CHAPTAR 7

GEOTHERMAL ENERGY DEVELOPMENT

Chapter 7 GEOTHERMAL ENERGY DEVELOPMENT

1. Introduction

1-1 The Project Area

The project area is situated in the southern mountains at the south-eastern part of Cuzco province and belongs to the village of Ocoruro, district of Espinar in terms of administrative divisions. The center of project area is situated at 71° 02' 30" of west longitude and of 15° 05' 30" of south latitude and consists of the plains 4,100 m and ranging hills 4,400 m above the sea level.

The climate is cold at the highland and subjected to the periodic wind, having rainy and dry seasons. In the Quisicollo area, there are no big colonies, and dwelling houses are dotted. As a showing for geothermal resources some gushing springs are observed along the Collpa River.

1-2 Outline of Survey

Project area approximately 50 km^2

Items

(1) Drilling work (including the temperature measurement of drill holes)

300 m 1 drill hole (measurement point: 15 points)

20 m 10 drill holes (" : 200 points)

(2) Geophysical prospecting

Schlumberger method: Total of survey line approximately 20 km (37 stations)

1-3 Survey Lines for Geophysical Prospecting and Drilling Position

Survey lines for the geophysical prospecting are set as shown in the Fig. 7-1 (Appendix), consisting of one line in the N-S direction and two lines in E-W. Survey lines in total are 20 km long and measured stations amount in all to 37.

	Length of survey lien	Number of measured station
Survey line A	10 km	19 stations
Survey line B	5 km	9 stations
Survey line C	5 km	9 stations
Total	20 km	37 stations

Direction and vertical angle of lines are measured with the pocket compass from the original point (p.p.) of 1978-th geothermal prospecting taken as a starting point and the oblique distances is measured with a measuring tape. Land marks with numbers are set at 250 m intervals in horizontal and the measurement of geophysical prospecting was made at 500 m intervals in horizontal.

Drilling sites are selected at near the graben in the direction N-S being thought to be connected with the geothermal showing and at near known hot spring as are shown in the Fig. 7-1 (Appendix).

1-4 Equipments

Equipments used in the survey are shown in the Table 7-1.

2. Geology

2-1 General Geology

Project area is situated at the east-southern part of Yauri Basin and at the boundary between the Basin and Laramani Massif at its east. Laramani Massif is composed mainly of sedimentary rocks of the Cretaceous and Tertiary and the Yauri Basin consists of lake deposits of the Pliocene. Tacaza volcanic rocks of the Eocene are extruded along the said boundary.

Furthermore glacial deposits at the end of the Quarternary, covering these ones are distributed. Geothermal showings are dotted along the River Jaruma and its upper stream of the Collpa River and the gushing-out of hot springs and calcareous sinters are recognized.

On the other hand, diorites and porphyries from the end of the Mesozoic to the Palaeogene are distributed around the south-western end of the Yauri Basin and as the result of this activity exist such copper deposits as Atalaya, Tintaya, Coroccohuayco, Quechua. (See Fig. 7-2)

2-2 Detailed Description of Geological Features

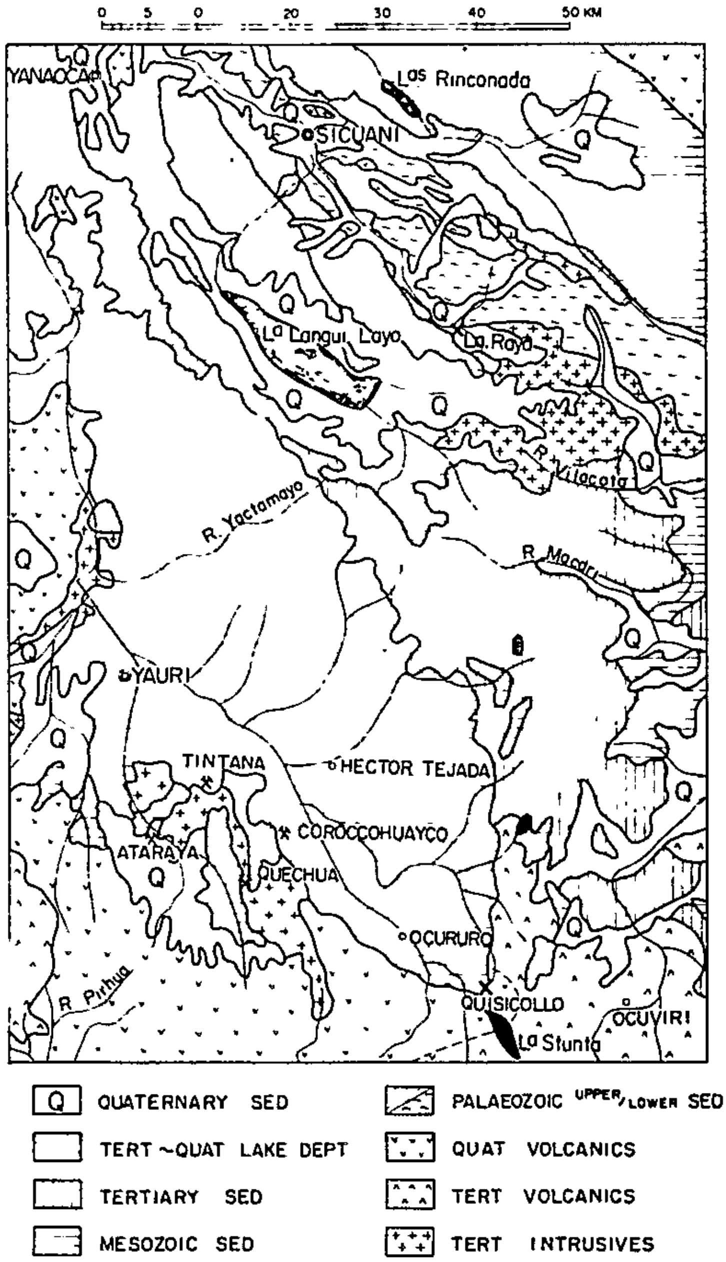
Geological surveys were effected over this area twice in 1976 and 1978 and rocks, distributed within the project area were examined with the reference to the results.

Rocks, distributed within the project area are Ayabacas limestone of the lower part of Moho formation in the Cretaceous fime, Tacaza volcanic rocks of the Eocene, Barroso volcanic rocks of the Plio-Pleistocene and their deeper facies, and glacial deposits of the late Quarternary and Recent deposit. (See Fig. 7-3, Appendix)

Table 7-1 Measurement Equipments

	Name	Model	Specifications	Quantity
Geophysical prospecting	Electric generator with gasoline engine	Geotronics Company M421	maximum output 2.0 kw frequency 400 Hz nominal voltage 115 V (single phase)	1
	Transmitter	CH-508 A,B Chiba Denshi Kenkyujyo	maximum output 2.5 kw output voltage 200 - 800 V output current 0.1 - 3.0 A (9 step switching) frequency 0.1 - 5.0 Hz (5 step switching)	1
	Receiver	Pen recorder EPR 100 A Toh'a Denpa Kogyo	range of received voltage 1 mV - 100 V/75 mm input inspectance 2 MΩ power supply AC 100V 50 - 60 Hz DC 12 - 24 V	2
		Pre-box Yokohama Denshi Kenkyujyo	SP compensation x 100 DC amplifiers	1
Drilling work	Drilling machine	L-44	drilling capacity NX: 760 m BX: 975 m inner diameter of spindle 98 m/m	2
	Engine for drilling machine	GMC3-53	diesel engine 1,800 rpm/60 ps	2
	Drilling pump	535-RQ	pressure 20 - 50 kg/cm^2	3
	Engine for drilling pump	F-23481	diesel engine 2,200 rpm/60 ps	3
	Electric generator	Wisconsin	2 kvA 200 V	3
	Mixer	MCE-100	capacity 100	2
Temperature Measurement	Sensor of Temperature and Water Level	Kaihatsu Kogyo	platinum type	1
	Winch	Kaihatsu Kogyo	Capacity 350 m	1
	Recorder	Watanabe Sokki	Servocorder	1
	Depth Indicator	Tamagawa Seiki	Pulse Generator	1

Fig. 7-2 Regional geological Map of Sicuani Yauri Area



2-2-1 Sedimentary Rocks

1) Moho formation (Ayabacas limestone)

This formation is distributed at the western half of project area and it is usually massive and fine and little lithofacies change, but sometimes contains the pelitic or silicerous part and calcites veinlets develops partially. Tones of color are mainly agray or dark gray.

This formation strickes N-S or NNW-SSE and steeply dips west or east, though it varies a little in each fault block. This formation forms the basement of this area, corresponding to the lower part of the Moho formation of the Cretaceous and named generally Ayabacas limestone. The lower limit is not clarified but the upper one is covered unconformably by Tacaza volcanic rocks of the Palaeogene.

2) Glacial deposits

They are distributed from the northern coast of Lake Stunta over the plain in the center of Quisicollo and at the northern part of Cerro Aguas Calientes.

These deposits are composed mainly of gravels of volcanic rocks with minor amounts of limestone gravel and grits, reflecting the local feature of this area. The roundness are sub-angular and the sorting is poor and the matrix consists of mainly sand. The thickness of the deposit is supposed to be more than 150 - 200 m in this area as this year's drilling result confirmed about 200 m thickness.

These deposits are formed at the glacial period of the Quarternary covering unconformably formation formed prior to the formation of Barroso volcanic rocks.

3) Recent deposits

These deposits are distributed at the riverbeds and marshy area along the River Jaruma and its branched rivers, flowing to the north through the center of project area, and composed of mud, sand and gravel, forming the newest ones in this area, which cover lower ones unconformably.

2-2-2 Volcanic Rocks

1) Tacaza volcanic rocks

This rocks is distributed at the eastern half of project area.

They are generally composed of andesitic rocks and agglomerate and partly of sandstone of pyroclastic origin and present brown purple or light brown color. Its strike and dip vary greatly in each faulted block.

These rocks erupted at the Eocene cover the lower Ayabacas Limestone unconformably.

2) Barroso volcanic rocks

These rocks, distibuting at the north east-coast of Lake Stunta located in south-east of the project area are composed of andesite, basalt and agglomerates. The stratification is nearly horizontal. They are effusive rocks through the volcanic activity of the Plio-Pleistocene, and cover unconformably Tacaza volcanic rocks.

2-2-3 Intrusive Rocks

Distribution of intrusive rocks is very limited. On the surface dolerite in the from of dyke with striking N16°E, dipping 80°W and 1 m width is observed among the Tacaza volcanic rocks, distributed at the left coast about 500 m downstream from the hot spring at the bottom of River Jaruma and the extension in N-S direction is obscure due to lacking of outcrops.

On the other hand, hole IQ-11 catches dolerite and porphyrite just under the glacial deposits. The width is about 37 m ranging from the depth 196.30 m to 223.20 m and it suffered from the hydrothermal alteration by the geothermal action as will be explained below.

2-3 Geological Structure

Fault systems in the project area consist of N-S direction and E-W ∿NE-SW direction.

The N-S fault direction are represented by the fault extending to NNW-SSE one near the River Jaruma in the northern part of project area. This fault converts its direction to NNE-SSW as it extends toward the south.

In the center of project area graben structure opening toward the south is formed by NNE-SSW fault and the one branched from this in SE direction.

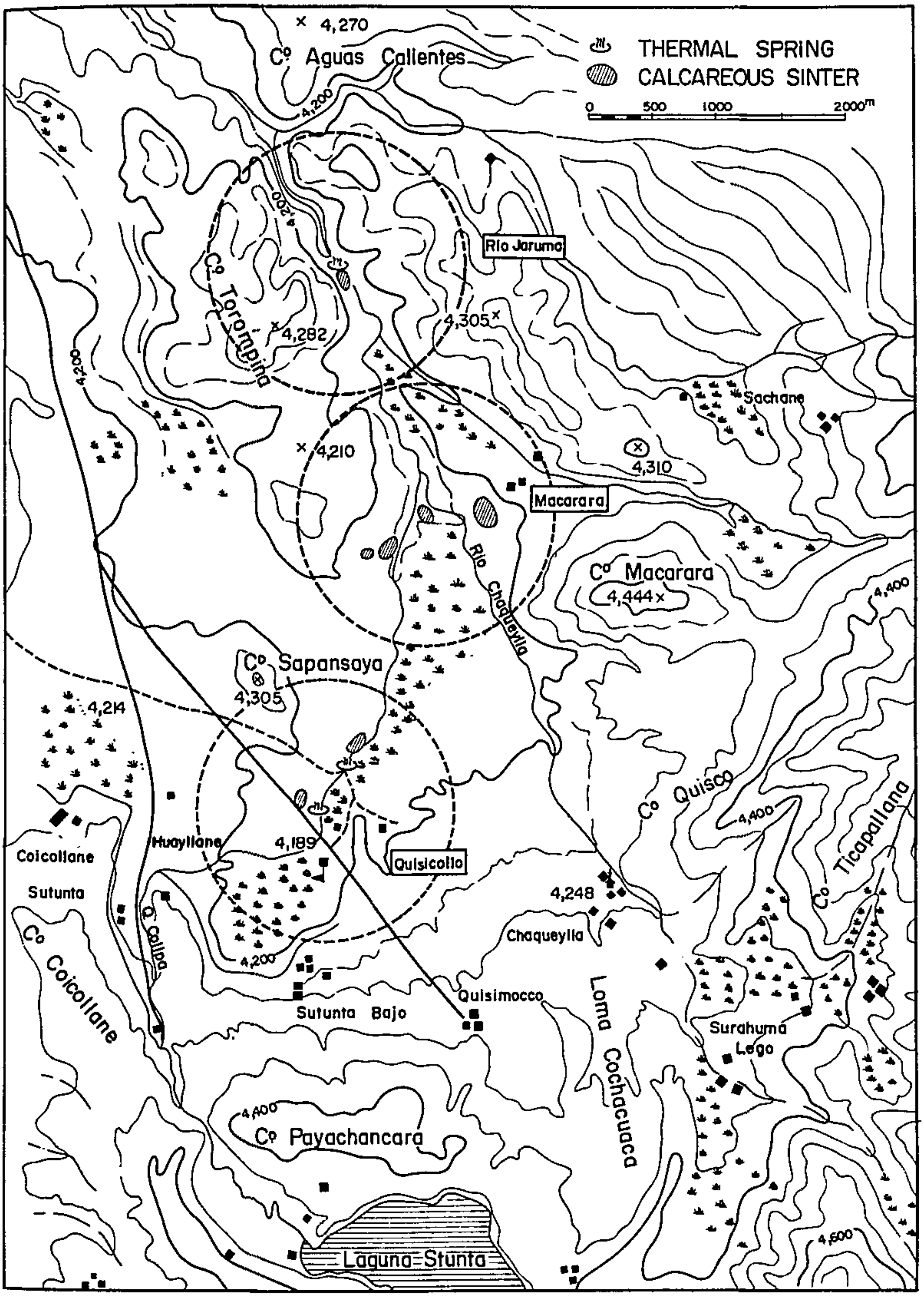
This graben part forms a grassland where recent deposits are distributed.

E-W ∿ NE-SW faults cutting N-S fault are developed at the intervals one to a few kilometers and the formations are suffered block movement. Each block varies in its inclination and the direction consequently stratification seems to be discontinuous among blocks.

2-4 Geothermal Showing

Geothermal showing in the project area are marked by hot spring and the existence of calcareous sinter. They are distributed over about three parts; districts Rio Jaruma, Macarara and Quisicollo respectively from the north. (See Fig. 7-4.)

Fig. 7-4 Geothermal showing in Project Area



2-4-1 Rio Jaruma Area

Hot spring with thick calcareous sinter are gushing out at the bottom of the Jaruma River. There are two gushing holes and the temperatures of hot spring water show 50.7° and 40°C respectively. No alteration minerals accompanied by the geothermal activity could be observed macroscopically in the limestones outcropping around the hot spring except the small veinlet of calcite.

Hot spring are located near the point where ENE-WSW fault intersects with NNE-SSW fault in bounding the Ayabacas Limestone and Tacaza volcanic rocks.

2-4-2 Macarara Area

In this area calcareous sinters are distributed extensively at the meeting point of the Collpa River at the upper stream of the Jaruma River and its branched rivers but hot spring is not observed. This is situated at the meeting point of N-S faults and NW-SE one, which the former forms the graben structure opened to the south.

2-4-3 Quisicollo Area

In the Quisicollo area two showings are observed in 400 m apart each other along the Collpa River flowing north through the flat grassland in the N40°E direction and three to four gushing out of hot springs are observed at the each among which the temperature of hot spring at downstream side is 53.5°C and the one of upperstream is 58°C.

The later temperature constitutes the maximum one within the project area where clacareous sinter is thickly deposited with such a configuration about 1 m as a small hill and hot springs are gushing out of its central part. The area near geothermal showing has no outcrop because of grassland and geological situation is not obvious, but according to the survey of surface geology, it is assumed that the fault runs near this showing in NNE-SSW direction and that E-W fault intersect obliquely with each other at the north side of this showing.

2-5 Core Analysis and the Geological Features of Drill Holes

2-5-1 Core Analysis

Geological logs of drill holes at the depth of 20 m (IQ-1 ∿ IQ-10) and the drill hole at the depth of 300 m (IQ-11) are as follows:

1) Geology of hole IQ-1

0 - 2.80 m: Soil
Weathered reddish brown soil whose upper part is rather sandy.

2.80 - 5.60 m: Gravel
Pebble gravel consisting of mainly andesitic gravels. Roundness is sub-angular. Sorting coefficient is poor.

5.60 - 20.50 m: Agglomerate
Peddish purple colored agglomerate composed of mainly andesites and of rarely limestone breccia. It shows 30° dipping.

2) Geology of hole IQ-2

0 - 17.45 m: Soil
Reddish brown colored soil consisting of weathered andesite.

17.45 - 20.00m: Agglomerate
Consisting of mainly breccia of reddish purple andesitic rocks.

3) Geology of hole IQ-3

0 - 3.00 m: Soil
Black colored soil at the upper of 1 m and brown colored one at the lower. Composed of weathered andesite.

3.00 - 20.00 m: Agglomerates
Reddish purple colored agglomerates composed of mainly andesitic breccia and matrix of andesitic origin. Rocks between the depth 7 - 9 m is sheared and clay bearing.

4) Geology of hole IQ-4

0 - 5.15 m: Sand and gravel
Composed of very coarse sand or granule to be Recent deposits.

5.15 - 7.00 m: Mud
Gray or ocher colored mud partly containing granule.

7.00 - 20.00 m: Gravel
Gravel consisting of mainly andesitic rock. Roundness is sub-rounded. Matrix is muddy medium sand. Sorting coefficient is rather poor.

5) Geology of hole IQ-5

0 - 5.30 m: Sand
Brown colored medium sand of recent deposit at the riverbed.

5.30 - 8.40 m: Gravel
Pebble gravel composed of mainly sub-rounded andesite gravel and brown sandy mud matrix.

8.40 - 14.00 m: Agglomerate
Composed of mainly fine or medium andesitic breccia and basic metrix showing reddish purple color.

14.00 - 20.00 m: Sandstone
Reddish purple colored coarse sandstone composed of andesitic materials and presenting stratification.

6) Geology of hole IQ-6

0 - 7.60 m: Gravel
Pebble gravel containing large cobble gravel at the lower part. Composed of andesitic materials. Matrix consisting of sandy mud. Sorting coefficient is poor.

7.60 - 20.70 m: Mud
Dark gray or light brown colored sandy mud partly containing granule or pebble gravel.

7) Geology of hole IQ-7

0 - 2.10 m: Soil
Dark brown colored weathering soil containing pebble gravel.

2.10 - 20.40 m: Gravel
Pebble to cobble gravel consisting of mainly andesitic materials.
Matrix consisting of muddy coarse grained sand.
Containing muddy coarse sand at the depth of 7.60 - 10.70 m. Roundness is sub-angular.
Sorting coefficient is poor.

8) Geology of hole IQ-8

0 - 2.00 m: Soil
Black colored humic soil containing pebble gravel.

2.00 - 20.00 m: Gravel
Cobble bearing pebble gravel with muddy sand matrix.
Gravel consisting of mainly andesitic rocks.
Sorting coefficient is poor.

9) Geology of hole IQ-9

0 - 4.50 m: Soil
Reddish brown colored weathering soil partly containing granule or pebble gravel.

4.50 - 13.00 m: Sand
Muddy medium sand containing pebble gravel at the intermediate part.
Sorting coefficient is poor.

13.00 - 20.80 m: Gravel
Cobble bearing pebble gravel consisting of mainly andesitic matrix.
Roundness is sub-angular.
Sorting coefficient is poor.

10) Geology of hole IQ-10

0 - 1.70 m: Soil
Weathered soil presenting the reddish brown color.

1.70-4.10 m: Andesite
Andesite showing breccia-like due to weathering along to joint. Weathered part formed reddish brown colored sandy mud.

4.10-17.50 m: Andesite
Coarse andesite presenting the reddish purple color.
Showing dip of 30 - 45°.

17.50-20.00 m: Agglomerate
Composed of andesitic breccia of granule size, and presenting bluish gray color.

11) Geology of hole IQ-11

0 - 35.80 m: Pebble gravel
Cobble bearing pebble gravel consisting of mainly andesitic gravel and small amount of porphyry and diorite.
Matrix consisting of brown colored sandy mud or muddy medium sand.
Sorting coefficient is poor.

35.30-52.50 m: Sand
Brown colored muddy sand partly containing pebble gravel and intercalated sandy mud at lower part.
Sorting coefficient is poor.
Grain size is ranging fine to course.

52.50-61.60 m: Pebble gravel
Brown colored pebble gravel consisting of andesitic gravel with muddy fine-medium sand matrix.
Intercalating thin muddy sand at upper part. Roundness is sub-rounded.
Sorting coefficient is rather well.

61.60-76.00 m: Alternative mud and sand
Reddish brown colored alternation of sandy mud and muddy sand uniting 1 ∿ 5 meters and partly containing pebble gravel.
Sorting coefficient is rather well.
Limonite stain is observed and becomes gradually stronger toward lower part.

76.00 - 80.20 m:	Pebble gravel Pebble gravel consisting mainly volcanic rock gravels with muddy sand matrix. Roundness is sub-angular. Sorting coefficient is very poor.
80.20 - 85.00 m:	Mud Dark brown colored massive sandy mud partly containing granule and lacking bedding.
85.00 - 175.70 m:	Gravel Partly cobble bearing pebble gravel containing two layers of thin mud or sand ranging 0.3 ∿ 1.5 meters thickness at the upper and lower parts respectively. Gravel consists of mainly volcanic rocks. Matrix consists of muddy medium to coarse sand. Roundness changes sub-angular to sub-rounded. Sorting coefficient is very poor. Under 110 meters depth, limonite stain is observed and consolidation of matrix is rather high to become good coring partly.
175.70 - 180.60 m:	Sand and mud Brown colored massive sand and mud showing rather high consolidation. Muddy part contains coarse sand and sandy part consists of muddy medium to coarse sand and contains granule.
180.60 - 187.20 m:	Gravel Cobble bearing pebble gravel consisting of mainly andesitic gravel and muddy medium to coarse sand matrix. Consolidation is rather high. Roundness is sub-angular. Sorting coefficient is poor.
187.20 - 196.30 m:	Mud intercalating gravel Brown colored mud containing granule or pebble gravel partly and intercalating three layers of cobble bearing pebble gravel of about 1 meter thickness. Consolidation is rather high and soring is good.
196.30 - 213.15 m:	Dolerite Composed of coarse-grained feldspar quarz pyroxene and mica, and weakly chloritized and weakly argillized as a whole. Partially developed gypsum veinlet. Showing limonite stain. The upper part is soften due to the alteration and the weathering prior to the sedimentation of gravel deposit.

213.15 - 233.20 m: Porphyrite
Greenish gray colored porphyrite. Phenocrysts are feldspar, amphibole and pyroxene. Weakly chlorilized, and strongly argillized along a crack, especially a part between the depth 229.00 - 230.00 m altered into white clay. In rare cases epidote is dotted.

233.20 - 253.90 m: Andesite
Blueish gray or grey colored andesite. Phenocrysts are feldspar and amphibole. As a whole weakly chloritized and weakly argillized, and strongly argillized along crushed part.

253.90 - 300.50 m: Shear zone
Consisting of fault breccia of andesitic rocks and of a minor amount of limestone, and reddish brown fault clay with partly developed gypsum veinlet. Partially decolored and argillized.

2-5-2 Alteration

The markedly altered outcrops are not almost distributed within the project area except the deposits of calcareous sinters accompanied by the gushing out of hot spring.

Alteration confirmed in this survey is observed at dikes, andesite and shear zone catched by the hole IQ-11.

In order to understand the feature of this alteration, the microscopic observation of cores and the X-ray diffractive analysis of clay minerals were performed and their results are shown in Table 7-2 and 7-3.

Argillization and chloritization is predominant and sericite, epidote, prehnite, gypsum and pyrite are accompanied.

The argillization is observed in volcanic rocks and shear zone at the lower part of hole IQ-11.

Generally it is recognized to be altered phenocryst of feldspars and decolored rocks. Strong argillization proceeds along the cracks, especially at strongly crushed part.

Porphyrite at the depth of hole IQ-11 between 229.00 - 230.00 m and andesite at the depth between 241.40 - 242.50 m are altered to white clay mineral and the former is accompanied by blackened pyrite.

According to the X-ray diffractive analysis, the saponite belonging to the montmorollorite family are main component of clay minerals. Argillization is classified to three, namely strong, moderate and weak according to the degree of alteration. They are shown in the geological logs and results of X-ray diffractive analysis.

Its standards are based on general classification in the geothermal alteration survey of Japan as follows.

Weakly argillized zone: Texture of original rocks remains but phenocryst of feldspar alters.

Moderately argillized sone: Groundmass is partially altered but texture of original rocks remains.

Strongly argillized sone: Texture of original rocks disappears and rock is altered into the clay for the most part.

Chloritization is observed in the volcanic rocks at the lower part of the hole IQ-11 showing change of color of mafic minerals and matrix to greenish one. Chloritization tends to proceed along strongly crushed part alike argillization.

Chloritization is classified to weak degree showing chloritized mafic minerals and moderate degree showing greenish colored ground mass still more.

This is shown at gological logs. As the result of X-ray diffractive analysis, the clay of shear zone, meeted at the lower part of hole IQ-11 contains a large amount of quartz and at the same time a large amount of calcite.

Gypsum is seen as a veinlet in shear zone and volcanic rocks and as coating of fault breccia. Sericite and prehnite are observed in the sandstone of the holes IQ-2 and IQ-3 and in the volcanic rocks of the hole IQ-11.

Epidote is seen sporadically in the porphyrite of the hole IQ-11.

Main component of clacareous sinter distributing on ground surface has been determined as calcite by X-ray diffractive analysis in 1978.

Table 7-2 Microscopic Observation of This Sections

Spl. No.	Loc.	Rock Name	Microscopic Observation
No. 1	IQ-1 10.00∿10.10m	Conglomerate	Consisting of rock fragments (2 to 4mm), and grains (0.1 to 0.3mm) of quartz and plagioclase. Rock fragments is composed of sandstone, granitic rock and limestone with fossil. Matrix consists of calcite, quartz, feldspar, limestone and clay minerals. Secondary minerals including calcite and sericite are also present.
No. 2	IQ-5 18.00∿18.10m	Arkose sandstone	Consisting of grains (0.1 to 0.4mm) of plagioclase, quartz, biotite and white mica, and rock fragments of andesite and granite porphyry. Matrix is composed of calcite, limonite, and clay minerals. Secondary minerals are prehnite, sericite and chlorite.
No. 3	IQ-10 18.60∿18.70m	Arkose sandstone	Consisting of grains (0.1 to 0.5mm) of plagioclase and quartz, and fragments (0.1 to 1.5mm) of andesite, sandstone, granitic rock and limestone. Matrix are composed of calcite, and secondary minerals of sericite, prehnite and limonite.
NO. 4	IQ-11 207.60 ∿207.70m	Dolerite	The rock consists mainly of coarse-grained plagioclase (0.5 to 1mm), quartz, clinopyroxene, and biotite. Secondary minerals are sericite chlorite and sphene.
No. 5	IQ-11 215.30 ∿215.40m	Porphyrite	The rock consists of lath-like plagioclase (0.1 to 0.4mm), clinopyroxine (0.2 to 0.5mm), hornblende and accessary minerals of sphene. Secondary mineral is prehnite.
No. 6	IQ-11 234.60 ∿234.70m	Andesite	The rock consists of lath-like plagioclase (0.1 to 0.3mm) and porphyritic hornblende (0.5 to 1.0mm). Secondary minerals are prehnite, sericite and chlorite.
No. 7	IQ-11 240.00 ∿240.10m	Andesite	Consisting of lath-like plagioclase (0.1 to 0.2mm), and porphyritic hornblende (0.3 to 0.5mm). Secondary minerals are actinolite, prehnite, chlorite and sericite.
No. 8	IQ-11 250.50 ∿250.60m	Andesite	Consisting of lath-like plagioclase (0.1 to 0.2mm), porphyritic hornblende and augite (0.3 to 0.5mm). Secondary minerals are sericite and calcite.
No. 9	IQ-11 270.60 ∿270.70m	Gypsum	The rock consists mainly of gypsum (0.1 to 1.0mm) including euhedral calcite (0.05mm)

Table 7-3 X-ray Analysis of Clay Minerals

	Spl. Loc.	IQ-11 229.7m	IQ-11 241.7m	IQ-11 246.50	IQ-11 255.30
	Occurrence	White clay along a fissure in porphyrite	Strongly argillized andesite	Strongly argillized andesite	Sheared clay
Mineral	Saponite	◎	◎	○	○
	Ganophyllite	○	○		
	Tale		△	○	△
	Oligoclase	○	○	○	○
	Microcline			△	○
	Quartz	△	•		◎
	Calcite	△	•	△	◎
	Gypsum				△
	Halite				•

◎ : Large amounts

○ : Usual amounts

△ : Small amounts

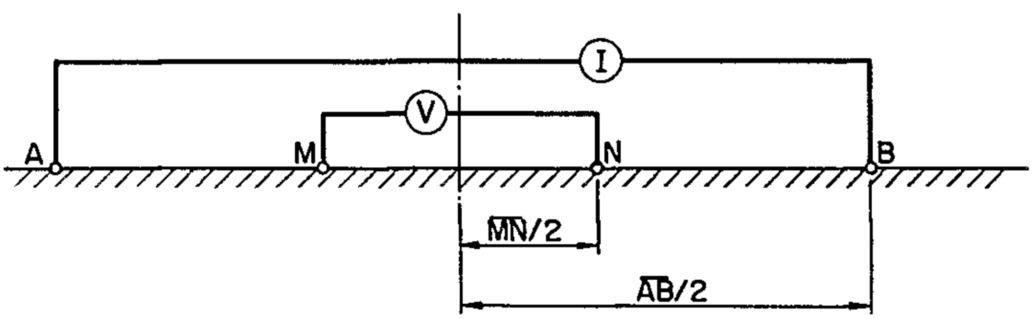
• : Traces

3. Geophysical Prospecting

3-1 Prospecting Method

The Vertical electric sounding (VES) was performed as shown in the Fig. 7-5 with the Schlumberger electrode configuration in such a way that the maximum length of electrode spacing reaches AB/2=2000m.

Fig. 7-5 Schlumberger Electrode Configuration



The apparent resistivity was calculated in accordance with following formulas by transmitting the alternating current 0.1 Hz and 0.3 Hz from electrodes A and B and measuring the electric potential V between potential electrodes M and N.

$$\rho a = K \cdot \frac{V}{I} \ (\Omega m) \qquad K = \frac{\pi}{4} \cdot \frac{(\overline{AB})^2 - (\overline{MN})^2}{\overline{MN}} \ (m)$$

where; K : Geometric factor

$\overline{AB}$: Current electrode spacing (m)

$\overline{MN}$: Potential electrode spacing (m)

V : Potential difference received (mV)

I : Sending current (mA)

$\overline{AB}/2$ and $\overline{MN}/2$ are combined in accordance with the Table 7-4 so as to obtain the inequality $\overline{AB}/2 > 5\ \overline{MN}/2$.

Table 7-4 Schlumberger Electrode Configuration

$\overline{MN}/2$ / $\overline{AB}/2$ (m)	2 m	7 m	30m	100m	250m
10	↑				
15	│				
25	│	↑			
35	│	│			
50	↓	│			
70		│			
100		│			
150		│	↑		
250		↓	│		
500			│	↑	
750			↓	│	
1000				│	
1250				│	↑
1500				↓	│
2000					↓

3-2 Analysing Method

Values of apparent resistivity ρa, calculated in accordance with the result of measurement was taken along the axis of ordinates of logarithmic section paper and the length of AB/2 along the axis of coordinates to formulate the VES curve.

Out of these VES curbes the ones, corresponding with the standard[1/] curves groups are selected out to analyse the underground resistivity structure.

Note : 1/ P.K. Bhattachacherya and H.P. Patra, 1968, Direct current geoelectric sounding, Elsevier, Amsterdam.

In the case of VES curve which will be supposed to reflect the three or more layered structure, auxiliary curves (four types of A,K,H and Q) were used.

Resistivity (ρ) structures analysed in accordance with the standard curve checkup method were input to the electronic computer and the VES curves[2/] calculated theoretically in accordance with the said resistivity structures were written with the help of the plotter and these curves were compared with the acutually measured values.

This operation was repeated in such a way that theoretical values may coincide with acutually measured ones as closely as possible.

As the resistivity structural graphs in the above-mentioned way do not often correspond to the actual geological structures, the combination of resistivities with the layer thickness is changed in accordance with the principle of equivalence and with reference to the after all efforts discontinuous lines are assumed at discontinuous part. Table 7-5 shows analysing flow chart.

3-3 Results

3-3-1 Trends Observed in the Cross Sections of Apparent Resistivity Distribution

We drew vertical lines below the each station on the terrain cross section along each profile line and set the distance AB/2 from the surface of earth on the above vertical lines to write apparent resistivities measured on the position $\overline{AB}/2$.

This diagram is called the apparent resistivity profile. (In case for one $\overline{AB}/2$ is measured with two different $\overline{MN}/2$, its geometrical average value is selected.) In this case as $\overline{AB}/2$ within 35 m is difficult to write in, the axis of ordinates is expressed by the logarithmic scale and the contour is also expressed at the logarithmic intervals (1, 1.4, 1.9, 2.7, 3.7, 5.2, 7.2,10.etc to make the resistivity distribution easily visible:

The apparent resistivity distribution is described for each survey line as the succeeding description. Consider the convenience of analysis it is divided by the proper contour.

10 37 72 190 (Ωm)

Very low	Low	Medium	High	Very high
VL	L	M	H	VH

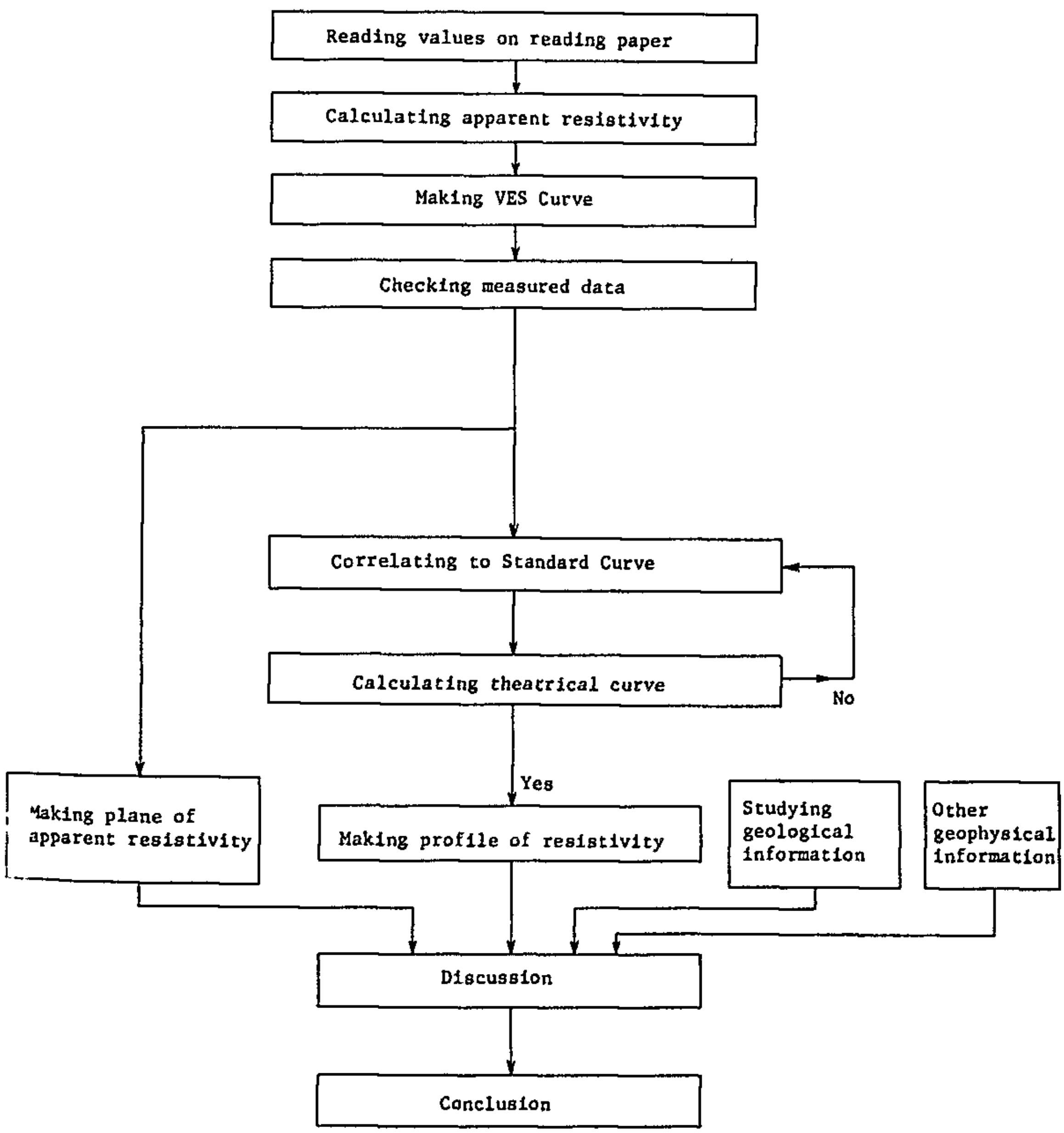
Note : 2/ H.K. Johanse, 1975, An interactive computer graphic display-terminal system for interpretation of resistivity soundings, Geophysical prospecting, Vol. 23, pp 449-458.

1) Survey line A (See Fig. 7-6, Appendix)

This survey line interesecting at the right angle with survey lines B and C is set in the north-south direction.

Except the fact that the high apparent resistivity zone is distributed from the shallow part of earth's surface around the station 14 toward south, low apparent resistivity zones are extensively distributed.

Table 7-5 Analysing Flow Chart



Observing in detail, the high apparent resistivity ones are, ; extensively distributed from around the station 14 toward south and dipping south to depth, ; are observed at the shallow part of the earth's surface near the station 22, 26 and 34.

The very low and low apparent resistivity zones, bounding above mentioned high apparent resistivity zone is for the south side distributed from around the station 18 with the dipping to south, and for the north side extends from around the station 18 ∿ 20 vertically to the depth.

The minimum apparent resistivity shows 2 m and the very low apparent resistivities under 10 Ωm range from the station 18 up to 14.

When the line connected with the maximum and minimum points is considered for the south of the station 24, the minimum one is situated around -250 ∿ -500 m from the earth's surface, showing the trend to approximately horizontally to extend to the north-south.

Besides, considering the H-type VES curve, if the change of resistivity is assumed around here, the basement can be assumed around the depth of -250 m ∿ -500 m from the earth's surface. The line, connected with the maximum point extends from around the station 8 to the depth at the south side and if the line, connected with the maximum point around the station 12 is also taken into consideration, the distribution of rocks, having the high resistivity from the depth at the south end of survey line can be assumed. Moreover, from the shape of VES the type of curves at the stations can be roughly divided into H type one (station 20, 18, 16 and 14) and K type one (south of the station 12 and north of the station 22) and the change of the underground resistivity structure can be assumed around the station 14 and 20 ∿ 22.

2) Survey line B (See Fig. 7-7, Appendix)

Field diagram is generally divided into low apparent resistivity zone around the stations 10 ∿ 17 and the high apparent resistivity zone west of the station 17 and east of the station 10.

When locally checked, the high apparent resistivity zones show following;

i) ; distributed from around the measured stations 2 ∿ 3 to the station 10, gradually dipped from the shallow part of the earth's surface, but steeply toward the depth beyond the station 10,

ii); around the station 18 the high resistivity zone, extends from the shallow part of earth's surface vertically toward the depth.

When checked the low apparent resistivity zones, i); the zone around the station 14 ∿ 16 extends vertically to the depth from the shallow part.

ii); and that the other one lies at the shallow part around the station 10 and at the intermediate part, around the station 12.

And now, when the maximum and minimum points are connected in each measurement station, VES curve shows the type of K at its east side and the type of H at the west side with the respect to the station 10. This is assumed that between them there is a boundary of apparent resistivity. Besides, from the line, connecting the maximum point (K type) a structure, extending steeply toward the upper west can be assumed from the depth at the eastern end of survey line.

Roughly speakly, the high apparent resistivity at the east side is stratifiedly distributed and the low apparent resistivity from the center of measurement line toward the west is vertically distributed, and thus when the foregoing assumption is taken into consideration, it can be assumed that the change of the resistivity structure is observed around the station 9 ∿ 10.

3) Survey line C (See Fig. 7-8, Appendix)

Over the whole survey line the high apparent resistivity is extensively distributed, but the low apparent resistivity is situated at the depth of the station 12 succeeding moreover to the depth.

Except the above-mentioned low apparent resistivity zone, the apparent resistivity is distributed approximately paralled to the earth's surface and the resistivity structure of this survey line can be assumed to form approximately the stratification structure.

Assuming from the resistivity contour, the low apparent resistivity zone at the lower part of the station 12 has a change in underground resistivity structure.

According to the survey of the surface geology, the fault is assumed around here, so the existence of the resistivity line of discontinuity can consistently be assumed from the apparent resistance distribution.

On the other hand, when the minimum and maximum points are connected at each station, the shape of VES curve is K type at the east side and H type at the west side with the station 10 as its center, and around here the change of resistivity structure can be assumed from the apparent resistivity.

3-3-2 Trends Observed in the Apparent Resistivity Plan

In order to check the trend of apparent resistivity for its each depth, a plan was profiled at the depth of $\overline{AB}/2$=250m and $\overline{AB}/2$=500m and the contour with logarithmic space was used as well as in the apparent resistivity cross section.

1) $\overline{AB}/2$=250m (See Fig. 7-9, Appendix)

Generally speaking, at the east side of survey area is distributed the high apparent resistivity and at the west side the low and medium apparent resistivities and at the central part low and very low apparent resistivities approximately in the direction of NNE-SSW.

The center of the apparent resistivity 3.7 Ωm and below is situated around stations 16 ∿ 18 and in such a way to surround it the very low apparent resistivity 10 Ωm and below extends toward the direction of NNE-SSW.

The low apparent resistivity zone 37 Ωm and below extends for the north side up to around the station 19 and it is assumed not to extend eastward with respect to both survey line B and C.

This may be due to the restriction by the NNW structural line passing the station 25 on A survey line and the station 3 on C survey line according to the geological survey.

Assumed from the apparent resistivity distribution of survey lines A and C, it has no chance either to extend southward.

It is necessary to note the facts that this low apparent resistivity is distributed along the structural line described in the geological survey and coincide with the geothermal showing.

Around the meeting point of B survey line and A survey line at the north side, the average apparent resistivity 52 Ωm and below is distributed. Along the Jaruma river the hot spring is observed and the apparent resistivity is assumed to have become low through the hydrothermal alteration, accompanied by the assumed geological structural line and the geothermal showings.

Around the north end of A survey line the low apparent resistivity is distributed, but geothermal showing cannot be observed and on account of the deficient data it cannot be clearly observed.

2) $\overline{AB}/2$=500m (See Fig. 7-10, Appendix)

This has nearly the same distribution as the one $\overline{AB}/2$= 250m, but the range of very low apparent resistivity is small; namely ①; the apparent resistivity 3.7 Ωm and below disappeared and ②; the range of apparent resistivity 14 Ωm and below is small. The distribution range of low apparent resistivity is not changed even at this depth.

As can be assumed from the apparent resistivity distribution profile, this low apparent resistivity zone is still deeply distributed.

At the north end of A survey line the low resistivity zone can be observed but is obscure as well as the distribution $\overline{AB}/2$=250m because it is situated at the end of survey line.

3-3-3 Trends Observed in the VES Curve

Many of VES curves show 4∿5 layer structures over the survey lines A, B and C. Trends observed in the VES curves are classified for each station in Table 7-6.

Table 7-6 List of VES Curve Type

No. of station	Line A classification	Line A type	Line B classification	Line B type	Line C classification	Line C type	Note
2	$\rho_1<\rho_2<\rho_3>\rho_4$	K	$\rho_1<\rho_2>\rho_3<\rho_4$	H	$\rho_1<\rho_2>\rho_3<\rho_4$	H	
4	$\rho_1<\rho_2>\rho_3>\rho_4$	Q	$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5$	H K	$\rho_1<\rho_2>\rho_3<\rho_4$	H	1)
6	$\rho_1>\rho_2>\rho_3<\rho_4$	H	$\rho_1<\rho_2<\rho_3>\rho_4$	K	$\rho_1<\rho_2>\rho_3<\rho_4$	$\rho_1>\rho_2$	
8	$\rho_1>\rho_2>\rho_3<\rho_4$	H	$\rho_1>\rho_2<\rho_3<\rho_4>\rho_5$	K	$\rho_1<\rho_2>\rho_3<\rho_4$	H	
10	$\rho_1<\rho_2>\rho_3<\rho_4$	H	$\rho_1<\rho_2>\rho_3<\rho_4$	H	$\rho_1<\rho_2>\rho_3<\rho_4$	H	
12	$\rho_1<\rho_2>\rho_3<\rho_4$	H	$\rho_1>\rho_2<\rho_3>\rho_4<\rho_5$	K H	$\rho_1<\rho_2>\rho_3<\rho_4$	H	2)
14	$\rho_1>\rho_2>\rho_3<\rho_4$	H	$\rho_1<\rho_2>\rho_3<\rho_4$	H	$\rho_1<\rho_2>\rho_3<\rho_4$	H	
16	$\rho_1>\rho_2>\rho_3<\rho_4$	H	$\rho_1<\rho_2>\rho_3<\rho_4$	H	$\rho_1<\rho_2>\rho_3<\rho_4$	H	
18	$\rho_1>\rho_2>\rho_3<\rho_4>\rho_5$	H K	$\rho_1>\rho_2<\rho_3>\rho_4$	K	$\rho_1>\rho_2<\rho_3$	H	
20	$\rho_1<\rho_2>\rho_3>\rho_4<\rho_5$	H					
22	$\rho_1<\rho_2>\rho_3<\rho_4$	H					
24	$\rho_1<\rho_2>\rho_3<\rho_4$	H					
26	$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5<\rho_6$	K H					
28	$\rho_1<\rho_2>\rho_3<\rho_4>\rho_5$	H K					
30	$\rho_1>\rho_2<\rho_3>\rho_4$	K					
32	$\rho_1>\rho_2<\rho_3>\rho_4<\rho_5$	K H					
34	$\rho_1>\rho_2<\rho_3>\rho_4<\rho_5$	K					
36	$\rho_1>\rho_2<\rho_3>\rho_4<\rho_5$	H					
38	$\rho_1<\rho_2>\rho_3<\rho_4$	H					

(Notes) 1) The station 4 of C survey line is changed to 5.

2) The station 12 of B survey line is changed to 13.

When the assumed 3 or more layer structures are analysed, they are classified as follows in accordance with the range of resistivities of successive layers.

H type; $\rho_1>\rho_2<\rho_3$ HK type; $\rho_1>\rho_2<\rho_3>\rho_4$

K type; $\rho_1<\rho_2>\rho_3$ KH type; $\rho_1<\rho_2>\rho_3<\rho_4$

Q type; $\rho_1>\rho_2>\rho_3$

A type; $\rho_1<\rho_2<\rho_3$

ρ_1, ρ_2 and ρ_3 relate to the resistivities of successive layer and the smaller number belong to the upper layers.

Trends observed in the VES curve are described as follows;

1); On the A survey line stations 16 - 18 - 20 change successively from H type, HK type to H type and the stations 24-26-28-30 from H type, KH type to HK type and K type.

2); On the B survey line they change from K type to H type around the station 10 ∿ 12.

3); On the C survey line they are almost H type and from the difference of thickness of resistivity layers between the adjacent stations the resistivity line of discontinuity can be conceived.

In the analysis of next items the geological discontinuous line is assumed.

3-3-4 Resistivities of Rock and Water

Out of rock samples taken out of the field, 13 samples were measured in the resistivity.

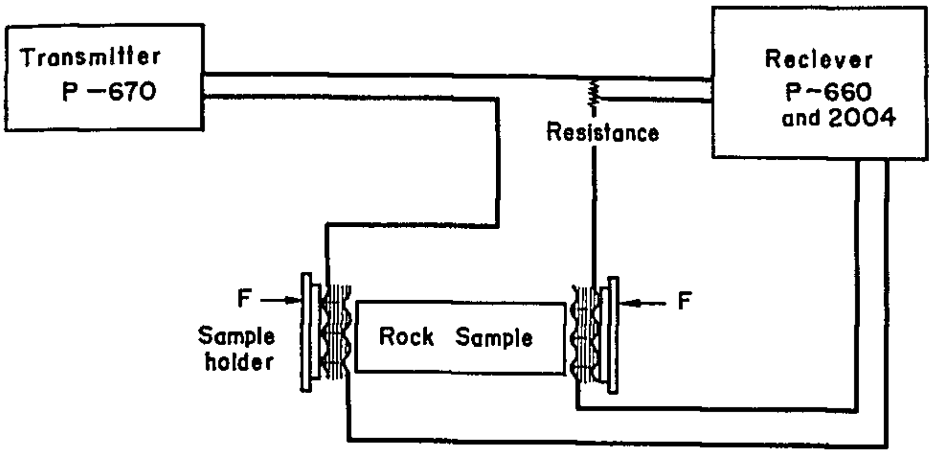
Samples were transformed into the rectangular parallelepiped 4cm x 3cm x 2cm with the diamond cutter and the drill cores into the column their own diameter x 4cm and then immersed in the solution Kcl, 0.1N (resistivity 50 Ωm, water temperature 15°C) for 48 hours and measured in the wet condition. The resistivity of rocks is obtained in accordance with the following formula.

$$\rho = \frac{S}{\ell} \cdot \frac{V}{I} \times 10^{-2} \quad \ldots\ldots\ldots\ldots\ldots \quad (\Omega.m)$$

where;

S; the area of cross section of sample (cm^2)
ℓ; length of sample (cm)
V; the difference of electric potentials (mV)
I; Supplied current (mA)

Rock resistivity measurement system is as follows.



measurement resulted in as follows.

Rock	Resistivity Ωm	Porosity %
Andesite	1.280 ∿ 8.130	1.41 ∿ 2.43
Limestone	4.900 ∿ 22,100	0.34 ∿ 1.34
Agglomerate	1.380	9.41
Conglomerate	690	8.74
Dolerite	-	15.12
Altered andesite	63 ∿ 226	6.84 ∿ 14.39

Considering this data, it is clear that andesite and limestone outcropping surface is low porosity and high resistivity, on the other hand altered andesite at the depth of under 243 m in IQ-11 is high porosity and low resistivity.

Reistivity of surface water etc. (See Table 7-7)

In measuring the resistivities of surface water and hot waters etc. a portable conductivity meter CM-1K made by Tooa Denpa Co., Ltd. was used to convert results into 20°C.

River Water (hot spring water included)	0.41 ∿ 1.30 Ωm
Hot spring hot water	0.34 ∿ 0.35 Ωm
River water	9 ∿ 39 Ωm
Gushed-out water (Coroccohuayco drilling hole)	25 Ωm

The river water at this area include the hot spring water. So the difference resistivities are great between the pure river water and the hot spring water.

Table 7-7 Resistivity of Surface Water

No.	Locality	Resistivity Measured (Ωm/°C)	Resistivity at 20°C (Ωm/20°C)	Note
1	Stangnant water, behind the school Quisicollo	45/12	38 *	Hot spring 0.34~0.35 Ωm/20°C River water, containing Hot spring 0.41~1.30 Ωm/20°C
2	Riverwater behind the school Quisicollo	41/16	36 *	
3	Riverwater behind the school Quisicollo	42/13	37 *	
4	Quisicollo hot spring	0.22/51	0.35	
5	Meeting point of hot spring and the river water	1.4/22	1.4	
6	Swamp water	25/16	22 *	
7	River water right under the drilling site	0.51/27	0.55	
8	River water at the upper stream 100 m of drilling site	0.40/36	0.47	
9	River water at the upper stream 200 m of drilling site	0.41/39	0.52	Other Surface water 9~39Ωm/20°C
10	River water at the upper stream 250 m of drilling site	0.32/52	0.41	
11	River water at the lower stream 250 m of drilling site	0.62/25	0.63	
12	Meeting point of rivers at the lower stream 100 m of drilling site	12/14	9 *	
13	Meeting point of rivers containing and not containing salt	1.4/16	1.3	
14	Jaruma hot spring	0.19/53	0.34	
15	Condoroma River	41/18	39 *	
16	Accommodations water service in Coroccohuayco (water, gushing out of drill holes)	32/12	25 *	

(Notes)

1) Using Schlumbergers graph* of relationship between salinity and resistivity in NaCl solution to convert measured resistivity in to resistivity at 20°C.

2) Marks * relates to the rivers water which does not contain the salt.

According to the analysis of chemical components of hot spring waters effected in 1978, Na^+, Cl^- is 14,680 p.p.m. for the Quisicollo spring and 19,000 p.p.m. for the Jaruma spring.

According to the graph of "Resistivity graph for salinity and Temperature of NaCl solution"[3/] , 15,000 p.p.m. shows 0.25 Ωm (52°C) 0.3 Ωm (38°C) and it is concluded that the above measured values contain a large amount of salt, while they are proper values.

3-4 Analysis and Interpretation

The analysis were performed in accordance with the following procedures.

a) After checking the apparent resistivity profile and VES curves one by one, grouping is made in accordance with VES curves shape, values of apparent resistivities as a whole, VES curves, matching with each other (move them parallel with each other).

b) Considering the VES curves of the adjacent station for each group analyze the resistivity structures in accordance with the standard curve checkup method and input them in the electronic computer and iterate the comparison of theoretically calculated VES curves with the actually measured value until both ones will coincide with each other and analyze the underground resistivity structure.

c) Analyze the depth of basement in accordance with the method, using the position $\overline{AB}/2$ of minimum point ρa and the method, using the longitudinal conductance.

   Check these results whether they are proper compared with the analysis, effected in b) and grouping is proper or not in itself.

3-4-1 Analysis

Results of analysis are described as follows;

In this analysis the accent was laid on the A survey line along the main geological structures at this area and B and C survey line were put only to consideration.

Note : 3/ Resistivity Departure Curves 1949 issue;- Well Surveying Corporation Schlumberger Document Number 3

For a) above mentioned four groups were classified as follows;

Group		Apparent resistivity	Type of VES curve
1	stations 2∿12	high to very high	KH type
2	stations 14∿18	very low	H type
3	stations 20∿26	Medium to high	KH type
4	stations 28∿38	Medium to low	nearly one-layer

For groups 1 and 3 the depth of basement can be assumed to be at the same level as the position of ascent and descent of VES curve is nearly the same.

(The absolute values are also similar.)

For b) and c) considering the VES curve of the adjacent station for each group, results analyzed in accordance with the standard curve checkup method are arranged in the columnar way to understand easily the relation between each of them. (See Fig. 7-6, Appendix)

Dotted lines relate to positions of $\overline{AB}/2$ at the minimum point of ρa' one-dotted chain line to the depth, which can be read from the intersecting point of resistivity value just over the layer assumed to be the basement and an asymptotic curve 45° at each measurement point and two-dotted chain line to the depth which can be read from the intersecting of the lowest resistivity just over the basement out of each group and the asymptotic curve 45°, when the former is assumed to be the value over the whole group. (so-called longitudinal conductance method. Hereafter it is referred to as S-line method).

From the above consideration, the following can be assumed.

① The station where the contour of apparent resistivity distribution between the measurement station 18 and 20 are directed in the vertical direction and the position of resistivity discontinuous line, assumed from the results of analysis correspond with each other.

② As the resistivity distribution at the stations 12-10-8 out of group ①, they are thought to have the analogous horizontal layer structures.

③ When the apparent resistivity distribution is checked in the light of the results of ① and ②, it is not still explicit at this stage whether this distribution continuous successively from the station 18 toward 12 or the resistivity line of discontinuity can be set between the station 14 ∿ 12.

④ In the group ① as the stations move in the order 8-6-4-2, the high apparent resistivity layers become thicker.

⑤ Considering that the contour of apparent resistivity distribution at the depth of group ③ is horizontal, the depth is assumed to have the horizontal layer structure.

3-4-2 The Assumption of Basement Depth

The depth of basement, analyzed by the result ① ∿ ⑤ is as follows;

For this group the depth $\overline{AB}/2$ at the minimum point of ρa, the depth analyzed in accordance with the S-line method (one-dotted and two-dotted chain lines) and the depth, analyzed in accordance with the standard curve checkup method have relatively similar trend and analysed depths of basement were assumed to be proper.

Assumed depths are as follows;

i) Group 3 Assumed depth of basement 460 m ∿ 760 m

ii) Group 2 Assumed depth of basement 150 m ∿ 260 m

iii) Group 1 Assumed depth of basement 500 m ∿ 600 m

3-4-3 Interpretation

The underground structure of A survey line, assumed from the results of apparent resistivity profile and the analysed profile is shown in Fig. 7-6 (Appendix).

a) Interpretation on profile

As the resistivity line of discontinuity is set between the station 18 and 20 in accordance with the resistivity profile, the geological discontinuity line was assumed around here.

Reasons why this discontinuous line is set oblique are as follows;

(1) When the potential electrodes are at the same position, the type of VES curve is changed as follows;

No. of station	Character of VES curve
A-14	The Ascending part of right branch goes up to near of $\frac{\overline{AB}}{2}$=1500m and from near of $\frac{\overline{AB}}{2}$=2000m tends to descend.
A-16	The ascending part of right branch goes up to near of $\frac{\overline{AB}}{2}$=1250m and from near of $\frac{\overline{AB}}{2}$=2000m tends to descend.
A-18	The ascending part of right branch goes up to near of $\frac{\overline{AB}}{2}$=500m and slowly up to near of $\frac{\overline{AB}}{2}$=2000m.
A-26	The ascending part of right branch goes up to near of $\frac{\overline{AB}}{2}$=750m, 1000m and then 1250m and descend from near of $\frac{\overline{AB}}{2}$=1500m and rather ascend from near level of 2000m.

(2) When these facts are thought to be due to the influence of the site of current electrodes (the influence of earth's surface), their changed positions are shown as follows;

No. of station	AB/2	Locating of current electrode	Character of curve
A-14	1500m	8 - 20	goes up
	2000m	6 - 22	goes down
A-16	1250m	11 - 21	goes up
	1500m	10 - 20	goes down
A-18	500m	16 - 20	goes up
	750m	15 - 21	slowly goes up
A-26	1250m	21 - 31	goes up
	1500m	20 - 30	goes down

As is obvious from this table the point where the downward trends of VES curves, namely the depths of $\overline{AB}/2$ coincide comparatively with each other is found within the range of stations 20 ~ 22 (center 21).

Consequently, the low resistivity zone is assumed to be situated at the shallow part of earth's surface around the station 21.

(3) The resistivity line of dicontinuity assumed within the range of stations 18 ~ 20 is situated in the dept.

From the above facts (2) and (3), inclined structure is assumed, and the geological discontinuous line is drawn under the following conditions;

The resistivity discontinuous line, assumed between the stations 12 ~ 14 has the throw of basement depth between groups 1 and 2, and there is a difference in the resistivities in the intermediate layer.

Thus, the resistivity discontinuous line can be set, and this gradient is assumed to show the same trend as the left resistivity discontinuous line does.

As can be inferred from the underground structure profile, groups 3 and 1 were formerly continuous and it is interpreted that the group 2 was blocked and ascended through the structural movement.

As the resistivity discontinuity line in the north of the station 28 is not obvious, the exact resistivity discontinuous line cannot be decided.

(4) The foregoing relates to the interpretation for each group. Out of VES curves for the group 2 which should be especially emphasized, the one at the station 18 tends to ascend, when $\overline{AB}/2$ is 1250m and above, more slowly compared with the curve at stations 14 and 16.

After the detailed consideration, it turned out that the existence of low resistivity zone is probable at the depth of 340m and below.

This low resistivity zone is situated at the place, coinciding nearly with the geological discontinuous line, assumable around this area and there is near this area a possibility of alteration took place.

(5) From the underground structure profile (Fig. 7-6, Appendix) following can be interpreted; the influence of alteration through hot water and vapor, ascending from the depth around the station 18 along the fault or geologic weak line is concentrated on the station 18 and this found its expression in the low resistivity 1.5 ∿ 1.6 Ωm.

This low resistivity layer is underlaid at the shallow part comparable with gravel in accordance with the geological profile. It is conceivable that the hot water and vapor moved to sideways through the gravel at the shallow part and gushed out as the hot spring to the ground surface along the geologic weak line.

Geological features around the drill hole IQ-11 are assumed to be generated by the low-temperature hot water, which ascended in accordance with knowledgment about the cores and the center of heat source around this area is supposed to be at the depth around the station 18, when judged from the resistivity value.

c) Interpretation on plane

Fig. 7-11 (Appendix) was prepared, compared with the $\overline{AB}/2$=500m apparent resistivity distribution plane and the surface geological map. As its result the following was obtained.

(1) The resistivity discontinuous line assumed between the stations 18∿20 at the survey line A coincide with the E-W geological discontinuous line, passing around the station 20.

(2) The resistivity discontinuous line, assumed between the stations 12 ∿ 14 on the survey line A coincides with the E-W geological discontinuous line, passing around the stations 14 12.

(3) The resistivity of the second formation at the station 12 on the survey line C is low one compared with the other at the adjacent station. So if the resistivity discontinuous line is assumed at the shallow part, this coincides with the N-S geological discontinuous line, passing around the station 12.

(4) The formation around and north of the station 28 on the survey line A and around and east of the station 10 on the survey line B can safely be one. The resistivity values are high at the east side and low at the north side. The difference between the limestones and volcanic rocks is not distinct from the analyzed resistivity values.

(5) Resistivity discontinuous line, though not so clear, can be assumed between the station 10 ∿ 8 on the survey line C. The resistivity value is high at the east side and its trend coincides well with the apparent resistivity distribution plane. Generally speaking, the compact and consolidated rock formations have high resistivities and the one at this area is assumed to be comparable with volcanic rocks according to geological survey. From the foregoing the interpretation on the plane can be summarized as follows;

1) Extremely low resistivity formation is distributed, surrounded by the two geological discontinuous line, which is assumed to show alteration and existence of hot water.

2) Because the survey line A is set so as to go paralled with the N-S geological discontinuous line connected closely with the geothermal showings at this area, the E-W discontinuous line could clearly be grasped, but the N-S discontinuous line was not clear. But according to the core of hole IQ-11, the hydrothermal alteration caused by the activity of hot spring is observed at the volcanic rocks and the shear zone just under the moraine and the low resistivity is also continuously grasped on the survey line A, passing around. If this alteration is closely related with the geothermal showing, it can be assumed that the influence of the N-S geological discontinuous line is also strong as well as in the case of 1).

4. Measurement of Temperatures in Drill Holes

The geothermal measurement was effected at the depth 20 m and 300 m as a step to infer the underground geothermal structure. For the depth 300 m the temperature recovery test was made at the same time. Measured holes amounted in all to 11, out of which 10 holes relate to the depths 20 m and 1 hole to the depth 300 m.

4-1 Geothermal Survey at the Depth of 20 m

4-1-1 Measuring equipment

Water level sensor, and thermal sensor	;	metallic resistor type	;	Kaihatsu Kogyo Co., Ltd.
Winch	;	capacity 350 m	;	"

Recorder	;	thermometric recorder	;	Watanabe Sokuki Co., Ltd.
Depth recording system	;	pulse encoder	;	Tamagawa Seiki Co., Ltd.

4-1-2 Measuring Method

After drilling the hole of depth 20 m, the rod of size BX was inserted to avoid the corruption of hole wall and furthermore, it was left with a cap on it as it is for over 3 days to avoid the inclusion of foreign matters from the head and removed the disturbance of geothermal distribution, conceivable during the drilling work. Then the temperature measurement was made, using the above equipment. In the temperature measurement after holding the sensor at the level of the head for five minutes the temperature within the hole was measured continuously at the rate of about 4 m/min.

As used units can record automatically the temperatures and levels the results from the recording paper were read out after the work.

The arrangement of units are shown in Fig. 7-12.

4-1-3 Results

Measured results are shown as follows;

Drilling sites are shown in the geological map, Fig. 7-3 (Appendix) and measured results in Table 7-8. Furthermore, the results of geothermal measurement are shown on the geological log in a graphical way.

a) Geothermal measurement of hole IQ-1

The water level within the hole was reached at the depth of 5.2 m. The influence of atmospheric temperature is strong up to the depth of 6 m, but from the depths of 7 m on, the geothermal gradient is generally uniform (1°C/10m), reaching 11.3°C at the depth of 20m. The geology is composed of agglomerate.

b) Geothermal measurement of hole IQ-2

The water level within this hole is 11.5 m the lowest out of ten. As the depth grows beyond 12 m, the geothermal temperature grows with the gradient of about 1°C/10 m and the bottom-hole temperature shows 10.9°C. Geology consists of soil of weathered andesitic rocks at the depth of 0 ∿ 17.45 m and agglomerates at 17.45 ∿ 20.50 m.

c) Geothermal measurement of hole IQ-3

The water within the hole is reached at the depth of 3.1 m. As the hole is deepened beyond 4 m, the temperature grows with the gradient about 0.6°C/10 m but bottom-hole temperature is 8.3°C, the lowest one out of 10 holes. Geology consists of soil of weathered andesitic rocks at the depth of 0 ∿ 3.00 m and andesitic rocks at 3.00 ∿ 20.00 m.

Fig. 7-12 Equipment of Temperature Measurement

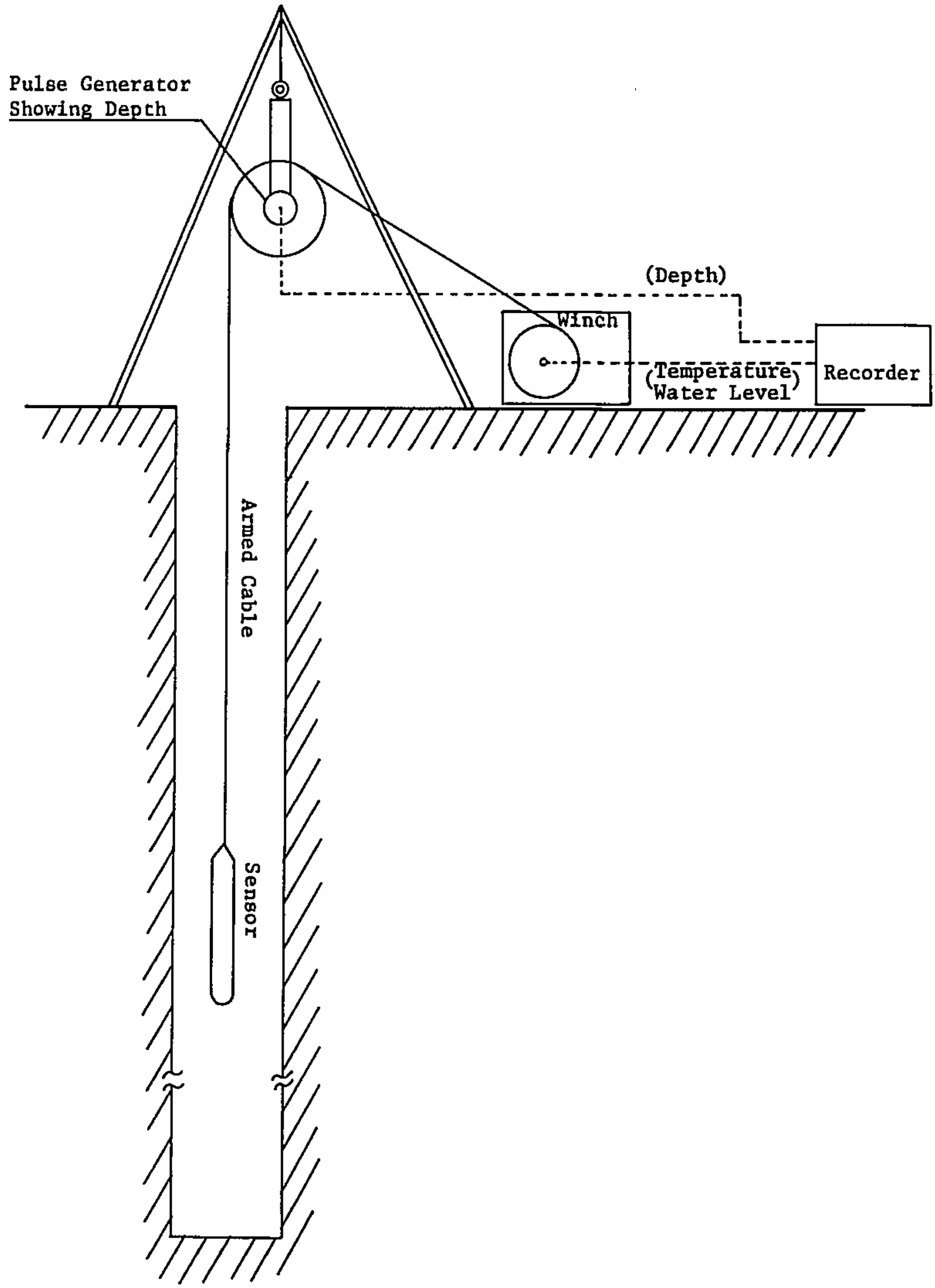


Table 7-8 Results and Conditions of Temperature Measurement (IQ-1 ~ IQ-10)

No. of Drill Hole	IQ-1	IQ-2	IQ-3	IQ-4	IQ-5	IQ-6	IQ-7	IQ-8	IQ-9	IQ-10
Working Period (1979) From	Oct.8	Oct.9	Oct.4	Oct.6	Oct 2	Sep.21	Oct.11	Sep.25	Sep.28	Sep.30
Working Period (1979) To	Oct.9	Oct.10	Oct.5	Oct.7	Oct.3	Sep.24	Oct.12	Sep.27	Sep 29	Oct.1
Measuring Day	Oct.13 11°20'	Oct.13 10°35'	Oct.12 11°00'	Oct.12 10°10'	Oct.8 11°00'	Oct.6 11°15'	Oct.16 14°30'	Oct.4 11°23'	Oct.8 10°30'	Oct.6 13°15'
Weather	Fine	Fine	Fine	Fine	Cloudy	Fine	Cloudy	Cloudy	Fine	Fine
Direction of Wind	Windless	Windless	West Breathing	North-East Breathing	North-East Winding	North-East Breathing	West Breathing	North Breathing	North-East Breathing	North-East Breathing
Atmospheric Temperature	25°C	20°C	20°C	19°C	19°C	23°C	17°C	12°C	17°C	24°C
Depth	20.50m	20 00m	20 00m	20 00m	20.60m	20.70m	20.40m	20 80m	20.00m	20.00m
Water Level in Drill Hole	5.2m	11.5m	3.1m	0.0m	3.5m	0 0m	0.2m	0 2m	8 2m	2 8m
0m	15.2°C	18.5°C	16.8°C	17.7°C	16.7°C	10.6°C	17.1°C	12.5°C	15.6°C	17.8°C
1m	15.0°C	18.2°C	16.2°C	11.6°C	15.7°C	10.8°C	9.4°C	12.5°C	15.0°C	17.0°C
2m	14.8°C	17.8°C	15.7°C	11.3°C	15 0°C	9 4°C	9.4°C	11.2°C	14.6°C	16.2°C
3m	14.5°C	17.3°C	15.4°C	11.3°C	14.5°C	9 4°C	9.6°C	11.3°C	14.3°C	14.2°C
4m	14.3°C	16.7°C	7.3°C	11.3°C	8.6°C	9 7°C	9.5°C	12.0°C	14.1°C	10.0°C
5m	14.1°C	16.2°C	7.2°C	11.3°C	8.7°C	10.0°C	9.5°C	13.1°C	13.7°C	9.7°C
6m	10.7°C	15.8°C	7.3°C	11 3°C	9.0°C	10.4°C	9.8°C	13.7°C	13.6°C	9.6°C
7m	10.6°C	15.4°C	7.3°C	11.3°C	9.1°C	11.0°C	10.2°C	14.5°C	13.5°C	9.5°C
8m	10.6°C	15.0°C	7.3°C	11.3°C	9.2°C	11.4°C	10 4°C	15.2°C	13.2°C	9.5°C
9m	10.7°C	14.7°C	7.4°C	11.4°C	9.2°C	11.8°C	10 6°C	15.7°C	9.4°C	9.5°C
10m	10.7°C	14.4°C	7.5°C	11.4°C	9.2°C	12.1°C	11.0°C	16.2°C	9.3°C	9.8°C
11m	10.8°C	14.2°C	7.6°C	11.5°C	9.1°C	12.4°C	11.0°C	16.8°C	9.4°C	9.9°C
12m	10.9°C	10.2°C	7.7°C	11.5°C	8.9°C	12.6°C	10 5°C	17.3°C	9.5°C	9.7°C
13m	11.0°C	10.2°C	7.7°C	11.5°C	8.8°C	13.0°C	10.5°C	17.8°C	9.6°C	9.5°C
14m	11.0°C	10.2°C	7.8°C	11.7°C	8.8°C	13.3°C	10.5°C	18.3°C	9.7°C	9.3°C
15m	11.0°C	10.3°C	7.8°C	11.8°C	8.8°C	13 6°C	10.5°C	18.6°C	–	9.2°C
16m	11.1°C	10.4°C	7.9°C	11.9°C	8.8°C	14.0°C	10 4°C	18 7°C	–	9.1°C
17m	11.1°C	10.5°C	8.2°C	12 6°C	8.8°C	14.3°C	10.5°C	18.8°C	–	9.1°C
18m	11.2°C	10.6°C	8.3°C	12.1°C	8 8°C	14.5°C	10.7°C	19.4°C	–	9.1°C
19m	11.3°C	10.8°C	8.3°C	12 2°C	8.9°C	14.7°C	11.0°C	20.2°C	–	9.1°C
20m	11.3°C	10.9°C	8.3°C	12.2°C	8.9°C	15.0°C	10.9°C	20 6°C	–	9.1°C

d) Geothermal measurement of hole IQ-4

As this hole is situated near the junction of branched rivers, the hole is filled with water up to the head. The gradient is about 0.2°C/10 m from the head up to 13 m, but from this zone on it rises to about 1°C/10 m and at the bottom reaches 12.2°C. The geology is composed of gravel.

e) Geothermal measurement of hole IQ-5

The water level is reached at the depth of 3.5 m. The temperature rises with the gradient of about 1°C/10 m between 4 ∿ 10 m, but beyond this range it is hardly changed. The bottom-hole temperature is 8.9°C. The section 0   8.4 m consists of gravel and the section 8.4 m ∿ 20 m of volcanic rocks.

f) Geothermal measurement of hole IQ-6

The hole is filled with water up to the head. Under the depth of 2 m where no atmospheric influence is conceived, the gradient shows about 3°C/10 m and at the bottom-hole temperature reaches 15°C. This is the highest next to the hole IQ-8 for the ones at the bottom. The geology consists of gravel from the head up to the bottom.

g) Geothermal measurement of hole IQ-7

The water level is reached at the depth of 0.2 m. The temperature of water ranges from 9.4°C to 11.0°C, but it changes not linearly. The maximum temperature are observed at the two points 10 ∿ 11 m and 19 m. Temperature changes with the gradient -5°C/10 m to 4°C/10 m. The geology is composed of gravel from 0 m up to 20 m.

h) Geothermal measurement of hole IQ-8

The water level is reached at the depth of 0.2 m. The temperature reaches 11.2°C at the depth of 2 m and 20.6°C at the bottom which is maximum one in all.

The temperature is changed with the gradient of about 5.2°C/10 m in the average term, but within the range of 1 ∿ 11°C/10 m. The geology consists of gravel.

i) Geothermal measurement of hole IQ-9

The water level is reached at the depth of 8.2m, which is deepest next to the one of hole IQ-2. The temperature within the hole is hight near the head of hole (as the atmospheric temperature) under the influence of the one on the ground. The water temperature within the hole rises with the gradient of about 1°C/10 m, showing 9.7°C at depth of 14 m. The geology consists of gravel. The measurement of temperature beyond the depth 15 m could not be done owing to the inclusion of foreign matters.

j) Geothermal measurement of hole IQ-10

The water level is reached at the depth of 2.8 m. Values of water temperature within the hole are changed downward in wavelike manner; they show 10°C at the depth of 4 m and 9.1°C at the depth of 11 m. The temperature is changed at the gradient -3 ∿ 3°C/10 m. The geology consists of weathered soil at the depth of 0 ∿ 4.10 m and andesitic pebble at the depth of 4.10 ∿ 20.00 m.

4-2 Geothermal Survey at the Depth of 300 m

4-2-1 Measuring Equipments

They are the same one as used in 4-1-1.

4-2-2 Measuring Method

It is the same one as used in 4-1-2.

4-2-3 Results

Measured results are as follows; Table 7-9 relates to the record of measured temperature, Table 7-10 to the results of measured temperature.

Table 7-9 Conditions of Temperature Measurement (IQ-11)

Date	Oct. 22, 1979
Weather	Fine
Atmospheric Temperature	8°C
Beginning Time of Measurement	21°34'
Finishing Time of Measurement	22°14'
Depth of Measurement	290m
Speed of Sensor	7.2m/min.
Water Level	5.5m
Temperature of Bottom	39.3°C
Space Time	0.5 Hour
Water in Drill Hole	Natural Water
Note	0∿ 75m: in Casing and Full Cementation 75∿220m: in Casing 220∿276m: in Rod 276∿290m: in Open

Table 7-10 Results of Temperature Measurement (IQ-11)

Depth (m)	Tempera-ture (°C)	Temperature Gradient (1) (°C/10m)	Temperature Gradient (2) (°C/10m)
0	9.5		
10	17.3	7.8	-
20	20.7	3,4	-
30	22.8	2,1	3,8
40	25.5	2,7	2,7
50	28.4	2,9	2,3
60	30.7	2,3	2,2
70	32.4	1,7	1,8
80	33.8	1,4	1,4
90	34.6	0,8	1.0
100	35,2	0,6	0,6
110	35.6	0.4	0.4
120	35,9	0,3	0,3
130	35.9	0	0,2
140	36.2	0,3	0,2
150	36.5	0,3	0,2
160	36.6	0,1	0,2
170	36.8	0,2	0,2
180	37.0	0,2	0,1
190	37,1	0,1	0.1
200	37.2	0,1	0.1
210	37.4	0.2	0.1
220	37,3	-0,1	0,2
230	37.8	0.5	0,2
240	37.9	0,1	0,3
250	38,2	0,3	0.3
260	38,8	0.6	0.3
270	38.9	0,1	0,3
280	39.1	0.2	-
290	39.3	0,2	-

(1) : Interval 10m

(2) : Interval 10m, Running Average Five Points

Fig. 7-13 to the graphic presentation of measured temperature and Fig. 7-14 to the temperature gradient curve. The measured depth ranges from 0 m to 290 m and the condition within the hole was with casing and cementation between the depth

0 ∿ 75 m, with casing between 75 ∿ 220 m, with rod between 220 m ∿ 276 m and open between 276 m ∿ 290 m.

Descent of sensor was impossible under 290 m because the corruption of hole walls took place around 290 m when the rod was inserted to protect the hole walls during the temperature measurement.

Water level is reached within the hole at the depth of 5.5 m.

Up to the depth around 80 m the rise of temperature is remarkable, reaching 33.8°C beyond 17.3°C of water temperature within the hole at the depth of 10 m.

From that depth up to 290 m the rise of temperature is slow, reaching only 39.3°C.

The temperature gradient is steep, 5.6 1.6°C/10 m up to the depth around 80 m and 0.7 ∿ 0.1°C/10 m up to the depth 210 m. It tends to be slow as the depths increases and at the depth of 220 m it shows negative value, -0.1°C/10 m.

However, it converts again into positive value and it is found in the range of 0.6 0.1°C/10 m between 230 m 290 m. At the depth of 230 m it reaches 0.5°C/10 m and 0.6°C/10 m at the depth of 260 m.

Correlation of measured result to the geology within the hole is as follows;

Between the depth 0 m 80 m where the rise of temperature is remarkable and the temperature gradient is also steep the geology corresponds to the gravel which is loose in the consolidation.

Others are composed of gravel consolidated rather tight (up to the depth 196.30 m), dolerite and porphyrite in the form of dyke (depth 196.30 ∿ 233.20 m), andesite (233.20 ∿ 253.90 m) and sheared zone by fault (253.90 ∿ 300.50 m).

The negative temperature gradient at the depth of 220 m corresponds to the part of dolerite which suffered from the weak alteration.

Points at the depth of 230 m and 260 m where the temperature gradient is relatively high correspond respectively to the part where porphyrite suffered from the hydrothermal alteration converted into the white clay and to the sheared zone converted into the clay.

Results of temperature measurement within the hole by the maximum thermometer during the drilling are shown in Table 7-11 and Fig. 7-15.

Besides, the remarkable lost circulation was not observed during the drilling work.

Fig. 7-13 Results of Temperature Measurement (1Q-11)

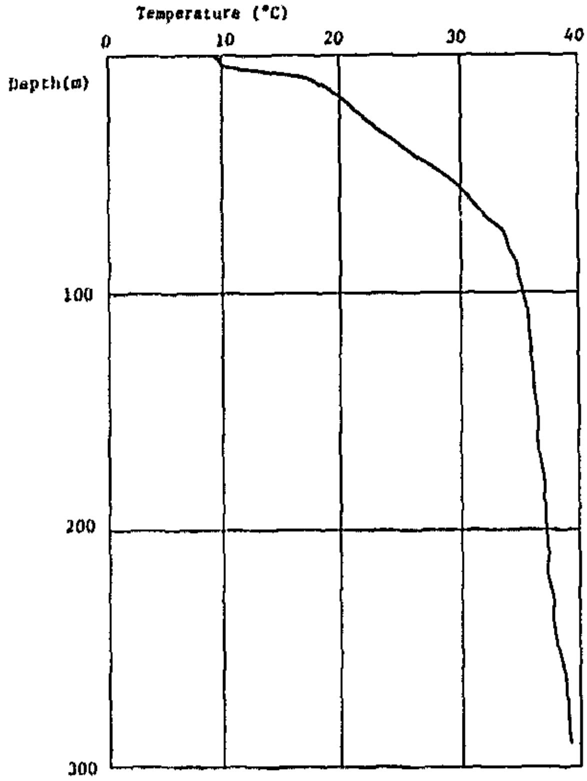


Fig. 7-14 Temperature Gradient Curve (1Q-11)

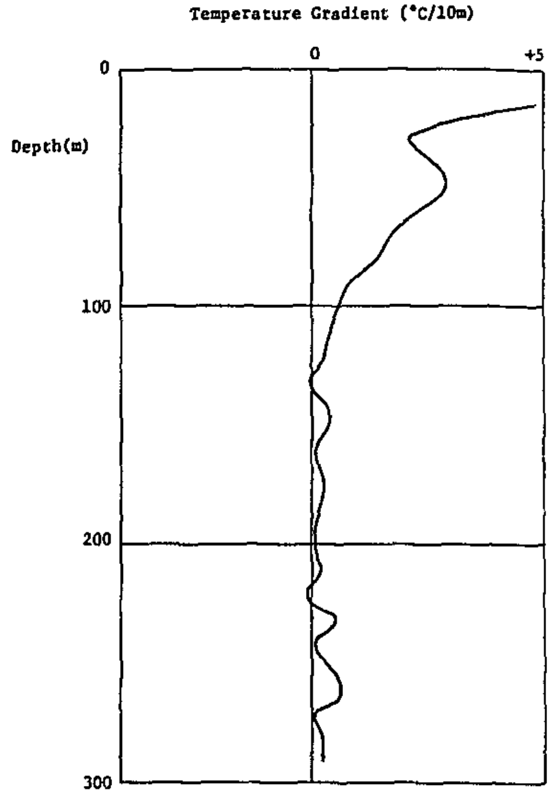
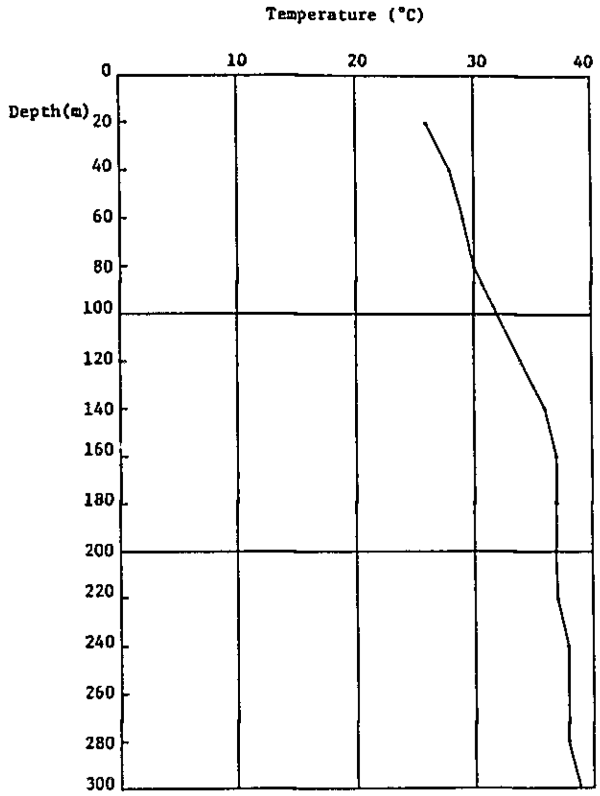


Table 7-11 Bottom-Hole Temperature in Drilling Work (Logged by Maximum Thermometer)

Date	Depth (m)	Temperature (°C)	Temperature (°C) of Mud Water In	Temperature (°C) of Mud Water Out	Atmospheric Temperature (°C)	Space Time (Hour)
Oct. 2	20.00	26	15	20	11	1.0
"	40.00	28	-	-	11	1.0
"	60.00	29	-	-	13	1.0
Oct. 10	80.00	30	15	20	18	1.0
"	100.00	32	-	-	-	1.0
"	120.00	34	-	-	-	1.0
"	140.00	36	-	-	-	1.0
"	160.00	37	-	-	-	1.0
Oct. 20	180.00	37	10	15	10	1.0
"	200.00	37	-	-	-	1.0
"	220.00	37	-	-	-	1.0
"	240.00	38	-	-	-	1.0
"	260.00	38	-	-	-	1.0
"	280.00	38	-	-	-	1.0
"	300.50	39	-	-	-	1.0

Fig. 7-15 Bottom-Hole Temperature In Drilling Work (Logged by Maximum Thermometer)



4-3 300 m Depth Temperature Recovery Test

4-3-1 Measuring Equipments

They are the same as used in 4-1-1.

4-3-2 Measuring Method

It is the same one as used in 4-1-2.

4-3-3 Results

The rod were inserted up to the bottom of hole and within the 72 hours after washing the hole, the temperature logging was performed 10 times to observe the temperature recovery.

Measured sections is depth 0 m ∿ 293 m and the conditions within the hole is as follows;

0 m ∿ 75 m; with casing and cementation

75 m ∿ 220 m; with casing

220 m ∿ 276 m; with rod

276 m ∿ 293 m; open

It was impossible to measure a temperaure under 293 m due to caving around 290 m during insertion of washing rod. The record of temperatures log and measured values over 1 10 times are shwon in the table 7-12, 7-13, and 7-14.

To obtain the equilibrium temperature the following formula is often used.

$$T\theta = T\theta \to \infty \left\{ 1 - \exp\left(\frac{\theta}{t+\theta} \right) \right\}$$

where θ; elasped time (hour since the circulation of cooling water interrupted.

t; time (hour) from the time when drilling proceeded beyond the depth till the interruption of cooling water circulation.

$T\theta\to\infty$; Inferred equilibrium temperature.

Accordingly, value of $\frac{\theta}{t + \theta}$ is plotted along the axis of abscissas (logarithmic), Tθ along the axis of ordinates and then the inferred equilibrium temperature is obtained through the value of Tq where

$$\lim_{Q\to\infty} \frac{\theta}{t + \theta} = 1$$

This relation between the temperature and time is shown

Table 7-12 Conditions of Temperature Recovery Test(IQ-11)

Item \ No	No 1	No 2	No 3	No 4	No. 5	No 6	No 7	No 8	No. 9	No 10
Space Time	0 6 Hr	4 8 Hr	8 1 Hr	12.5 Hr	17.9 Hr	23 8 Hr	36.0 Hr	47.8 Hr	59 9 Hr	66.8 Hr
Date(1979)	Oct 22	Oct 23	Oct 23	Oct.23	Oct 23	Oct 23	Oct.24	Oct 24	Oct.25	Oct.25
Weather	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Fine	Cloudy
Atmospheric Temperature	8°C	1°C	-1°C	18°C	22°C	7°C	18°C	9°C	19°C	13°C
Beginning Time of Measurement	21°34'	1°45'	5°03'	9°27'	14°53'	20°44'	9°00'	20°46'	8°54'	15°45'
Finishing Time of Measurement	22°14'	2°24'	5°44'	10°05'	15°05'	21°22'	9°37'	21°25'	9°31'	16°21'
Depth	290m	290m	291m	290m	290m	289m	292m	292m	293m	293m
Speed of Sensor	7 2 m/min	7 4 m/min	7 1 m/min	7 6 m/min	7.8 m/min	7 6 m/min	7.9 m/min	7.5 m/min	7.9 m/min	8 1 m/min
Water Level	5.5m	5.5m	5 0m	4.5m	5.2m	4.5m	4 2m	4.0m	3.8m	L4m
Temperature of Bottom	39 3°C	39 4°C	39 4°C	39.6°C	39.5°C	39.5°C	39 4°C	39.2°C	39.3°C	39.5°C
Water in Drill Hole	Natural Water									
Note	0~75m in Casing and Full Cementation, 75 00~220 00m in Casing, 220.00~276.00m in Rod, 276 00~293m in Open Cleaning in drill hole with natural water stopped at 21 00 of Oct.22, 1979									

Table 7-13 Results of Temperature Recovery Test (IQ-11)

Depth \ No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
0m	9.5°C	8.7°C	0.0°C	13.5°C	16.8°C	6.2°C	15.6°C	7.0°C	15.0°C	10.8°C
20m	20.7°C	21.5°C	19.5°C	19.2°C	18.5°C	18.7°C	18.6°C	18.6°C	18.4°C	19.9°C
40m	25.5°C	28.0°C	24.5°C	24.3°C	23.7°C	24.4°C	24.0°C	23.5°C	23.9°C	23.7°C
60m	30.7°C	32.1°C	30.2°C	30.3°C	29.9°C	30.5°C	30.2°C	31.1°C	30.3°C	29.5°C
80m	33.8°C	34.6°C	34.0°C	33.9°C	34.1°C	34.2°C	34.2°C	33.4°C	34.8°C	33.2°C
100m	35.2°C	33.5°C	35.4°C	35.5°C	35.5°C	35.7°C	35.9°C	35.8°C	36.0°C	35.1°C
120m	35.9°C	36.0°C	36.0°C	36.0°C	36.3°C	36.4°C	36.4°C	36.4°C	36.5°C	36.4°C
140m	36.2°C	36.6°C	36.5°C	36.6°C	36.6°C	36.8°C	36.8°C	36.7°C	36.9°C	37.0°C
160m	36.2°C	36.9°C	36.9°C	36.9°C	37.0°C	37.0°C	37.0°C	37.0°C	37.1°C	37.3°C
180m	37.0°C	37.1°C	37.0°C	37.2°C	37.2°C	37.3°C	37.2°C	37.3°C	37.3°C	37.6°C
200m	37.2°C	37.5°C	37.6°C	37.7°C	37.7°C	37.8°C	37.6°C	37.7°C	37.7°C	38.0°C
220m	37.3°C	37.4°C	37.3°C	37.4°C	37.4°C	37.6°C	37.4°C	37.4°C	37.3°C	37.8°C
240m	37.9°C	38.0°C	38.0°C	38.1°C	38.0°C	38.3°C	38.1°C	38.0°C	38.0°C	38.3°C
260m	38.8°C	38.8°C	38.8°C	38.9°C	38.9°C	38.9°C	39.0°C	38.7°C	38.8°C	39.1°C
280m	39.1°C	39.1°C	39.2°C	39.3°C	39.3°C	39.3°C	39.2°C	39.0°C	39.1°C	39.4°C
290m	39.3°C	39.4°C	39.6°C	39.4°C	39.5°C	39.5°C	39.4°C	39.2°C	39.3°C	39.5°C

Table 7-14 Average Temperature Gradient (IQ-11)

Depth \ No	No 1	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No 10
0 ~ 20m	5.6°C/10m	6.4°C/10m	9.8°C/10m	2.9°C/10m	0.9°C/10m	6.3°C/10m	1.5°C/10m	5.8°C/10m	1.7°C/10m	4.6°C/10m
20 ~ 40m	2.4°C/10m	3.3°C/10m	2.5°C/10m	2.6°C/10m	2.6°C/10m	2.9°C/10m	2.7°C/10m	2.5°C/10m	2.8°C/10m	1.9°C/10m
40 ~ 60m	2.6°C/10m	2.1°C/10m	2.9°C/10m	3.0°C/10m	3.1°C/10m	3.1°C/10m	3.1°C/10m	3.8°C/10m	3.2°C/10m	2.9°C/10m
60 ~ 80m	1.6°C/10m	1.3°C/10m	1.9°C/10m	1.8°C/10m	2.1°C/10m	1.9°C/10m	2.0°C/10m	1.2°C/10m	2.3°C/10m	1.9°C/10m
80 ~ 100m	0.7°C/10m	0.5°C/10m	0.7°C/10m	0.8°C/10m	0.7°C/10m	0.8°C/10m	0.9°C/10m	1.2°C/10m	0.6°C/10m	1.0°C/10m
100 ~ 120m	0.4°C/10m	0.3°C/10m	0.3°C/10m	0.3°C/10m	0.4°C/10m	0.4°C/10m	0.3°C/10m	0.3°C/10m	0.3°C/10m	0.7°C/10m
120 ~ 140m	0.2°C/10m	0.3°C/10m	0.3°C/10m	0.3°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.3°C/10m
140 ~ 160m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.1°C/10m	0.1°C/10m	0.2°C/10m	0.1°C/10m	0.2°C/10m
160 ~ 180m	0.2°C/10m	0.1°C/10m	0.1°C/10m	0.2°C/10m	0.1°C/10m	0.2°C/10m	0.1°C/10m	0.2°C/10m	0.1°C/10m	0.2°C/10m
180 ~ 200m	0.1°C/10m	0.2°C/10m	0.3°C/10m	0.3°C/10m	0.3°C/10m	0.3°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m
200 ~ 220m	0.1°C/10m	-0.1°C/10m	-0.2°C/10m	-0.2°C/10m	-0.2°C/10m	-0.1°C/10m	-0.1°C/10m	-0.2°C/10m	-0.2°C/10m	-0.1°C/10m
220 ~ 240m	0.3°C/10m	0.3°C/10m	0.4°C/10m	0.4°C/10m	0.3°C/10m	0.4°C/10m	0.4°C/10m	0.3°C/10m	0.4°C/10m	0.3°C/10m
240 ~ 260m	0.5°C/10m	0.4°C/10m	0.4°C/10m	0.4°C/10m	0.5°C/10m	0.3°C/10m	0.5°C/10m	0.4°C/10m	0.4°C/10m	0.4°C/10m
260 ~ 280m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.1°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m
280 ~ 290m	0.2°C/10m	0.3°C/10m	0.2°C/10m	0.3°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.2°C/10m	0.1°C/10m

in Fig. 7-16. When the equilibrium temperature is inferred from this, table 7-15 is obtained.

Temperature recovery curve is shown in Fig. 7-17 and the data for obtaining the inferred equilibrium temperature is shown in Table 7-16.

As the result of recovery test the reduction of temperature was observed between the depth 10 m ∿ 110 m, but from the depth 110 m to the bottom the temperature is recovered with the range of 0.2 ∿ 0.8°C and its maximum range is 0.8°C at the depth of 140 m and 220 m.

The equilibrium temperature at the bottom is about 40°C.

5. Drilling Work

5-1 Outline of Drilling Work

The drilling work was executed for the purpose of obtaining the data on the judgement of possibilities of geothermal development as a step to securing the electric power, accompanied by the mine development around the southern part of Cuzco province.

It was initiated on the 21st, Sept. 1979 and completed on the 20th, Oct. 1979.

The number of holes, drilled during this period amounts to 10 for the depth of 20 m. and 1 for the depth 300 m., and the whole depth drilled to 502.90 m.

During the work a Japanese supervisor and the Geotec Co., Ltd. on the actual location teamed up with each other in two shifts of twelve hours with the help of two drilling machines.

For the drilling the wire line method was applied.

Furthermore, the bentnitic mud mingled with CMC (25 QT) and LIBONATE was applied to protect the wall of the hole.

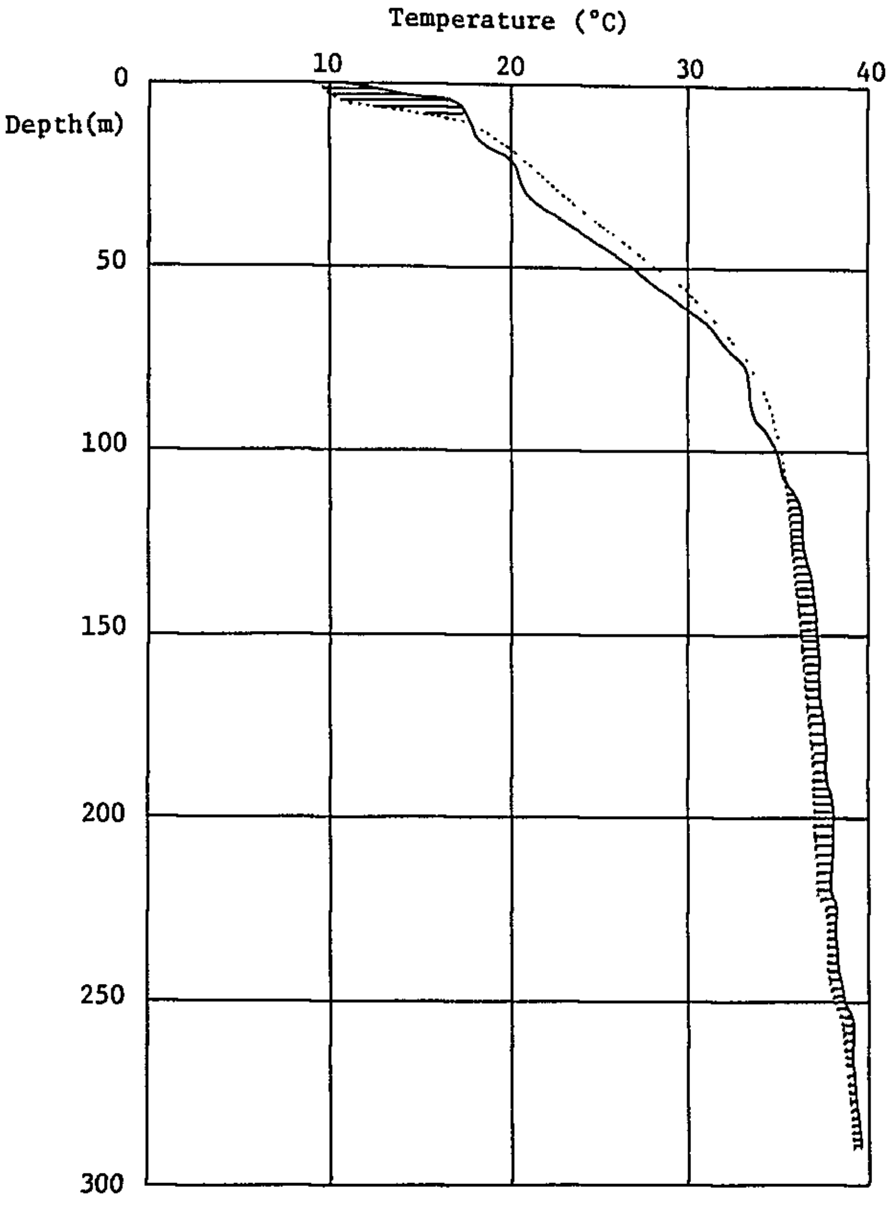
As the lithology is made of gravel and andy mud, caving, swelling and, balling up were generated, which affected the efficiency of working process, but the work was completed happily without any labor accidents and big troubles.

Drilling efficiency per shift is 3.45 m/shift in the worst and 10.25 m/shift in the best, and 6.29 m/shift on the average. Table 7-17 shows summary data of drilling.

5-2 Drilling Work and Rigs Used

As the geology at the site planned for the drilling work were supposed to be grovel, sandy mud and andesite, the drilling work was performed with mud water which based on bentnite and casing.

Fig. 7-16 Temperature Recovery Test (IQ-11)



------- : Temperature Measurement of No. 1

——— : Temperature Measurement of No. 10

▬ : Width of Temperature Recovery

Table 7-15 Inferred Equilibrium Temperature vs Depth(IQ-11)

Depth	Inferred Equilibrium Temperature
100m	36.3°C
200m	38.0°C
290m	39.5°C

Fig. 7-17 Temperature Recovery Curve (ID-11)

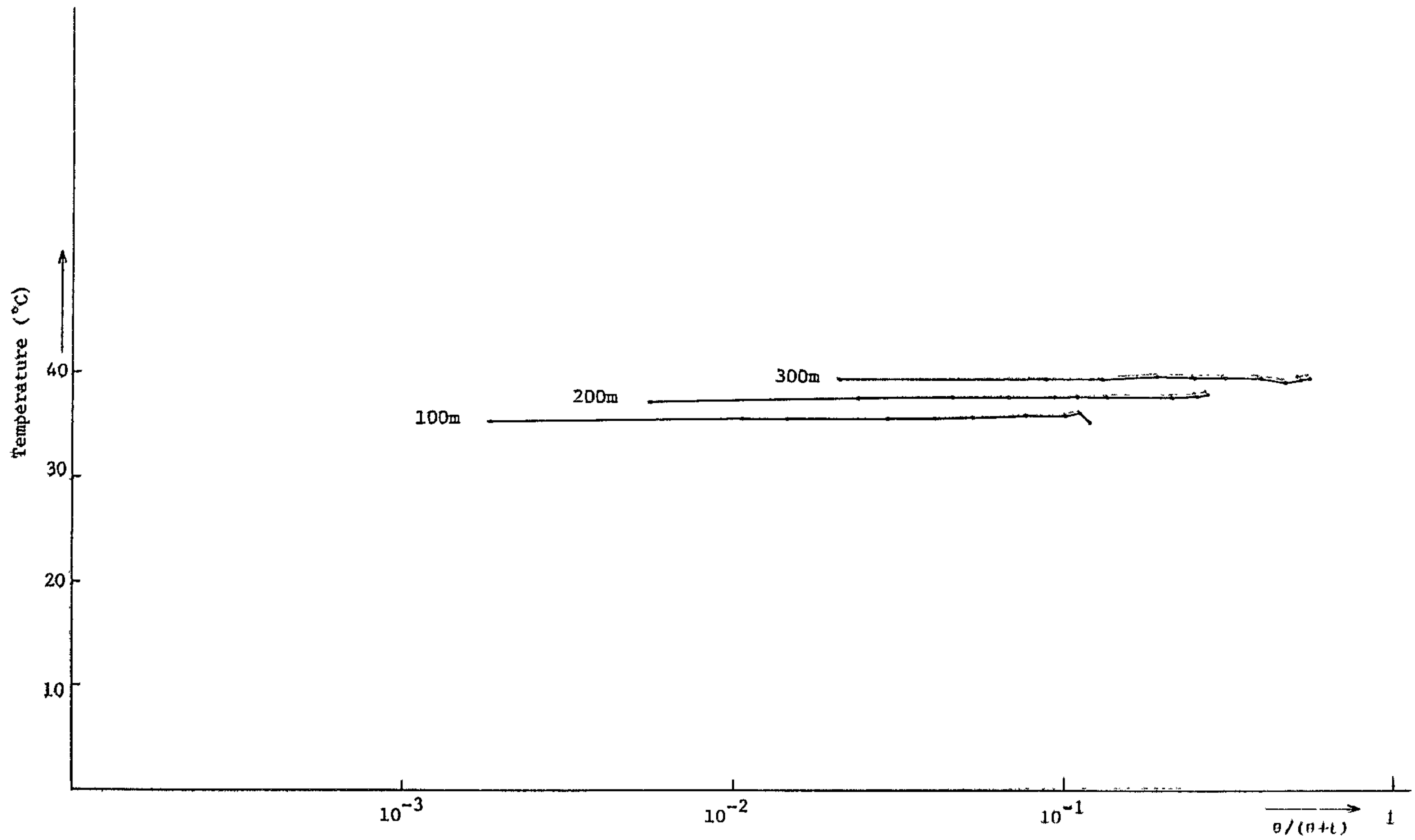


Table 7-16 Data used for Temperature Recovery Calculation

Depth	t	θ	θ/(θ+t)	Temperature
100m	429 Hr	0.8 Hr	1.86×10^{-3}	35.2°C
		5.0 Hr	1.15×10^{-2}	35.5°C
		8.3 Hr	1.90×10^{-2}	35.4°C
		12.7 Hr	2.88×10^{-2}	35.5°C
		18.1 Hr	4.05×10^{-2}	35.5°C
		24.0 Hr	5.30×10^{-2}	35.7°C
		36.2 Hr	7.78×10^{-2}	35.9°C
		48.0 Hr	1.01×10^{-1}	35.8°C
		60.1 Hr	1.23×10^{-1}	36.0°C
		67.0 Hr	1.35×10^{-1}	35.1°C
200m	178 Hr	1.0 Hr	5.59×10^{-3}	37.2°C
		5.2 Hr	2.84×10^{-2}	37.5°C
		8.5 Hr	4.56×10^{-2}	37.6°C
		12.9 Hr	6.76×10^{-2}	37.7°C
		18.3 Hr	9.32×10^{-2}	37.7°C
		24.2 Hr	1.20×10^{-1}	37.8°C
		36.4 Hr	1.70×10^{-1}	37.6°C
		48.2 Hr	2.13×10^{-1}	37.7°C
		60.3 Hr	2.53×10^{-1}	37.7°C
		67.2 Hr	2.74×10^{-1}	38.0°C
290m	56 Hr	1.2 Hr	2.10×10^{-2}	39.3°C
		5.4 Hr	8.79×10^{-2}	39.4°C
		8.7 Hr	1.34×10^{-1}	39.4°C
		13.1 Hr	1.90×10^{-1}	39.6°C
		18.5 Hr	2.48×10^{-1}	39.5°C
		24.4 Hr	3.03×10^{-1}	39.5°C
		36.6 Hr	3.95×10^{-1}	39.4°C
		48.4 Hr	4.64×10^{-1}	39.2°C
		60.5 Hr	5.19×10^{-1}	39.3°C
		67.4 Hr	5.46×10^{-1}	39.5°C

Table 7-17 Summary Data of Drilling

Drill hole No.	Type of drill	Period	Depth	Core		No. of drilling shift			Drilling speed		Remarks
				Length	Recovery	Drilling	Cas-ing etc.	Total	* m/shift	** m/shift	
IQ-1	L-44	8th Oct.'79~9th Oct.'79	m 20.50	m 19.40	% 94.6	2	-	2	10.25	10.25	
IQ-2	L-44	9th Oct.'79~10th Oct.'79	20.00	18.50	92.5	2	-	2	10.00	10.00	
IQ-3	L-44	4th Oct.'79~5th Oct.'79	20.00	19.20	96.0	3	-	3	6.67	6.67	
IQ-4	L-44	6th Oct.'79~7th Oct.'79	20.00	16.50	82.5	4	-	4	5.00	5.00	
IQ-5	L-44	2nd Oct.'79~3rd Oct.'79	20.00	19.00	95.0	4	-	4	5.00	5.00	
IQ-6	L-44	21st Sep.'79~24th Sep.'79	20.70	17.20	83.1	6	-	6	3.45	3.45	
IQ-7	L-44	11th Oct.'79~12th Oct.'79	20.40	16.00	78.4	3	-	3	6.80	6.80	
IQ-8	L-44	25th Sep.'79~27th Sep.'79	20.00	10.20	51.0	5	-	5	4.00	4.00	
IQ-9	L-44	28th Sep.'79~29th Sep.'79	20.80	10.00	48.1	3	-	3	6.93	6.93	
IQ-10	L-44	30th Sep.'79~1st Oct.'79	20.00	17.50	87.5	3	-	3	6.67	6.67	
IQ-11	L-44	25th Sep.'79~20th Oct.'79	300.50	279.60	93.0	45	1	46	6.68	6.53	
Total			502.90	443.10	88.1	80	1	81	6.29	6.21	

The depth of 20 m was at first planned to have the final diameter BX-WL and the rod BX-WL was planned to be set until the completion of temperature measurement. But as the caving was unexpectedly intensive, the whole depth was drilled by NX-WL and with the rod BX-WL in the hole the temperature log was made.

The depth of 300 m was drilled in accordance with the plan with tri-corn bit 5 5/8", HX-WL and bit BX-WL.

Furthermore, a blowout preventer was installed to avoid the blowout, and a cooling tower to cool the circulating water for drilling. Table 7-18 shows machines and materials for drilling, Table 7-19 (1) - (2) show consumption goods for drilling.

5-3 Drilling Sites

Quisicollo where the drilling work was executed is situated about 11 km south of the village Ocoruro which is found 55 km south of the town Yauri, the Cuzco province toward Arequipa along the national highway.

5-4 Preparation for the Work (See Table 7-20 (1)-(2))

On the 8th, Sept. 1979 a Japanese supervisor entered Quisicollo to make a survey of the drilling site.

After the completion of survey, leveling of drilling sites and the confirmation of points of taking drilling water were made and the working programs were filed on the road construction and improvement.

Along with the foregoing the plans on the hired laboures and warehouses, hired land and water-utilization were negotiated.

5-4-1 Construction of Roads

The construction and maintenance and improvement were carried out with the help of human powers over the whole work.

The construction of road toward the holes No. IQ-1, 2, 5, 7, 8, 9 and 10 was made over 600 m in total and maintenance and improvement over 300 m in total.

Maintenance and improvement of the road for the holes No. IQ-3, and 4 was made over 2 km.

5-4-2 Transportation of Rigs

The rigs for the depth of 20 m and the depth of 300 m were brought in via Arequipa from the storehouse in Lima with the help of three trucks (capacity 10 t) and three trucks (capacity 4 t) on 15th, Sept. and 20th, Sept. respectively.

Table 7-18 Machines and Materials for Drilling: L-44

Item	Model	Quantity	Capacity, Type, and Specification
Drilling Machine	L-44	2	Capacity NX 760m BX 975m Inner diameter of spindle 98m/m weight (excl. engine) 1,650kg
Engine for Drill	GMC3-53	2	Diesel Engine 1,800rpm/60Ps
Pump	535-RQ	3	Piston ϕ70m/m capacity 140, 83, 45, 22, 18 Pressure 20 ∿ 50kg/cm^2
Engine for Pump	F-23481	3	Diesel Engine 2,200rpm/16Ps
Generator	SISCONSIN	3	2kvA 220V
Derrick		1	Wood
Derrick		1	Weight 20ton, lifting 9m height
Mud Mixer	MCE-100	2	Volume 100ℓ
Temperature Measuring Tools		1	The subterranean heat
Blowout Preventor		1	
Cooling Tower		1	
Drill rods	HX NX BX	40 100 120	3.00m/CP 3.00m/CP 3.00m/CP
Casing Pipes	4" 3" BX	4 25 100	3.00m/GP 3.00m/GP 3.00m/CP

Table 7-19 (1) Consumption Goods for Drilling

Description	Specification	Unit	Quantity										
			IQ-1	IQ-2	IQ-3	IQ-4	IQ-5	IQ-6	IQ-7	IQ-8	IQ-9	IQ-10	IQ-11
Light oil		ℓ	200	200	270	440	330	660	330	550	330	330	5,720
Mobil oil		ℓ	20	20	15	-	20	30	-	20	-	20	60
Hydraulic oil		ℓ	-	-	-	-	-	40	-	-	-	40	40
Gasoline		ℓ	42	42	42	84	63	126	63	105	63	63	546
Grease		kg	-	-	10	-	-	10	-	-	-	10	30
Bentonite		Bag	9	6	10	18	13	20	17	35	10	13	172
Libonite		kg	-	-	-	-	-	-	-	-	-	-	235
C.M.C. 25QT		kg	2	1	2	6	2	6	5	10	2	2	43
Cement		Bag	-	-	-	-	-	-	-	-	-	-	26
Toricone bit	5 5/8"	pcs	-	-	-	-	-	-	-	-	-	-	1
Diamond bits	HX-WL	"											2
	NX-WL	"	1	1	1	1	1	2	1	2	1	1	6
	BX-WL	"											4
Reaming shells	HX-WL	"											4
	NX-WL	"											1
	BX-WL	"	1	1	1	1	1	1	1	1	1	1	2
Wire line core barrel	HXx3.00m	"											1
"	NXx3.00m	"				1		1					1
"	BXx3.00m	"											1
Innter tube assembly	HXx3.00m	"											1
"	NXx3.00m	"				1		1					1
"	BXx3.00m	"											1
Outer tube	HXx3.00m	"											1
"	NXx3.00m	"				1		1					1
"	BXx3.00m	"											1
Inner tube	HXx3.00m	"											1
"	NXx3.00m	"				1		1					1
"	BXx3.00m	"											1
Casing metal shoe	HW	"											
"	NW	"											
"	BW	"											1
Rag		kg		10				10	10				40
Core box		pcs	4	4	5	4	4	4	4	3	2	4	60
Wire	10#	kg											
"	12#	"											
Nail		"											
Wire rope	6mmx550m	Roll											
"	12mmx 40m	"											1

Table 7-19 (2) Consumption Goods for Drilling

Description	Specification	Unit	Quantity										
			IQ-1	IQ-2	IQ-3	IQ-4	IQ-5	IQ-6	IQ-7	IQ-8	IQ-9	IQ-10	IQ-11
Manila rope	18mmx30m	pcs											1
Vinyl rope	8mmx100m	"											
Pump packing		"											
Valve steel ball	38.1ϕ												
Piston rod		pcs											
Guide pipe	HX	"											
"	NX	"				1							1
"	BX	"											
Guide coupling	HX	"											1
	NX	"						1					1
	BX	"											
Suction hose	50mmx4.5m	"											
Water swivel packing		"			2			3					4
Water swivel spindle		"											
V-belt		Sets											
"		pcs											
Core lifter	HX	"								2			2
"	NX	"	1	1	1	1		3		2	1	1	5
"	BX	"											3
Core lifter case	HX	"											1
	NX	"		1		1		1	1	1			3
	BX	"											2
Casing pipes	4" GP	pcs											4
	3" GP	pcs											25

Table 7-20 (1) Preparation and Moving for Drilling

Item \ Hole No.			IQ-1		IQ-2		IQ-3		IQ-4		IQ-5		IQ-6		IQ-7		IQ-8	
Preparation and moving	In		8th Oct. '79		9th Oct. '79		4th Oct. '79		5th Oct. '79		2nd Oct. '79		18th Sep.'79		10th Oct.'79		24th Sep.'79	
			8th Oct. '79		9th Oct. '79		4th Oct. '79		5th Oct. '79		2nd Oct. '79		20th Sep.'79		10th Oct.'79		25th Sep.'79	
	Out		9th Oct. '79		10th Oct.'79		5th Oct. '79		8th Oct. '79		3rd Oct. '79		24th Sep.'79		12th Oct.'79		27th Sep.'79	
			9th Oct. '79		10th Oct.'79		5th Oct. '79		8th Oct. '79		3rd Oct. '79		24th Sep.'79		12th Oct.'79		27th Sep.'79	
			Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts
Preparation	Access road												1	8				
	Haulage		0.2	2.5	0.2	2.5	0.2	4	0.3	4	0.3	4	1	15	0.3	4	0.3	4.5
	Installation		0.05	1.5	0.05	1.5	0.05	4	0.2	4	0.2	4	1	16	0.2	4	0.2	4
	Water pipe		-															
	Test run, etc.		-															
	Total		0.25	4	0.25	4	0.25	8	0.5	8	0.5	8	3	39	0.5	8	0.5	8.5
Moving	Dismantling		0.2	2	0.2	2	0.2	4	0.3	4	0.2	3	0.2	4	0.3	4	0.05	4
	Pipe removal		-															
	Haulage		-															
	Road reinstatement		-															
	Others		0.05	1	0.05	1	0.05	2	0.2	4	0.05	3	0.05	4	0.2	4	0.2	4
	Total		0.25	3	0.25	3	0.25	6	0.5	8	0.25	6	0.25	8	0.5	8	0.25	8
Grand Total			0.5	7	0.5	7	0.5	14	1	16	0.75	14	3.25	47	1	16	0.75	16.5

Table 7-20 (2) Preparation and Moving for Drilling

Item	Hole No.	IQ-9		IQ-10		IQ-11											
Preparation and moving	In	27th Sep.'79		30th Sep.'79		8th Sep. '79											
		28th Sep.'79		30th Sep.'79		24th Sep.'79											
	Out	29th Sep.'79		1st Oct. '79		21st Oct.'79											
		29th Sep.'79		1st Oct. '79		31st Oct.'79											
		Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts	Days	Man-shifts
Preparation	Access road					0.5	5										
	Haulage	0.3	4	0.3	4												
	Installation	0.2	4	0.2	4	0.5	5										
	Water pipe					3	57										
	Test run, etc.					8	155										
	Total	0.5	8	0.5	8	12	222										
Moving	Dismantling	0.3	4	0.2	4	1	10										
	Pipe removal																
	Haulage					1	10										
	Road rein-statement																
	Others	0.2	4	0.05	4	9	90										
	Total	0.5	8	0.25	8	11	110										
Grand Total		1	16	0.75	16	23	332										

5-4-3 Construction Work

The construction work was initiated from the hole No. IQ-6.

Along with this work the construction and maintenance of roads toward holes No. IQ-1, 2, 3, 4, 5, 7, 8, 9 and 10 and setting of drilling site were made with human powers.

For the hole of IQ-11 the establishment of drilling site and the construction of mud processing plant and pipelines for drilling water were initiated after the completion of survey of the area Quisicollo and the preparatory work was completed by the time of bringing in of drilling rigs.

5-4-4 Drilling Water

The water available around the area, planned for the drilling work turned out to be unsuitable for the drilling work because its temperature is high (about 30°C) and a large amount of salt is contained owing to the mixture of hot spring water. Consequently the drilling water for the depth of 300 m was pumped up from the Jaruma river (water supplying spot) and the water for the depth of 20 m was transported by 1,500 ℓ tank car.

5-5 Drilling Work (See Table 7-21)

The drilling conditions of each hole were as follows;

(1) Hole No. IQ-1 (See Table 7-22 (1))

. Depth:	20.50 m
. Length of core:	19.40 m
. Core recovery:	94.6%

The bentnitic mud was applied for NX-WL during the drilling.

The hole consists of the weathered soil at the depth 0 - 2.80 m and agglomerates at the depth further on.

(2) Hole No. IQ-2 (See Table 7-22 (2))

. Depth:	20.00 m
. Length of core:	18.50 m
. Core recovery:	92.5%

The bentnitic mud was applied for NX-WL during the work.

The hole consists of the weathered soil at the depth 0 - 17.45 m and agglomeratic rocks at the depth further on.

(3) Hole No. IQ-3 (See Table 7-22 (3))

. Depth:	20.00 m
. Length of core:	19.20 m
. Core recovery:	96.0%

The bentnitic mud was applied for NX-WL during the work.

The hole consists of weathered soils at the depth of 0 - 3.00 m and agglomerate at the depth further on.

(4) Hole No. IQ-4 (See Table 7-22 (4))

. Depth:	20.00 m
. Length of core:	16.50 m
. Core recovery:	82.5%

The bentnitic mud was applied for NX-WL during the work.

The hole consists of sand and gravel at the depth 0 - 5.15 m, mud at 5.15 - 7.00 m and gravel at 7.00 - 20 m, which caused the frequent caving, so the work was carried on under reaming.

(5) Hole No. IQ-5 (See Table 7-22 (5))

. Depth:	20.00 m
. Length of core:	19.00 m
. Core recovery:	95.0%

The bentnitic mud was used for NW-WL during the work.

The hole consists of sand from the depth 0 to 5.30 m, gravel at 5.30∿8.40 m, agglomerate at 8.40∿14.00 m and sandstone composed of andesite grains for the depth further on.

(6) Hole No. IQ-6 (See Table 7-22 (6))

. Depth:	20.70 m
. Length of core:	17.20 m
. Core recovery:	83.1%

The bentnitic mud was used for NX-WL during the work.

The hole consists of gravel at the depth 0 - 7.6 m and mud at the depth further on, which caused the frequent caving of wall, so the work was carried on under reaming.

(7) Hole No. IQ-7 (See Table 7-22 (7))

. Depth:	20.70 m
. Length of core:	16.00 m
. Core recovery:	78.4%

The bentnitic mud was used for NX-WL during the work.

The hole consists of weathering soil at the depth of 0 - 2.10 m and gravel at the depth further on, which caused frequent caving of wall, so the work was carried on under reaming.

(8) Hole No. IQ-8 (See Table 7-22 (8))

. Depth:	20.00 m
. Length of core:	10.20 m
. Core recovery:	51.0%

The bentnitic mud was used for NX-WL during the work.

The hole consists of weathered soil at the depth 0 - 2.00 m, gravel at the depth further on, which caused the frequent caving, so the work was carried on under reaming.

(9) Hole No. IQ-9 (See Table 7-22 (9))

. Depth:	20.80 m
. Length of core:	10.00 m
. Core recovery:	48.1%

The bentnitic mud was used for NX-WL during the work.

The hole consists of weathered soil at the depth 0 - 4.5 m, sand at the depth 4.5 - 13.00 m and gravel at the depth further on, which caused the frequent caving of wall, so the work was carried on under reaming.

(10) Hole No. IQ-10 (See Table 7-22 (10))

. Depth:	20.00 m
. Length of core:	17.50 m
. Core recovery:	87.5%

The bentnitic mud was used for NX-WL during the work.

The hole consists of weathered soil at the depth 0 - 1.7 m, andesite at the depth 1.7 - 1.75 m and agglomerate at the depth further on.

(11) Hole No. IQ-11 (See Table 7-22 (11))

. Depth:	300.50 m
. Length of core:	279.60 m
. Core recovery:	93.0%

0 - 9.15 m; The work was initiated with the help of tri-corn bit 5 5/8", using the bentnitic mud.

4" GP was inserted up to the depth 9.15 m to effect the full hole cementing and fixed to the ground.

9.15 m - 40.45m; The work was executed with the help of HX-WL, under the application of bentnitic mud mingled with CMC and LIBONATE.

The hole consists of sand, mud and gravel.

40.45 - 75.00 m; The work was executed with the help of NX-WL using bentnitic mud mingled with CMC and LIBONATE. Geology consists of sand and mud causing the frequent caving, swelling and balling up, so the work with NX-WL was changed to ream the range about 35 m (40.45 - 75.00 m) with the help of bit HX-WL.

After reaming 3" GP was inserted up to the depth 75 m to perform the full hole cementing.

After fixing work a blowout preventer was installed.

75.00 - 220.40 m; The work was carried on with the help of NX-WL under the application of bentnitic mud, mingled with CMC and LIBONATE.

The caving, swelling and balling up became frequent, so BX-CP was inserted up to the depth 220.40 m.

220.40 - 300.50 m; The work was carried on with the help of BX-WL under the application of bentnitic mud, mingled with CMC and LIBONATE.

The hole consists of volcanic rocks at the depth 220.40 m - 253.9 m and sheared zone, so the caving, swelling and balling up have occured, but thanks to the efforts, made on the mud control the expected aim (300.50 m) was attained successfully.

After the work washing the hole and the preparation for the temperature logging were made.

5-6 Moving and Withdrawal Work

In the moving work rigs were moved by large-sized truck, or in the self-propelled way between each drilling site (depth 20 m) and in the withdrawal work after demantling machines L-44 for the hole of the depth 20 m they are firstly carried from Quisicollo to Lima and stored there.

Subsequently, machines L-44 for the depth 300 m were demantled on 27th, Oct. after the completion of the work of temperature logging carried from Quisicollo to Lima and stored there.

Table 7-21 Time Distribution in Drilling

No. of Drill hole	Drilling hr	Hoisting & lowing TOD & I.T. hr		Miscellaneous hr			Repairs hr	Others hr	Moving operation hr	Total hr
		Rod	Inner tube	Casing insertion	Hole reaming	Otehrs				
IQ-1	12°00'	-	-	-	-	6°00'	-	-	6°00'	24°00'
IQ-2	10°00'	-	-	-	-	6°00'	-	-	8°00'	24°00'
IQ-3	10°00'	-	-	-	5°00'	10°00'	-	-	11°00'	36°00'
IQ-4	20°00'	-	-	-	10°00'	9°00'	13°00'	-	20°00'	72°00'
IQ-5	14°00'	-	-	-	5°00'	17°00'	3°00'	-	9°0 '	48°00'
IQ-6	23°00'	-	-	-	11°00'	10°00'	20°00'	-	42°00'	106°00'
IQ-7	20°00'	-	-	-	6°00'	5°00'	12°00'	-	17°00'	60°00'
IQ-8	15°00'	-	-	-	30°00'	10°00'	5°00'	-	12°00'	72°00'
IQ-9	15°00'	-	-	-	-	10°00'	3°00'	-	20°00'	48°00'
IQ-10	20°00'	-	-	-	5°00'	10°00'	2°00'	-	11°00'	48°00'
IQ-11	215°00'	-	-	20°00'	20°00'	273°00'	109°00'	168°00'	92°00'	897°00'
Total	374°00'	-	-	20°00'	92°00'	366°00'	167°00'	168°00'	248°00'	1,435°00'
					478°00'					

Table 7-22 (1) <u>Respective Data of Drillhole, No. IQ-1 Hole</u>

		Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
Working Period	Preparation	8th Oct.'79-8th Oct.'79	0.25	0.25	-	4
	Drilling	8th Oct.'79-9th Oct.'79	0.5	0.5	-	3.5
	Removing	9th Oct.'79-9th Oct.'79	0.25	0.25	-	3
	Total	8th Oct.'79-9th Oct.'79	1	1	-	10.5

Drilling Length	Planned Length	20.00 m	Over-burden	m
	Increase or Decrease in Length	0.50 m	Core Length	19.40 m
	Length Drilled	20.50 m	Core Recovery	94.63 %

Core Recovery for each 100m section

Depth of Hole	Section	Total
0∿20.50 m	94.63 %	94.63 %
100∿ m	%	%
∿ m	%	%

Working Time		Drilling	12°00	66.7 %	500 %
		Hoisting & Lowering Rod		%	%
		Hoisting & Lowering I.T.			
		Miscellaneous	6°00	33.3 %	25.0 %
		Repairing		%	%
		Others		%	%
		Total	18°00	100.0 %	75.0 %
	Removing	Preparation	4°00	-	16.7 %
		Moving	2°00	-	8.3 %
		G. Total	24°00	-	100.0 %

Efficiency of Drilling

20.50 m/Work Period	20.5 m/day
20.50 m/Working Days	20.5 m/day
20.50 m/Drilling Period	41.0 m/day
20.50 m/Net Drilling Days	41.5 m/day
Total workers/ 20.50 m	0.51 Man/m
Total Drilling Workers/20.50 m	0.17 Man/m

	Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
Casing Pipe Inserted	NX m	%	%
	BX m	%	%

Table 7-22 (2) Respective Data of Drillhole, No. IQ-2 Hole

Working Period		Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
	Preparation	9th Oct.'79-9th Oct.'79	0.25	0.25	-	4
	Drilling	9th Oct.'79-10thOct.'79	0.5	0.5	-	3.5
	Removing	10thOct.'79-10thOct.'79	0.25	0.25	-	3
	Total	9th Oct.'79-10thOct.'79	1	1	-	10.5

Drilling Length		m		m
	Planned Length	20.00	Over-burden	
	Increase or Decrease in Length	-	Core Length	18.50
	Length Drilled	20.00	Core Recovery	92.50 %

Core Recovery for each 100m section		
Depth of Hole	Section	Total
0∿20.00 m	92.50 %	92.50 %
100∿ m	%	%
∿ m	%	%

Working Time				
	Drilling	10°00	62.5 %	41.7 %
	Hoisting & Lowering Rod		%	%
	Hoisting & Lowering I.T.			
	Miscellaneous	6°00	37.5 %	25.0 %
	Repairing		%	%
	Others		%	%
	Total	16°00	100.0 %	66.7 %
Removing	Preparation	6°00		25.0 %
Removing	Moving	2°00		8.3 %
	G. Total	24°00		100.0%

Efficiency of Drilling	
20.00m/Work Period	20.00m/day
20.00m/Working Days	20.00m/day
20.00m/Drilling Period	41.00m/day
20.00m/Net Drilling Days	41.00m/day
Total workers/ 20.00 m	0.51Man/m
Total Drilling Workers/20.00 m	0.17Man/m

Casing Pipe Inserted	Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
	NX m	%	%
	BX m	%	%

Table 7-22 (3) Respective Data of Drillhole, No. IQ-3 Hole

Working Period		Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
	Preparation	4th Oct.'79-4th Oct.'79	0.25	0.25	-	8
	Drilling	4th Oct.'79-5th Oct.'79	1.0	1.0	-	27
	Removing	5th Oct.'79-5th Oct.'79	0.25	0.25	-	6
	Total	4th Oct.'79-5th Oct.'79	1.5	1.5	0	41

Drilling Length				
Planned Length	20.00 m	Over-burden	m
Increase or Decrease in Length	- m	Core Length	19.20 m
Length Drilled	20.00 m	Core Recovery	96.00 %

Core Recovery for each 100m section		
Depth of Hole	Section	Total
0∿20.00 m	96.00 %	96.00 %
100∿ m	%	%
∿ m	%	%

Working Time				
	Drilling	10°00	40.0 %	27.8%
	Hoisting & Lowering Rod		%	%
	Hoisting & Lowering I.T.			
	Miscellaneous	15°00	60.0 %	41.7%
	Repairing		%	%
	Others		%	%
	Total	25°00	100.0 %	69.4%
Removing	Preparation	8°00	-	22.2%
Removing	Moving	3°00	-	8.3%
	G. Total	36°00	-	100.0%

Efficiency of Drilling	
20.00m/Work Period	13.33m/day
20.00m/Working Days	13.33m/day
20.00m/Drilling Period	20.00m/day
20.00m/Net Drilling Days	20.00m/day
Total workers/ 20.00 m	2.05 Man/m
Total Drilling Workers/20.00m	1.35 Man/m

Casing Pipe Inserted		
Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
NX m	%	%
BX m	%	%

Table 7-22 (4) Respective Data of Drillhole, No. IQ-4 Hole

Working Period

	Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
Preparation	5th Oct.'79-5th Oct.'79	0.5	0.5	-	8
Drilling	6th Oct.'79-7th Oct.'79	2.0	2.0	-	27
Removing	8th Oct.'79-8th Oct.'79	0.5	0.5	-	8
Total	5th Oct.'79-8th Oct.'79	3.0	3.0	-	43

Drilling Length

Planned Length	20.00 m	Over-burden	m
Increase or Decrease in Length	- m	Core Length	16.50 m
Length Drilled	20.00 m	Core Recovery	82.5 %

Core Recovery for each 100m section

Depth of Hole	Section	Total
0∿20.00 m	82.50 %	82.50 %
100∿ m	%	%
∿ m	%	%

Working Time

Drilling	20°00	38.5 %	27.8 %
Hoisting & Lowering Rod		%	%
Hoisting & Lowering I.T.			
Miscellaneous	19°00	36.5 %	26.4 %
Repairing	13°00	25.0 %	18.0 %
Others		%	%
Total	52°00	100.0 %	72.2 %
Removing: Preparation	12°00	-	16.7 %
Removing: Moving	8°00	-	11.1 %
G. Total	72°00	-	100.0 %

Efficiency of Drilling

20.00 m/Work Period	6.67m/day
20.00 m/Working Days	6.67m/day
20.00 m/Drilling Period	10.00m/day
20.00 m/Net Drilling Days	10.00m/day
Total workers/ 20.00m	2.15 Man/m
Total Drilling Workers/20.00m	1.35 Man/m

Casing Pipe Inserted

Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
NX m	%	%
BX m	%	%

Table 7-22 (5) Respective Data of Drillhole, No. IQ-5 Hole

Working Period		Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
	Preparation	2nd Oct.'79-2nd Oct.'79	0.5	0.5	-	8
	Drilling	2nd Oct.'79-3rd Oct.'79	1.25	1.25	-	27
	Removing	3rd Oct.'79-3rd Oct.'79	0.25	0.25	-	6
	Total	2nd Oct.'79-3rd Oct.'79	2	2	-	41

Drilling Length				
Planned Length	20.00 m	Over-burden	m
Increase or Decrease in Length	- m	Core Length	19.00 m
Length Drilled	20.00 m	Core Recovery	95.00 %

Core Recovery for each 100m section		
Depth of Hole	Section	Total
0∿20.00 m	95.00 %	95.00 %
100∿ m	%	%
∿ m	%	%

Working Time			
Drilling	14°00	35.9 %	29.2 %
Hoisting & Lowering Rod		%	%
Hoisting & Lowering I.T.			
Miscellaneous	22°00,	56.4 %	45.8 %
Repairing	3°00	7.7 %	6.2 %
Others		%	%
Total	39°00	100.0 %	81.2 %
Removing: Preparation	6°00	-	12.5 %
Removing: Moving	3°00	-	6.3 %
G. Total	48°00	-	100.0 %

Efficiency of Drilling	
20.00 m/Work Period	10.00m/day
20.00 m/Working Days	10.00m/day
20.00 m/Drilling Period	16.00m/day
20.00 m/Net Drilling Days	16.00m/day
Total workers/ 20.00 m	2.05 Man/m
Total Drilling Workers/20.00 m	1.35 Man/m

Casing Pipe Inserted		
Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
NX m	%	%
BX m	%	%

Table 7-22 (6) Respective Data of Drillhole, No. IQ-6 Hole

Working Period	Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
Preparation	18thSep.'79-20thSep.'79	3	3	-	39
Drilling	21stSep.'79-24thSep.'79	3.5	3.5	-	104.5
Removing	24thSep.'79-24thSep.'79	0.25	0.25	-	8
Total	18thSep.'79-24thSep.'79	6.75	6.75	-	151.5

Drilling Length			
Planned Length	20.00 m	Over-burden	m
Increase or Decrease in Length	0.70 m	Core Length	17.20 m
Length Drilled	20.70 m	Core Recovery	83.09 %

Core Recovery for each 100m section

Depth of Hole	Section	Total
0∿20.70 m	83.09 %	83.09 %
100∿ m	%	%
∿ m	%	%

Working Time			
Drilling	23°00	35.9 %	21.7 %
Hoisting & Lowering Rod		%	%
Hoisting & Lowering I.T.			
Miscellaneous	21°00	32.8 %	19.8 %
Repairing	20°00	31.3 %	18.9 %
Others		%	%
Total	64°00	100.0 %	60.4 %
Removing: Preparation	36°00	-	34.0 %
Removing: Moving	6°00	-	5.6 %
G. Total	106°00	-	100.0 %

Efficiency of Drilling	
m/Work Period	3.07 m/day
m/Working Days	3.07 m/day
m/Drilling Period	5.94 m/day
m/Net Drilling Days	5.94 m/day
Total workers/ 20.70 m	7.31 Man/m
Total Drilling Workers/ 20.70m	5.04 Man/m

Casing Pipe Inserted: Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
NX m	%	%
BX m	%	%

Table 7-22 (7) Respective Data of Drillhole, No. IQ-7 Hole

Working Period		Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
	Preparation	10thOct.'79-10thOct.'79	0.5	0.5	-	8
	Drilling	11thOct.'79-12thOct.'79	1.5	1.5	-	17
	Removing	12thOct.'79-12thOct.'79	0.5	0.5	-	8
	Total	10thOct.'79-12thOct.'79	2.5	2.5	-	33

Drilling Length				
Planned Length	20.00 m	Over-burden	m
Increase or Decrease in Length	0.40 m	Core Length	16.00 m
Length Drilled	20.40 m	Core Recovery	78.43 %

Core Recovery for each 100m section		
Depth of Hole	Section	Total
0∿20.40 m	78.43 %	78.43 %
100∿ m	%	%
∿ m	%	%

Working Time			
Drilling	20°00	46.5 %	33.4 %
Hoisting & Lowering Rod		%	%
Hoisting & Lowering I.T.			
Miscellaneous	11°00	25.6 %	18.3 %
Repairing	12°00	27.9 %	20.0 %
Others		%	%
Total	43°00	100.0 %	71.7 %
Removing: Preparation	6°00	-	10.0 %
Removing: Moving	11°00	-	18.3 %
G. Total	60°00	-	100.0 %

Efficiency of Drilling	
20.40 m/Work Period	8.16m/day
20.40 m/Working Days	8.16m/day
20.40 m/Drilling Period	13.60m/day
20.40 m/Net Drilling Days	13.60m/day
Total workers/ 20.40 m	1.61 Man/m
Total Drilling Workers/20.40 m	0.83 Man/m

Casing Pipe Inserted		
Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
NX m	%	%
BX m	%	%

Table 7-22 (8) Respective Data of Drillhole, No. IQ-8 Hole

Working Period

	Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
Preparation	24thSep.'79-25thSep.'79	0.5	0.5	-	8.5
Drilling	25thSep.'79-27thSep.'79	2.25	2.25	-	66
Removing	27thSep.'79-27thSep.'79	0.25	0.25	-	8
Total	24thSep.'79-27thSep.'79	3.00	3.00	-	82.5

Drilling Length

Planned Length	20.00 m	Over-burden	m
Increase or Decrease in Length	m	Core Length	16.20 m
Length Drilled	20.00 m	Core Recovery	51.00 %

Core Recovery for each 100m section

Depth of Hole	Section	Total
0∿20.00 m	51.00 %	51.00 %
100∿ m	%	%
∿ m	%	%

Working Time

Drilling		15°00	25.0 %	20.8 %
Hoisting & Lowering Rod			%	%
Hoisting & Lowering I.T.				
Miscellaneous		40°00	66.7 %	55.6 %
Repairing		5°00	8.3 %	6.9 %
Others			%	%
Total		60°00	100.0 %	83.3 %
Removing	Preparation	6°00	-	8.3 %
Removing	Moving	6°00	-	8.3 %
G. Total		72°00		%

Efficiency of Drilling

20.00 m/Work Period	6.67 m/day
20.00 m/Working Days	6.67 m/day
20.00 m/Drilling Period	8.89 m/day
20.00 m/Net Drilling Days	8.89 m/day
Total workers/ 20.00 m	4.12 Man/m
Total Drilling Workers/20.00 m	3.3 Man/m

Casing Pipe Inserted

Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
NX m	%	%
BX m	%	%

Table 7-22 (9) Respective Data of Drillhole, No. IQ-9 Hole

		Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
Working Period	Preparation	27thSep.'79-28thSep.'79	0.5	0.5	-	8
	Drilling	28thSep.'79-29thSep.'79	1.25	1.25	-	43
	Removing	29thSep.'79-29thSep.'79	0.5	0.5	-	8
	Total	27thSep.'79-29thSep.'79	2.25	2.25	-	59

Drilling Length	Planned Length	20.00 m	Over-burden	m
	Increase or Decrease in Length	0.80 m	Core Length	10.00 m
	Length Drilled	20.80 m	Core Recovery	48.08%

Core Recovery for each 100m section		
Depth of Hole	Section	Total
0∿20.80 m	48.08 %	48.08 %
100∿ m	%	%
∿ m	%	%

Working Time	Drilling	15°00	53.6 %	31.3 %
	Hoisting & Lowering Rod		%	%
	Hoisting & Lowering I.T.			
	Miscellaneous	10°00	35.7 %	20.8 %
	Repairing	3°00	10.7 %	6.2 %
	Others		%	%
	Total	28°00	100.0 %	58.3 %
	Removing: Preparation	14°00	-	29.2 %
	Removing: Moving	6°00	-	12.5 %
	G. Total	48°00	-	100.0 %

Efficiency of Drilling	
20.80 m/Work Period	9.24m/day
20.80 m/Working Days	9.24m/day
20.80 m/Drilling Period	16.64m/day
20.80 m/Net Drilling Days	16.64m/day
Total workers/ 20.80 m	2.83 Man/m
Total Drilling Workers/20.80m	2.06 Man/m

	Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
Casing Pipe Inserted	NX m	%	%
	BX m	%	%

Table 7-22(10) Respective Data of Drillhole, No. IQ-10 Hole

Working Period		Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
	Preparation	30thSep.'79-30thSep.'79	0.5	0.5	-	8
	Drilling	30thSep.'79-1st Oct.'79	1.25	1.25	-	33
	Removing	1st Oct.'79-1st Oct.'79	0.25	0.25	-	8
	Total	30thSep.'79-1st Oct.'79	2	2	-	49

Drilling Length				
Planned Length	20.00 m	Over-burden	m
Increase or Decrease in Length	- m	Core Length	17.50 m
Length Drilled	20.00 m	Core Recovery	87.50 %

Core Recovery for each 100m section		
Depth of Hole	Section	Total
0∿20.00 m	87.50 %	87.50 %
100∿ m	%	%
∿ m	%	%

Working Time				
Drilling		20°00	54.1 %	41.7 %
Hoisting & Lowering Rod		-	%	%
Hoisting & Lowering I.T.				
Miscellaneous		15°00	40.5 %	31.2 %
Repairing		2°00	5.4 %	4.2 %
Others			%	%
Total		37°00	100.0 %	77.1 %
Removing	Preparation	8°00	-	16.7 %
Removing	Moving	3°00	-	6.2 %
G. Total		48°00	-	100.0 %

Efficiency of Drilling	
20.00 m/Work Period	10.00m/day
20.00 m/Working Days	10.00m/day
20.00 m/Drilling Period	16.00m/day
20.00 m/Net Drilling Days	16.00m/day
Total workers/ 20.00 m	2.45 Man/m
Total Drilling Workers/20.00m	1.65 Man/m

Casing Pipe Inserted		
Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
NX m	%	%
BX m	%	%

Table 7-22(11) Respective Data of Drillhole, No. IQ-11 Hole

Working Period

	Period	Number of Days	Actual Working Days	Day Off	Total Number of Workers
Preparation	8th Sep.'79-24thSep.'79	17	12	5	222
Drilling	25thSep.'79-20thOct.'79	26	26	-	354.5
Removing	21stOct.'79-31stOct.'79	11	11	-	110
Total	8th Sep.'79-31stSep.'79	54	49	5	686.5

Drilling Length

Planned Length	300.00 m	Over-burden	m
Increase or Decrease in Length	0.50 m	Core Length	279.60 m
Length Drilled	300.50 m	Core Recovery	93.00 %

Core Recovery for each 100m section

Depth of Hole	Section	Total
0~100 m	82.90 %	82.90 %
100~200 m	99.40 %	91.20 %
200~300.5 m	96.70 %	93.00 %

Working Time

Drilling		215°00	26.7 %	23.9 %
Hoisting & Lowering Rod			%	%
Hoisting & Lowering I.T.				
Miscellaneous		313°00	38.9 %	34.9 %
Repairing		109°00	13.5 %	12.2 %
Others		168°00	20.9 %	18.7 %
Total		805°00	100.0 %	89.7 %
Removing	Preparation	70°00	-	7.8 %
Removing	Moving	22°00	-	2.5 %
G. Total		897°00	-	100.0 %

Efficiency of Drilling

300.50 m/Work Period	5.56m/day
300.50 m/Working Days	6.13m/day
300.50 m/Drilling Period	11.56m/day
300.50 m/Net Drilling Days	11.56m/day
Total workers/ 300.50 m	2.28 Man/m
Total Drilling Workers/ 300.50 m	1.18 Man/m

Casing Pipe Inserted

Pipe Size & Materage	Inserted Length / Drilling Length %	Recovery of Casing Pipe
4" 9.15 m	3.0 %	0 %
3" 75.0 m	24.9 %	0 %
BX 220.0	73.2	100

6. Synthetic Analysis

6-1 Results of Geological Survey

The geology and the geothermal structure around this area are inferred as follows.

After the sedimentation of Ayabacas limestone of the Cretaceous which forms the basement and Puno formation of the Palaeogene which covers unconformably Ayabacas limestone, a sequence of volcanic activity were repeated along the N-S structural line controling the western end of Raramani Massif since the middle Tertiary.

As the forerunner of the activities, the eruption and the deposition of Tacaza volcanic rocks took place during Eocene time.

In the servey area the uplift and erosion was intense in the pre-Palaeocene time, consequently the Puno formation was eroded out and Tacaza volcanic rocks unconformably covers Ayabacas limestone.

Still after the activity of Tacaza volcanic rocks, the activity of the structural line is continued and its west side subsided to form the basin structure. In early Pliocene time Yauri lake deposit sedimented in the basin.

The volcanic activity was vigorous around Yauri basin and Senca volcanic activity was known near the western side of the basin from Miocene to Pliocene time.

At the south-eastern corner of Yauri basin, including the survey area Barroso volcanic activity took place again along the N-S structural line in Plio-Pleistocene time resulting in eruption and deposition of volcanic rocks.

Through the quiet upheaval and down movement, after that time, moraine deposited in late Quarternary time.

Geothermal showings in survey area are represented by the gush-out of hot springs and accompanying distribution of calcareous sinters at the both area of the Rio Jaruma and of Quisicollo and widely distributed calcareous sinters at Macarara.

These showings are distributed along the N-S fault shown by the earth's surface survey and that they are located at the point where the N-S fault intersects with E-W fault.

On the other hand, the drill hole IQ-11 at Quisicollo shows dolerite, porphyrite and shear zone being subject to hydrothermal alteration.

Informing from the drilling of IQ-11 the hole is thought to represent the part of shear zone, meeting with the above mentioned N-S fault.

This shear zone has the fault breccias consisting of mainly andesitic rocks and of a small amount of limestone.

Moreover considering surface distribution of rocks, it seems that the N-S fault cuts the Cretaceous Ayabacas limestones and the Eocene Tacaza volcanic rocks, and the age of the faulting is judged to be after the deposition of Tacaza volcanic rocks and prior to the deposition of glacial deposit.

The characteristics of volcanic rocks conformed at the depth of IQ-11 are unobvious by the data of hole IQ-11, but considering the facts that the dolerite at the Jaruma river area takes a dyke like form and the direction of the dyke is concordant with N-S fault running nearby volcanic rocks confirmed at IQ-11 seems to take a dyke rock form also.

Activity of these dyke rocks seems to be after the faulting of N-S direction and prior to the deposition a moraine, moreover judging from the regional volcanic activity, the activity of the dyke rocks in Quisicollo are seems to be correlative with the activity of Barroso volcanic rocks of Pleistocene age and especially to its deeper facies according to lithofacies.

Dyke like volcanic rock, andesite and shear zone, especially to strongly crushed part are subjected to the alteration observed in the hole of IQ-11.

The alteration seems to be hydrothermal one accompanyed by the activity of these dykes and continued after it. The alteration is mainly argillization producing Saponite, (montmorillonite family) chlorite, serecite etc.

This mineral assemblage belongs to poly-basic clay mineral type and seems to be product at low temperature condition.

Hydrothermal solution producing this alteration is slightly acidic to intermediate.

P.H. of the hot spring in Quisicollo is PH = 6.87 to 6.94 according to the survey in 1976, so this PH is not conflict with above mentioned assuming.

Montmorillonite family argillization seems to form a marginal facies of alteration and it assumes that the alteration changes progressively to kaolinite argillization and to silicification of a center of alteration toward depth, in the case of Matsukawa and Ohdake representing a geothermal area of Japan.

When the close time-space relationship of geothermal showing and N-S fault, especially crossing with E-W fault, moreover relation between the N-S fault and the activity of dyke rocks with alteration correlating to Barroso volcanic rocks, is considered, the geothermal structure at this area assumes that geothermal showing in ascribed to the pliocene-pleistocene Barroso volcanic activity along the N-S fault after the deposition of Tacaza volcanic rocks of the Eocene, and thermal source seems to be deeper igneous activity corresponding to Barroso activity and hot springs comes through the N-S fault, especially crossing with the E-W fault from deep.

This geothermal activity is assumed to be continuing through the Glacial epoch up to the present since the Barroso volcanic activity period in the light of hydrothermal alteration of volcanic dyke rocks observed in the IQ-11 and the gushing out of hot spring.

Although its path is interpreted to be remarkably found mainly at the N-S fault, especially at the meeting point of the E-W fault, the path of hot water is assumed to have been changed together with the times, judging from the facts that the colcarous sinters distributing in Macarara area where the gushing out of hot spring is stopped and slow rising of temp rature in dyke rocks in the IQ-11 in spite of hydrothermal alteration.

6-2 Results of Geophysical Prospecting

As the result of analysis, described in the section 3-2, the following underground resistivity structure can be assumed.

(1) Profile line A

1) The lowest apparent resistivity layers amont this area are distributed within the range of measured stations 18 ∿ 14 and the resistivity values analyzed through the VES curve show 1.5 ∿ 3Ωm.

2) Discontinuous lines of resistivity can be set between measured stations 18∿20.

These positions coincide with the stations where contour of apparent resistivity distribution extend and at their depth geological discontinuous lines are assumed.

3) The above-mentioned geological discontinuous lines are assumed to be inclined structure.

For if current electrodes AB/2 at measured stations 14-16-18 and 26 are 1500 m and more, the VES curve tends to descend and these trends to descend correspond comparatively to each other between the stations 20-22.

So the low resistivity zone is assumed at the shallow part of the surface, shallow and deep points can inconsistently be connected.

4) Resistivity discontinuous lines can be assumed between the measured stations 14 and 12.

Apparent resistivity distribution has a trend to continue horizontally from the measured stations 18 toward the station 12. And for this reason it is assumed to have a horizontal structure, but considering the analysed result which shows the difference between the resistivities of second layers in the stations 12 and 14 the throw in their depth of basement, the resistivity discontinuous line can safely be assumed.

This discontinuous line which shows the similar trend as with the above-mentioned one is adjacent to each other so the geological discontinuous line is domed.

5) In order to consider the analysis depth in accordance with the standard curve checkup method, their comparison with theoretical curves with the aid of electronic computors was made and S-line method through the longitudinal conductance was executed with the result that analysed depths of basement were rightly assumed as follows.

Group	Location	Assumed depth of basement
3	Between measured stations 20 ∿ 26	About 460 ∿ 760 m
2	Between measured stations 18 ∿ 14	About 120 ∿ 260 m
1	South of the measured stations 12	About 500 ∿ 600 m

6) Considered the facts that the ascending and descending positions of group 1 and 3 VES curves coincide approximately with each other and their absolute values are similar, depths of basement are assumed to be situated originally at the same level. Group 2 layers are assumed to have been blocked and uplifted by the tectonic movement.

7) Analyzing VES curve at measured station 18 of group 2 in detail, low resistivity layer is assumed to exist under the depth of 340 m though high resistivity one is detected above it.

Considering this low resistivity layer to geological discontinuous line near here, it is assumed that deep part of under the station 18 is affected by hydrothermal alteration and there is possibility of hydrothermal rotation or vapor ascending from more deep.

(2) Profile line B

1) The number of resistivity layer east of station 8 is assumed to be one.

The resistivity discontinuous line can be set between the stations 8 - 10 and around here a geological discontinuous line were assumed.

2) Resistivity layers west of the station 10 show three or four-layer structures. And the assumed upper layer of basement is low resistivity one, extending eastward.

3) The depths of basement in the west of the station 10 is assumed to be 200 - 500 m.

(3) Profile line C

1) A resistivity line of discontinuity can be formed around the station 10 and the geological discontinuous line was assumed.

2) The resistivity discontinuous line is not distinct around the station 12, but judging from the disturbed distribution of low arrarent resistivity, the change of resistivity structures were assumed to be signed and the geological discontinuous line assumed.

3) The depths of basement are assumed to be dipped by 200∿500 m from east toward 500 m with the head of about 100 m.

(4) Resistivity plane distribution.

1) A extremely low resistivity layer is distributed in the direction of NNE-SSE, surrounded by the geological discontinuous lines of assumed between stations 18 ∿ 20 and 12 ∿ 14 respectively.

These low resistivity layers are assumed to have been generated through the alteration or the existence of hot water.

2) The center of low resistivity layer is assumed to be situated at the depth between the stations 18 ∿ 16.

Moreover it is remarkable that the N-S fault related closely to geothermal showing in survey area passes through this this center.

3) Because the profile line was set so as to be along the N-S line could not be clearly assumed at this profile line, but the N-S line could not be assumed at this profile line, but the N-S system geological discontinuous line can be assumed around the C profile line measuring station 12.

According to the core analysis of IQ-11 performed around the N-S fault, the alteration though hot water of hot spring is observed at volcanic rocks and shear zone.

If this alteration is connected with the signs for geothermal generation, the N-S geological discontinuous line is also assumed to have a close connection with the geothermal signs along with the E-W system geological discontinuous line.

6-3 Results of Temperature Within Holes

6-3-1 Measurement of Temperatures Within the Drilled Hole (depth 20 m)

For the measurement of temperature within the holes from the head to the level of water, the influence of atmospheric temperature is great, so the results of measurement of water within the hole are analyzed carefully.

The water temperature at its upper most part ranges from 7.3°C to 11.6°C, while at the bottom hole, the maximum and maximum ones are 20.6°C (hole IQ-8) and 8.3°C (hole IQ-3) respectively.

An isothermal line, concerning the temperature at the bottom-hole is shown in the geological map (Fig. 7-3, Appendix).

Considering the relation of 20 m depth temperature measurement anomaly with the geology, drilled holes within the isothermal line (15°C) relate to IQ-6 and IQ-8 whose geology consists of gravel lasting up to the bottom of the hole.

Drilled holes in the 10°C isothermal line relate to IQ-1, IQ-2, IQ-4 and IQ-7, out of which the first two reach to andesites and the latters end at the gravel as well as the drilled one within the 15°C isothermal line.

Owing to the inclusion of foreign matters the temperature measurement of IQ-9 is ended at the depth of 14 m whose core consists of gravel up to the bottom of hole and when the temperature gradient up to the depth of 14 m is considered, it is assumed to reach 10°C and above at the bottom.

The temperatures of each hole of IQ-3, IQ-5 and IQ-10 which are not anomalous reached the andesitic rock and the temperature at the bottom does not reach 10°C.

When the above-mentioned distribution of temperatures at the bottom-hole and the geology within the holes are considered, the anomalous range is distributed from the Jaruma river to the south along the N-S fault with the direction of NNW-SSE to NNE-SSW and the high anomaly is assumed to be developed within the gravel area.

Besides, the anomaly is stretched out westward as shown in the hole IQ-7.

Consequently it coincides with the hypothesis that geothermal showings develop at the N-S fault, especially at the point, meeting with the E-W fault.

The isothermal line of 15°C extends along the N-S fault to the south of hole IQ-6, and furthermore to the south of hole IQ-8, including the geothermal showings in Quisicollo with the scale of about N-S 2,000 m more and E-W 700 m.

6-3-2 Measurement of Temperatures Within the Drilled Hole (depth 300 m)

When the temperature distribution and gradients, and the geology within the hole are considered as described in the section 4-2-3, the geothermal structure is assumed as follows in accordance with the result of temperature measurement within this hole.

Geothermal showings of this hole are composed of the zone at the depth of 0 ∿ 80 m where the temperature rises markedly and the its gradient is also large and the one from its lower part up to the bottom where the temperature rises slowly and its gradient is small.

The section at the depth of 0 ∿ 80 m is composed of gravel with low degree of consolidation and thus the surface water and the underflow are assumed to be rather easy to move, so the rise of temperature within this section are rightly interpreted to be caused by the reduced degree of influence of them on the geothermal showings as the depth goes down from the land surface toward the depth.

The depth 80 ∿ 290 m is composed of rather high consolidated gravel, dyke rocks, andesite and shear zone and the rate of rise of temperature is slow and its gradient is uniformly small. Thus it is assumed to correspond to the section of rise of temperature caused by the thermal conduction from the geothermal source at the depth.

The negative temperature gradient at the depth of 220 m corresponds to the part of altered and softened dolerite dyke, where the low temperature underground water supposedly flew in and cooled down the inner part of the hole.

At the depth of 230 m and 260 m where the temperature gradients are relatively high correspond to the porhyrite and shear zone respectively and furthermore they are suffered from the hydrothermal alteration.

As dyke rocks and the hydrothermal alteration are assumed to be related to geothermal sources at this area, the abnormal temperature gradients at the depth of 230 m and 260 m are supposed to represent directly the one from the deep source of heat caused by deep igneous activity corresponding to the Barroso volcanic activity.

But their temperature gradients are 0.5°C/10 m and 0.6°C/10 m twice as large as the one at the non-geothermal area and they are not very favorable showings but the hydrothermal alteration is observed, so the vigorous geothermal activity can be supposed at that time.

At the riverbed of Collpa river 250 m south-east away from the hole IQ-11, two places of hot springs in Quisicollo are located whose temperatures are 53.5°C and 58°C respectively. Nevertheless the hole IQ-11 is meeting the N-S fault no gushing out of hotsprings are observed and the temperature at the bottom-hole shows only 39.3°C. Consequently the hot water from the depth seems to ascend along the N-S fault not via its whole line, but via its narrow passage owing to properties of substances of shear zone and existence of a precipitate from hot water.

6-3-3 Results of Recovery Test

In the temperature recovery tests (first to tenth) the values show negative up to the depth of around 110 m and the ones from that depth up to the bottom recover with the range of 0.2 ∿ 0.8°C..

The maximum value 0.8°C is observed at the depth of 140 m and 200 m.

The phemonenon, observed up to the depth of 110 m is assumed to be caused by the surface water and underflow, moving through the unconsolidated gravel.

For the depth of 110 m and below the temperature within the hole is not almost changed since the sixth measurement and the equilibrium temperature is assumed to have been reached.

The equilibrium temperature is assumed to be 35.5°C at the bottom when S.T. (= θ) is infinite at mentioned in the page 50.

Heat flow unit (HFU) for each lithofacies and mean heat flow unit (HFU), for the depth below 110 m which is considered to be free from atmospheric influence are shown as follows, based on the mean temperature gradient calculated from table 7-14 and near thermal conductivity assuming from existence data.

Section	Rock	Mean temperature gradient (°C/10m)	Mean thermal conductivity 10^{-3} (cal/cm.sec.°C)	HFU	Mean HFU
110∿196m	gravel	0.21	1.5	0.31	
196∿254m	volcanic rocks	0.17	3.2	0.54	0.43
254∿300m	shear zone	0.25	2.2	0.55	

H.F.U. for volcanic rocks and shear zone are almost equal to each other, accordingly the rise of temperature of this hole is assumed to have been caused from the heat source at the rather depth.

6-4 Comparison with the Results of Former Survey

This area had been surveyed twice in 1976 and 1978. In 1976 the geological, geothermal and chemical surveys and surveys of carbon dioxide and the rate of radiant heat were made in Quisicollo area and around there as a step to surveying for the development of geothermal resources at the southern part of Peru by Geothermal Energy Research & Development Co., Ltd.

And in 1978, as survey for infrastructure development planning phase 1, to research the prospects for geothermal development which serves as a step to securing the electric power accompanying the mine development the geological, geothermal and chemical surveys and the survey of radiant heat at the Jaruma river, Macarara, and Quisicollo area were carried out.

The outline of these results are described in Table 7-23, 7-24.

These results of survey can be summarized as follows;

As for the Quisicollo area, the anomaly equivalent to the one at Nigorigawa area in Hokkaido, Japan (50 MW is under development) is observed in the 1 m - depth geothermal survey, but the chemical analysis and the temperature estimation by the chemical thermometer show the doubtful results compared with the geothermal areas in Japan.

The survey of radiant heat through gushing out of hot spring shows the value 66 x 10^7 Cal/min. corresponding to the heat energy index of class V and if the geothermaly as four or five times as that is assumed to be contained, the power generation 2.2 - 2.7 x 10^4 kw/H can be estimated.

And the Jaruma river area has a tenth part radiant heat of Quisicollo area corresponding to the heat energy index of class III.

However, the former survey was based upon geothermal showings of earth's surface, and the detailed information concerning the thermal source at the depth of underground was expected in future.

According to the result of this survey, the geothermal structure at this area is so composed that hot water, ascending along the passage restricted by the N-S fault, moves sideways through the gravel with high porosity near the land surface, gushing out of the hotspring.

According to the geophysical survey data, the narrow low resistivity zone, one of above passage, connected via the surface of earth with the depth is detected.

Others relate to high resistivity zones and the low resistivity zones around which the existence of reservoir rock formations could be assumed could not be found.

Accordingly, though the survey data obtained by the foregoing year may have slightly suffered from the influence of surface water and underflow, they relate to measured values concerning the geothermal showing, assumed to have ascended from the depth through the narrow passage and are considered to be effective in evaluating the geothermal potentiality at this area.

Table 7-23 Outline of Survey in 1976

Survey	Work amount	Results of survey	Remarks
Geo-thermal survey	1m-depth 49 points 100m grid	Anomaly extending toward ENE-WSW above 16°C: 550x200m above 20°C: 400x70m	Results are equivalent roughly to ones at Nigori-gawa area which is under development of 50 MW.
Chemical survey	Chemical analysis of hot-spring water; PH and 12 components 5 samples The assumption of temperature with the chemical thermometer	Cl^-, HCO_3^-, SO_4^{--} Ca^{++}, Mg^{++}; markedly much in amount. SiO_2, HBO_2, F; a little. Chemical thermometer Na-K; 111∿116°C SiO_2; 87-93°C	Compared with other areas, Mg^{++}, and SO_4^{--} is highly contained and a large amount of $CaSO_4$ contained. The existence of heat is doubtful. The temperature is rather low compared with the one at the other areas.
Carbon dioxide survey	1m depth(30∿40 cm deep owing to the glavel) 19 points at the intervals of 100m.	0.8% around the high temperature zone and 0.3% and below at other zones. There is no maximum values.	Because measured depth was small, sufficient data could not be obtained.
Radiant heat survey	The assumption of heat discharge using chlorine ion density and surface water temperature measurement	Chlorine ion concentration method; 10×10^3 Kcal/sec Water temperature method; 7.0×10^3 Kcal/sec	The result corresponds to the heat energy index of class V. When the heat 4 ∿ 5 times as large as the heat discharge is expected, the power generation 2.2 - 2.7×10^4KW/H can be expected.

Table 7-24 Outline of Survey in 1978

Survey	Work amount	Results of survey	Remarks
Geo-thermal survey	General Survey of Quisicollo Macarara Jaruma Area. Detailed Survey of Macarara area 1m depth 112 points	Anomaly 13°C and above Jaruma River; 2000x800m Macarara; 800x400m Quisicollo; 2000x1200m	Anomaly is assumed along the structural line.
Chemical survey	Temperature estimation by the chemical thermometer.	Jaruma river Ka-K SiO_2 116°C 89°C Quisicollo Ka-K SiO_2 114°C 87°C	Temperatures assumed through the chemical components are not so high.
	Analysis of mercury and arsemic within the soil 8 samples (only at Macarara area)	max min Hg: 5490^{ppb} 45^{ppb} As: 41^{ppm} 10^{ppm}	Values are approximately equivalent to ones at the Hachimandaira area, a typical geothermal area in Japan
Radiant heat survey	It was estimated through the water temperature and Na concentration.	Jaruma river: $(5.0\sim8.4)\times10^7$ Cal/min	One tenth as large as the one at Quisicollo area. Corresponds to the heat energy index of class III.

6-5 Conclusion and Further Work

6-5-1 Conclusions

According to the results of survey of this year in the Quisicollo area, having been as the promissing geothermal showing area by 1976 and 1978 years' survey, the following thermal structure was assumed on the base of this year's survey.

Geothermal showing at this area is genetically related to the N-S fault especially the meeting point with the E-W fault and ascending from the depth through faults. Its geothermal source is due to the newest volcanic activity at this area along the N-S fault and seems to originate in its igneous activity at the depth.

In the geophysical survey, though the low resistivity zone is distributed near the land surface, such a low resistivity where the existence of large-scale geothermal reservoir can be assumed is not detected.

On the other, around the measurement stations 16 - 18 on the A survey line a narrow low resistivity structure ranging from the intermediate part of high resistivity structure up to its depth is assumed.

The position of this low resistivity showing corresponds to the part of N-S fault closely connected with the geothermal showing at this area.

According to the geological survey, as the N-S fault is affected by the argillization corresponding to peripheral portion with depth.

According to the geological survey, as the N-S fault is affected by the argillization corresponding to peripheral portion of alteration, it is assumable that it approaches the central portion of alteration with depth.

When this low resistivity is brought about from the markedly thermally altered part, formed along the N-S fault, it is assumable that the more highly altered zone and the geothermal activity exist at the depth.

Its potentiality may be compared with the heat radiation 66 x 10^7 Cal/min., assumed from the former survey, namely heat energy index of class V.

From the geological and geophysical surveys, however, this geothermal showing are judged to come from considerably deep part and such geothermal resources having been developed in the world are difficult to extract at this area.
(See Fig. 7-19, Appendix)

6-5-2 Prospect for the Future

As above mentioned, the geothermal showing at this area is due to the existence of geothermal source at the considerable depth and is interpreted to be ascending through the part of N-S fault. Around the measurement station 18 on the A survey line the anomaly which is assumed to correspond to one of their paths is catched.

This anomaly belongs to the one of anomalies catched during this geophysical survey and is thought to be the central part of geothermal showing at this survey area.

However, this area is covered with the thick glacial deposits and the geothermal showing at the surface of earth is narrow and restricted by the fault, moreover the existence of geothermal source and possible reservoir are expected at considerably deep point.

So if the survey of geothermal resources at this area will be carried further on, it is necessary to make clear the nature of low resistivity zones at the lower part of thick high resistivity layer and within the high resistivity zone, ranging from the intermediate to deep parts and then pilot drilling at least at the depth 1,000 m and more around the station 18 on the A survey line.

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CHAPTER 8

AGRICULTURAL DEVELOPMENT

Chapter 8 Agricultural Development

1. Relation with the Previous Year's Survey

Since this survey on agricultural development is a continuation of the previous year's survey, the scope and contents of this survey have been based on the last year's findings and recommendations for further detailed studies. In the following an outline will first be given of the contents of last year's survey, followed by the description of the methods and contents of this year's survey.

1-1 Summary of the Previous Year's Survey

In the previous year's survey, agricultural conditions in the Project Area were reviewed by using various types of statistical data, such as the 1972 agricultural census to investigate land utilization and land ownership Patterns. Data on the land under agricultural cultivation, yields per hectare, number of head of livestock and livestock production in 1977 - 1978 were obtained from the Sicuani Statistical Office. Information obtained from the Espinar (Yauri) Branch Office was used to review cropping patterns, costs of producing potatoes, etc. in the Product Area.

The Project Area defined in the previous year's report covers the whole of Espinar Province, apparently due to the availability of statistical data for this province as a unit. The following describes the characteristics of agriculture in the Project Area as compared to neighboring provinces (Canchis, Canas, Acomayo, Chumbivilcas, etc.). The types of crops cultivated were limited to several varieties (potatoes, cañihua, etc.) because of the presence of severer high altitude climate than in the other provinces. The productivity was also the lowest in Espinar Province. Thus, this Area is predominantly an extensive livestock raising one depending only on natural grasses.

The low productivity of the agriculture in this region is due mainly to the severe natural conditions resulting from the high altitude. A comparison of such meteorological factors as air temperature, precipitation and humidity for each month was made between low altitude areas (Arequipa : 2,350 m above sea level, Huanchac : 3,399 m and Sicuani : 3,550 m) and a high altitude area (Yauri : 3,915 m) based on data from the Meteorological Agency. For the ground conditions, there was a geological investigation of topographical factors such as glacial action, and records of observations of soil sections and the results of soil analyses performed on samples collected from three locations.

Based on interviews and observations, general crop farming and the raising of livestock in the Project Area are outlined. In the case of crop farming, some oxen were used, but there was almost no use of farm machinery and almost all farming depends on man power. There is also insufficient grading, etc. of seed beds, no use of agricultural chemicals, and fertilizers are limited to wood ash and manure. In the case of livestock raising, the animals are allowed to graze on natural grass and there is no use of stored fodder. Therefore, the pasturage is plundered and the nutritional condition of the liverstock becomes very bad in the dry season when the grass withers. Because there are no fences, the grazing animals are controlled by elderly men and women (most of the younger adult males work in other areas except for during the busy farming season) who watch over the grazing animals all day and then lead them back to an earthen enclosure near their homes at sundown.

The distribution of farming and livestock products may be summarized as follows, based mainly on the results of interviews. Most of the agricultural products, especially vegetables but excluding potatoes and cañihua, are brought in from Arequipa. In the case of livestock products, beef, mutton and wool are marketed in the Arequipa and Puno, while alpaca and llama meat is sold in Lima via Arequipa. One interesting point was that, since the cattle shipped are too thin and the quality of the carcasses is low, the cattle would be taken first to Arequipa and fatten them up for a fixed period.

Various types of projects planned or in progress have been undertaken under the governmental agricultural and livestock development plan in Cuzco Department. These agricultural modernization projects are all aimed at increasing production in Cuzco Department, especially in areas where there is already production. However, this Project Area is not included because productivity is exceptionally low.

In its conclusion, the last year's report accorded a high priority to the development of livestock industry in the Project Area through the introduction of improved varieties of pasture as well as through the introduction of small-scale irrigation facilities which are also useful for improving the productivity of the potato cultivation.

1-2 Contents and Methods of this Survey

Based on the aforementioned conclusion of last year's study, the following four points are investigated in depth this year.

1) Selection of improved pasturage grasses
2) Selection of suitable areas for agricultural and livestock development
3) Consultations with experts in water resources and investigation of methods and scale of agricultural irrigation
4) Consultations with geothermal experts and investigation of geothermal utilization in agriculture

The selection of improved varieties of pasturage grasses is essentially a technical problem. Involved in our survey are collection of as much data as possible concerning experimental studies and the diffusion of improvements, performing investigations by means of inductive methods and attempting a theoretical analysis by estimating on the basis of meteorological data such factors as the amount of grass which can be grown.

For the selection of suitable areas for agricultural and livestock raising development, the Project Area must first be clearly defined in the light of regional development prospects including the proposed mining development. In the selection of an area suitable for agricultural development, the present status of the river system and the land topography and soil are carefully examined by means of maps and site surveys.

In the case of irrigation, selection of the rivers for proposed water intake and water intake sites, the locations and sizes of the fields to be irrigated, etc. were determined from maps and site surveys together with a survey on water resources development. In this case, in the investigation of the possibility of introducing irrigation in agriculture, a wide range of experimental data from both Peru and foreign countries were reviewed as well as data on similar cases in neighboring areas used as a reference.

Concerning agricultural utilization of geothermal heat, the prospects of introducing greenhouse farming are explored as compared with bringing in vegetables from other regions, rather than technical investigation of greenhouse farming. In view of the above, what was attempted was to investigate market prices of vegetables in the Project and surrounding areas (cities), interview as many related persons as possible concerning distribution systems currently in practice between the producing areas, to arrive at a final conclusion.

Since, in the previous year's survey, statistical information was considerably abundant, stress in this year's survey, was not placed on obtaining statistical data, and new findings obtained in the course of varous interviews are introduced where appropriate.

In this year's survey, attempts were made to hold interviews with as many people in as many fields as possible, including government authorities, researchers, farmers and businessmen.

In the case of technical problems involved in the selection of suitable areas for agricultural and livestock development, improved varieties of pasturage grass, as well as methods of agricultural irrigation, it was often difficult to make judgement from existing data only. In investigations on irrigation and especially on the prospects of greenhouse farming, it was impossible to obtain reference data to permit economic analysis. The knowledge obtained from an exchange of opinions was, therefore, very valuable in making final conclusions.

2. Selection of Suitable Areas for Agricultural and Livestock Development

2-1 Basic Principles Determining the Project Area

As mentioned earlier, in the selection of suitable areas for agricultural and livestock development, the Project Area must first be determined. Since the area proposed for mining development is predominantly agricultural, with livestock being the main industry, agricultural development in this survey should be based on an overall regional development. In the previous year's survey, the whole of Espinar Province was designated as the Project Area but this was only a tentative delineation for the sake of convenience, since statistical data available are only for the province as a whole.

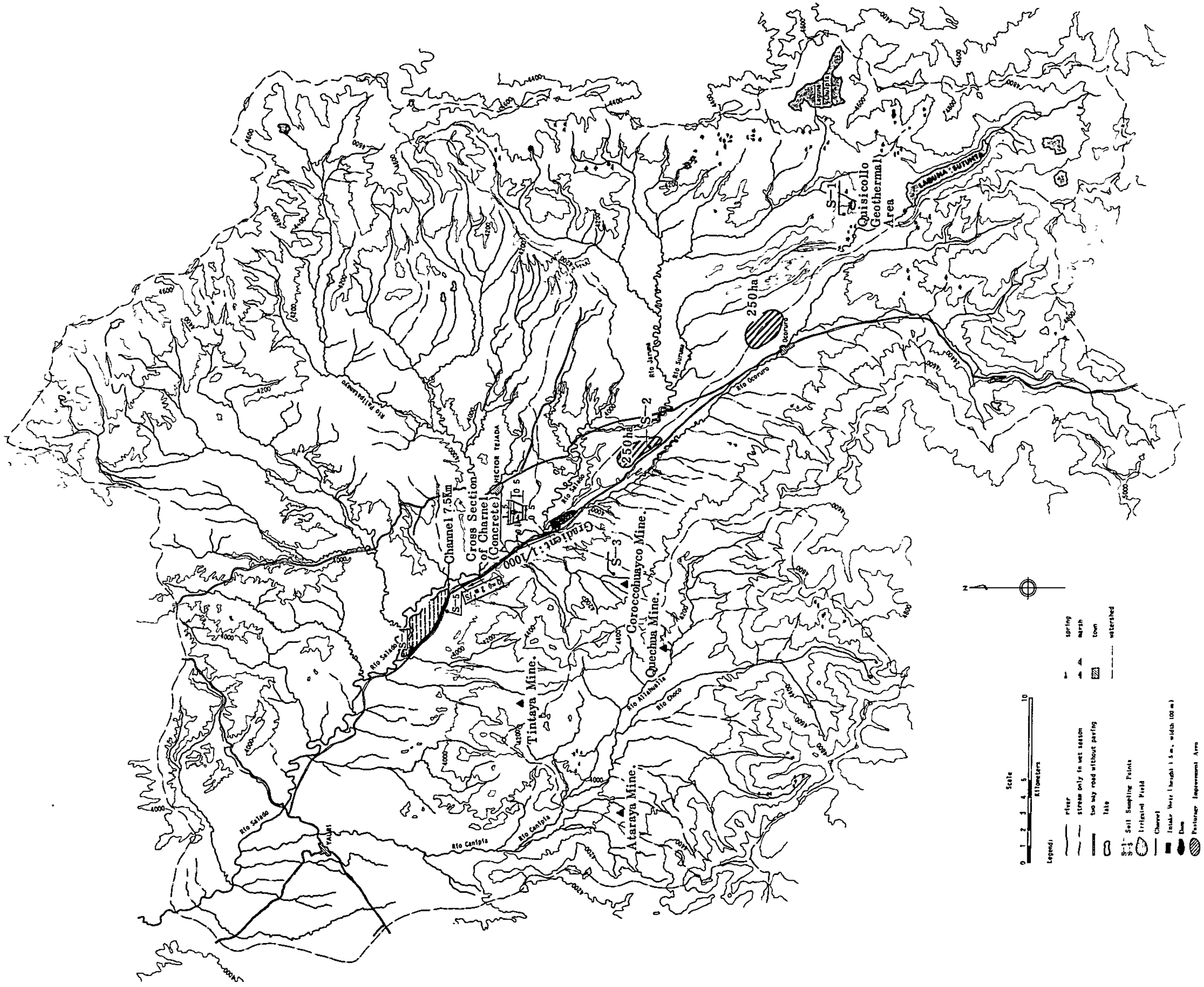
The areas proposed for mining development will not necessarily be located only in Espinar Province but might also be in neighboring Provinces such as Sicuani and Ayaviri because of such considerations as the removal of ore and the bringing in of various types of products and living necessities. However, in an investigation of the selection of suitable areas for agricultural and livestock development, it is more realistic to limit the Project Area to as small an region as possible. An alternative to delineate the Project Area for agricultural development is to limited to that connected directly with mining development. In such a case, the borders of the area are usually determined in accordance with local municipal administrative units.

However, in Peru, management and utilization of water resources are decisive factors in agricultural and livestock development in the Andes mountain region. Since it is convenient to use river systems when formulating development plans, all of the prospective areas for mining and geothermal development should be within the range of river systems. Therefore, it was considered highly desirable that the Project Area for agricultural and livestock development be within such a range.

2-2 Outline of the Project Area

As shown in Fig. 8-1, the Project Area determined for agricultural and livestock development in accordance with the above-mentioned basic principles is the area which includes the entire Salado upstream river system up to the point where the Apurimac River flows into the Salado River, about 10 km north of Yauri City. The Apurimac River basin is not included.

Fig. 8-1 Agricultural Development Survey Area



Such a Project Area covers about 2,000 km² and includes the five communities of Espinar (Yauri), Tocroyo (Paipata), Ocoruro, Condoroma and Pichiqua. More than one-half of the area lies in Espinar Province and in addition to the three prospective mining areas of Coroccohuayco, Quechua and Tintaya, it also includes the Atalaya mine and the prospective geothermal development area of Quisicollo.

The basin which runs along the main course of the Salado River in the northwestern part of the Project Area (downstream from the point where the Ocoruro River, from which water intake for mining and irrigation is planned, flows into the Salado River) is 3,900 - 4,000 m above sea level, but the greatest part of the Project Area is a plateau of more than 4,000 m with mountain ranges of 4,500 - 4,700 m running from the Northeast to the East of the area and of 4,700 - 4,900 m running from the Southwest to the South and Southeast parts of the area. There are many lakes of various sizes in these mountainous areas which serve as sources for the river system. Swamps are found everywhere and since it is possible for grass to live in the dry season, many farmers have settled as far up as the mountain ridges. This area serves as a grazing area for the farmers of the basin in the dry season when the grass becomes poor.

Among the five Provinces connected with the Project Area, Tocroyo, Espinar and Ocoruro cover the greatest areas and for these three, the populations, areas under crop cultivation and number of livestock raised are shown for each Comunida (community cooperatives) in Table 8-1. The borders of the Project Area were drawn up according to the river system rather than the community borders. The Comunida borders do not always match those of the communities, therefore, it is impossible to identify clearly the number and distribution of farmers, the areas managed and number of liverstock raised per household in the Project Area only from the values given in Table 8-1.

At the stage of preparation of agricultural and livestock development plans, it is necessary to clarify the relationship between land ownership and land utilization and to explore the agricultural improvement plans of local farmers when choosing suitable areas for development.

2-3 Suitable Areas for Agricultural and Livestock Development

The Project Area, located at a high altitude, consists mostly of basin and plateau and the land conditions are poor. The topographical conditions include coarse, steep mountainous areas and there are areas of exposed rock which are not beneficial with respect to soil condition. Generally, with the exception of some areas such as those mentioned above, it seems that about half of the region is arable land and pasturage which can be improved. However, since there are large areas where land improvement and accompanying agricultural improvement cannot be started, naturally it is better to begin with areas where development results will clearly be better when selecting suitable areas for agricultural and livestock development. When deciding the scale of development in such case,

Table 8-1 State of Farming Operations by Communida

Comunida	Population	Cultivated Area			Domestic Animals				
		Potatoes	Quinua	Canihua	Cattle	Sheep	Alpacas	Llamas	Chickens
TOCROYO									
Pallpata Alcasana	-	-	-	-	1,250	2,500	120	60	-
Mamanocca	-	6	-	1	650	2,960	150	100	-
Antaycama	-	20	-	2	250	3,100	250	100	-
Alpaccomaña	-	15	-	2	180	2,000	25	10	-
Chañi	-	5	-	-	110	1,150	10	45	-
Chelgno	-	6	-	-	175	1,250	50	30	-
Ichulahua	-	7	-	1	150	1,350	76	25	-
Jaruma Alccasan	-	3	-	-	220	250	-	45	-
Cruz pampa	-	7	-	-	190	2,100	100	50	-
Total	-	69	-	6	3,175	18,460	751	465	-
ESPINAR									
Suero y Cama	4,300	11	3	7	570	2,380	80	105	70
Chisicata	700	12	2	8	1,020	3,200	120	155	100
Pampahuarca	410	16	3	10	480	1,360	235	170	60
Alto Huarca	860	10	1	5	1,300	6,700	200	360	30
Bajo Huancane	1,140	14	4	11	230	2,100	50	100	120
Alto Huancane	1,200	25	6	17	450	4,650	140	220	70
Cruz cunca	1,500	5	-	4	110	1,800	30	155	30
Tintaya	1,100	9	2	3	490	3,100	180	260	140
Huisa Culuyo	1,780	2	-	1	360	3,400	270	800	75
Huanchuano	960	3	2	1.5	260	2,680	90	410	35
Hanocollahua	1,500	5	-	1.5	1,800	5,750	570	300	20
Total	15,450	112	23	70	7,070	37,120	1,565	3,342	750
OCCORURO									
Occoruro	370	7	2	1	230	650	120	120	50
Marquiri Alto	210	4	1	-	330	520	60	90	45
Huisa	180	2	-	1	145	620	100	130	70
Ceollana	230	2	-	-	315	210		160	20
Chaquella	430	5	2	3	530	3,100	210	346	150
Anta Alto	170	4	-	1	75	420	175	90	20
Anta Bajo	220	5	3	2	130	910	80	65	15
Marquiri Bajo	110	7	2	2	260	3,750	160	200	140
Chorrillo	216	11	4	1	395	1,360	185	150	60
CONDOROMA	210	-	-	-	35	170	1,300	1,100	10
Chañi	70	-	-	-	18	110	750	1,350	30
Alccasani	120	-	-	-	10	60	1,200	500	20
Rumihuasí	210	-	-	-	25	85	850	450	15
Pampa Ceollani	190	-	-	-	14	55	320	230	10
Total	3,086	50	15	12	2,652	12,091	5,935	5,161	685

(Source) Ministerio de Agricultura y Alimentacion management elements such as management systems and the relation with land ownership cannot be overlooked, but a more basic decision which accords with the conditions of the location is possible.

In such a location, it is essential to consider the severe meteorological factors caused by the high altitudes. Land conditions such as topography and soil are also important, but in this survey, water utilization conditions are extremely important since remarkable improvements in productivity can be expected in both cultivated and grazing land by irrigation.

Next comes the scale of agricultural and livestock development. Some investment is required in all development and when the necessity of the introduction of improvement techniques is considered, it is desirable to have gradual development within a feasible range based on a realistic understanding of the economic resources of local farmers and of the agricultural technology. More spontaneous initiative of the local farmers toward development can be expected to some extent by means of educational efforts, and introduction of improvement techniques is not impossible, depending on the efforts made and the methods used. Therefore, the main problem appears to be the economic resources of the farmers.

At the present time, not much governmental assistance to basic agricultural enterprises with a public character such as those involved in land improvement can be expected in Peru. There are government financial measures concerning low interest funding, but farmers with no surplus capital might have problems in repaying loans (collection of invested business expenses). Many local farmers do not depend only on agriculture for living expenses as most go elsewhere to work for varying periods. Farming income shows individual differences according to such factors as work scale, but according to the statistical data in the previous year's survey, more than 60% of the farms in the area are petty farms with worked areas of less than 5 hectares.

In this survey, an interviewer was conducted on the status of his farms with a farmer working an area of 4 ha and raising five head of cattle, 50 sheep and 15 llama. As shown in Table 8-2, his estimated agricultural income was only 300,000 soles. The agricultural expenses on this farm considered on only small cash outlays for pasturage charges (only for cattle sent to the mountains for grazing in the dry season), etc., since the farmer was self-sufficient in feed and fertilizer. Because the depreciation on facilities and tools was not taken into account, an accurate calculation would probably be slightly higher and this would further decrease agricultural income.

The farmer surveyed also depended on work other than agriculture, but he can be considered as a typical medium-scale farmer in this area from point of view of scale of land worked, etc. Therefore, it appears that there are limits on the amount of new investments for agricultural improvement which can be recovered from only the agricultural income.

Table 8-2 Agricultural Income of a Medium Size Farmer

(Unit: Soles)

A. Agricultural Income				292,400
(1) Farm Product Income				
1) Sales Income	Potatoes 2,100, Cañihua 300	2,400	34,400	
2) Own Consumption	Potatoes21,600, (@150xChuno144kg); Canihua 8,400 (@42x200kg); Quinua 1,000 (@50x20kg); Onion Straw 1,000 (@100x10kg)	32,000		
(2) Livestock Income				
1) Sales Income	Sheep 120,000, (@4,000x30heads); Cattle 25,000 (@25,000x1heas); Llamas 36,000 (@9,000x4heads)	181,000	158,000	
2) Own Consumption (Including breeding stock)	Cattle 50,000 (@25,000x2heads); Llamas 27,000 (@9,000x3heads)	77,000		
B. Agricultural Expenditures				5,400
(1) Cash Expenditures	Farming Tools 1,200; Pasturage Charge 4,000 (@200x500headsx4months); Others 200	5,400		
(2) Depreciation		0		
C. Agricultural Income (A - B)				287,000

Under such conditions, it is desirable when selecting suitable areas for agricultural and livestock raising development in the Project Area to set as a minimum limit the burden on farmers making a profit and use small scale pilot farms under only favorable land conditions where good development results can be expected. It is proposed that such a plan include a total of 1,000 ha consisting of an irrigated field area of 500 ha and an improved pasturage area of 500 ha.

For such a land area, suitable areas in the Project Area can be selected in consideration of the location and the relation with mining development as one location on the left bank of the Salado River downstream from the confluence with the Ocoruro River for field irrigation and two locations on the plateau on the right bank of the Ocoruro River for pasturage improvement. In the case of pasturage improvement, it is desirable to select areas with good land conditions and plan in practice the preparation of pasturage of the tilled type based on making land arable.

In addition, it is desirable to find a suitable area for experimental improvement of sloping pasturage (introduction of grazing grass) by means of introduction of lake water and spring water (irrigation). It is also intended to investigate a provisional development plan for hothouse farming using geothermal heat near the proposed geothermal development area of Quisicollo.

3. Methods for Introducing Patures and Selection of Pasture Varieties

3-1 *Regional Characteristics and Pasture Cultivation*

3-1-1 Meteorological Conditions

Since the Project Area lies at a high altitude of about 4,000 m above sea level, meteorological conditions are very severe for the cultivation of pasture. Table 8-3 shows the basic meteorological conditions (average monthly air temperature, precipitation and hours of sunlight) in comparison with other cold areas.

First, the annual average of the air temperatures in Yauri in the Project Area are 1 - 2°C lower than those in Switzerland and Denmark, but somewhat higher than those in Kushiro Japan, and the Project Area generally resembles the other areas. However, it is noteworthy that there were remarkable differences in the monthly temperature distribution between the Project Area and other areas. Since there is a difference between the southern and northern hemispheres, a comparison between the summer and winter seasons showed that there were few differences in the survey region. In the winter, the temperature is around 2 - 3°C and in the summer, it does not exceed 10°C.

It is known that the growth limit for cold-type pasturage grass is an average monthly air temperature of at least 5°C and that for normal pasturage grass is at least 10°C. Therefore, the growth of pasturage grass in the summer in the Project Area is clearly not as good as that in the other areas.

Table 8-3 Area Comparison Table of Meteorological Conditions

	Month / Area	1	2	3	4	5	6	7	8	9	10	11	12	Average or Total
Average Air Temperature (°C)	Yauri	8.8	8.4	8.2	7.5	6.2	4.0	2.6	3.4	4.8	7.1	7.8	8.8	6.4
	Huancayo	10.7	11.0	10.9	10.1	9.5	9.1	8.1	9.7	10.4	11.7	12.0	11.5	10.4
	Denmark	0.1	-0.1	1.6	5.5	10.7	14.2	16.0	15.3	12.3	8.1	4.1	1.6	7.5
	Switzerland	1.1	0.4	3.6	7.9	12.4	15.8	17.6	16.7	13.6	8.2	3.4	-0.3	8.2
	Kushiro	-6.7	-6.4	-2.5	3.1	7.4	11.1	15.8	18.6	15.3	9.3	2.7	-2.7	5.4
Precipitation (mm)	Yauri	209	241	158	94	18	13	0	58	14	16	28	72	921
	Huancayo	119	148	115	48	16	15	2	26	30	81	47	75	722
	Denmark	44	34	41	40	42	47	64	80	57	66	53	58	626
	Switzerland	55	53	69	84	101	123	123	119	100	93	70	70	1,060
	Kushiro	61	38	63	85	112	83	100	128	165	130	72	69	1,106
Sunlight Hours (Hours)	Yauri	-	-	-	-	-	-	-	-	-	-	-	-	-
	Huancayo	140	126	167	192	242	234	285	229	204	205	198	174	2,396
	Denmark	36	64	119	175	248	254	246	214	159	98	49	27	1,689
	Switzerland	50	88	148	166	200	230	249	225	172	111	55	38	1,733
	Kushiro	177	177	213	188	179	141	134	139	166	195	182	175	2,066

(Note) Yauri (3,920 m above sea level), Huancayo (3,320 m above sea level)
Data taken from 2-year average in 1974 and 1975.
Denmark, Switzerland and Kushiro: Long-term average
Denmark, Switzerland: Average data from main domestic weather stations.

(Source) SENAMHI

However, in the winter, temperature conditions below the glowth limit are good and the annual period of possible growth tends to be long.

Precipitation in the Project Area is not as great as that in Kushiro or Switzerland, but considerably more than in Denmark. However, annual distribution of the precipitation deserves attention. In other areas, there are few differences between summer and winter, but in the Project Area, there is a clear separation into dry and rainy seasons. A long continuing dry season causes various damages to crop production in the Project Area, but the fact that the rainy season is in the summer is beneficial with respect to grazing grass cultivation.

Lastly, there were unfortunately no data available for the hours of sunlight in Yauri, and, therefore, comparisons were made using data for Huancayo, which is also located in the Andes.

Since the difference in altitudes between Yauri and Huancayo is about 600 m, there are considerable temperature differences as well as some differences in precipitation (the dry and rainy seasons are the same). However, there should not be such large differences in the hours of sunlight between the two locations.

When comparisons were made with foreign areas on the basis of this assumption, it was found that the annual hours of sunlight in the Project Area should be considerably more than those for Denmark and Switzerland, but the problem is the seasonal distribution. There are many hours of sunlight in the summer in Denmark and Switzerland, while in the Andes region, there is a little more sunlight in the winter than in the summer. This is not favorable for cultivation of grazing grass in the summer and the same trend is found in Kushiro where there are dense fogs in the summer.

Another meteorological condition which deserves attention in relation to the high altitude of the Project Area is the problem of the thinning of air as the air pressure drops. This has a physiological effect on the respiration of the pasturage grass. As the air becomes thinner, the absolute value of the oxygen in the air increases, there is a rapid decrease in the respiratory capacity as the temperature drops, and there is no rapid increase in the respiratory capacity due to movement as in the case of animals. In consideration of these factors, asphyxiating disorders due to a lack of oxygen appear to present no problem.

The point of greatest interest with respect to the thinning of the air, however, is the decrease in the concentration of carbon dioxide which has a direct effect on photosynthesis and, therefore, grazing grass production. The carbon dioxide concentration decreases with altitude and at altitudes of 4,400 m in Tibet, it has been reported that the value is 0.[illegible] mg/l (135 ppm) which is about half of that at sea level. Since increased carbon dioxide concentrations enhances photosynthesis and vegetable production, attempts have been made at carbon dioxide fertilization and favorable results have been reported in the field of hothouse farming. Therefore, the problem of carbon dioxide concentration is of great interest with respect to pasturage grass production in the Project Area. However, the influence of carbon dioxide concentration on photosynthesis sharply decreases in accordance with drops in temperature, as in the case of respiration, and this does not actually present a problem.

3-1-2 Land Conditions

Among land conditions which affect pasture cultivation the location and topography present inconveniences with respect to distance in the former case and mechanization in the latter. They are controlling factors from the viewpoint of labor productivity. However, as pointed out in Part 2 of this Chapter, there are farmers settled sporadically as far as the mountainous areas on the peripheries of the Project Area so there is little impression of isolated areas within the Project Area. The mountain slopes are generally not steep and there are many plateau-like areas. There are few places which present any problems topographically.

In technical investigations of pasturage grass, land conditions which represent the most serious problem are the soil conditions, which are closely connected with land productivity. In the previous year's survey report, detailed geological explanations were given concerning soil in the Project Area in the chapters on mining and geothermal development. In the chapter on agricultural development, soil analysis values were given together with a general outline of the soil.

In this year's survey, suitable areas for development have been provisionally selected and, to supplement last year's survey, soil samples were taken and analyzed. The results are shown in Table 8-4. A simple explanation based on soil science is given here with mention of the relation to crop cultivation. The soil samples were taken at the sites shown in Fig. 8-1 as follows.

(1) Sample 1 (S-1) - existing pasturage

Near the prospective geothermal development in the Quisicollo area of No. 1 is the surface soil (0 - 5 cm) and No. 2 the subsoil (10 - 15 cm).

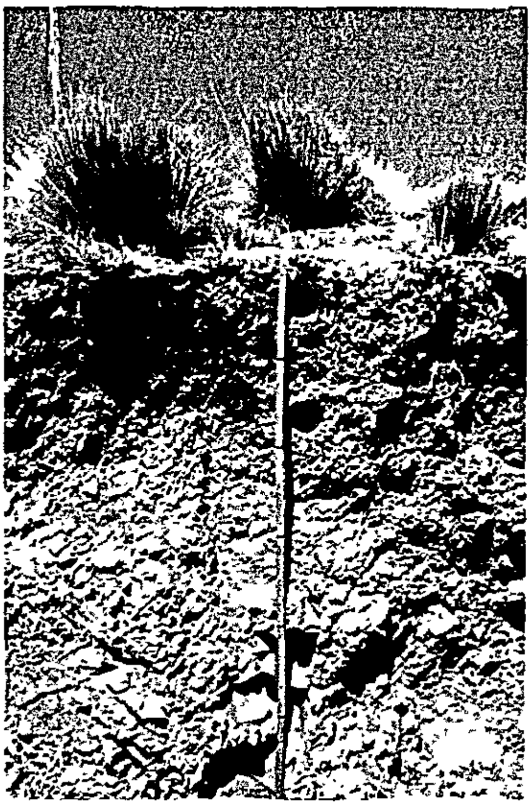
(2) Sample 2 (S-2) - existing pasturage

On a river terrace near the prospective reservoir area on the right bank of the Ocoruro River; No. 3 is surface soil (0 - 10 cm).

(3) Sample 3 (S-3) - existing paved area

Behind the Coroccohuayco Camp building; No. 4 is surface soil (5 - 10 cm) and No. 5 is deep soil (25 - 30 cm): refer to soil section shown in Photo 8-1.

Photo 8-1 Soil Cross Section



(Behind the Coroccohuayco Camp building)

Table 8-4 Soil Analytical Data

Sample No.	Sampling Spot	Depth of Soil (cm)	Soil Color	Particle Size Classification Under 2 mm Diameter (%)					Pebble (ø > 2mm) Contents (%)	pH		Y_1 (Daikuhara's Acididy)
				Soil Texture	Coarse Sand 2–0.2	Fine Sand 0.2–0.02	Micro Sand 0.02–0.002	Clay < 0.002		H_2O	KCℓ	
No. 1	S-1	SS(0- 5)	7.5YR 3/3	CL	17.6	32.0	27.5	15.1	10.8	5.12	3.91	6.47
2	"	DS(10-15)	" 4/3	SL	40.8	22.8	16.3	10.0	59.7	5.72	4.13	1.59
3	S-2	SS(0- 5)	" 4/2	CL	19.0	31.2	26.2	22.4	9.1	5.78	3.90	2.94
4	S-3	S (5-10)	" 4/3	CL	23.2	25.5	27.7	20.9	35.4	8.38	7.30	0.29
5	"	DS(25-30)	10YR 6/3	SCL	26.8	31.3	19.7	16.4	18.1	5.42	3.82	0.59
6	S-4	SS(0- 5)	7.5YR 4/3	SCL	25.0	34.5	19.3	16.1	19.4	5.52	4.00	1.76
7	"	DS(10-15)	" 3/3	SCL	24.2	36.2	19.7	16.9	7.7	6.00	3.97	0.59
8	S-5	SS(0- 5)	" 4/2	CL	24.3	24.7	18.5	24.8	51.7	5.88	4.00	6.17
9	"	DS(10-15)	" 4/2	L:C	12.4	25.8	23.6	31.9	16.2	5.85	4.05	0.59

(Note) SS: Surface Soil S: Subsoil DS: Deep Soil

Sample No.	CEC (me/100g)	Exchangeable cations (me/100g)				Base Saturation Point (%)	Total Carbon (%)	Total Nitrogen (%)	Phospheric Abroption Coef (P_2O_5 mg/100g)	Available Phospheric Acid (P_2O_5 mg/100g)	Very Small Qty. Minerals (ppm)			
		Ca	Mg	K	Na						Fe	Zn	Cu	Mn
No. 1	10.60	1.40	0.26	1.04	0.06	26	6.4	0.60	686	36.6	17.63	4.74	0.78	36.25
2	11.20	3.20	0.46	0.48	0.13	38	4.6	0.52	935	51.2	6.25	1.70	0.58	28.13
3	12.75	4.40	1.75	0.89	0.24	57	3.8	0.37	561	3.2	61.25	1.25	1.25	34.38
4	24.05	28.00	2.00	1.05	0.20	130	2.0	0.18	1,194	5.9	0.30	0.40	0.25	5.38
5	22.23	12.30	2.83	0.94	0.22	73	2.2	0.26	706	59.0	34.38	1.15	0.57	12.13
6	9.73	4.10	1.17	0.85	0.07	64	1.8	0.25	364	16.9	42.13	1.79	3.33	23.50
7	9.90	4.90	1.25	0.64	0.11	70	1.2	0.19	364	8.7	33.75	1.24	3.40	11.25
8	16.43	9.70	2.17	0.40	0.17	76	4.0	0.39	644	3.2	93.75	3.65	6.93	50.88
9	19.55	11.00	2.33	0.21	0.18	70	3.2	0.33	779	1.2	168.75	4.28	2.50	30.63