Fig.4-4-11 shows groundwater velocity plane and cross sectional map. The rainy season map is of the 150th day, and the dry season map is of the 360th day, counted from the first day from the rainy season, respectively

The velocity is presented by X, Y, and Z components, i.e. E-W, N-S, and vertical direction, respectively.

The fourth layers map of the rainy season indicates clear flow directions which concentrates to the Parral mine tunnel. On the northern and southern side of the mine, flow velocity is remarkable. From the composite of X and Y components, The flow directions are south-eastward and north-eastward and westward on the northern, southern, and eastern side of the mine, respectively. At the boring B-3 site, the flow direction shows east because of pumping up from the mine tunnel and this flow is opposite direction to the down-flow the Parral river.

The boring B-1,2,4 sites don't show remarkable groundwater flow. This results correspond with the field observation of micro flow measurement in the boring holes.

The influence of the pumping from the mine ranges within a radius of 1km from the mine tunnel judging from this simulation and micro flow measurements data. The eastern area apart from the mine shows weak flow from the high to the low place which flow is controlled by the topography. The fourth layers map of the dry season indicates the same flow directions as the rainy season ,but the velocity and influence area is small. The eastern area apart from the mine shows no flow in the dry season.

The cross sectional maps shows down-flow in the surface layers and up-flows in the deep layers around the mine tunnel, apart from the tunnel,lateral flow is recognized. This lateral flow is rapid in the surface layers.

The mineral dressing waste water and the tailing dam waste water are discharged at the sites of PW and PD on the map, respectively These sites underground is not so saturated by the groundwater that infiltrate easily these waste water.

No anomaly from the waste water infiltration is recognized from this time chemical tests because of owing the large portion of shallow groundwater flow to the small infiltration flow of waste water.

Even though not critical observation, The suspicion of actual influence would arise in the case of the drawdown of the water level in the dry season and increasing of the waste water discharge to the river or underground, judging from this simulation.

Consequently, The extraction of pollutants from the waste water and the recycle of waste water should be conducted to prevent the discharged of pollutants to the river and infiltration underground.

4-5 Soil

4-5-1 Assay results

Fig.4-5-1 shows the soil sampling map of 22 samples taken in and around the Parral tailing dam. The assay values are given in Table4-5-1. Fig.4-5-1 shows the areal distribution map of each element.

(1) Cu:

Samples PS-B2,PS-B3,PS-B4 and PS-B9 contain the higher levels of 170, 160, 130 and 200ppm respectively. Others are between 15 ~ 40ppm.

(2) Pb:

Samples, PS-B2, PS-B3, PS-B7 and PS-B9 contain the higher levels of 8,300, 1,500, 1,300, 800 and 1,200ppm respectively. Others are between 40 ~ 150ppm.

(3) Zn:

Samples, PS-10, PS-B2, PS-B4,PS-B7 and PS-B9 contain the higher levels of 770, 14,000, 1,400, 1,500 and 3,000ppm respectively. Others are between 90 ~ 200ppm.

(4) Fe:

The highest value is 6.8% of sample PS-B3. Others average 3.2%.

(5) Cd:

Samples showing over 10ppm are PS-B2, PS-B4, PS-B7 and PS-B9. Others are mostly below 5ppm.

(6) Sb:

Samples, PS-2, PS-5 and PS-10 show the highest level of 100ppm.

Samples, PS-B2, PS-B3 and PS-B4 taken around the dam show the lower, 55,20, 22ppm respectively.

(7) Cr:

All the samples average 17ppm. The highest is 45ppm of PS-B2.

(8) As:

Samples, PS-5, PS-B2, PS-B3, PS-B4 and PS-B9 contain the higher levels of 300, 6,000, 1,000, 120 and 150ppm respectively. Others are mostly below 50ppm.

(9) Hg:

The highest level is 3.8ppm of PS-B2. By comparing the assay results of 22 samples taken in the area, concentration over 0.95ppm can be considered as highly abnormal. 8 samples are in this high range. Since Hg comes up through the fissures as gaseous state from the deep ground, high anomaly is sometimes found locally. Thus, high concentrations are often seen in the area.

4-5-2 Chemical Analysis of Soluble Metal Components in the Soil Samples

Then, soluble metal components of the ten soil samples (PS-B1 ~ PS-B10) that were taken in the rainy season were detected after extraction of these metals. Conditions of the extraction process are mostly based on the Japanese standard. Thus, 10g of each sample was leached with 100ml of 0.1N HCl solution for 90 minutes at room temperature (20° C) and then filtered to separate the solution. For extraction of arsenic and lead, however, 50ml of 1N HCl and 100ml of ammonium acetate solution (pH 4.5) were used respectively. To extract cyanide, each sample was leached with 100ml of 0.05N NaOH solution for 120 minutes. After extraction each metal element was detected with ICP (Inductive Cupled Plasma) method, only cyanide was with the cyanide analyzer.

Assay results are shown in Table 4-5-2.

4-5-3 Results and Discussions

From the assay results of the soil samples and the extracted solution, it is obvious that the soils in this area are highly contaminated with harmful metals as well as cyanide. It is also remarkable that cyanides are not decomposed in the soil but remain in stable condition after aging.

4-6 Tailing Dam

4-6-1 Purpose of the Survey

The purpose of survey of the tailing dam is to obtain the data for examining the following issues. The purpose is almost the same in the survey in El Bote tailing dam.

(1) Stability test of the tailing dam for making the counterplan.

(2) Examining the condition of drainage under rain condition for making the counterplan.

(3) Examinig the scouring of slope for making the counterplan.

4-6-2 Outline of the Survey

(1) The survey of present situation of the tailing dam

(2) Observation of water level(Phreatic surface measurement in the tailing dam)

(3) Sampling of undisturbed cores in order to make laboratory soil tests

(4) Boring works

(5) Laboratory soil tests

(6) Measurement of the cross section and levelling of the tailing dam

(7) Environmental study

4-6-3 Results of the Survey

(1) Present situation of the tailing dam

As the slime is discharged to the western side of the tailing dam, the surface water usually exists in a part of the south eastern side(approximately 1/4 of total surface area of the tailing dam) and the south western side. The surface water level rises due to rain. Traces of the water flown over the slope are recognized in the eastern part of the dam. Traces of slime flown over the dam through a collapsed part of the dam due to rain in the rainy season are also recognized in the western part of dam where the surface water is stagnant. Therefore, it is necessary to install the drainage in order to prevent these phenomena.

(2) Pore Water Pressure Measurement

For estimation of saturation water level in the dam, water level was observed at each stage of boring works. Then, water head between the static water level and boring depth was obtained to estimate the pore water pressure.

As the result of observation, no water was observed either in hole BD-1 or BD-2 throughout the dry and rainy season. In the hole BD-3 drilled in the rainy season, water was not observed either. These results indicate that there occurs no pore water pressure in the dam. Thus, there is no dangerousness of "Liquefaction of sand" by occurrence of pore water pressure in the dam embankment at present.

(3) Soil sampling and laboratory soil tests

Undisturbed samples were taken at DB-3 and other two points, and laboratory soil tests were carried out with those samples.

① The location and number of the samples for the laboratory soil tests are shown below. Fig.4-6-1 shows sampling site for soil tests. The quantity is shown in the Table 4-6-1.

② The laboratory soil tests are carried out about the same 8 items as El Bote area.

③ The results of the laboratory soil tests are summarized in Table 4-6-2.

i) Specific gravity test

The specific gravity of the particles of soil of the dam is 2.61 to 2.67, and the mean value was 2.63. As the specific gravity of general alluvial soil is 2.6 to 2.8, the sand is judged to be the accumulation of the average particles of soil. The specific gravity of deposits inside of the dam is 2.6 to 2.8, and the average is 2.62. From this fact, the soil of the dam is the same of the inside deposits of the dam.

ii) Water content and density tests

As Wet density(ρ_t) and natural water content(w) have close relationship, they are shown together in the table 4-6-3. The mean values of ρ_t and w of the dam and deposits are shown in Table 4-6-3.

Natural water content of deposits is extremely higher than that of the dam. This is because the deposits were sampled near the stagnant water. Wet density of the dam is higher than that of the deposits and more compact. According to the standard penetration test, mean N value of the dam material is 32, which shows that is comparatively dense. N value and the results of wet density test are consistent. Therefore, the material near the dam has nearly the proper water content.

iii) Grain size analysis

Grain size accumulation curves of the soil of dam and the deposits are shown in Fig.4-6-2. Fig.4-6-2 shows that the distribution range of grains are between 0.005 mm and 0.85 mm, which means that the grains are uniform. The relation between coefficient uniformity(Uc) and coefficient of curvature(U'c)is as follows;

$Uc \geq 10$, $1 < U'c \leq \sqrt{Uc}$ (good grading);1 sample

$Uc < 10$,(uniform grading, bad grading) ;6 samples

$Uc \geq 10$, $U'c \leqq 1$ or $U'c > \sqrt{Uc}$;0 sample

(composite grain size distribution, bad grading)

Judging from the analysis, samples are judged "poor grading" on the whole.

iv) Liquid limit test and plastic limit test

As the result of the test, mean values of LL, LP and w of the dam material and deposits are shown in Table 4-6-4.

As the result of plasticity test on the dam material, all the samples were N.P. (Non-plastic). This means that the content of finer components than silt is small. In order to study the characteristics of deposits, plastic index(Ip) and consistency index(Ic)are calculated as below.

$Ip = LL - PL = 38.0 - 22.5 = 15.5\%$

$Ic = (LL - W) / Ip = (38.0 - 28.4) / 15.5 = 0.62$

According to the above result that Ip=15.5%<20%,the characteristics shows that the adhesive power is easily lost in case of high water content. Ic=0.62<1 means that stability of soil is low.

v) Permeability test

The mean values of the permeability coefficients of the soil of dam and deposits are as follows;

Soil of dam	$k=5.06 \times 10^{-3}$ cm/sec
Deposits	$k=0.93 \times 10^{-3}$ cm/sec

vi) Summary of the laboratory soil tests

The nature of soil materials is as follows;

(dam)

a) Water content is low and degree of condensation is comparatively high.
b) Classification of the soil is "SM"(silty sand).
c) Grain size is uniform, and grading is not good. Therefore, the soil will easily be quick sanded, and stability of slope is low.
d) In case of high water content, the soil easily makes liquefaction. In case of low water content, it easily losses plasticity.
e) Permeability is normal or slightly impermeable.

(deposits)

a) Classification of soil is "SM"(silty sand). Compared with dam, the deposits include much more fine grained components.
b) Grading is not good as same as that of dam.
c) Easy liquefaction and narrow plasticity range.
d) Normal to slight impermeable in permeability.

(4) Estimated section of tailing dam

The geological cross section of the tailing dam estimated from cross sectional measurement and boring works is shown in Fig.4-6-3.

The boundary of the dam(sediment-1) and sediments(sediment-2) was decided with the same method used in the survey of El Bote tailing dam. Phreatic surface was decided considering safety side in calculation, because of no water observed in the drilling holes.

(5) Estimation of present stability of the tailing dam

The stability of this tailing dam was estimated with the data above mentioned. Stability test was carried out using the same standard and equation in case of the study on El Bote tailing dam.

① Section of stability analysis

Effective height of the eastern slope of this dam is approximately 2 to 3 m, while the effective height of the western slope of this dam is considered to be 15 to 20 m. Therefore, examination was carried out on the section of the part of the western slope which is with stagnant water due to rain and is considered to have the highest effective height. The modeled section for computer input is shown in Fig.4-6-4.

② Soil constant

Soil constants for stability analysis was decided as following;

i) Deposit-1(Zone- ①)

The deposit is coarse-grained deposits classified with cyclone. Soil constants are as follows;

$Gs = 2.62 \quad W = 7.9\% \quad \rho_t = 1.910 g/cm^3$

$\rho_d = \rho_t / (1+ \frac{W}{100}) = 1.91/(1+ \frac{7.9}{100}) = 1.77 g/cm^3$

$e = (Gs/\rho d) - 1 = (2.62/1.77) - 1 = 0.48$

$Sr = \frac{W \cdot Gs}{e} = \frac{7.9 \times 2.62}{0.48} = 43.1\%$

Density and water content when the water is saturated is estimated with the datav above shown.

ρ_{sat} = (weight of soil) + (weight of pore water)

$= \rho_d + (1 - \rho_d / Gs)$

$=1.77+(1-1.77/2.62)$

$=2.094 \ g/cm^3$

Shear strength is as follows;

Angle of shear resistance $\phi = 30.0°$

Cohesion $c = 0.00 \ tf/m^2$

ii) Deposit-2(Zone- ②)

The deposits is fine-grained after classified with cyclone. It is so-called slime.

$$Gs = 2.63 \quad W = 28.3\% \quad \rho_t = 1.689 g/cm^3$$

$$\rho_d = \rho_t / (1 + \frac{W}{100}) = 1.689 / (1 + \frac{28.3}{100}) = 1.316 g/cm^3$$

$$e = (Gs / \rho d) - 1 = (2.63 / 1.316) - 1 = 0.998$$

$$Sr = \frac{W \cdot Gs}{e} = \frac{28.3 \times 2.63}{0.998} = 74.6\%$$

Density and water content are estimated with the data shown above.

ρ_{sat} = (weight of soil) + (weight of pore water)

$= \rho_d + (1 - \rho_d / Gs)$

$= 1.316 + (1 - 1.316/2.63)$

$= 1.816\ g/cm^3$

Shear strength is as follows;

Angle of shear resistance ϕ = 23.0 °

Cohesion c = 1.00 tf/ m^2

③ Other conditions

Horizontal seismic intensity and increment of circular arc(Δ R) are the same as those in the examining of El Bote Tailing Dam, and those are Kh=0.15 and Δ R=1.0 m, respectively.

④ Calculation results

Calculation results on the model shown in Fig.4-6-4 are reviewed in Table-4-6-5. The detailed result of stability analysis in ordinary condition(Kh=0.00) is shown in Fig.4-6-5, and the arcs(or the position of the arcs where sliding plane locates in the deepest) which have minimum safety factor in each distance at that time are shown in Fig.4-6-6. The detailed results of the stability analysis during earthquake(Kh=0.15) and their arcs are shown in Fig.4-6-7 and Fig.4-6-8, respectively.

As the result, the minimum safety factor of this tailing dam is under 1.0 both in ordinary condition and during earthquake. Safety factor on other sliding surfaces also turned out to be less than 1.0 during earthquake.

Therefore, stability of this tailing dam against collapse is presumed to be extremely dangerous.

The reasons are as follows;

i) As regards prevention power of the dam, the section of the dam is too small to prevent.

ii) The gradient of the slope of the lower reaches is steep.

It is necessary to make immediate measure against the instability factors according to the study mentioned above.

As the instability factors mentioned above are the same as those of El Bote tailing dam, the other tailing dams constructed by the same method in Mexico might have risks of collapse.

⑤ Judgement of dangerous by liquefaction.

There are some risks of liquefaction during earthquake condition, because the major material of this dam is sand. Therefore, it is necessary to judge about the dangerousness of liquefaction.

Judgement of dangerousness by liquefaction was made based on the "Construction Standard of tailing Dam".

When the soil meets any conditions shown below, liquefaction can occur.

i) The shallower part than 20m below tailing dam surface.

ii) The deeper part from phreatic surface.

iii) The part of less than 20 of N value.

The risky area on liquefaction in this tailing dam which meets the above conditions is shown in Fig.4-6-9. The area of ① in the Fig corresponds to i) and ii). However, as N value of the area of ③ is over 20, the area of iii) does not belong to the risky area.

Therefore, the liquefaction in this tailing dam is impossible.

4-7 Dust Problem

Possible dust sources that may have an effect on the Parral residetial district are the CFM tailing dam as well as surrounding dry areas around the city. Due to the existence of multiple dust sources, it is so difficult to identify the dust particles only from the tailing dam. Measurement of dust concentration was carried out in the rainy season, when dust scattering from the surrounding areas are mostly depressed.

4-7-1 Matters for Investigation

(1) Meteorological survey with a self-recording anemometer

(2) Measurement of dust density by LVS in the atmosphere

(3) Dust sampling by dust jars

(4) Long term observation of dust density by digital type monitors at fixed points

(5) Collection of existing meteorological records

4-7-2 Survey results

(1) Meteorological observation

Observation points are illustrated in Fig.4-7-1. Wind direction and velocity observed by the self-recording anemometer are shown in Table 4-7-1 and 4-7-2 respectively. This observation was run for about one month starting August 4, 1991. The maximum wind velocity recorded during this period was 8.0 m/sec. The minimum and mean velocity are 0 m/sec and 2.2 m/sec respectively. Wind direction was mostly from the west. Throughout the observation period, the velocity hardly exceeded 5 m/sec.

(2) Dust jar

Dust jars were installed at the fixed points as shown in Fig. 4-7-2. Table 4-7-3 shows the measurement results.

D-1 On the roof of a residence at the southern part of the Parral city

D-2 On the roof of the laboratory by the mine office

D-3 West of the tailing dam

D-4 East of the tailing dam

D-5 On the roof of a hotel in the city

D-6 Inside the military base

(3) Low volume air sampler (LVS)

Low volume air sampler was set at the three points as shown in Fig. 4-7-3. Measurement condition and the results are shown in Table 4-7-4 and 4-7-5 respectively. At the point L1, measurement ran successively for 72 hours starting at 11:00 of August 2nd. Sample volume collected was 3.0 mg and concentration of dust in the atmosphere was 0.046 mg/m^3. At the point L2, 4.4 mg of dust sample was collected after successive measurement for 48 hours starting at 15:00 of August 8. Concentration of dust in the atmosphere counted 0.102 mg/m^3. At the point L3, measurement ran successively for 48 hours starting at 10:00 of August 12. Sample volume collected was 5.7 mg and concentration of dust was 0.132 mg/m^3.

(4) Digital type dust monitor

Measurement points and results are shown in Fig. 4-7-4 and Table 4-7-6 respectively. This measurement was carried out for 11 days from August 5 at ten fixed points. The maximum and minimum values were 29 and 23 cpm. The mean value was 24 cpm and no characteristic variation or distribution was seen in each point nor in each day.

4-7-3 Dust distribution in Parral area

In the rainy season, when the measurement of dust was carried out, no characteristic features of dust distribution was observed. This is because the soil surface was so wet as to depress dust scattering from the dam and the wind velocity hardly exceeded 5 m/sec.

As the results of digital type dust monitors background value of dust concentration in the city of Parral seemed to be around 25 cpm, nearly the same as in Zacatecas. Sample volume collected by dust jars was too scarce to chemically analyze, however, at the points L2 and L3 located close to the dam the volume collected was 2.5 to 3 times as much as point L1.

As mentioned above, dust fall into the city of Parral is supposedly so little during the rainy season. On the other hand, in the dry season sand storm was visibly seen when the wind blows hard. It is possible that some particles reach the city falling down to the residential area.

4-8 Summary of the Investigation

This area is formed on the Parral Formation of early Cretaceous Period and is mainly composed of shale layers partly accompanied with thin sandstone seams.

The River Parral, the main stream of the area, runs zigzagging from west to east merging some branch rivers close to the tailing dams. The River Parral shows a big variation in water volume throughout a year, almost draught in the dry season, while muddy and rushing in the rainy. Ground water also rises in the rainy season with increased current movement. The ground water stream is likely to flow from the aquifer below the dam site toward north-east direction.

Into the Parral River flows the waste water from CFM mineral processing plant and other effluent of near-by privately owned plants as well. Among the surface water samples, P-R3, taken from the upper-most stream,was clear and metal ion free in the dry season. On the other hand, in the rainy season, all the heavy metal ions analysed were found in the sample. This results, by rain-fall, from washout of soils and bank deposits into the river. In the samples of P-R2, taken from the branch river to the south and P-R4 from its merging point into the main Parral River, higher levels of metal ions and cyanide are detected. These results from the effluents of CFM plant and dam as well as other private plants. Samples P-D1 and P-W1 represent filtrate solutions of CFM plant tailing dam deposits respectively. Since Cu, Zn and Cr are highly contained in both of them, these pollutants are assigned to CFM mining operation. On the other hand, Fe and As may result from other sources than CFM. In the sample of P-R5, taken from the downstream of the river,contents of heavy metals are considerably lowered because of dilution.

Ground water samples also contain all heavy metals but Cr^{6+} and these could be derived from mineralization zone widely distributed in this area. Cyanide has not been detected in the ground water samples. This suggests that penetrated water from the dam is unlikely affect the groundwater.

In the soil samples heavy metals are highly concentrated. Especially, Cu, Pb, Zn and As are contained at remarkably high levels at some points.

Some countermeasures are urgently required to prevent collapse of the tailing dam embankment, because its stability was found so dangerous as in El Bote. Furthermore, in the rainy season, dam water level might increase and overflow the embankment. Suitable drainage system is required.

Influence of dust particles carried away by the wind from the dam was not recognized during the rainy season. In the previous dry season measurement of

dust concentration was practically impossible due to time shortage, however, sand storm was visually observed so often.
Consequently, some countermeasures are inevitable as in El Bote tailing dam. Chemical treatment of mine effluents is also inevitable before they are discharaged into the river.

4-9 Measures against Mine Pollution

4-9-1 Measure against Collapse of Tailing Dam

(1) Selection of the counterwork

The following reasons can be pointed out as the major reasons of dangerous situation of the dam collapsing described in chapter 4-6 "Tailing Dam".

① As regard prevention power of the dam, the section of the dam is too small to prevent.

② The gradient of the slope of the lower reaches is steep.

These conditions are closely resemble in case of El Bote tailing dam.
Parral tailing dam has the following features compared to El Bote dam.

(2) Optimum counterworks

Compared with El Bote tailing dam,

① Height of the dam is lower

② Slope of the dam is more gentle

③ Width of the dam is wider and the dam material is well condensed

Therefore, in case of this tailing dam, Earth removal work together with Counter weight fill work is recommended as the counterwork.

(3) The section of Counter weight fill work

The section of Counter weight fill work is shown in Fig.4-9-1. Considering the stability of slope, inclination of the slope is 40 % and there are steps of 5 m width every 10 m in height. In Fig.4-9-1, zone of ① consists of rock material, ② is cutting parts and ③ is banking parts. Banking with rock material is performed up to EL=1767m at first, followed by the work of cutting of ② and banking of ③, and then banking with rock material finally.

(4) Stability test

The target of the safety factor by the counter weight fill work is over 1.2. The same equation and computer program in the stability analysis were used as that of El Bote tailing dam.

Model of the section for the stability analysis is shown in Fig 4-9-2.

① Soil constant and other conditions

Soil constants in each zone shown in Fig.4-9-2 are the same constants in chapter 4-6 "Tailing Dam". The constants of gravelly soil for Counter weight fill work is used with the following values as in case of El Bote tailing dam.

ρ_d = 1.800 g/cm^3

ρ_{sat} = 1.912 g/cm^3

c = 0.00 tf/cm^2

ϕ = 37.0 °

Horizontal seismic intensity during earthquake(Kh=0.15) and increment of circular arc($\triangle$R=1.0 m) are used the same as in chapter " 4-6 Tailing Dam".

② Calculation result

The calculation result with the analysis model in Fig.4-9-2 is shown in Table 4-9-1. The detailed result in ordinary condition(Kh=0.00) and the deepest circular arc or sliding plane which has the minimum safety factor in each distance are shown in Fig.4-9-3 and Fig.4-9-4, respectively. The detailed results during earthquake and circular arc are shown in Fig.4-9-5 and Fig.4-9-6 respectively.

The result satisfies the target value over 1.2 as the minimum safety factor. Therefore, the stability of model section in Fig.4-9-2 can be judged as "stable".

4-9-2. Measure for Drainage of Tailing Dam

As result of survey of the present situation, it was recognized the surface water to flow out the dam due to the rising of surface water level in rainy weather. Therefore, for prevention of over flow of surface water, it is necessary to install drainage. As regard to the drainage system of the tailing dam, the systems are different whether the dam is now used or not. In case of this tailing dam,the eastern part of the tailing dam was already finished to use. On the other hand, the western part is still being used. Therefore, the drainage differs from the eastern part and the western part. For prevention of surface water flowing into the tailing dam from the surface of the southern hill slope due to rainfall,facilities of outside drainage of the tailing dam are installed.

E0ach section of drainage is shown below.

the plan of drainage	Fig.4-9-7
the cross section of drainage	Fig.4-9-8
the standard plan of drainage	Fig.4-9-9

(1) Drainage inside of the dam

① Drainage of the eastern part

The drainage is installed after covering soil on the surface as the same work of El Bote tailing dam, because the eastern part of the dam was already finished to use.

The clayey soil that distributes in the western part of the dam is used to covering work of the surface. Thickness of soil is planned about 30 cm. The spreading work uses the original inclination of 1 ~ 3 % from the center to dam. U type Colgate flume will be used as drainage.

② Drainage of the western part

Slime is still discharged in the western part. Surface water due to rain and waste water are discharged by inclined pipe to water treatment in the lower reaches.

Surface water in the eastern part is able to be discharged directly into rivers or to reuse in the plant because of inpolluted. On the other hand, surface water in the western side cannot be discharged directly into the rivers because of pollution. Therefore, the drainage system must be different in the eastern part and the western part.

(2) Drainage outside of the tailing dam

The channel is constructed on the southern slope of the hill as the drainage facility. The installation position of drainage shall be 1m higher than the surface of the final depositing. The channel is the canal with no lining.

(3) Drainage capacity

Drainage capacity for surface water inside the dam is decided by the amount of precipitation flowing into the dam estimated by probable precipitation amount for 100 years and the amount of stagnant water after settling the slime. The drainage capacity for outside of the dam was decided by the amount of water flowing into the area of basin estimated by probable precipitation amount for 100 years.

① Probable precipitation amount in a day

Table 4-9-2 shows the data of daily total amount of precipitation data in Parral observatory during 1977 to 1990 orderly arranged by the amount.

Probable precipitation amount for 100 years(R_{24}) is obtained by Fig.4-9-10;

R_{24}=130 mm/day

② Water collecting area

Water collecting area of each drainage is as following;

$A1=0.074\ km^2$

$A2=0.019\ km^2$

$A3=0.024\ km^2$

③ Run-off time

The equation is shown below;

$$T = 1.67 \times 10^{-3}(L / \sqrt{S})^{0.7}$$

T; reaching time (h)

L; distance of flowing to the farthest point (m)

S; inclination(%)

$T_1=1.67 \times 10^{-3}(350/\sqrt{9/40})^{0.7}=0.17$ h

$T_2=1.67 \times 10^{-3}(100/\sqrt{3/100})^{0.7}=0.14$ h

$T_3=1.67 \times 10^{-3}(200/\sqrt{3/100})^{0.7}=0.23$ h

④ Average maximum precipitation intensity

The equation is shown below;

$$R = \frac{R_{24}}{24} \times \left(\frac{24}{T} \right)^{2/3}$$

R ; average maximum precipitation intensity (mm/h)

R_{24}; (designed)precipitation amount in a day (mm)

T ; reaching time of flood (h)

$$R_1 = \frac{130}{24} \times \left(\frac{24}{0.17} \right)^{2/3} = 147 \text{ mm/h}$$

$$R_2 = \frac{130}{24} \times \left(\frac{24}{0.14} \right)^{2/3} = 167 \text{ mm/h}$$

$$R_3 = \frac{130}{24} \times \left(\frac{24}{0.23} \right)^{2/3} = 120 \text{ mm/h}$$

⑤ Design amount of flood water

The equation is shown below;

$$Qp = \frac{1}{3.6} \times f \times R \times A$$

Q; the maximum amount of flood water (m^3/sec)

f; coefficient of flow

(stagnant water surface 1.0, grassland 0.9 forest 0.8)

A; area of basin (km^2)

i) A1 area (the southern slope)

Qp1=1/3.6 × 0.8 × 147 × 0.074=2.42 m^3/sec

ii) A2 area (stagnant water surface of the eastern side)

Qp2=1/3.6 × 0.9 × 167 × 0.019=0.79 m^3/sec

iii) A3 area (stagnant water surface of the western side)

Qp3= Qp4+Qp5

Qp4'=1/3.6 × 1.0 × 120 × 0.024=0.80 m^3/sec

The amount of surface water ;

Qp5= 5,200 m^3/month=173.3 m^3/day=0.002 m^3/sec

Qp3= Qp4+Qp5= 0.80 m^3/sec + 0.002 m3/sec=0.802 m^3/sec

(4) Section of drainage

① Drainage outside of the dam(channel on the slope of hill)

Assumed section of drainage outside of the dam is shown in Fig.4-4-9 (A);

$$Q = V \cdot A = \frac{1}{n} \cdot A \cdot R^{2/3} \cdot I^{1/2}$$

$$= \frac{1}{0.035} \times 0.9 \times 0.34^{2/3} \times 0.05^{1/2}$$

$$= 2.80\ m^3/sec > QP_1 = 2.42\ m^3/sec \cdots\cdots\cdots\cdots O.K$$

Therefore, the section is decided as in Fig.4-4-9(A).

② Drainage inside of the dam

i) surface water in the eastern part(U type Colgate pipe)

Assumed section of U type Colgate flume is shown in Fig.4-9-9 (B);

$$Q = V \cdot A = \frac{1}{n} \cdot A \cdot R^{2/3} \cdot I^{1/2}$$

$$= \frac{1}{0.022} \times 0.469 \times 0.400 \times 0.02^{1/2}$$

$$= 1.21\ m^3/sec > QP_2 = 0.79\ m^3/sec \cdots\cdots\cdots\cdots O.K$$

Therefore, the section is decided as in Fig.4-9-9(B).

ii) surface water in the western part(slope gutter)

Assumed section of slope gutter is shown in Fig.4-9-9(C);

$$Q = V \cdot A = \frac{1}{n} \cdot A \cdot R^{2/3} \cdot I^{1/2}$$

$$= \frac{1}{0.015} \times 0.225 \times 0.161^{2/3} \times 0.05^{1/2}$$

$$= 0.995\ m^3/sec > QP_3 = 0.802\ m^3/sec \cdots\cdots O.K$$

Therefore, the section is decided as in Fig.4-9-9(C). The water through the Colgate pipe is led to the outlet through polyethylene pipe with ϕ 500mm

4-9-3. Measure against Dust Scattering

Powder dust scatters due to drying of the dam surface in the dry season.

The same consideration in case of El Bote tailing dam is necessary, because the slime deposition in the central to the eastern part of Parral tailing dam has already been finished. Therefore, soil covering work on the dam slope and the upper surface of the dam is the most suitable as the countermeasure.

As regards soil covering work, it is already explained in the chapters"4-9-1 Measures against the Dam Collapse" and "4-9-2 Measures against Drainage of the Dam".

Soil covering work is the most suitable as the measures against powder dust scattering for the central to the western part of the dam where slime deposition continues at present and will continue in future. Covering the surface of the dam slope with soil is performed every 1 ~ 2 m in height at any time. After the time when the height of the dam reaches the upper limit and deposition is finished, the upper surface of the dam is covered with soil. The depositing surface is considered to be wet by discharged water with slime. For the part where powder dust comes out of due to dry up, water is sprinkled with sprinkler.

4-9-4 Final Treatment of Waste Water

The waste water including cyanide ion cannot be discharged into the river without decomposing of cyanide by some methods. Although there are many treatment methods, the most popular method is the decomposing and oxidation of cyanide by sodium hypochlorite(NaClO) dosing in waste water in alkaline environment. There are reactions of the following two stages.

$$NaCN + NaClO = NaCNO + NaCl$$

$$2NaCNO + 3NaClO + H_2O = 2NaHCO_3 + 3NaCl + N_2$$

Two reaction tanks are usually used. The solution is agitated during 10 ~ 15 minutes in each tank. The treated water can be discharged into the river.

A series of laboratory tests should be carried out before treatment method is finally decided.

4-9-5 Measures against Groundwater Pollution

According to the hydraulic observation, the Parral river is losing river in the dry season, but change to gaining river in the rainy season. This losing means that infiltration rate exceeds recharge rate. The gaining means that recharge rate exceed infiltration rate. Eventually, in the dry season surface water easily infiltrate underground. In the rainy season it does not infiltrate so much ,but flows in to the river and pollutants would be transported to the long distance down to the Parral city.

Consequently, to prevent of the underground pollution, the next measures should be conducted. The first measure is to cover tailing dam by soil covering method and planting in the same way as El Bote mine. The second is to set up drainage system and a simple deposition pond. The third is to take waste water recycle system, so that the waste water from the tailing dam can not flow into the Parral river.

We suggest that to make a deposition (settling) pond between the tailing dam and Parral river and connect it to the drainages from the dam,

① to expand the evaporating area in the dry season, and

② to prevailing the discharge of tailings with an unexpected big storm rainfall in the rainy season.

This plan play a significant role in the prevailing sub-system as "prevailing the transportation of pollutants by the Parral river".

Groundwater from the tunnel of the Parral mine indicates strongly acid. This water is pumped up and used for the mine plant and sewerage system of Parral municipality. This water is no adequate to drink. Chemical composition of this water is anomalous compared to surface water or shallow groundwater. It is thought that this groundwater is deep-seated origin.

The Parral river runs in the upside of this area. It is considered that there exists no deep polluted groundwater in the shallow aquifer, because the unconfined groundwater consists by water that originate in rainwater, from the view points of topography and river morphology.

To improve this water quality , new shallow aquifer along the Parral river should be utilized by boring work, because more clean groundwater can be got.

4-9-6 Work Program and Construction Cost

Work program and construction cost for completion of each countermeasure plan on the tailing dam are roughly estimated as follows.

(1) Work program

Work program is illustrated in the following figure.

Type of Work	Amount	5 month 10 month
Earth Removal Work	14,000 m^3	2.5 month
Counter Weight Fill Work	66,000 m^3	4 month
Soil Covering Work	6,000 m^3	0.6 month
Drainage Inside The Dam	300 m	0.9 month
Drainage Outside The Dam	780 m	1 month
Temporary Passage	100 m	0.2 month

(2) Construction Cost

According to the construction basis in Mexico, total costs are estimated as follows.

Type of Work	Amount	Unit Cost (US$)	Total Cost (US$)
Countermeasures against			
Dam Collapse and Dust Problem			
Earth Removal Work	14,000 m^3	1.7	24,000
Counter Weight Fill Work	66,000 m^3	6.3	416,000
Soil Covering Work	6,000 m^3	4.0	24,000
(Sub Total)			(464,000)
Drainage			
Inside the Dam	300 m	120.0	36,000
Outside the Dam	780 m	113.3	88,000
(Sub Total)			(124,000)
TOTAL			588,000

(3) Specification of Work

Specification of the works and necessary equipment are listed in the following Table.

Type of Work	Equipment	Unit Capacity	Unit
Earth Removing Work	Bulldozer (15t class)	33 m^3/h	1
Counter Weight Fill Work			
Rock excavation at borrow pit	Bulldozer with Ripper (32t class)	53 m^3/h	1
Loading of crushed rock	Backhoe (1.0m^3 class)	51 m^3/h	1
Transportation	Dumptruck (11t class)	17 m^3/h	3
Spread and Roll	Bulldozer (21t class)	64 m^3/h	1
Soil Covering Work			
Excavation and loading of clayey soil	Backhoe (0.6m^3 class)	41 m^3/h	1
Transportation	Dumptruck (11t class)	18 m^3/h	3
Spread and Roll	Bulldozer (11t class)	41 m^3/h	1

Remarks

1. Transportation during the Counter Weight Fill Work is estimated as 1km.
2. Transportation during the Soil Covering Work is estimated as 0.7km.
3. Working hours are 7 hours a day and working days are 25 days per month.

Then, for chemical treatment of the waste water, main equipment and their purchase prices are described below. If the Alkali Chlorination method is adopted to treat approximately 200m^3 per day of waste water, they are roughly estimated as follows. The operation costs are not included.

Main Equipment and Prices for the Alkali Chlorination Method

Equipment	Specification	Unit	Unit Price (US$)	Total(US$)
Reaction Tank	1,800x1,800mm, SS made with agitator	2	15,000	30,000
Reagent Feeding Tank	1,000x1,000mm, SS made with agitator	2	6,000	12,000
Reagent Feeding Tank	1,000x1,000mm, SS made FRP lining, with agitator	1	7,000	7,000
Reagent Feeding Pump	Plunger Type	3	8,000	24,000
Process Control System	pH Regulators and others	1 set		70,000
Piping and Others		1 set		7,000
Total				150,000

It will take about eight months before completion, i,e, approximately seven months of delivery and one month of setting up respectively.

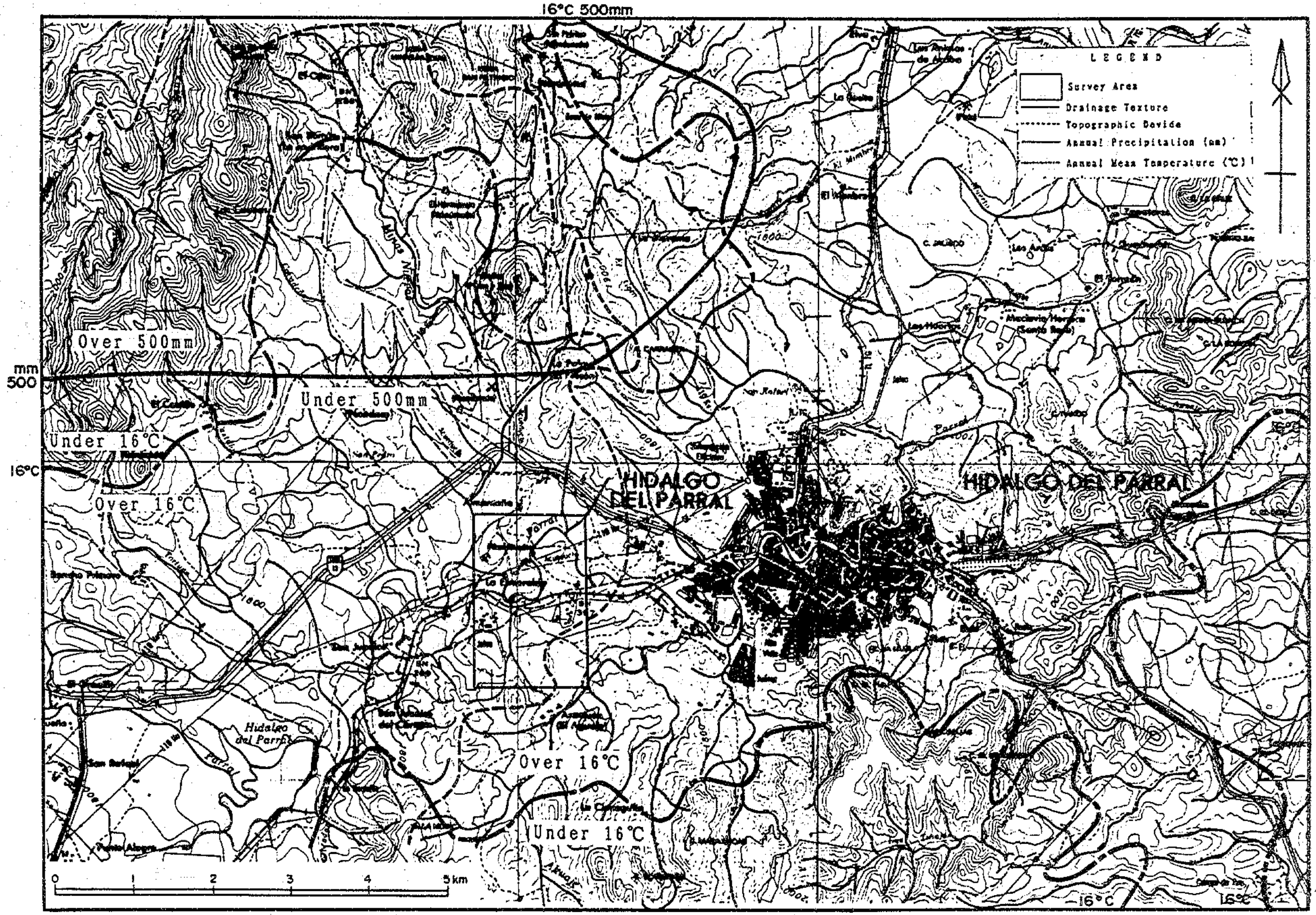


Fig. 4-1-1 Hydrologic and Meteorologic Map

Geological Age		Symbol	Explanation
Quaternary	Recent	Qr	River deposits
		Qt	Terrace deposits
Tertiary	Oligocene	Tr	Rhyolite(dyke)
		Td	Dacite and Rhyolite
		Ta	Andesite
Early Cretaceous		Ms	Parral Formation : shale
		———	Fault

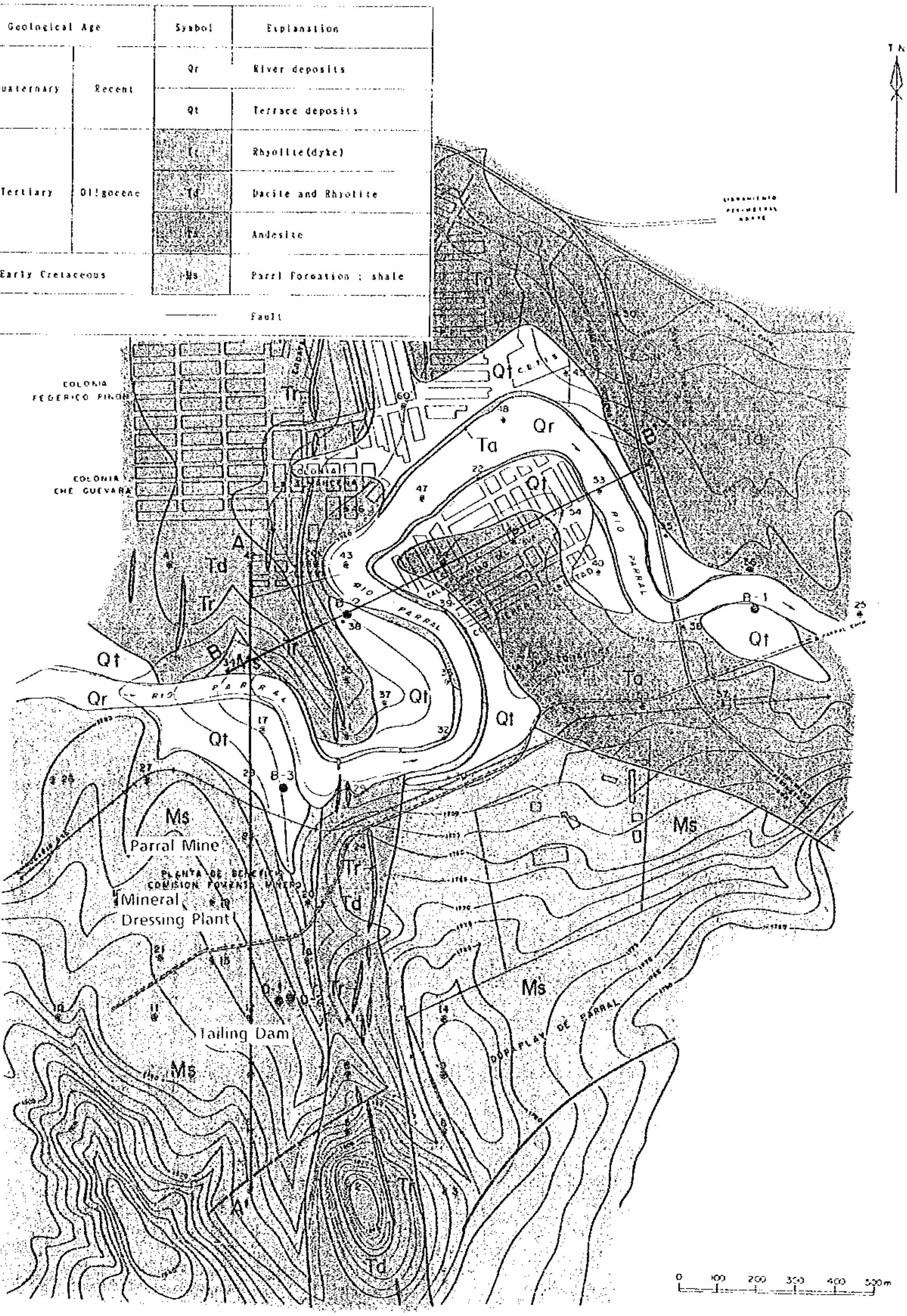


Fig. 4-2-1 Geological Plane Map (Parral)

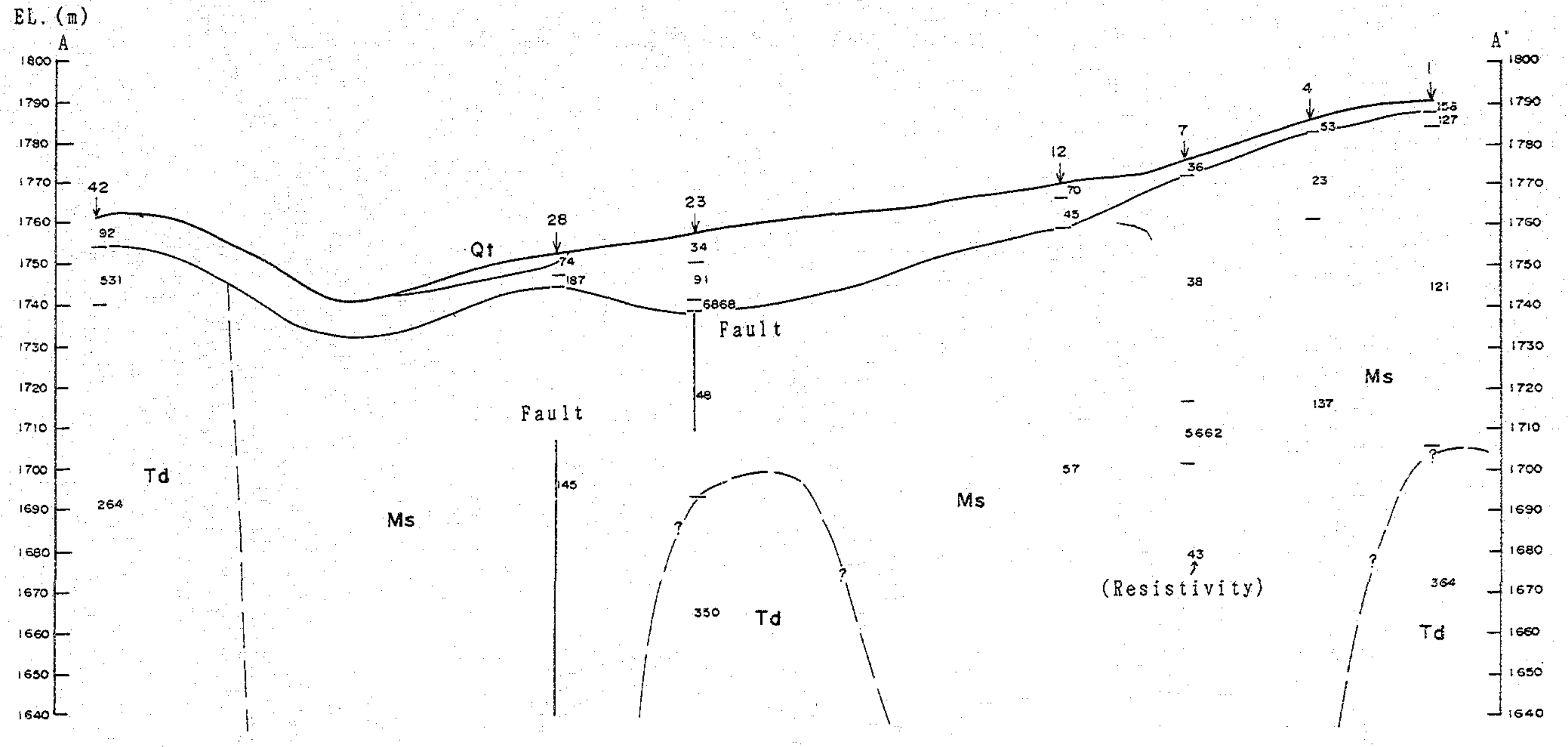


Fig. 4-2-2 Geological Cross Section (Parral) (1)

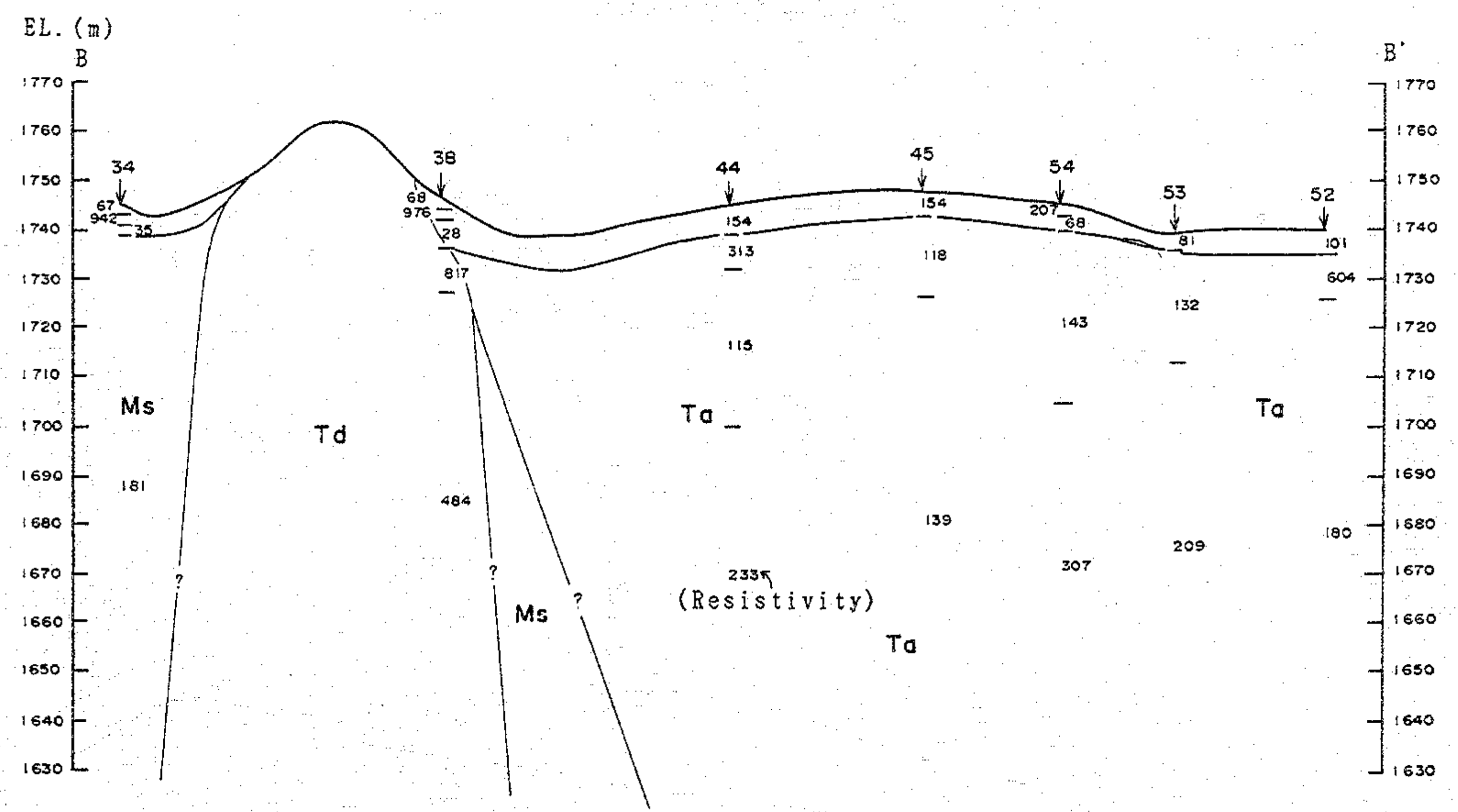


Fig. 4-2-2 Geological Cross Section (Parral) (2)

(2) Parral

Geological Age		Symbol	Explanation
Quaternary	Recent	Qr	River deposits
		Qt	Terrace deposits
Tertiary	Oligocene	Tr	Rhyolite(dyke)
		Td	Dacite and Rhyolite
		Ta	Andesite
Early Cretaceous		Ms	Parral Formation : Shale
		————	Fault

Fig. 4-2-3 Geologic Column (Parral)

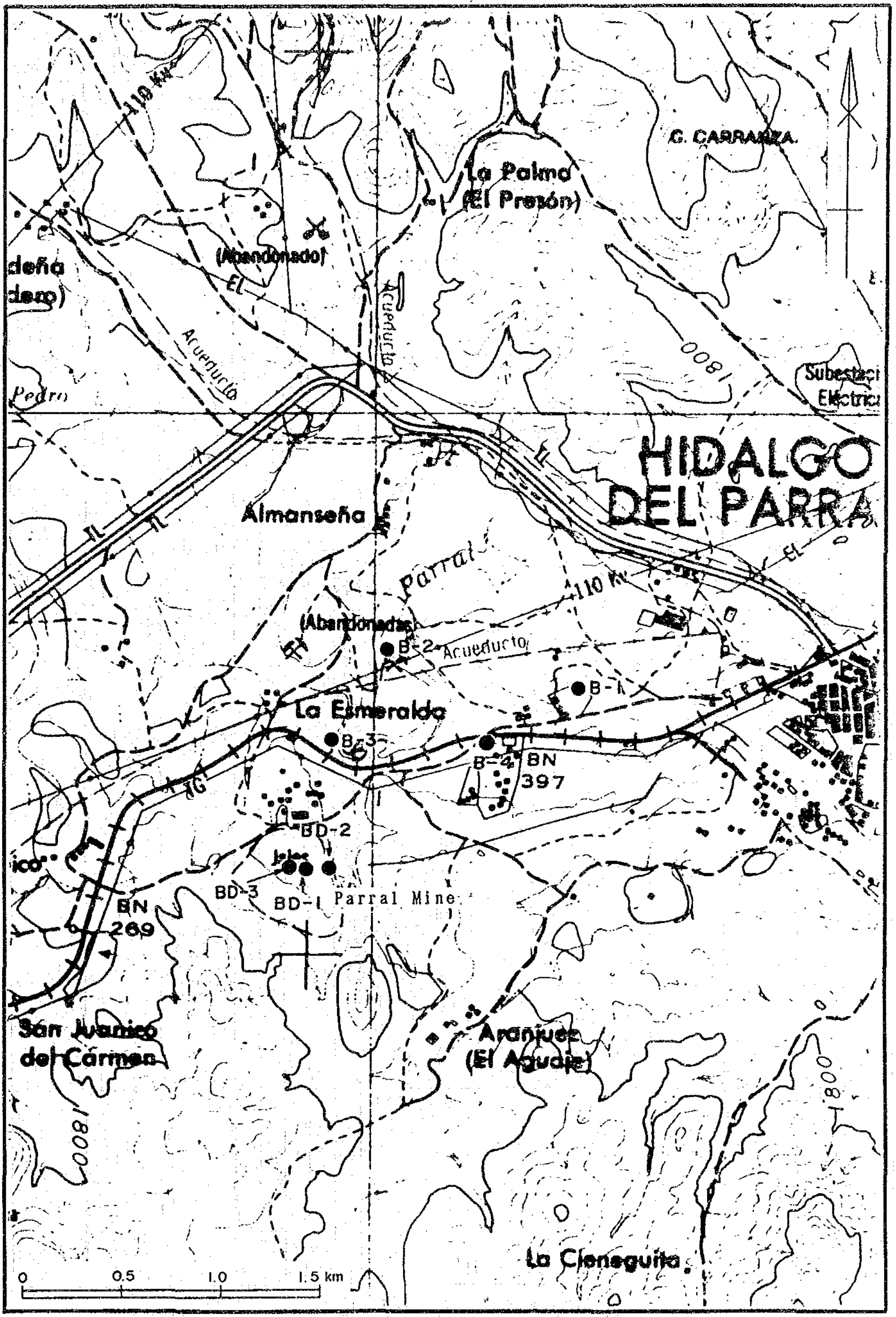


Fig. 4-2-4 Location Map of Boring Site

Parral B-1

Depth (m)	Formation	Lithology	Description
0.00–0.40	Terrace deposits	sand and gravel	The gravel consists of rounded andesite, shale and sandstone, ranging in size 1 to 8cms.
0.40–2.90		gravelly sand	The gravel consists of the same rocks as upper bed. The matrix is composed of brown, poorly sorted, silty and fine-grained sand.
2.90–3.10		gravel	The gravel consists of rounded basalt, dacite and welded tuff, ranging is size 3 to 8cms. The matrix is the same as upper bed.
3.10–10.00	Extrusive rocks	andesite	The andesite is light gray to grayish white and be characterized by megaphenocrysts of feldspar and pyroxene ranging up to 1cm in diameter, like as porpyrite. 8.60~8.80m Joint surface is covered with light brown limonite skin. 8.80m Joint; dip angle 75°. 9.80m Joint; dip angle 45°, straight quartz vein.

Core Shape: >20cm, 10-20cm, 5-10cm, 2mm~5cm, >2mm

Water Flow (cm/sec)

Dry Season: 0.40, 0.40, 0.40, 0.40, 0.40, 0.40, 0.40, 0.40, 0.40, 0.40

Rainy Season: 0.40 / 0.40; 0.63 / 0.40; 0.87 / 1.34; 1.22 / 1.11; 0.51 / 1.70; 0.40 / 1.46

Water Level / Lost Circulation: 2.60m (3/11) pH 7.55; (9/2) (8/29)

Fig. 4-2-5 Boring Log (1)

Parral B-2

Depth (m)	Formation	Lithology	Description	Core Shape (>20cm / 10-20cm / 5-10cm / 2mm~5cm / <2mm)	Water Flow (cm/sec) Dry Season	Water Flow (cm/sec) Rainy Season	Water Level Lost Circulation
0.00–0.70	Terrace deposits	silty sand	This layer consists of grayish brown, silty and very fine-grained sand.				
0.70–1.50	Terrace deposits	sandy silt	This layer consists of grayish brown sandy silt.				
1.50–8.00	Terrace deposits	silty sand	This layer consists of brown, well sorted, silty and fine-grained sand.				
8.00–8.50	Terrace deposits	gravelly sand	The gravel consists of rounded andesite, slate and acidic rocks, ranging in size 2 to 3cms. The matrix is composed of light grayish brown, silty and fine-grained sand.				
8.50–8.90	Terrace deposits	gravel	The gravel consists of the same rocks as upper bed, ranging in size 2 to 5cms. The matrix is also same.				
8.90–12.00	Extrusive rocks	andesite	The andesite is light gray to grayish white and be characterized by altered mega-phenocrysts of feldspar looks like porphyrite. Small pyrite grains have occurred in this rock 10.50~15.25m Especially, this part has hardly undergone kaolinization and chloritization, so that this texture is not clear.			0.40 0.51 0.40 0.63	(8/29) (9/2)

Fig. 4-2-5 Boring Log (2)

Parral B-2

Depth (m)	Drilling Log	Formation	Lithology	Description	Core Shape <20 cm	Core Shape 10-20cm	Core Shape 5-10cm	Core Shape 2mm ~5cm	Core Shape >2 mm	Water Flow (cm/sec) Dry Season	Water Flow (cm/sec) Rainy Season	Water Level Lost Circulation
12.00 – 15.25	L L	Extrusive rocks	andesite	This is the same rock above mentioned.							0.40 0.4 2.17 0.51 1.22 0.75	(8/29) (9/2)

Fig. 4-2-5 Boring Log (3)

Depth (m)	Drilling Log	Formation	Lithology	Description	Core Shape >20cm	10-20cm	5-10cm	2mm ~5cm	> 2 mm	Water Flow (cm/sec) Dry Season	Rainy Season	Water Level Lost Circulation
0.00		Terrace deposits	silty sand	This layer consists of pale brown, silty and fine-grained sand.								
			silt	The silt is brown, weakly consolidated and clay-rich.								
			gravelly silt	This layer consists of yellowish brown sandy silt with gravel. The gravel is composed of subrounded slate and acidic rocks, ranging in size 0.5 to 1cm.								
			sandy silt	The silt is dark grayish brown, weakly consolidated and sandy. Sandy element is fine-grained and well sorted.								
			sand	This layer consists of pale brown, loose, well sorted and very fine-grained sand.							5.01 4.42 5.01 3.47	(9/2) (8/29)
6.75		Parral formation	shale	The shale is pale greenish gray, hard and consolidated. Lamina has developed in it. This rock is affected by silicification and mineralization, so that many veins of quartz or pyrite has occurred in it. 9.00m Lamina; dip angle 60°. 9.90m Lamina; dip angle 45°.							3.12 2.76 4.54 3.00 4.89 2.05 3.95 1.22 4.42 2.41	
12.00												

Fig. 4-2-5 Boring Log (4)

Depth (m)	Drilling Log	Formation	Lithology	Description	Core Shape (<20cm, 10-20cm, 5-10cm, 2mm~5cm, >2mm)	Water Flow (cm/sec) Dry Season	Water Flow (cm/sec) Rainy Season	Water Level Lost Circulation
12.00		Parral formation	shale	This is the same rock above mentioned.			3.95 / 3.00	(9/1) (8/29)
				12.80m Lamina; dip angle 45°.				
							3.95 / 1.22	
				14.40m Lamina; dip angle 50°.			3.95 / 1.58	
				15.60m Lamina; dip angle 40°.			4.54 / 1.46	
							4.18 / 0.40	
							5.01 / 0.40	
							4.77 / 0.40	
				18.80m Lamina; dip angle 60°.				
							2.88 / 0.40	
							1.82 / 0.40	
							3.47 / 0.40	
				22.20m Lamina; dip angle 40°.			3.83 / 0.40	
							2.64 / 0.40	23.92
24.00								(3/11) pH 6.36

Fig. 4-2-5 Boring Log (5)

Parral B-3

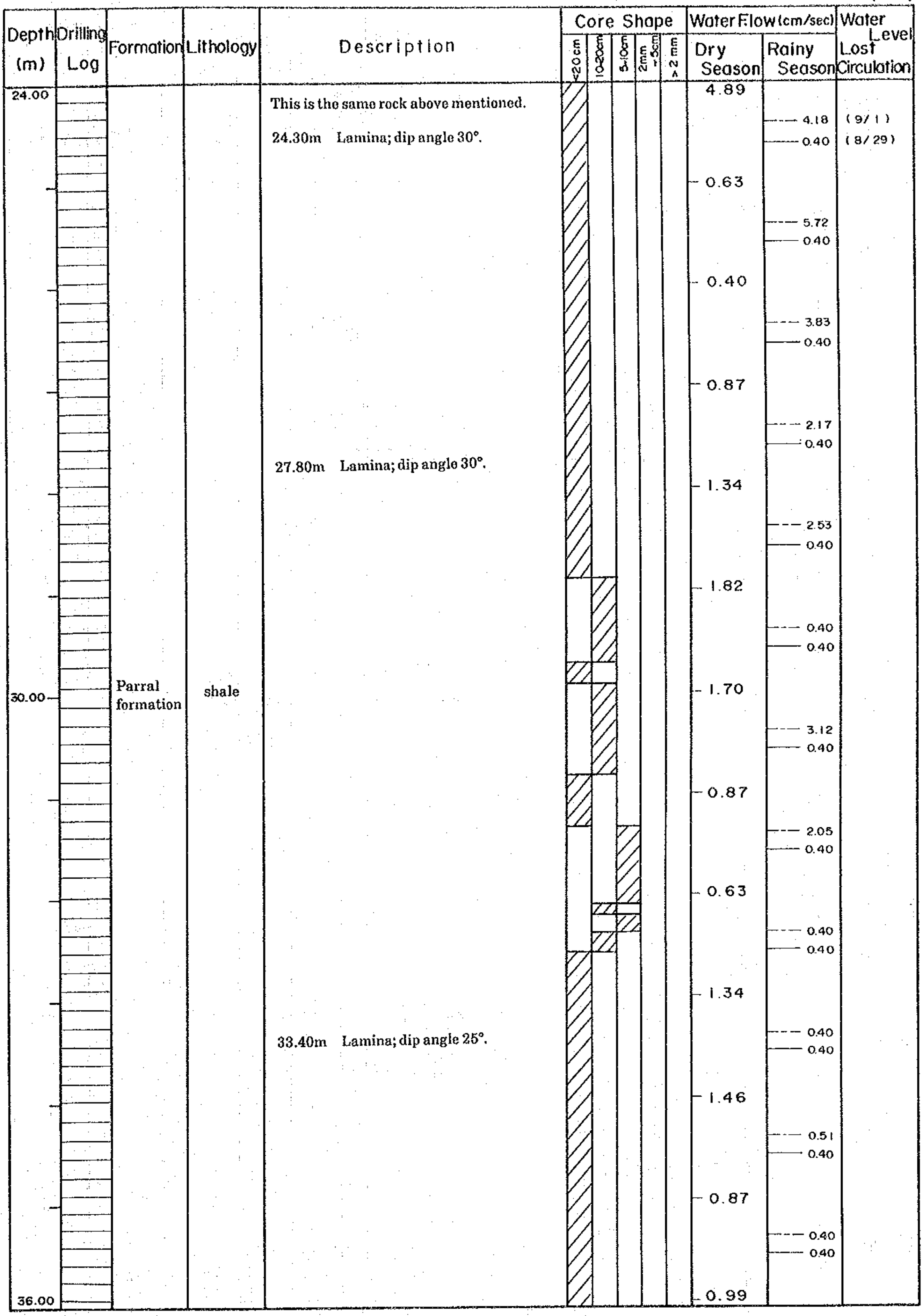


Fig. 4-2-5 Boring Log (6)

Depth (m)	Drilling Log	Formation	Lithology	Description	Core Shape <20 cm	10-20cm	5-10cm	2mm ~5cm	>2 mm	Water Flow (cm/sec) Dry Season	Rainy Season	Water Level Lost Circulation
36.00		Parral formation	shale	This is the same rock above mentioned. 36.80~39.60m This part is grayish white. 37.60m Lamina; dip angle 60°.						0.51 0.40 0.40	0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40	(9/2) (8/29)
39.60 40.00			sand stone	This layer consists of grayish white, arkose and coarse-grained sandstone.						0.40		

Fig. 4-2-5 Boring Log (7)

Depth (m)	Formation	Lithology	Description	Water Flow (cm/sec) Rainy Season	Water Level Lost Circulation
0.00	Terrace deposits	sandy silt	This layer consists of dark yellowish brown and sandy silt.		
		silty sand	This layer is composed of pale brown, moderately well sorted, silty and fine to medium grained sand. The grain size has a general tendency to become coarser toward the bottom in this layer.		
		sandy clay	This layer consists of brown and sandy clay.		
		sand	This layer consists of brown, moderately well sorted, and medium to coarse grained sand.		
		clay	This part is composed of brown clay.		
6.20	Extrusive rocks	andesite	The andesite is pale greenish gray, hard and altered. This rock has undergone chloritization and small pyrite grains have occurred in this matrix. Partly, calcite veins have developed. 6.20~10.10m This part is pale yellowish gray and weathered. Dark brown limonite has occurred on surface of joints. 9.80m Joints; dip angle 25°, 45° and 75°. Dark brown limonite occurred on surface of joints. 10.10~15.20m This part is pale greenish gray.	0.40 0.48 0.40 0.51 0.40 0.99 2.29 0.40 0.40 0.40 0.40 0.40	(8/29) (9/2)

Column headings also printed: Drilling Log; Core Shape (>20 cm, 10-20 cm, 5-10 cm, 2 mm~5 cm, <2 mm); Water Flow (cm/sec) Dry Season.

Fig. 4-2-5 Boring Log (8)

Parral B-4

Depth (m)	Drilling Log	Formation	Lithology	Description	Core Shape >20cm	10-20cm	5-10cm	2mm~5cm	>2mm	Water Flow (cm/sec) Dry Season	Rainy Season	Water Level Lost Circulation
12.00	L L L L L L L L L L L L L L L L L L L L	Extrusive rocks	andesite	This is the same rock above mentioned. 12.60m Joint; dip angle 20°. This surface is covered with brown limonite. 13.60m Joint; dip angle 25°. Pyrite has occurred on this surface. 13.65m Joint; dip angle 20°. Pyrite has occurred on this surface.	▨						0.40	(8/29)
15.20												

Fig. 4-2-5 Boring Log (9)

Soil Columnar Section

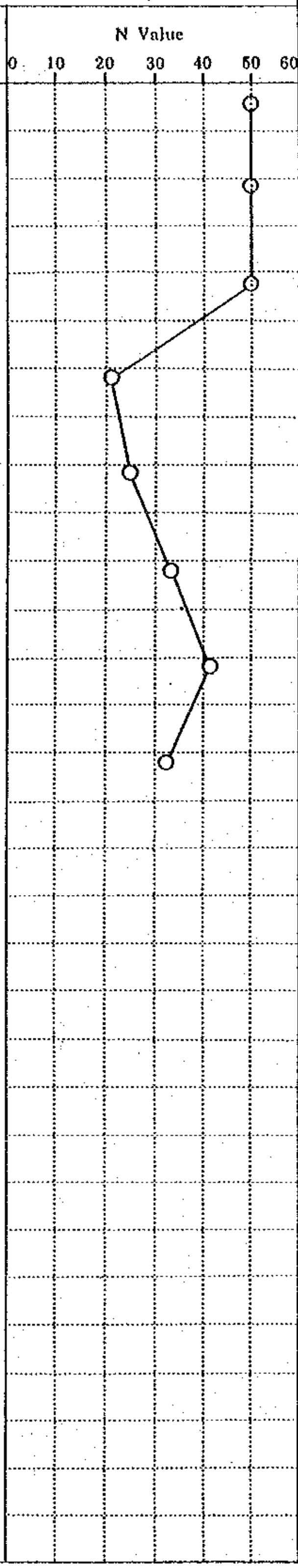
Survey Area: Parral Tailing Dam | Elevation: 1,787.41 m | Date: Feb 2 ~ Feb , 1991

Drilling No. BD-1 | Water Level: なし m

Scale (m)	Elevation (m)	Depth (m)	Thickness (m)	Drilling log	Soil Name	Color	Remarks
0–6.50		6.50	6.50		Silty sand	Dark gray	
6.50–15.00		15.00	8.50		Fine sand ~ Medium sand	Dark gray	
15.00–17.00		17.00	2.00		Shale	Brown	

Standard Penetration Test

Depth (m)	Batting Count
0.30–0.60	50
2.00–2.30	50
4.00–4.30	50
6.00–6.30	21
8.00–8.30	25
10.00–10.30	33
12.00–12.30	41
14.00–14.30	32



Sampling: No. | Depth (m)

Fig. 4-2-5 Boring Log (10)

Soil Columnar Section

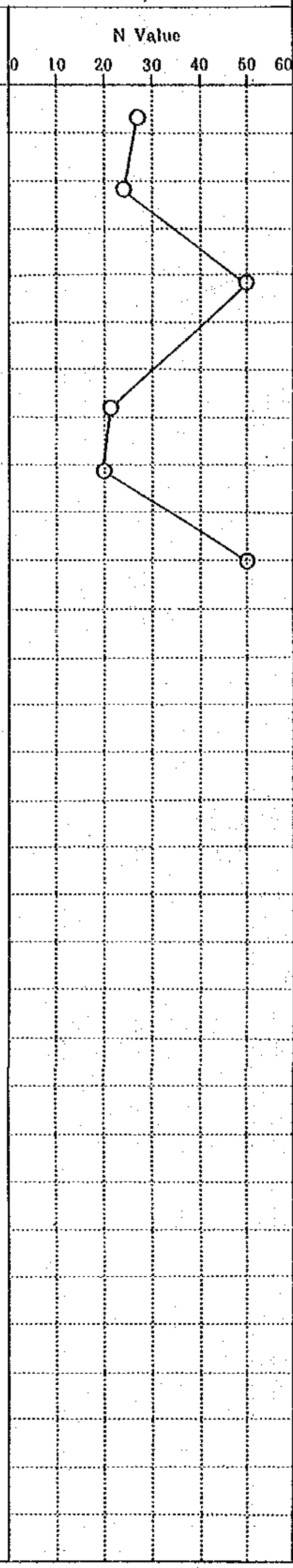
Survey Area: Parral Tailing Dam
Elevation: 1,782.27 m
Date: Feb. 2~Feb. 10, 1991

Drilling No.: BD-2
Water Level: N.W m

Scale (m)	Elevation (m)	Depth (m)	Thickness (m)	Drilling log	Soil Name	Color	Remarks
0–10.10		10.10	10.10		Fine sand	Whity yellow ~ Dark gray	
10.10–12.00		12.00	1.90		Shale	Brown	

Standard Penetration Test

Depth (m)	Batting Count
0.55–0.85	27
2.00–2.30	24
4.00–4.30	50
6.60–6.90	21
8.00–8.30	20
10.00	50



Sampling: No. / Depth (m)

Fig. 4-2-5 Boring Log (11)

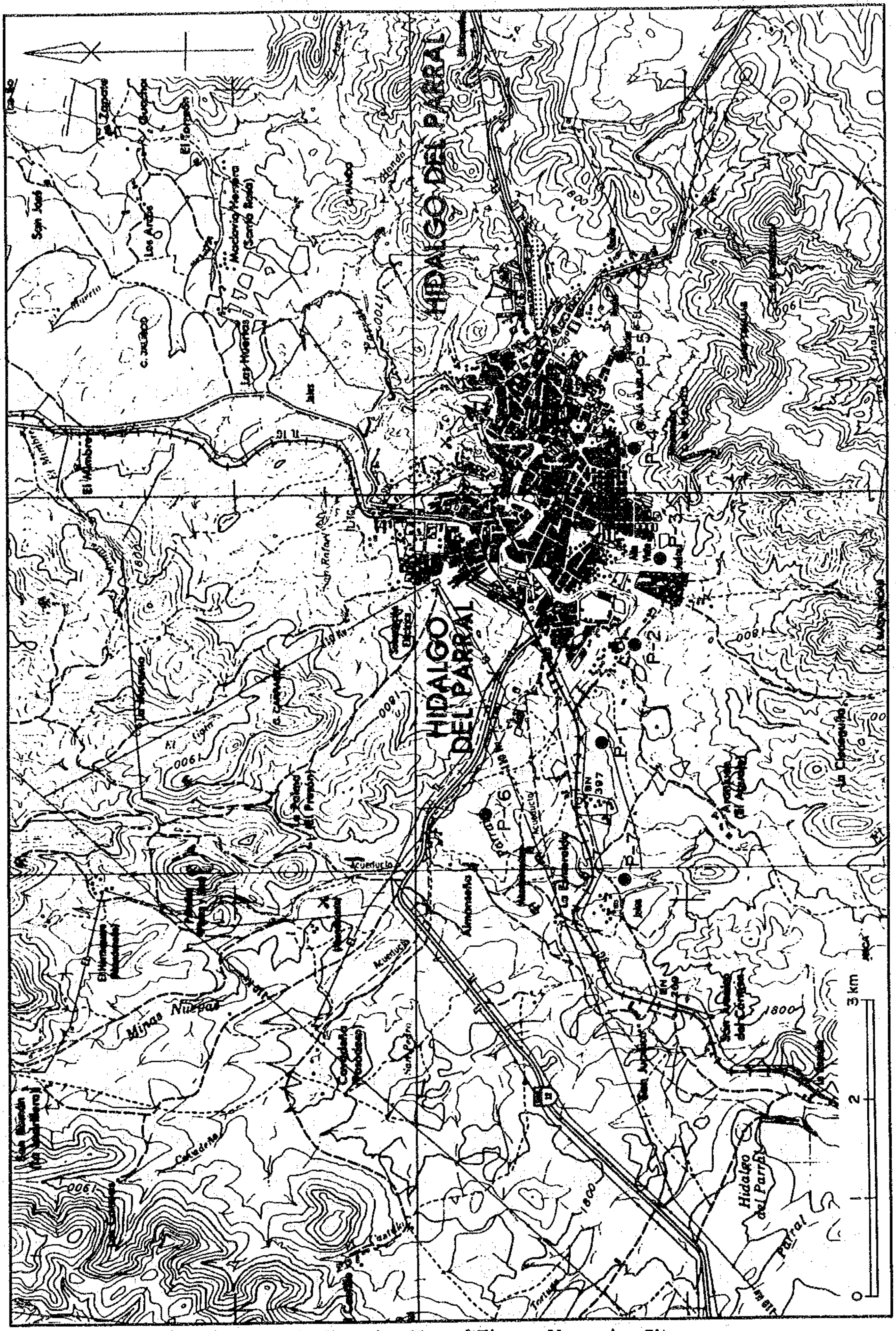


Fig. 4-2-6 Location Map of Fissure Measuring Site

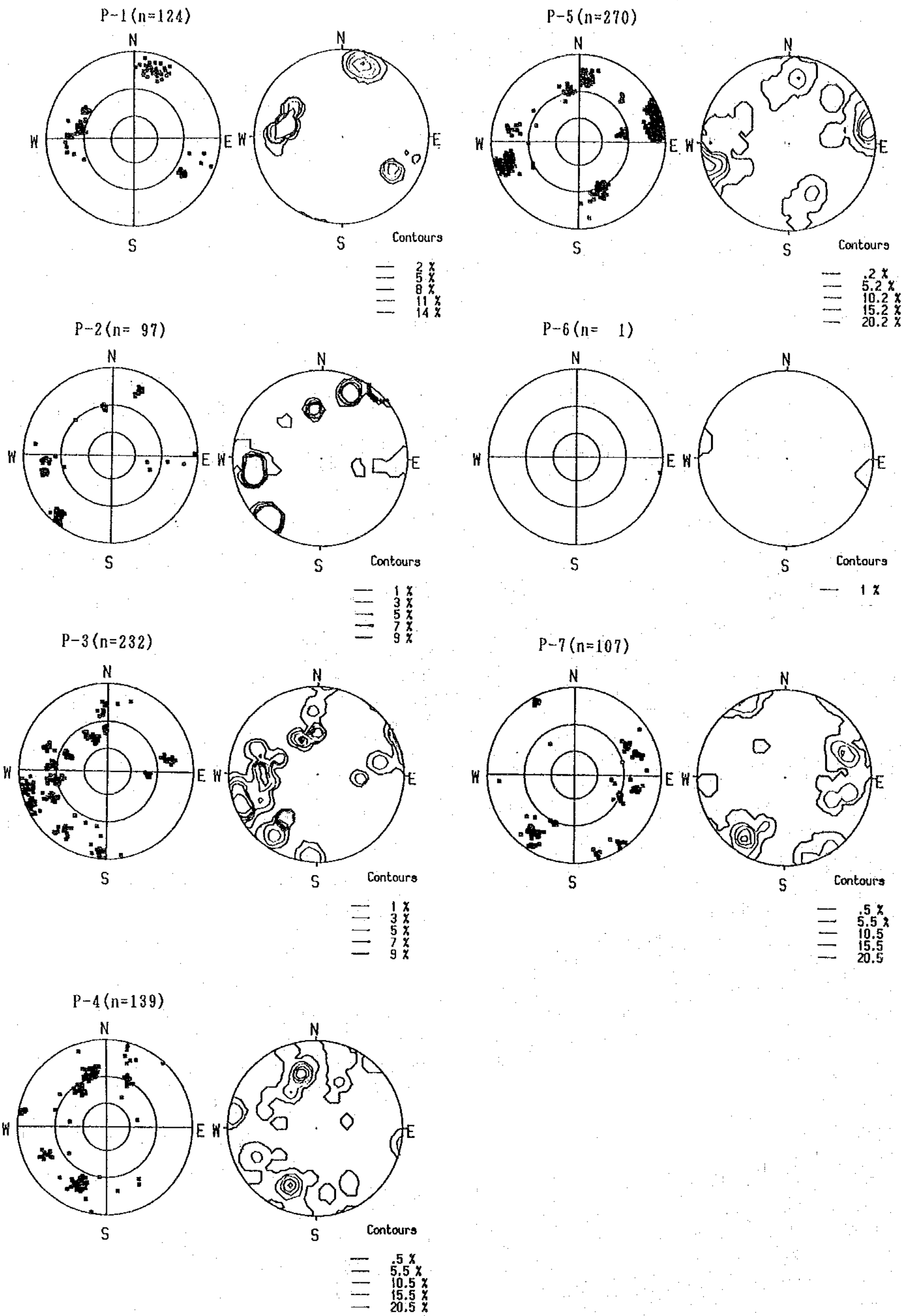


Fig. 4-2-7 Wulff's Net of Fissure Direction

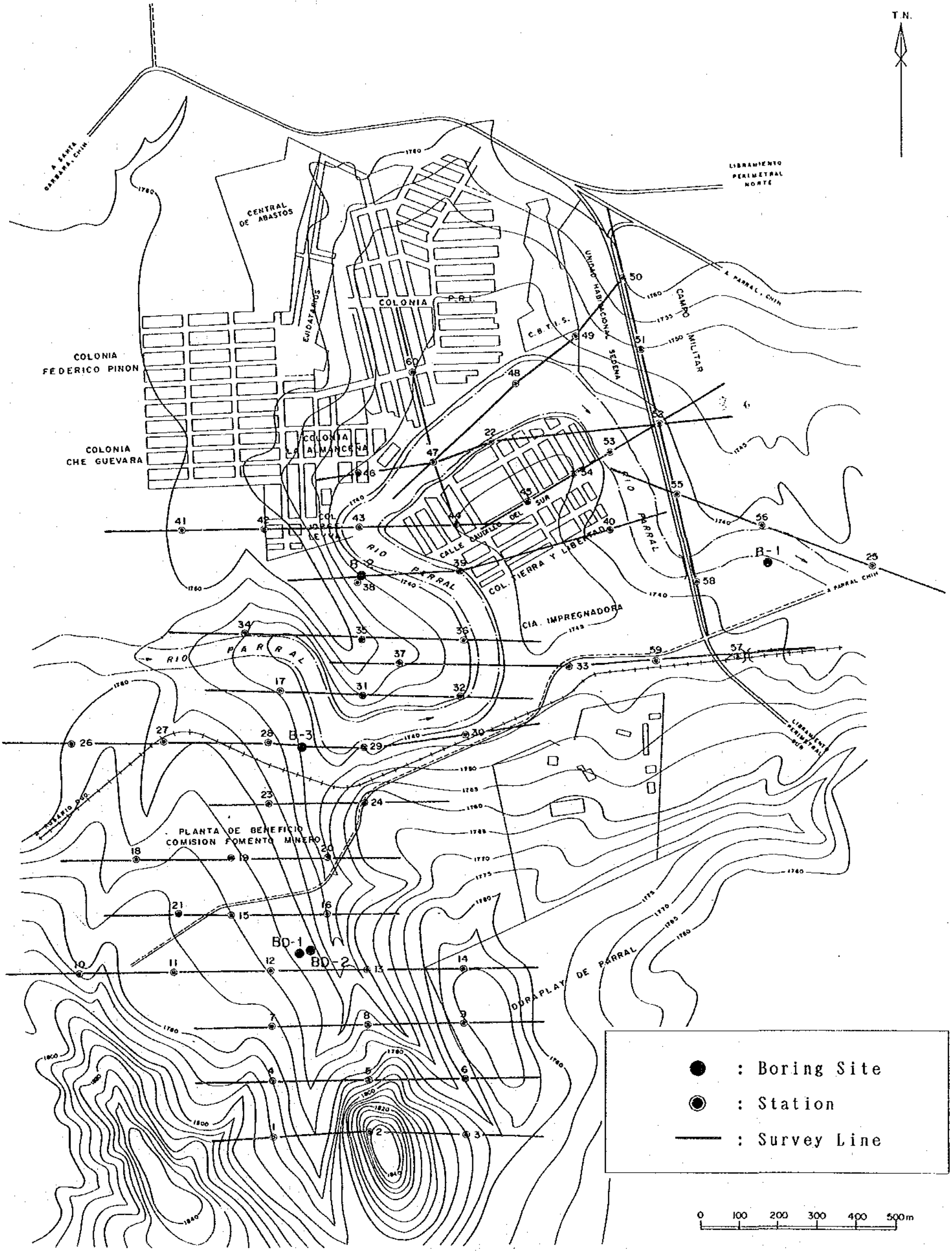


Fig. 4-3-1 Location Map of Electrical Prospecting Station (Parral)

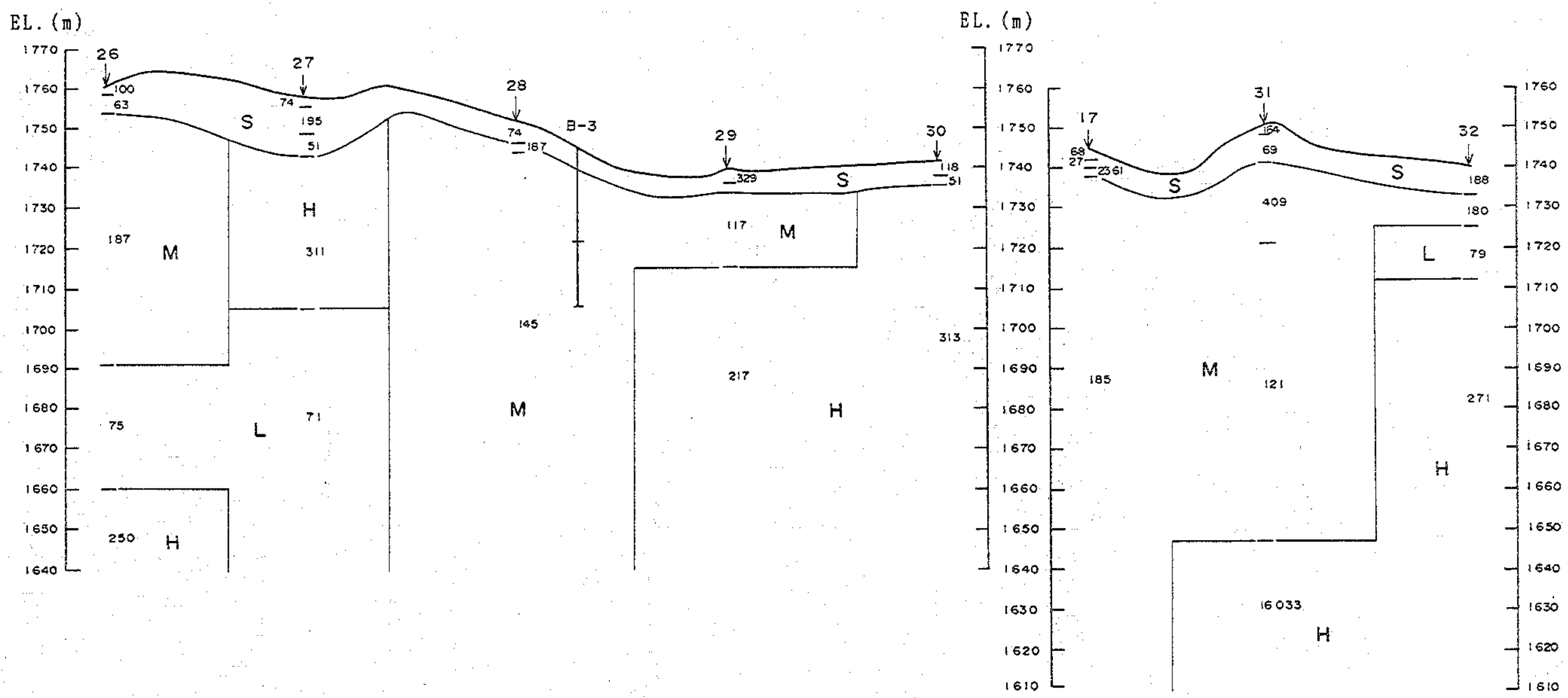


Fig. 4-3-2 Resistivity Cross Section (1)

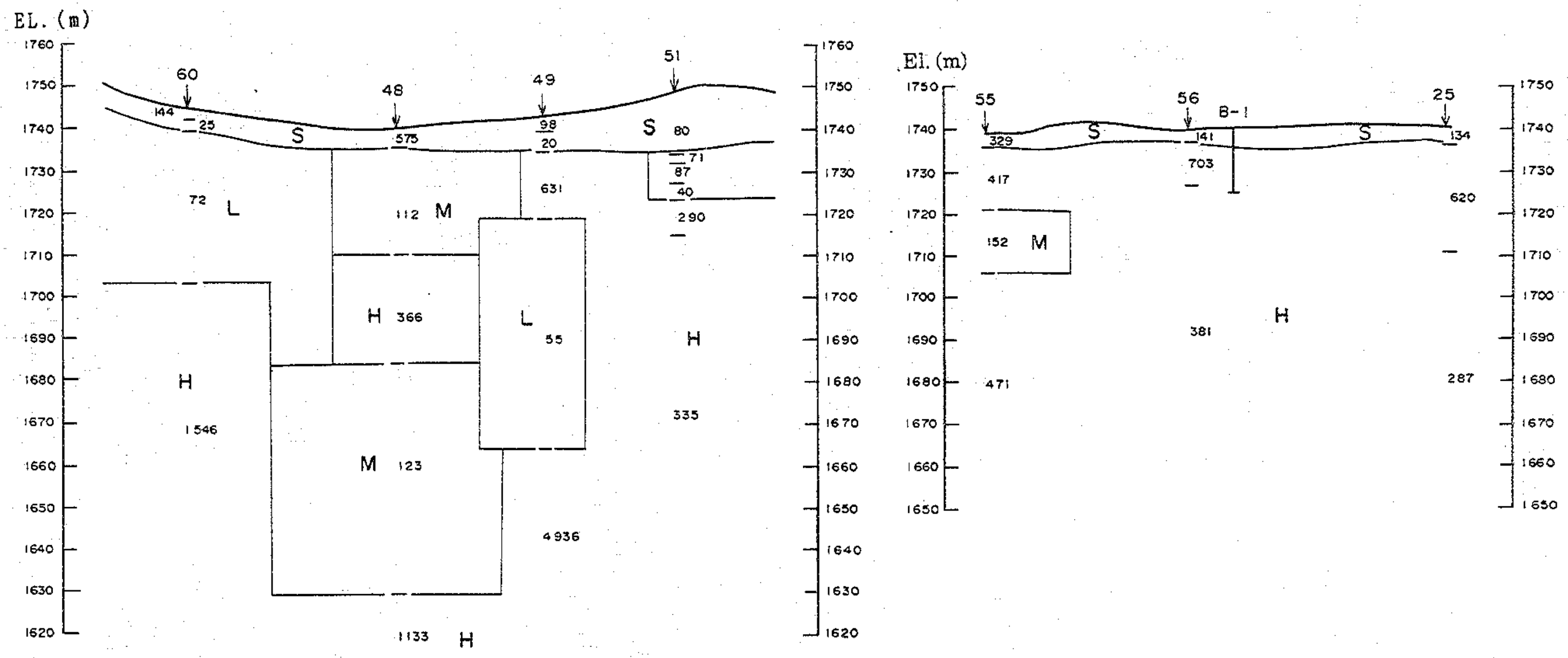


Fig. 4-3-2 Resistivity Cross Section (2)

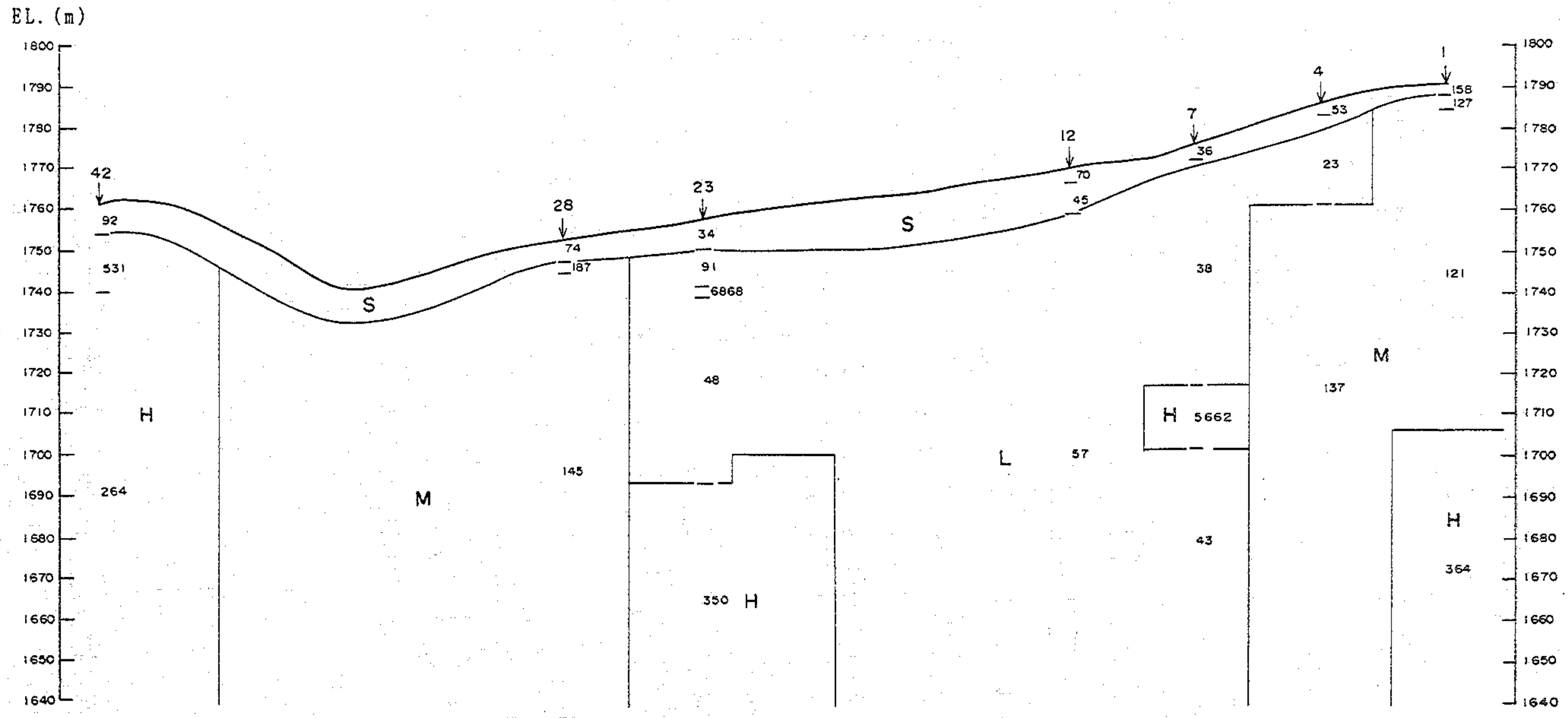


Fig. 4-3-2 Resistivity Cross Section (3)

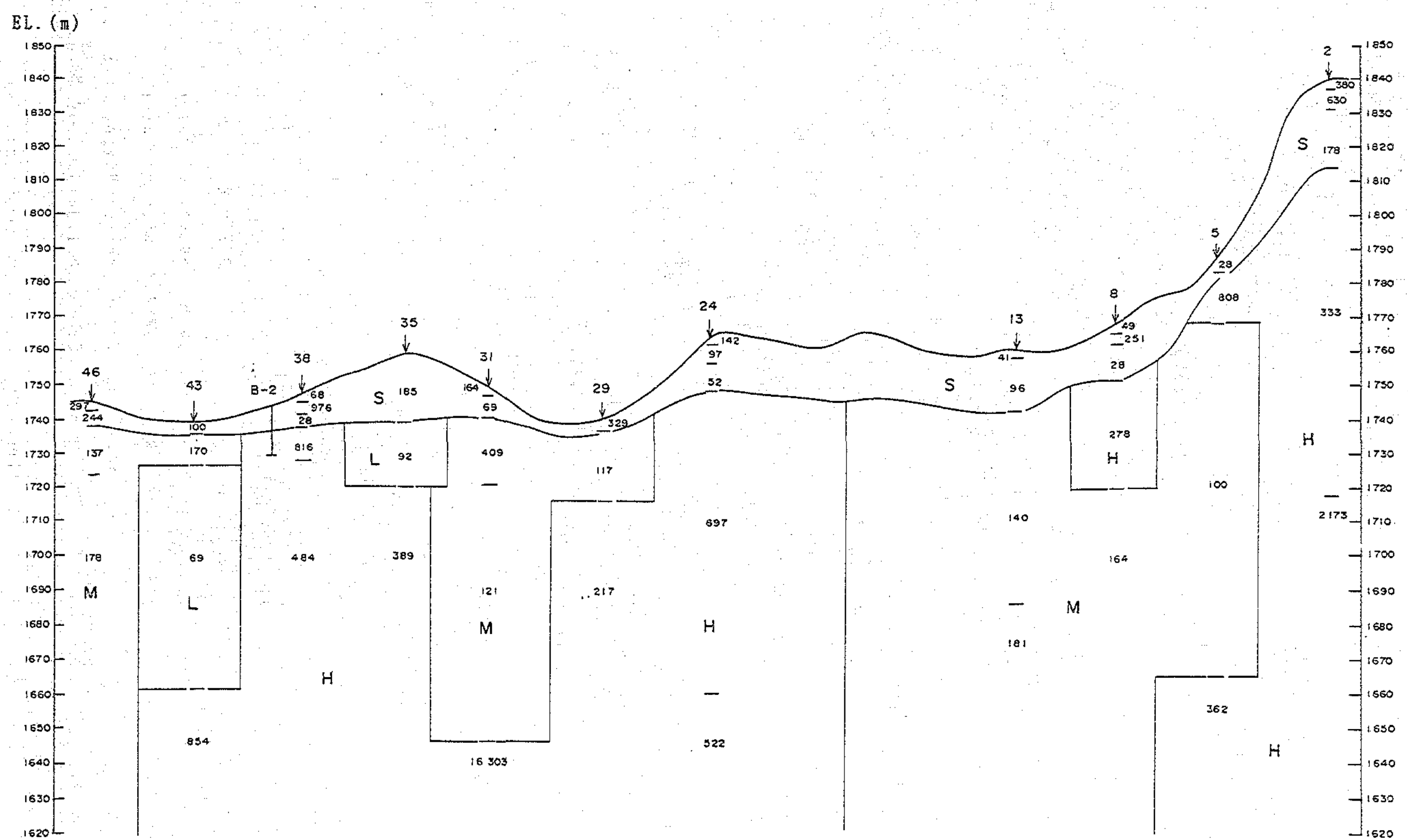


Fig. 4-3-2 Resistivity Cross Section (4)

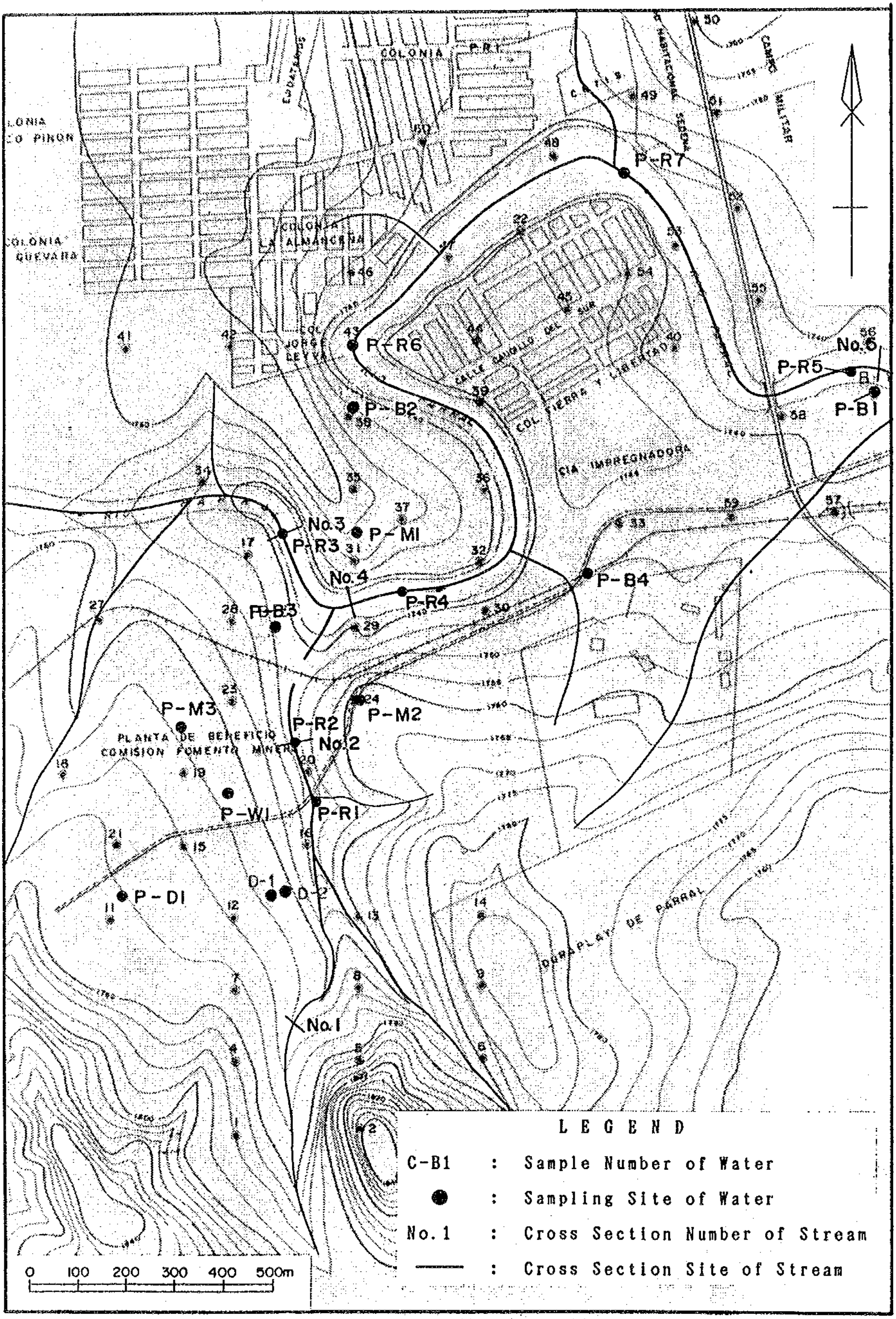


Fig. 4-4-1 Location Map of Flow Rate Measurement and Chemical Analysis of Water

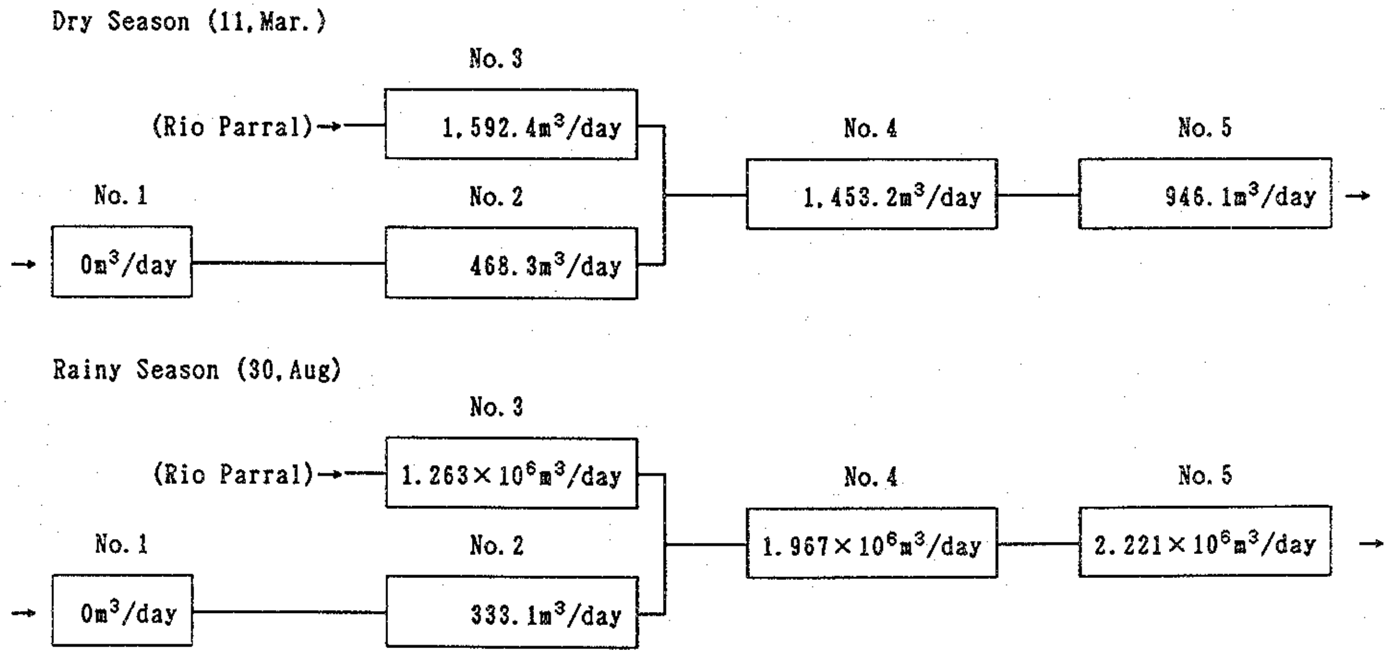


Fig. 4-4-2 Surface Water Balance (Parral)

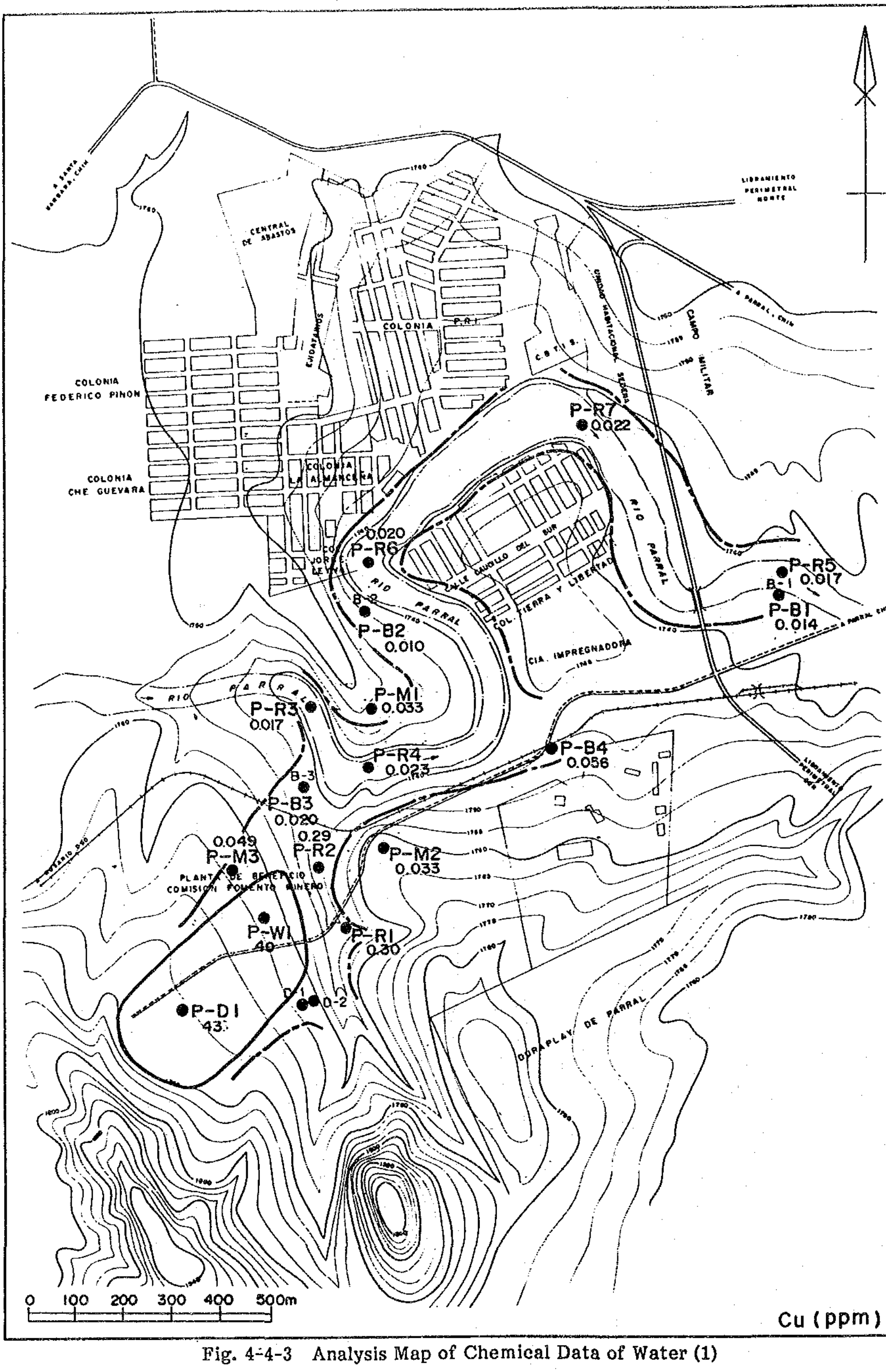


Fig. 4-4-3 Analysis Map of Chemical Data of Water (1)

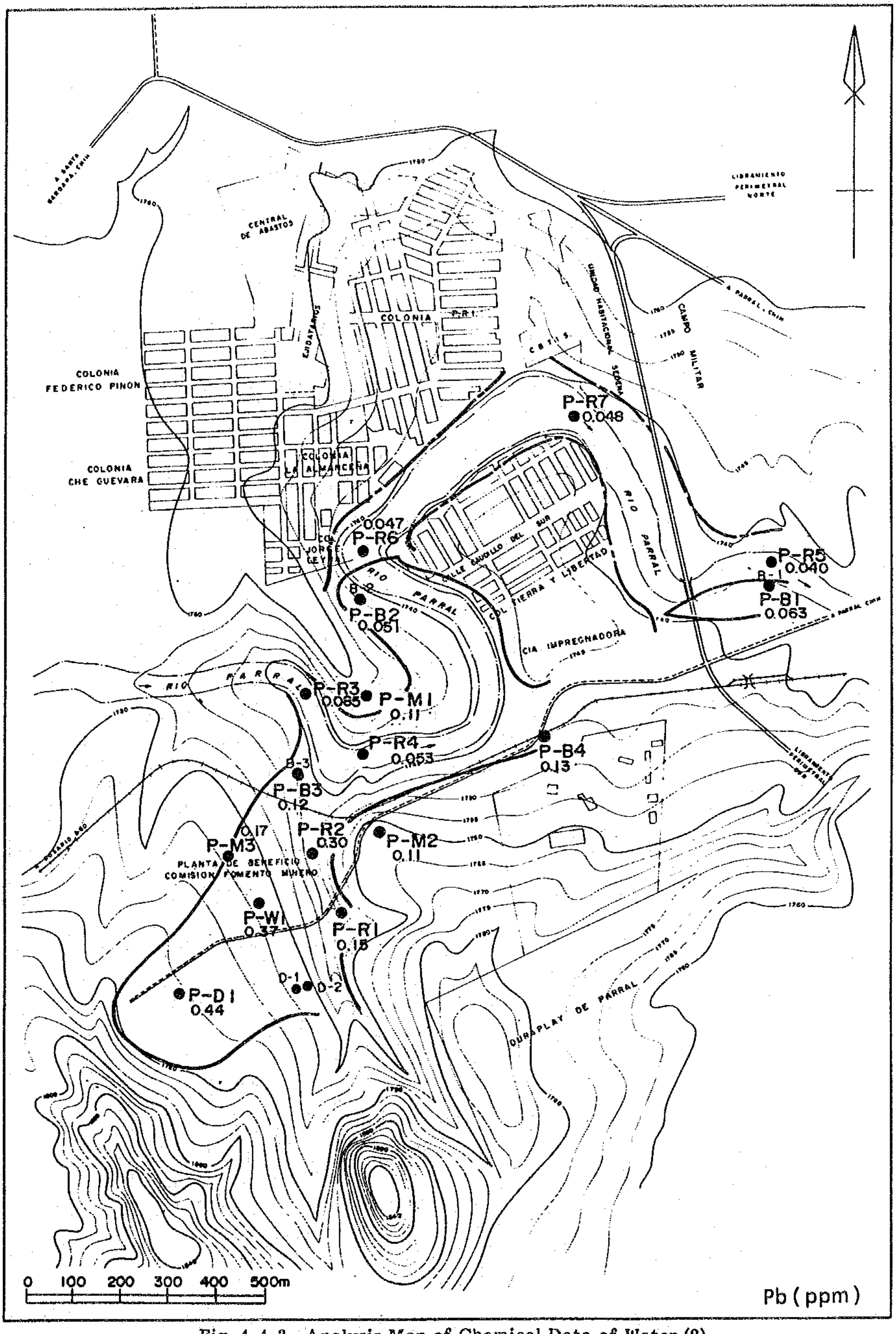


Fig. 4-4-3 Analysis Map of Chemical Data of Water (2)

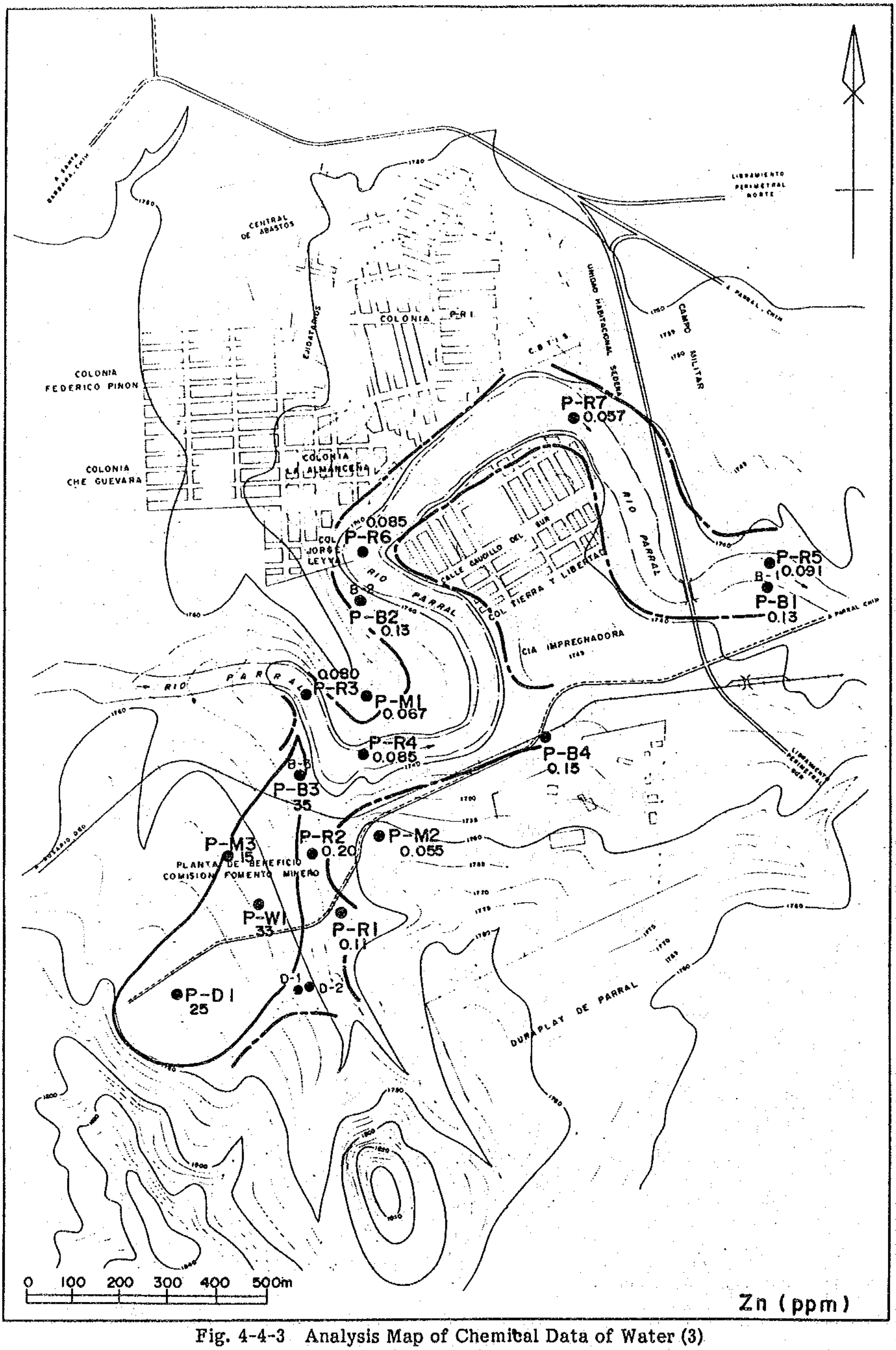


Fig. 4-4-3 Analysis Map of Chemical Data of Water (3)

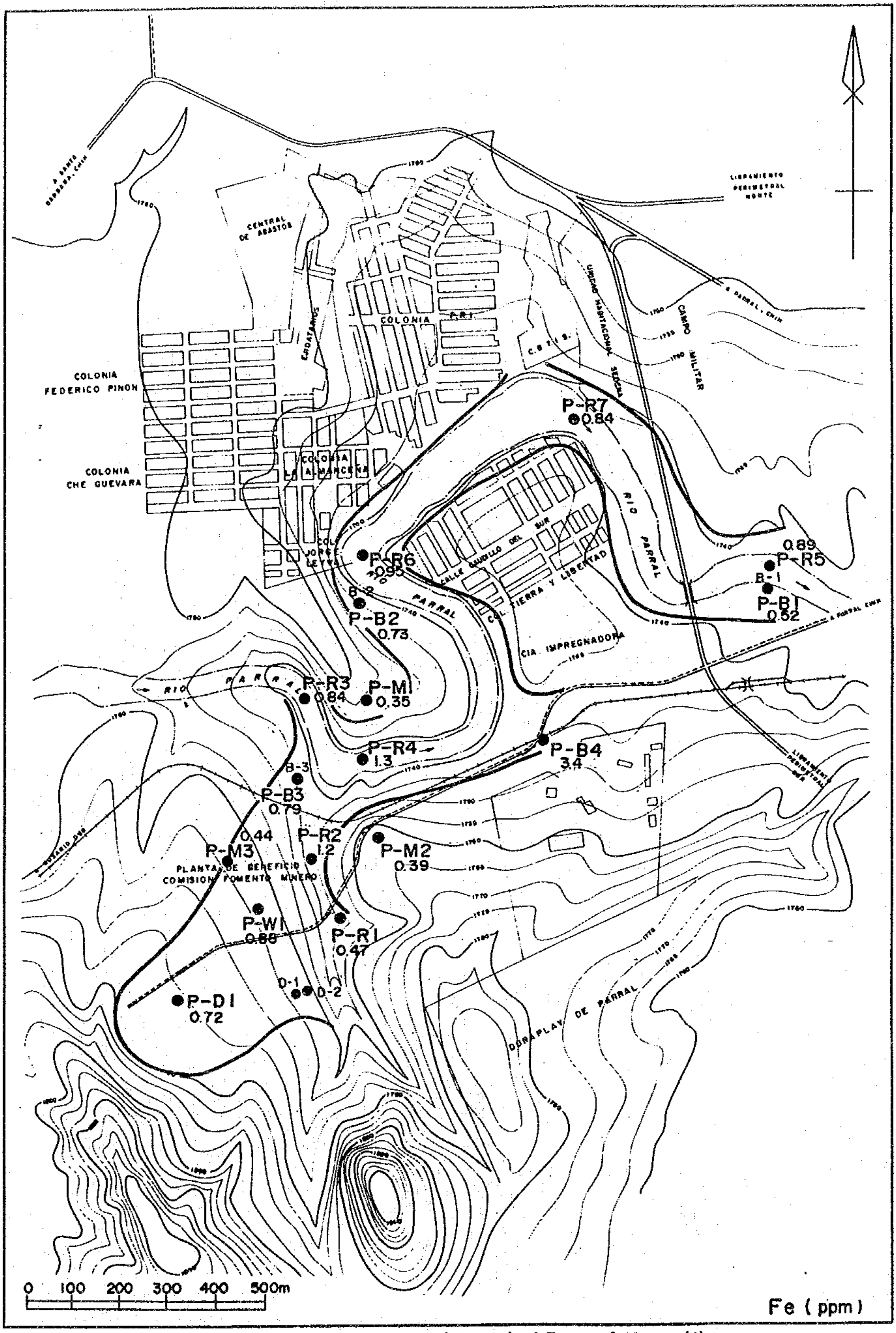


Fig. 4-4-3 Analysis Map of Chemical Data of Water (4)

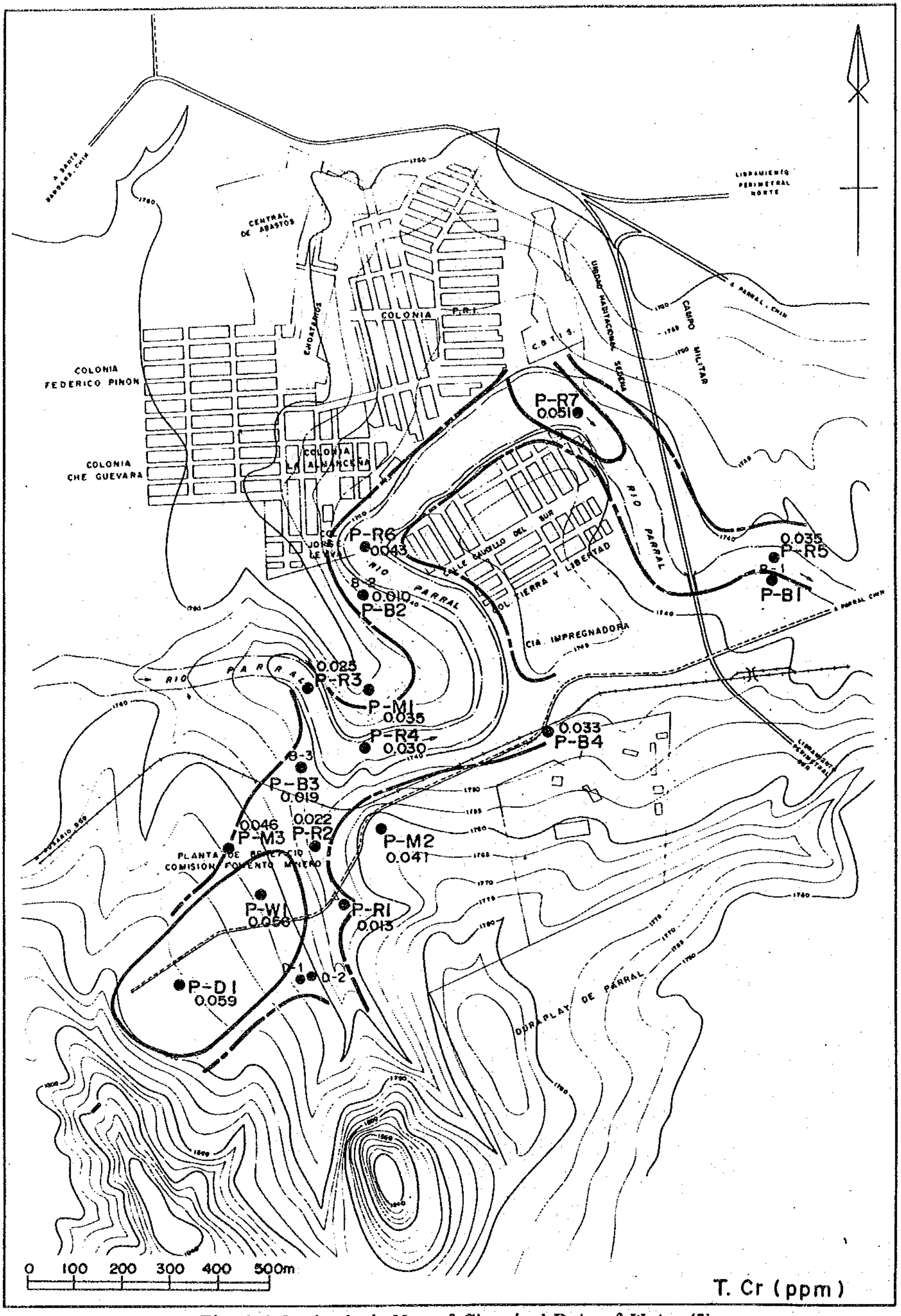


Fig. 4-4-3 Analysis Map of Chemical Data of Water (5)

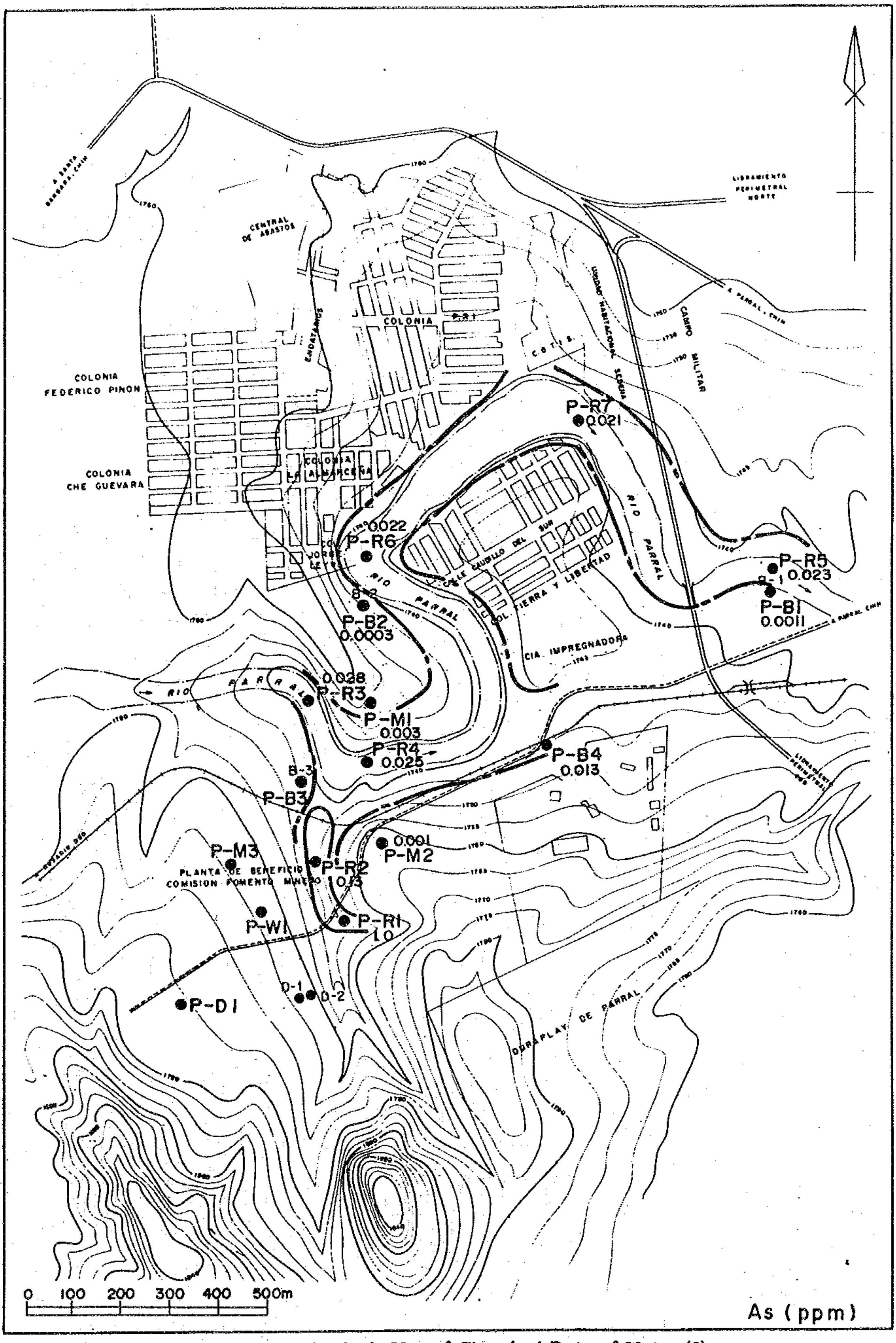


Fig. 4-4-3 Analysis Map of Chemical Data of Water (6)

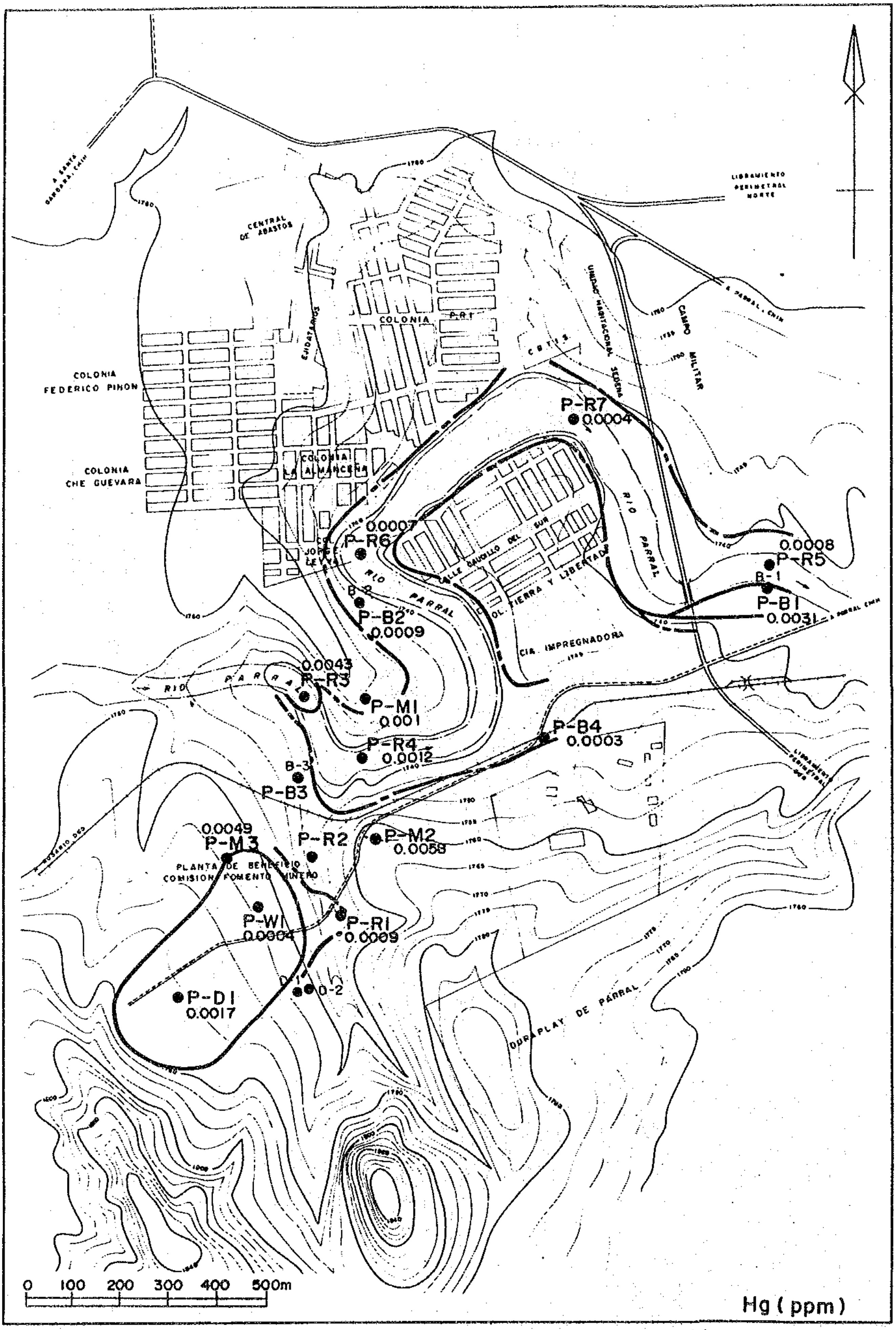


Fig. 4-4-3 Analysis Map of Chemical Data of Water (7)

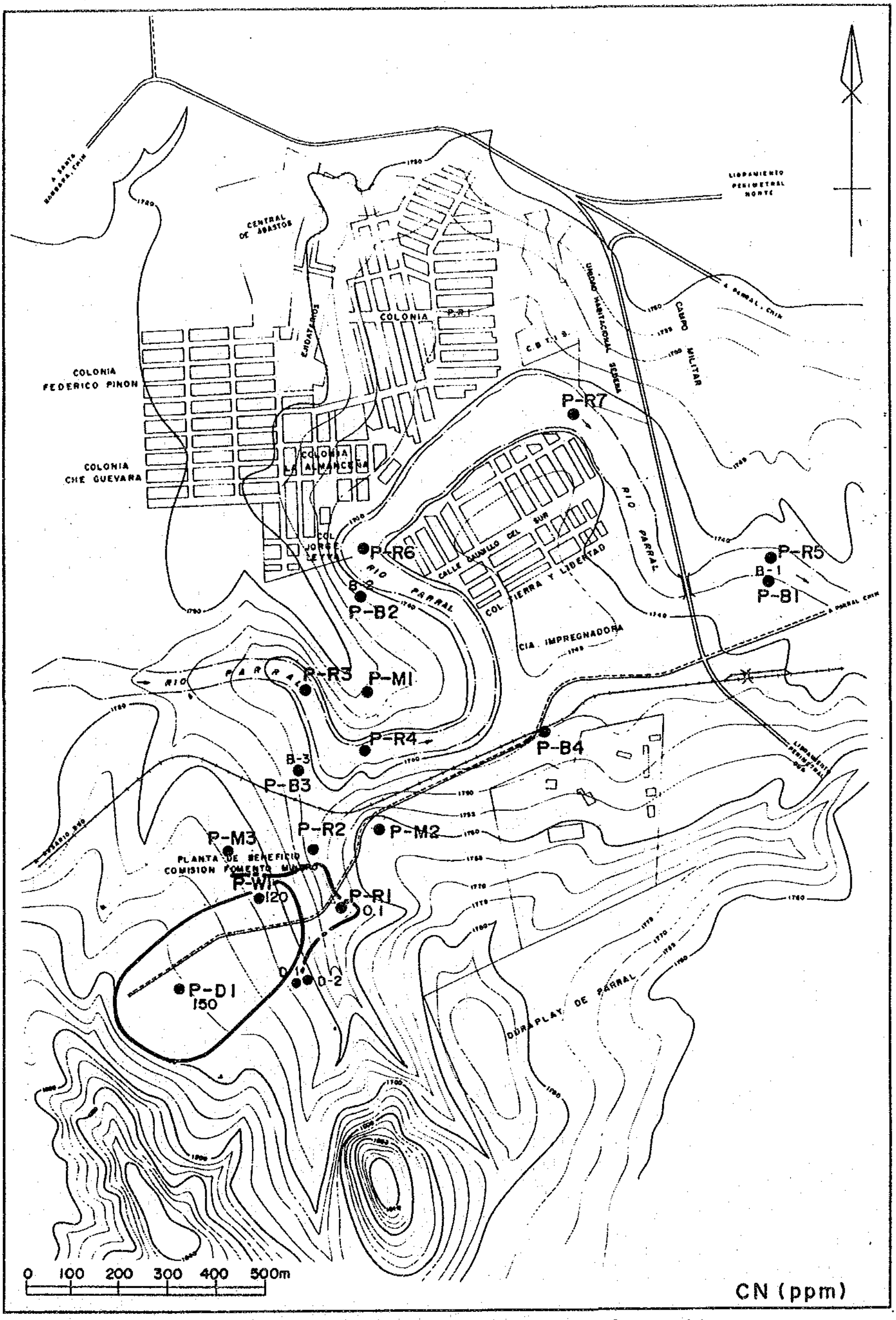


Fig. 4-4-3 Analysis Map of Chemical Data of Water (8)

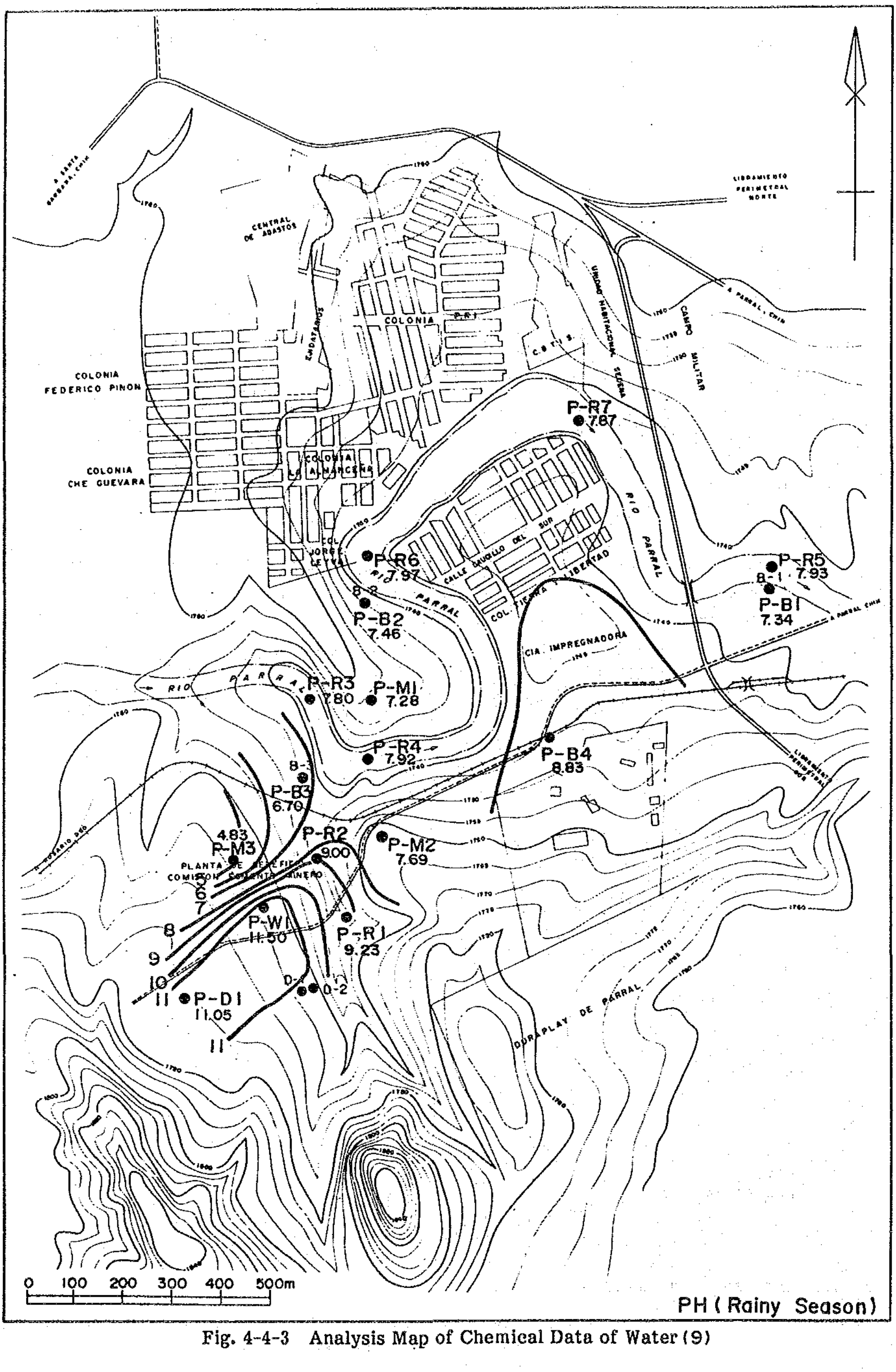


Fig. 4-4-3 Analysis Map of Chemical Data of Water (9)

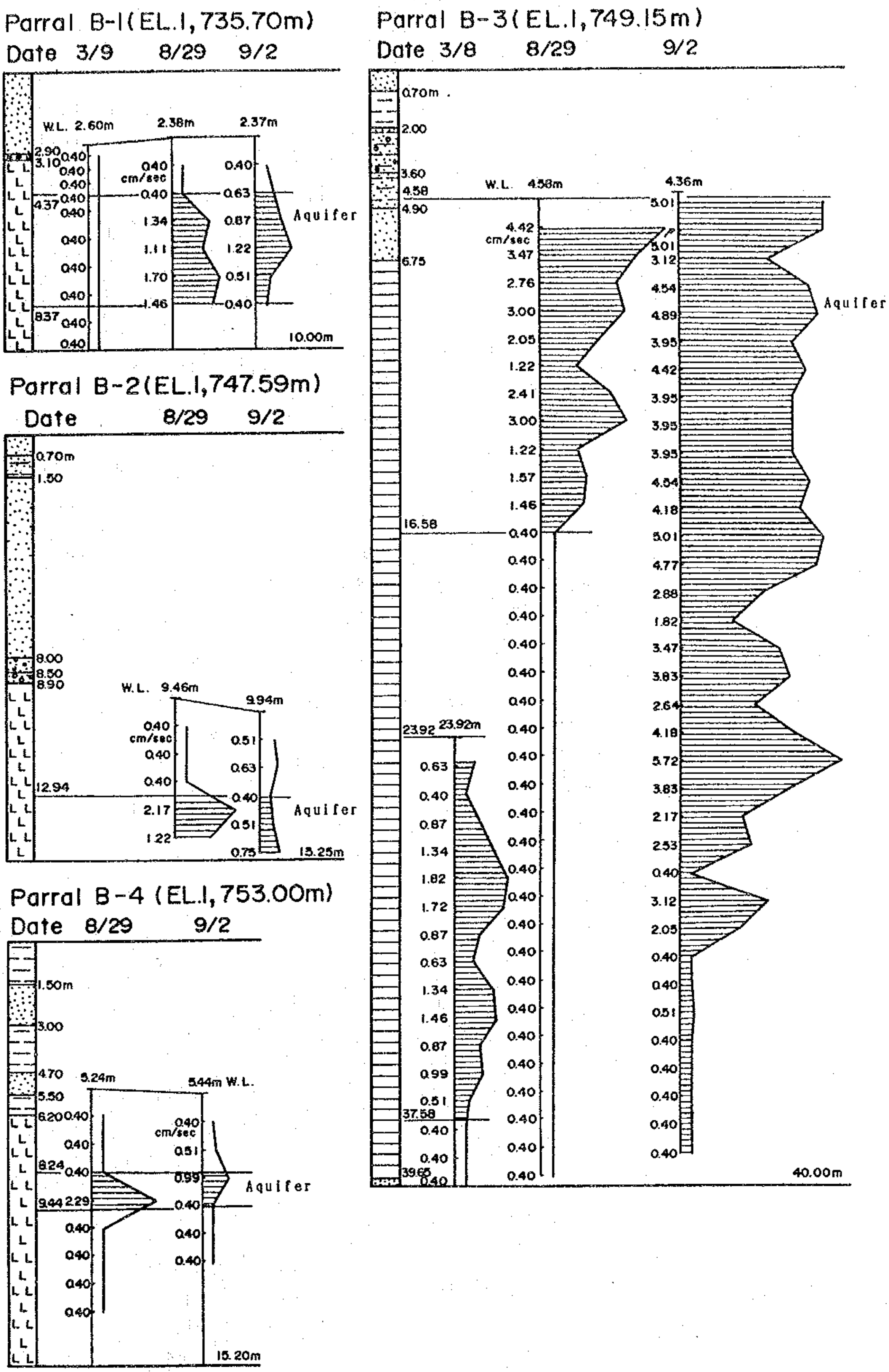


Fig. 4-4-4 Micro Flow Analysis

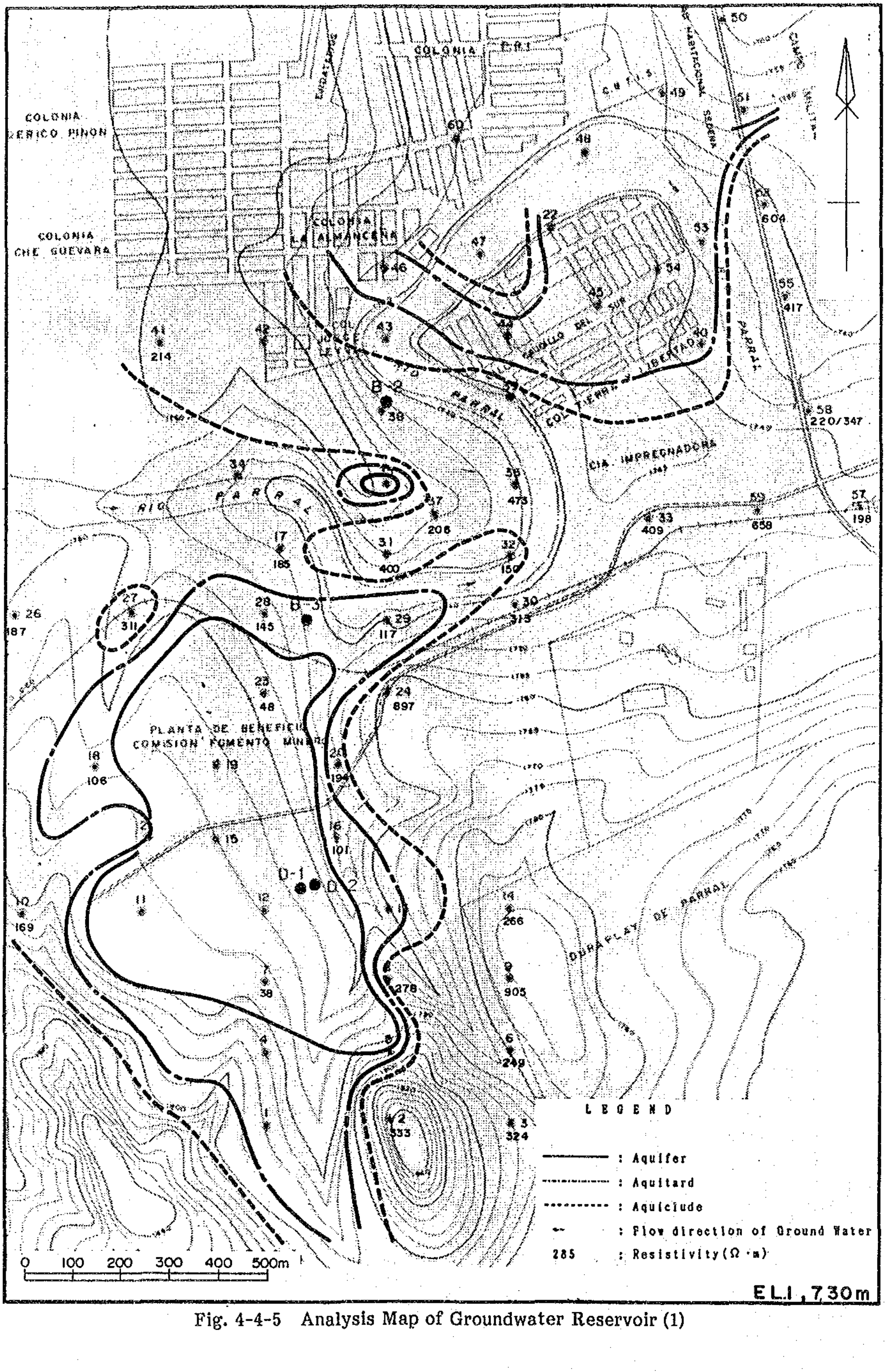


Fig. 4-4-5 Analysis Map of Groundwater Reservoir (1)

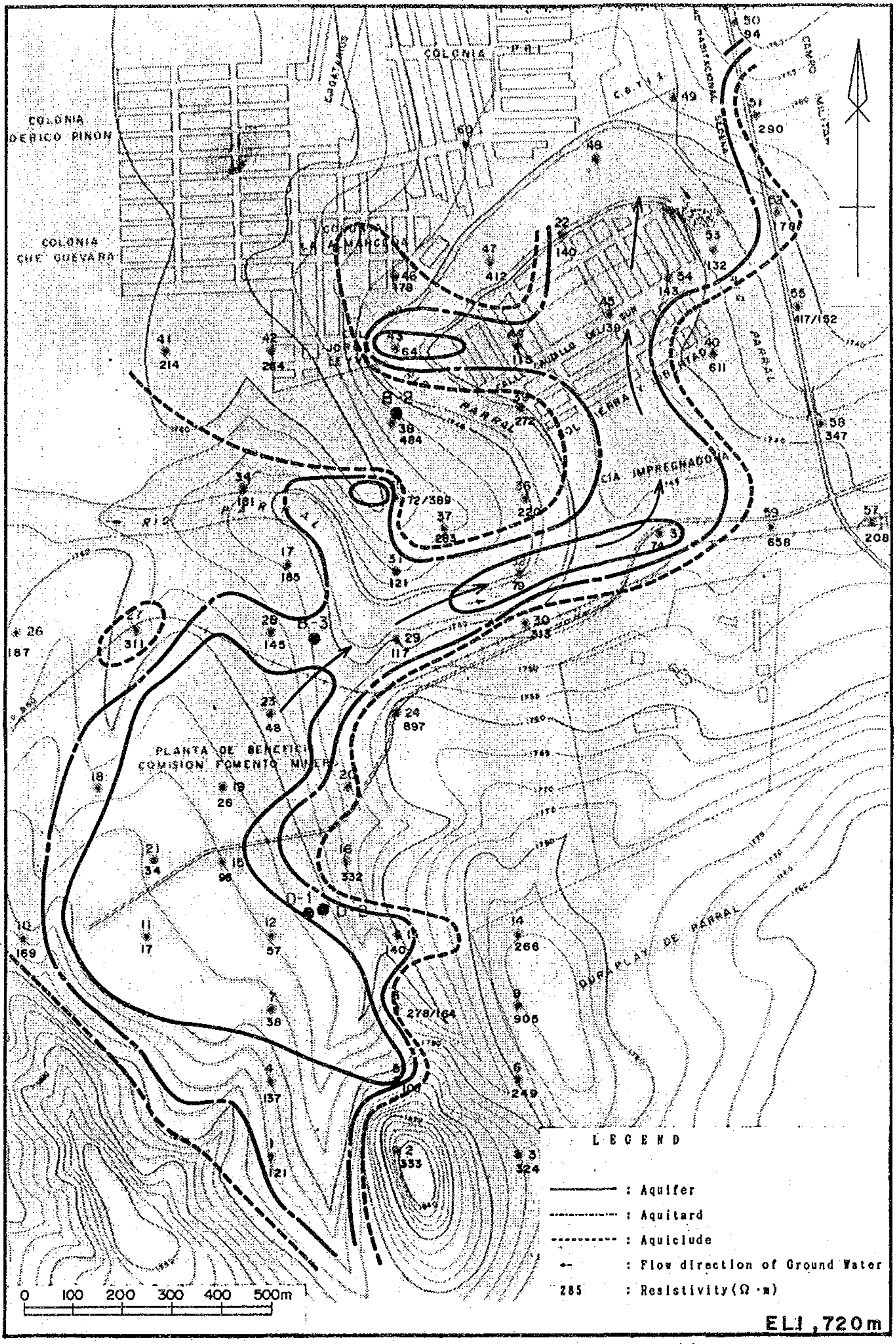


Fig. 4-4-5 Analysis Map of Groundwater Reservoir (2)

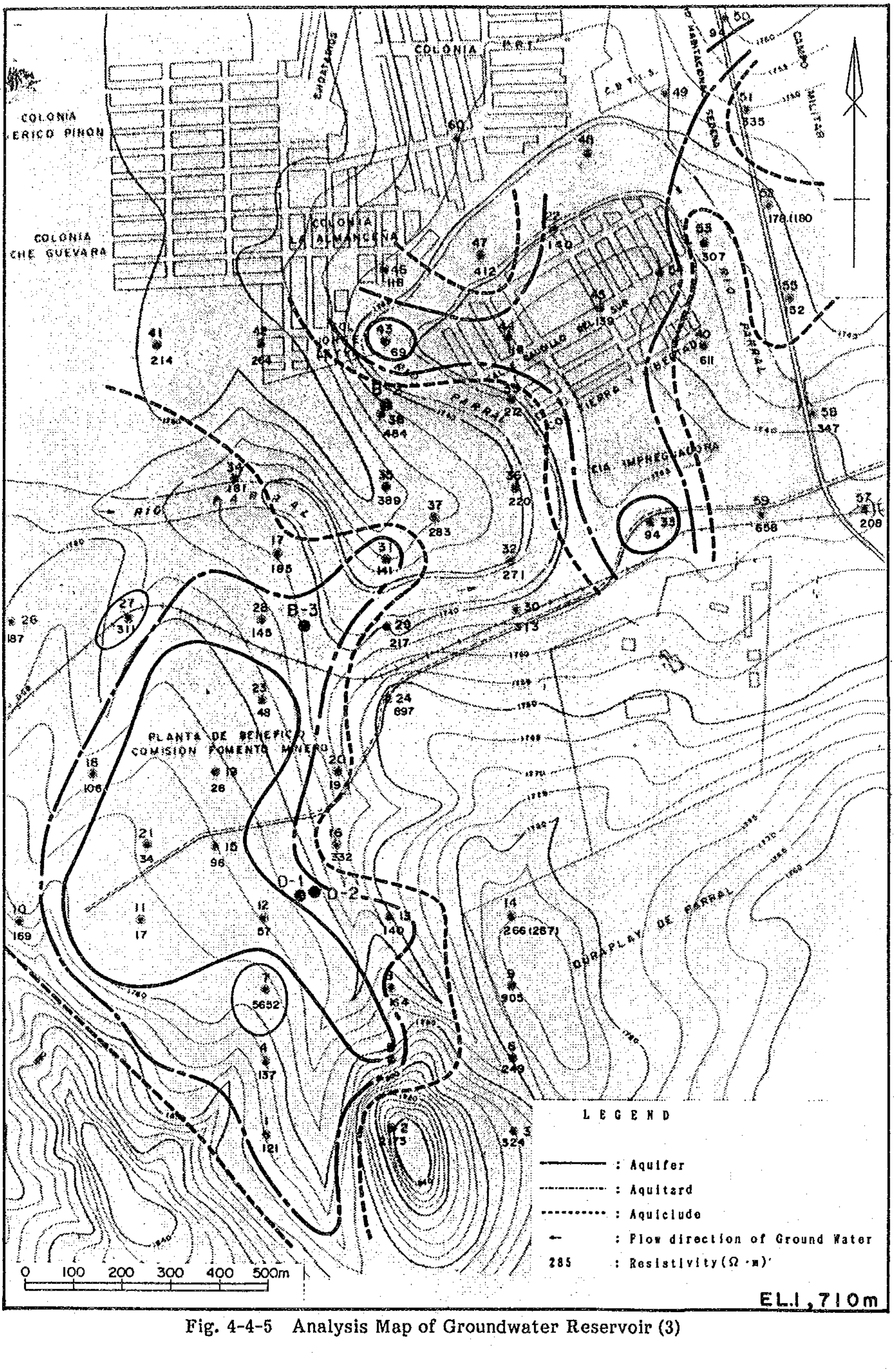


Fig. 4-4-5 Analysis Map of Groundwater Reservoir (3)