fragments rich massive hornblende andesite porphyry.	111.00, θ=85, crack with calcite film. Pyrite impregnation very strongly.		
112.85				

SAMPLING

Depth (m)	M	X	C	V	T	D	P	R	H
21.20	O	O	O	O	O	O	O	O	O
45.20	O	O	O	O	O	O	O	O	O
75.60	O	O	O	O	O				
102.20	O	O	O	O	O	O	O	O	O

LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

Fig. Ⅲ-4-2 Columnar Chart (AGH-1)

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH- 2 (0 m – 150 m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature	SAMPLING: Depth (m)	Analysis and Test: M	X	C	V	T	D	P	R	H
			terrace deposit													
		4.00	granodiorite, grey in color, mafic 20%.	4.00 to 20.00, fractured and strongly limonite staining.												
10																
20		20.00		20.00 to 24.00, moderately to intensely argillized, limonite staining.												
		24.00		24.00 to 41.00, moderatry to strongly fractured and argillized, fractures filled by quartz veins partly.			26.70	O	O	O						
30																
40		41.00		41.00 to 43.00, silicified.												
		43.10		43.00 to 49.50, some to the 24.0 to 41.0m calcite vein occasionaly occur (fissure filling), chloritized, pyrite dissemination, epidotized. θ=40 to 60. Gypsum and calcite vein.												
50		49.50					51.50	O	O	O	O	O				
		59.00														
60		60.00		59.60 to 60.00, intensely argillized. θ=30 to 60, quartz vein.												
			-greenish color.		Virac Granodiorite											
70			xenolith of fine grained andesite, mineralized, dark grey in color.	70.00, θ=30 to 60, gypsum calcite veinlet, quartz vein, width : 1 to 2 mm. silicified moderately.												
							77.00	O	O	O	O	O				
80							83.30	O	O	O	O	O				
90				90.00, weakly argillized, weak to moderate silicification. $CaSO_4$ and $CaCO_3$ acts as cementing, as veinlets and as dissemination.												
	xxxxxxxx						98.00	O	O	O	O	O				
100	xxxxxxxx			100.00, θ=30 to 50, fractured and slikenside, feldspar argillized, intensely bleached, mafic minerals brecciated and argillized strongly.												
110	xxxxxxxx															
		112.00														
		113.00					118.50	O	O	O	O	O	O	O	O	O
120																
130																
140	xxxxxxxx	140.00				45.9°C	139.50	O	O	O	O	O				
		140.50	hornblende-plagioclase andesite porphyry dyke, greenish grey in color.	140.00 to 140.50, fractured at contact, calcite and gypsum veinlets, width 1 mm.												
150																

LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

Fig. III-4-3 Columnar Chart (AGH-2)

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH-2 (150 m - 300 m)

Depth (m)	Rock Facies	Remarks
150.30 – 152.30	hornblende-biotite granodiorite with xenolith of andesite porphry.	151.00 to 154.50, strongly crashed.
152.30 – 168.80	hornblende-plagioclase andesite porphyry, hornblende: 5% ±, plagioclase: 20 to 30%, greyish green in color.	160.00, feldspar altered to epidote and chlorite 162.00 gypsum vein, plagioclases, altered to epidote and chlorite.
168.80 – 182.30	granodiorite, greyish green in color.	170.00 to 171.00, pyrite/quartz and quartz stringer, gypsum and calcite stringer width 1 mm.
182.30 – 183.30	hornblende andesite porphry, hornblende: 20%, 1 to 4 mm, deep green in color.	
183.30 – 187.30	granodiorite.	
187.30 – 188.00	fault breccia and clay. θ=20.	188.00, gypsum vein, width 1 mm.
188.00 – 194.00	granodiorite.	188.00 to 195.00, horizontal fracture dominantly, very few quartz stringer seen.
194.00 – 195.00		198.00 to 199.00, calcite and gypsum stringer.
195.00 – 202.10		201.00 202.00, calcite (+ gypsum) stringer.
202.10 – 207.10	hornblende andesite porphyry, greenish grey in color.	
207.10 – 209.30	granodiorite.	
209.30 – 212.60	hornblende andesite porphyry.	212.60, gypsum veinlets.
212.60 – 217.00	granodiorite.	
217.00 – 219.00	fault breccia and clay.	
222.20 – 230.60	hornblende andesite porphry, deep green in color, fine grained.	224.50, gypsum vein. 226.00, quartz vein, width 5 mm.
230.60 – 282.00	granodiorite, greyish green in color.	235.00, chlorite + epidote. 240.00, quartz and calcite/pyrite vein, plagioclase altered to epidote. 270.00, gypsum vein, width 2 mm. 273.00, horizontal crack rich, epidote rich. 280.00, quartz/chlorite vein.
282.00 – 285.00	fault breccia and clay.	
285.00 – 294.00	hornblende andesite porphyry.	285.00 to 300.00, intensely argillized.
294.00 – 295.00	fault breccia and clay.	290.00 to 300.00, intensely argillized and brecciated chloritization and pyritization.
295.00 – 300	hornblende andesite porphyry.	θ=30 to 60, gypsum filled in fractures, calcite stringer.

Scale (m): 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300

Geological Column

Formation: Virac Granodiorite

Bottom Temperature: 56°C, 66°C, 73°C

SAMPLING

Depth (m)	M	X	C	V	T	D	P	R	H
158.50				○	○				
164.50	○	○	○	○	○	○	○	○	○
192.50	○	○	○	○	○	○	○	○	○
213.50	○	○	○	○	○				
242.30	○	○	○	○	○				
269.50	○	○	○	○	○				
295.00	○	○	○	○	○				

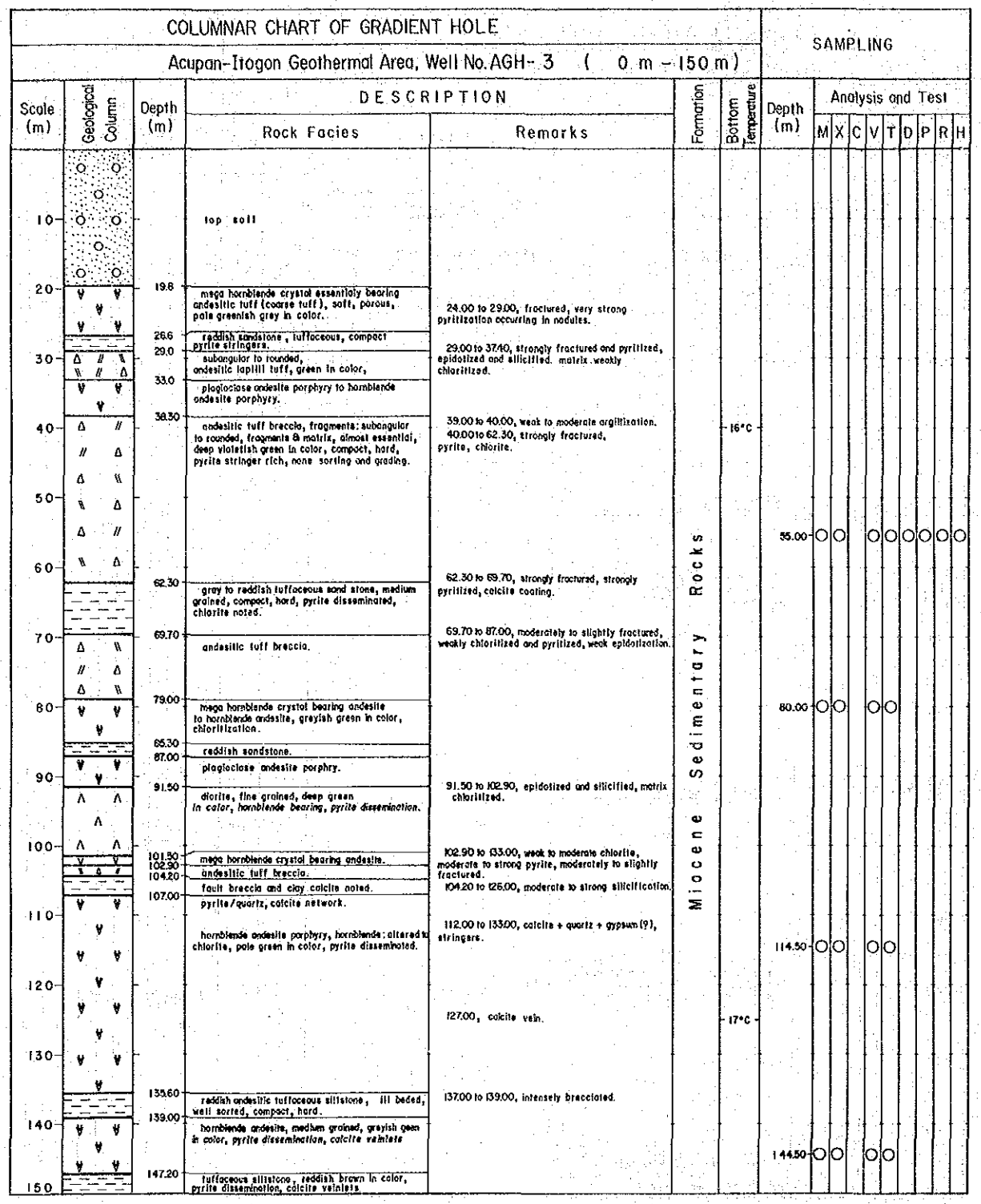
LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH-2 (300 m – 357.50m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature	SAMPLING: Depth (m)	Analysis and Test: M	X	C	V	T	D	P	R	H
300			granodiorite.	300.00 to 308.30, epidote and chlorite, calcopyrite dissemination, silicified.	Virac Granodiorite											
		308.30		308.30 to 313.00, calcite veinlets rich, pyrite disseminated moderately, epidote and chlorite												
310			hornblende andesite porphyry.													
		312.00	non core.			81.2°C										
		313.00	granodiorite, deep green in color, hornblende: fresh.													
320			321.0 to 322.5, fault breccia and clay.	317.50 to 322.50, argillized, white in color, θ=40, argillized along the fractures.												
				320.00, calcopyrite and pyrite dissemination, epidote very rich, calcite vein rare, quartz vein observed, silicified.			322.70	○	○	○	○	○				
330			332.0 to 332.10 fault clay and calcite, θ=30.													
		334.20	hornblende andesite porphyry, grey in color, medium grains.													
340		341.10	fault breccia.	341.10 to 343.00, epidote rich, pyrite dissemination, quartz veinlet and stringers.												
		343.00														
350				over 355.00, horizontal crack, developed strongly epidoted, quartz veins along cracks, silicified.												
						96.4°C	355.00	○	○	○						
		357.50														
360																
370																

LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat



LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

Fig. III-4-4 Columnar Chart (AGH-3)

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH- 3 (150 m - 300m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature
150		150.50	reddish brown sandstone.		Miocene Sedimentary Rocks	
			andesitic essential fine tuff, light green in color, pyrite dissemination, calcite veinlets.			
		153.90	reddish tuffaceous siltstone.	154.80 to 155.40, gorgy and strongly brecciated. 158.00 to 162.00, weakly silicification. 158 to 164, chloritiation epidote, pyrite.		
		158.00	essential andesitic fine tuff, calcite veinlet network boarly chlorite and epidote.			
160						
		164.50	andesite tuff breccia, deep green in color.	166.2 to 167.55, calcite + pyrite stringers.		
		166.00	black mudstone.			
		167.50	andesitic fine tuff.			
170		170.20	brownish grey sandstone to reddish sandstone (or andesitic pyroclastic rock ?)			17°C
		172.00	aphanitic andesite, light green in color, compact, hard.			
		177.00	black mudstone.			
		177.50	andesitic fine tuff, essential hornbrende phenocryst bearing deep green in color compact, hard.			
180		179.50	grey sandstone to red tuffaceous sandstone.			
		185.30	plagioclase-hornblende andesitic essential fine tuff, green in color.			
190						
		192.00	grey sandstone, andesitic tuff breccia in lower part.			
		194.80	194.8 to 194.9, fault breccia and clay, θ=60. hornblende-biotite granodiorite. hornblende andesite porphyry and argillized (fault breccia ?)	194.00 to 194.60, fault breccia. 195 to 208, brecciated, chloritized, pyritized and epidotized, calcite stringers.	Virac Granodiorite	
200		200.40	200.40 to 202.00, fault breccia and clay.			16°C
		202.00				
210			hornblende-biotite granodiorite, epidotized and chloritized, pyrite disseminated strongly, light greenish grey color.			
220						
230						15°C
240		241.00				
		241.50	brecciated and argillized.			
250						18°C
260						
		265.20	hornblende andesite porphyry, fine grained, hornblende : 1mm ±, plagioclase completely epidotized, light green in color, cracks not seen, massive, compact, hard, pyrite disseminated strogly, calcite vein.			
270						
280						
290						
		294.00	aplite/granodiorite, contact at 294.0m, θ=0. hornblende-biotite granodiorite, light grey in color, epidote rich, chloritization, calcite vein, pyrite disseminated strongly.			
300						

SAMPLING

Depth (m)	M	X	C	V	T	D	P	R	H
172.30	O	O		O	O	O	O	O	O
204.00	O	O		O	O				
237.30	O	O		O	O				
271.00	O	O		O	O				
300.00									

Analysis and Test

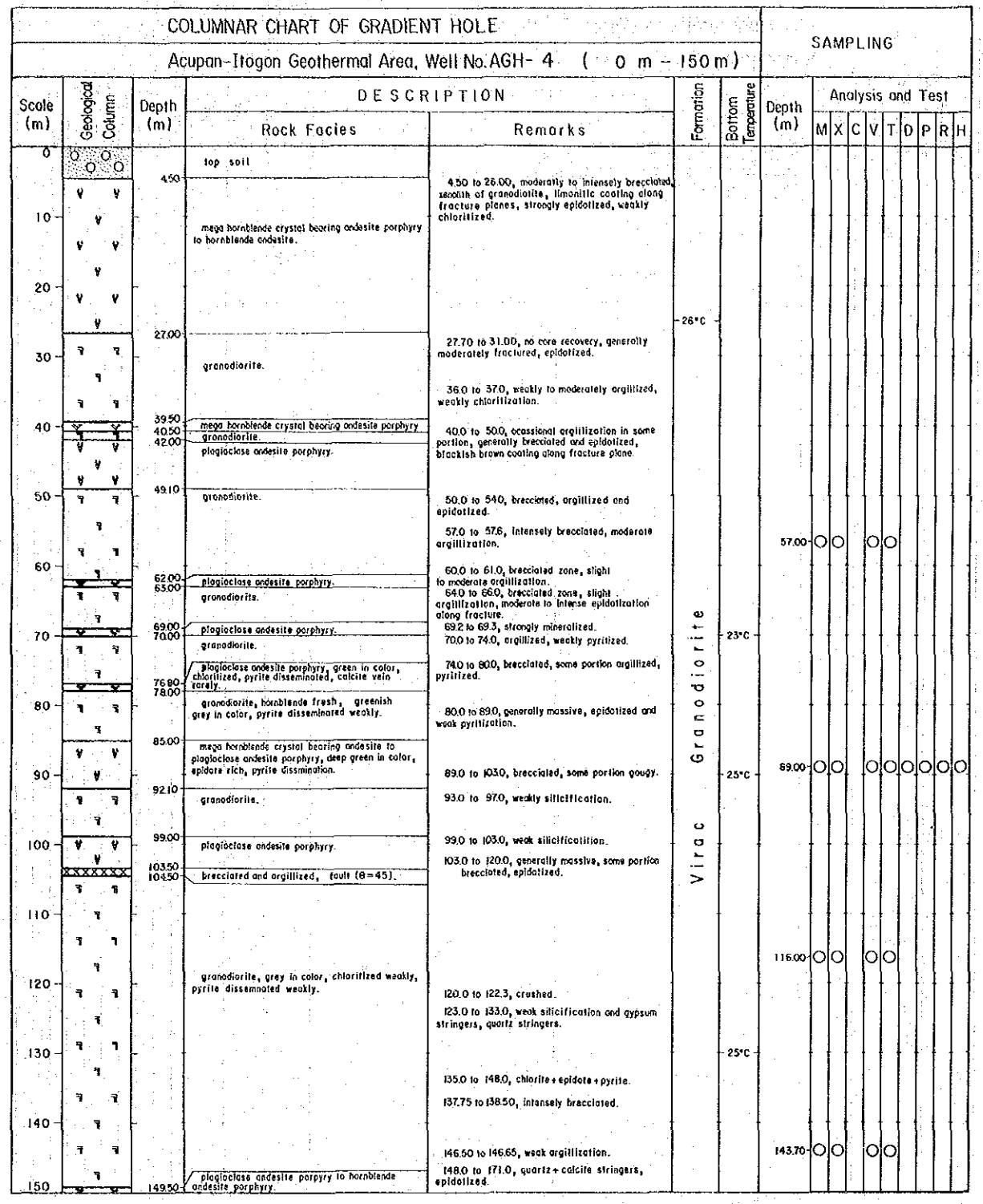
LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance .
H : Specific heat

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH- 3 (300 m -322.50m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature	SAMPLING: Depth (m)	Analysis and Test: M	X	C	V	T	D	P	R	H
300		301.00	granodiorite		Virac Granodiorite											
		303.50	aplitic granodiorite													
310			hornblende-biotite granodiorite, fresh hornblende epidote not so much, pyrite disseminated weakly, calcite vein (θ=0) at 310.0m.													
320		322.50				24.1°C										
330																

LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat



LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

Fig. Ⅲ-4-5 Columnar Chart (AGH-4)

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH- 4 (150 m - 300 m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature
150			granodiorite, plagioclase altered to epidote and chlorite		Virac Granodiorite	
		153.50	plagioclase andesite porphyry, very fine grained, deep green in color.			
		156.70	granodiorite, plagioclase altered to epidotized			
		159.20	andesite porphyry, fine grained, deep green in color, chloritization, epidotization, θ=20 boundary			
160		162.70	hornblende-biotite granodiorite, chloritization, epidotization, pyrite dissemination weak, light grey in color.	165.0, epidotized in intensity.		
170				170.0 to 171.0, epidote + quartz along cracks. 174.0 to 184.0, epidote + quartz + calcite		
180				184.65 to 184.85, argillized. 184.0 to 189.0, moderate silicification, epidotized.		
190		190.00	fine grained andesite, deep geen in color, pyrite disseminated strongly, chloritized.	190.0 to 201.0, massive. epidote, chlorite, pyrite calcite stringers, occassional argillization and brecciation.		
		194.50				
		195.00	brecciated and clay in fault, θ=60.			
200			hornblende-biotite granodiorite, some amounts of epidote vein, pyrite disseminated weakly, light grey in color.			21.9°C
210						
220						
		226.00	fine grained andesite, deep green in color, plagioclase altered to epidote, calcopyrite and pyrite disseminated strongly, θ=50 boundary of dyke.			
		226.50	hornblende-biotite granodiorite, epidote veinlets.			
230						
240						
250						
260						
		267.50	sheared and argillized, θ=10 to 20 calcite veinlet rich.			
		269.00				
270			hornblende-biotite granodiorite, greenish grey in color, pyrite disseminated weakly, compact, hard.			
280				280.0 to 280.5, calcite vein, width 3 mm. 283.50, calcite vein θ=20, width 5 mm. 283.50 to 283.90, argillized, soft, light green in color.		
290						
300						

SAMPLING

Depth (m)	M	X	C	V	T	D	P	R	H
160.50	O	O		O	O				
211.00	O	O		O	O				
235.50	O	O		O	O				
261.50	O	O		O	O				
283.40	O	O		O	O				

LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH- 4 (300 m - 450 m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature	SAMPLING: Depth (m)	Analysis and Test: M	X	C	V	T	D	P	R	H
300			granodiorite.	300 to 304, strongly brecciated, foliation observed (α = 80°), alteration chlorite + epidote + pyrite, some fracture still open, calcite stringer presente. 305 to 320, generally massive granodiorite, alteration epidote + pyrite + chlorite + calcite occassional weak argillization noted.	Virac Granodiorite										
310																
320				327.5 to 228.25, open fracture, moderately brecciated, calcite stringers noted,												
		327.50	aphanitic andesite													
		328.25	granodiorite.	228.25 to 335.0, massive to slightly brecciated.												
330																
		335.00	aphanitic andesite.	335.0 to 335.5, calcite stringers in all direction.												
		335.50	granodiorite.	335.5 to 340.0, absence of epidote noted												
340		340.00	hornblende andesite porphry.	340.0 to 342.0, massive, absence of alteration mineral												
		342.00	granodiorite.	342.0 to 372.0, slightly fractured, quartz + calcite + epidote + pyrite intensity												
350																
360																
370																
		372.00	hornblende-plagioclase andesite porphry.	372.0 to 374.0, dark grey, moderately brecciated, calcite coating along planes.												
		374.00	granodiorite.	374.0 to 380.8, slightly brecciated, quartz + calcite + epidote,												
380		380.80	plagioclase andesite porphry.	380.8 to 401.0, greenish grey, moderately brecciated, occassional hornblende phenocrysts, calcite veinlets along cracks.												
390																
400																
		401.00	granodiorite	401.0 to 406.5, moderatly to intensily brecciated, quartz + calcite + gypsum.												
		406.50	plagioclase andesite porphry.	406.5 to 407.0, grey, slightly argillized.												
		407.00	granodiorite.	407.0 to 411.5, moderatly brecciated, epidote + pyrite + calcite.												
410		411.50	aplitic granodiorite.	411.5 to 415.0, silicic alteration, epidote + pyrite.												
				415.0 to 416.0, pyrite + calcopyrite. 416.0 to 420.0, moderately brecciated, veinlets, quartz + calcite, abundant pyrite.												
420		420.00	hornblende andesite porphry.	420.0 medium grained groudmass, moderatly brecciated, epidote + calcite + pyrite.												
		424.80	hornblende andesite porphry.													
		426.50	granodiorite.													
430		431.00	plagioclase andesite porphry.													
		431.50	granodiorite.	431.5 to 438.0, slightly brecciated.												
		438.00	plagioclase andesite porphry.													
		438.50	granodiorite.	438.5 to 440.0, slightly brecciated.												
440		440.00		440.0 to 441.5, grey, moderatly brecciated, few plagioclase phenocryst + calcite.												
		441.50	plagioclase andesite porphry.													
			granodiorite.	441.5 to 445.0, slightly fractured.												
		445.00	plagioclase andesite porphry.	445.0 to 447.5, grey, slightly brecciated, fine few plagioclase phenocryst, slightly argillized, + calcite veinlets												
		447.50	granodiorite.													
450																

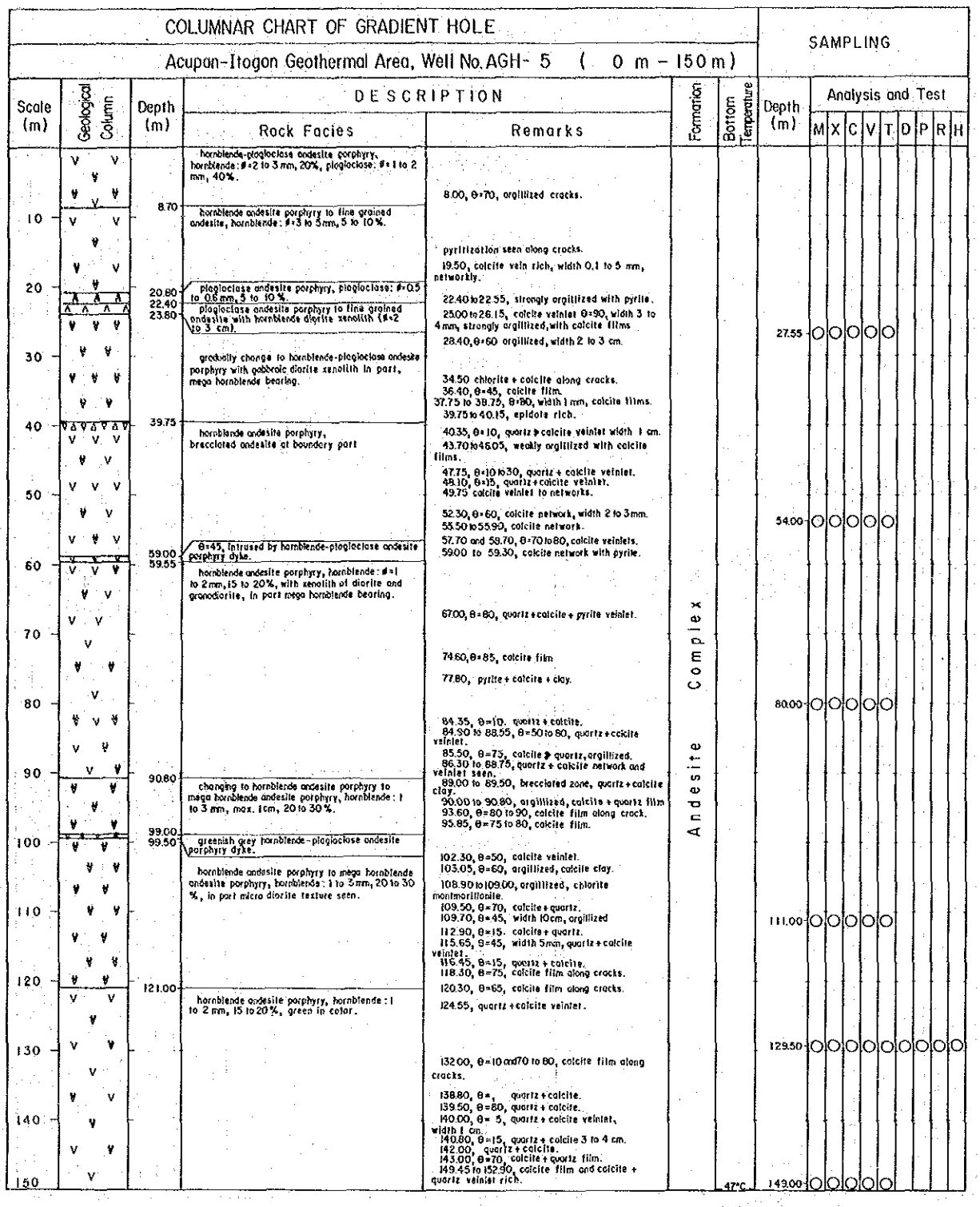
LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH- 4 (450 m -538.20m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature	SAMPLING: Depth (m)	Analysis and Test: M	X	C	V	T	D	P	R	H
450			granodiorite.	447.5 to 461.0, slightly brecciated, calcite quartz veinlets, weak to moderate epidotization, occassional weak argillization + pyrite.	Virac Granodiorite											
460		461.00	aplitic granodiorite	461.0 to 468.0, moderately fractured, pyrite + epidote + calcite stringers.												
470		468.00	granodiorite.	468.0 to 493.0, generally massive, slightly brecciated in part, calcite + chlorite, stringers of dark sulfied noted.												
480																
490		493.00	hornblende andesite porphry.	493.0 to 493.5, strongly mineralized and epidotized, few calcite stringers.												
		493.50	granodiorite.	493.5 to 510.0, massive, epidote + pyrite + chlorite + calcite.												
		498.00	hornblende andesite porphry.													
500		498.25	granodiorite.													
		503.00	aplitic granodiorite.													
		507.00	granodiorite.													
510		510.00	micro diorite to medium grained andesite porphry.													
		511.00	granodiorite.													
				518.3 to 518.5, gouge.												
520				520.0 to 532.0, generally slightly fractured, alteration mineral												
530				532.0 to 538.2, strongly brecciated, moderate to strong silicification, strongly pyritized, weakly argillized.												
540		538.20														

LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat



LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

Fig. Ⅲ-4-6 Columnar Chart (AGH-5)

COLUMNAR CHART OF GRADIENT HOLE

Acupon-Itogon Geothermal Area, Well No. AGH- 5 (300 m - 400m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature
300			brecciated diorite.		Itogon Quartz Diorite	
				304.55 to 305.90, argillized and silicified with calcite film.		
				306.65 to 308.45, argillized and silicified with calcite film.		
310				312.10 to 312.40, argillized.		47°C
				319.30 to 320.40, θ=70, quartz + calcite vein.		
320				321.00, calcite + pyrite film.		
330						
		335.10	θ=20 aphanitic andesite dyke.			
		335.80				
		337.20	brecciated diorite.			
340			dark grey hornblende-plagioclase andesite porphyry, hornblende: 3 to 4 mm, 15 to 20 %, plagioclase: 1 to 2 mm, 10 % ±			
		346.20	brecciated diorite.			
350						
		355.80	hard compact hornblende andesite porphyry.			
360		362.80	strongly argillized brecciated diorite.	362.40 to 372.75, suddenly change to strogly argillized zone with calcite + pyrite + calcopyrite.		
				369.00 to 369.70, strongly altered zone, green to greyish, argillized.		
370		372.75	strongly epidotized andesite.	372.75 to 374.50, spots of epidote, vein rich		
		374.50	brecciated diorite.	375.25 to 377.15, strongly argillized calcite + pyrite + chlorite.		
380						
				387.10, θ=60, width 1 cm, calcite + quartz veinlet.		
390				387.30, θ=60, width 1 cm, calcite + quartz veinlet.		
				396.50 to 400.00, weakly argillized with calcite + epidote networks.		
400		400.00				61.5°C

SAMPLING

Depth (m)	M	X	C	V	T	D	P	R	H
302.15	O	O	O	O	O				
326.00	O	O	O	O	O	O	O	O	O
349.60	O	O	O	O	O				
372.50	O	O	O	O	O				
399.50	O	O	O	O	O				

LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

COLUMNAR CHART OF GRADIENT HOLE

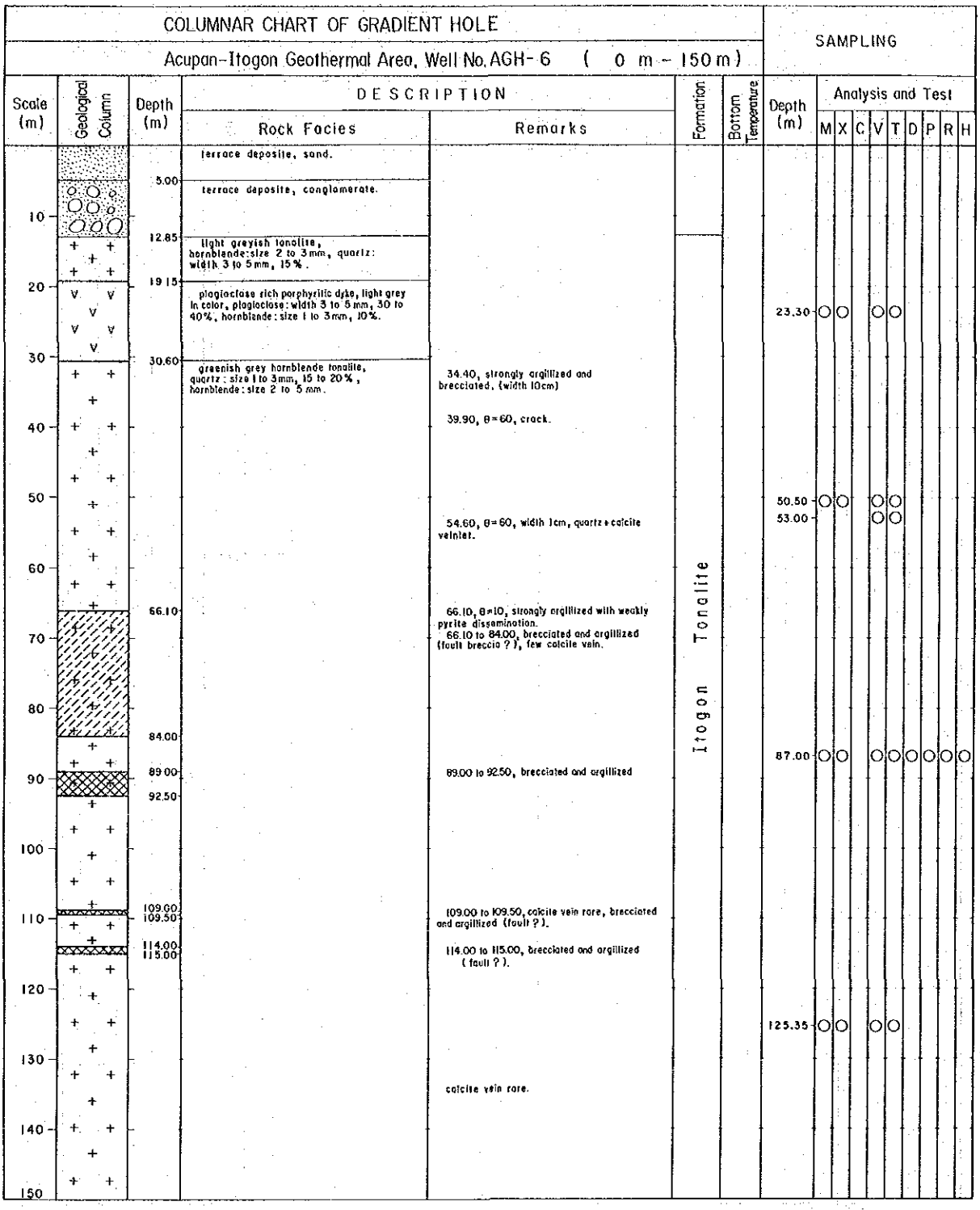
Acupan-Itogon Geothermal Area, Well No. AGH-5 (150 m – 300 m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature
150			hornblende andesite porphyry.		Andesite Complex	
		155.80		155.80 to 157.40, θ=60, pyrite + calcite vein.		
		157.40				
160				161.70, θ=60, crack, pyrite 162.80 to 163.40, calcite clay.		
170		170.70		170.70 to 170.90, θ=60, argillized and brecciated		
		173.10		173.50 to 170.80, θ=50, pyrite + calcite, brecciated.		
		178.00		177.10, θ=40 and 80 to 90, calcite films and networks.		
180						
		187.95		187.50 to 187.90, θ=60, strongly argillized.		
190		191.20		187.95 to 191.20, strongly argillized and weakly silicified.		
		195.00		195.10 to 196.90, strongly argillized and weakly silicified.		
		196.90				
200			brecciated diorite	198.40 to 198.50, strongly argillized. 198.70 to 199.00, strongly argillized. 200.60 to 200.90, argillized with pyrite	Itogon Quartz Diorite	
						49°C
210		212.10		212.10 to 213.10, θ=40, strongly argillized with calcite film & networks.		
		213.10	brecciated diorite	217.20 to 220.60, strongly argillized with calcite film & networks.		
220				221.10, θ=60, width 1cm to 5mm, calcite + quartz veinlet. 222.50, θ=60, 5mm, calcite veinlet.		
			andesite porphyry	228.00, θ=45, 5mm, calcite veinlet.		
230			brecciated diorite	234.50, θ=10, calcite veinlet. 235.00, θ=10, width 3 to 4 cm, calcite clay. 236.00, θ=60, width 10cm, quartz + calcite vein.		
240						
250				249.95 to 251.30, strongly argillized with pyrite 253.00 to 254.40, θ=50, argillized and calcite + quartz film.		
				258.00 to 258.20, argillized. 258.80 to 258.90, argillized.		
260				263.70 to 263.90, θ=60, argillized.		
270				270.00 to 270.30, pyrite dissemination		
280				280.20 to 280.90, strongly argillized. 282.40, θ=60, strongly argillized.		
290						
				296.80 to 299.30, calcite veinlet with pyrite and epidote. 296.80 to 300.45, argillized zone.		
300						

SAMPLING

Depth (m)	M	X	C	V	T	D	P	R	H
175.00	O	O	O	O	O	O	O	O	O
201.80	O	O	O	O	O				
226.20	O	O	O	O	O				
253.10	O	O	O	O	O	O	O	O	O
274.50	O	O	O	O	O				

LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat



LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

Fig. III-4-7 Columnar Chart (AGH-6)

COLUMNAR CHART OF GRADIENT HOLE

Acupan-Itogon Geothermal Area, Well No. AGH-6 (150 m -207.15m)

Scale (m)	Geological Column	Depth (m)	DESCRIPTION: Rock Facies	DESCRIPTION: Remarks	Formation	Bottom Temperature	SAMPLING: Depth (m)	Analysis and Test: M	X	C	V	T	D	P	R	H
150			tonalite		Itogon tonalite											
160																
				calcite vein rare.		34.0°C	165.50	○	○		○	○	○	○	○	○
170																
180																
190			189.00 to 189.30, aplitic diorite, deep green in color.													
200						31.7°C	204.10	○	○		○	○				
		207.15				31.8°C										
210																

LEGEND ; M : Thin section
X : X-ray diffraction
C : Chemical analysis
V : Sonic velocity
T : Thermal conductivity
D : Density
P : Permeability
R : Specific electric resistance
H : Specific heat

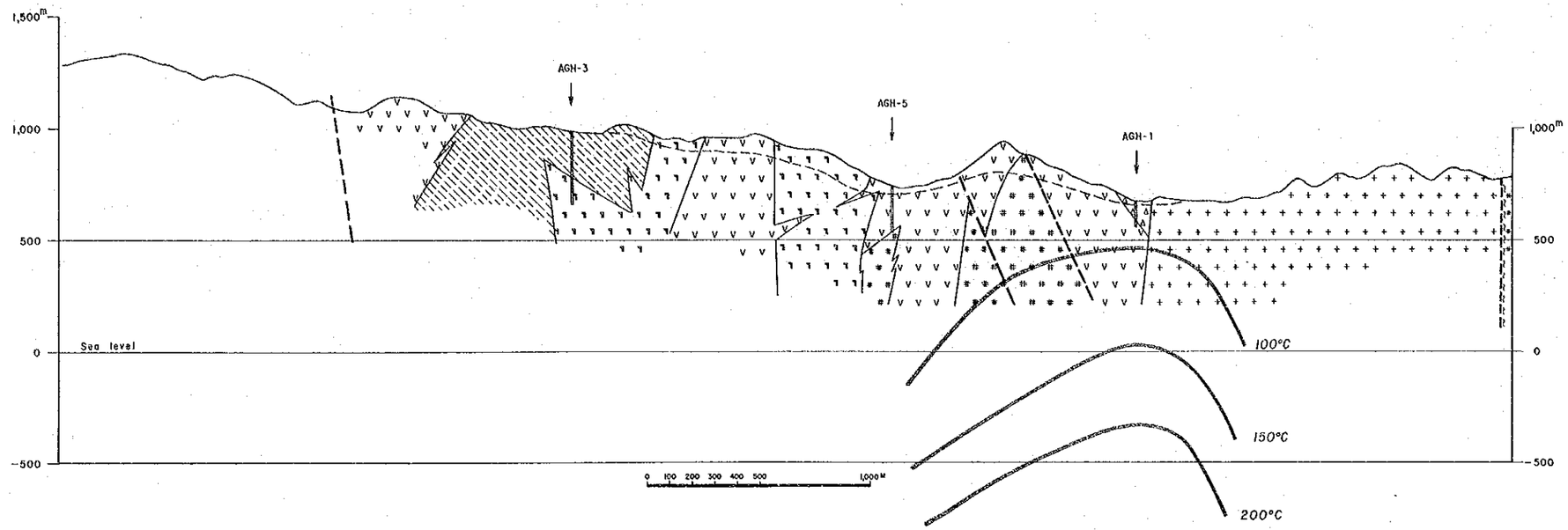


Fig. Ⅲ-4-8 (a) Profile of Through AGH-3,5,1

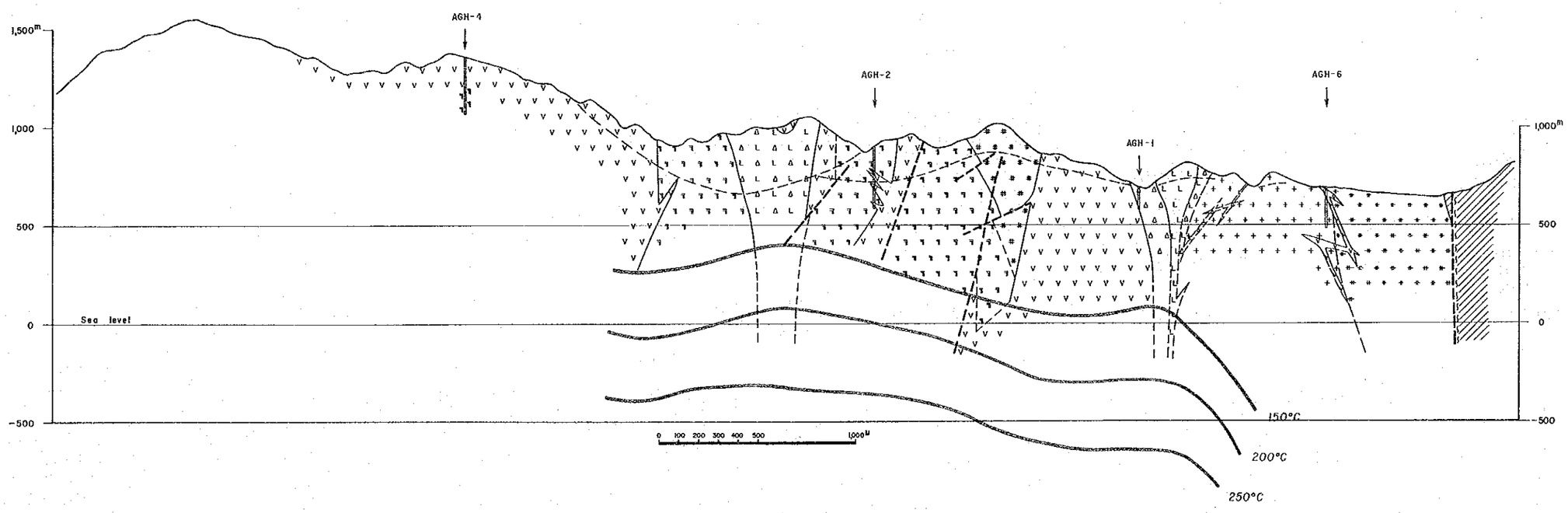


Fig. Ⅲ-4-8 (b) Profile of Through AGH-4,2,1,6

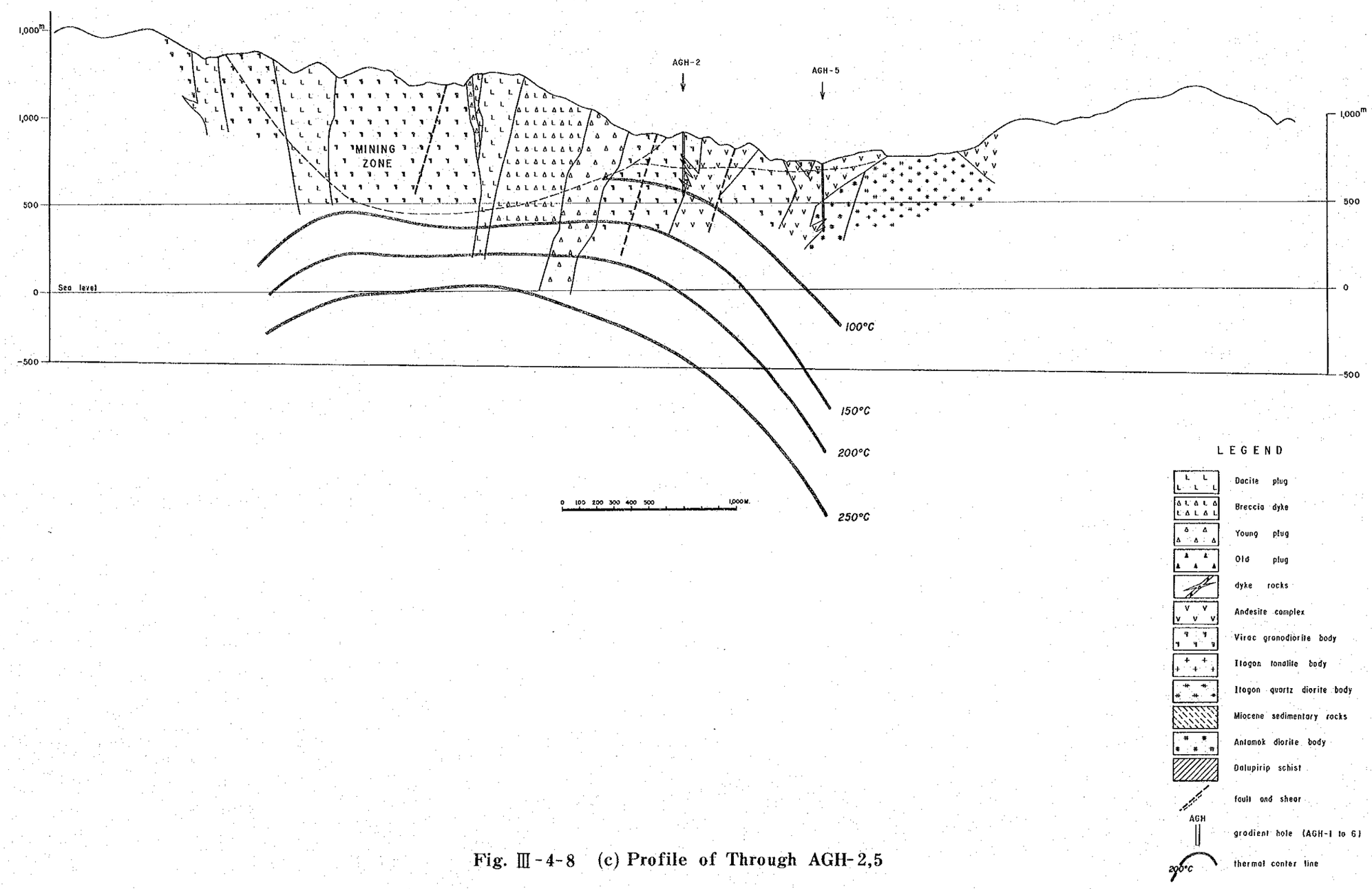


Fig. Ⅲ-4-8 (c) Profile of Through AGH-2,5

In this method, the following variables and conditions were set for the assumed cylindrical coordinates:

– the axial direction of the hole is regarded as the Z-axis;

– temperature is a function of a homogenous infinite medium which reacts vertically with the pit axis;

– the time (θ) which elapses after circulation of water is ceased (stand-by time);

– the time (t) for the circulating water to cool down after the target depth has been reached.

Then, in a semi-logarithmic graphing paper, the $\theta/(t + \theta)$ is plotted as the abscissa with T (temperature) as the ordinate. The temperature at the point at which $\theta/(t + \theta)$ is equal to 1 will be taken as the stabilized formation temperature for a particular hole. The thermal gradients are then derived from the plotted stabilized formation temperatures at either 50- or 100-meter depth intervals.

Equipment used:

1. Thermometer

   Types: D-226 and D-661

   Maker: Takara Kogyo Co., Ltd.

   Range: 0–200°C

   Resolution: 0.1°C

2. Recorder

   Type: EPR-2 (pen recorder)

Maker: Toa Dempa Co., Ltd.

3. Electrode

Combined resistance type thermistor (ϕ 32 mm)

4. Cable

Type: 4-core, heat-proof, armoured cable (ϕ 8 mm)

Maker: Nippon Taiyo Kaitei Densen Co., Ltd.

5. Winch

Type: KIC 3787 electric cable winch;

3 HP (500 m. winding).

Maker: Kaihatsu Kogyo Co., Ltd.

4.3.2 Discussion of Results

Results of the measurements are shown in Figs. III–4–9 to III–4–14.

(a) Gradient Hole AGH-1

Location: Poblacion, Itogon

Elevation: 690.67 meters

Depth drilled: 112.85 meters

Highest temperature measured: 91°C at 104 meters

Drilling started: November 18, 1983

Drilling ended: December 7, 1984

Drilling rig: Mindrill F-31-A

AGH-1 is located along the river bank of Ambalanga in Poblacion, Itogon. It is around 70 m from the portal of the drain tunnel of Acupan Mines and approximately 100 m and 20 m, south of Itogon hot springs and west of Itogon plug,

respectively. The hole which is programmed to a depth of 350 meters was terminated at 112.85 meters after flowline and bottom hole temperatures reached 67°C and 96°C, respectively.

Measurements were conducted during the drilling works 20–30 minutes after circulation of drilling fluid was stopped. Free flowing water at 100 li/hour was measured at 60°C which was reduced to about 1.0 li/min. after the G.I. pipes were inserted (Table III–4–1). Likewise, measurements were taken at stand-by times of 0.50, 287, 528 and 1,368 hours (Table III–4–1). The stabilized formation temperatures is shown in Fig. III–4–15 and is summarized as follows:

Depth (m)	Stabilized Temp. (°C)	Thermal Gradient (°C/10 m)
25	86.5	+1.32
50	89.8	+0.16
75	90.2	+0.20
100	90.7	

The depth at which the thermal water is entering the borehole is unknown. The temperature of fluids is higher at depth but is subsequently cooled by the ground water before reaching the surface.

Measurements taken after completion of drilling indicate temperatures of 70°C at the collar and 91°C at 104 meter depth. The logging tool was not able to penetrate the bottom due to clogged G.I. pipe.

(b) Gradient Hole AGH-2

Location: Sitio Dalicno, Barrio Ampucao

Elevation: 921.68 meters

Depth Drilled: 357.60 meters

Highest temperature measured: 104°C at 350 meters

Drilling started: December 4, 1983

Drilling ended: February 20, 1984

Drilling rig: Mindrill 5-52-A

AGH-2 is about 850 m. Southsouthwest (SSW) of AGH-5 and 1.5 kilometers southwest of Itogon hot springs. It was programmed to be drilled to 400 m. depth, but was terminated at 357.6 meters when the bottom temperature was observed to be over 100°C.

Three initial measurements were conducted at stand-by times of 3.50, 8.5 and 22.5 hours after completion of drilling. Drilling records show circulation losses at 190 and 300 meters depths. However, from thermal logging charts, the losses are registered at depths of approximately 220, 260, and 290 meters.

Thermal logging charts and the process of calculating the stabilized temperatures are shown on Table III–4–2 and Fig. III–4–16. The summary of the calculations appears below:

Depth (m)	Stabilized Temp. (°C)	Thermal Gradient (°C/m)
100	32.0	+2.3
200	55.0	+5.7
250	83.5	+3.5
300	101.0	+2.8
350	115.0	

Thermal gradient reaches +4.0°C/10 m. below the ground water level which is about 196 m.

On the other hand, actual downhole temperature measurements conducted by BED after completion of the well showed strongly anomalous thermal gradient starting at 20 meters and persisted to the bottom. From 20 to 200 meters, the gradient is about 2.0°C/10 m, then rises to 2.6°C/10 meters from 200 meters to the bottom. A slight decrease in temperature was noted at 280–290 meters which can be attributed to an open fracture with circulating fluid that was intersected by the hole.

(c) Gradient Hole AGH-3

Location: Barrio Virac, Itogon
Elevation: 975.21 meters
Depth Drilled: 322.50 meters
Highest temperature measured: 24.2°C at 320 m. depth
Drilling started: January 11, 1984
Drilling ended: February 6, 1984
Drilling rig: Mindrill F-31-A

The third gradient hole is approximately 1.5 kilometer northwest of AGH-2 and about 2.4 kilometers west of Itogon hot springs. The hole was drilled to 322 meters which is the balance to complete the proposed total meterage of 2,200 meters. At depths of 119 and 149 meters, artesian wells were intersected with a flow rate of 5 to 6 liters per minute. Downhole temperature measurements were taken inside the drill rods as G.I. pipes were not brought down the hole. This was done to consider the request of BC to donate the hole for irrigation purposes. Build-up temperatures were measured at stand-by times of 0.25, 16.30, 23.30 and 40.30 hours. No rise in temperature was observed (see Fig. III–4–11). The water table was measured at 1.5 meters below the surface.

Records of the thermal logging and the process of calculating the stabilized temperatures are shown in Tables III–4–3 and Fig. III–4–17. It is worthy

to note the insignificant rise in the thermal gradient in the borehole, as shown below:

Depth (m)	Stabilized Temp. (°C)	Thermal Gradient (°C/10 m)
100	23.3	0
200	23.3	+ 0.14
250	23.5	+ 0.10
300	24.0	0
320	24.0	

(d) Gradient Hole AGH-4

Location: Barrio Ampucao, Itogon

Elevation: 1,350.4 meters

Maximum depth drilled: 538.2 meters

Highest temperature measured: 29.2°C at 403 meters

Drilling started: January 8, 1984

Drilling ended: June 6, 1984

Drilling rig: Mindrill F-66

AGH-4 is located some two kilometers southwest of AGH-2 and about 1.4 kilometers west southwest of Balatoc plug. The planned depth to be drilled was 800 meters, but the hole was terminated at 538 meters at the request of BC because of drilling difficulties. Problems such as lack of water supply and no return water were often encountered during drilling. The drilling work attained its drawback at 538.2 meters depth when the wash rods dropped to 543.6 meters. The drilling department of BC reported that the hole encountered an open cavity possibly brought about by the intersection of three (3) steeply dipping fractures.

Build-up temperatures were measured at stand-by times of 2.15, 18.00 and 42.25 hours down to 200 meters. Records of the logging and the process of calculating the stabilized temperatures are shown in Tables III–4–4 and Fig. III–4–18. The calculated stabilized temperatures are:

Depth (m)	Stabilized Temp. (°C)	Thermal Gradient (°C/10 m)
50	19.4	0
100	19.4	+ 0.26
150	20.7	+ 0.66
200	24.0	

The water table was not encountered in the hole; this could have been drawn off to the nearby existing underground workings of Acupan Mines. Temperature profiles indicate a thermal gradient below normal which can be attributed to its higher elevation in relation to the depth drilled.

At present, G.I. pipes are lowered to a depth of only 403 meters due to subsequent wall collapse in the hole from 400 to 538 meters.

(e) Gradient Hole AGH-5

Location: Sitio Batuang, Virac, Itogon
Elevation: 746.77 meters
Depth drilled: 400.00 meters
Highest temperature measured: 61.8°C at the bottom
Drilling started: November 17, 1983
Drilling ended: December 13, 1984
Drilling rig: Mindrill F-66

AGH-5 is situated above one (1) kilometer westnorthwest of Itogon hot springs and approximately 1.2 kilometer northeast of Balatoc plug. Drilling proceeded smoothly except when the core barrel was accidentally disconnected from the NQ drill rods and the subsequent snapping of the NW casing. Fishing operations to retrieve NW casing and core barrel lasted eight (8) days.

After the G.I. pipes were inserted, logging was performed at stand-by times of 3.45, 14, 329, 634, 1,190 and 1,401 hours. The chart is shown in Fig. III–4–13. Records and calculations are on Tables III–4–5 and Fig. III–4–19.

Depth (m)	Stabilized Temp. (°C)	Thermal Gradient (°C/10 m)
100	35.0	+ 1.0
200	45.0	+ 0.86
300	53.6	+ 0.84
400	62.0	

Logging charts indicate the water level at approximately 10 meters depth and circulation losses at 315 and 385 meters depths. However, loss zones from 275–284 and 360 meters were not identified from the thermal logging charts although drilling records indicated their presence. Formation temperatures increase linearly with depth below the water level.

Measurements conducted by BED show an anomalous thermal gradient which starts at a depth of 50 meters and persists to the bottom. Gradient is 0.5°C/10 m from 10 to 50 meters which rises to 0.6°C/10 m up to 280 meters and increases to 1.3°C/10 m to the bottom. Small drop in temperature was noted at 260–280 meters and 300–310 meters and no return water was also encountered at these depths. Geological logging indicates the presence of gouges and dominantly horizontal fractures.

(f) Gradient Hole AGH-6

Location: Poblacion, Itogon
Elevation: 689.6 meters
Depth drilled: 207 meters
Highest temperature measured: 31.8 at 206 meters
Drilling started: December 11, 1983
Drilling ended: January 4, 1984
Drilling rig: Mindrill F31-A

AGH-6 tested the northeastern margin of the thermal area. It is around 1.3 kilometers northeast of the Itogon plug and about 2.2 kilometers east northeast of AGH-5.

Target depth of 300 meters was not attained as downhole temperature measurements indicated a normal gradient throughout the borehole. The hole was terminated at 207 meters with collar and bottom temperature ranges of 23–24°C and 31–32°C, respectively. Water table was encountered at 30 meters from the surface.

Thermal logging was done at stand-by times of 3,401 and 58 hours (chart is shown in Fig. III–4–14). Records of logging and the stabilized temperature are shown in Table III–4–6 and Fig. III–4–20. Formation temperature is very low and the thermal gradient approximates that of non-volcanic region.

Depth (m)	Stabilized Temp. (°C)	Thermal Gradient (°C/10 m)
50	25.7	+ 0.46
100	28.0	+ 0.36
150	29.8	+ 0.44
200	32.0	

(g) Gradient Hole AGH-7

Location: Barrio Ampucao, Itogon
Elevation: 1,415.2 meters
Depth drilled: 301.5 meters
Highest temperature measured: 29.5°C at 301 meters
Drilling started: April 15, 1984
Drilling ended: May 28, 1984
Drilling rig: Mindrill F31-A

AGH-7 is the last hole to be spudded resulting from the early termination of AGH-4. This is to complete the required meterage of 2,200 meters. The hole is about 3.5 kilometers southwest of Itogon hot springs and around one (1) kilometer south of Balatoc plug. It was drilled within the Virac granodiorite and lies and lies adjacent to the newly identified dacite plug in the south.

Drilling was carried out continuously up to its target depth of 300 meters. However, no return water was encountered throughout its length. This could be attributed to the intensely fractured rocks intersected by the hole. Core logging shows that the water table is at 55 meters from the surface.

4.3.3 Analysis of Results

The results gathered from the seven (7) gradient holes drilled over an area of eight square kilometers revealed the existence of a significant thermal anomaly. Two of the holes drilled, AGH-2 and AGH-5 exhibit a temperature profile ranging from 0.5°C/10 m to 2.7°C/10 m. Whereas, AGH-3, AGH-4, AGH-6 and AGH-7 disclosed a nil to normal thermal gradient. The exceptionally high gradient of AGH-1 was not considered. It is apparently superficial as it is affected by the proximity of Itogon hot spring and free flowing water.

Based on the measured gradient of the holes, a hypothetical isotherm map is presented as shown in Fig. I–3–1. It shows the form of the 150°C, and 250°C isotherm at 500 meters below sea level. From the temperature data available, it is not possible to complete the isotherm satisfactorily throughout its whole length more especially in the southwest sector. However, dashed outlines are believed to represent its shape within fair limits. The total hot area within the 200°C isotherm is approximately 4 square kilometers. The anomaly is still open on the southwest side. Therefore its real extent must be greater.

4.4 Resistivity Logging

4.4.1 Method of Measurement

In general, resistivity of rocks can be expressed by the formula:

$$\rho = F \times \rho w$$

where ρ is the apparent resistivity of the rock F, formation resistivity factor ρw, resistivity of pore water contained in the rock.

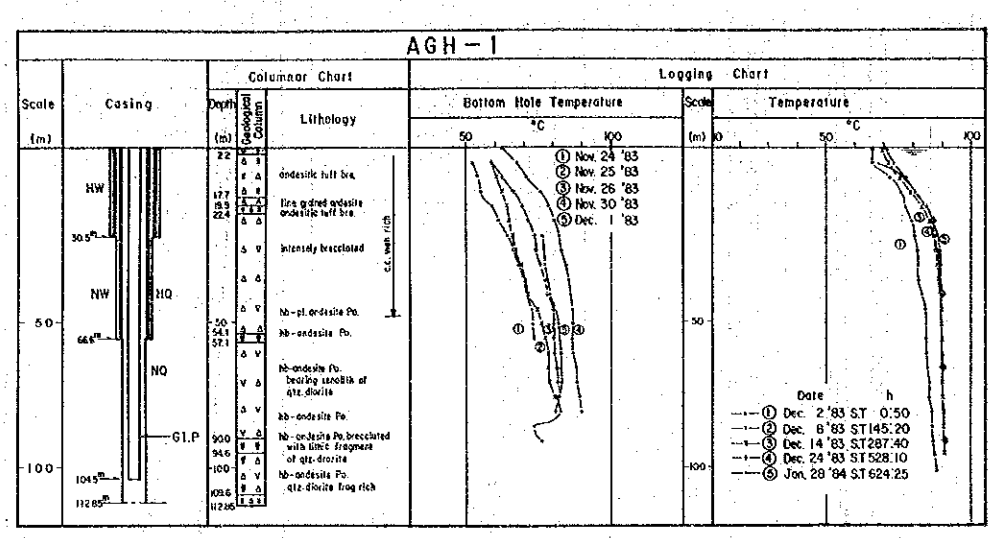


Fig. Ⅲ-4-9 Thermal Logging Chart of AGH-1

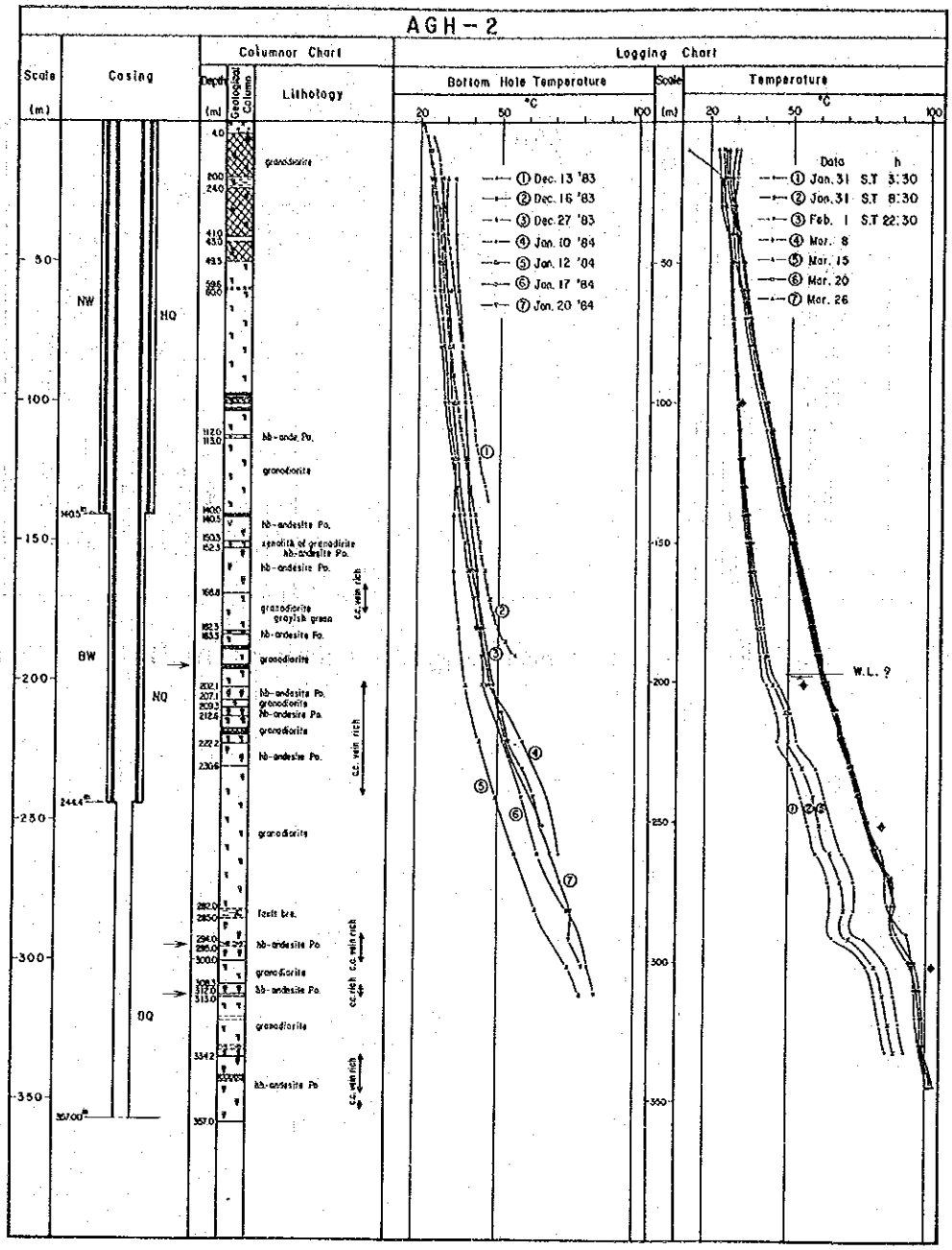


Fig. Ⅲ-4-10 Thermal Logging Chart of AGH-2

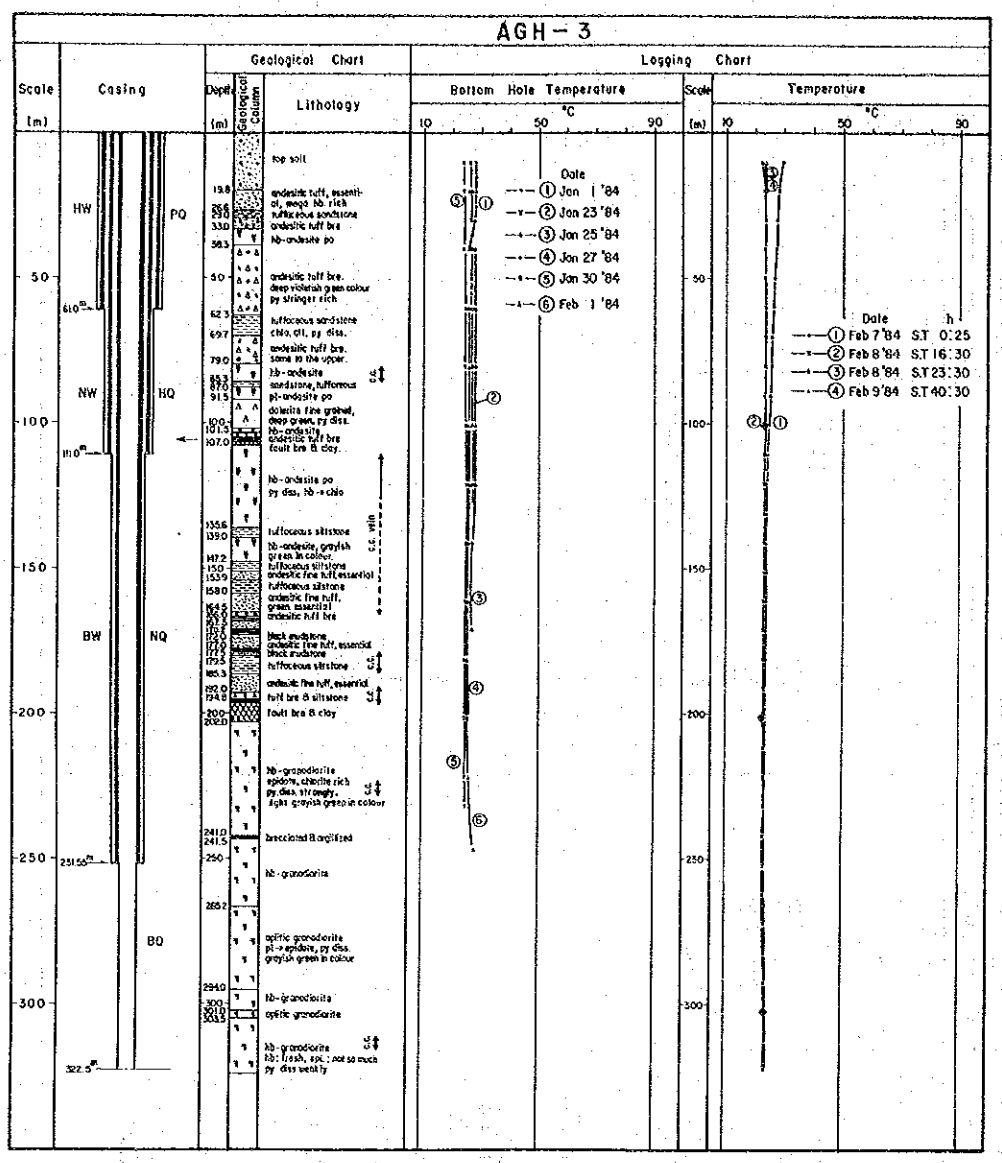


Fig. Ⅲ-4-11 Thermal Logging Chart of AGH-3

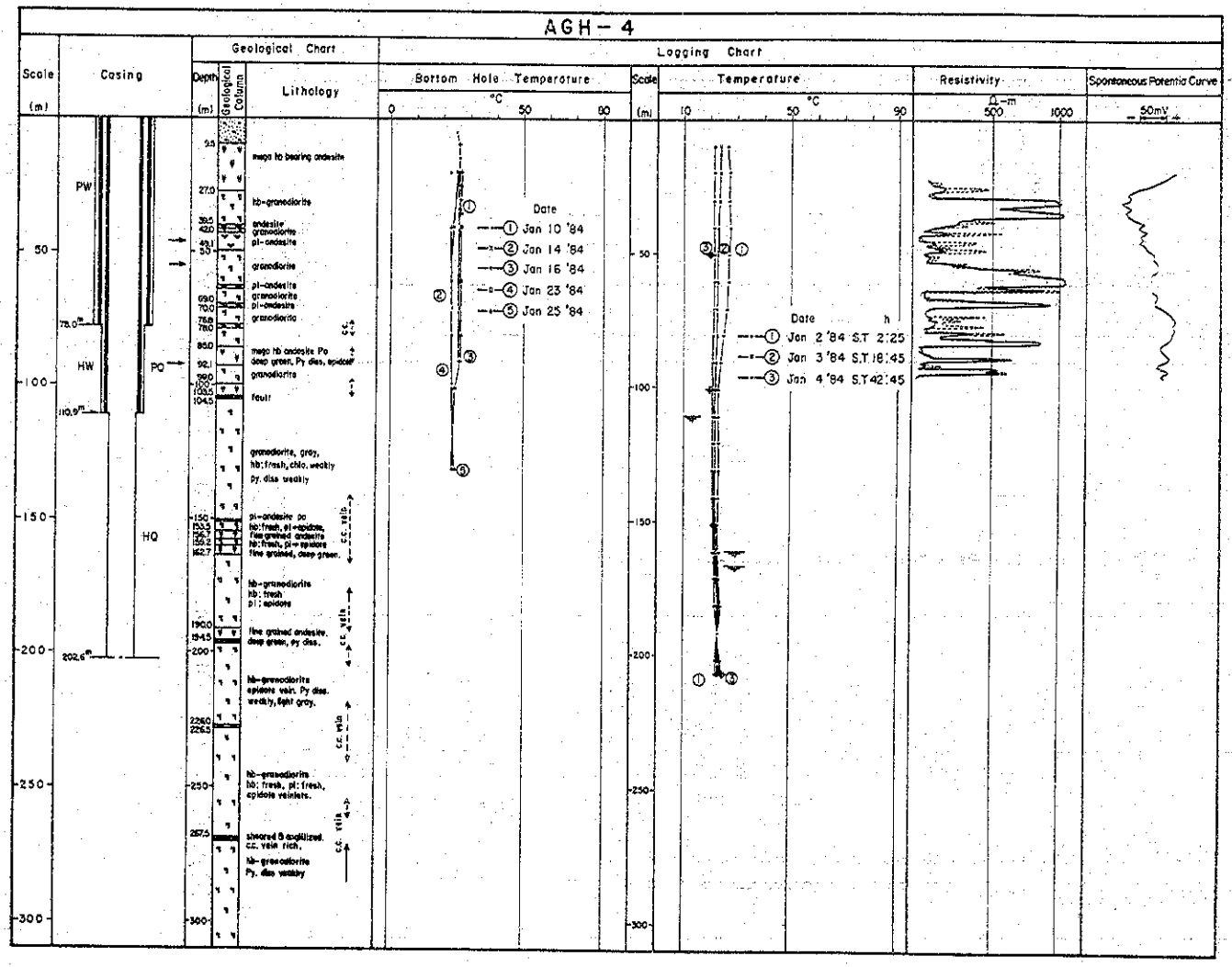


Fig. Ⅲ-4-12 Thermal Logging Chart of AGH-4

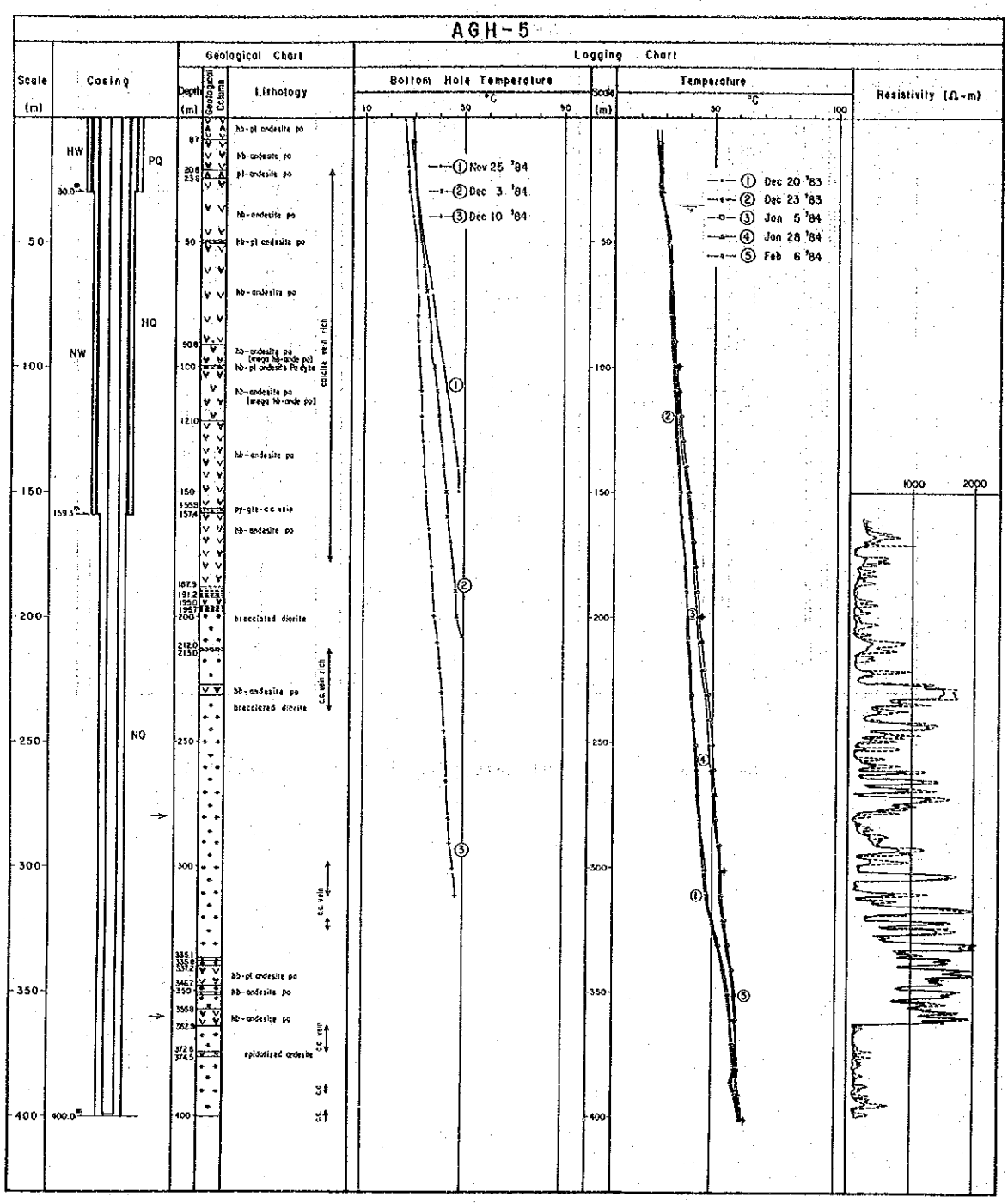


Fig. Ⅲ-4-13 Thermal Logging Chart of AGH-5

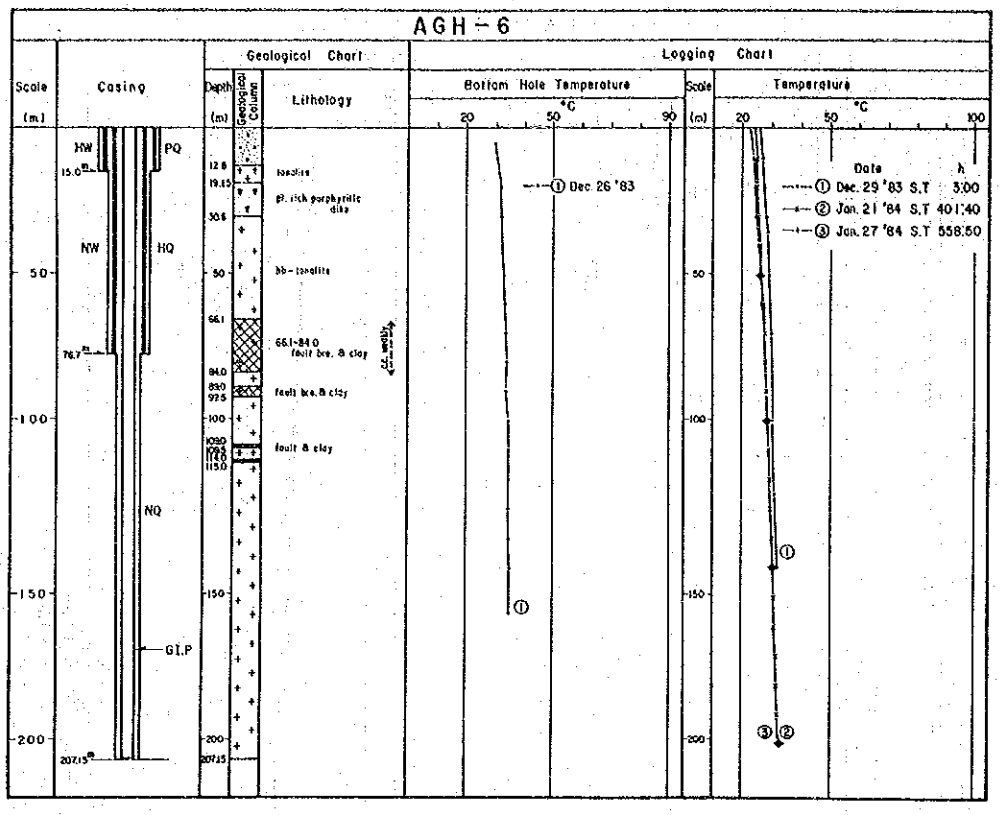


Fig. Ⅲ-4-14 Thermal Logging Chart of AGH-6

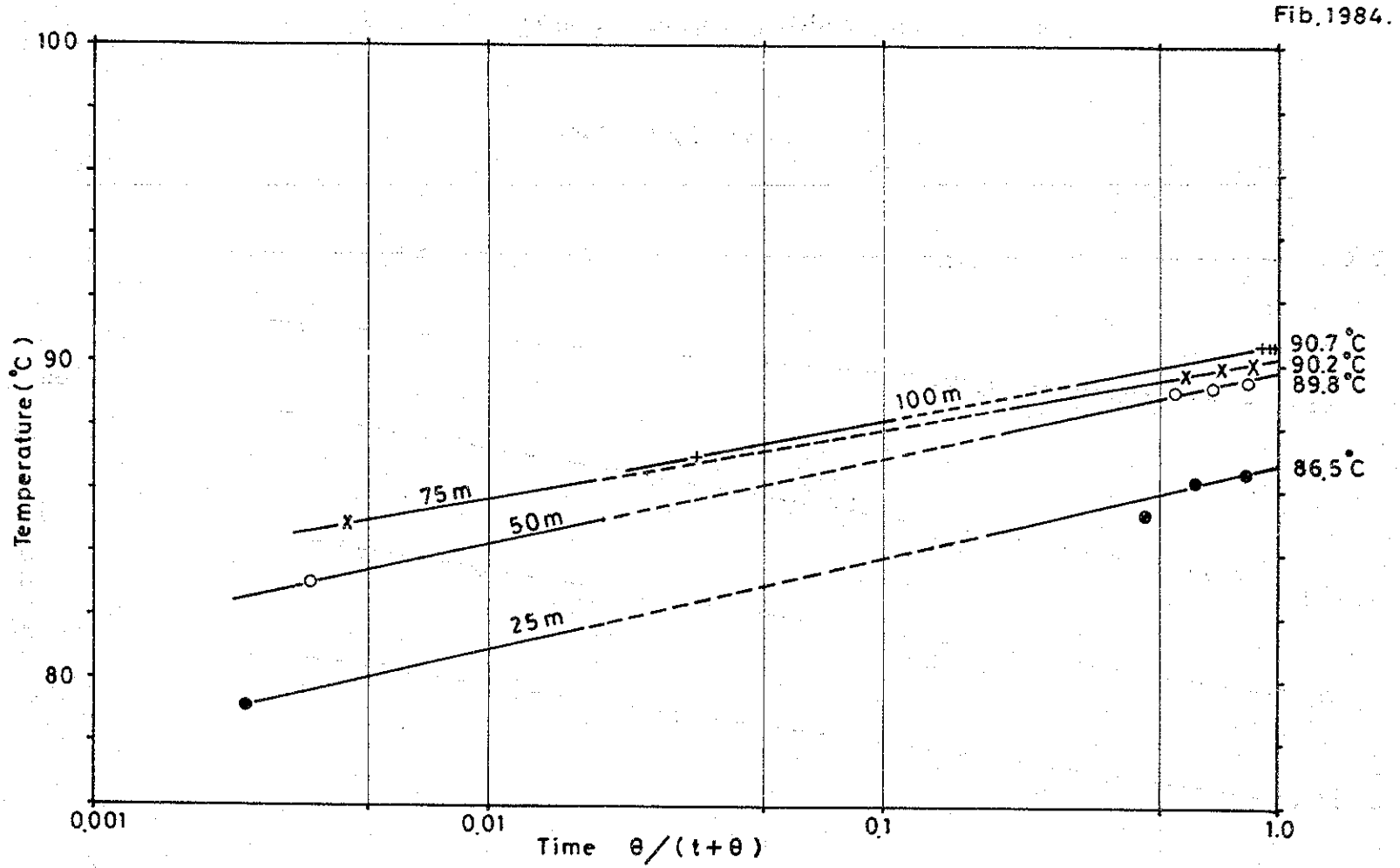


Fig. Ⅲ-4-15 True Formation Temperature of AGH-1

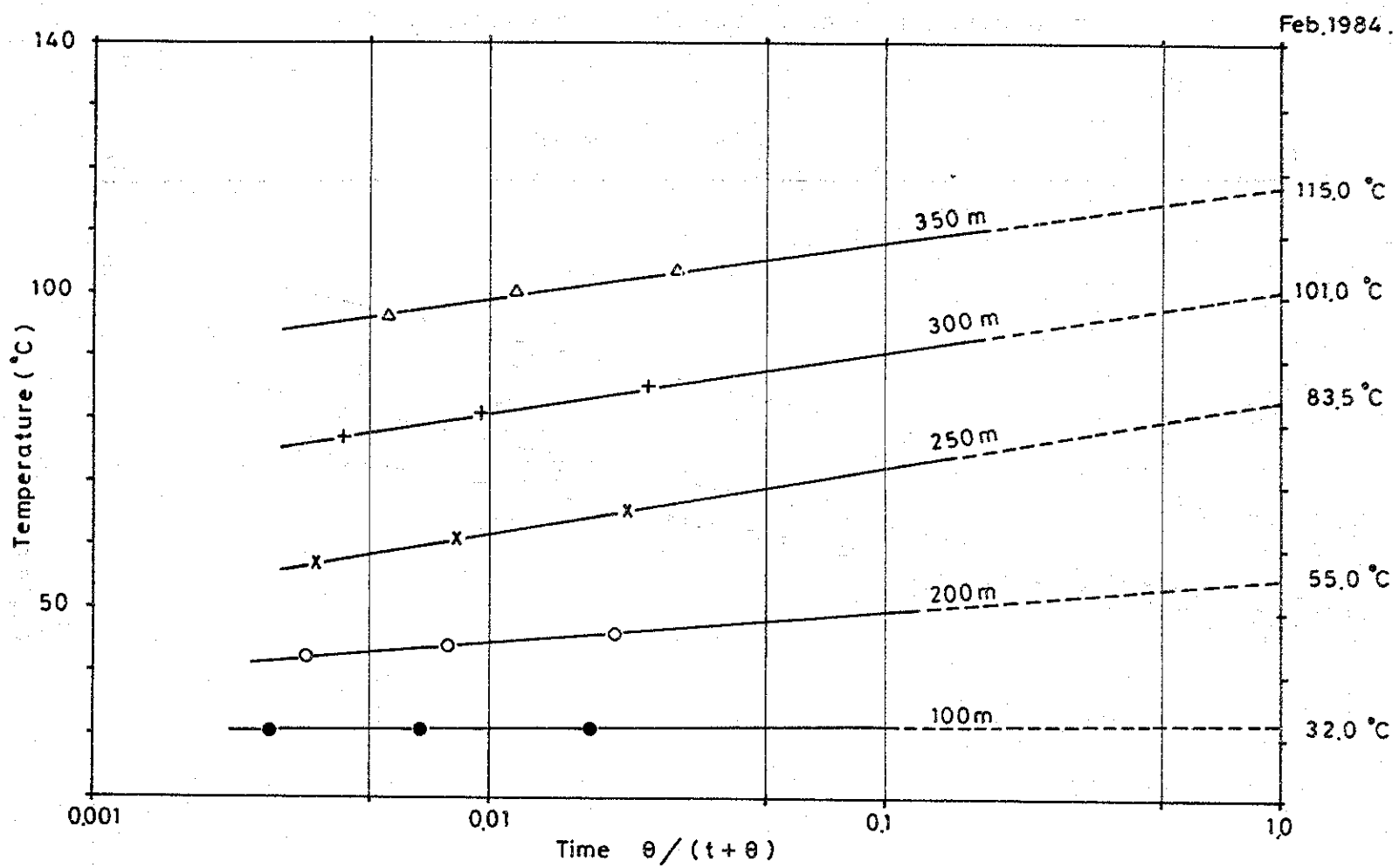


Fig. Ⅲ-4-16 True Formation Temperature of AGH-2

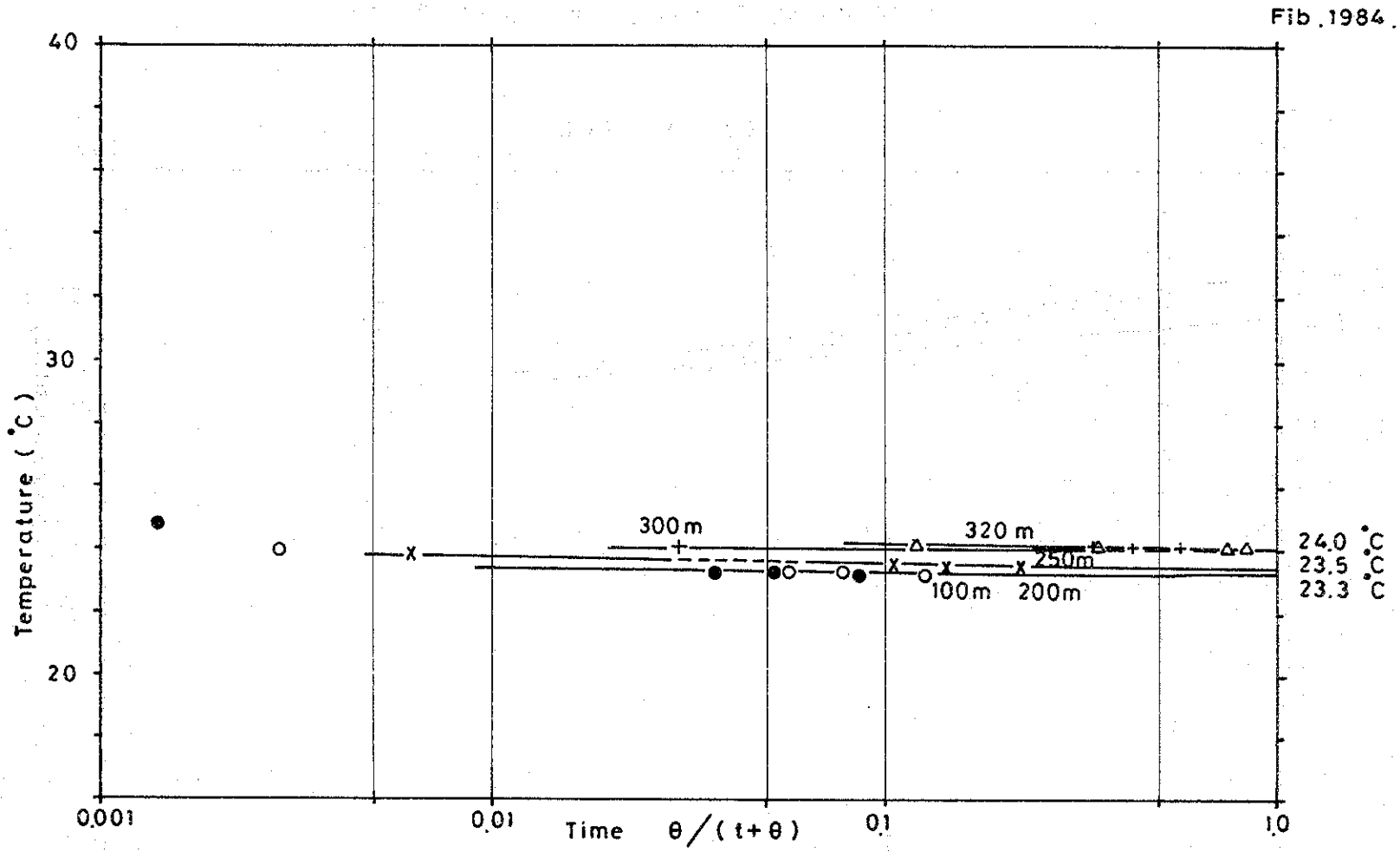


Fig. Ⅲ-4-17 True Formation Temperature of AGH-3

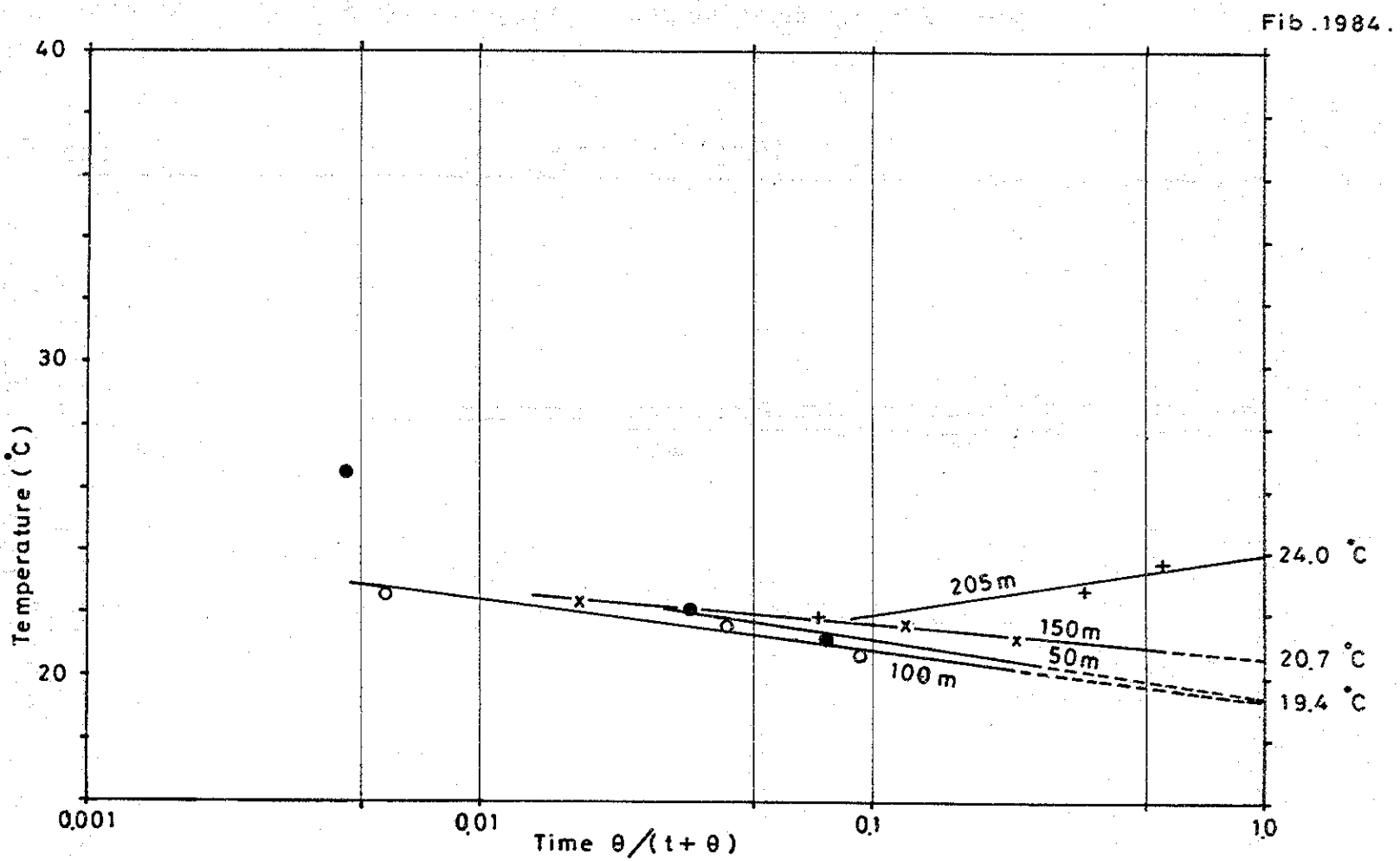


Fig. Ⅲ-4-18 True Formation Temperature of AGH-4

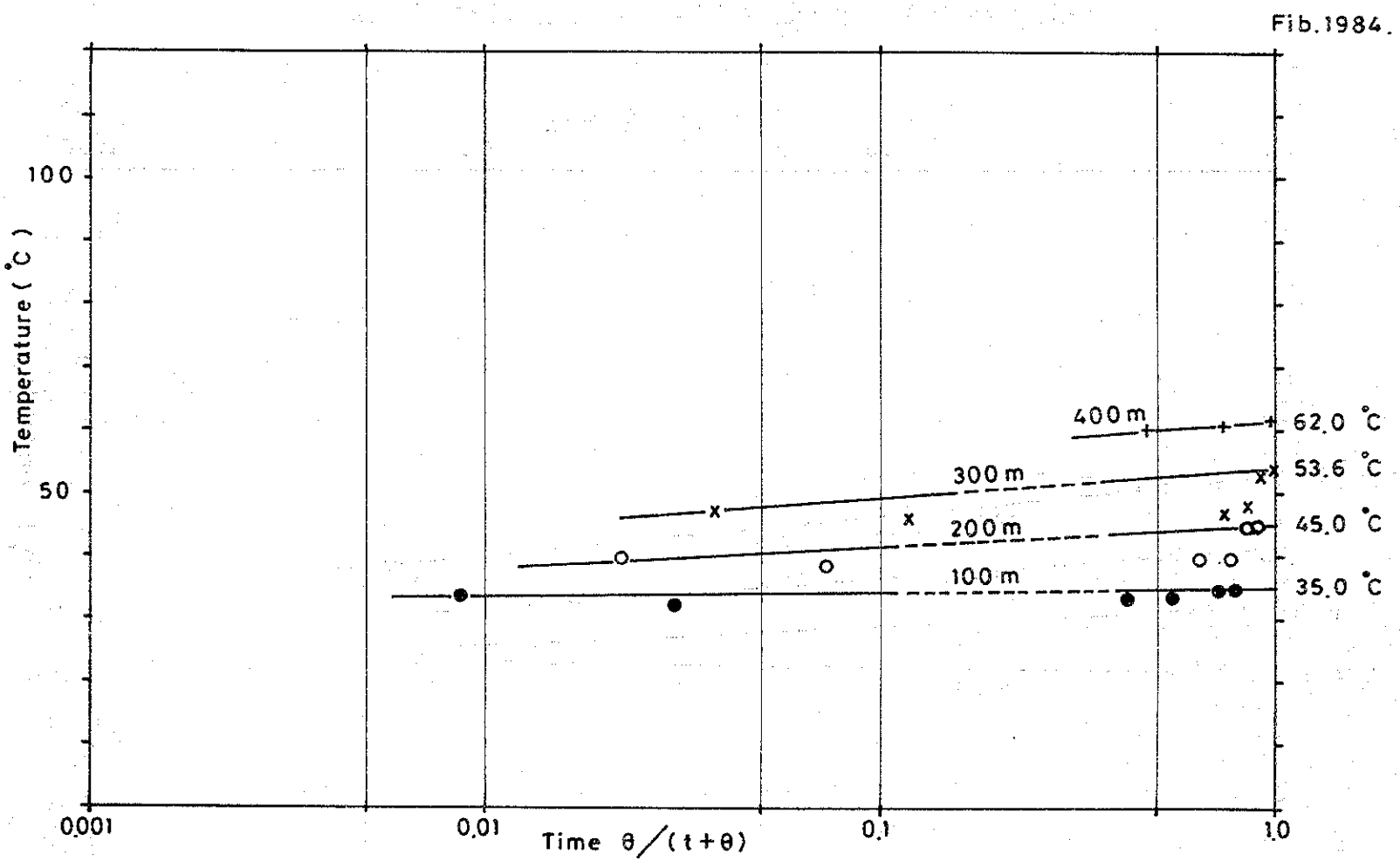


Fig. Ⅲ-4-19 True Formation Temperature of AGH-5

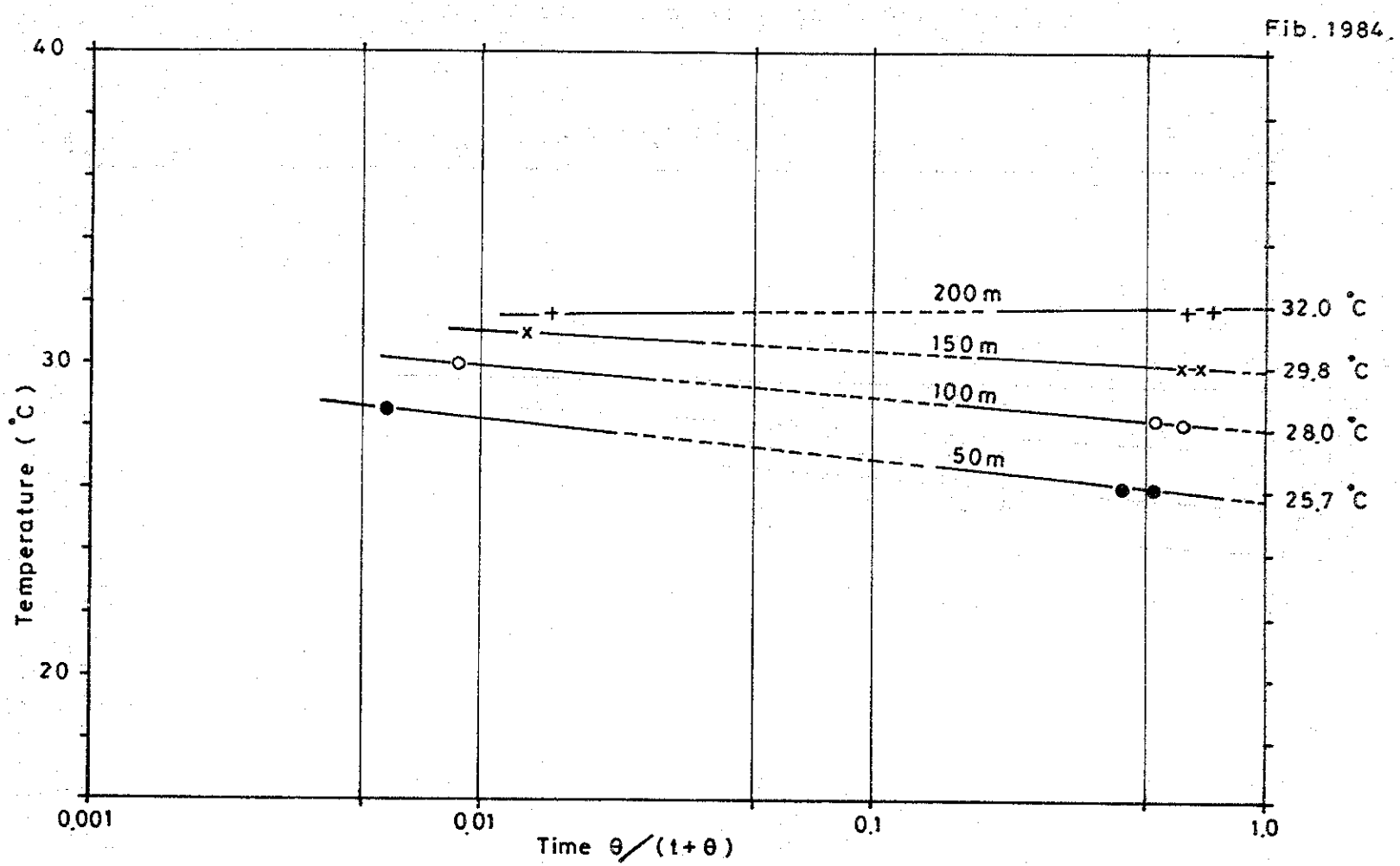


Fig. Ⅲ-4-20 True Formation Temperature of AGH-6

Table Ⅲ-4-1 Thermal Record of AGH-1

No.	1	2	3	4	5	6	7	8	9
Log date	'83 Nov. 24	'83 Nov. 25	'83 Nov. 26	'83 Nov. 30	'83 Dec. 1	'83 Dec. 2	'83 Dec. 14	'83 Dec. 24	'84 Jan. 28
Standing time (hrs)	0:20	0:30	0:30	0:30	0:25	0:50	287:40	528:10	1,368:25
Temperature (°C) / Depth (m)									
0	N.D.	N.D.	62.5	49.4	N.D.	66.0	59.6	70.7	31.8
5	52.0	58.7	67.7	58.2		66.0	71.9	73.2	
10	54.0	60.6	71.7	62.2	N.D.	72.0	75.1	77.1	76.9
15	54.8	62.3	75.4	66.1		75.8	79.0	80.1	80.4
20	58.9	63.8	78.5	69.3	N.D.	77.2	82.8	84.6	84.1
25	61.0	64.6	80.5	71.4		79.3	85.3	86.3	86.5
30	64.2	65.9	82.1	73.4	66.5	80.5	87.0	87.7	88.0
35	66.3	66.9	83.0	74.0		81.5	87.7	88.3	88.5
40	68.2	68.0	84.2	75.8	67.1	81.5	88.2	88.7	88.9
45	69.6	69.4	85.1	77.1		81.9	88.7	89.0	89.2
50	70.7	70.9	86.0	78.0	68.5	83.0	89.1	89.2	89.4
55	72.9	74.9	86.8	80.5		84.0	89.4	89.5	89.6
60	72.8	76.0	86.5	80.1	72.0	84.2	89.6	89.6	89.8
65	73.2	77.2	87.4	80.4		84.5	89.9	89.8	90.0
70		78.7	88.1	80.8	73.0	84.5	89.7	89.7	89.9
75		78.1	87.4	81.8	72.8	84.9	89.7	89.8	90.0
80		78.9	88.1	81.9	72.8	85.4	90.0	89.9	90.1
85		80.8	89.0	82.0	70.6	85.4	90.1	90.1	90.2
90			89.7	80.6	72.9	86.0	90.4	90.2	90.3
95					73.4	86.5	90.5	90.4	90.5
100					76.0	87.0	90.6	90.5	90.6
–						87.5	90.8	90.6	90.7
–						88.2			

Table Ⅲ-4-2 Thermal Record of AGH-2

No.	1	2	3	4	5	6	7	8	9	10
Log date	'83 Dec. 13	'83 Dec. 16	'83 Dec. 27	'84 Jan. 10	'84 Jan. 12	'84 Jan. 16	'84 Jan. 20	'84 Jan. 31	'84 Jan. 31	'84 Feb. 1
Standing time (hrs)	0:20	0:40	0:20	0:35	0:30	0:30	5:00	3:30	8:30	22:30
Temperature (°C) / Depth (m)										
0	25.0	21.0								
10	25.6	23.3	30.9				23.2	23.2	24.4	12.0
20	27.6	25.0	30.4	24.5	29.9	33.0	24.0	23.8	24.4	23.8
30	28.9	27.0	30.1				25.7	24.0	25.7	25.6
40	30.0	28.0	30.0	24.7	30.7	33.6	27.0	26.7	26.8	26.8
50	31.5	28.6					27.3	27.5	27.5	27.4
60	32.7	29.6	30.1	25.9	31.2	34.2	27.7	27.8	27.9	28.0
70	34.2	30.6					28.5	28.5	28.5	28.7
80	35.8	31.9	30.7	28.6	31.8	35.5	29.5	29.2	29.2	29.3
90	37.6	33.3					30.2	30.0	30.2	30.5
100	39.2	35.0	32.4	29.9	32.6	37.0	31.1	30.4	30.6	31.0
110	40.9	36.7					31.9	31.1	31.4	31.7
120	42.9	38.5	34.7	33.0	33.3	38.2	33.0	31.6	32.0	32.5
130	45.0	40.2					34.5	32.4	33.0	33.5
140	45.9	42.4	37.6	35.8	33.6	39.7	35.8	33.3	34.0	34.7
150		43.8					37.9	34.5	35.2	36.0
160		45.2	40.6	39.0	33.7	42.0	39.1	35.4	36.3	37.3
170		47.0					41.2	36.9	38.2	39.3
180		50.0	44.6	43.0	35.8	43.5	42.3	38.1	39.3	40.6
190		56.2					44.0	39.1	41.3	42.5
200			48.0	47.5	38.2	44.0	46.7	42.0	44.0	46.0
210			50.9				51.0	45.5	48.3	50.7
220			53.3	59.4	43.6	47.0	53.1	45.9	49.5	52.8
230							59.5	51.2	54.9	59.5
240				68.6	49.0	51.9	63.4	54.2	58.3	62.9
250							66.4	57.0	60.8	65.7
260				72.7	56.4	57.1	69.1	59.8	64.3	69.3
270							73.6	64.0	68.1	73.3
280					64.3	61.7	76.6	64.5	69.8	73.2
290							76.6	66.5	71.6	77.0
300					76.8	74.3	81.2	77.4	80.8	85.1
310					80.4	75.9		80.2	83.5	87.4
320								82.4	85.7	89.6
330								84.9	87.8	91.4
340								89.2	92.2	96.0
350								96.4	100.8	104.0

Table Ⅲ-4-3 Thermal Record of AGH-3

No.	1	2	3	4	5	6	7	8	9	10	11
Log date	'84 Jan. 13	'84 Jan. 16	'84 Jan. 23	'84 Jan. 25	'84 Jan. 27	'84 Jan. 30	'84 Feb. 1	'84 Feb. 7	'84 Feb. 8	'84 Feb. 8	'84 Feb. 9
Standing time (hrs)	0:15	0:15	0:15	0:30	0:15	0:30	0:30	0:25	16:30	23:30	40:30
Temperature (°C) / Depth (m)											
0								29.7	22.0	22.5	22.6
10	27.8	26.2						29.7	22.7	23.3	23.3
20	27.8	26.2	26.1	27.6	26.0	23.9	26.0	28.0	23.1	23.4	23.3
30	27.7	26.4						27.5	23.2	23.4	23.4
40	26.1	26.5	26.3	27.6	26.0	24.0	26.0	27.1	23.3	23.4	23.4
50		26.5						26.8	23.4	23.4	23.4
60		26.5 (55m)	26.6	27.6	26.0	24.3	25.8	26.3	23.4	23.4	23.4
70								25.9	23.4	23.3	23.3
80			27.0	27.6	26.0	24.6	25.7	25.4	23.3	23.3	23.3
90								25.0	23.3	23.3	23.3
100			27.2	27.6	25.9	25.1	25.4	24.8	23.3	23.3	23.3
110								24.1	23.4	23.3	23.4
120			27.1	26.8	25.7	25.2	25.4	23.9	23.3	23.3	23.3
130			27.1 (125m)					23.9	23.3	23.3	23.2
140				26.8	25.8	25.2	25.4	23.9	23.3	23.3	23.2
150								23.9	23.3	23.3	23.2
160					25.7	25.2	25.5	23.9	23.3	23.3	23.2
170				27.2				23.9	23.3	23.3	23.2
180					25.8	25.1	25.6	23.9	23.3	23.3	23.2
190								23.9	23.3	23.3	23.2
200					26.0 (196m)	25.2	25.8	23.9	23.3	23.3	23.3
210								23.8	23.3	23.3	23.3
220						25.3	26.9	23.8	23.3	23.3	23.3
230						25.5		23.8	23.4	23.4	23.4
240								23.8	23.5	23.4	23.4
250						(245m)	28.5 (245m)	23.8	23.5	23.5	23.5
260								23.8	23.6	23.6	23.5
270								23.9	23.7	23.7	23.7
280								24.0	23.9	23.9	23.8
290								24.1	24.1	24.0	24.0
300								24.1	24.1	24.1	24.0
310								24.2	24.2	24.2	24.0
320								24.2	24.1	24.0	24.0

Table Ⅲ-4-4 Thermal Record of AGH-4

No.	1	2	3	4	5	6	7	8	9
Log date	'84 Jan. 10	'84 Jan. 14	'84 Jan. 16	'84 Jan. 23	'84 Jan. 25	'84 Feb. 2	'84 Feb. 2	'84 Feb. 3	'84 Feb. 4
Standing time (hrs)	0:30	0:30	0:30	1:00	0:30	0:30	2:25	18:45	42:45
Temperature (°C) / Depth (m)									
0							22.0	20.0	20.1
10	25.4		25.5				25.8	23.6	21.1
20	25.6	25.2	25.5	26.5	22.4		26.5	23.0	20.8
30	25.7		25.7				26.6	22.7	20.9
40	26.4 (35m)	23.3	25.7	26.0	22.5		27.1	22.2	21.0
50							26.6	22.1	21.2
60		22.5		25.4	22.6		26.1	22.0	21.0
70		22.7	25.7				25.5	21.8	20.9
80				25.4	22.8		24.0	21.8	20.7
90			25.8				23.1	21.6	20.6
100				23.6	23.0		22.6	21.6	20.7
110				22.9			22.4	21.2	21.0
120							22.6	21.1	20.7
130					23.7		22.5	21.4	20.8
140							22.4	21.5	20.9
150							22.3	21.6	21.2
160							22.7	22.3	21.6
170							22.9	22.5	21.5
180							22.7	22.6	21.8
190							22.5	22.7	22.3
200							22.2	22.7	22.8
							21.9 (205m)	22.7	23.6

Table Ⅲ-4-5 Thermal Record of AGH-5

No.	1	2	4	5	6	7	8	9
Log date	'83 Nov. 25	'83 Dec. 3	'83 Dec. 7	'83 Dec. 10	'83 Dec. 23	'84 Jan. 5	'84 Jan. 28	'84 Feb. 6
Standing time (hrs)	24 : 00	0 : 30	3 : 45	14 : 00	329 : 00	634 : 00	1,190 : 00	1,401 : 30
Temperature (°C) / Depth (m)								
0	29.1			26.5				
10	29.6	28.8	27.0			27.9	28.4	28.6
20	29.8	29.6	27.5	27.0	28.0	28.0	28.2	28.5
30		30.5	27.7	27.5		28.6	29.0	29.0
40	32.3	31.5	30.2	29.0	29.8	29.9	29.9	30.0
50		32.4	32.0	30.1		31.4	31.2	31.3
60	35.0	33.4	32.2	30.5	31.5	31.7	31.8	31.9
70		34.5	32.6			32.0	32.2	32.4
80	38.1	35.5	32.8	31.0	32.1	32.3	32.8	33.2
90		36.5	33.0	31.5		32.7	33.6	34.0
100	42.0	37.9	34.0	32.0	33.1	33.5	34.4	34.8
110		38.9	34.4	32.5		33.9	35.5	35.9
120	44.7	39.9	34.8	33.0	34.3	34.4	36.6	36.8
130		40.9	35.4	33.5		34.9	37.3	37.7
140	47.1	41.8	35.9	34.0	35.4	35.6	38.4	38.8
150	47.1	42.8	36.4	35.0		36.3	39.4	39.9
160		43.6	37.0	36.0	36.6	36.7	40.7	40.6
170		44.6	37.8			37.5	41.3	41.8
180		45.9	38.2	37.0	37.5	37.8	41.9	42.7
190		46.8	38.8			38.5	42.9	43.6
200		47.1	39.8	38.0	39.3	39.5	44.0	44.9
210		49.0 (208m)	40.2	39.0		39.9	44.7	45.6
220			41.0	40.0	40.5	40.7	45.8	46.7
230			41.2	41.0		41.8	47.1	48.0
240			42.4	42.0	41.8	42.2	47.9	48.8
250			43.4			43.3	48.9	49.9
260			43.9	43.0	43.2	43.7	49.5	50.2
270			44.3			44.1	50.0	50.8
280			45.1	44.0	44.4	44.9	50.9	51.8
290			45.9	45.0		45.9	52.3	52.9
300			47.1	46.0	46.7	47.2	53.1	53.6
310			47.9	47.0		47.9	53.0	53.9
320			50.2		49.8	50.4	54.4	54.7
330			52.9			52.9	55.9	56.2
340			55.0		54.6	55.0	57.3	57.4
350			56.3			56.2	57.7	58.5
360			57.5		57.2	57.5	59.1	59.2
370			58.6			58.5	60.0	59.9
380			59.0		58.8	59.1	60.3	60.3
390			59.8			59.7	61.5	61.2
400					61.5	60.2	61.8	61.5

Table Ⅲ-4-6 Thermal Record of AGH-6

No.	1	2	3	4
Log date	'83 Dec. 26	'83 Dec. 29	'84 Jan. 21	'84 Jan. 27
Standing time (hrs)	0:20	3:00	401:40	558:50
Temperature (°C) / Depth (m)				
0		26.0	24.0	22.9
10	29.8	26.7	24.3	23.8
20	31.5	27.0	24.0	23.9
30	31.6	27.5	24.8	24.7
40	32.0	28.0	25.5	25.4
50	32.4	28.5	26.1	26.1
60	32.8		26.7	26.6
70	33.1	29.5	27.2	27.1
80	33.5		27.6	27.5
90	33.6		27.9	27.9
100	33.8	30.0	28.3	28.2
110	33.9		28.6	28.5
120	34.1		28.9	28.9
130	34.5	30.5	29.3	29.2
140	34.8		29.6	29.5
150	34.9	31.0	30.0	29.9
160			30.3	30.2
170	34.5 (165m)		30.6	30.6
180			30.9	30.9
190			31.3	31.3
200		31.7	31.6	31.6
			31.8 (207m)	31.8 (207m)

The factor F is inversely proportional to the square of porosity of the rock, as expressed in Archie's formula,

$$F = 1/\phi 2$$

The rock is more compact and resistive for bigger values of F as can be seen from the formula. The resistivity of pore water (ρw) depends on temperature as well as the chemical

- Electrode:

  Resistivity and heat-proof type Teflon-made, KES-5, ϕ32 mm.

- Cable:

  Armored type, 4-core heat-proof cable, ϕ8 mm,; Nippon Taiyo Kaitei Densen Co., Ltd.

- Winch:

  Electric cable winch, KIC 3787, 3 HP, 500 meters winding; Kaihatsu Kogyo co., Ltd.

4.4.2 Results of Measurement

The measurement of resistivity was conducted on two gradient holes, AGH-4 and AGH-5.

(a) AGH-4: Fig III-4-12 shows the logging chart. The section of approximately 100 meters intervals in granodiorite was measured. Resistivity in younger rocks indicated high values of 1,000 to 1,300 Ω-m and F≒15; while in the fractured, weathered and argillized zones, low values of 70–100 Ω-m.

(b) AGH-5: Resistivity logging was conducted at 160-400 meters. The rocks were hornblende andesites which show a resistivity of composition of the pore water.

In the resistivity logging conducted, two pole intervals were used simultaneously. One is short (a=25 cms) and the other normal (a=100 cms). After making necessary corrections on the pore water's resistivity and hole diameter on the Schlumberger departure curve, the value of F was estimated and subsequently, the true apparent resistivity. The resistivity values for the logging were determined from the formula.

$$P = 4\ na\ V/I$$

When the pole interval, a, and the current applied, I, (in mA), are kept constant, the potential difference, V (in mV), between the pole intervals can be used to determine the resistivity along the borehole.

Equipment used for the measurement are listed below:

Electric logging apparatus:

Type; CH-08, Chiba Denshi Kenkyujo; Output; 100 V, 2-50mA.

Frequency; 28±0.5 Hz, square wave.

Recorder:

Type; EPR-2, 2-pen recorder, Toa Dempa Co., Ltd.

660-840 and F≒10-15. The argillized and fractured zones and interbeds of siltstone partially show low resistivity values.

The section of 225-300 meters is composed of diorite, and gives a resistivity value of 1,000-1,400 Ω-m and F≒20-25, suggesting good compaction. Numerous low resistivity zones, presumably due to fracturing, are distributed at the levels of 235-240 meters, 250-260 meters and 275-300 meters.

Likewise, the section, 300-360 meters, is marked by fresh diorite and shows high resistivity value of 1,900 Ω-m and F≒3.8. Low resistivity zones also occur and may be due to fracturing and argillization.

The geology of 350-400 meters is mainly composed of diorite, with

interbeds of andesite. At greater than 360 meters, resistivity values rapidly decrease porbably due to presence of water as evidenced by the circulation losses registered from drilling records at these depths.

4.4.3 Analysis of Results

The measurements of resistivity were performed on AGH-5 and partially on AGH-4. Diorite, when fresh, shows high resistivity values of 1,100-1,900 Ω-m and when argillized and fractured low resistivity values are measured. Low resistivity in sections deeper than 360 meters in AGH-5 is considered to have largely been influenced by the presence of pore water.

4.5 Core Test

The following analyses were conducted on the core samples (61 samples) collected at different levels (25 meter - intervals) from boreholes AGH-1 to AGH-6 (Table III-4-7):

Types of Analyses:

(a) microscopic observation;
(b) powder x-ray diffraction;
(c) chemical;
(d) measurement of sonic velocity;
(e) measurement of thermal conductivity;
(f) measurement of density;
(g) measurement of permeability (coefficient);
(h) measurement of resistivity; and
(i) measurement of specific heat.

4.5.1 Microscopic Observation

Thin sections fifty-nine(59) core samples were petrographically analyzed and the results are shown in Table III-4-8.

(a) AGH-1 : From 21.20 to 102.80 meters, lithology is mainly composed of the old plug.

Old Plug

Rock name: Hornblende-andesitic tuff lapilli tuff to fine grained tuff.

Texture: Pyroclastic

Samples: Obtained from 21.20 meters, 45.20 meters, 75.80 meters and 102.20 meters.

Description: Fragments are mainly composed of hornblende andesite to andesite porphyry quartz diorite, and tonalite. Many angular to rounded fragments of 20 mm to several millimeters in size are observed. Grains are composed of plagioclase with some quartz, hornblende and biotite. Crystal fragments of plagioclase mainly comprise the matrix.

The main hydrothermal alteration minerals are quartz, calcite, sericite, chlorite and albite with minor amounts of montmorillonite and potash feldspar. Calcite, sericite and chlorite are dominant in general.

(b) AGH-2: The major rock type is the Virac granodiorite. Andesite porphyry is intrusive to the granodiorite.

Virac granodiorite

Rock name: Hornblende biotite granodiorite.

Table Ⅲ-4-7 List of the Samples for Laboratory Test

No. 1

Ser. No.	Hole No.	Depth (m)	Rock Name	Analysis or Test								
				M	X	C	V	T	D	P	R	H
1	AGH-1	21.20	andesitic tuff breccia	O	O	O	O	O	O	O	O	O
2	AGH-1	45.20	brecciated rock	O	O	O	O	O	O	O	O	O
3	AGH-1	75.80	ho andesite porphyry	O	O	O	O	O				
4	AGH-1	102.20	ho andesite porphyry	O	O	O	O	O	O	O	O	O
5	AGH-2	26.70	granodiorite	O	O	O						
6	AGH-2	51.50	granodiorite	O	O	O	O	O				
7	AGH-2	77.00	granodiorite	O	O	O	O	O				
8	AGH-2	83.30	granodiorite	O	O	O	O	O				
9	AGH-2	98.00	granodiorite	O	O	O	O	O				
10	AGH-2	118.50	granodiorite	O	O	O	O	O	O	O	O	O
11	AGH-2	139.50	granodiorite	O	O	O	O	O				
12	AGH-2	164.50	ho-pl andesite porphyry	O	O	O	O	O	O	O	O	O
13	AGH-2	192.50	granodiorite	O	O	O	O	O	O	O	O	O
14	AGH-2	213.50	granodiorite	O	O	O	O	O				
15	AGH-2	242.30	granodiorite	O	O	O	O	O				
16	AGH-2	269.50	granodiorite	O	O	O	O	O				
17	AGH-2	295.00	ho andesite porphyry	O	O	O	O	O				
18	AGH-2	322.70	granodiorite	O	O	O	O	O				
19	AGH-2	355.00	ho andesite porphyry	O	O	O						
20	AGH-2	55.00	andesitic tuff breccia	O	O		O	O	O	O	O	O
21	AGH-3	80.00	mega ho andesite porphyry to ho andesite porphyry	O	O		O	O				
22	AGH-3	114.50	ho andesite porphyry	O	O		O	O				
23	AGH-3	144.50	ho andesite	O	O		O	O				
24	AGH-3	172.30	aphanitic andesite	O	O		O	O	O	O	O	O
25	AGH-3	204.00	granodiorite	O	O		O	O				
26	AGH-3	237.30	granodiorite	O	O		O	O				
27	AGH-3	271.00	ho. andesite porphyry	O	O		O	O				
28	AGH-3	300.00	granodiorite	O	O		O	O				
29	AGH-3	57.00	granodiorite	O	O		O	O				
30	AGH-4	89.00	mega ho andesite porphyry	O	O		O	O	O	O	O	O

M : Thin section, X : X-ray diffraction, C : Chemical analysis, V : Sonic velocity
T : Thermal conductivity, D : Density, P : Permeability, R : Specific electric resistance,
H : Specific heat,

Ser. No.	Hole No.	Depth (m)	Rock Name	Analysis or Test								
				M	X	C	V	T	D	P	R	H
31	AGH–4	116.00	granodiorite	O	O		O	O				
32	AGH–4	143.70	granodiorite	O	O		O	O				
33	AGH–4	180.50	granodiorite	O	O		O	O				
34	AGH–4	211.00	granodiorite	O	O		O	O				
35	AGH–4	235.50	granodiorite	O	O		O	O				
36	AGH–4	261.00	granodiorite	O	O		O	O				
37	AGH–4	283.00	granodiorite	O	O		O	O				
38	AGH–5	27.55	ho-pl andesite porphyry	O	O	O	O	O				
39	AGH–5	54.00	ho andesite porphyry	O	O	O	O	O				
40	AGH–5	80.00	ho andesite porphyry	O	O	O	O	O				
41	AGH–5	111.00	ho andesite porphyry	O	O	O	O	O				
42	AGH–5	129.00	ho andesite porphyry	O	O	O	O	O	O	O	O	O
43	AGH–5	149.00	ho andesite porphyry	O	O	O	O	O				
44	AGH–5	175.00	ho andesite porphyry	O	O	O	O	O	O	O	O	O
45	AGH–5	201.80	brecciated diorite	O	O	O	O	O				
46	AGH–5	226.20	andesite porphyry	O	O	O	O	O				
47	AGH–5	253.10	brecciated diorite	O	O	O	O	O	O	O	O	O
48	AGH–5	274.50	brecciated diorite	O	O	O	O	O				
49	AGH–5	302.15	brecciated diorite	O	O	O	O	O				
50	AGH–5	326.00	brecciated diorite	O	O	O	O	O	O	O	O	O
51	AGH–5	349.00	brecciated diorite	O	O	O	O	O				
52	AGH–5	372.50	brecciated diorite	O	O	O	O	O				
53	AGH–5	399.50	brecciated diorite	O	O	O	O	O				
54	AGH–6	23.30	pl rich porphyritic rock	O	O		O	O				
55	AGH–6	50.50	tonalite	O	O		O	O				
56	AGH–6	87.00	tonalite	O	O		O	O	O	O	O	O
57	AGH–6	125.35	tonalite	O	O		O	O				
58	AGH–6	165.50	tonalite	O	O		O	O	O	O	O	O
59	AGH–6	204.10	tonalite	O	O		O	O				

Texture: Hypidiomorphic-granular; holocrystalline.

Samples: Obtained from 26.70 meters, 51.50 meters, 77.00 meters, 83.30 meters, 98.00 meters, 118.50 meters, 192.50 meters, 213.50 meters, 242.30 meters, 269.50 meters and 322.70 meters.

Description: A large quantity of euhedral plagioclase and hornblende quartz, potash feldspar, biotite, euhedral, and a small quantity of orthite are recognized.

Alteration minerals such as quartz, clacite, sericite and montmorillonite are observed. Secondary potash feldspar is observed occasionally. Sericite and chlorite are abundant in the samples from 26.70 meters, 83.30 meters and 295.50 meters, while abundant chlorite is seen in the sample from 164.40 meters.

Andesite porphyry dike

Rock name: Hornblende-andesite porphyry

Texture: Porphyritic

Samples: Obtained from 164.50 meters, 295.00 meters and 355.00 meters.

Description: Abundant euhedral plagioclases and a moderate amount of euhedral hornblende occur as phenocrysts. Groundmass is composed of abundant euhedral plagioclase microlites and a medium amount of euhedral hornblende.

Alteration minerals include secondary quartz, calcite, sericite, montmorillonite, chlorite and epidote. The plagioclase is partly altered to albite.

(c) AGH-3: The geology is composed of the Miocene sedimentary rocks, Virac granodiorite and andesite porphyry dike.

Miocene sedimentary rocks: These comprise of andesitic tuff breccia at the depth of 55.00 meters and andesite lava at the depth of 172.30 meters.

(i) Rock name: Andesitic tuff breccia.

Texture: Pyroclastic

Description: Rounded fragments (3.2-4 mm in size) of andesite, silicified and granitic rocks and tuff. Grains are mainly composed of quartz while matrix is mainly composed of a large quantity of quartz.

Alteration minerals include sericite, chlorite and epidote.

(ii) Rock name: Aphanitic andesite

Texture: Subophitic - intersertal

Sample: Obtained from the depth of 172.00 meters.

Description: A small amount of phenocrystal plagioclase is noted. Groundmass is mainly composed of plagioclase.

The main alteration minerals include secondary quartz, calcite, sericite, chlorite and epidote.

Virac granodiorite

Rock name: Hornblende-biotite granodiorite.

Texture: Hypidiomorphic-granular

Samples: Obtained from 172.3 meters, 204.0 meters, 237.0 meters and 300.0 meters.

Description: Primary minerals include abundant euhedral plagioclases, moderate amount of anhedral quartz, subhedral biotite and euhedral hornblende and minor amount of potash feldspar and albite. Alteration minerals include secondary quartz, calcite, sericite, montmorillonite, chlorite and epidote.

Andesite porphyry dike

Rock name: Hornblende andesite porphyry

Texture: Porphyritic

Samples: Obtained from 80.00 meters, 114.50 meters, 144.50 meters and 271.00 meters.

Description: The phenocrystal part consists of abundant euhedral plagioclases and moderate amounts of euhedral hornblende. They occur in a matrix primarily made up of abundant euhedral plagioclases with minor hornblende. The main alteration minerals are secondary quartz, calcite, sericite, montmorillonite, chlorite and epidote.

(d) AGH-4: The major rock type is the Virac granodiorite, that is intruded by andesite porphyry dikes.

Virac granodiorite

Rock name: Biotite hornblende granodiorite.

Texture: Hypidiomorphic-granular

Samples: Obtained from 57.00 meters, 116.00 meters, 143.00 meters, 180.50 meters, 211.00 meters, 235.50 meters and 283.40 meters.

Description: Abundant euhedral plagioclase, moderate amount of anhedral quartz, subhedral biotite, euhedral hornblende, and minor potash feldspar

were observed.

Alteration minerals mainly include calcite, sericite, montmorillonite, chlorite and epidote with minor secondary quartz.

Andesite porphyry dike

Rock name: Hornblende andesite porphyry.

Texture: Porphyritic

Samples: 89.00 meters

Description: The phenocrysts include abundant euhedral plagioclases and moderate quantity of euhedral hornblende and are embedded in a groundmass made up of abundant plagioclases and hornblende.

The major alteration minerals are calcite, sericite, chlorite and epidote.

(e) AGH-5: The major rock types encountered consit of the andesite complex and Itogon quartz diorite, with minor andesite porphyry dikes.

Andesite complex

Rock name: Hornblende andesite porphyry mega-hornblende bearing andesite prophyry.

Texture: Porphyritic

Samples: Obtained from 27.55 to 111.00 meters and 149.00 to 175.00 meters.

Description: Phenocrysts comprise mostly of euhedral plagioclase and hornblende. Groundmass is mainly composed of euhedral plagioclase with some horn-

blende. In the samples from 149.00 to 175.00 meters, minor to moderate amounts of biotite are observed in the groundmass.

Alteration minerals consists of calcite, sericite, and chlorite with minor secondary quartz.

Itogon quartz diorite

Rock name: Biotite hornblende quartz diorite-biotite quartz diorite.

Texture: Granular

Samples: Obtained from 129.50 meters, 201.80 meters, 253.10 meters, 274.50 meters, 302.15 meters, 326.15 meters, 349.60 meters, 372.50 meters and 399.50 meters.

Description: Abundant euhedral plagioclase and moderate amount of biotite are noted. Some samples are composed of abundant euhedral hornblende and moderate amount of quartz. Original mineral composition of the rocks in samples from 253.10 meters and 274.50 meters is unrecognizable because of strong alteration.

The main alteration minerals are secondary quartz, calcite, sericite and chlorite; with minor epidote and secondary potash feldspar.

Andesite porphyry dike

Rock name: Hornblende-augite andesite porphyry.

Texture: Porphyritic

Sample: Obtained from 226.20 meters

Description: Phenocrysts are made up of abundant euhedral plagioclase, moderate amount of euhedral pyroxene and minor hornblende. The groundmass

mainly consists of euhedral plagioclases.

Alteration minerals include secondary quartz, calcite, sericite, chlorite and secondary feldspar.

(f) AGH-6: The borehole geology is characterized by the Itogon quartz diorite with andesite porphyry dikes.

Itogon diorite

Rock name: Hornblende biotite quartz diorite.

Texture: Hypidiomorphic-granular

Samples: Obtained from 50.50 meters 87.00 meters, 125.35 meters, 165.50 meters and 204.10 meters.

Description: The rock comprises of abundant euhedral plagioclase, moderate amount of anhedral quartz and subhedral to euhedral biotite, and minor to moderate amounts of hornblende.

The alteration minerals are calcite, sericite and chlorite.

Andesite porphyry dike

Rock name: Hornblende andesite porphyry.

Texture: Porphyritic

Sample: Obtained from 23.30 meters.

Description: Phenocrysts mainly comprise of euhedral quartz and plagioclase. Groundmass is composed mainly of euhedral plagioclase.

Table Ⅲ-4-8 Results of Microscopic Observation of Thin Section

Ser. No.	Hole No.	Depth (m)	Formation or Body	Rock Name	Texture	Phenocrysts or Grains								Groundmass or Matrix								Lithic Fragments				Alteration Minerals										Note
						Q	K-f	Pl	Bi	Ho	Au	Al	Op	Q	Si	K-f	Pl	Bi	Ho	Cpx	Op	Gr	An	Sr	Tf	Q	Si	Cc	Ser	Mo	Chl	Ep	Ab	K-f	Op	
1	AGH-1	21.20	Old plug	ho andesitic lapilli tuff	pyroclastic	○		◎	•	○			•				◎	•	○		•	○	◎			◎	•	◎	◎	•	◎		○	•	•	fragment of quartz diorite to tonalite
2	AGH-1	45.20	Old plug	andesitic fine tuff	pyroclastic			◎					•				◎				•					◎	•	◎	◎	•	◎		○	•	•	
3	AGH-1	75.80	Old plug	andesitic lapilli tuff	pyroclastic			◎					•				◎				•	○	○			◎	•	○	◎	•	◎			•	•	
4	AGH-1	102.20	Old plug	ho andesitic lapilli tuff	pyroclastic	•		◎		○			•				◎		•		•		○			○		◎	◎	•	◎					
5	AGH-2	26.70	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	◎	○		•	•													◎	•	•	◎	•	◎			•		very strongly altered
6	AGH-2	51.50	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	○	◎	○	○		•	•													○		•	○		•					
7	AGH-2	77.00	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	○	◎	○	○		•	•															•	○	•	○					
8	AGH-2	83.30	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	○	◎	○	○		•	•													◎	•	•	◎	•	◎			•		very strongly altered
9	AGH-2	98.00	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	○	◎	○	○		•	•															•	○		•					
10	AGH-2	118.50	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	○	◎	○	○			•													•		•	○		○					
11	AGH-2	139.50	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	○	◎	○	○			•															•	•		•					
12	AGH-2	164.50	dyke	ho andesite porphyry	porphyritic			◎		○			•				◎		○		•					◎		◎	○	•	◎	◎	○			strongly altered
13	AGH-2	192.50	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•	•													•		•	•		○					
14	AGH-2	213.50	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○			•													•		•	○	•	◎					
15	AGH-2	242.30	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	○	◎	○	○			•													•		•	◎		◎					
16	AGH-2	269.50	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•	•															•	•		○					
17	AGH-2	295.00	dyke	ho -pl andesite porphyry	porphyritic			◎		○			•				◎				•					◎	•	○	◎	○	◎	○				very strongly altered
18	AGH-2	322.70	Virac granodiorite	ho -bi granodiorite	hypidomorphic granular	○	•	◎	○	○		•	•															•	•		○					
19	AGH-2	355.00	dyke	ho andesite porphyry	porphyritic			◎		○			•				◎				•					○		•	◎	•	◎	○				
20	AGH-3	55.00	Miocene sedimentary rocks	andesitic tuff breccia	pyroclastic	◎							•	◎								•	○	○	•				•		•	◎				
21	AGH-3	80.00	dyke	ho andesite porphyry	porphyritic			◎		◎			•				◎		○		•							•	•		•					
22	AGH-3	114.50	dyke	ho andesite porphyry	porphyritic			◎									◎									◎		•	◎		◎	◎			•	very strongly altered
23	AGH-3	144.50	dyke	ho andesite porphyry	porphyritic			◎		○							◎									◎		◎	◎		◎	◎		•		very strongly altered
24	AGH-3	172.30	Miocene sedimentary rocks	aphanitic andesite	subophitic ~ intersertal			•									◎									•					◎	◎				
25	AGH-3	204.00	Virac granodiorite	ho -bi granodiorite	hypidomorphic granular	○	•	◎	○	○																○		◎	○		○	•				
26	AGH-3	237.00	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•														•		○	○		○					
27	AGH-3	271.00	dyke	ho andesite porphyry	porphyritic			◎		○							◎									○		◎	◎		◎	◎				strongly altered
28	AGH-3	300.00	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○																		•			•					
29	AGH-4	57.00	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○																			•		•					
30	AGH-4	89.00	dyke	ho andesite porphyry	porphyritic			◎		○							◎		○									•	•		○	○				
31	AGH-4	116.00	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•	•															•	○	•	○	○				
32	AGH-4	143.00	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•	•																•		○	•				
33	AGH-4	180.50	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•	•															○	○	•	○	○				
34	AGH-4	211.00	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•	•															○	○	•	○	○				
35	AGH-4	235.50	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•	•													◎		○	◎	•	◎			•	•	very strongly altered
36	AGH-4	261.50	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•	•													○		•	○		○	•				
37	AGH-4	283.40	Virac granodiorite	ho -bi granodiorite	hypidiomorphic granular	○	•	◎	○	○		•	•													•			•		•	•				
38	AGH-5	27.55	Andesite complex	ho andesite porphyry	porphyritic			◎		◎			•				◎											○	•		○					
39	AGH-5	54.00	Andesite complex	ho andesite porphyry	porphyritic			◎		◎			•				◎		•									◎	◎		◎					
40	AGH-5	80.00	Andesite complex	mega ho andesite porphyry	porphyritic			◎		◎			•				◎		◎									○			○					
41	AGH-5	111.00	Andesite complex	ho andesite porphyry	porphyritic			◎		◎			•				◎		◎									•	○		○					
42	AGH-5	129.50	Itogon quartz diorite	bi -ho diorite	hypidiomorphic granular	○		◎	○	◎			•													○		◎	◎		◎					strongly altered
43	AGH-5	149.00	Andesite complex	ho andesite porphyry	porphyritic			◎		◎			•				◎	•	○							◎		◎	◎		◎					strongly altered
44	AGH-5	175.00	Andesite complex	meta au. ho andesite porphyry	porphyritic	○		◎	◎	◎	•		•		○		◎	○								○	•		•		•					
45	AGH-5	201.80	Itogon quartz diorite	bi diorite	hypidiomorphic granular	•		◎																				○	◎		◎					
46	AGH-5	226.20	dyke	ho -au. andesite porphyry	porphyritic			◎		•	○				•		◎									○	○		◎		◎					
47	AGH-5	253.10	Itogon quartz diorite	silicified rock	–																					◎	○	◎	◎		◎			○		very strongly altered
48	AGH-5	274.50	Itogon quartz diorite	silicified rock	hypidiomorphic granular																					◎		◎	◎		◎	○		•		very strongly altered
49	AGH-5	302.15	Itogon quartz diorite	diorite	hypidiomorphic granular	○		◎																		○		◎	○		◎	○				
50	AGH-5	326.00	Itogon quartz diorite	bi diorite	hypidiomorphic granular			◎	○																	○		◎	◎		◎					
51	AGH-5	349.60	Itogon quartz diorite	bi diorite	hypidiomorphic granular			◎	○																	◎		◎	◎		◎			•		strongly altered
52	AGH-5	372.50	Itogon quartz diorite	diorite	hypidiomorphic granular	○		◎																		○		◎	◎		◎	◎		•		very strongly altered
53	AGH-5	399.50	Itogon quartz diorite	diorite	hypidiomorphic granular	○		◎	○																	◎		◎	◎		◎			•		strongly altered
54	AGH-6	23.30	dyke	ho andesite porphyry	porphyritic	◎		◎									◎									○		○	◎		◎	•	○			
55	AGH-6	50.50	Itogon tonalite	ho -bi tonalite	hypidiomorphic granular	•		◎	○	○																					◎					
56	AGH-6	87.00	Itogon tonalite	ho -bi tonalite	hypidiomorphic granular	○		◎	○	•																		○	○		○					
57	AGH-6	125.35	Itogon tonalite	ho -bi tonalite	hypidiomorphic granular	○		◎	○	•																			•		○					
58	AGH-6	165.50	Itogon tonalite	ho -bi tonalite	hypidiomorphic granular	○		◎	○	•																		•	•		○					
59	AGH-6	204.10	Itogon tonalite	ho -bi tonalite	hypidiomorphic granular	○		◎	○	•																					○					

◎ : abundant ○ : common • : rare.

Table Ⅲ-4-9 Results of X-ray Diffraction

Ser. No.	Hole No.	Depth (m)	Rock Name	Formation or Body	Silicate Minerals: Clay minerals: montmorillonite	kaolinite	sericite	chlorite	sericite/ montmorillonite	chlorite/ montmorillonite	Silica mine: α-quartz	plagioclase	k-feldspar	others: amphibole	epidote	sulfate: anhydrite	sulfide: pyrite	carbonate: calcite	Note
1	AGH-1	21.20	ho andesitic lapilli tuff	Old plug	△	△	△	△	△		◎	◎					△	○	
2	AGH-1	45.20	andesitic fine tuff	Old plug	△	△	△	△	△		◎	◎				△	△	△	
3	AGH-1	75.80	andesitic lapilli tuff	Old plug	△		△	△			◎	◎				△	△	△	
4	AGH-1	102.20	ho andesitic lapilli tuff	Old plug			△	△			◎	◎	△	△			△		
5	AGH-2	26.70	ho-bi granodiorite	Virac granodiorite	△		○	○	△		◎						△		strongly altered
6	AGH-2	51.50	ho-bi granodiorite	Virac granodiorite	△		△	△	△		◎	◎	◎	○					
7	AGH-2	77.0	ho-bi granodiorite	Virac granodiorite	△		△		△		◎	◎					△	△	
8	AGH-2	83.30	ho-bi granodiorite	Virac granodiorite	△		○	○			◎						△		strongly altered
9	AGH-2	98.00	ho-bi granodiorite	Virac granodiorite	△			○	△		◎	◎	◎	△				△	
10	AGH-2	118.50	ho-bi granodiorite	Virac granodiorite	△		△	○			◎	◎	△	△				△	
11	AGH-2	139.50	ho-bi granodiorite	Virac granodiorite	△		△	△			○	◎	△	△					
12	AGH-2	164.50	ho andesite porphyry	dyke	△		△	○			◎	◎	△					△	
13	AGH-2	192.50	ho-bi granodiorite	Virac granodiorite	△		△	△			○	◎	△	○				△	
14	AGH-2	213.50	ho-bi granodiorite	Virac granodiorite	△		△	△	△		○	◎	△	△					
15	AGH-2	242.30	ho-bi granodiorite	Virac granodiorite	△		△	△	△		◎	◎	△	△				△	
16	AGH-2	269.50	ho-bi granodiorite	Virac granodiorite	△		△	△	△		○	◎	△	○				△	
17	AGH-2	295.00	ho-pl andesite porphyry	dyke	△		△	○			◎							○	strongly altered
18	AGH-2	322.70	ho-bi granodiorite	Virac granodiorite	△		△	△			◎	◎	△	○				△	
19	AGH-2	355.00	ho andesite porphyry	dyke	△		△	△	△		◎	◎	△	△				△	
20	AGH-3	55.00	andesitic tuff breccia	Miocene sadimentary rocks	△		△	○			◎	○			△				
21	AGH-3	80.00	ho andesite porphyry	dyke	△			△			○	○	△	○				△	
22	AGH-3	114.50	ho andesite porphyry	dyke	△		△	△			◎	△			△			△	
23	AGH-3	144.50	ho andesite porphyry	dyke	△		△	○			◎	○	△		△			○	
24	AGH-3	172.30	aphanitic andesite	Miocene sedimentary rocks	△		△	○			○	◎			△			△	
25	AGH-3	204.00	ho-bi granodiorite	Virac granodiorite	△		△	△			◎	◎	△	△				△	
26	AGH-3	237.30	ho-bi granodiorite	Virac granodiorite	△		△	○			◎	◎	△					△	
27	AGH-3	271.00	ho andesite porphyry	dyke	△		△	○			◎	◎	△		△			△	
28	AGH-3	300.00	ho-bi granodiorite	Virac granodiorite	△		△	△			◎	◎		○				△	
29	AGH-4	57.00	ho-bi granodiorite	Virac granodiorite	△		△	△			◎	◎	△	○				△	
30	AGH-4	89.00	ho andesite porphyry	dyke	△		△	○			◎	○	△	△	△			△	
31	AGH-4	116.00	ho-bi granodiorite	Virac granodiorite	△		△	△			○	◎	△	○				△	
32	AGH-4	143.70	ho-bi granodiorite	Virac granodiorite	△		△	△			◎	◎	△	△				△	
33	AGH-4	180.50	ho-bi granodiorite	Virac granodiorite	△		△	△			◎	◎	○	○				△	
34	AGH-4	211.00	ho-bi granodiorite	Virac granodiorite	△		△	△			◎	◎	○	○					
35	AGH-4	235.50	ho-bi granodiorite	Virac granodiorite	△		△	○			◎	○							
36	AGH-4	261.50	ho-bi granodiorite	Virac granodiorite	△		△	△			◎	◎	△	△					
37	AGH-4	283.40	ditto	Virac granodiorite	△		△	○			◎	◎	△	△					
38	AGH-5	27.55	ho andesite porphyry	Andesite complex	△		△	△			◎	◎	△	△			△	△	
39	AGH-5	54.00	ho andesite porphyry	Andesite complex	△		△	△	△		○	◎	△	△			△	△	
40	AGH-5	80.00	mega ho andesite porphyry	Andesite complex	△		△	△			△	◎	△	△			△	△	
41	AGH-5	111.00	ho andesite porphyry	Andesite complex	△		△	○	△		○	○	△	△			△	○	
42	AGH-5	129.50	bi-ho diorite	Itogon quartz diorite	△		△	○	△		○	◎	△	△				○	
43	AGH-5	149.00	ho andesite porphyry	Andesite complex	△		△	○	△		◎	○		△		○	△	○	
44	AGH-5	175.00	meta au-ho andesite porphyry	Andesite complex	△		△	△			◎	◎	△	△		△		△	
45	AGH-5	201.80	bi diorite	Itogon quartz diorite	△		△	○	△		○	○	△			△	△	△	
46	AGH-5	226.20	ho-au andesite porphyry	Itogon quartz diorite	△		△	△	△		◎	○	△	△			△	○	
47	AGH-5	253.10	silicified rock	Itogon quartz diorite			○	○			◎	△				○	△	△	
48	AGH-5	274.50	silicified rock	Itogon quartz diorite	△		△	○	△		◎	◎	△			○	△	△	
49	AGH-5	302.15	diorite	Itogon quartz diorite	△		△	○			◎	◎	△	△		○	△	△	
50	AGH-5	326.00	bi diorite	Itogon quartz diorite			△	○			◎	◎	△	△		△	△	△	
51	AGH-5	349.60	bi diorite	Itogon quartz diorite	△		△	○			◎	◎	△			△	△	△	
52	AGH-5	372.50	diorite	Itogon quartz diorite	△		△	○	△		◎	○	△				△	○	
53	AGH-5	399.50	diorite	Itogon quartz diorite	△		△	○	△		◎	○				△	△	○	
54	AGH-6	23.30	ho andesite porphyry	dyke			△	○			◎	◎	△		△		△	△	
55	AGH-6	50.50	ho-bi tonalite	Itogon tonalite			△	△		△	○	◎	△	○			△	△	
56	AGH-6	87.00	ho-bi tonalite	Itogon tonalite			△	△	△		◎	◎						△	
57	AGH-6	125.35	ho-bi tonalite	Itogon tonalite			△	△	△	△	◎	◎	△	△			△	△	
58	AGH-6	165.50	ho-bi tonalite	Itogon tonalite			△	△	△	△	◎	◎	△	△				△	
59	AGH-6	204.10	ho-bi tonalite	Itogon tonalite			△	△		△	◎	◎	△	△				△	

ho : hornblende, bi : biotite, pl : plagioclase, au : augite ◎ : abundant, ○ : modarate, △ : rare.

The alteration minerals are secondary quartz, calcite, sericite, chlorite and epidote.

4.5.2 X-ray diffraction

X-ray diffraction analyses were conducted on fifty-nine(59) core samples collected from the six gradient holes. The results are shown on Table III-4-9.

Results of X-ray diffraction analyses: The following minerals were identified: Clay minerals: i.e., montmorillonite, kaolinite, sericite, chlorite, and mixed-layers of sericite-montmorillonite and chlorite-montmorillonite; silicate minerals: i.e., α-quartz, plagioclase, potash feldspar, hornblende and epidote; and carbonate mineral: i.e., calcite.

Characteristics of the hydrothermal alteration for each borehole are described below:

AGH-1: The alteration is characterized by sericite, chlorite, α-quartz and pyrite. Locally prominent are: montmorillonite down to the depth of 75.80 meters, and kaolinite and mixed-layers of montmorillonite-sericite down to a depth of 45.20 meters. Montmorillonite is widely distributed in the upper levels implying formation under relatively low temperatures. However, calcite and kaolinite coexist with the mineral suggesting that the processes of alteration are somewhat complicated. At the depth of 102.20 meters, montmorillonite disappears and potash feldspar is first noted.

AGH-2: Montmorillonite and quartz are detected in all samples. Sericite and chlorite are also found in most samples except at 77.0 meters and 98.00 meters, respectively. Also noted are mixed-layered sericite-montmorillonite, calcite and pyrite. Plagioclase disappears at the depth of 26.70 m, 83.30 m and 295.00 meters. Degree of alteration is generally weak.

AGH-3: Identified in all samples are montmorillonite, sericite, chlorite, α-quartz and calcite. Alteration is weak in general.

AGH-4: Identified in all samples are montmorillonite, sericite, chlorite and α-quartz. Calcite is distributed in the upper levels up to a depth of 180.50 meters.

AGH-5: Sericite, chlorite and calcite are found in all sampled depths. Montmorillonite, mixed-layered of sericite-montmorillonite and pyrite are also recognizable in almost all samples. Gypsum is detected at levels deeper than 149 meters.

AGH-6: Sericite, chlorite and calcite occur in all samples while montmorillonite was not identified. Mixed-layers of sericite-montmorillonite and chlorite-montmorillonite as well as pyrite are recognized.

4.5.3 Chemical Analyses

Chemical analyses of 36 core samples from AGH-1, -2 and -5 were made for the following 20 elements and compounds:

SiO_2, Al_2O_3, MgO, MnO, CaO, K_2O, Na_2O, As, B, Ba, Be, Co, Cu, Hg, Li, Pb, Rb, Sb, Sr, and Zn.

The analytical results are shown on Table III-4-10 and the histogram on some elements is shown in Fig. III-4-21.

Analytical Results: The concentration of SiO_2 is 67.70% at the maximum, 49.72% at the minimum and 57.26% at an average. As shown on the histogram, the majority of the concentrations obtained are within the range of 49.72 - 61%, while some vaues beyond this range are observed. These values were obtained from the core samples of AGH-2 at the depth of 26.70 m, 83.30 m and 158.50 meters.

The concentration of Al_2O_3 is 18.30% at the maximum, 10.28% at the minimum and 16.10% at an average. Majority of the concentrations on the histogram are within the range of 14.72 - 18.30%, while some lower values such as 10.28% and 11.98% are detected. These values correspond to the depth of 253.10 meters in AGH-5

Table Ⅲ-4-10 Results of Chemical Analysis

Ser. No.	Hole No.	Depth	Rock Name	Formation or Body	SiO_2 %	Al_2O_3 %	MnO %	MgO %	CaO %	Na_2O %	K_2O %	As ppm	B ppm	Ba ppm	Be ppm	Co ppm	Cu ppm	Hg ppb	Li ppm	Pb ppm	Rb ppm	Sb ppm	Sr ppm	Zn ppm
1	AGH-1	21.20	andesitic tuff breccia	Old plug	60.68	14.84	0.14	2.14	5.84	3.53	1.24	7	15	214	7	12	108	5	18	14	7	2	238	85
2	AGH-1	45.20	brecciated rock	Old plug	56.90	15.26	0.12	2.73	7.56	3.02	1.66	2	16	144	6	15	122	5	17	16	17	10	237	71
3	AGH-1	75.80	ho andesite porphyry	Old plug	56.94	17.09	0.14	2.71	7.20	4.16	1.09	0	5	292	6	14	80	5	14	11	6	0	350	83
4	AGH-1	102.20	ho andesite porphyry	Old plug	54.25	18.08	0.25	3.35	7.82	3.88	1.12	2	9	222	6	16	53	5	10	7	7	0	323	105
5	AGH-2	26.70	granodiorite	Virac granodiorite	67.07	11.98	0.18	2.62	0.44	0.47	4.62	25	11	267	9	21	155	9	15	14	39	5	12	179
6	AGH-2	51.50	granodiorite	Virac granodiorite	59.58	17.48	0.22	3.08	6.01	3.69	2.44	0	8	465	9	17	98	5	10	13	10	3	325	149
7	AGH-2	77.00	granodiorite	Virac granodiorite	60.83	15.30	0.13	2.76	4.98	3.72	1.54	2	8	182	11	20	100	5	6	16	9	0	264	104
8	AGH-2	83.30	granodiorite	Virac granodiorite	65.55	15.78	0.23	3.05	0.57	0.59	4.19	4	14	216	5	27	51	5	15	1	41	3	8	196
9	AGH-2	98.00	granodiorite	Virac granodiorite	57.90	16.04	0.31	3.10	5.78	3.33	2.29	0	10	442	10	22	192	5	6	18	9	0	323	172
10	AGH-2	118.50	granodiorite	Virac granodiorite	60.02	17.04	0.22	3.06	6.00	3.18	1.81	0	9	274	9	18	194	5	8	18	7	0	275	143
11	AGH-2	139.50	granodiorite	Virac granodiorite	57.29	17.56	0.19	2.59	6.41	4.16	1.87	1	10	399	10	15	38	5	6	11	7	0	378	100
12	AGH-2	158.50	ho-pl andesite porphyry	dyke	64.04	15.24	0.22	1.93	4.35	3.88	2.59	5	28	343	9	12	5	5	7	10	24	2	334	199
13	AGH-2	164.50	ho-pl andesite porphyry	dyke	58.98	16.55	0.20	1.94	5.75	3.76	2.59	8	9	321	8	10	40	5	8	11	19	0	263	133
14	AGH-2	192.50	granodiorite	Virac granodiorite	54.70	17.58	0.19	3.41	7.67	4.16	1.78	0	12	343	10	22	104	5	6	15	10	2	376	100
15	AGH-2	213.50	granodiorite	Virac granodiorite	54.76	17.29	0.17	3.21	6.89	4.35	4.28	0	13	336	9	13	15	5	6	8	12	0	349	83
16	AGH-2	242.30	granodiorite	Virac granodiorite	59.28	15.58	0.18	2.88	6.66	3.76	2.38	0	17	407	10	22	62	5	5	10	11	0	254	81
17	AGH-2	269.50	granodiorite	Virac granodiorite	55.86	18.30	0.17	3.09	7.54	4.23	2.78	0	12	366	9	15	114	5	6	12	16	0	352	86
18	AGH-2	295.00	ho andesite porphyry	dyke	58.05	15.94	0.20	2.55	4.21	0.74	3.86	17	14	224	7	24	91	11	9	13	21	3	39	136
19	AGH-2	322.70	granodiorite	Virac granodiorite	57.51	17.24	0.19	3.33	7.52	3.80	2.41	0	13	325	9	23	94	5	6	11	12	1	352	107
20	AGH-2	355.00	ho andesite porphyry	dyke	60.90	17.31	0.15	2.15	6.26	4.31	2.81	3	18	332	9	7	13	5	7	14	11	0	389	88
21	AGH-5	27.55	ho-pl andesite porphyry	Andesite complex	53.55	17.10	0.18	4.38	6.70	3.49	1.21	0	16	133	6	26	281	5	9	11	6	1	210	82
22	AGH-5	54.00	ho-pl andesite porphyry	Andesite complex	52.11	18.26	0.18	3.80	8.59	4.23	1.90	2	17	281	5	23	220	5	8	15	19	2	283	101
23	AGH-5	80.00	ho andesite porphyry	Andesite complex	53.70	17.91	0.16	4.06	8.91	3.25	1.21	0	17	176	6	24	116	5	4	6	8	0	386	92
24	AGH-5	111.00	ho andesite porphyry	Andesite complex	50.36	16.94	0.22	4.62	7.74	3.65	1.96	0	17	187	7	18	97	5	11	12	19	0	226	113
25	AGH-5	129.50	bi-ho diorite	Itogon quartz diorite	49.72	17.18	0.21	4.17	9.59	2.78	1.63	0	17	153	6	27	97	5	9	17	15	0	253	123
26	AGH-5	149.00	ho andesite porphyry	Andesite complex	53.53	15.62	0.18	4.08	7.25	3.53	1.78	3	19	174	7	21	256	5	13	17	10	0	256	129
27	AGH-5	175.00	ho andesite porphyry	Andesite complex	53.63	16.16	0.22	4.18	8.68	3.76	1.42	0	17	238	6	22	262	5	10	17	7	1	298	82
28	AGH-5	201.80	bi diorite	Itogon quartz diorite	57.78	15.39	0.07	3.34	5.08	2.86	1.69	0	18	129	8	18	21	5	14	15	10	1	200	54
29	AGH-5	226.20	ho-au andesite porphyry	dyke	53.45	15.90	0.19	3.55	8.47	1.02	2.20	0	24	360	10	21	170	5	12	12	13	0	311	98
30	AGH-5	253.10	brecciated diorite	Itogon quartz diorite	53.34	10.28	0.40	2.37	7.12	4.43	2.59	8	21	209	4	16	33	5	16	14	21	2	213	270
31	AGH-5	274.50	brecciated diorite	Itogon quartz diorite	56.58	14.66	0.11	3.25	6.69	3.69	1.90	0	25	138	8	8	138	5	11	13	16	3	311	108
32	AGH-5	302.15	brecciated diorite	Itogon quartz diorite	60.10	15.24	0.08	2.72	7.05	3.69	1.18	0	24	202	8	14	93	5	10	11	8	0	296	57
33	AGH-5	326.00	brecciated diorite	Itogon quartz diorite	56.25	16.60	0.07	3.37	7.80	4.35	1.24	0	20	164	7	25	46	5	6	9	7	0	294	48
34	AGH-5	349.60	brecciated diorite	Itogon quartz diorite	59.22	14.72	0.04	3.01	6.82	4.16	1.39	1	22	202	8	14	154	5	10	18	10	3	336	55
35	AGH-5	372.50	brecciated diorite	Itogon quartz diorite	52.25	15.26	0.40	3.80	8.03	2.31	2.50	0	28	256	8	28	58	38	11	15	13	0	223	214
36	AGH-5	399.50	brecciated diorite	Itogon quartz diorite	54.59	14.79	0.29	3.35	7.17	2.71	1.93	2	25	240	8	17	118	27	13	18	21	3	263	97

ho : hornblende, pl : plagioclase au : augite

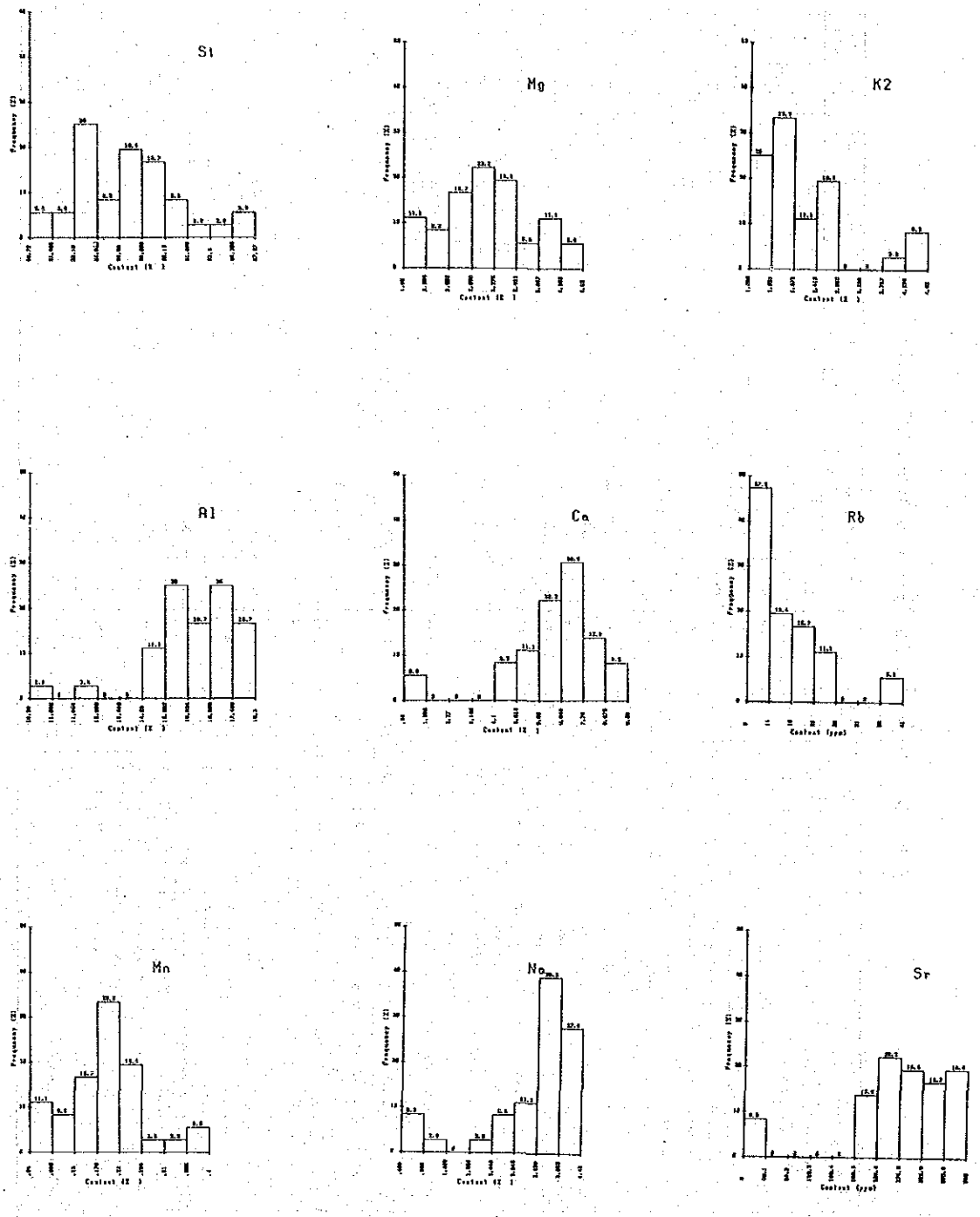


Fig. Ⅲ-4-21 Histogram of Elements (SiO_2, Al_2O_3, MnO, HgO, CaO, K_2O, Rb, Sr)

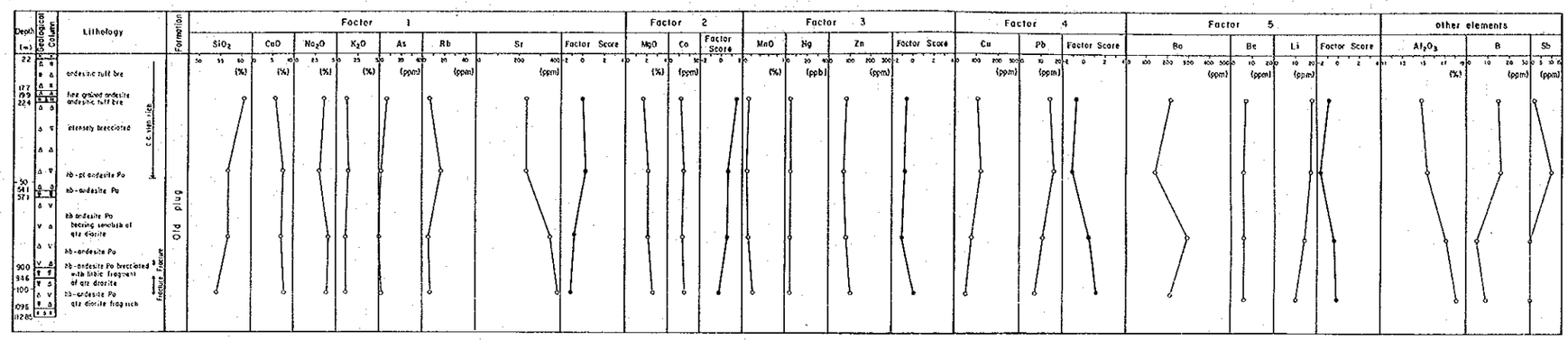


Fig. Ⅲ-4-22(a) Multielement Parameter Plots AGH-1

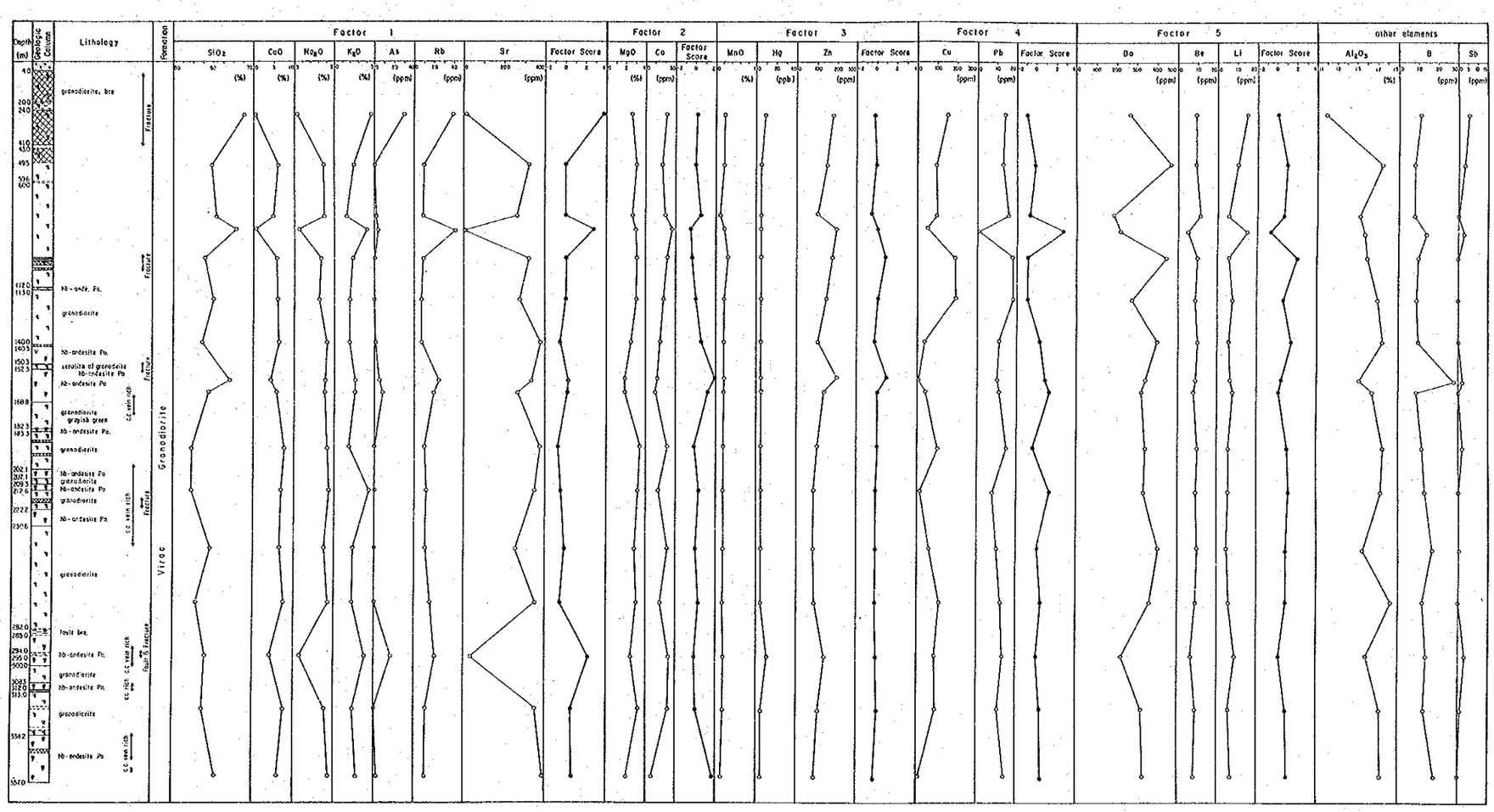


Fig. Ⅲ-4-22(b) Multielement Parameter Plots AGH-2

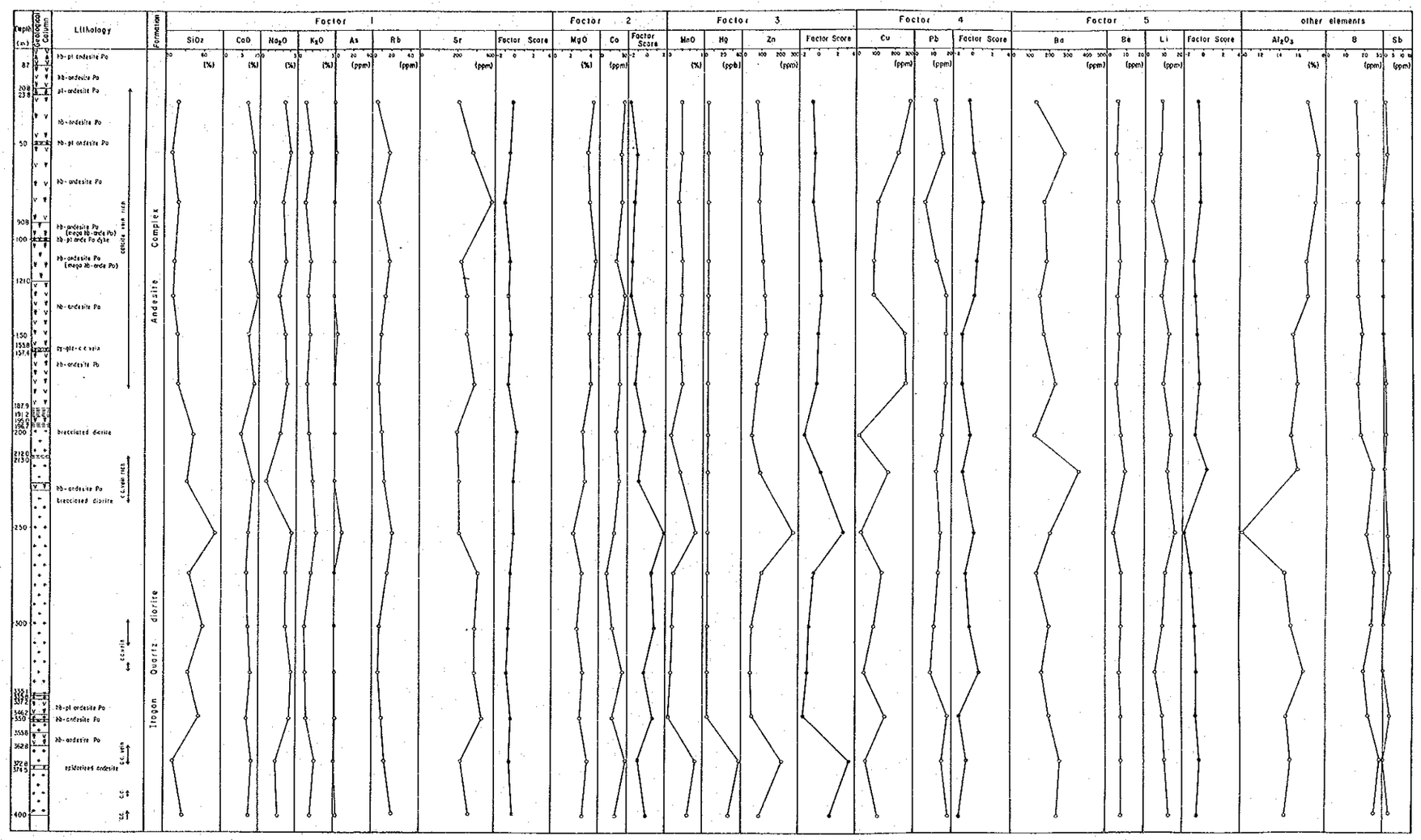


Fig. Ⅲ-4-22(c) Multielement Parameter Plots AGH-5

and 26.70 meters in AGH-2.

The MnO concentration values are 0.40% at the maximum, 0.04% at the minimum and 0.19% at an average. These values form two peaks (high and low concentration clusters) in the histograms. The concentrations in AGH-1 and -2 are relatively stable and constant. On the other hand, the values in AGH-5 show great variation in concentration, particularly in the levels deeper than 201.80 meters (i.e., 0.04% - 0.40%).

The MgO concentration values are 4.62% at the maximum, 1.93% at the minimum and 3.16% at an average. The histogram shows an approximately normal distribution pattern, with relatively high concentration found in the upper levels of AGH-5.

The CaO concentration values indicate 9.56% at the maximum, 0.44% at the minimum and 6.59 at an average. As shown on the histogram, majority of the values fall within the range of 4.21% and 9.59%. However, in the case of AGH-2, low values of 0.44% and 0.57% are recognized at the depths of 26.70 meters and 83.30 meters, respectively.

The Na_2O concentration values indicate 4.43% at the maximum, 0.47% at the minimum and 2.14% at an average. From the histogram, a high concentration peak and a minor low concentration peak include the values of 0.47% - 1.02% detected at the depths of 26.70 m, 83.30 m and 295.00 meters in AGH-2 and 226.20 meters in AGH-5.

The K_2O concentration values are 4.62% at the maximum, 1.09% at the minimum and 2.14% at an average. In contrast to the Na_2O peaks, the K_2O peak is sited at the low concentration section. The high concentration values of 3.86% - 4.62% are detected at the depth of 26.70 m, 83.30 m, 213.50 m and 295.00 meters in AGH -2.

The Rb concentration values are 41 ppm at the maximum, 6 ppm at the minimum and 13.8 ppm at an average. On the histogram, a peak is formed in the

low concentration section. High concentration values of 39 ppm and 41ppm are detected at the depths of 26.70 meters and 77.0 meters in AGH-2.

The Sr concentrations are 386 ppm at the maximum, 8 ppm at the minimum and 247 ppm at an average. They show a flat in the high concentration section. Low concentrations of 12 ppm and 2 ppm are detected at the depths of 26.70 meters and 83.30 meters in AGH-2.

High concentration values of As are known at the depths of 26.70 meters and 295.00 meters in AGH-2. No significant features are observed for the other micro-elements.

Considerations: For the 20 elements analyzed, statistical processing was undertaken to derive correlation coefficients of elements and the factor analysis.

The correlation coefficients of elements are shown in Table III-4-11. There are significant negative correlations between SiO_2 and MgO, SiO_2 and CaO, and Rb and Sr, while strong positive correlations exist between MnO and Zn, Na_2O and Sr, and K_2O and Rb.

From the factor analysis, groups of elements indicating causation were extracted (Table III-4-12), and the factor scores are shown in the core charts (Fig.III-4-22).

Elements of Factors extracted on Table III–4–12

Table III–4–12 Factor Components

Factor		1		2		3		4		5
Contribution (%)		37.73		19.22		16.60		9.45		17.00
Elements and factor loadings	SiO_2	0.612	SiO_2	0.649	MnO	0.889	Cu	–0.492	Ba	0.755
	K_2O	0.708	MgO	–0.847	Hg	0.601	Pb	–0.728	Be	0.715
	As	0.775	CO	–0.746	Zn	0.748			Li	0.641
	Rb	0.777								
	CaO	–0.858								
	Na_2O	–0.765								
	Sr	–0.843								

+++ correlation matrix +++

Table Ⅲ-4-11 Correlation Table

	SiO_2	Al_2O_3	MnO	MgO	CaO	Na_2O	K_2O	As	B	Ba	Be	Co	Cu	Hg	Li	Pb	Rb	Sb	Sr
Al_2O_3	−0.544																		
MnO	−0.063	−0.207																	
MgO	−0.782	0.344	0.087																
CaO	−0.813	0.402	0.031	0.505															
Na_2O	−0.203	0.291	−0.166	−0.040	0.533														
K_2O	0.445	−0.239	0.278	−0.302	−0.642	−0.503													
As	0.542	−0.529	0.106	−0.439	−0.656	−0.540	0.592												
B	−0.133	−0.381	0.065	0.150	0.219	−0.083	−0.089	−0.122											
Ba	0.176	0.269	0.282	−0.330	−0.072	0.131	0.339	−0.050	−0.316										
Be	0.177	0.113	−0.142	−0.268	−0.165	0.032	0.168	−0.075	−0.128	0.586									
Co	−0.303	0.103	0.281	0.603	0.050	−0.442	0.040	−0.014	0.005	−0.149	−0.195								
Cu	−0.321	0.055	−0.032	0.535	0.190	−0.112	−0.276	−0.055	−0.021	−0.165	−0.136	0.331							
Hg	−0.193	−0.195	0.518	0.125	0.049	−0.306	0.131	0.067	0.410	−0.036	0.032	0.256	−0.082						
Li	0.223	−0.592	0.084	−0.112	−0.266	−0.389	0.033	0.336	0.156	−0.413	−0.475	−0.123	0.078	0.150					
Pb	−0.175	−0.242	0.072	0.077	0.235	0.097	−0.255	0.008	0.104	−0.052	0.194	−0.058	0.447	0.218	0.147				
Rb	0.456	−0.432	0.247	−0.205	−0.657	−0.609	0.735	0.632	0.126	−0.039	−0.187	0.107	−0.162	0.146	0.355	−0.235			
Sb	0.300	−0.391	−0.109	−0.225	−0.308	−0.315	0.205	0.384	0.079	−0.212	−0.218	−0.095	0.090	0.042	0.532	0.163	0.465		
Sr	−0.367	0.511	−0.146	0.047	0.669	0.766	−0.527	−0.672	−0.028	0.344	0.289	−0.394	−0.075	−0.200	−0.520	0.058	−0.703	−0.394	
Zn	0.376	−0.471	0.795	−0.196	−0.382	−0.313	0.496	0.405	0.074	0.186	−0.134	0.172	−0.137	0.290	0.210	−0.025	0.549	0.079	−0.392

Five factors were recognized and these were: SiO_2, K_2, As, Rb, Cao, which suggest that Na_2O and Sr for Factor-1; SiO_2, MgO and Co, Factor-2; MnO, Hg and Zn, Factor-3; Cu and Pb, Factor-4; and Ba, Be and Li, for Factor-5.

Among the elements in Factor-1, SiO_2 and K_2O, which are contained in minerals like micas and potash feldspars, show positive loadings, whereas CaO and Na_2O, which are found in plagioclases, exhibit negative loadings. This observation is particularly true for AGH-2 and is substantiated by X-ray diffraction results, suggesting that alteration processes are characterized by the leaching of pagioclases and the precipitation of abundant sericite.

On the other hand, elements Mg and Co in Factor-2, have a correlation coefficient of 0.603 that is comparable to values derived from volcanic rocks in orogenic zones (i.e., 0.54 according to A. Ewart, 1982).

The behaviour of the elements in the other three factors cannot be accounted for.

4.5.4 Physical Test

(a) Sonic velocity: Sonic velocities in 59 core samples collected from the six boreholes were measured under forced-wet conditions. The results are shown in Table III-4-13.

The sonic velocities range from 1.52 km/sec. to 6.07 km/sec. with the average value at 5.13 km/sec.

Remarks for the individual boreholes are given.

AGH-1: The geology down to the depth of 102.20 meters is composed of andesite pyroclastics with upper levels characterized by very low velocities of 1.52 - 2.22 km/sec.

AGH-2: The rocks comprise of granodiorite and andesite porphyry

dikes. Low velocities of 2.64 km/sec. and 3.25 km/sec. are detected at the depths of 83.30 meters and 295.00 meters, while values of 4.93 - 6.07 km/sec. are observed in other depths.

AGH-3: Sedimentary rocks (andesitic tuff breccia) in the upper levels show velocity of 3.43 km/sec. The granodiorite and andesite porphyry dike show values of 4.55 to 5.46 km/sec.

AGH-4: The geology, comprised of granodiorite and andesite porphyry dike, is marked by sonic wave veolocity values of 4.78 - 5.91 km/sec.

AGH-5: The geology comprises of the andesite complex and granodiorite. Velocity values are 4.61 - 6.22 km/sec. except for the depth of 27.55 meters where 3.76 km/sec. recorded.

AGH-6: The geology comprises of quartz diorite and andesite porphyry dike, and velocity values are 4.34 - 5.93 km/sec.

The average sonic velocity values for each formation and rock type are shown on Table III-4-14. Low velocities of 3.63 km/sec. and 4.34 km/sec are characteristics of the old plug and the Miocene sedimentary rock, while high and relatively constant velocities of 5.07 - 5.45 km/sec are characteristic of andesite porphyry dikes and the Virac granodiorite.

(b) Termal conductivity: Thermal conductivity was measured on 59 core samples from the six boreholes. The measurement was carried out by the Box Probe method under forced-wet conditions.

Results of the measurement are shown in Table III-4-13. Values ranges from 5,194 x 10^{-3} to 8,056 x 10^{-3} cal/cm. sec. °C, with the average of 6,379 x 10^{-3} cal/cm. sec. °C.

Remarks for each borehole are given.

AGH-1: The average thermal conductivity value is 6,245 x 10^{-3} cal/cm. sec. °C while at the upper levels, relatively low values of 5,194 - 5,947 x 10^{-3} cal/cm. sec. °C.

AGH-2: The average thermal conductivity is 6,183 x 10^{-3} cal/cm. sec. °C. Thermal conductivity of the andesite porphyry dike is 6,681 - 6,947 x 10^{-3} cal/cm. sec. °C, which seem to reflect the difference in lithologies in the hole.

AGH-3: The average thermal conductivity is 6,503 x 10^{-3} cal/cm. sec. °C. The thermal conductivity of the andesite porphyry dike is in the range of 5,558 - 7,731 x 10^{-3} cal/cm. sec. °C. The Miocene sedimentary rocks and granodiorite have similar values.

AGH-4: The thermal conductivity of the granodiorite is not very different from the other holes, i.e., the average value is 6,311 x 10^{-3} cal/cm. sec. °C.

AGH-5: The average thermal conductivity of the rocks is 6,547 x 10^{-3} cal/cm. sec. °C. Low values are measured from upper level rocks and high values at the lower levels. However, some granodiorites give high values of 7,928 - 8,056 x 10^{-3} cal/cm. sec. °C at the depths of 253.10 meters, 274.50 meters and 349.60 meters. It is presumed that differences in the degree of silicification cause variations in the values.

AGH-6: No significant change is observed in the thermal conductivity values; the average value is 6,397 x 10^{-3} cal/cm. sec. °C.

The average values for the formation and rock are shown in Table III-4-14. It seems that although the Virac granodiorite show relatively low thermal conductivity, no remarkable differences in values are generally observed.

(c) Density and effective porosity: Density measurement was conducted on 15 samples selected from those for the measurement of sonic velocity and thermal conductivity. The measurements were carried out under three condition: natural, forced-wet and forced-dry. Effective porosity was calculated from the

measurements.

Results of calculations for the density and effective porosity are shown in Table III-4-13. The average values for the formation and rock are as shown in Table III-4-14.

Under forced-wet conditions, density values from 2.60 to 2.83 g/cm^3. and the average value is 2.73 g/cm^3. Generally, the density is low in the old plug (andesitic lapilli tuff) and in the Miocene andesitic tuff breccia and show 2.60 - 2.62 g/cm^3 and 2.58 g/cm^3, respectively. On the other hand, granodiorite, andesite complex and andesite porphyry dike show high density values of 2.75 - 2.83 g/cm^3.

Effective porosities range from 0.10 to 7.57% except for relatively high values of 7.20 - 7.57% in the old plug and the Miocene sedimentary rocks.

(d) Permeability: The permeability measurement was conducted on 15 selected samples.

Results of the measurement are shown in Table III-4-13 and III-4-14. Most samples have permeabilities which are under the detection limit and only three of them showed very small coefficients (i.e., 1.80×10^{-4} - 2.32×10^{-6} darcy).

(e) Resistivity: The measurement of resistivity was conducted on 15 selected samples.

Results of the measurement are as shown in Tables III-4-13 and III-4-14. Values range from 1.06×10^{-4} Ω-cm to 8.01×10^{-6} Ω-cm. Samples of the old plug (at the depth of 21.30 meters in AGH-1) and the quartz diorite (at the depth of 253.10 meters in AGH-5) exhibit relatively low resistivity values of 10^4 Ω-cm, while all other samples have high values of 10^5 - 10^6 Ω-cm.

(f) Specific heat: Measurement of specific heat was conducted on 15 samples.

Results of the measurement are as shown in Table III-4-13 and III-4-14. Values range from 0.205 cal/g to 0.239 cal/g., averaging at 0.217 cal/g. Only the andesitic lapilli tuff of the old plug in AGH-2 shows higher values of 0.235 cal/g., while all other figures are similar.

Table Ⅲ-4-13 Results of the Core Test (Sonic Velocity Thermal Conductivity, Density, Permeability, Specific Electric Resistance and Speicfic Heat)

Ser No.	Hole No.	Depth(m)	Rock Name	Formation or Body	Sonic velocity (km/sec)	Thermal conductivity ($\times 10^{-3}$ cal/cm·sec °C)	Density (g/cm^3) No. treatment	Density (g/cm^3) wet condition	Density (g/cm^3) dry condition	Porosity (%)	Permeability (darcy)	Specific electric resistance (Ω·cm)	Specific heat (cal/g)
1	AGH-1	21.20	ho andesitic lapilli tuff	Old plug	2.22	5.194 ± 0.250	2.57	2.60	2.53	7.20	impossible to measure	1.06×10^{6}	0.235
2	AGH-1	45.20	andesitic fine tuff	Old plug	1.52	5.947 ± 0.175	2.58	2.62	2.54	7.57	impossible to measure	impossible to measure	0.239
3	AGH-1	75.80	andesitic lapilli tuff	Old plug	5.50	7.203 ± 0.143							
4	AGH-1	102.20	ho andesitic lapilli tuff	Old plug	5.26	6.636 ± 0.067	2.82	2.82	2.82	0.10	dispermeable	1.84×10^{6}	0.214
5	AGH-2	51.50	ho-bi granodiorite	Virac granodiorite	4.93	5.631 ± 0.034							
6	AGH-2	77.00	ho-bi granodiorite	Virac granodiorite	5.07	6.617 ± 0.102							
7	AGH-2	83.30	ho-bi granodiorite	Virac granodiorite	2.64	5.408 ± 0.116							
8	AGH-2	98.00	ho-bi granodiorite	Virac granodiorite	5.19	5.812 ± 0.089							
9	AGH-2	118.50	ho-bi granodiorite	Virac granodiorite	5.26	7.303 ± 0.138	2.74	2.75	2.74	0.51	dispermeable	1.31×10^{6}	0.213
10	AGH-2	139.50	ho-bi granodiorite	Virac granodiorite	5.71	6.142 ± 0.076							
11	AGH-2	158.50	ho andesite porphyry	dyke	5.14	6.681 ± 0.076							
12	AGH-2	164.50	ho andesite porphyry	dyke	5.00	6.944 ± 0.074	2.71	2.71	2.70	1.58	dispermeable	1.16×10^{5}	0.219
13	AGH-2	192.50	ho-bi granodiorite	Virac granodiorite	5.57	5.761 ± 0.066	2.81	2.81	2.81	0.28	1.80×10^{-4}	1.87×10^{6}	0.214
14	AGH-2	213.50	ho-bi granodiorite	Virac granodiorite	5.58	5.722 ± 0.147							
15	AGH-2	242.30	ho-bi granodiorite	Virac granodiorite	5.38	5.889 ± 0.075							
16	AGH-2	269.50	ho-bi granodiorite	Virac granodiorite	5.41	6.064 ± 0.061							
17	AGH-2	295.00	ho-pl andesite porphyry	dyke	3.25	6.947 ± 0.095							
18	AGH-2	322.70	ho-bi granodiorite	Virac granodiorite	6.07	5.631 ± 0.061							
19	AGH-3	55.00	andesitic tuff breccia	Miocene sedimentary rocks	3.43	6.686 ± 0.114	2.52	2.58	2.50	7.50	dispermeable	1.15×10^{5}	0.222
20	AGH-3	80.00	ho andesite porphyry	dyke	5.14	5.558 ± 0.053							
21	AGH-3	114.50	ho andesite porphyry	dyke	4.55	7.731 ± 0.100							
22	AGH-3	144.50	ho andesite porphyry	dyke	4.63	7.403 ± 0.079							
23	AGH-3	172.30	aphanitic andesite	Miocene sedimentary rocks	5.30	6.550 ± 0.064	2.81	2.83	2.81	1.92	dispermeable	2.80×10^{5}	0.231
24	AGH-3	204.00	ho-bi granodiorite	Virac granodiorite	5.14	6.078 ± 0.085							
25	AGH-3	237.30	ho-bi granodiorite	Virac granodiorite	4.86	6.169 ± 0.082							
26	AGH-3	271.00	ho andesite porphyry	dyke	4.73	6.736 ± 0.151							
27	AGH-3	300.00	ho-bi granodiorite	Virac granodiorite	5.46	5.619 ± 0.095							
28	AGH-4	57.00	ho-bi granodiorite	Virac granodiorite	5.38	5.944 ± 0.099							
29	AGH-4	89.00	ho andesite porphyry	dyke	5.91	6.475 ± 0.038	2.83	2.83	2.82	0.13	dispermeable	8.01×10^{6}	0.219
30	AGH-4	116.00	ho-bi granodiorite	Virac granodiorite	5.67	6.069 ± 0.098							
31	AGH-4	143.70	ho-bi granodiorite	Virac granodiorite	5.90	6.047 ± 0.067							
32	AGH-4	180.50	ho-bi granodiorite	Virac granodiorite	5.60	6.169 ± 0.082							
33	AGH-4	211.00	ho-bi granodiorite	Virac granodiorite	5.67	6.294 ± 0.062							
34	AGH-4	235.50	ho-bi granodiorite	Virac granodiorite	4.78	7.478 ± 0.175							
35	AGH-4	261.50	ho-bi granodiorite	Virac granodiorite	5.65	6.514 ± 0.273							
36	AGH-4	283.40	ho-bi granodiorite	Virac granodiorite	5.50	5.806 ± 0.091							
37	AGH-5	27.55	ho andesite porphyry	Andesite complex	3.76	5.942 ± 0.086							
38	AGH-5	54.00	ho andesite porphyry	Andesite complex	5.54	5.447 ± 0.129							
39	AGH-5	80.00	mega ho andesite porphyry	Andesite complex	6.22	5.736 ± 0.058							
40	AGH-5	111.00	ho andesite porphyry	Andesite complex	5.67	5.939 ± 0.065							
41	AGH-5	129.50	bi-ho diorite	Itogon quartz diorite	6.00	5.889 ± 0.071	2.78	2.78	2.78	0.75	dispermeable	1.25×10^{6}	0.221
42	AGH-5	149.00	ho andesite porphyry	Andesite complex	4.86	6.764 ± 0.109							
43	AGH-5	175.00	meta au.-ho andesite porphyry	Andesite complex	5.67	6.792 ± 0.051	2.79	2.79	2.79	0.18	dispermeable	2.68×10^{5}	0.208
44	AGH-5	201.80	bi diorite	Itogon quartz diorite	5.71	6.253 ± 0.181							
45	AGH-5	226.20	ho-au. andesite porphyry	Itogon quartz diorite	5.83	5.869 ± 0.062							
46	AGH-5	253.10	silicified rock	Itogon quartz diorite	4.70	8.056 ± 0.136	2.70	2.73	2.69	3.46	dispermeable	3.56×10^{4}	0.211
47	AGH-5	274.50	silicified rock	Itogon quartz diorite	5.45	7.922 ± 0.065							
48	AGH-5	302.15	diorite	Itogon quartz diorite	5.65	6.900 ± 0.102							
49	AGH-5	326.00	bi diorite	Itogon quartz diorite	5.71	5.928 ± 0.025	2.75	2.75	2.74	0.31	dispermeable	2.13×10^{6}	0.211
50	AGH-5	349.60	bi diorite	Itogon quartz diorite	5.66	7.986 ± 0.265							
51	AGH-5	372.50	diorite	Itogon quartz diorite	5.81	6.806 ± 0.059							
52	AGH-5	359.50	diorite	Itogon quartz diorite	4.61	6.519 ± 0.086							
53	AGH-6	23.30	ho andesite porphyry	dyke	5.45	6.272 ± 0.018							
54	AGH-6	50.50	ho-bi tonalite	Itogon tonalite	5.93	5.697 ± 0.040							
55	AGH-6	53.00	ho-bi tonalite	Itogon tonalite	5.33	5.506 ± 0.055							
56	AGH-6	87.00	ho-bi tonalite	Itogon tonalite	4.34	6.711 ± 0.051	2.67	2.68	2.66	1.75	1.55×10^{-5}	2.15×10^{5}	0.210
57	AGH-6	125.35	ho-bi tonalite	Itogon tonalite	5.69	6.333 ± 0.059							
58	AGH-6	165.50	ho-bi tonalite	Itogon tonalite	5.40	7.336 ± 0.078	2.67	2.67	2.66	0.77	2.32×10^{-5}	8.58×10^{5}	0.205
59	AGH-6	204.10	ho-bi tonalite	Itogon tonalite	5.45	6.892 ± 0.129							

Table Ⅲ-4-14 Means of the Sonic Velocity, Thermal Conductivity. Density Permeability, Specific Electric Resistance and Specific Heat

Formation or Body	Sonic velocity (km/sec)	Thermal conductivity ($x10^3$ 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		$9.25x10^5$	0.230
Andesite porphyry dykes	5.07	6.828	2.77	2.77	2.76	0.83		$4.06x10^6$	0.219
Andesite complex	5.29	6.103	2.79	2.79	2.79	0.18		$2.68x10^5$	0.208
Virac granodiorite body	5.42	5.880	2.78	2.78	2.78	0.40		$1.59x10^6$	0.214
Itogon quartz diorite body	5.45	6.663	2.71	2.72	2.71	1.41		$8.98x10^5$	0.212
Miocene sedimentary rocks	4.34	6.623	2.67	2.71	2.66	4.71		$1.98x10^5$	0.222

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