5 Sources and the Mechanism of Water Pollution

5-1 The Source of Water Pollution by Mining Activity

5-1-1 Mine Drainage, Infiltrating Water from Tailing Dam and Waste Ore Stockpile

(1) Water Pollution Sources

The pollution source of mining activity can be divided into the following three classes about three river streams which flow from the slope of the Mt. Cerro Rico de Potosi. (Rio Huaynamayu river, Rio Korimayu river and Rio Agua Dulce after receiving Quebrada Jayajmayu and its branch stream)

① Mine drainage (Mine water)

This is the water flowing out from inside of the mine.

② Infiltrating water from low grade ore stockpile

This is the infiltrating water from a stockpile of waste rock that was mined out and left.

③ Infiltrating water from tailing dams

This is the infiltrating water from tailing dams, and can be categorized in the following types:

③-1 :

The infiltrating water from waste ore, called "SUCU", which was generated from gravity concentration ore dressing ② on the surface.

③-2 :

This is the infiltrating water from tailings dams which was generated from the gravity concentration of tin processing plant, which activity was carried out until 10 years ago.

③-3 :

This is the infiltrating water from tailings dams which was generated from the flotation of lead and zinc that was carried out 10 years ago.

③-4 :

This is the infiltrating water from the idled heap leaching pad for silver.

(2) Characteristics of Sampling Points

The following thirty sampling points were selected in order to study the mechanism of water pollution by mining acid effluent in Potosi[*1]. There are many stockpiles of both waste rock and low-grade ore in close on the three mining sites. The wide rainfall streams run both, on surface and underground and flow into rivers during the rainy season. It is difficult to decide a sampling point at each source of water pollution, because the rainfall streams run down widely over these pollution sources making acid effluent. Therefore, samplings were carried out at streams located near pollution sources, springs, pools, a well and so on to get hold of the pollution conditions.

The remaining water pollution sources are household and processing plant wastewater. Some sampling points were also selected to study the present state of water pollution.

Sampling points are shown in Figure 5-1-1. Characteristics of each sampling point are illustrated in Table 5-1-1.

(3) Result of Water Survey

1) The survey method

Water surveys were carried out during both seasons, rainy and dry. Sampling was carried out from 31/January to February during the rainy season and in June during the dry season in 1998. Analyses were carried out immediately after sampling.

Since it did not rain as we had expected, some selected sampling points did not have any water for analysis.

Water analyses were carried out according to ASTM. At some points, we measured the sections and the velocity of the fluid to calculate the water volume. This primitive measuring system was used because the size and the current of the streams were too small.

2) Results of Water Analysis and consideration

Results of both water analysis and water volume at each sampling point are shown in Table 5-1-2.

Water qualities at each sampling point are as follows:

On site, it was very difficult to distinguish between ② low grade ore stockpiles and ③-1 tailings dams called "SUCU", because both are stockpiled at the same place and mixed together. Wastewater characteristics were considered and representative data collection points were selected.

① Mine drainage

Typical wastewater is from sampling point No.12. When water quality from the rainy and the dry seasons are compared, the pH was 2.28 and 2.22, and they are low values for either season. The concentrations of Cu are 182mg/L and 198mg/L, Zn 1,050mg/L and 1,110mg/L, Cd 16.4mg/L and 24.0mg/L and concentrations of heavy metals were higher than the other sampling sites. The concentration of SO4 is 31,000mg/L that is the highest among all samples. The ratio of Fe3+ to T-Fe is high, so one can surmised that the wastewater is oxidized inside of the mine. The high concentration of As was detected during the dry season. This stream flows into Rio Huaynamayu river.

② Infiltrating water from low grade tailings dams

The representative sample is No.13. The wastewater quality has almost same characteristics as the mine drainage. The pH value of 1.86 was the lowest value among all samples. The concentration of Cu is 112mg/L, Zn 710mg/L and Cd 4.6mg/L and concentrations of heavy metals were high.

The concentration of SO4 was 19,600mg/L that is the second height, so one can guess that the wastewater was oxidized. After raining, this water flows into Rio Huaynamayu river.

③-1: Infiltrating water from waste ore called "SUCU"

The typical wastewater samples are no.1 and No.18. The value of each parameter is not as high as

No.12 or No.13. For No.1 and No.18, pH are 2.58 and 3.09, Cu 60.0mg/L and 4.40mg/L, Zn 144mg/L and 916mg/L, Cd 14.0mg/L and 45.0mg/L, and Sn 43.3mg/L and 21.9mg/L, respectively. The wastewater quality has almost same characteristics as No.12 or No.13. These streams flow into Quebrada Jayajmayu river.

③-2: Infiltrating water from tailings dams generated from the gravity concentration of tin processing plant

The typical pollution source is the tailing dams of San Miguel. The typical wastewater is No.26. A spring flows during all the seasons. This stream flows into Rio de La Ribera, directly.

The values of each parameter during both the rainy and the dry season are pH 3.14 and 2.99, Cu 5.20mg/L and 6.20mg/L, Zn 60.0mg/L and 75.0mg/L, respectively. The concentration of SO4 during the rainy season was 1,290mg/L.

③-3: Infiltrating water from tailings dams generated from the flotation of lead and zinc

The typical pollution source is the tailing dams of San Miguel. The typical wastewater is No.16. There is no water during the dry season.

The value of pH is 2.38, Cu 96.0mg/L, Zn 529mg/L and Cd 1.50mg/L, and SO_4 is 9,690mg/L.

③-4: Infiltrating water from the idle heap leaching pad for silver

The PLAHIPO silver leaching plant is located on the area of Potosi. This sampling point is No.27, but it is difficult to take a sample because of the shutdown. On the other hand, COMCO is located south of Potosi. Since the water system location is different from the Potosi area, this problem was excluded from our consideration.

There is no great difference between the dry season and the rainy season. The well water that is used for household water is slightly polluted. The river water has high level of suspended solids, so probably it was polluted by the wastewater from ore-processing plants and households.

(4) The Mechanism of pollution origin in the mountain

The rivers in Potosi are polluted daily by three types of water discharge: mine drainage, household wastewater and ore processing plant wastewater. On the other hand, the infiltrating water from both tailings dams and low-grade ore stockpiles in the Cerro Rico Mountain also pollutes the rivers in the rainy season.

Since mainly sulfide ores are extracted at the metal mines, minerals such as pyrite, chalcopyrite, sphalerite and galena still remain at the mining site even after closure of the mine. They react with the oxygen in ground water or air and generate acid water containing heavy metals.

The tailings are carried out of a mine also become a source of mine pollution because the metals dissolve in rainwater. Moreover, tailings flow out or are scattered by winds and cause environmental pollution[*2].

Of Mt. Cerro Rico, there are three "SUCU" at the west, the northwest and the southwest. Their extents are 32,000m2, 400,000m2 and 90,000m2, respectively. Many stockpiles of waste rock and low-grade ore are in close on slopes of mining sites. In case of Mt. Cerro Rico, oxide ores are stockpiled at above 4,400m height, and sulfide ores below 3). Outside of Real Socavon at the foot of Mt. Cerro Rico, the presence of mine drainage can be seen all year round. There is the PLAHIPO silver leaching plant at the east of Mt. Cerro Rico that is idle now. The San Miguel tailing dams is located at the west of the urban area, at the north of which there is a spring, and from where water is flowing out into Rio de La Ribera River all year round. The wide rainfall streams run both, on surface and underground of these stockpiles, and springs and infiltrating water may flow into rivers again.

There are three places where acid mine effluent is flowing now; No.12 of mine drainage, No.26 of spring near the San Miguel tailings dams and No.24 of Quebrada Jayajmayu river water. The representative places, where the infiltrating water flow out from stockpiles or tailings dams, are many stockpiles located on mining sites and the San Miguel tailings dams. The water flowing from these places indicate acid of sulfuric acid, and contain heavy metals and arsenic. These heavy metals in the acid mine effluent reacts with alkalinity in both river water and processing plants wastewater to form hydroxide and concentration of soluble ones will be reduced by coprecipitation mechanism.

*1: Metal Mining Agency of Japan Technical Development Department, Technical Development of Mine Pollution Control in Japan

*2: Bo Lundberg (1996) CORPORACION MINERA DE BOLIVIA Environmental audit of the Cerro Rico Project, Potosi

(5) Map of pollution source and polluted route

Colored part of Figure 5-1-1 cover is presented the map of pollution source around Mt. Cerro Rico. The polluted routes are classified along Rio Huaynamayu, Rio Korimayu, and Quebrada Jayajmayu from the mountain as illustrated in Figure 5-1-1 cover. Besides these three, upper part of Rio Vilacollomayu river has a potential risk of polluted route because ore stockpiles is located there.

Rio de La Ribera is polluted by discharged tailings from ingenios, too.

5-1-2 Tailing out of Ingenio (SS and Alkaline Water)

All the ingenios (42 in total) discharge all of their mineral processing tailings without any treatment into all the rivers, to begin with the La Ribera river, which belong to the four fluvial systems in the Potosi city area. This causes serious water pollution in these rivers. The said tailing is composed of SS (Solid portion) and alkaline water(Aqueous portion). Both of these components of the tailing, SS and alkaline water, are the sources of fluvial water pollution caused by the ingenios. The said pollution associated with the mineral processing sector as well as that associated with the mining sector are the major sources of the fluvial water pollution.

In recent years, the fluvial water pollution brought about by the ingenios grows worse due to the reasons mentioned below.

As a tin (Sn) quotation took a sudden big drop in 1985 as a result of a collapse of the ITC, the ingenios in Potosi City changed their operational processes from conventional gravity concentration to flotation. Up to that time, gravity concentration was used to recover tin oxide mineral (Cassiterite: SnO_2), and after that, flotation was employed to start to recover lead sulfide mineral (Galena: PbS) and zinc sulfide mineral (Sphalerite: ZnS). The said conversion of their operational processes resulted in the following four items of alteration;

① Grain fining: Grain size of the tailing turned to be fine because the grain size for ore treatment was switched from coarse and medium size (several mm～0.5mm) in conventional gravity concentration to medium and fine size (0.3～0.05mm) in newly employed flotation.

② Start of flotation reagent use: In accompany with excessive addition of flotation reagents, residual reagents left in the tailings, such as frother, collector (xanthates etc.,) and depressor (cyanide etc.,) were discharged into the rivers without any treatment.

③ Rise of pH: The pH of the tailing turned to high alkalinity because a raise of pH in flotation is an optimum condition for recovery of lead sulfide and zinc sulfide minerals.

④ Insufficient technology: The majority of ingenios have empirically conducted their operations. Therefore, it is hard to say that they have employed the optimum process flow and operational conditions to the treatment of current ore out of the Potosi Mine. As a result, they came to discharge the tailings containing great quantities of unrecovered heavy metals due to insufficiency of their recovery.

The former Figure 2-2-4 shows the relationships (as of Oct. '98) between the locations of the ingenios, rivers and sampling points for analysis of the fluvial water quality.

The survey concerning the tailings out of the ingenios met with difficulties, however, shot samplings were eventually allowed at the sites of six ingenios. These analytical results are shown in Table 5-1-4. In this table, such amphoteric elements as As, Sb, Cd, Cr, Pb, Zn, Sn etc., which dissolve in high alkaline water are considered as a result of redissolution of their amphoteric compounds. All the data concerning ingenio A, C and F are omitted as anomalous values because, judging from the analytical data of pH or lead and zinc, their operations at the time of sampling were considered not to be in normal conditions.

The rest of data concerning ingenio B, D and E are taken as the indications of alkaline water (Aqueous portion). In addition to these data, the major operational factors of the ingenios are shown in Table 5-1-5 including the analytical data of raw ores, concentrates and tailings (SS: Solid portion). The effluent standard in Bolivia and the corresponding evaluation of the operational results in comparison with the level of the standard are jointly shown in the column of tailings (Aqueous portion) in Table 5-1-5.

The results are summarized as follows;

① Evaluation according to the effluent standard in Bolivia

Factors exceeding the level of the standard, inclusive of partial or individual excess, are SS (corresponding to solid portion of tailing), pH and Fe(dissolved), Pb, Zn, Sn, As, Cd and CN.

It is unable to evaluate dissolved ions of Hg and Cr because these analytical data are not available.

② Total load of fluvial water pollution caused by the tailings out of ingenios ([ ]: The daily effluent standard)

②-1 SS

・SS 31,800～97,300mg/L [<60.0mg/L]

・Estimated total amount of tailings 1,040～1,280t/d--------------343～422 thousand t/y

・ Estimated metal amount in tailings

Pb 70～214mg/L [<0.6mg/L] 0.22% : 2.3～2.8t/d → 759～942t/y

Zn 700～2,141mg/L [<3.0mg/L] 2.2% : 22.8～28.1t/d → 7,524～9,273t/y

Sn 146～448mg/L[<2.0mg/L] 0.46%: 4.8～5.9t/d → 1,584～1,947t/y

As 25～78mg/L[<1.0mg/L] 0.08%: 0.8～1.0t/d → 264～330t/y

Cd 2.2～6.8mg/L[<0.3mg/L] 0.007%: 0.07～0.09t/d → 23～30t/y

②-2 Alkaline Water Standards of Discharge of Effluent(*1)

・pH 11.4～12.4 [6.9]

・ Dissolved heavy metals etc.,

Fe(dissolved): 32～135mg/L [< 1.0mg/L] : 328～2,222kg/d -> 108～733t/y

Pb: 0.5~2.2mg/L [<0.6mg/L]　　: 5.4~40.1kg/d -> 1.8~13.2t/y

Sn: 22.6~87.7mg/L [<2.0mg/L]　　: 232~1,443kg/d -> 77~476t/y

As: None of analysis

Cd: 0.04~0.09mg/L[<0.3mg/L]　　: 0.40~1.49kg/d -> 0.1~0.5t/y

CN: 0.04~0.22mg/L [CN^- <0.2mg/L]　　: 0.40~3.63kg/d -> 0.1~1.2t/y

③ Sectional load of fluvial water pollution caused by the tailings out of the corresponding ingenios

Table 5-1-6 and Table 5-1-7 indicate the sectional or intervallic loads of fluvial water pollution.

Figure 5-1-2 illustrates a general view of the fluvial water pollution and so on caused by the pollutants in mining and mineral processing sectors in the Potosi area as so far mentioned.

Table 5-1-1 Samplig Points for Acid Contaminants Sources

No.1:	It is located at the crossing point of Jayajimayu Ravine and the railway. There is a "SUCU" in and around it. Volume of effluent is low during the dry season.
No.2:	It is located at the crossing point of the railway and the Huackajchimayu branch. During the dry season, there is usually no water.
No.3:	The spring is located at the crossing point of the railway and the Agua Dulce River.
No.4:	This sampling point is located at the end of the small stream, which is a branch of the Vilacoya Mayu River. The mine entrances can be found upstream. There is no water during the dry season.
No.5:	It is located on the branch of the Vilacollo Mayu River before it mixed with water from No.4 sampling point. There is same water because a dam for agricultural use was built upstream.
No.6:	It is situated on the west flank of the Juckuy Huacajchi Mountain, in the Canta Canta Valley, upstream of the Vilcollo Mayu River. Water can be easily seen during the dry season. There are some ore stockpiles upstream.
No.7:	It is located after the mixing point of No.4 and No.5 sampling points.
No.8:	It is a dam located in the branch of the Vilacollo Mayu River
No.9:	This sampling point is infiltrating water coming from inside of the tailing dam, located at the beginning of Huaynamayu branch. We can see some water even in the dry season.
No.10:	This spring is located besides the Huaynámayu branch.
No.11:	It is located before the household wastewater is discharged from Campamento Pailaviri.
No.12:	It is located outside of Real Socavon, at the foot of the Cerro Rico Mountain. The presence of water can be seen all year round. This is considered a typical mine drainage pollution.
No.13:	It is located on the northeast foot of the Cerro Rico Mountain, which is covered by low-grade ore stockpiles. There are some small pools of infiltrated water from the stockpiles.
No.14:	It is located on the north side of the Cerro Rico Mountain. During the dry season, there is no infiltrating water from this "SUCU" which is the largest in this area. When it rains, great water runoff that flows north towards the Korymayu branch.
No.15:	It is located in the center of Korymayu branch. There is no water during the dry season except from the tailings of the processing plants using flotation methods.
No.16:	This sampling point of infiltrating water from the tailing dams of San Miguel has some water during the dry season. San Miguel has two types of tailings dams; ③-2 and ③-3. At this sampling point, the infiltrating water is ③-3.
No.17:	This spring is located a few meters from the railway at the bottom west side of the Mojon Punta Mountain. It is surrounded by mine entrances.
No.18:	It is located in the Qda. Jayajimayu River, below the electrical power lines. There is some infiltrating water from the nearest "SUCU" during the dry season.
No.19:	This spring is located a few hundred meters upstream of the No.18 sampling point. The water flows into the Jayajimayu River.
No.20:	This spring is located at the beginning of Huackajchimayu branch.
No.21:	This sampling point is situated at a spring. It is located near and upper side of sampling point No.20.
No.22:	It is located in the Cantu Marca village. This sampling point is a well for household wastewater pollution.
No.23:	The spring is located at the bottom of the Chapini Punta Mountain and crosses the river in front of the tailing dams of San Miguel. There are no discharges during the dry season.
No.24:	It is located at the crossing point of the Jayajimayu River and the road to Uyuni, beside the bridge. There is a stream all year around.
No.25:	We did not see any infiltrating water from the tailing dams of Ingenio Taiton.
No.26:	This spring is located in the north part of San Miguel tailing dams, we can see the stream all year round.
No.27:	There is monitoring equipment for groundwater at this point that is located near the PLAHIPO silver leaching plant.
No.28:	It is located at the southeast base of the Cerro Rico Mountain in a new mining area that is generating mine drainage. A gray stream was found that seams to be water from rock drilling.
No.29:	It is located at the Rivera River, before household pollution occurs.
No.30:	It is located at the end of the Rivera River before the joint with the Aljamayu River. Ore-processing plants have already polluted the water at this point.

Table 5-1-2 (1) Water Quality Analysis Results and Flow Measurements for Acid Contaminants Sources (Rainy Season)

No.	pH	COD	BOD	SS	Cu	Pb	Zn	Cd	Mn	Hg	Sn	T-Cr	As	CN	SO_4	T-Fe	Fe^{2+}	Fe^{3+}	Volume m^3/s
1	2.58	99	—	3,130	60.0	0.15	144	14.0	21.48	3.54	43.3	0.36	62.3	—	8,810	455	202	253	130
2	7.59	18	<1	0.5	<0.003	<0.03	0.42	<0.002	0.13	0.61	39.6	<0.005	39.1	—	27	6.98	5.23	1.75	13.0
3	7.94	14	<1	<0.2	<0.003	0.09	0.07	<0.002	0.18	3.89	—	<0.005	13.3	—	52	377	157	220	21.6
4	7.17	9	<1	482	0.04	0.01	0.13	<0.002	0.16	4.05		<0.005	39.8	—	215	15.9	14.8	1.05	64.8
5	8.50	9	<1	498	0.04	0.03	0.05	<0.002	0.14	6.76		<0.005	41.7	—	170	10.5	4.22	6.32	0.5
6	7.70	5	<1	66.5	<0.003	<0.03	1.05	<0.002	8.93	2.68	—	<0.005	78.7	—	262	3.49	—	—	39.0
7	7.92	4	<1	547	0.01	0.04	0.07	0.01	0.10	5.77		<0.005	3.94	—	170	15.7	9.49	6.32	86.4
8	6.75	9	<1	45.5	<0.003	<0.03	3.77	<0.002	0.78	2.88	—	<0.005	10.4	—	291	5.23	—	—	0
9	3.10																		5.76
10	8.44	9	<1	21.5	<0.003	<0.03	0.15	<0.002	0.05	4.40	—	<0.005	63.5	—	144	0.03	—	—	0
11	3.17	5	<1	2.5	1.80	0.08	111	0.41	6.02	5.17	—	<0.005	31.9	—	1,230	17.5	10.5	6.98	188
12	2.28	257	<1	41.5	182	<0.03	1,050	16.4	0.78	3.59	—	<0.005	19.5	—	31,000	1,640	69.8	1,570	86.4
13	1.86	414	—	48.5	112	0.34	710	4.60	2.26	3.59	—	0.49	19.7	—	19,600	2,800	227	2,570	0
14	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—	—	—	—
15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16	2.38	368	—	42.5	96.0	0.24	529	1.50	13.1	1.67	—	0.03	24.1	—	9,690	1,140	52.3	1,090	2.76
17	7.19	30	<1	556	0.10	0.05	0.36	<0.002	0.16	4.43		<0.005	20.6	—	37	26.3	8.47	17.9	0
18	3.09	9	<1	75.0	4.40	0.10	916	45.0	22.8	3.08	21.9	<0.005	7.81	—	4,900	12.2	5.23	6.98	147
19	6.91	5	<1	<0.2	0.02	<0.03	0.54	<0.002	1.23	5.06	21.2	<0.005	31.1	—	164	5.23	3.49	1.73	8.64
20																			5.04
21																			0
22	7.01	5	<1	17.0	0.03	<0.03	<0.002	<0.002	0.34	4.30	29.1	<0.005	8.68	—	951	6.98	5.23	1.75	0
23	6.92	5	<1	38.5	<0.003	0.20	0.31	<0.002	0.93	3.59	—	<0.005	34.4	<0.001	103	0.70	—	—	0
24	4.00	4	<1	16.5	1.00	<0.03	245	0.99	0.46	2.07	38.4	<0.005	16.9	—	1,580	6.98	3.49	3.49	17.3
25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	3.14	5	<1	45.5	5.20	0.22	60.0	0.43	3.56	7.33	—	<0.005	28.4	—	1,290	14.0	—	—	147
27	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	3.54																		5.00
29	11.9	103	<1	413,000	0.06	0.80	0.36	<0.002	0.09	10.6	20.0	<0.005	26.3	<0.001	1,040	50.0	4.20	45.8	1,890
30	7.78	77	—	42,600	0.03	0.09	8.00	0.45	0.23	8.85	24.3	0.18	32.8	0.104	1,380	26.3	5.27	21.1	3,460

(Note) 1) The units for As and Hg are in $\mu g/L$. The rest of parameters are in mg/L except pH.

2) There were no water at point No. 14, 15, 25 and 27.

Table 5-1-2 (2) Water Quality Analysis Results and Flow Measurements for Acid Contaminants Sources (Dry Season)

No.	pH	COD	BOD	SS	Cu	Pb	Zn	Cd	Mn	Hg	Sn	T-Cr	As	CN	SO_4	T-Fe	Fe^{2+}	Fe^{3+}	Volume m^3/s
1																			
2																			
3																			
4																			
5																			
6	7.72	—	0.12	176	0.033	0.19	0.40	0.01	0.06	3.81	<0.10	0.01	1.79	—	—	0.09	0.01	0.08	—
7																			
8																			
9																			
10	8.11	39	0.23	140	0.03	0.15	0.08	0.01	0.41	0.1	7.27	0.06	4.02	109	—	0.12	<0.01	0.12	—
11	3.11	34		160	2.70	0.22	96.0	0.43	22.0	0.1	2.97	<0.01	8.95	1,150	—	25.2	5.21	20.0	—
12	2.22	250	2.32	160	198	0.69	1,110	24.0	21.0	<0.1	3.25	0.01	5,090	9,130	—	4,770	1,280	3,490	—
13																			
14																			
15																			
16																			
17																			
18																			
19																			
20																			
21																			
22	7.01	2	—	180	0.003	0.25	0.22	0.01	0.06	<0.1	1.28	<0.01	1.82	968	—	0.03	0.01	0.02	—
23	7.00	—	0.18	178	0.08	0.15	0.20	0.002	0.56	<0.1	<0.1	0.01	3.87	63	—	0.05	0.01	0.04	—
24	4.38	2	—	170	0.49	0.31	12.6	1.20	10.0	<0.1	<0.1	<0.01	1.66	1,710	—	<0.01	<0.01	<0.01	—
25																			
26	2.98	—	0.01	180	6.20	0.31	75.0	0.54	17.0	<0.1	<0.1	0.01	10.74	—	—	7.7	0.6	7.1	—
27																			
28																			
29	12.29	158	—	320,000	0.57	0.16	0.27	0.04	0.01	5.53	5.35	0.02	237	1,100	—	0.01	<0.01	0.01	—
30	10.32	180	0.54	345,000	0.43	0.16	0.17	0.06	0.02	<0.1	9.05	0.01	15.7	1,300	—	0.07	<0.01	0.07	—

(Note) 1) The units for As and Hg are in μg/L. The rest of parameters are in mg/L except pH.

2) There were no water at point No. 14, 15, 25 and 27.

Table 5-1-3 Distribution and Classification of Contaminants Sources

No.	Contaminants Receipts	Impact Grade		Notes
		High	Less or Unknown	
1	Huaynamayu River	Sampling points 9, 11, 12, 13 and 28. Acid water with heavy metals in solution	Points 10 and 27	High amounts of rock waste sparkled at Cerro Rico mountain surroundings. Acid water drainage form new mineral extraction galleries. (Point 28)
2	Korumayu and De la Ribera Rivers	Points 14, 15, 16 and 26. Acid water with heavy metals in solution	Points 22	The biggest sucu located at top part. Drainage form sucu (points 14 and 15). Drainage form mineral waste deposits (points 16 and 26). Point 26 inflows to De la Ribera River.
3	Jayajmayu Ravine	Points 1, 18 and 24. Acid water with heavy metals in solution	Points 19	Mine gallery and sucu located at the top part.
4	Vilacomayu River (latent pollutant)	Points 5, 6, 7 and 8. Heavy metals	Points 4	Waste rocks located at top part of point 6. Not detected contaminants on analysis results, but they are latent contaminants.
5	De la Ribera River	Points 29 and 30. Alkaline water with heavy metals content in SS		Affected with high alkaline tailings drainage from ingenios.

Table 5-1-4 Analysis of Tailings of Some Ingenios(Concentrators)

: analysis of samples obtained by shot-sampling('98.2.9,10)

			Ingenio A	Ingenio B	Ingenio C	Ingenio D	Ingenio E	Ingenio F
Ore	Sn	%	0.17	0.68	0.55	0.24	0.66	0.27
	Pb	%	1.10	0.10	4.57	0.15	0.19	0.11
	Ag	g/t	171.90	14.00	666.70	152.90	130.90	56.90
	Zn	%	3.90	0.62	6.34	0.48	0.92	0.60
	Ca	%	0.18	0.02	0.006	0.19	0.04	0.01
	Fe	%	15.90	7.84	21.08	17.75	7.61	4.74
Wa-ter	SS	mg/l	152,000.00	97,300.00	31,800.00	75,200.00	79,500.00	95,800.00
	P.D. *1	%	13.9	9.1	3.1	7.2	7.6	9.1
	pH *2		12.09	11.39	6.01?	12.40	11.66	7.24?
	As	μ g/l						
	Sb	μ g/l	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
	Cd	mg/l	0.03	0.04	32.00	0.09	0.09	0.57
	Cu	mg/l	0.05	0.04	0.05	0.04	0.05	0.19
	Cr	mg/l	<0.005	0.041	0.207	0.467	0.429	<0.005
	Fe	mg/l						
	Fe(II)	mg/l	85.40	17.92	69.95	79.08	59.05	42.20
	Fe(III)	mg/l	9.49	13.71	70.14	43.42	55.93	34.43
	Hg	μ g/l	4.55	2.21	1.47	0.61	1.59	6.14
	Mn	mg/l	0.43	0.54	14.66	0.44	0.34	3.55
	Pb	mg/l	1.45	0.52	2.70	2.44	0.68	0.67
	Zn	mg/l	0.78	0.10	1.45	0.73	0.27	15.50
	Sn	mg/l	99.22	87.73	31.59	23.32	22.59	15.54
	CN	mg/l	0.146	0.22	0.059	0.186	0.043	0.018
	SO_4^{2-}	mg/l						
	COD	mg/l	159.00	60.00	26.00	120.00	47.00	34.00
	BOD	mg/l	Non	0.06	0.76		0.67	1.14

Note *1: Pulp Density, *2: 14.5~17.0 °C

○ Investigated by Itoh

Table 5-1-5 Principal Results of Ingenios(Total), Standards of Discharge of Effluent of Bolivia and Judgement

1. Head(Run of Mine Ore)/Concentrate/Tailing : Solid Division

	Grade %	Quantity of Ore or Metal t/d			Standards of Discharge of Effluent(*1)		
	assumption	assumption : Min.	assumption : Max.	assumption : range	judgement(*2)	value of day mg/l	value of month mg/l
Run of Mine Ore		1,300	1,600	1,300~1,600			
Concentrate		262.6	323.2	260~320			
Pb Conc.		22.1	27.2	22~27			
Zn Conc.		240.5	296.0	240~300			
Tailing(*3)		1,037	1,277	1,040~1,280			
Pb	0.22	2.3	2.8	2~3			
				70~214mg/l	×	0.6	0.3
Zn	2.2	22.8	28.1	23~28			
				700~2,141mg/l	×	3.0	1.5
Sn	0.46	4.8	5.9	5~6			
				146~448mg/l	×	2.0	1.0
As	0.08	0.8	1.0	0.8~1			
				25~78mg/l	×	1.0	0.5
Cd	0.007	0.07	0.09	0.07~0.09			
				2.2~6.8mg/l	×	0.3	0.15

2. Tailing(Soluble, etc.) : Liquid Division

	Measured Values except unusual values(*4)	Standards of Discharge of Effluent(*1)		
		judgement(*2)	value of day mg/l	value of month mg/l
SS	31,800~97,300mg/l	×	60mg/l	
PD	7.2~9.1%			
pH	11.4~12.4	×	6.9	6.9
As	None of analysis(μ g/l)	----	1.0mg/l	0.5mg/l
Sb	<0.10 μ g/l	O	1.0mg/l	
Cd	0.04~0.09mg/l	O	0.3mg/l	0.15mg/l
Cu	0.04~0.05mg/l	O	1.0mg/l	0.5mg/l
Cr	0.041~0.467mg/l	Δ	Cr(III)1.0mg/l	Cr(III)0.5mg/l
			Cr(VI)0.1mg/l	Cr(VI)0.05mg/l
Fe Total	31.63~135.01mg/l	×	1.0mg/l	0.5mg/l
Fe(II)	17.92~79.08mg/l			
Fe(III)	13.71~55.93mg/l			
Hg	None of analysis(μ g/l)	----	0.002mg/l	0.001mg/l
Mn	0.34~0.54mg/l			
Pb	0.52~2.44mg/l	×	0.6mg/l	0.3mg/l
Zn	0.10~0.73mg/l	O	3.0mg/l	1.5mg/l
Sn	22.59~87.73mg/l	×	2.0mg/l	1.0mg/l
CN	0.043~0.220mg/l	×	CN^- 0.2mg/l	CN^- 0.1mg/l
COD	47.00~120.00mg/l	O	250mg/l	
BOD	0.06~0.67mg/l	O	80mg/l	

注) *1 : Limites Permisibles para Descargas Liquidas[Propuesta]
(Reglamentos a la Ley de Medio Ambiente: Bolivia), There is no standard in column with slant lines.
*2 : O : under the standard, Δ hard to judge, × : over the standard, ---- none of analysis
*3 : The tailing corresponds to " SS " at 2. Tailing: Lquid Division
*4 : Refer to Table 5-1-4

Table 5-1-6 Tailing 1 discharged from Ingenios between Each Section of Sampling Points for River Water Quality : Solid Division

Section *1	Ingenio *2	Ores	Pb		Zn		Sn		As		Cd	
		t/d*3	%*3	t/d	%*3	t/d	%*3	t/d	%*3	t/d	%*3	t/d
1. The upper stream of Ribera river ~ Sampling point 1	None											
2. Sampling point 1 ~ Sampling point 5	No.1~15, 35, 39, 40 Total 18	411 ~ 507	0.22	0.9 ~ 1.1	2.2	9.1 ~ 11.2	0.46	1.9 ~ 2.3	0.08	0.33 ~ 0.41	0.007	0.03 ~ 0.04
3. The upper stream of Huaynamayu ri. ~ Sampling point 2	None											
4. Sampling point 2 ~ Sampling point 4	No.16~19, 36 Total 5	76 ~ 93	0.22	0.2	2.2	1.7 ~ 2.1	0.46	0.4	0.08	0.06 ~ 0.07	0.007	0.01
5. The upper stream of Korimayu ri. ~ Sampling point 3	None											
6. Sampling points 4 and 5 ~ Sampling point 6	No.20~22 Total 3	46 ~ 56	0.22	0.1	2.2	1.0 ~ 1.2	0.46	0.2 ~ 0.3	0.08	0.04 ~ 0.05	0.007	0.00
7. Sampling point 3 ~ Sampling point 13	No.23~25 Total 3	116 ~ 143		0.3		2.6 ~ 3.1		0.5 ~ 0.7		0.09 ~ 0.11		0.01
8. Sampling point 6 ~ Sampling point 11	No.26~31, 37, 38, 41, 42 Total 10	261 ~ 322		0.6 ~ 0.7		5.7 ~ 7.1		1.2 ~ 1.5		0.21 ~ 0.26		0.02
9. Sampling point 8 and 9 ~ Sampling point 10	No.34 Total 1	19 ~ 23		0.0 ~ 0.1		0.4 ~ 0.5		0.1		0.02 ~ 0.02		0.00
10. Sampling point 10 and 11 ~ Sampling point 12	No.32, 33 Total 2	108 ~ 133		0.2 ~ 0.3		2.4 ~ 2.9		0.5 ~ 0.6		0.09 ~ 0.11		0.01
Total	No.1~42 Total 42	1,037 ~ 1,277	↓	2.3 ~ 2.8	↓	22.9 ~ 28.1	↓	4.8 ~ 5.9	↓	0.83 ~ 1.02	↓	0.07 ~ 0.09

注) *1 : As for sampling points, refer to Figure 1-2-4 and Figure 2-2-4.
*2 : As for number of Ingenios, refer to Table 2-2-3 and Figure 2-2-4.
*3 : Assumption. Refer to Table 5-1-5.

Table 5-1-7 Tailing 2 discharged from Ingenios between Each Section of Sampling Points for River Water Quality : Liquid (Soluble, etc.) Division

Section	SS g/l	PD %	Water Quan m³/d	pH	As Conc μg/l	As Quan kg/d	Sb Conc μg/l	Sb Quan kg/d	Cd Conc mg/l	Cd Quan kg/d	Cu Conc mg/l	Cu Quan kg/d	Cr Conc mg/l	Cr Quan kg/d	Fe-Total Conc mg/l	Fe-Total Quan kg/d
1. The upper stream ~ Sampling point 1																
2. Sampling point 1 ~ Sampling point 5	32 ~ 97	7.2 ~ 9.1	4105 ~ 6535	11.4 ~ 12.4	No analysis	----	< 0.10	----	0.04 ~ 0.09	0.16 ~ 0.59	0.04 ~ 0.05	0.16 ~ 0.33	0.04 ~ 0.47	0.16 ~ 3.07	31.6 ~ 135	130 ~ 882
3. The upper stream of Huaynamayu ri. ~ Sampling point 2																
4. Sampling point 2 ~ Sampling point 4	32 ~ 97	7.2 ~ 9.1	759 ~ 1199	11.4 ~ 12.4	No analysis	----	< 0.10	----	0.04 ~ 0.09	0.03 ~ 0.11	0.04 ~ 0.05	0.03 ~ 0.06	0.04 ~ 0.47	0.03 ~ 0.56	31.6 ~ 135	24 ~ 162
5. The upper stream of Korimayu ri. ~ Sampling point 3																
6. Sampling point 4,5 ~ Sampling point 6	32 ~ 97	7.2 ~ 9.1	459 ~ 722	11.4 ~ 12.4	No analysis	----	< 0.10	----	0.04 ~ 0.09	0.02 ~ 0.06	0.04 ~ 0.05	0.02 ~ 0.04	0.04 ~ 0.47	0.02 ~ 0.34	31.6 ~ 135	15 ~ 97
7. Sampling point 3 ~ Sampling point 13			1159 ~ 1843			----		----		0.05 ~ 0.17		0.05 ~ 0.09		0.05 ~ 0.87		37 ~ 249
8. Sampling point 6 ~ Sampling point 11			2607 ~ 4150			----		----		0.10 ~ 0.37		0.10 ~ 0.21		0.10 ~ 1.95		82 ~ 560
9. Sampling point 8,9 ~ Sampling point 10			190 ~ 296			----		----		0.01 ~ 0.03		0.01 ~ 0.02		0.01 ~ 0.14		6 ~ 40
10. Sampling point 10, 11~ Sampling point 12			1079 ~ 1714			----		----		0.04 ~ 0.15		0.04 ~ 0.09		0.04 ~ 0.81		34 ~ 232
[reference] Total	↓	↓	10358 ~ 16459	↓	↓	----	↓	----	↓	0.41 ~ 1.48	↓	0.41 ~ 0.84	↓	0.41 ~ 7.74	↓	328 ~ 2222

Section	Fe(II) Conc mg/l	Fe(II) Quan kg/d	Fe(III) Conc mg/l	Fe(III) Quan kg/d	Hg Conc μg/l	Hg Quan kg/d	Mn Conc mg/l	Mn Quan kg/d	Pb Conc mg/l	Pb Quan kg/d	Zn Conc mg/l	Zn Quan kg/d	Sn Conc mg/l	Sn Quan kg/d	CN Conc mg/l	CN Quan kg/d	COD Conc mg/l	COD Quan kg/d	BOD Conc mg/l	BOD Quan kg/d
1. The upper stream ~ Sampling point 1																				
2. Sampling point 1 ~ Sampling point 5	17.9 ~ 79.1	73 ~ 517	13.7 ~ 55.9	56 ~ 365	No analysis	----	0.34 ~ 0.54	1.40 ~ 3.53	0.52 ~ 2.44	2.1 ~ 15.9	0.10 ~ 0.73	0.41 ~ 4.77	22.6 ~ 87.7	92 ~ 573	0.04 ~ 0.22	0.16 ~ 1.44	47 ~ 120	193 ~ 784	0.06 ~ 0.67	0.25 ~ 4.38
3. The upper stream of Huaynamayu ri. ~ Sampling point 2																				
4. Sampling point 2 ~ Sampling point 4	17.9 ~ 79.1	14 ~ 95	13.7 ~ 55.9	10 ~ 67	No analysis	----	0.34 ~ 0.54	0.26 ~ 0.65	0.52 ~ 2.44	0.4 ~ 2.9	0.10 ~ 0.73	0.08 ~ 0.88	22.6 ~ 87.7	17 ~ 105	0.04 ~ 0.22	0.03 ~ 0.26	47 ~ 120	36 ~ 144	0.06 ~ 0.67	0.05 ~ 0.80
5. The upper stream of Korimayu ri. ~ Sampling point 3																				
6. Sampling point 4,5 ~ Sampling point 6	17.9 ~ 79.1	8 ~ 57	13.7 ~ 55.9	6 ~ 40	No analysis	----	0.34 ~ 0.54	0.16 ~ 0.39	0.52 ~ 2.44	0.2 ~ 1.8	0.10 ~ 0.73	0.05 ~ 0.53	22.6 ~ 87.7	10 ~ 63	0.04 ~ 0.22	0.02 ~ 0.16	47 ~ 120	22 ~ 87	0.06 ~ 0.67	0.03 ~ 0.48
7. Sampling point 3 ~ Sampling point 13		21 ~ 146		16 ~ 103		----		0.39 ~ 1.00		0.6 ~ 4.5		0.12 ~ 1.35		26 ~ 162		0.04 ~ 0.41		54 ~ 221		0.07 ~ 1.23
8. Sampling point 6 ~ Sampling point 11		47 ~ 328		36 ~ 232		----		0.89 ~ 2.24		1.4 ~ 10.1		0.26 ~ 3.03		59 ~ 364		0.10 ~ 0.91		123 ~ 498		0.16 ~ 2.78
9. Sampling point 8,9 ~ Sampling point 10		3 ~ 23		3 ~ 17		----		0.06 ~ 0.16		0.1 ~ 0.7		0.02 ~ 0.22		4 ~ 26		0.01 ~ 0.07		9 ~ 36		0.01 ~ 0.20
10. Sampling point 10, 11~ Sampling point 12		19 ~ 136		15 ~ 96		----		0.37 ~ 0.93		0.6 ~ 4.2		0.11 ~ 1.25		24 ~ 150		0.04 ~ 0.38		51 ~ 206		0.06 ~ 1.15
[reference] Total	↓	185 ~ 1302	↓	142 ~ 920	↓	----	↓	3.53 ~ 8.90	↓	5.4 ~ 40.1	↓	11 ~ 120	↓	232 ~ 1443	↓	0.40 ~ 3.63	↓	488 ~ 1976	↓	0.6 ~ 11.0

Note As for sampling points, refer to Figure 1-2-4 and Figure 5-1-2. There is no ingenio in section 1, 3 and 5.
SS, pH and concentrations are values measured by shot-sampling. Water quantity is calculated with ore quantity (assumption) and PD.
Values, particularly water quantity in total may be different from actual water quantity because major ingenios use a large quantity of water which is contained in tailing of the ingenio and previous ingenio as recycling water.

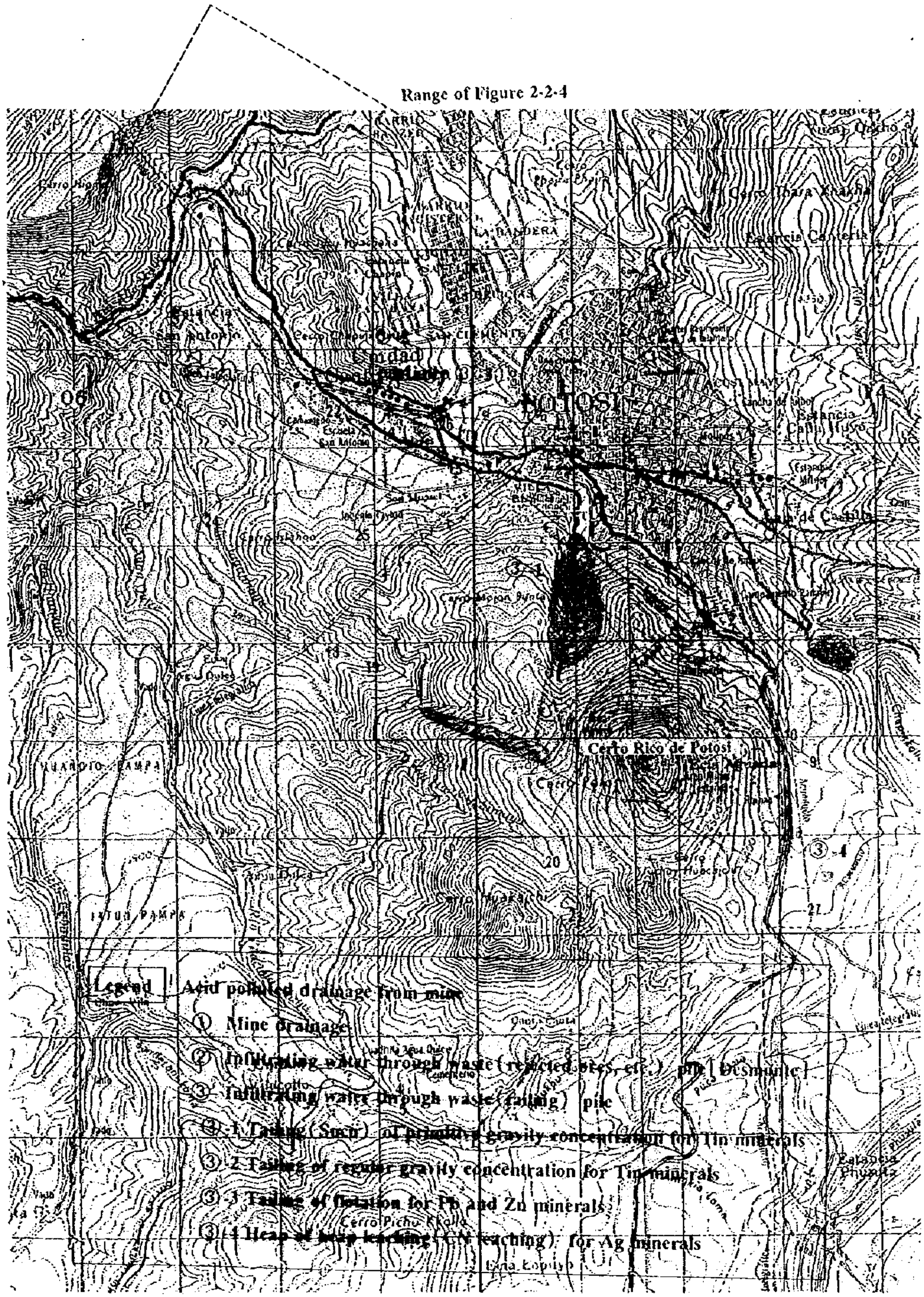
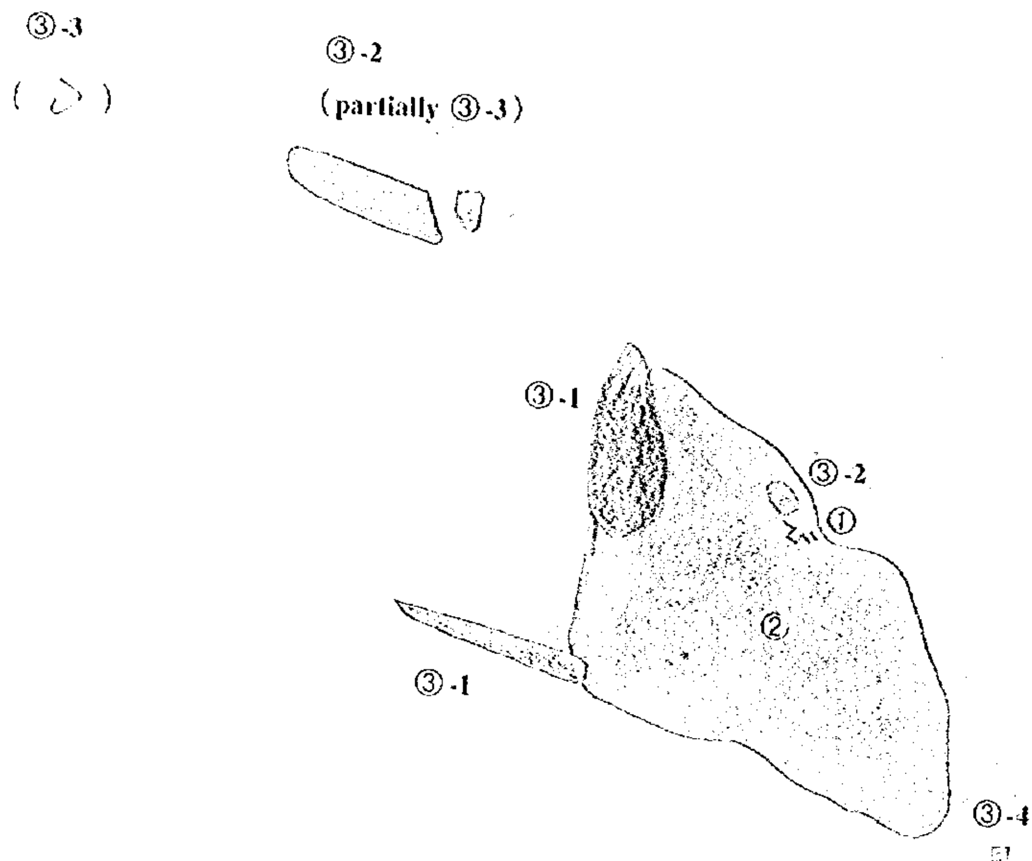


Figure 5-1-1 Sampling Point for Mining Pollution Division



Legend	Acid polluted drainage from mine
	① Mine drainage
	② Infiltrating water through waste (rejected ores, etc.) pile [Desmonte]
	③ Infiltrating water through waste (tailing) pile
	③-1 Tailing (Sucu) of primitive gravity concentration for Tin minerals
	③-2 Tailing of regular gravity concentration for Tin minerals
	③-3 Tailing of flotation for Pb and Zn minerals
	③-4 Heap of heap leaching (CN leaching) for Ag minerals

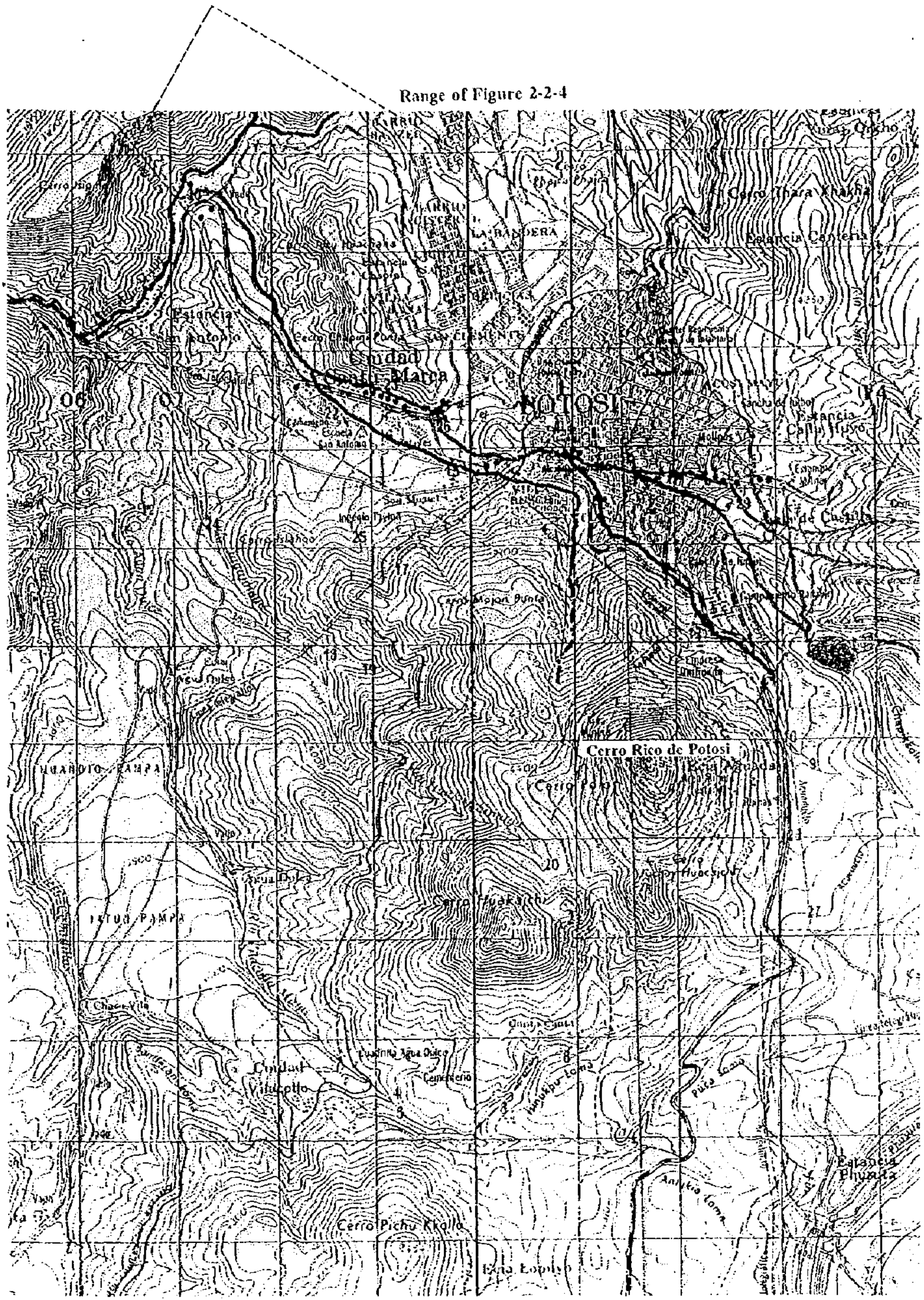


Figure 5-1-1 Sampling Point for Mining Pollution Division

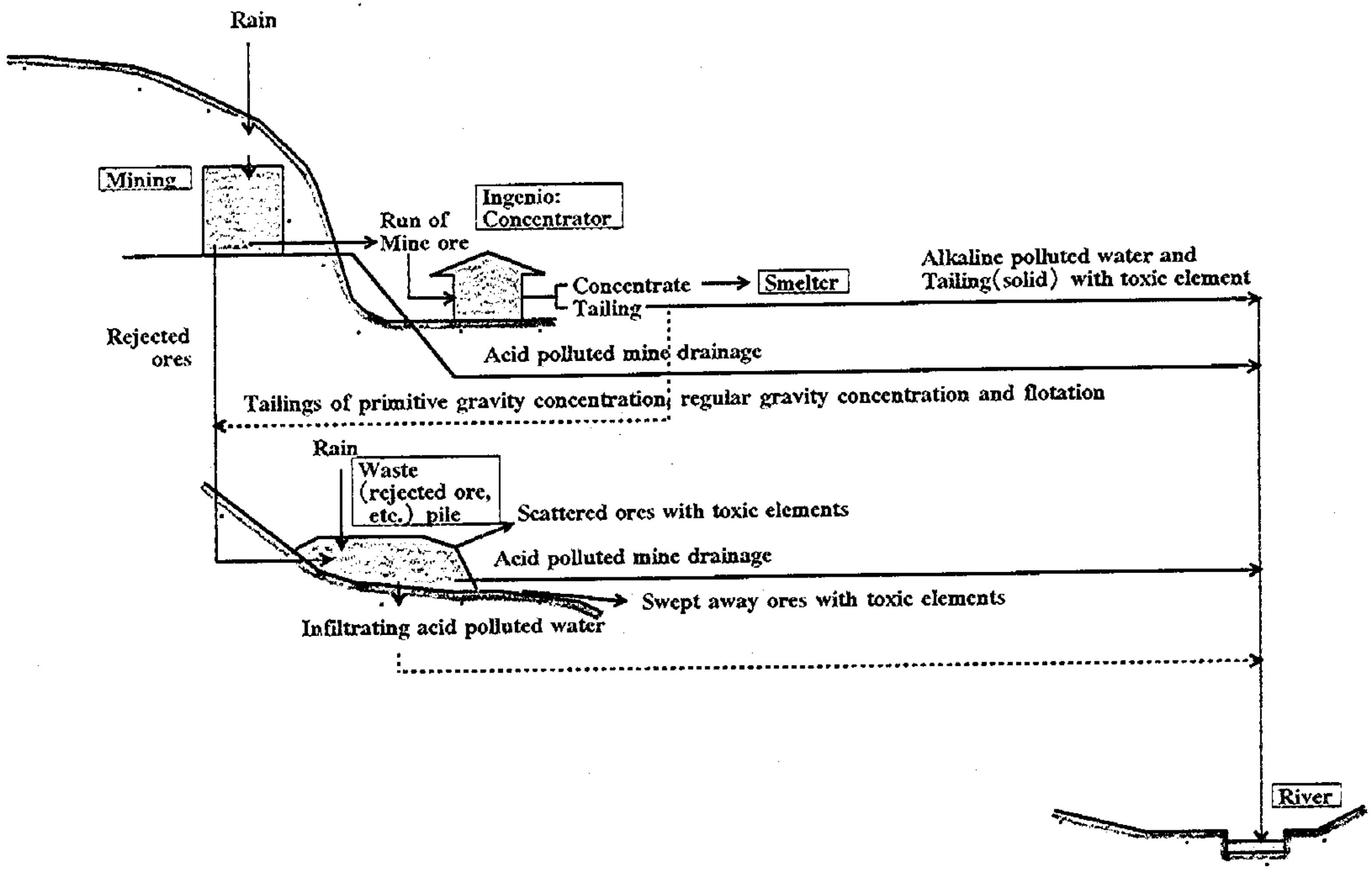


Figure 5-1-2 Pollution Mechanism Map in Potosi Area (Concept) [Present]
: Concept of pollution for river, etc. caused by mine and Ingenio with toxic elements

5-2 The Mechanism of Water Pollution in Rivers

5-2-1 Water Pollution in Rivers

The worst polluters are acid mine water which contains heavy metal ions, acid infiltrating water from waste ore stockpiles, Sucu, and tailing dams which also contain heavy metal ions and untreated discharged tailings from ingenios to Rio de La Ribera and other river streams. There tailings consist of 0.05 – 0.3 mm diameter of gangue mineral partilates containing unrecovered heavy metals and alkaline water of pH between 9.5 and 12 containing residual chemicals which are used for mineral processing processes. Solid content of discharged tailing is 10% or slightly less than that.

The results of water pollution mechanism are shown in the following paragraphs using laboratory analysis data of water and sediment samples from Rio de La River until Rio Pilcomayo. Table 5-2-1 shows the mechanism of water pollution and Figure 1-2-4 and Figure 5-2-1 illustrate examples.

5-2-2 Water Quality of De La Ribera, Tarapaya and Pilcomayo Rivers

(1) SS and pH variations

The analysis of water samples suggests that the SS content in water of the Tarapaya river system decreases as sampling points moved downstream from Rio de La Ribera, Rio Alja Mayu and Rio Tarapaya river, as shown in Figure 5-2-2. There are two major factors that contribute to this. First of all, the river system merges with various rivers on its course, which have relatively a high level of flow, namely (starting from the upper stream) Rio Huayuamayu, Rio Jesus Valle (mainly Rio Huarampaya) and Rio Huancarani. Secondly, the SS content seems to settle into the bottom as it is carried by river water.

Although the general trend was seen commonly among all the rivers surveyed, different patterns and levels were found between different sampling points, including some seasonal variations, as summarized in Figures 5-2-3 and 5-2-4. For instance, the concentration level of SS in Rio Pilcomayo was much lower than that in the Tarapaya river system. Then, the concentration level in the Tarapaya river system remained constant up to May and tended to rise in deep dry season. In contrast, the concentration level in Rio Pilcomayo showed a gradual decline after March. The river in lower flow contains less SS ordinarily, the seasonal change of SS concentration in the Tarapaya river system is quite strange, because large amount of SS is obligated to put into the river.

Within the Tarapaya river system, the pH in Rio de La Rivera changed greatly after the confluence with Rio Huaynamayu, and it then stabilized at 8-9 in Rio Tarapaya. These changes are shown in Figure 5-2-5.

(2) Relationship between dissolved ions in river water and SS constituents

In the Tarapaya river system, there was a tendency that, as the pH of river water turned from acidity to alkalinity, metals dissolved in water decreased and became less than metallic constituents contained in solid matters suspended in water. A typical example is shown in Table 5-2-2. The original data of this table are extracted in Table 4-2-2 which obtained from analysis of water quality and sediments using samples collected in mid-April (the ninth round of sampling).

For example, water collected at sampling point No.4 showed acidity and a high percentage of metals dissolved in water. On the other hand, water samples taken from point Nos.11, 12 and 15 showed alkalinity and contained a higher percentage of heavy metals carried as part of SS, particularly iron and zinc.

Thus, the analytical method to use only the filtrate after removing the SS content does not reveal the true picture of water pollution in Potosi as it neglected heavy metals contained in solid matters. We supposed that such pretreatment of samples is customarily carried out at UATF laboratory or other facility in the city. Instead, the filtrate and the solid content should be separately analyzed to determine heavy metal contents, which must be added up to attain accurate data.

An alternative method is to dissolve the sample including the solid content by means of acid treatment under heated and pressurized conditions (the method to pretreat a specimen for analysis, as specified in ASTM D1971), which allows analysis of the whole sample.

(3) Variation of heavy metal constituents in river water

Theoretically, there must be some relationship between the pH of a water solution and heavy metals dissolved in it. The general trends observed in Rio de La Rivera and Rio Tarapaya are shown in Figures 5-2-6 through 5-2-14.

First of all, solubility levels of cadmium, iron, manganese and zinc declined largely with the rise in the pH. The decline of solubility occurs in a linear manner when data are plotted on an semi-logarithmic graph paper. This is because metallic hydroxides produced by alkalinity show low solubility, as illustrated in Figure 5-2-1. The reaction is actually occurred in the river, not in the laboratory.

Secondly, solubility levels of arsenic, copper and lead also declined with the rise in the pH and tended to show signs of rising again. These three elements appear to have dissolved again at pH8 to pH9. The re-dissolving process may have started by forming complex ions. For instance, lead seems to have re-dissolved at a level pH1 or 2 lower than the theoretical level. It is interesting to note that cadmium and zinc did not indicate a clear re-rise in solubility due to alkalinity, whereas copper showed an apparent rising trend.

In contrast, no close association between variations of pH and solubility was confirmed in mercury and antimony. Antimony is present in SS and sediments, while its dissolution level in water is extremely low. However, its variation is not clearly identified compared to arsenic. Mercury is another mysterious constituent.

Water in Rio Huaynamayu, Rio Korimayu and Quebrada Jayajmayu, which are originated in acidic sources, contains arsenic. On the other hand, a very small amount of arsenic is dissolved in alkaline river water. In all the rivers surveyed, SS and sediments contain a large amount of arsenic. Variation of arsenic is similar to that of heavy metals, although there are some differences in quantity.

As seen in Table 4-2-2, analysis of water samples taken from all the points detected little chrome and free cyanide ion.

Absence of chrome reflects the fact that it is not contained in the ores produced in and around Potosi. Thus, there seems to be no risk of water contamination by chrome.

As a large amount of cyanide is used by ingenio's floating separation process, cyanide should be found in water samples. However, analysis showed very few signs of cyanide, and it is not confirmed as to what metal combines with cyanide. At this point of time, therefore, the environmental behavior of cyanide is largely unknown.

Cyanide tends to form a complex ion with cadmium, copper, lead, iron and/or zinc. Thus, either combined cyanide or a complex compound with any of the above metals must be detected in the water samples. However, the analytical method used here is not able to detect a combined cyanide, so that a metal(s) that form a complex ion with cyanide needs to be detected. At the same time, complex ions with cyanide may be small in number or do not exist at all in the alkaline water samples that dissolve a very small amount of metal ions.

The COD, a key indicator of water contamination by organic substances, was high in Rio de La Rivera and Rio Hualampaya where municipal waste water flew in. Also, the effect of chemical agents used in the metal concentration process cannot be negated. The COD was low in rivers that had no urban areas upstream.

4) Relationship between constituents in river water and sediments

In the dry season during which a rapid change in water flow or soil discharge due to the heavy rain is not likely to occur and most SS contents come from ingenio facilities, SS contents may settle in Rio de La Ribera and Rio Aljamayu to become major constituents of sediments. To examine validity of this hypothesis, the relationship between composition of heavy metal contents in the SS and that in the sediments was analyzed. The results of analysis of major pollutants (arsenic, cadmium, lead and zinc) and tin (an important resource available in Potosi) are presented in Figures 5-2-15 through 5-2-19.

As seen in these figures, each constituent is present in both the SS and the sediment, with relatively high levels of concentration. More specifically, sediments in Rio Tarapaya and Rio Pilcomayo, until Puente Mendez, are heavily contaminated by arsenic and heavy metals. At all the sampling points of the Tarapaya river system, the level of concentration reaches a few hundred ppm for arsenic, a few ten ppm for cadmium, a few thousand ppm for lead, and a few ten thousand ppm for zinc.

Concentration of tin also reached a few thousand ppm level. Although much lower levels, serious contamination was detected in the sediments taken at Puente Mendez of Rio Pilcomayo. While data on the SS contents and sediments show same order concentration level, the two sets of data are necessarily consistent with each other; compared to the contents of heavy metals in the SS, those in the sediments varied in a wider range. A reason for this is not known at present. It is quite important to make well organized program to continue monitoring and to know water contamination more exactly.

Finally the level of concentration used for calculation of quantitative pollution analysis in chapter 4 are As 220ppm, Cd 50-60ppm, Pb 1,500ppm, Zn 15,000-20,000ppm and Sn 2,000ppm.

Table 5-2-1 Rivers Pollution Mechanism

Classification	Contaminant Sources		Contaminants
Source characteristics	Mine originated effluents	Acid drainage from mines	Acidity, solved heavy metals
		Infiltrated water drainage form waste rocks	Acidity, solved heavy metals
		Infiltrated water drainage form tailings deposits	Acidity, solved heavy metals
	Ingenios waste originated effluents	Alkaline effluents	Alkalis, SS
		Solids contents in tailings	Solid particules of heavy metals
Phenomenon ocuured in rivers	Chemical phenomena	Neutralization reaction (decrese of acidity, neutralization or smouth alkalinization)	Microscopic particules of heavy metals hydroxids
		Generation of precipitants caused by neutralization	Heavy metals SS and sediments
	Physical phenomena	Precipitation of solids	Accumulation of heavy metals
		Transport of SS and sediments caused by hydraulic force	Transport of heavy metals

Table 5-2-2 Heavy metals content in solution and SS

Monitoring point		pH	As	Sb	Cd	Cu	Fe	Hg	Mn	Pb	Zn
		-	mg/L	μg/L	mg/L	mg/L	mg/L	μg/L	mg/L	mg/L	mg/L
No.4	Solución	2.8	0.001	0.001	2.7	25	568	0.39	18.2	3.39	408
(Potosí City)	S.S.		0.186	0.337	0.048	0.517	64.9	0.67	0.02	2.23	9.1
(Huaynamayu)											
No.5	Solución	11.6	0.088	0.001	0.002	0.43	0.08	0.23	0.01	0.1	0.38
(Potosí City)	S.S.		12.8	34.0	8.23	36.5	3675	49	7.7	272	1010
(De la Ribera)											
No.6	Solución	5.0	0.019	0.001	1.2	0.05	11.8	1.07	8.9	0.23	159
(Potosí City)	S.S.		7.8	18.4	2.94	29.0	2650	27.9	1.84	128	496
(De la Ribera)											
No.11	Solución	8.4	0.022	0.001	0.05	0.16	0.02	0.13	0.03	0.03	0.16
(Outside Potosí)	S.S.		11.6	15.0	2.42	33.7	3520	31.0	20.6	120	626
(De la Ribera)											
No.12	Solución	8.7	0.02	0.001	0.05	0.15	0.06	<0.10	0.33	0.03	0.21
(San Antonio)	S.S.		6.94	26.5	2.48	30.3	4260	26.1	20.3	141	625
(Aljamayu)											
No.15	Solución	8.1	0.01	0	0.1	0.02	5.12	0.55	5.7	0.03	36
(La Puente)	S.S.		11.6	40.9	2.31	19.7	4410	33.0	23	313	881
(Aljamayu)											

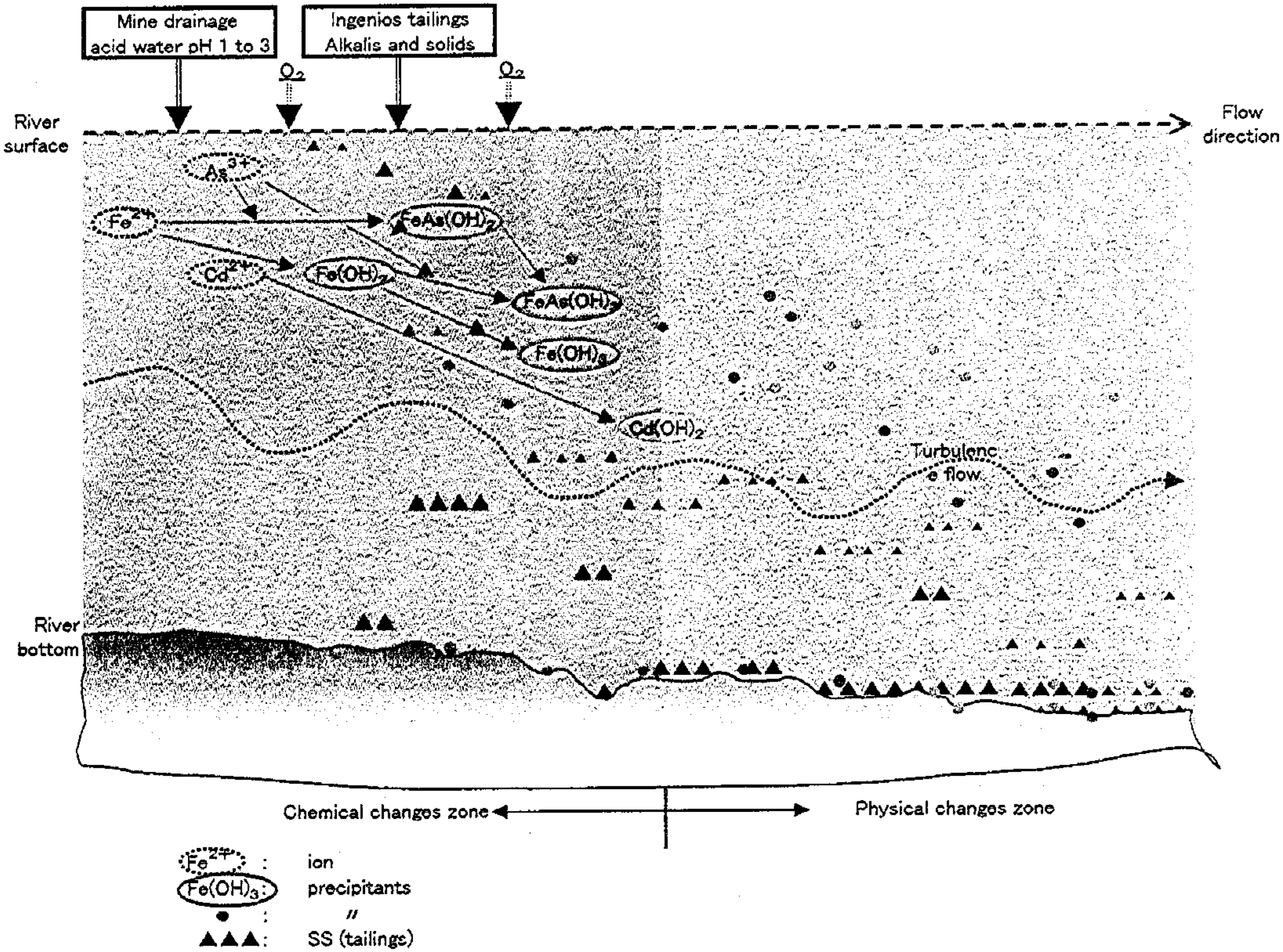


Figure 5-2-1. River Pollution Mechanism

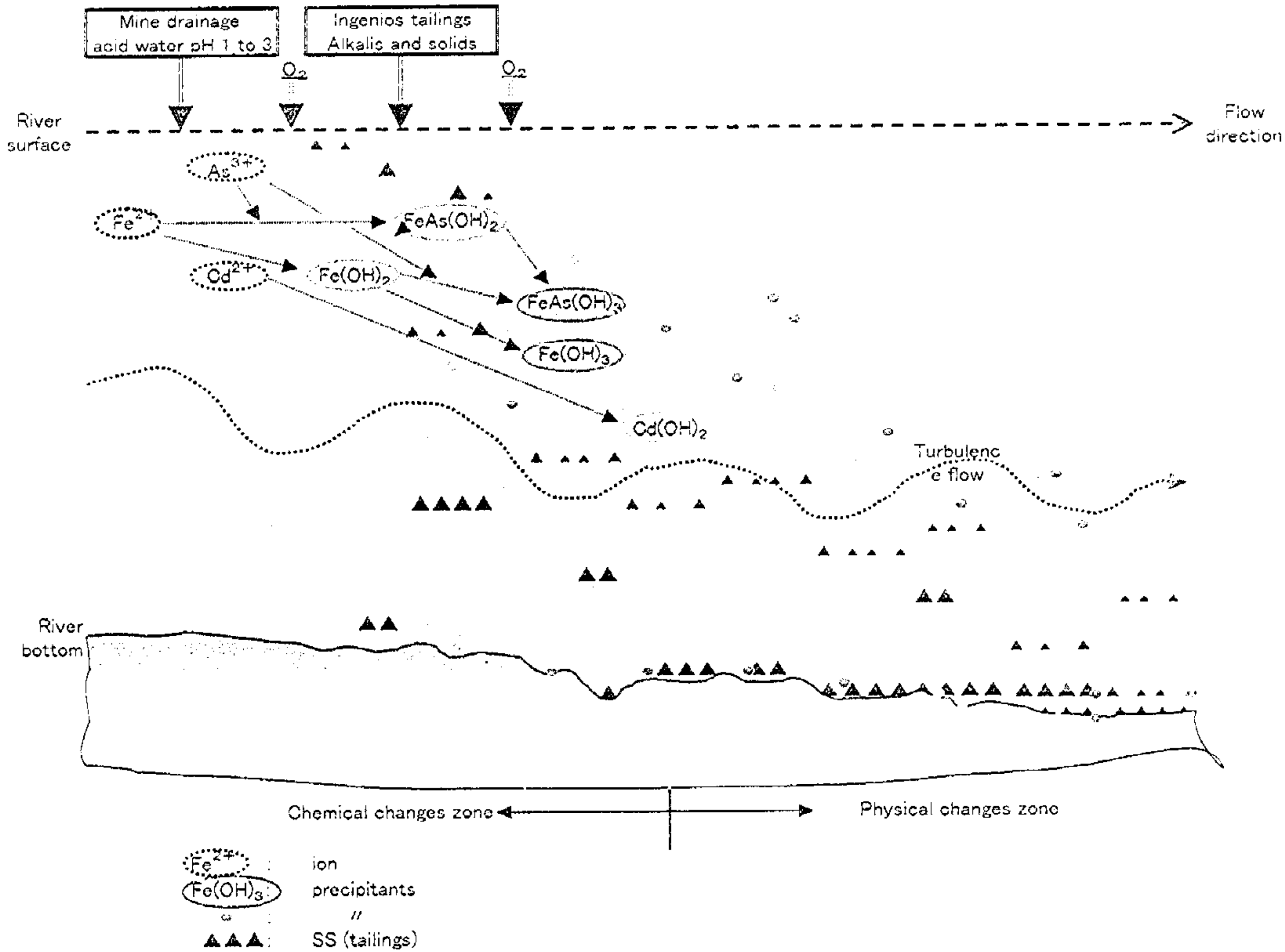


Figure 5-2-1. River Pollution Mechanism

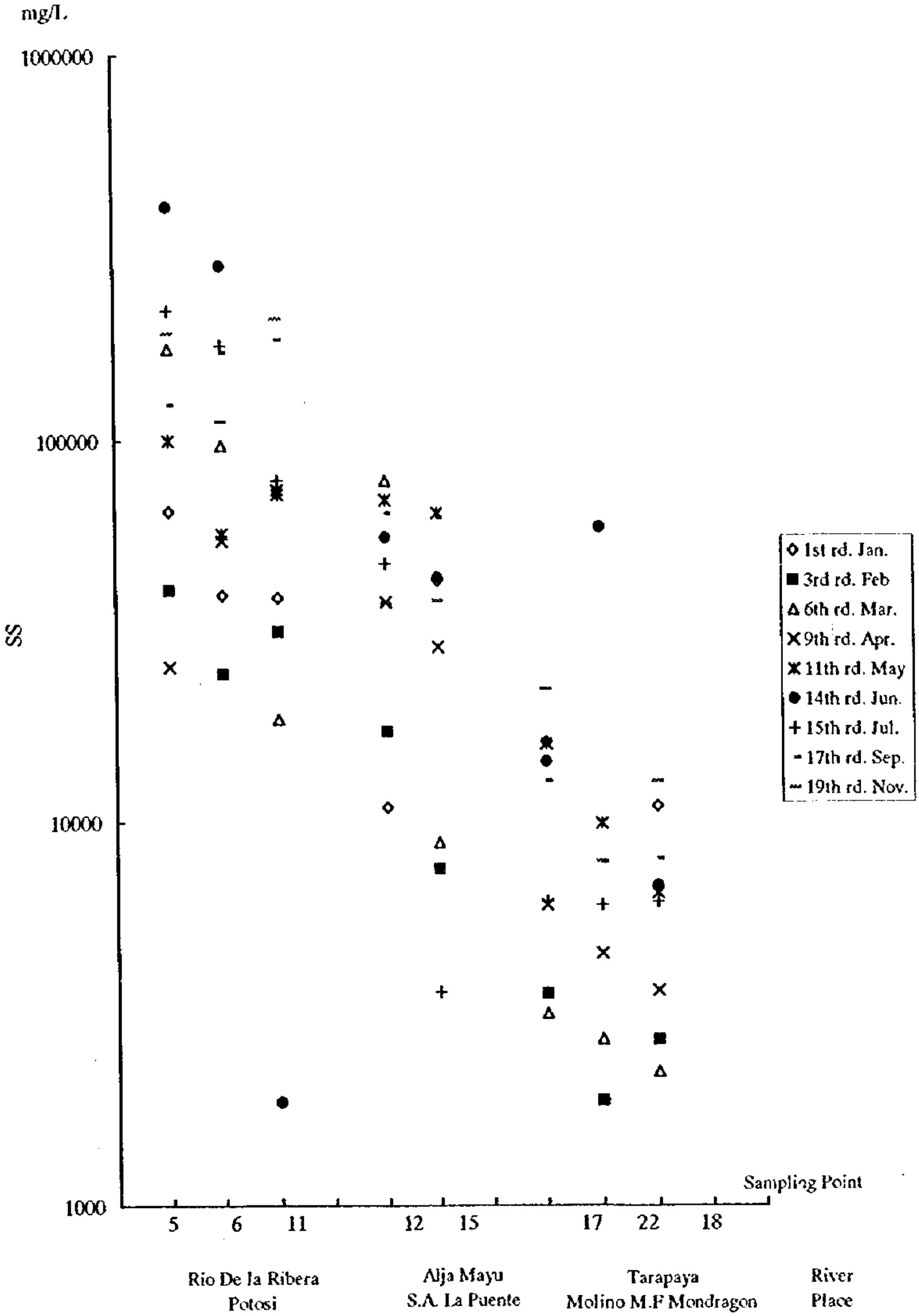


Figure 5-2-2 Trend of SS contents in Rio De la Ribera-Aljamayu-Tarapaya

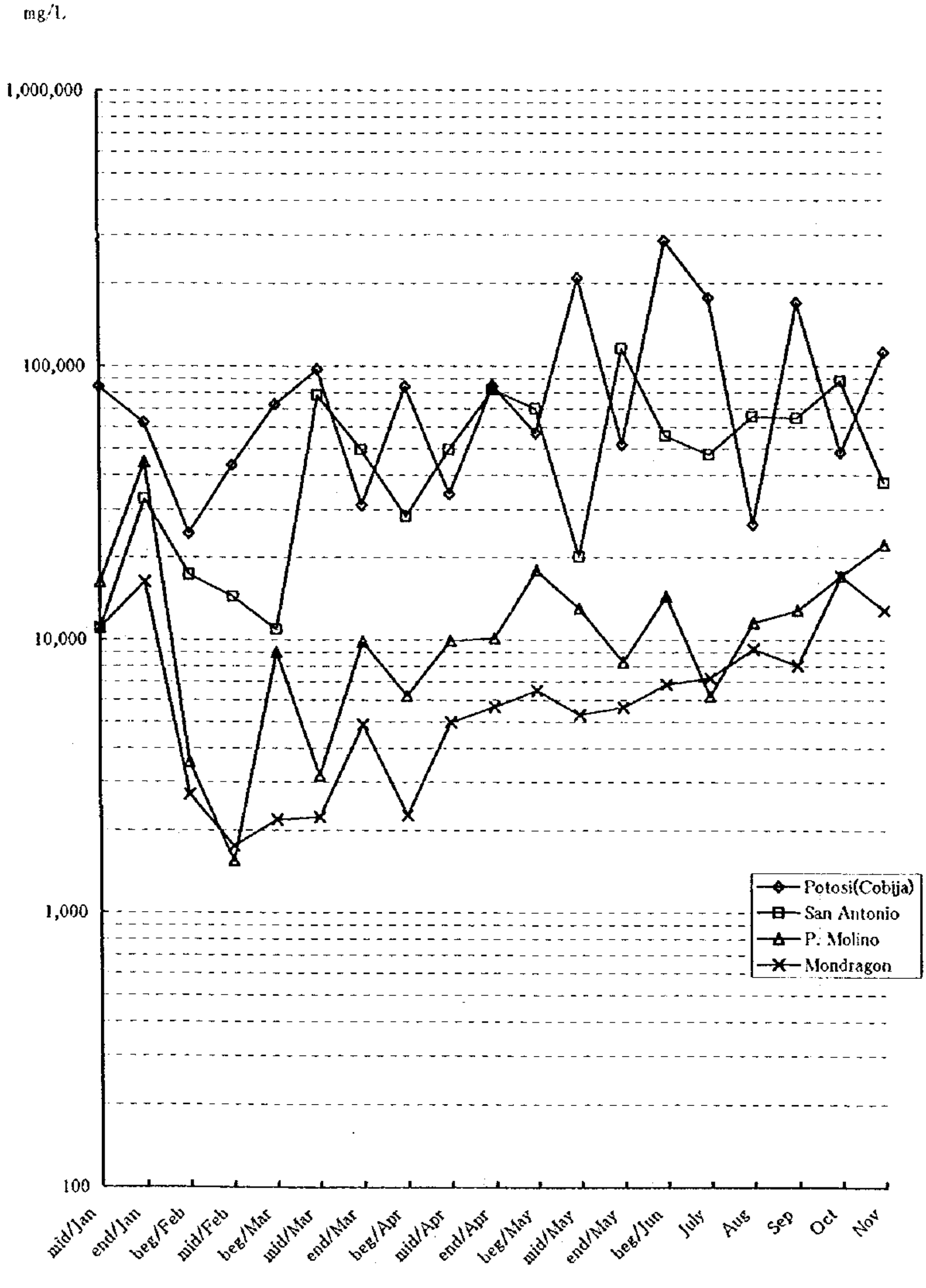


Figure 5-2-3 Seasonal change of SS contents in Rio de La Rivera-Alja mayu-Tarapaya

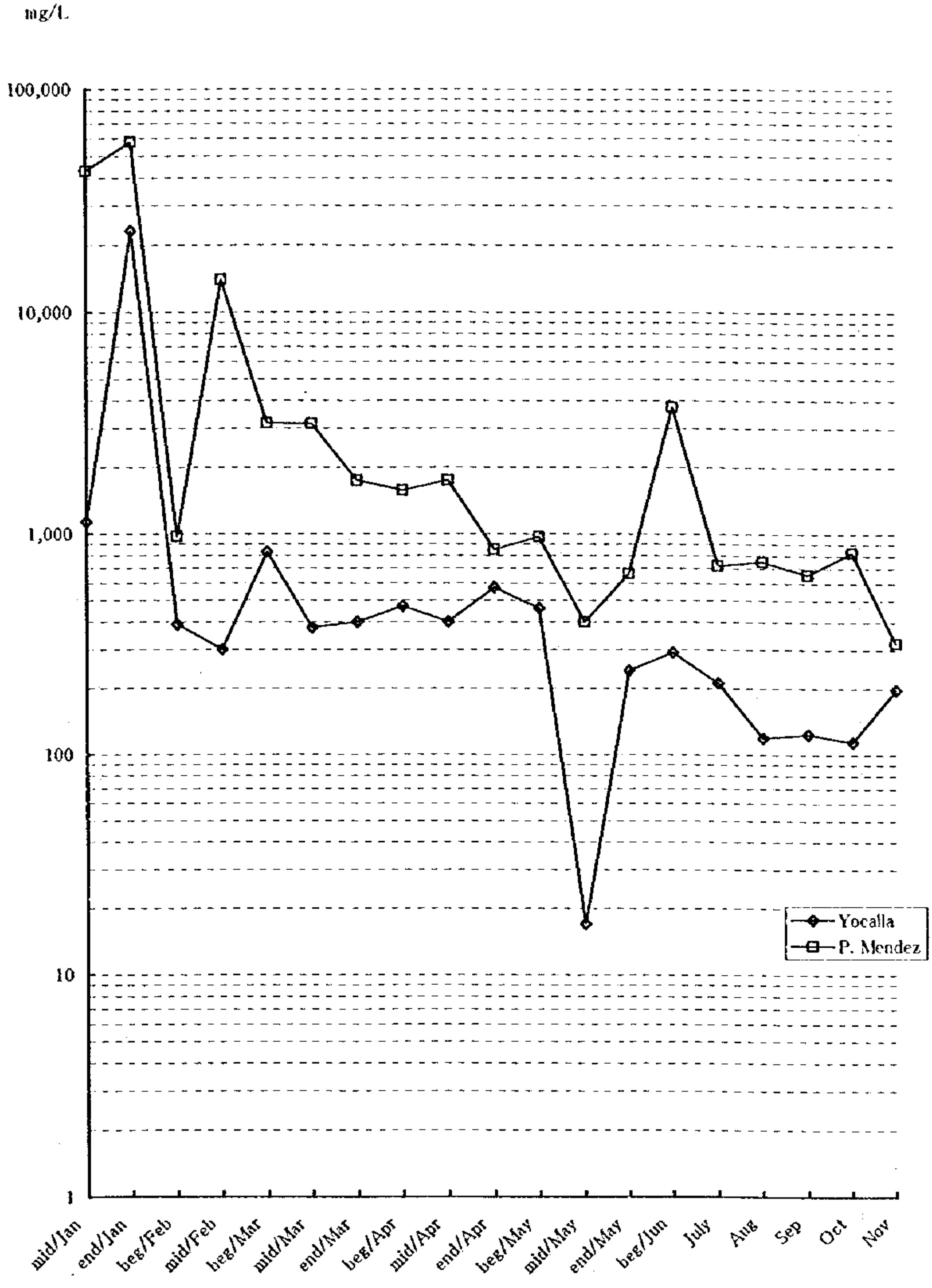


Figure 5-2-4 Seasonal change of SS contents in Rio Pilcomayo

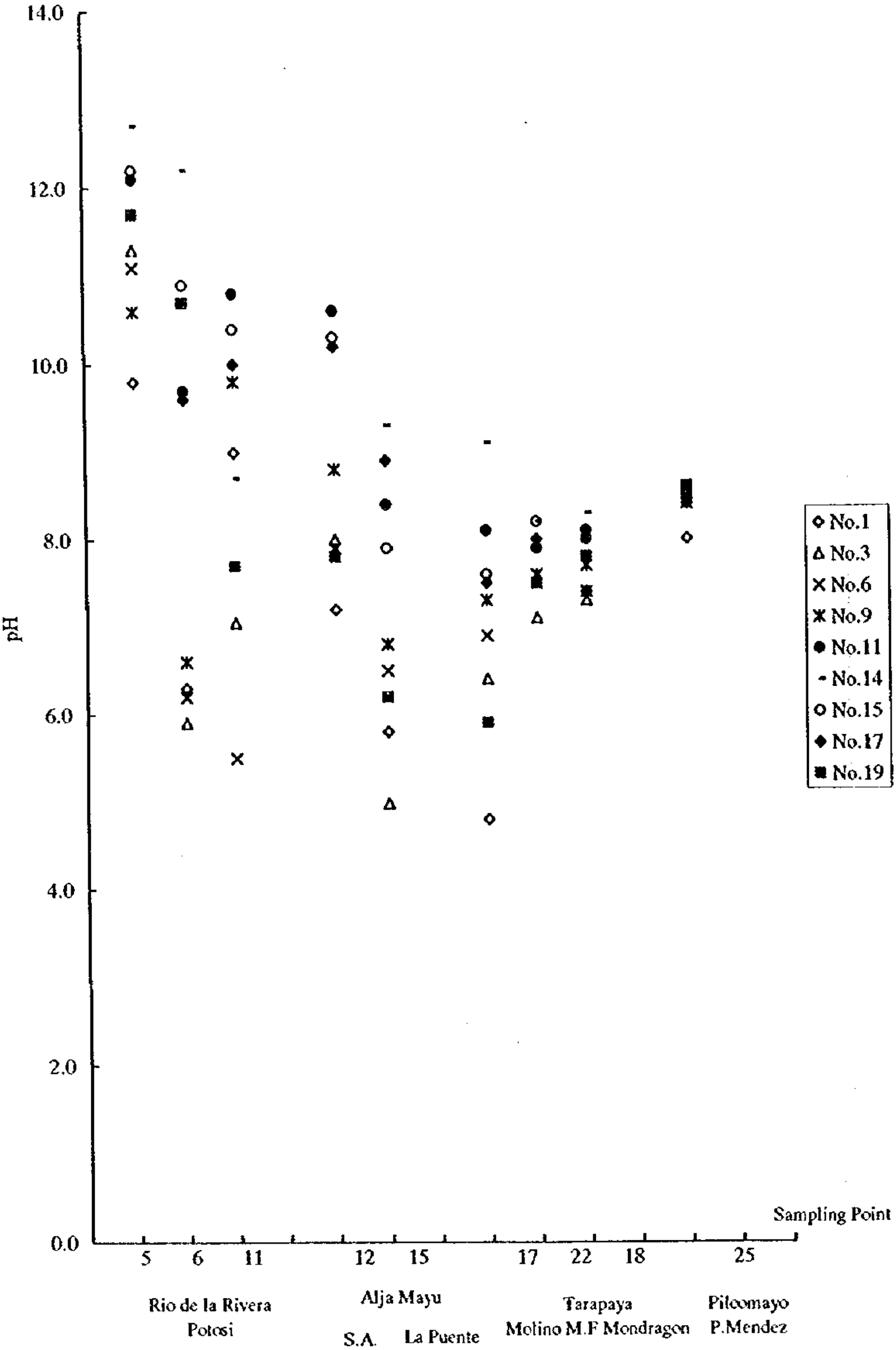


Figure 5-2-5 Trend of pH in Rio de La Rivera-Alja mayu-Tarapaya-Pilcomayo

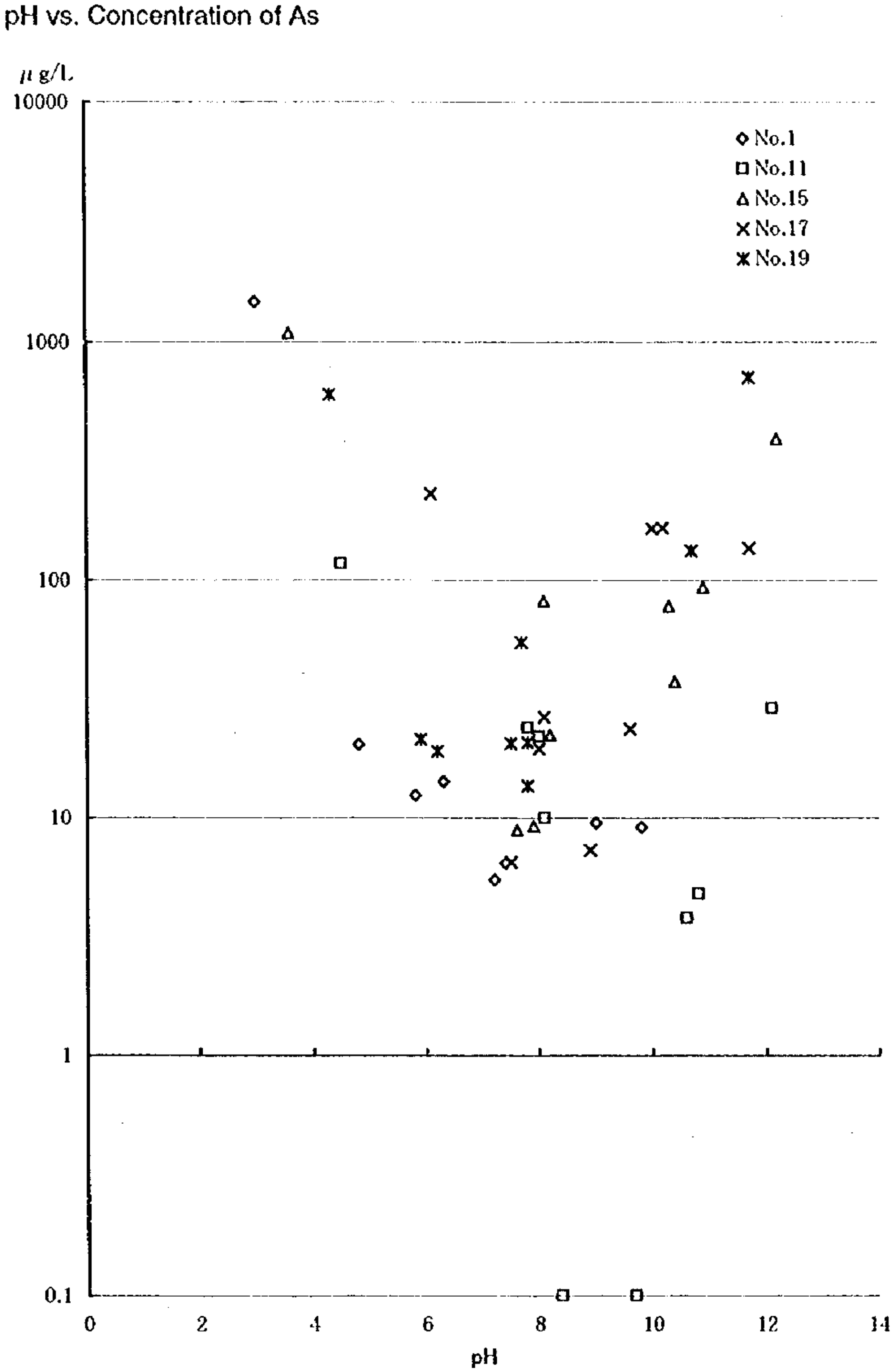


Figure 5-2-6 pH vs. concentration of As

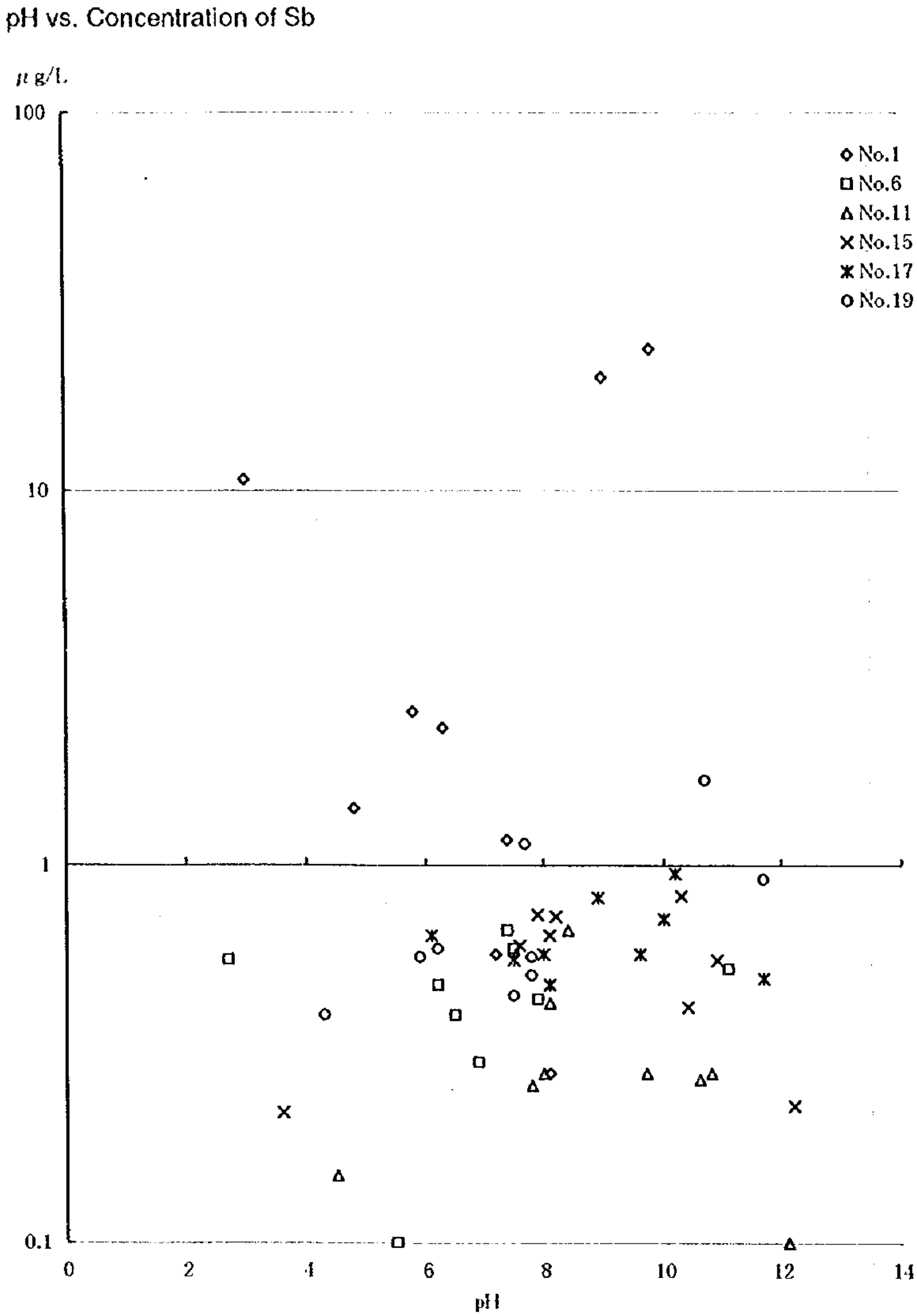


Figure 5-2-7 pH vs. concentration of Sb

pH vs. Concentration of Cd

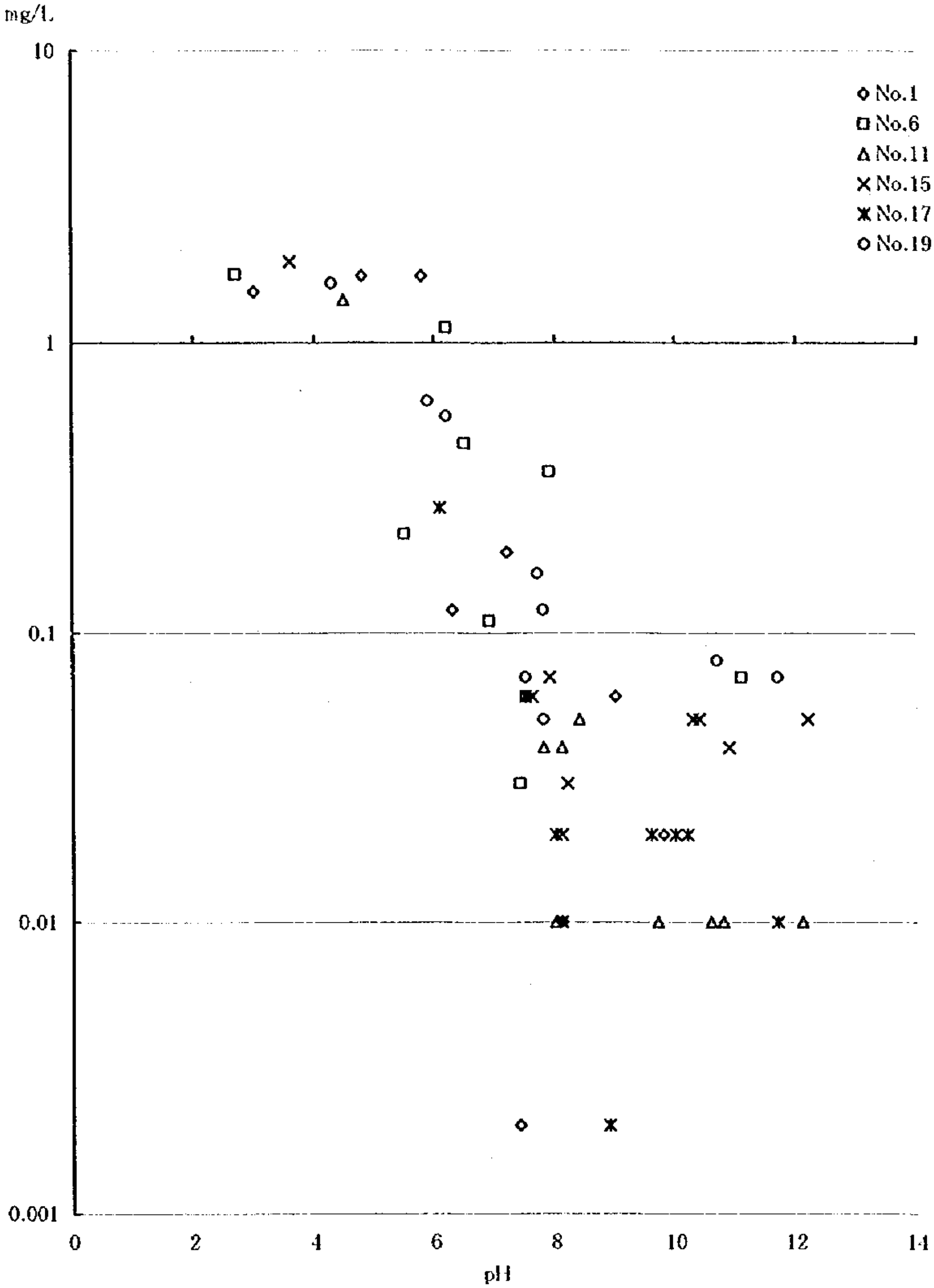


Figure 5-2-8 Relation between pH vs. Concentration of Cd

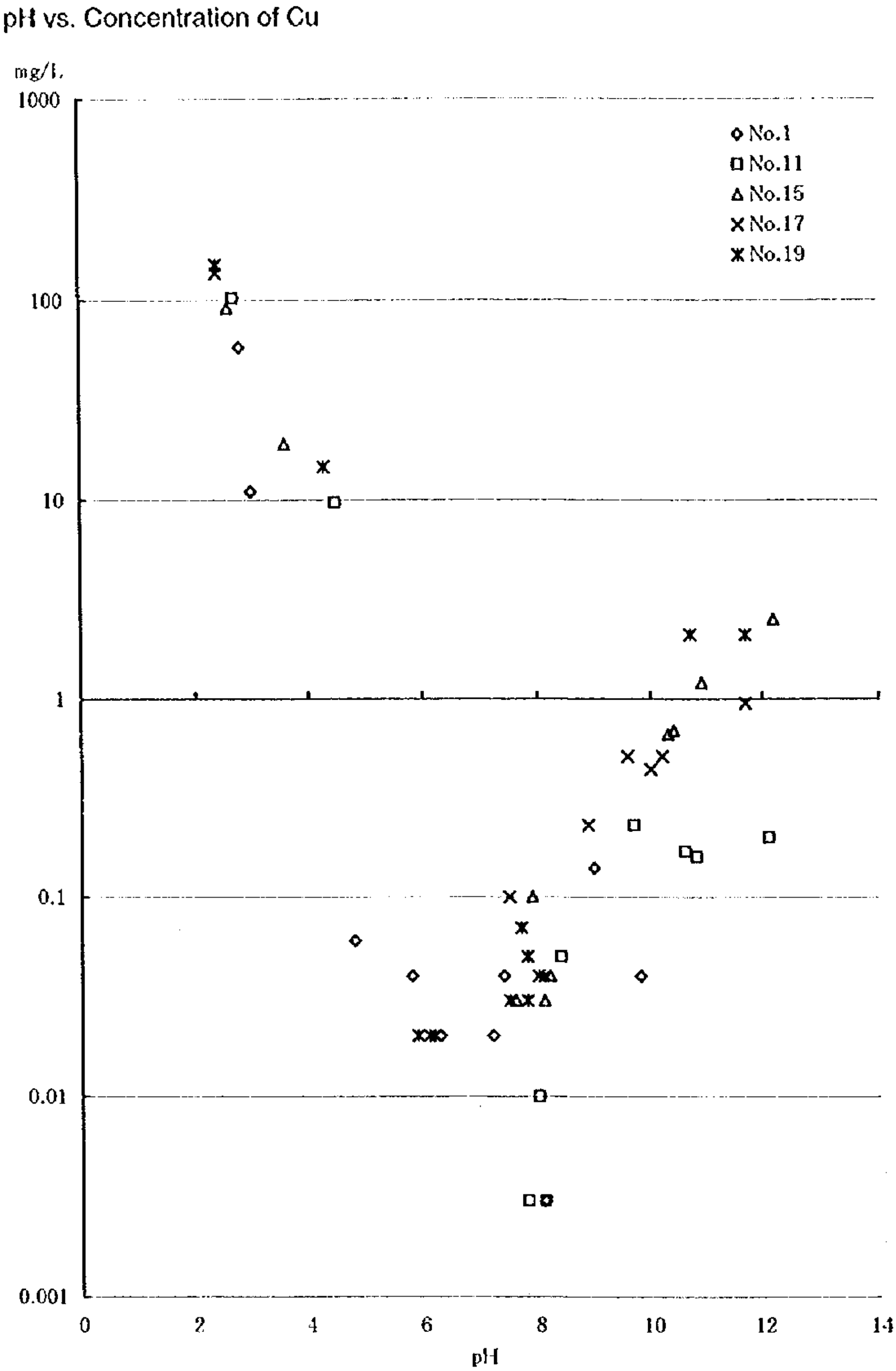


Figure 5-2-9 Relation between pH vs. Concentration of Cu

pH vs. Concentration of Fe

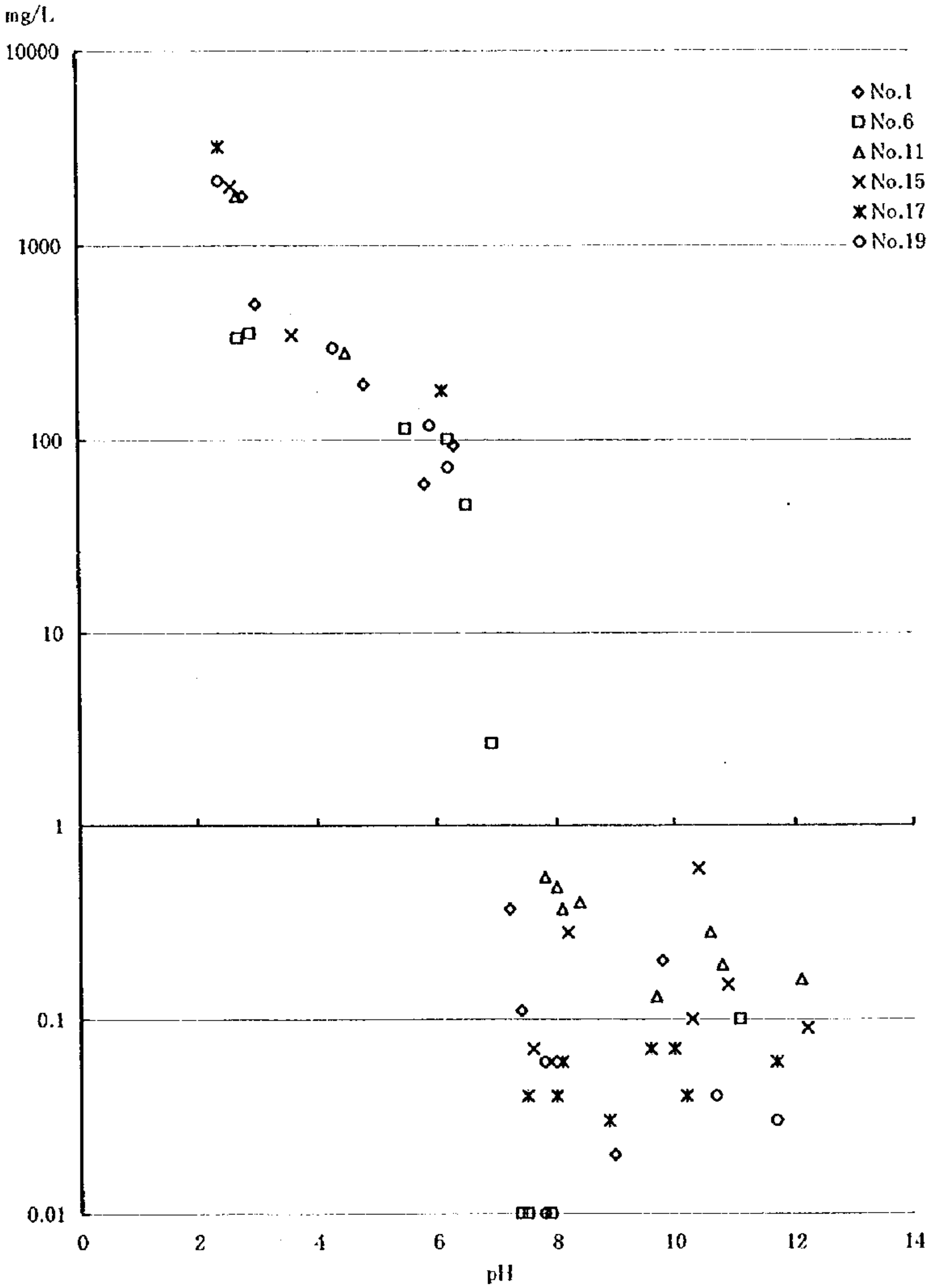


Figure 5-2-10 Relation between pH vs. Concentration of Fe

pH vs. Concentration of Hg

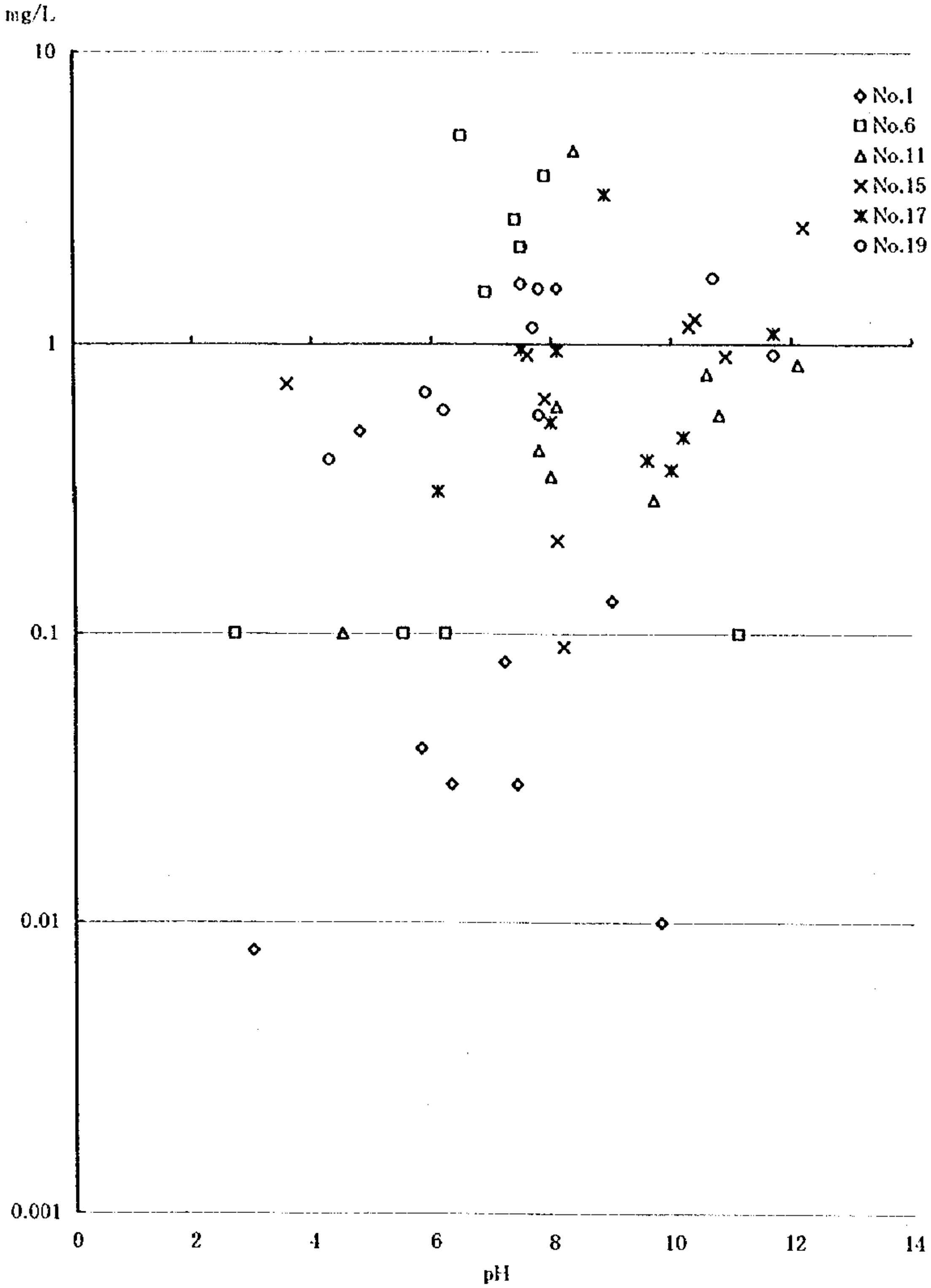


Figure 5-2-11 Relation between pH vs. Concentration of Hg

pH vs. Concentration of Mn

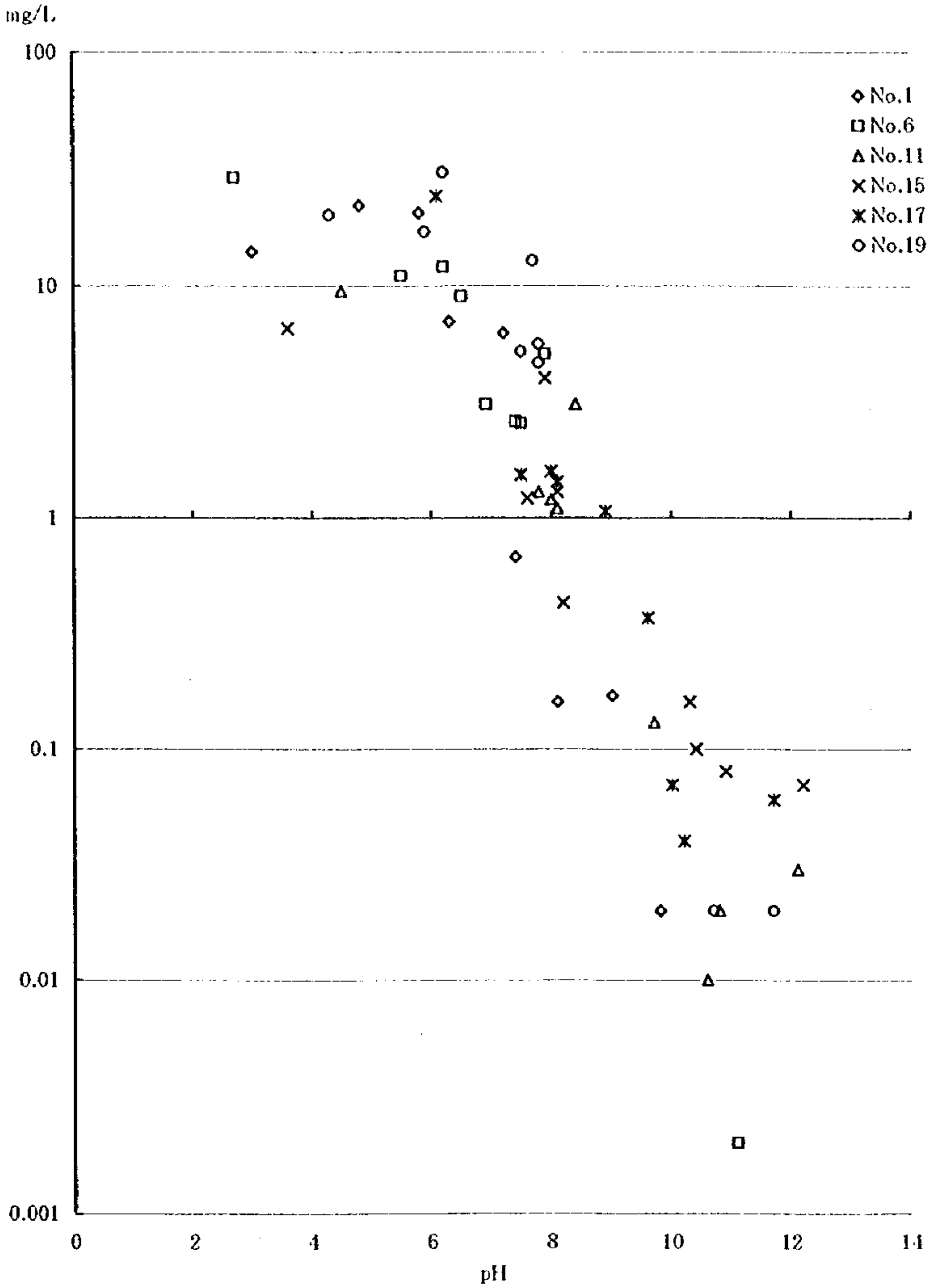


Figure 5-2-12 Relation between pH vs. Concentration of Mn

pH vs. Concentration of Pb

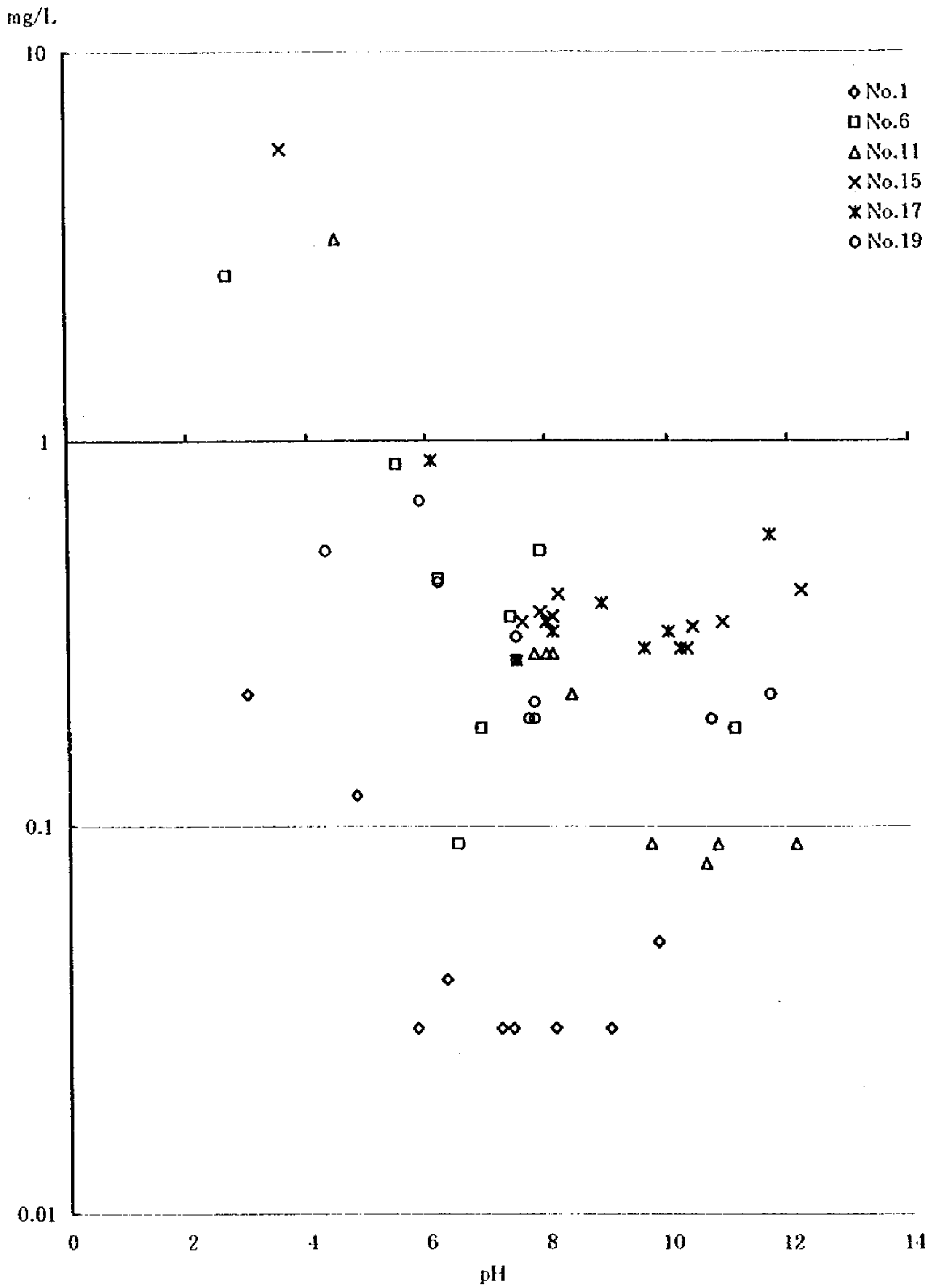


Figure 5-2-13 Relation between pH vs. Concentration of Pb

pH vs. Concentration of Zn

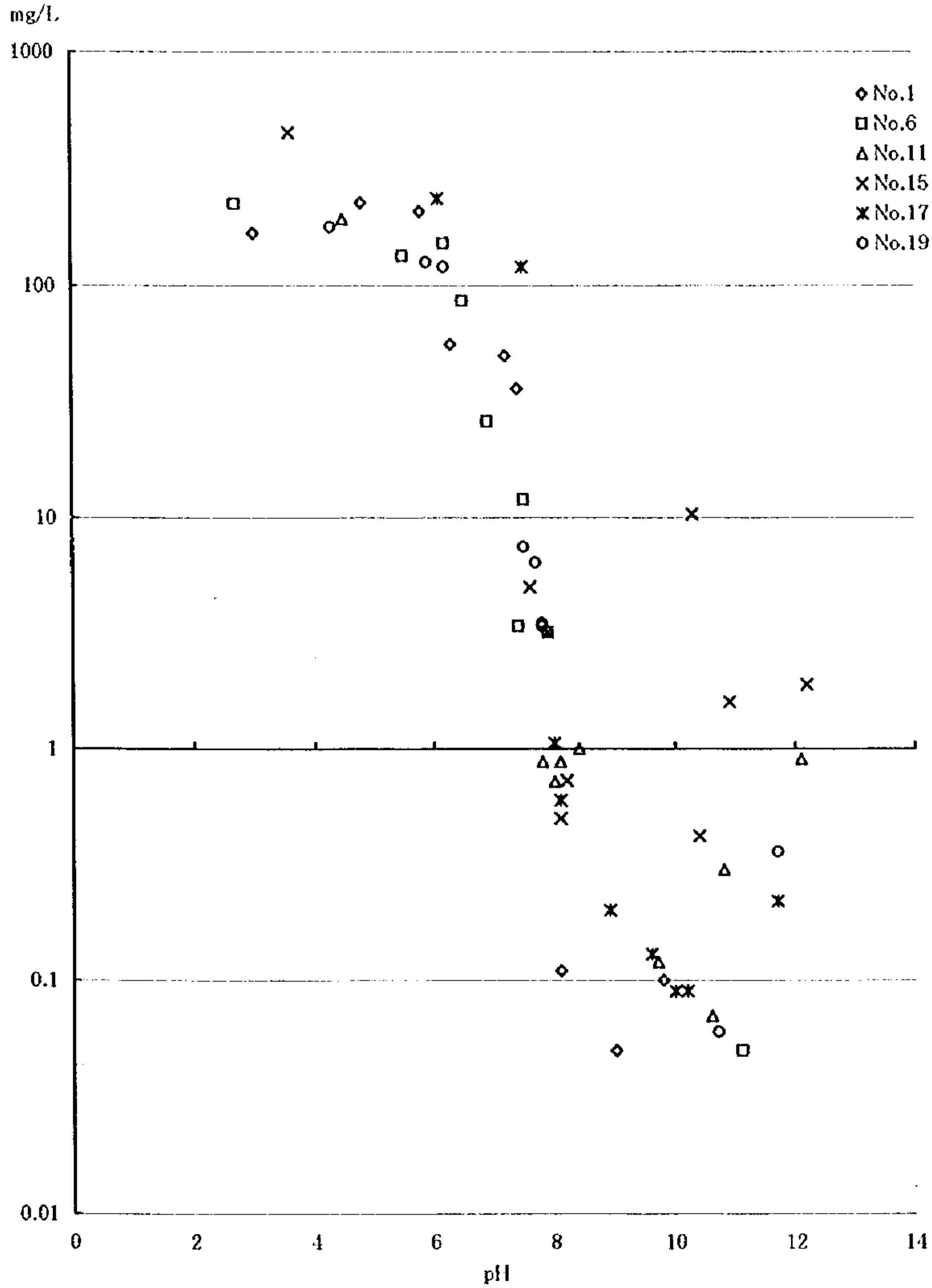


Figure 5-2-14 Relation between pH vs. Concentration of Zn

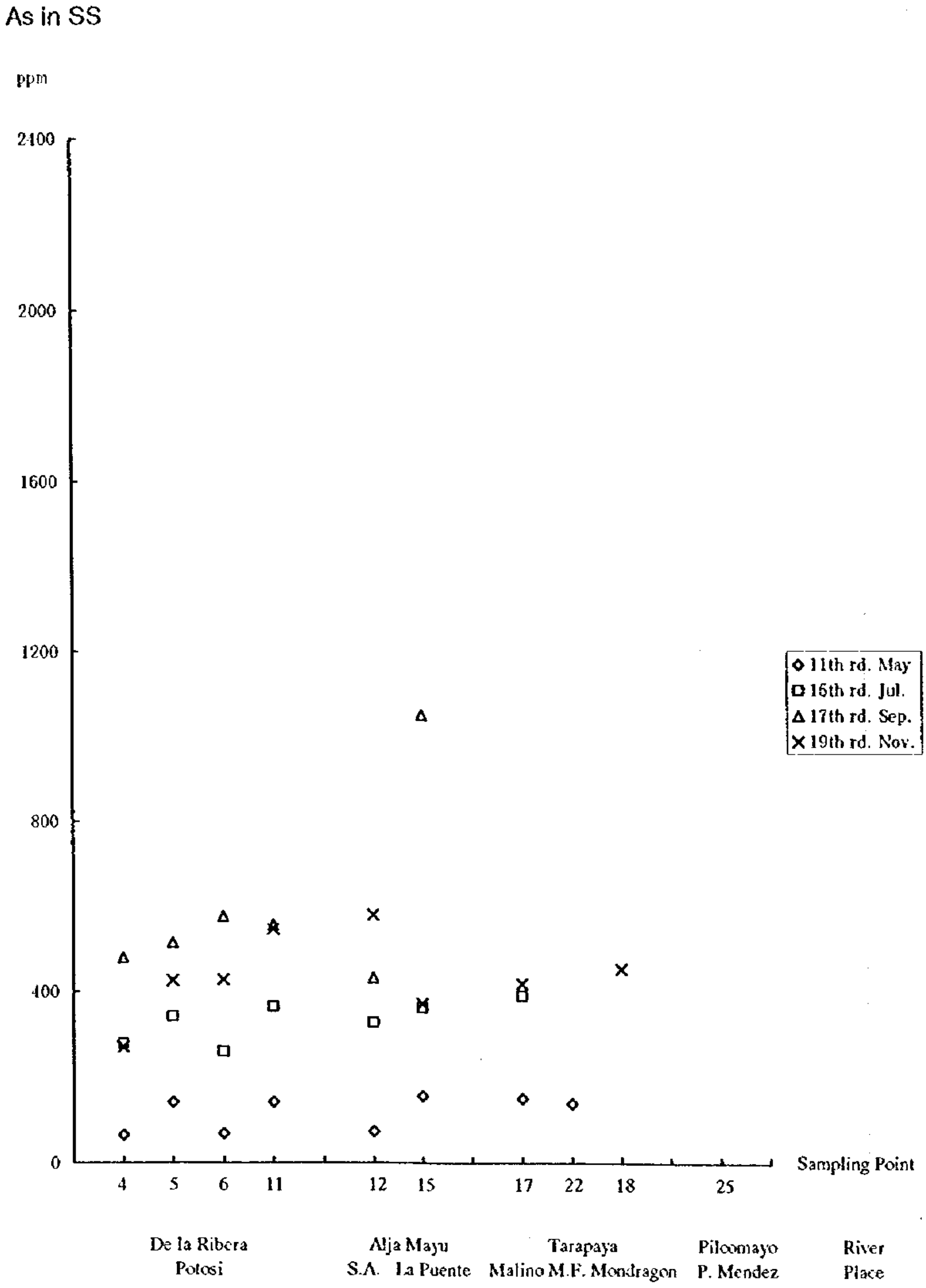


Figure 5-2-15a Contents of As in SS

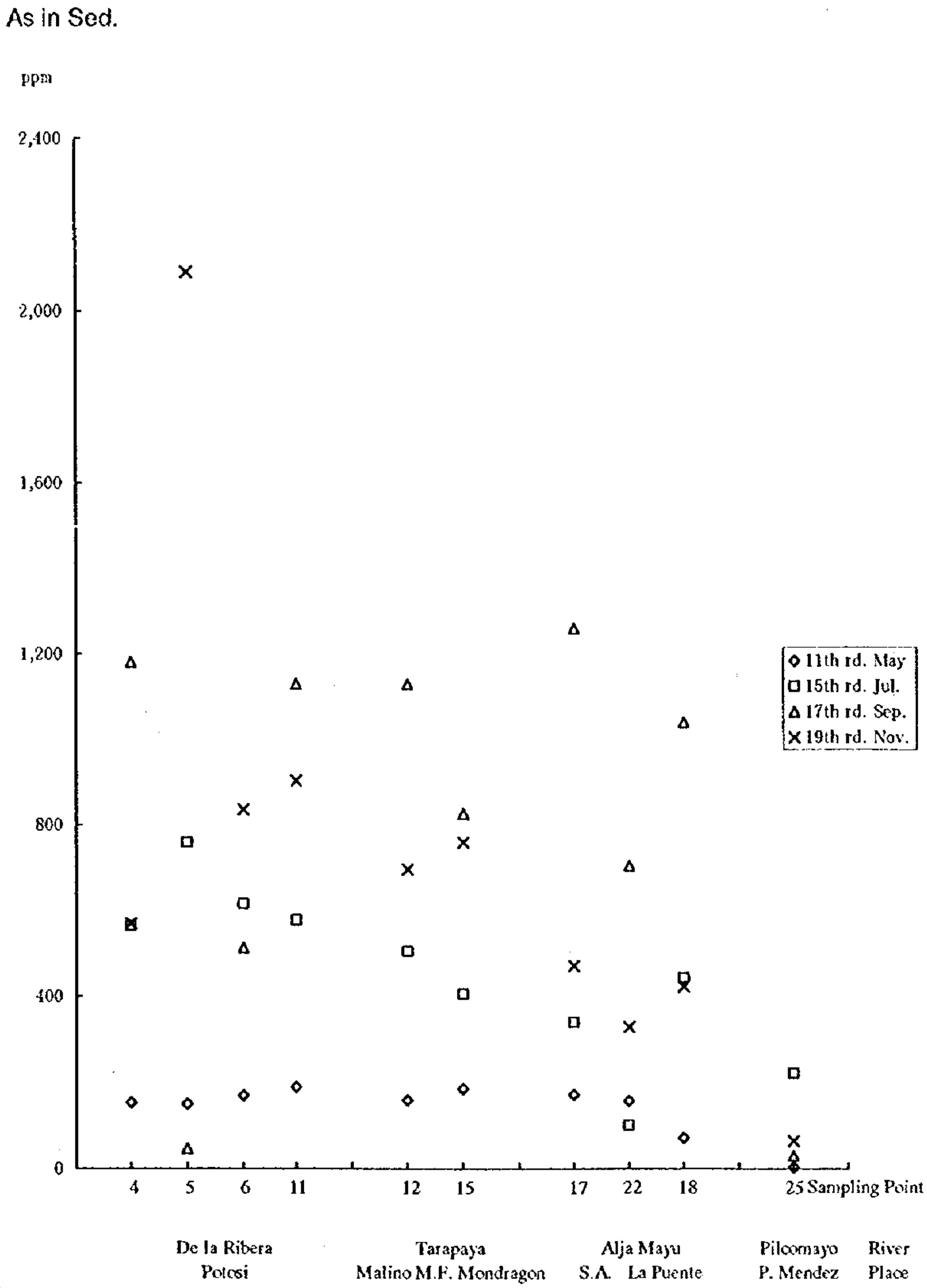


Figure 5-2-15b Contents of As in sediments

Cd in SS

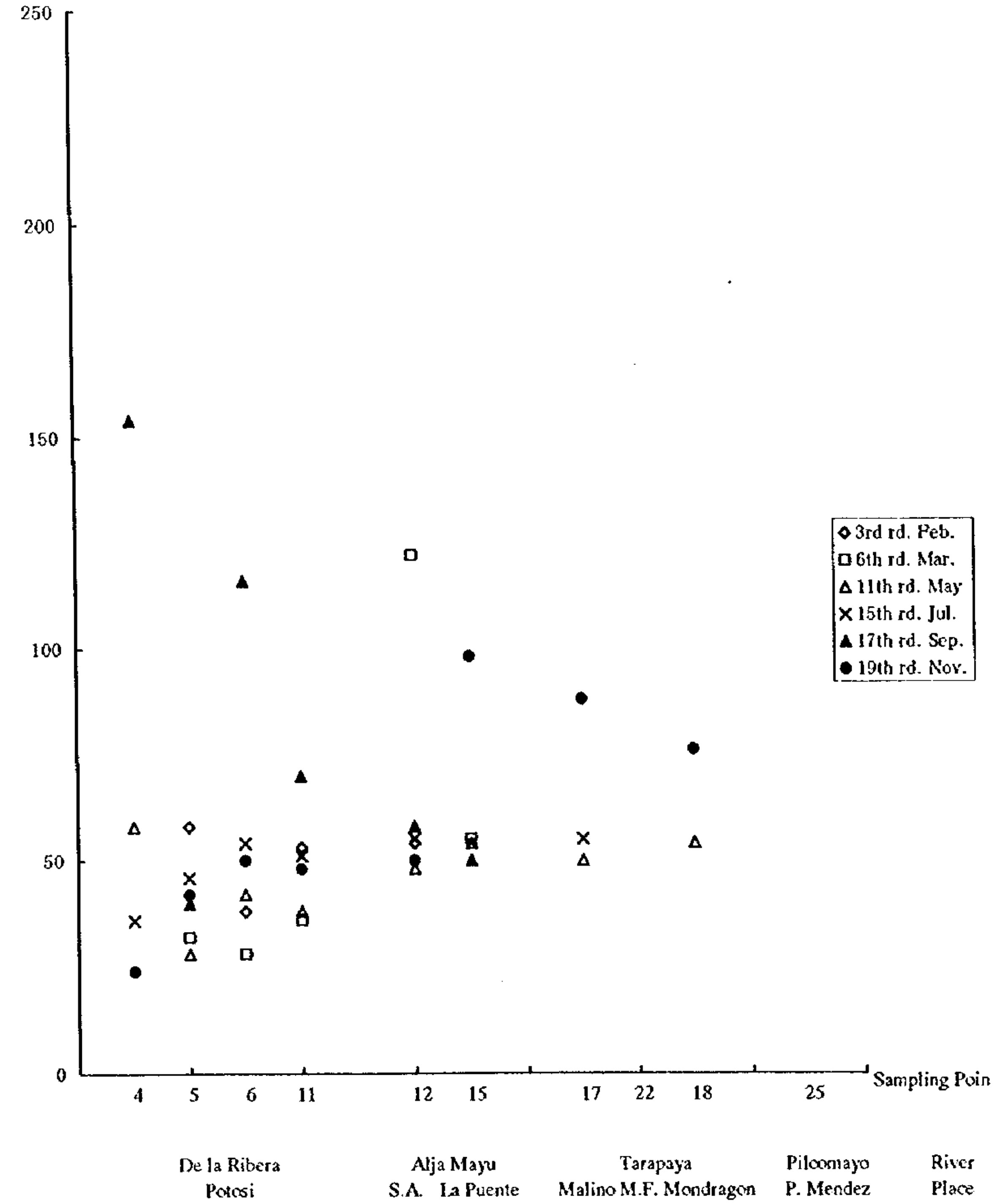


Figure 5-2-16a Contents of Cd in SS

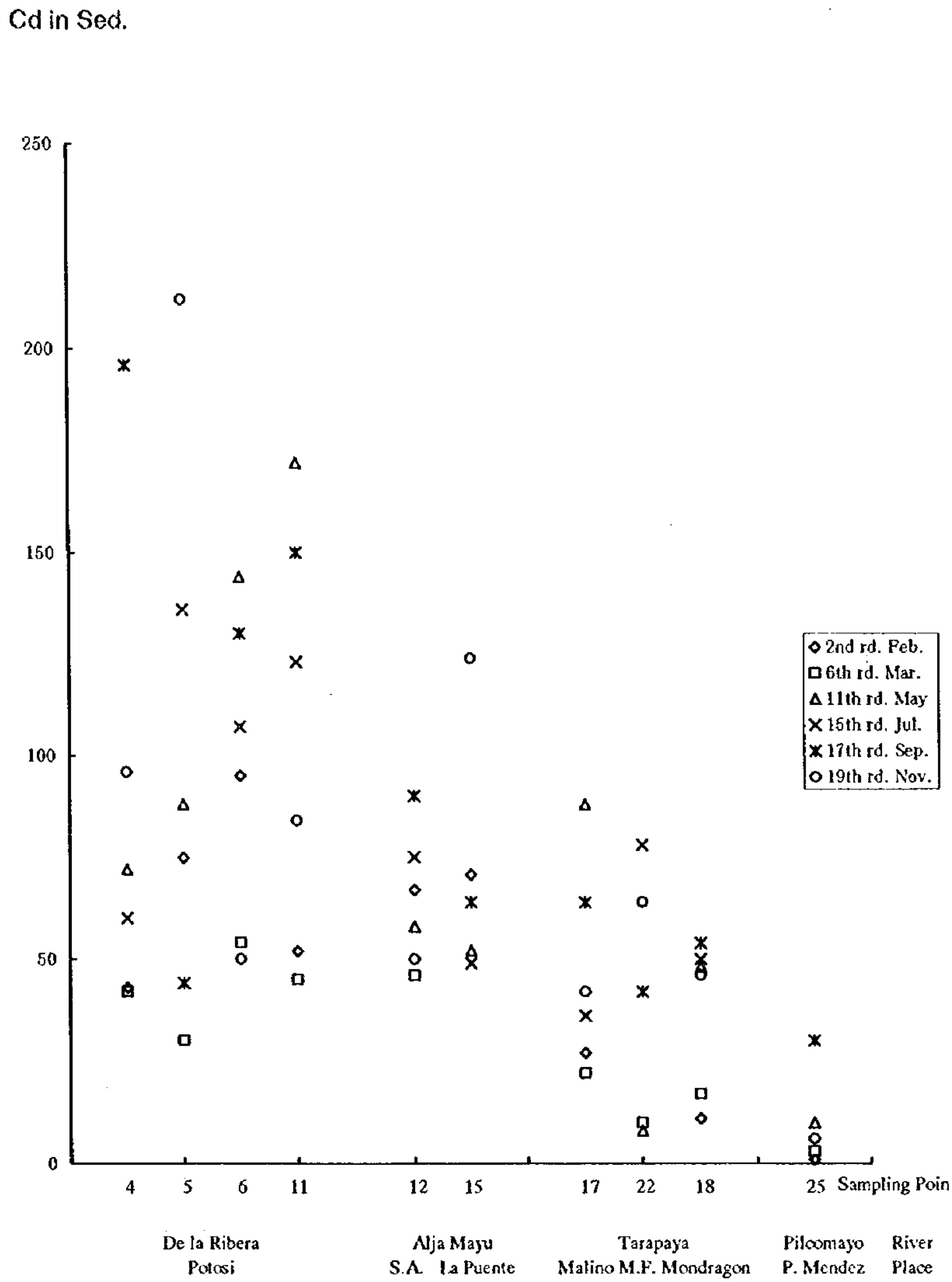


Figure 5-2-16b Contents of Cd in sediments

Pb in SS

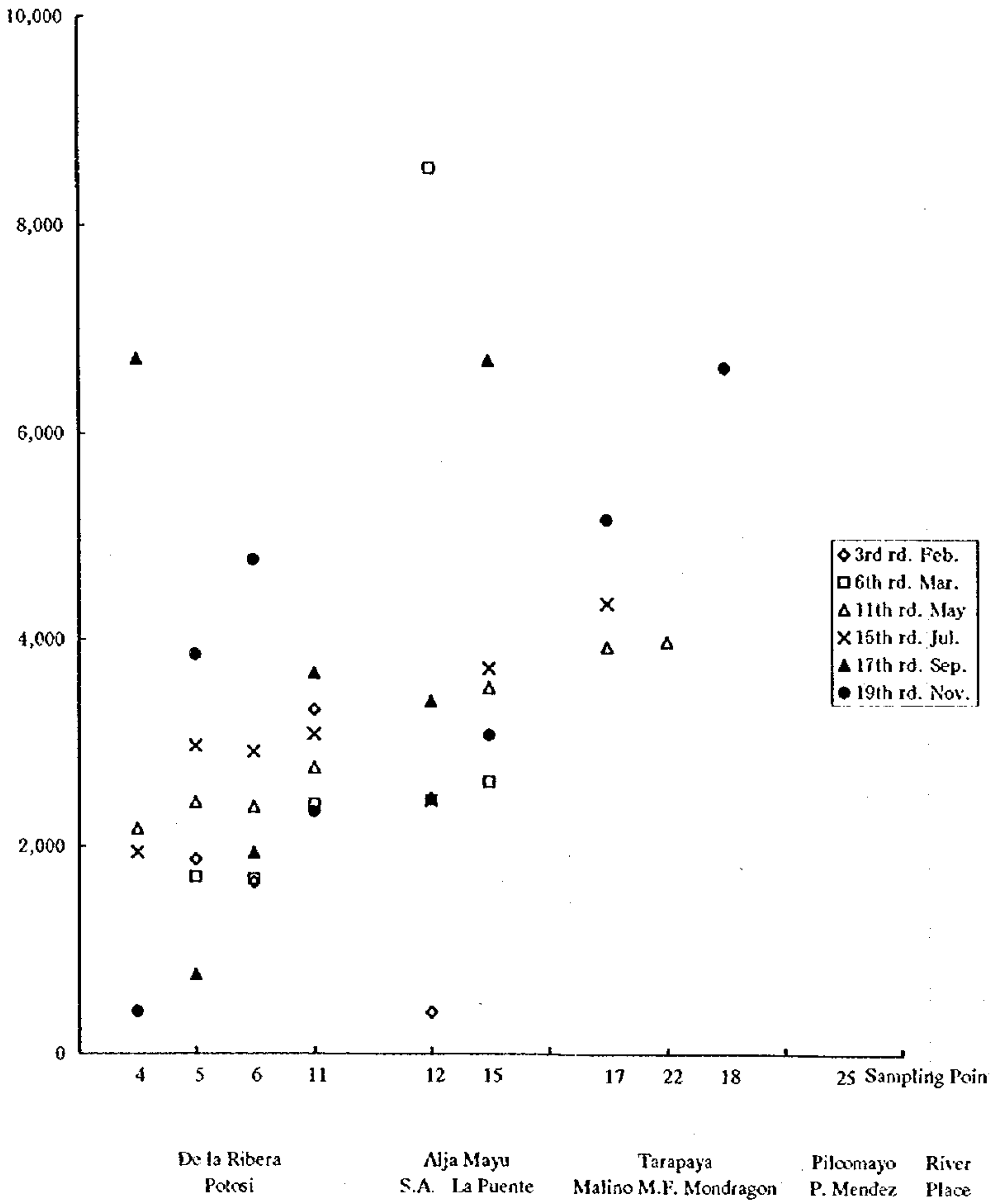


Figure 5-2-17a Contents of Pb in SS

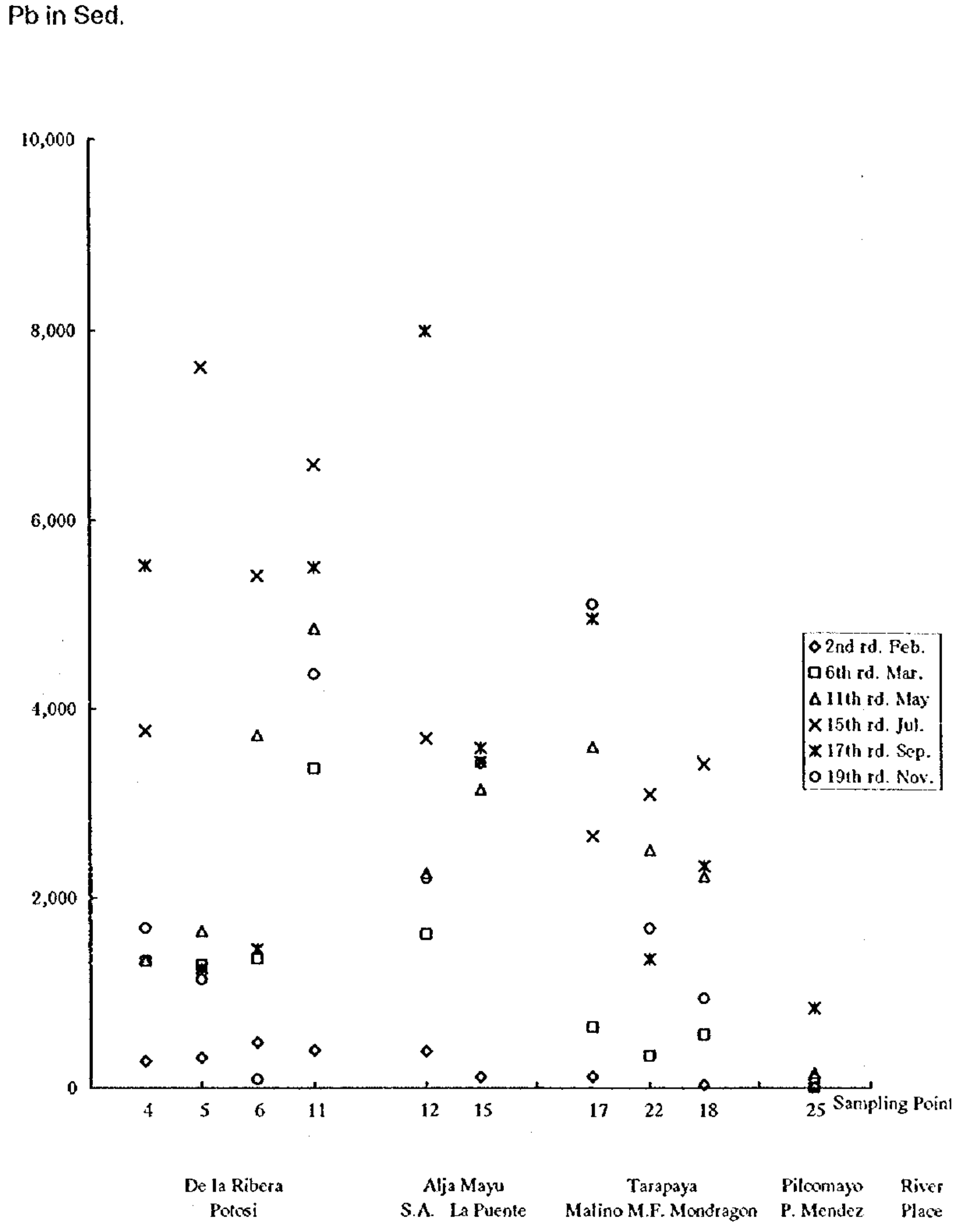


Figure 5-2-17b Contents of Pb in sediments

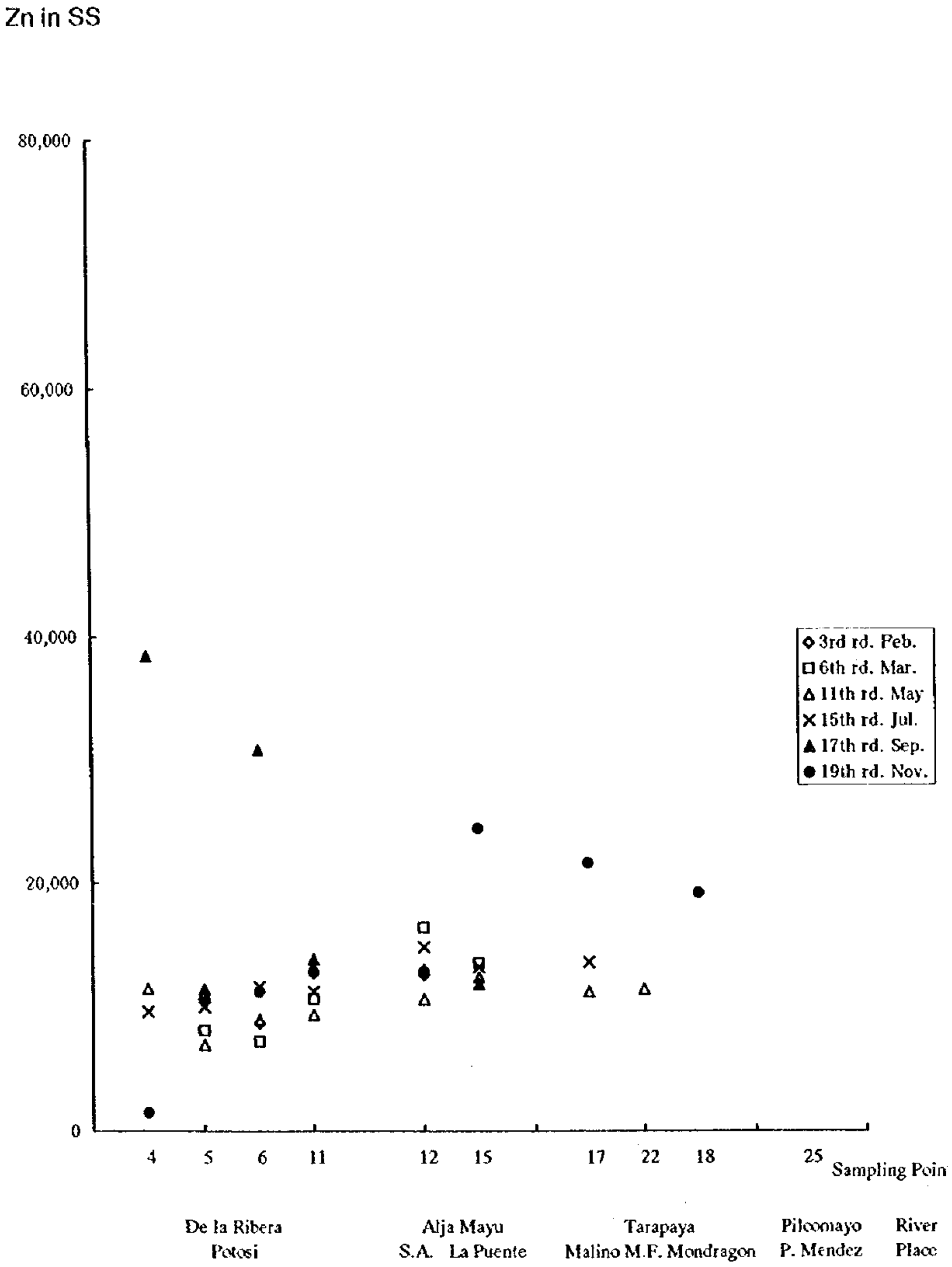


Figure 5-2-18a Contents of Zn in SS

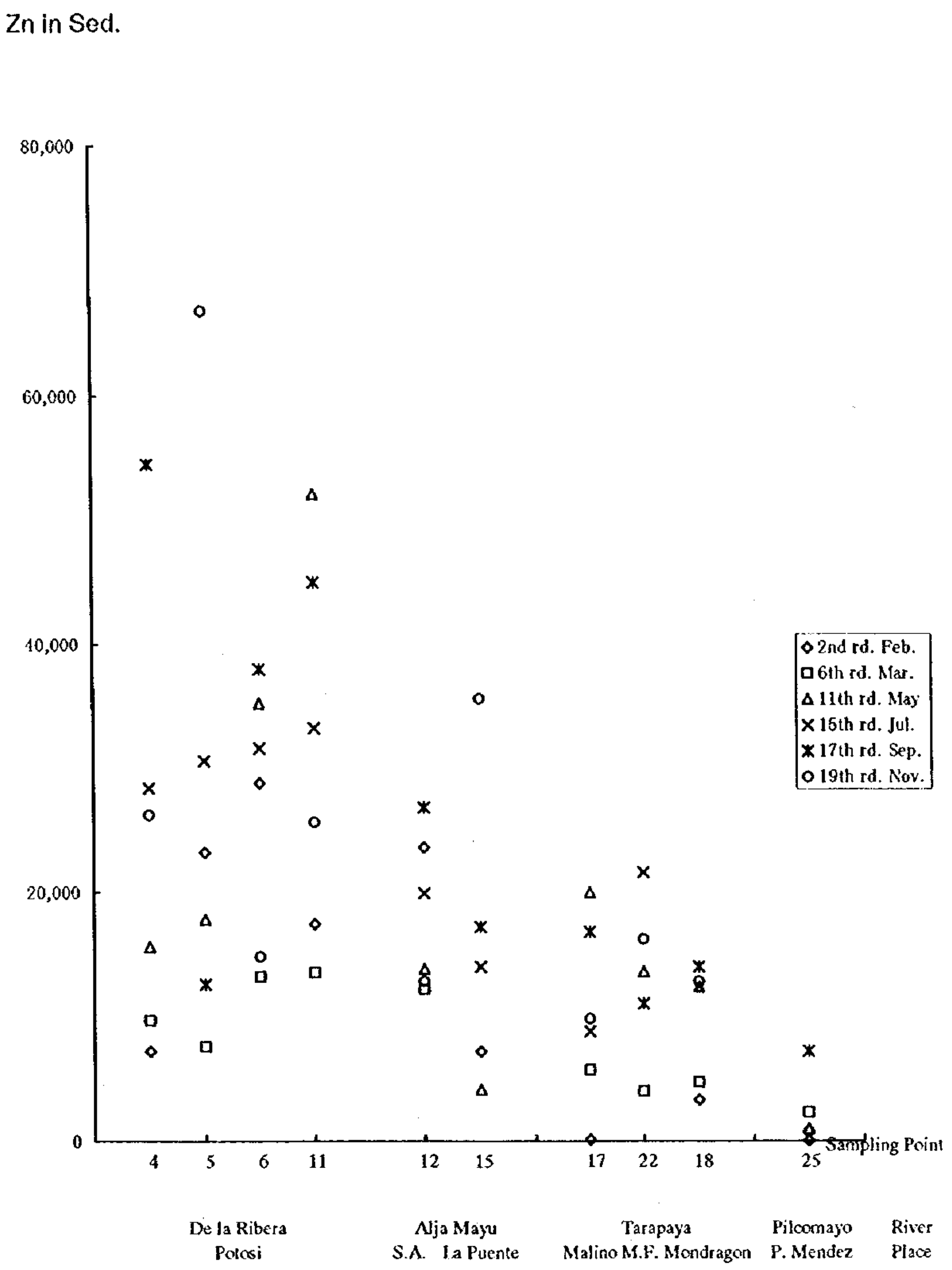


Figure 5-2-18b Contents of Zn in sediments

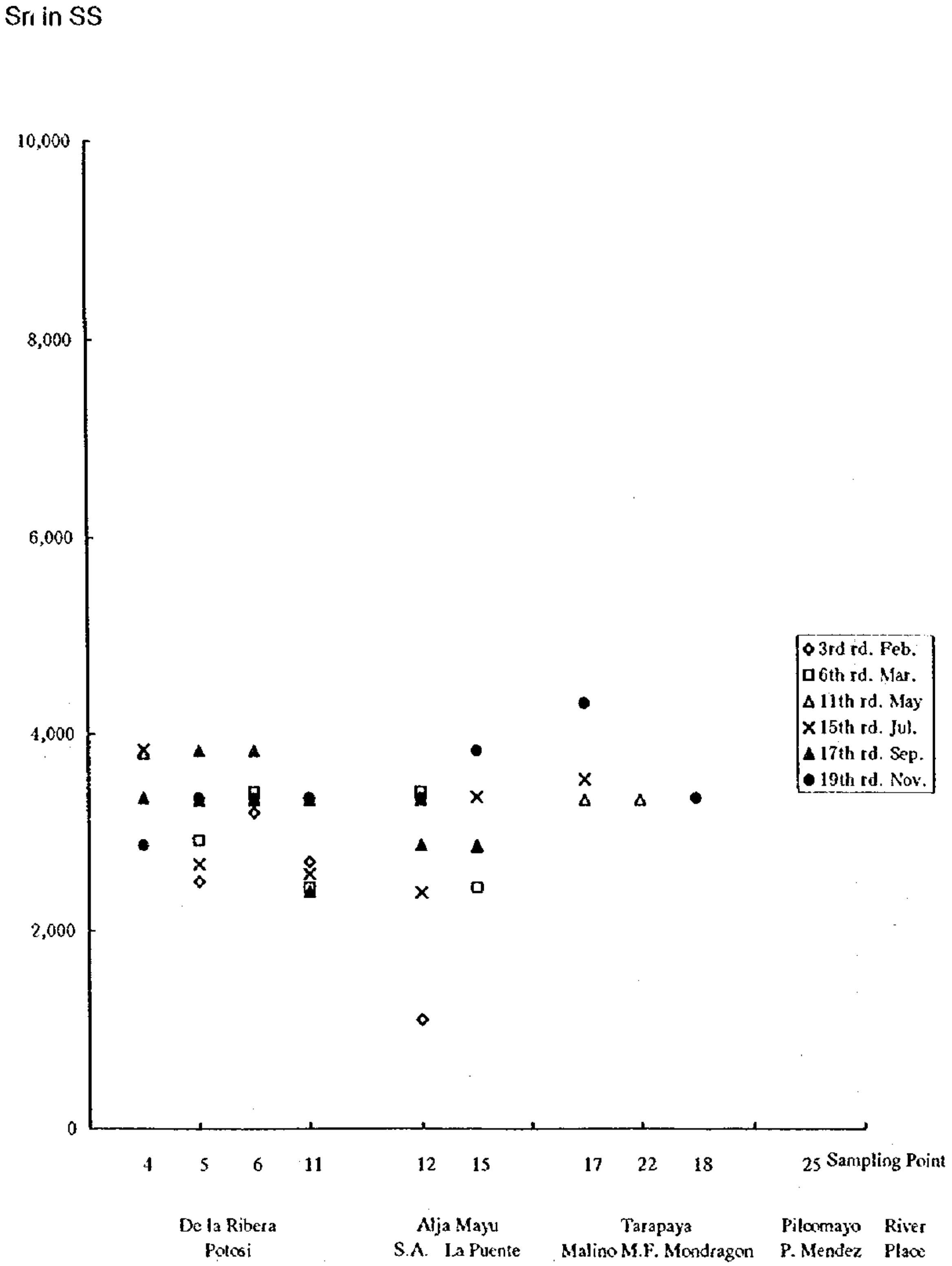


Figure 5-2-19a Contents of Sn in SS

Sn in Sed.

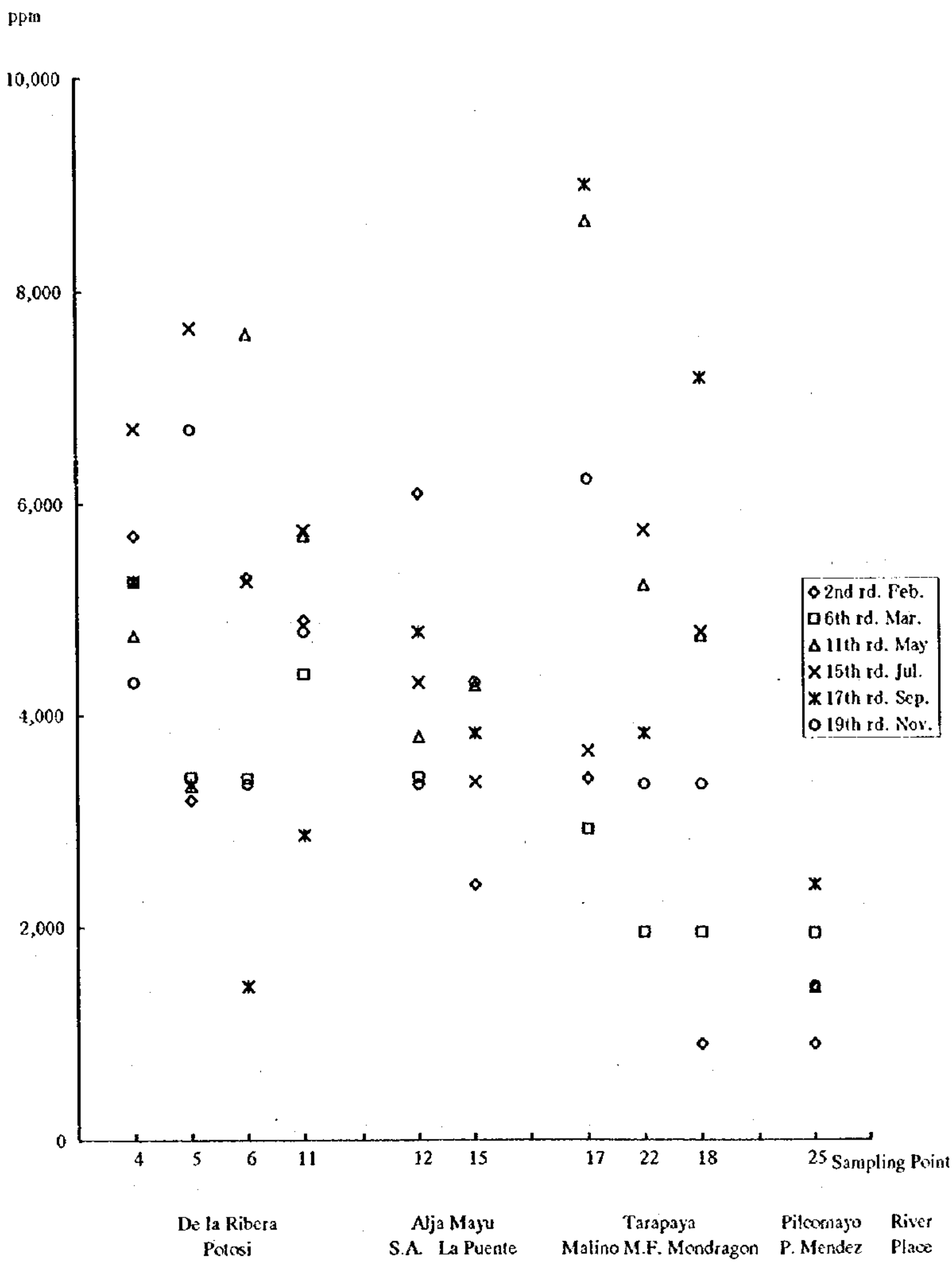


Figure 5-2-19b Contents of Sn in sediments

6 Study on Countermeasures

The countermeasures for improvement are studied from the viewpoint of such three aspects as of mine pollution control plan, environmental management plan, and enlightenment, education and human resources development. The mine pollution control plan is composed of two categories of countermeasures. The one is to directly perform mine pollution control and the other is to indirectly support the implementation of mine pollution control through a securement of the resources of environmental costs. The environmental management plan is to perform environmental improvement on the standpoint of environmental management.

6-1 Mine Pollution Control Plan

The proposal of countermeasures for environmental improvement is shown below, which is made from the standpoint of mine pollution control plan. Target of mine pollution control is to accomplish effluent standard of environmental law in Bolivia.

The technologies for mine pollution control with regard to the direct countermeasures are generally shown in Table 6-1-1. These technologies are classified into two categories in the table.

The first one is applicable and should be put into practice in the mine pollution area in Potosi City, and the second one is inapplicable and impossible to be carried out. The technologies in the first category are summarized below, by classifying mine pollution sources into two sectors such as mining sector and mineral processing sector. The pollution sources in mining sector are mine water and drainage, waste rock etc., (waste rock: Desmonte, waste out of primitive gravity concentration: Sucu, tailing out of gravity concentration, tailing out of flotation, heap in heap leaching), seepage water from waste dump and tailing dam, and piled dump. The pollution sources in mineral processing sector are tailings out of the ingenios and so on. The general concept is illustrated in Figure 6-1-1.

Direct Countermeasures for Mining Pollution Control

① Mining sector

①-1 Mine : Contaminated mine water and drainage (acid)→ A. Water treatment (neutralization, neutralized sludge*1 treatment)

①-2 Waste rock and waste dump :

Contaminated seepage water (acid) → A. Water treatment (neutralization, neutralization sludge*1 treatment)

B. Vegetative stabilization: plantation

Piled dump contaminated by hazardous substance

→ B. Construction of bank, retaining wall

B. Vegetative stabilization

② Mineral processing sector

②-1 Ingenio (Concentrator) :

Tailing 1 (Fine particle mineral contaminated by hazardous substance (SS)) [Solid portion]

→ A. Treatment in final disposal dam (sedimentation in tailing dam)

Tailing 2 (Polluted waste water (alkaline)) [Aqueous portion]

→ A. Water treatment (neutralization, neutralization sludge*1 treatment)

* 1: Reaction product by neutralization

The technologies for pollution control indicated above by A or B are categorized as follows;

- A : Useful countermeasures against the current mine pollution and the effects will be remarkable and perceptible. Urgent performance is required.
- B : Countermeasures expected to prevent from further outbreak of mine pollution. Steady performance is indispensable even if spending many times before accomplishment.

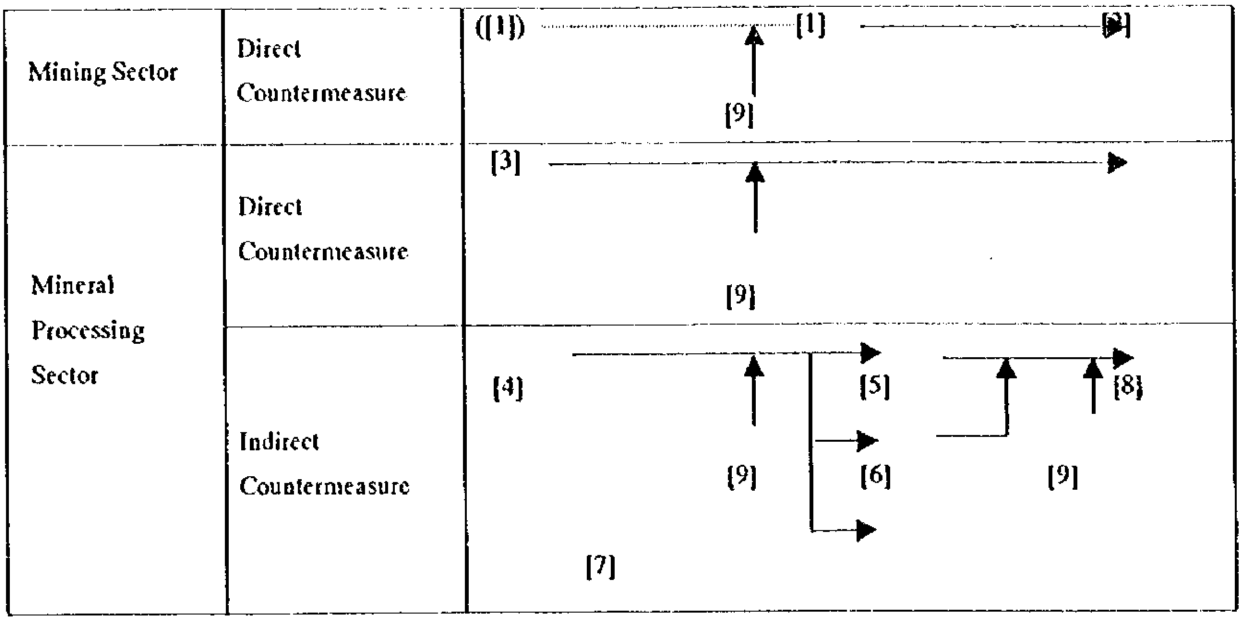
The direct countermeasures against mine pollution are, as so far mentioned, practical execution of the pollution control technologies. Meanwhile, the indirect countermeasures are to secure resources of environmental costs which the ingenios are currently unable to burden due to poor management and financial situation. The indirect countermeasures eventually contribute to control mine pollution by facilitating the ingenios to burden environmental costs and to put into practice the direct countermeasures.

First of all, as one of the indirect countermeasures, "An improvement of a current production process at ingenio" will be carried out to better its financial situation. This is, however, still insufficient to fully secure resources of environmental costs. "Establishment of the Environment & Safety Research Center" will be planned chiefly aiming at human resources development required to maintain mine pollution control technology and technical capability in the field of mineral processing for securement of enough resources of environmental costs for mine pollution control.

Subsequently, based on analysis and studies on the research results obtained from the research center mentioned above, more countermeasures will be introduced for the purpose of further improvement of financial situation of the ingenios. These will be "Introduction of a tin recovery concentrator out of ingenios' tailings", "Introduction of a model concentrator" and "Recovery of valuable metals from waste rock and Sucu". As a final stage of a series of countermeasures, the team proposes "Construction of an integrated concentrator" in view of an intensive operation through unification of the current operations in the ingenios which lie scattered and remain in the medium, small and petty scales. As a result, the ingenios will be able to sufficiently secure the resources of environmental costs and come to be consistent with "Environment" and "Production".

The basic policy for the implementation of the mine pollution control plan (Short, medium and long terms) is illustrated in the following "Basic Flow of Mine Pollution Control Plan" with applicable technologies and their priorities in an individual sector of pollution sources (Mining and mineral processing).

Basic Flow of Mine Pollution Control Plan



Note: The items above in time series are shown as follows;

6-1-1	Treatment of tailing and waste water control at tailing dam:	[3]
6-1-2	Study on production process improvement at ingenios	[4]
6-1-3	Treatment of mine water and seepage water from waste rock dump :	[1]
6-1-4	Introduction of tin recovery concentrator out of Ingenios' tailings :	[5]
6-1-5	Introduction of model concentrator :	[6]
6-1-6	Recovery of valuable metals from waste rock and Sucu :	[7]
6-1-7	Construction of integrated concentrator (Industrial estate) :	[8]
6-1-8	Vegetative stabilization on waste rock dump and old tailing dam	[2]
6-1-9	Establishment of Environment & Safety Research Center :	[9]

The study on economic feasibility for these countermeasures is carried out and the result is shown in Chapter 7, FINANCIAL AND ECONOMIC ANALYSIS.

The basic idea and the fundamental plan for mine pollution control in the mineral processing sector are shown in Figure 6-1-2 and Table 6-1-2, respectively.

6-1-1 Treatment of Tailing and Waste Water Control at Tailing Dam : Aforesaid item [3]

Under the economic assistance by Germany (KfW), the municipality of Potosi City plans to construct a tailing dam (DCSA) to treat the tailings discharged from the Ingenios (Concentrator) in the city. Potosi City instructs to manage the operation of DCSA under the leadership by the Water Service Bureau (AAPOS), as a core body, in participation with all the Ingenios in the city.

Utilization of a tailing dam is recognized as the most suitable way for tailing disposal. The study team exchanged views with responsible persons of the DCSA construction project and proposes to start its early operation in line with the utilization of the planned tailing dam.

Countermeasures :

① Tailings from all the Ingenios → Slurry transportation*2 to tailing dam

② Tailing 1 (SS: Solid portion) → Sedimentation in tailing dam

③ Tailing 2 (Alkaline water: Aqueous portion) → Neutralization*3, sedimentation of neutralization sludge in tailing dam
pH control of decanted water and its recycle, discharge

*2: When the pH is adjusted between neutral and weak alkalinity, concentration of dissolved hazardous metals will be kept below the effluent standard level

*3: Co-precipitation of hazardous heavy metals like As etc., is utilized during the formation of hydroxide of Fe^{3+} etc., in acidity approximately between pH 4 and 6, Among flotation reagents, cyanide is recognized as a form of CN^- because of its low concentration, and is oxidized or optically decomposed in the same manner as xanthates during the transportation to a tailing dam and the retention in a tailing pond.

Performance of all these countermeasures will bring about perfect control of mine pollution caused by tailings out of the Ingenios, which are the pollution sources in the mineral processing sector.

Required items :

① Slurry transportation technology of tailings into a tailing dam.

② Operation and management technology for slurry transportation.

③ Operation and management technology with regard to a tailing dam.

④ Solid/liquid separation technology

⑤ Treatment technology of alkaline water

6-1-2 Study on Production Process Improvement at Ingenios : Aforesaid item [4]

The team grasps an optimum process condition of mineral processing through investigation, mineral processing test and analysis, and is carrying forward technical guidance through the meeting with the owners of Ingenios to achieve harmonization of productivity improvement with environmental conservation. The team proposes to every owner of the Ingenios a positive employment of the optimum technology that will be consistent with environmental conservation.

An estimated character of the current tailing is shown as follows, jointly with metal quotations for reference.

- Grain size of grinding output (Flotation feed) : +65 mesh(+0.208 mm) 20～30%
- Flotation pH : 11.4～12.4
- Flotation density : PD (Pulp Density) : 7.2～9.1%
- Lead : Grade 0.22%, metal amount 2.3～2.8 t/d, quotation('97LME Settlement) 624 $/Mt

  Zinc : Grade 2.2%, metal amount 22.8～28.1 t/d, quotation('97LME SHG) 1,317 $/Mt

  Silver : Grade 111 g/t, metal amount 115～142 kg/d, quotation('97H&H N.Y.) 489¢/TR. OZ.

  Tin : Grade 0.46%, metal amount 4.8～5.9 t/d, quotation('97LME HG) 5,647 $/Mt

  Note : Tin sulfide mineral (Stannite: Cu_2FeSnS_4) is included in lead or zinc concentrate and tin is sometimes an element for penalty in the custom ore market. Tin oxide mineral (Cassiterite: SnO_2) is included in the tailing out of lead/zinc flotation.

The amount of metals left in the tailing shown above indicates that the tailing is discharged accompanied by great quantities of valuable metals, such as lead, zinc, silver and tin. In view of this situation, the team has carried out technical guidance so as to recover valuable metals as much as possible.

The following countermeasures are planned based on the results of survey and mineral processing test. The specifications, results and analysis of the mineral processing test are shown in "Mineral Processing" in ANNEX(6).

Countermeasures :

- As for lead, zinc silver : Improvement of individual recovery of lead, zinc and silver, in particular.

① Improvement of grinding efficiency : Optimum grain fining of flotation feed

A liberation grain size of sphalerite (ZnS) out of the Potosi Mine is approximately 0.10 mm. Meanwhile, the present grain size of flotation feed remains in too coarse to liberate sphalerite satisfactorily. There is a concern that current grinding operation is conducted under continual and unreasonable overload in order to increase in production volume and results in unsatisfactory flotation efficiency and low recovery. Improvement of the recovery will be promoted by proper grain fining of flotation feed.

② Extension of flotation time : Increase in flotation pulp density

The current flotation pulp density is very weak, 7～9 %, and, as a result, flotation time remains in short. Improvement of the recovery will be achieved by raising flotation pulp density up to approximately 20～25 %, with resultant extension of flotation time about three times or more as long as current one.

③ Looking over flotation reagents

Improvement of the recovery will be achieved by looking over each flotation reagent(collectors, etc.), in particular.

By means of the countermeasures mentioned above, there is a possibility for improvement of the recovery (approximately, lead by 4 %, zinc by 2.5 %, silver by 3 %) even if the current facilities were left as they are.

- As for tin : Start of new recovery of tin

① Separation and recovery of stannite out of lead concentrate and zinc concentrate.

② Separation and recovery of coarse size cassiterite out of lead/zinc tailing, which is liberated in the said grain size.

Both of these have a possibility to substantially improve the recovery (additional recovery of tin sulfide : approximately 70 %, and tin oxide: approximately 30 %) only through the introduction of gravity concentration (Shaking table).

The results of the said mineral processing are estimated and shown in the former Table 6-1-3(1). A general idea of the aforesaid countermeasures is shown in Figure 6-1-3.

Required items :

① Mineral determination technology (Mineral composition, mineral grain size [decision of liberation size] etc.,)

② Latest technology of mineral treatment

③ Designing technology of mineral processing facilities

6-1-3 Treatment of Mine Water and Seepage Water from Waste Rock Dump : Aforesaid item [1]

Outflowing water from suspended or abolished mines and from new or old waste rock dumps are in acidity and contain hazardous heavy metals and so on. The said water directly pour into the rivers causing a wide range of environmental deterioration as a result of washing away of these metals to the downstream as forms of ions and SS. Therefore, close attention has to be paid to the outflowing water control, such as discharge into the river after the treatment for pollution-free like neutralization and neutralized sludge sedimentation.

It is currently under the study that the aforesaid outflowing water are neutralized with the alkaline waste water out of the Ingenios inside of the tailing dam (DCSA) of which construction is under planning. However, it is concern of this process that the dam life would come to short and the bank would become weak. The team proposes to treat the said outflowing water in the manner of optimum condition in conformity with economic principles.

It is considered as poor feasibility to newly build a large type of neutralization facility. Therefore, it is recommended to study on a smaller facility taking into consideration environmental advantages in the geographical condition, variation of flow volume, water quality and so on.

It is necessary for the proposal to give careful consideration both to environmental impact and to quality variation of the waste water discharged into the rivers, brought about by the construction of a new neutralization facility.

Countermeasure : Treatment of contaminated acid water, such as mine water and seepage water from waste rock dump

Plan① Neutralization of acid water in the mining sector with alkaline water in the mineral processing sector

Plan② Independent neutralization of acid water in the mining sector : Single or double stages

In the neutralization in both Plan① and ②, co-precipitation reaction of hazardous heavy metals like As etc.,is utilized during a hydroxide formation of Fe^{3+} in acidity approximately between pH4 and 6.

As a result of the study on the plans above, the process flow is shown in Figure 6-1-4. The treatment method of resultant neutralization sludge is shown in Table 6-1-1.

Required items :

① Treatment technology of acid water

② Treatment technology of neutralization sludge

③ Designing technology of neutralization facilities

④ Knowledge concerning reactions in neutralization chemistry and heavy metal ions

⑤ Knowledge concerning oxidation process of ore body and ore

6-1-4 Introduction of Tin Recovery Concentrator out of Ingenios' Tailings : Aforesaid item [5]

The current operation of the Ingenios directly discards the tailings in which great quantities of valuable metals such as lead, zinc and tin are left. In view of this, the team has carried out technical guidance to recover the valuable metals as much as possible before discharge of the tailings into the river.

As for re-treatment of the tailings, the team proposes to build a common facility rather than individual one, where some of more than 40 Ingenios jointly re-treat their tailings with share in the advantages of large scale.

In addition, the team recommends to study on a construction site of the tailing re-treatment facility taking the upper part of the plateau as a first priority, where the new San Antonio tailing dam (DCSA) mentioned in Paragraph 6-1-1 is planned to be built.

Among the valuable metals remaining in the tailings, lead, zinc, tin sulfide and a part of tin oxide will be able to be recovered, to a certain extent, by means of the operational process improvement of the current Ingenios. However, a recovery of the rest of tin oxide has to be dealt with in the tin recovery concentrator because the operational process improvement of the Ingenios is unable to cope with that.

Namely, in case of the Potosi Mine ore, tin oxide mineral (Cassiterite: SnO_2) left in the lead/zinc flotation tailing is considerably fine in its liberation particle size, approximately dozens of μm. For this reason, a recovery of coarse cassiterite by means of gravity concentration (Shaking table) mentioned in ②, Paragraph 6-1-2, "Study on Production Process Improvement at Ingenios", is estimated as at most approximately 1/3 of the total amount of cassiterite. The balanced 2/3 of cassiterite is of fine/micro-fine in its liberation particle size and moves into the tailing because of difficulty in its recovery during the gravity concentration.

Countermeasure :

Fine/micro-fine cassiterite left in the tailing will be recovered by means of flotation after the said gravity concentration (Shaking table) followed by regrinding.

Figure 6-1-5 shows the process flow obtained by the results of mineral processing test.

By this method, there is a possibility to considerably improve a tin recovery, approximately by 40 % as tin oxide. Table 6-1-3(2) shows an estimated mineral processing result in case of adding the said tin recovery process to the Ingenios that would achieve the production process improvement mentioned in Paragraph 6-1-2.

Required items :

① Treatment technology of tin ore

② Designing technology of concentrator for tin mineral processing

6-1-5 Introduction of Model Concentrator : Aforesaid item [6]

The team has made suitable advises to the existing Ingenios and proposes to construct a model concentrator which realizes an application of the latest technology and an optimization to the local conditions. The team proposes also the necessity of constructing a continuous mineral processing test facility prior to the construction of the model concentrator.

The model concentrator takes aim at high economic features and facilities consistent with environmental conservation by use of the latest technology. Although the model concentrator by itself is a competitive one, the target is that its facilities will give practical and precise examples when a local business proprietor, taking into consideration the local conditions, would plan to build a further competitive concentrator by equity fund in the future.

The continuous mineral processing test facility isn't for actual production but for full study on distinctive character of the local ores and so on in view of a successive construction of a optimum model concentrator. In order to be consistent with "Environment" and "Production", it is necessary to finally achieve an intensive operation by means of an integrated concentrator (considered as approximately 1,500 t/d) installed with the latest facilities. As a preparatory stage, it is planned to build a model concentrator (200 t/d) which will function in the same manner as the said integrated concentrator. It will be important to confirm the effect of the model concentrator first and then to promote integration of the Ingenios.

The said model concentrator will be built on the upper part of the plateau where the new tailing dam (DCSA) is planned to be built, and will be included in the integrated concentrator after its construction. Figure 6-1-6 shows the process flow based on the results of mineral processing test.

Designing of facilities and estimation of construction costs are made based on the process flow obtained from the test results.

The construction costs are estimated by use of the survey results on 9 machinery and equipment suppliers in Bolivia and 7 local sub-constructors in Potosi City.

Construction cost of the 200 t/d model concentrator is estimated as 1,430 million yen (11.92 million dollars [Y120/$]) in total (Refer to the following table).

	Cost
Mechanical	820 Mil. Y
Electrical	350 Mil. Y
Civil & Building	240 Mil. Y
Adjustment & Test Run	20 Mil. Y
Total	1,430 Mil. Y

The construction costs are estimated based on a turn-key and within the scope of the indications shown in the flow sheet, P & ID and the equipment list in ANNEX(8). The costs for site preparation (land readjustment, soil improvement, piling etc.,) are not included in the estimation. It is assumed that power and water supplies are available in the neighborhood of the construction site and access roads are sufficiently arranged.

The exchange rate is set as Y 120/ $ and its variation and cost escalation aren't taken into account.

6-1-6 Recovery of Valuable Metals from Waste Rock and Sucu : Aforesaid item [7]

Waste rock (Desmonte) and waste (Sucu) from a primitive gravity concentration are left in heap on a mountainside of the Potosi Mine, which were discharged from old mining only limited to of silver and tin minerals. These volumes are said to be as much as one hundred million tons. Some private enterprises have already carried out metal recovery business out of a certain waste rock. The team proposes to start on a large scale, in the future, a recovery business of valuable metals out of waste rock and Sucu by selecting a certain suitable and economically feasible place*6.

It is meaningful also for future vegetative stabilization on the mountainside to remove and utilize waste rock and so on which were left in the past.

*6 : As a example, Desmonte "Cero Rico" 5,608 thousand tons (Ag 213.1 g/t, Sn 0.27 %)

Countermeasures : Recovery of valuable metals like silver, tin etc., out of waste rock etc.,

Plan ①, After crushing, silver recovery by means of heap leaching with cyanide solution

Plan ②, Recovery of coarse cassiterite by means of crushing, grinding and gravity concentration (Shaking table), then, making all slime through regrinding, and recovering cassiterite in its liberation particle size of fine/micro-fine by means of flotation. Successive recovery of silver from the flotation tailings by means of tank leaching with cyanide

An general idea of the said countermeasures is shown in Figure 6-1-7.

Required items :

① Technology of cyanide leaching

② Technology of heap leaching

③ Technology of valuable metal recovery, such as zinc precipitation, CIP etc.,

6-1-7 Construction of Integrated Concentrator (Industrial estate): Aforesaid item [8]

The problems in the existing ingenios in the neighborhood of Potosi City are, as mentioned in the other paragraphs in this report, difficulty in burden of environmental costs due to individually small scale and poor management basis and resultant international incompetitiveness.

For the solution of these problems, the team proposes to construct an integrated concentrator with 1,500 t/d of treatment capacity, in order to conduct intensive operation by unifying the existing ingenios.

For the purpose of promotion of the operation under a reasonable reduction of environmental costs by means of the latest and modified facilities referred to the model concentrator, it is considered most rational that all the facilities concerned are concentrated near a tailing dam.

Therefore, the team would like to propose, as a future view, establishment of an industrial estate including as well the tailing re-treatment facilities previously mentioned.

The team recommends to study on a construction site of the integrated concentrator taking the upper part of the plateau as a first priority, where the new San Antonio tailing dam (DCSA) mentioned in Paragraph 6-1-1 is planned to be built

The process flow in the said concentrator is the same as in the model concentrator and shown in

Figure 6-1-6.

The investment costs are tried to estimate by applying a 0.65 th power method to the sum of the investment costs for the 200 t/d model concentrator.

The estimated mineral processing results are shown in the former Table 6-1-3(2). As it is expected some deterioration of crude ore grade comparing to those at the present ingenios, the metal amount in crude ore is planned to be kept unchanged by increasing in the treatment volume of crude ore. The said increase in the treatment volume will be achieved without any rise of mineral processing cost as a result of reduction of the unit cost ($/t) brought about by mass-production effect. An improvement of mineral processing results will be ensured through application of optimum process flow and conditions to the Potosi Mine ore and introduction of the latest technology (for example: micro bubble type column flotation machine) to tin flotation to realize recovery of fine/micro-fine cassiterite.

As a result, an individual recovery will be considerably improved such as, lead 60.0→72.0 %, Zinc 81.9→89.3 %, silver 74.8→83.8 % and tin 0→70 %.

Finally, financial foundation will be intensified and coexistence of "Environment" and "Production" will be realized.

Required items :

① Designing technology of mineral processing plant in large scale

② Operational technology of mineral processing plant in large scale

6-1-8 Vegetative Stabilization on Waste Rock Dump and Old Tailing Dam : Aforesaid item [2]

Old waste rock dumps and tailing dams are so far left as they are, where the recovery of valuable metals is not feasible through the current technology. If leaving the situation as it is hereafter still, environmental deterioration in the neighborhood will continue, which is caused by heavy metal dissolution into acid water flowing out of the said dumps and dams.

In order to prevent the said pollution, vegetative stabilization is eventually required.

However, huge funds are necessary for its implementation even though that is technically available.

Therefore, the positive participation of the residents is indispensable for promotion of the plan for soil heap-up and vegetative stabilization on the said dumps and dams. The team proposes to establish an implementation structure capable of steady deliberate advance of the plan, even if slow, extending over long terms in view of utilization of public funds in case of the absence of mine owners.

It is necessary to take suitable countermeasures which will be able to prevent from new and additional pollution at the said dump and dam sites.

Countermeasures : Prevention or reduction of outflowing of contaminated seepage water, and prevention from scattering and effluxion of dumped pile containing hazardous substance
① Construction of bank and retaining wall
② Vegetative stabilization : Adjustment of decant discharge equipment, soil heap-up, vegetation

Figure 6-1-1 shows a general view of the said countermeasures and so on.

On the occasion of the implementation of the said countermeasures, it is necessary to survey beforehand the presence and volume of sulfide minerals, especially pyrite (FeS_2), in the dumped pile, which are the sources of acid water. It is as well necessary to survey beforehand the presence and volume of hazardous heavy metals in the dumped pile, which cause water pollution dissolved with acid water out of sulfide minerals. Then, the necessity and priority are to be clarified for the implementation of each countermeasure.

Required items :

① Expertise of soil heap-up and vegetation

② Consideration of environmental conservation

③ Civil construction and management

6-1-9 Establishment of Environment & Safety Research Center: Aforesaid item (9)

It becomes clear through the survey that the current systems in the Bolivian side with regard to "Environment" and "Safety" are insufficient and have the problems shown below.

1.Tech-nology	1) Mining pollution control	(1)Direct counter-measures	① Insufficient understandings of mine pollution control technology as a whole, and insufficient study on applicable technology. ② Insufficient approach and study on optimum process conditions of applicable technology. ③ Insufficient actual proof of applicable technology.
		(2)Indirect counter-measures	① Insufficient understandings of mineral processing technology as a whole, and insufficient study on applicable technology. ② Insufficient approach and study on optimum process conditions of applicable technology. ③ Insufficient actual proof of applicable technology.
	2)Environmen-tal control	(1) Insufficient monitoring system (2) Insufficient laws and regulations (3) Insufficient organization for environmental conservation (4) Insufficient environmental characteristics	
2.Human resour-ces	1)Mine pollution control	· Several dozens of technicians are centering around the mining and chemical departments of UATF, and in private mines and Ingenios. However, they are insufficient in practice due to poor condition of aforesaid item 1.1).	
	2)Environmen-tal control	· Some persons in charge are in the state and prefecture, and insufficient in practice due to poor condition of aforesaid item 1.2). Furthermore, the environmental section in the prefecture has as small as only 3 persons in charge.	
3.Equip-ment	1)Mine pollution control	· UATF has no continuous test facilities concerning environment and mineral processing, and is poor in other possessing equipment and analytical equipment.	
	2)Environmen-tal control	· Insufficient monitoring equipment	

In order to solve these problems and to activate the mining activity in conformity with environmental conservation, the team proposes the establishment of the Environment & Safety Research Center and the responsible grappling with its management by the Potosi prefecture.

Namely, for the purpose of securing technical expertise cope with the aforesaid problems, it is required to human resources development and introduce proper facilities.

The said research center will be organized to perform development of new technology, formation of new technical and management systems and implementation of monitoring in view of environmental control and improvement, bearing in mind how to achieve conformity of mining activity with environmental administration.

It is another major purpose of the said research center that home and foreign environmental monitoring technology and equipment are arranged and introduced in acceptable way to the actual situation of Potosi Prefecture, and that the proper administrative and technical systems are established, which are self-sustainable by Potosi Prefecture. The research of both optimum process flow and optimum conditions will be carried out through various environmental and mineral processing tests by means of newly installed continuous test facilities in the said research center.

Furthermore, achievements made by the said research center will be applied to the other relevant places in Bolivia.

Table 6-1-1 Mine Pollution Prevention Technologies and Adoption of the Technology Concerned for Potosi Region

: Adoption judgement ○ Suitable, △ It is necessary to study the most suitable method, × Unsuitable

Measures and Purpose	Target Area	Target Pollution	Mine Pollution Prevention Technology	Adoption to Potosi
1. Measures against pollution sources: Polluted drainage, and ore or waste containing toxic materials must not be discharged to public water area (river, lake : groundwater, etc.) from mines, refuse/slug piles and mineral processing tailing dams.	1.1 Mine: Prevention or reduction of effluence of polluted drainage	1.1.1 Polluted drainage (acid)		
		1) Mine drainage	1) Sealing ore bodies	
			① Separating clean water from polluted water	(○)
			② Separation of gallery walls from mine drainage	×
			③ Covering deposit	×
			④ Sealing mineralized zone	×
			2) Closure of level	
			① Zero discharge type which bears pressure	×
			② Over flow type which bears pressure	×
			③ Air-seal type which bears no pressure	×
			④ Mixed type which bears pressure	×
		2) Infiltrating drainage (open pit, the remains, crop, etc.)	1) Maintenance and plantation for open pit, the remains, etc.	×
	1.2 Rejected ore or slag pile/dam: prevention or reduction of flowing out of infiltrating acid polluted water; prevention of flowing out and scattering of ores with toxic elements	1.2.1 Polluted drainage: acid		
		1) Infiltrating drainage	1) Sealing ore bodies	×
			2) Plantation: covering with soil, plantation, etc.	○
		1.2.2 Waste with toxic element		
		1) piled ores	1) Banking and plantation	○
			2) Stabilization of dam	×
	1.3 Concentrator (Ingenio): Prevention of discharge of tailing (waste)	1.3.1 Polluted discharge: acid/alkaline		
		1) Tailing: liquid	1) Treatment at final treatment area: tailing dam	○
			2) Putting tailing into under ground mining caves	×
		1.3.2 Waste with toxic element		
		1) Tailing: solid	1) Treatment at final treatment area: tailing dam	○
			2) Putting tailing into under ground mining caves	×
2. Treatment of polluted water to be not toxic before the water may be discharged into public water area	2.1 Mine, rejected ore or slag pile/dam and concentrator (Ingenio)	2.1.1 Polluted drainage (acid) and Polluted discharge (acid/alkaline)	1) Neutralization treatment	○
			2) Treatment of neutralized sludge	○
			① Neutralized sludge without dehydration	△
			· Piling at tailing dam	
			· Piling at neutralized sludge dam	
			· Returning into under ground mining caves	
			② Neutralized sludge with dehydration	△
			· Densification of sludge, thickening, hydration and piling at the dam	
			· Densification of sludge, thickening, hydration, making hard with a little cement and piling	
			3) The others	×
			① Metal recovery: ferrite or hematite method	×
			② Biological treatment: with sulfate-reducing bacteria, etc.	×
			③ Deep underground injection	×
			④ Catalytic oxidation with chelating resin	×
3. Measures against soil				
4. The others: Installation of water pipe/canal				△

Table 6-1-2 Proposal on Basic Plan for Mining Pollution Prevention in Mineral Processing Field

Items	Environment: Tailing : Waste	Production : Measures(Steps) to Secure Funds for Environmental Costs of Ingenios — Run of Mine Ore of "Cerro Rico de Potosi": Pb, Zn : Ag	Run of Mine Ore of "Cerro Rico de Potosi": Sn	Rejected Ore Left out of Mine: Sn, Ag
Present	·Discharge of all tailing to rivers: occurence of mining pollution	·Mineral processing operation: existing Ingenios [concentrators] (total 42 plants: cap.5~370t/d/plant [27 plants: cap. ≦ 50t/d/plant]) ·Treatment rate: total 1,300~1,600t/d ·Mineral processing treatment: individual ·Mineral processing results: insufficient	·Mineral processing operation: no recovery (but, a little recovery at only one Ingenio)	·Mineral processing operation: one cyanide leaching process plant ·Recovery object: only Ag
Future in short-term	·Treatment of all tailing at DCSA(*1) constructed by KFW of Germany: prevention of mining pollution	·Mineral processing operation: existing Ingenios: process improvement ·Treatment rate: total 1,300~1,600t/d ·Mineral processing treatment: individual ·Mineral processing result: a little improvement improvement items: particularly for recovery of Pb and Zn both with Ag ① Improvement of grinding efficiency: optimum particle size suitably fine for flotation ② Extension of flotation time: increase of pulp density ③ Reconsideration on flotation reagents ·Economic effect: all effect × 1/3	·Mineral processing operation: existing Ingenios: process improvement ·Mineral processing result: new appropriation of Sn recovery improvement items: particularly for recovery of Sn ① Separation and recovery of sulfide Sn (stannite) from Zn concentrate and Pb concentrate ② Separation and recovery of oxide Sn (cassiterite) from Pb, Zn flotation tailing → adoption of shaking tables for ① and ② ·Economic effect: the same as left	
Future in medium-term	·The same as above	·Construction of continuous plant for investigation (cap. several t/d)	·The same plant as left	·The same plant as left
	·The same as above	·Mineral processing operation: construction of model plant(cap. 200t/d) ·Plant site: plateau above DCSA ·Circumstances of present Ingenios: scrap & build	·Mineral processing operation: the same plant as left(*2) ·Treatment objects: tailing of Pb, Zn flotation ·Plant site: the same as left	·Mineral processing operation: construction of model plant (cap. about 10t/d)
	·The same as above	·The same as same items of future in short-term	·Mineral processing operation: construction of tailing reprocessing plant(*2) ·Treatment object: collected tailings of present Ingenios ·Recovery objects: (left Pb, Zn and) Sn ·Plant site: plateau above DCSA ·Economic effect: all effect	
Future in long-term	·The same as above	·Mineral processing operation: construction of integrated mineral processing plant ·Treatment rate: about 1,500t/d ·Mineral processing treatment: integration ·Mineral processing result: sufficient ·Plant site: plateau above DCSA ·Economic effect: all effect ·Circumstances of present Ingenios: abandonment & integration	·Mineral processing operation: the same plant as left: the same as item of construction of tailings reprocessing plant in future in medium-term(*3) ·Treatment object: Pb, Zn flotation tailing ·Mineral processing treatment: the same as left ·Mineral processing result: the same as left ·Plant site: the same as left ·Economic effect: the same as left	·Mineral processing operation: construction of mineral processing plant for rejected ore, etc. ·Treatment object: part of rejected ore(Desmonte, etc.) ·Recovery object: Sn, Ag or only Ag

Note: *1 Dique de Colas(San Antonio), *2 Treatment facilities(1) for Sn: regrinding and Sn flotation, *3 Treatment facilities(2) for Sn: shaking table, regrinding and Sn flotation

Table 6-1-3 (1) Estimation of Mineral Processing Result of Ingenios at Present/in Future[1]

(1/2)

	Present	Future
1 .Mined ore	Existing Ingenios(total 42): individual treatment	Integrated concentrator: integrated treatment
1 Run of mine ore		
1) Ore quantity	Research by the prefecture(1998) Facilities capacity(A) 2,365t/d Treatment scale(B) 1,702~1,742t/d Treatment ratio(B/A) 72~74% Annual operation days 330d/y[sup.] Operation ratio 75~90%[sup.] Treatment rate 1,277~1,568t/d :1,327t/d[sup.] 421~517 thousand t/y :438 thousand t/y [sup.]	→ Increase of treatment rate → × about 1.13 = 1,500t/d[sup.] → × about 1.13 = 495 thousand t/y [sup.]
2) Grade	Pb 0.85~2.50%(→ 1.1%[sup.]) Zn 8.0~17.0% (→ 11.6%[sup.]) Ag 125~700g/t (→ 350g/t[sup.]) Sn ? (→ 0.6%[sup.]) Deposit data: · Ag-Zn ore: 1994 COMIBOL Ag 644g/t (→ 350g/t) Zn 11.58% · Sn ore: 1986 COMIBOL Sn 1.01% (→ 0.6%[sup.])	Pb 1%[sup.] Zn 10%[sup.] Ag 310g/t[sup.] Sn 0.5%[sup.] → Decrease of grade → × about 87% → × 〃 → × 〃
3) Metal quantity	Pb 1,327t/d × 1.1% = 15.0t/d Zn 1,327t/d × 11.6% = 150.0t/d Ag 1,327t/d × 350g/t = 464.5kg/t Sn 1,327t/d × 0.6% = 7.5t/d	Pb 1,500t/d × 1.0% = 15.0t/d Zn 1,500t/d × 10.0% = 150.0t/d Ag 1,500t/d × 310g/t = 464.5kg/t Sn 1,500t/d × 0.5% = 7.5t/d
2 Unit cost	1	0.7
3 Pb concentrate :Pb flotation	Recovery and concentrate grade: insufficient Evaluation objects: Pb, Ag	Recovery and concentrate grade: up Evaluation objects: Pb, Ag
1) Ore quantity	Ore distribution 1.1~2.9% → 1.7%[sup.] 1,327t/d × 1.7% = 22.6t/d	→ 1.6%[sup.] 1,500t/d × 1.6% = 24.0t/d
2) Grade	Pb (30)~52% (→ 40%[sup.]) (Zn 9~(20)% (→ 15%[sup.])) Ag (2,000)~6,000g/t(→ 4,500g/t [sup.])	Pb 45%[sup.]: objective 60% up (Zn 10%[sup.]) Ag 5,060g/t[sup.]
3) Metal quantity	Pb 22.6t/d × 40% = 9.0t/d (Zn 22.6t/d × 15% = 3.4t/d) Ag 22.6t/d × 4,500g/t = 101.7kg/d	Pb 24.0t/d × 45% = 10.8t/d (Zn 24.0t/d × 10% = 2.4t/d) Ag 24.0t/d × 5,060g/t = 121.4kg/d
4) Recovery	Pb (40)~65%[tests: 54~76%] → 60.0% Ag (23)~37%[tests: 18.5~72%] → 21.9%	Pb 72.0%: objective 85% up Ag 26.1%: objective 90% up(*1)
4 Zn concentrate :Zn flotation	Recovery and concentrate grade: insufficient Evaluation objects: Zn, Ag	Recovery and concentrate grade: up Evaluation objects: Zn, Ag
1) Ore quantity	Ore distribution 14.0~28.6% → 18.5%[sup.] 1,327t/d × 18.5% = 245.5t/d	→ 17.5%[sup.] 1,500t/d × 17.5% = 262.5t/d
2) Grade	(Pb 1.2~(3.1)%(→ 1.5%[sup.]) Zn (49.0)~53.5%(→ 50.0%[sup.]) Ag (300)~4,400g/t(→ 1,000g/t[sup.])	(Pb 1.0%[sup.]) Zn 51.0%[sup.]: objective 55% up Ag 1,020g/t[sup.]
3) Metal quantity	(Pb 245.5t/d × 1.5% = 3.7t/d) Zn 245.5t/d × 50.0% = 122.8t/d Ag 245.5t/d × 1,000g/t = 245.5kg/d	(Pb 262.5t/d × 1.0% = 2.6t/d) Zn 262.5t/d × 51.0% = 133.9t/d Ag 262.5t/d × 1,020g/t = 267.8kg/d
4) Recovery	Zn (83)~88%[tests: 58~83%] → 81.9% Ag (30)~48%[tests: 13.2~58.8%] → 52.9%	Zn 89.3%: objective 90% up Ag 57.7%: objective 90% up(*1)

Note sup.: supposition, Improvement effect in Pb, Zn flotation of existing Ingenios should be estimated to be 1/3 of effect in above table., *1: total recovery of Pb, Zn conc.

5 Sn concentrate	No recovery, evaluation object: Sn Sn grade: 0.3% of oxide Sn(Cassiterite :SnO_2)/sulfide Sn(Stannite:Cu_2FeSnS_4) = 1/1[sup.]	New recovery, evaluation object: Sn Sn grade: 0.25% of oxide Sn+0.25% of sulfide Sn = total Sn 0.5%
5-1 Sulfide Sn concentrate with table	At present, ore containing sulfide Sn has been mined as hardly as possible, but, in case to mine it major of sulfide Sn should be contained in Pb, Zn concentrates. · Ore quantity 268.1t/d · Grade Sn 1.1%[sup.] · Metal quantity Sn 3.0t/d · Distribution 80% of sulfide Sn[sup.]	Separation of sulfide Sn from Pb, Zn concentrates with shaking tables · Ore quantity 17.3t/d · Grade Sn 15%[sup.] · Metal quantity Sn 2.6t/d · Recovery 70% of Sulfide Sn[sup.]
5-2 Oxide Sn concentrate with table	At present, oxide Sn has been insufficiently recovered a little at Ingenio 'Santa Catalina'.	Liberated coarse oxide Sn will be recovered with shaking table. · Ore quantity 5.5t/d · Grade Sn 20%[sup.] · Metal quantity Sn 1.1t/d · Recovery 30% of oxide Sn[sup.]
5-3 Oxide Sn concentrate with flotation		After 5-2, oxide Sn will be recovered with regrinding and flotation · Ore quantity 10.0t/d · Grade Sn 15%[sup.] · Metal quantity Sn 1.5t/d · Recovery 40% of oxide Sn[sup.]
6 Tailing		
1) Ore quantity	Calc. 1,327-22.6-245.5 = 1,058.9t/d : 349 thousand t/y	Calc. 1,500-24.0-262.5-17.3-5.5-10.0 = 1,181t/d: 390 thousand t/y
2) Grade	Pb 0.25~0.94%[sampling : 0.11~4.57%](calc. 0.22%) Zn 0.5~3.0%[sampling: 0.48~6.34%] (calc. 2.2%) Ag 50~100g/t[sampling: 14~670g/t] (cal. 111g/t) Sn (calc. 0.46%)	Pb calc. 0.14% Zn calc. 1.2% Ag calc. 64g/t Sn calc. 0.19%
3) Metal quantity	Pb 15.0-9.0-3.7 = 2.3t/d Zn 150.0-3.4-122.8 = 23.8t/d Ag 464.5-101.7-245.5 = 117.3kg/d Sn 7.5-2.6 = 4.9t/d	Pb 15.0-10.8-2.6 = 1.6t/d Zn 150.0-2.4-133.9 = 13.7t/d Ag 464.5-121.4-267.8 = 75.3kg/d Sn 7.5-2.6-1.1-1.5 = 2.3t/d
4) Distribution	Pb calc. 15.3% Zn calc. 15.9% Ag calc. 25.3% Sn calc. 65.3%	Pb calc. 10.7% Zn calc. 9.1% Ag calc. 16.2% Sn calc. 30.0%
2. Rejected ore (Desmonte), etc.	At Present, Ag has been recovered with heap leaching(cyanide leaching process) at Conco plant.	Idea 1. After crushing, Ag will be recovered with heap leaching (cyanide leaching process). 1)Ore quantity 1,000t/d: 330 thousand t/y 2)Grade Ag 213g/t 3)Leaching rate Ag 60% 4)Metal recovery Ag: 1,000t/d × 213g/t × 60% = 127.8kg/d Idea 2. After crushing, oxide Sn will be recovered with grinding, table, regrinding and flotation, and after that Ag will be recovered with tank leaching (cyanide leaching process). 1)Ore quantity 1,000t/d: 330 thousand t/y 2)Grade Ag 213g/t Sn 0.27% 3)leaching rate Ag 90% recovery Sn 70% 4)Metal recovery Ag: 1,000t/d × 213g/t × 90% = 191.7kg/d Sn: 1,000t/d × 0.27% × 70% = 1.9t/d

Note *: Objective Desmonte: Cerro Rico 5,608 thousand t(Ag 213.1g/t, Sn 0.27%), etc.

Table 6-1-3 (2) Estimation of Mineral Processing Result of Ingenios at Present/in Future [2]

Note: As for integrated concentrator, reduction of run of mine ore → increase of quantity of run of mine ore → maintenance of quantity of metal of run of mine ore

			Existing Ingenios at present : Total 42 concentrators with individual treatment	Existing Ingenios with improved processes	Existing Ingenios with improved processes + Tin recovery concentrator from tailing	Integrated concentrator : Total one concentrator with integrated treatment
Run of mine ore	Quan	t/d	1,300~1,600 → 1,327: assumption	1,300~1,600 → 1,327: assumption	1,300~1,600 → 1,327: assumption	1,500 : assumption
	Grad	Pb %	1.1: assumption	1.1: assumption	1.1: assumption	1.0: assumption
		Zn %	11.6: assumption	11.6: assumption	11.6: assumption	10.0: assumption
		Ag g/t	350 : assumption	350 : assumption	350 : assumption	310 : assumption
		Sn %	0.6: assumption	0.6: assumption	0.6: assumption	0.5: assumption
	Metal distribu.	Pb %	100	100	100	100
		Zn %	100	100	100	100
		Ag %	100	100	100	100
		Sn %	100	100	100	100
Concentrate						
Pb Conc.	Quan	t/d	22.6: assumption	24.1: assumption	24.1: assumption	24.0: assumption
	Grad	Pb %	40 : assumption	40 : assumption	40 : assumption	45 : assumption
		Zn %	15 : assumption	15 : assumption	15 : assumption	10 : assumption
		Ag g/t	4,500 : assumption	4,500 : assumption	4,500 : assumption	5,060 : assumption
		Sn %				
	Recovery	Pb %	60.0: calculation	64.0: calculation	64.0: calculation	72.0: calculation
		Zn %				
		Ag %	21.9: calculation	23.3: calcuration	23.3: calculation	26.1: calculation
		Sn %				
Zn Conc.	Quan	t/d	245.5: assumption	252.9: assumption	252.9: assumption	262.5: assumption
	Grad	Pb %	1.5: assumption	1.5: assumption	1.5: assumption	1.0: assumption
		Zn %	50.0: assumption	50.0: assumption	50.0: assumption	51.0: assumption
		Ag g/t	1,000 : assumption	1,000 : assumption	1,000 : assumption	1,020 : assumption
		Sn %				
	Recovery	Pb %				
		Zn %	81.9: calculation	84.3: calculation	84.3: calculation	89.3: calculation
		Ag %	52.9: calculation	54.4: calculation	54.4: calculation	57.7: calculation
		Sn %				
Sn Conc.	Quan	t/d			32.8: assumption	32.8: assumption
	Grad	Pb %				
		Zn %				
		Ag g/t				
		Sn %			15.8: assumption	15.8: assumption
	Recovery	Pb %				
		Zn %				
		Ag %				
		Sn %			70.0: calculation	70.0: calculation
Tailing	Quan	t/d	1,058.9 : calculation	1,050.0 : calculation	1,017.2 : calculation	1,180.7 : calculation
	Grad	Pb %	0.22: calculation	0.15: calculation	0.16: calculation	0.14: calculation
		Zn %	2.2 : calculation	1.9 : calculation	2.0 : calculation	1.2 : calculation
		Ag g/t	111 : calculation	98 : calculation	102 : calculation	64 : calculation
		Sn %	0.46: calculation	0.46: calculation	0.26: calculaton	0.19: calculation
	Metal distribu.	Pb %	15.3: calculation	10.7: calculation	10.7: calculation	10.7: calculation
		Zn %	15.9: calculation	13.3: calculation	13.3: calculation	9.1: calculation
		Ag %	25.3: calculation	22.3: calculation	22.3: calculation	16.2: calculation
		Sn %	65.3: calculation	65.3: calculation	30.0: calculation	30.0: calculation

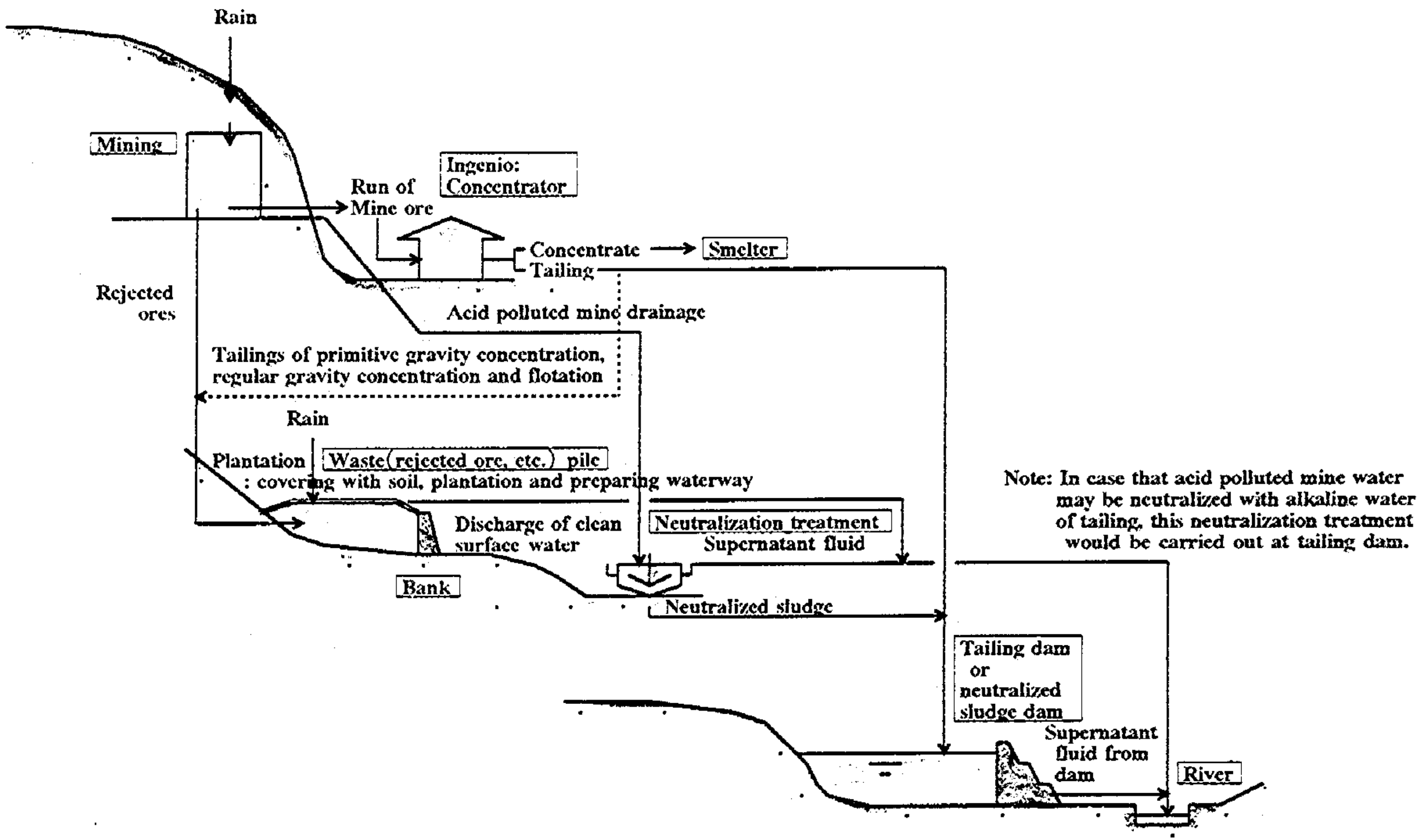


Figure 6-1-1 Mine Pollution Control/Prevention Technology to be applied in Potosi Area(Concept)
Note: Neutralization treatment for acid polluted mine drainage from waste(rejected ore, etc.) pile would be necessary,
because acid polluted mine drainage still generated at waste(rejected ore, etc.) pile until plantation may be completed.

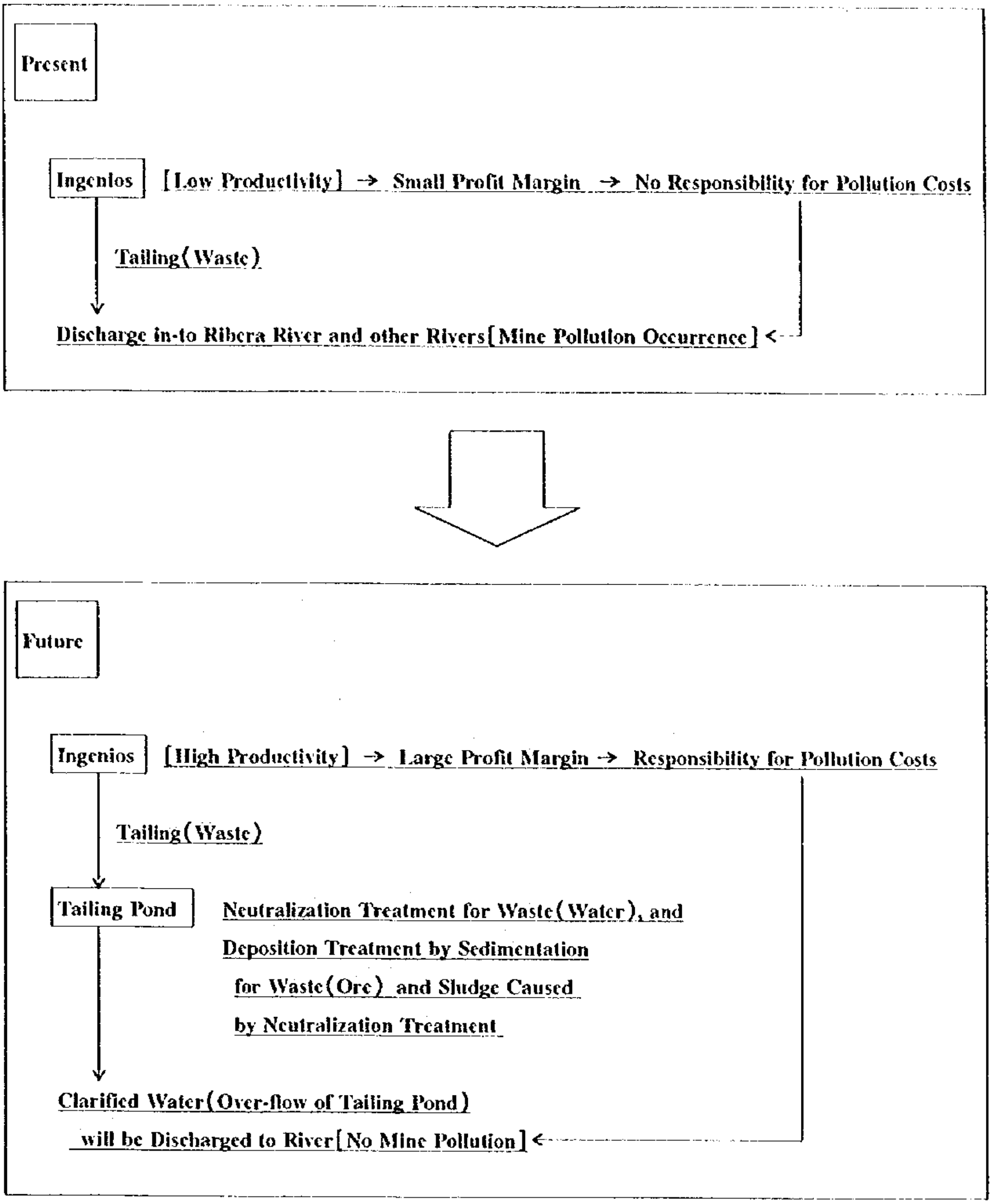


Figure 6 - 1 - 2 Present/Future Situation of Ingenios as a Result of Background Analysis

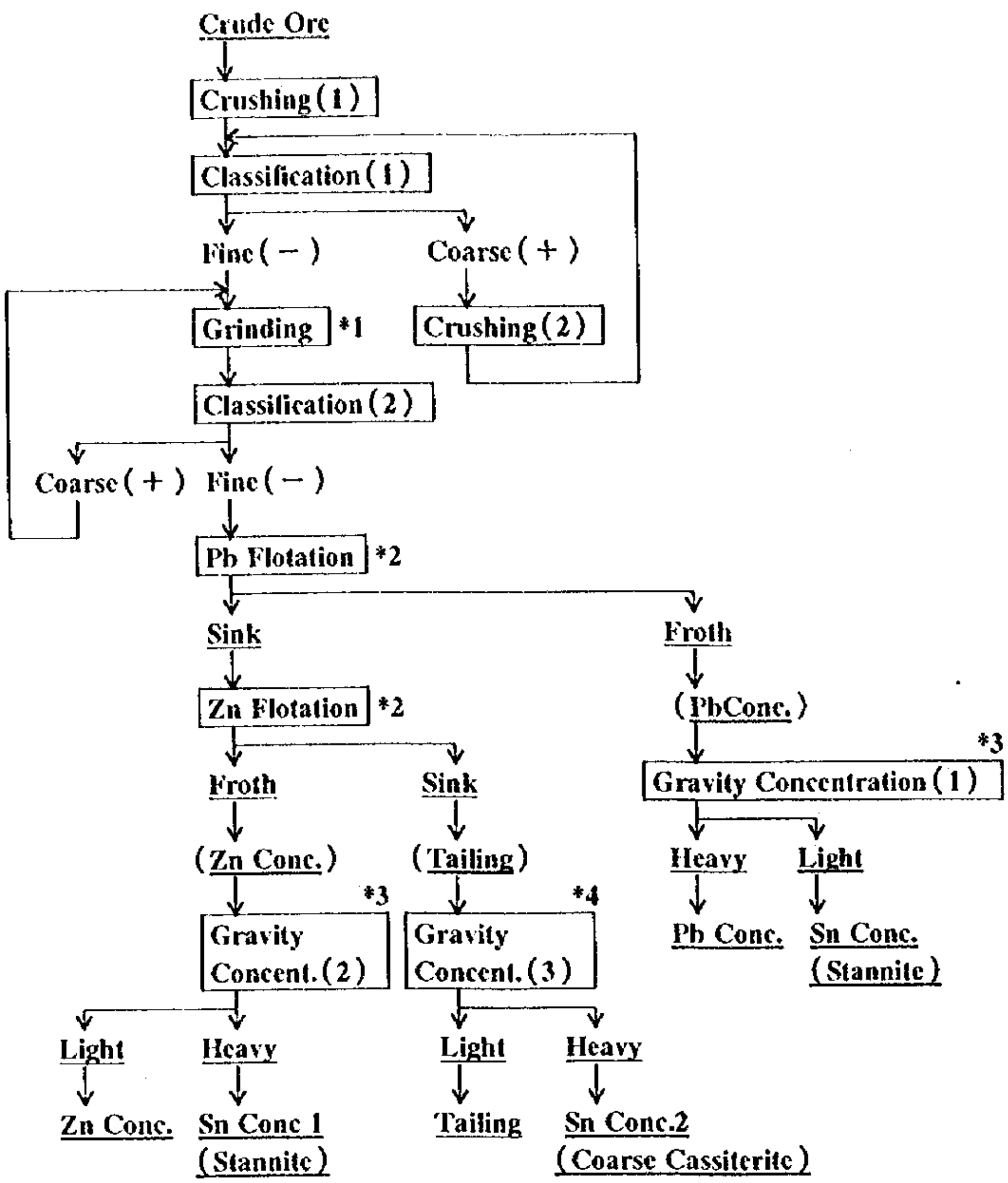


Figure 6 - 1 - 3 Measures for Process Improvement of Existing Ingenios (Concept)

○ As for recovery of Pb and Zn

*1 Improvement of grinding efficiency: making particle size of flotation fine in optimum

*2 Extension of flotation time: increase of flotation pulp density, and revue of flotation reagents

○ As for recovery of Sn

*3 Stannite may be recovered from Pb Conc. and Zn Conc.

*4 Liberated coarse size Cassiterite may be recovered from Pb/Zn flotation.

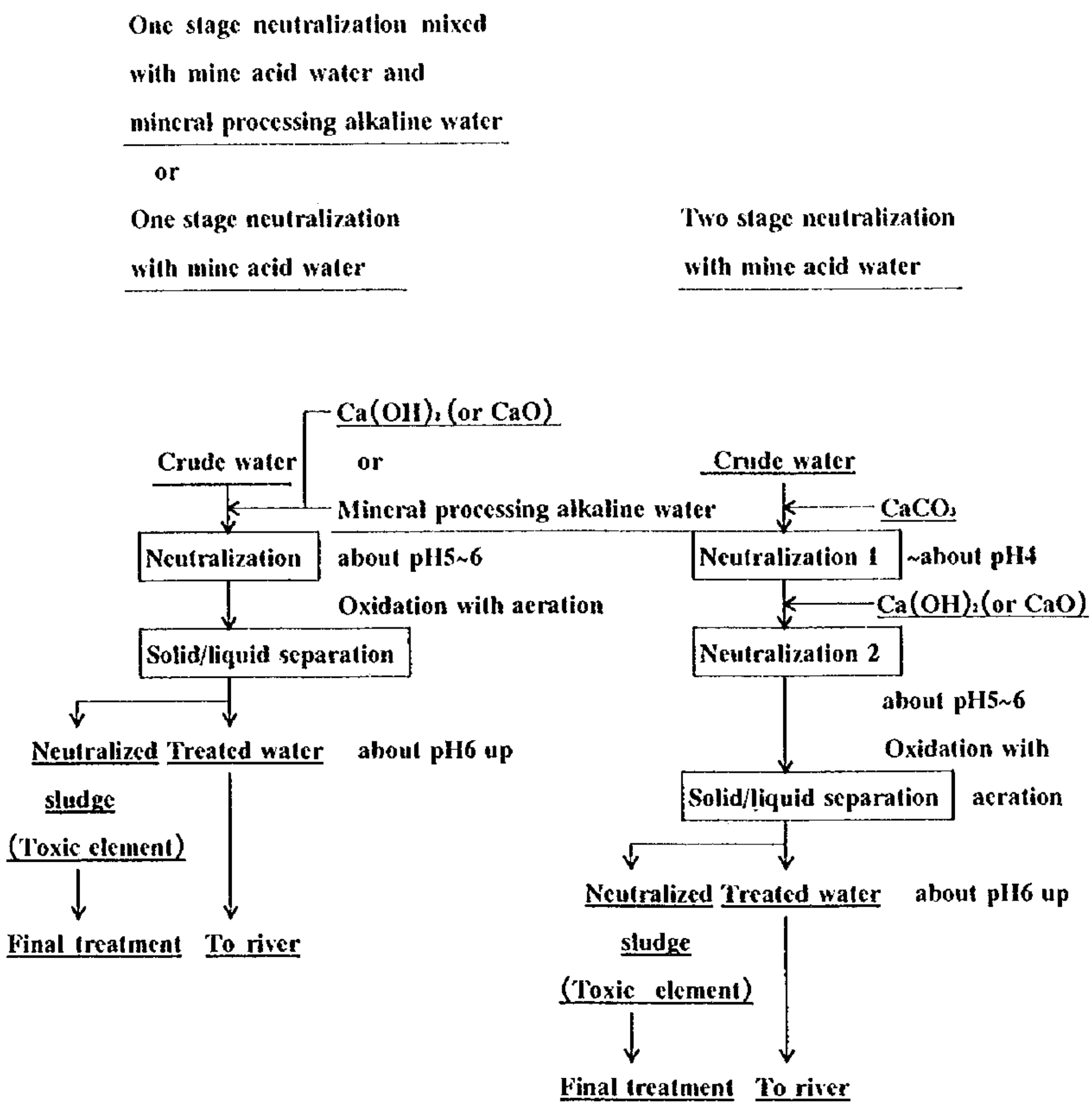


Figure 6-1-4 Neutralization of Mine Acid Water(Study Example)

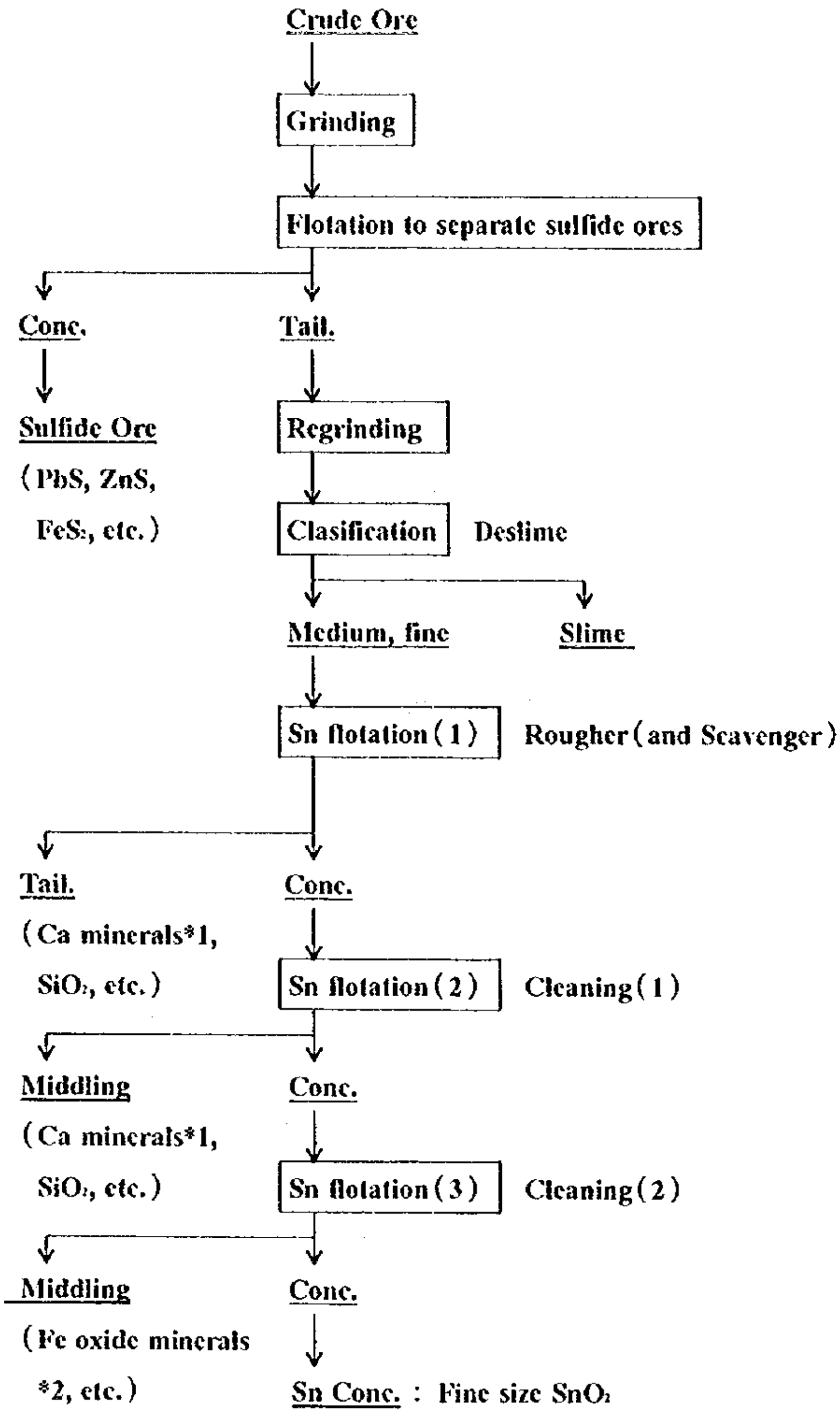


Figure 6 - 1 - 5 Flow Chart of Sn Flotation

Note *1: CaF, etc., *2: $FeCO_3$, etc.

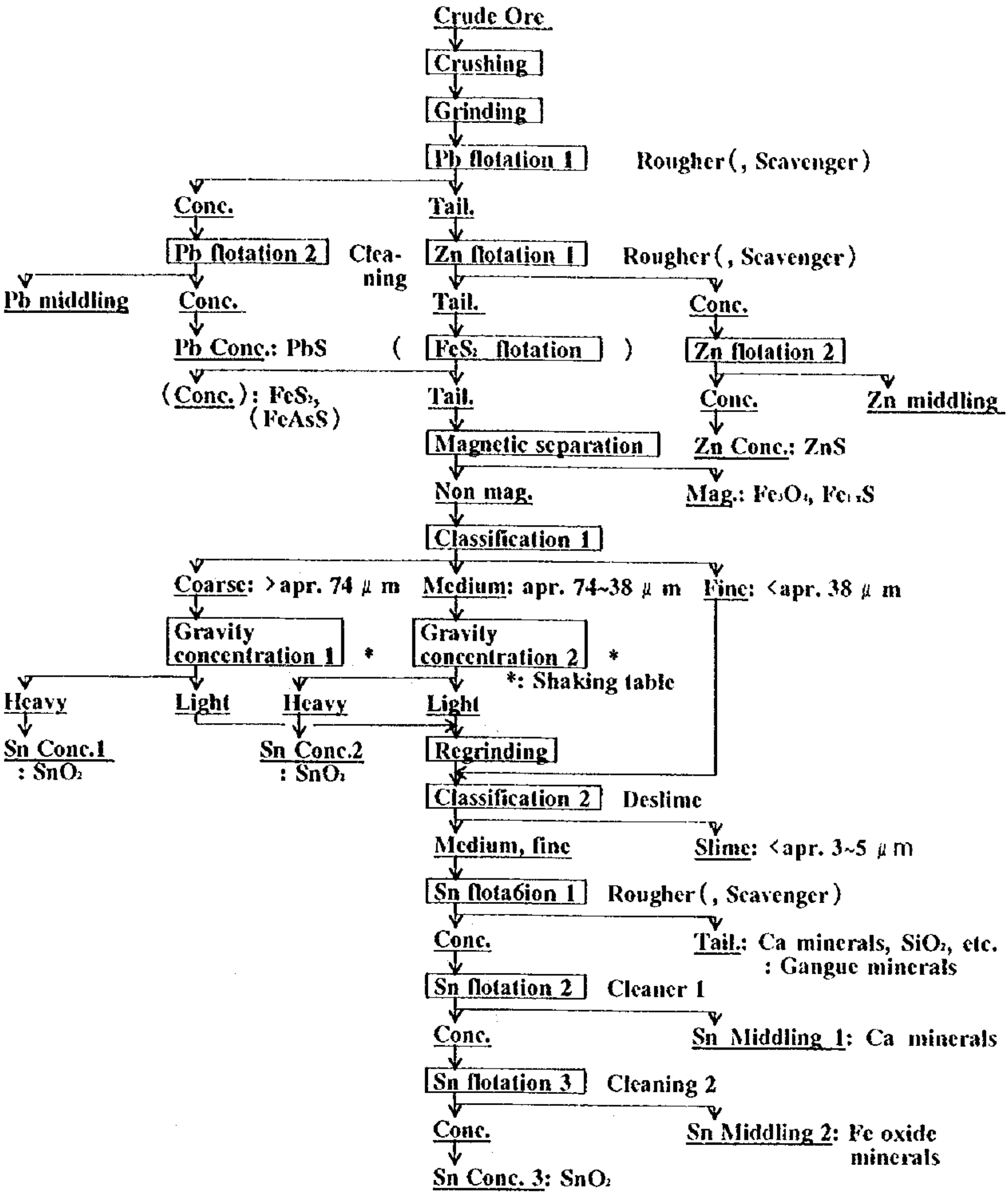


Figure 6 - 1 - 6 Flow Chart of Model Concentrator
: Recovery of PbS, ZnS (both with Ag) and SnO_2

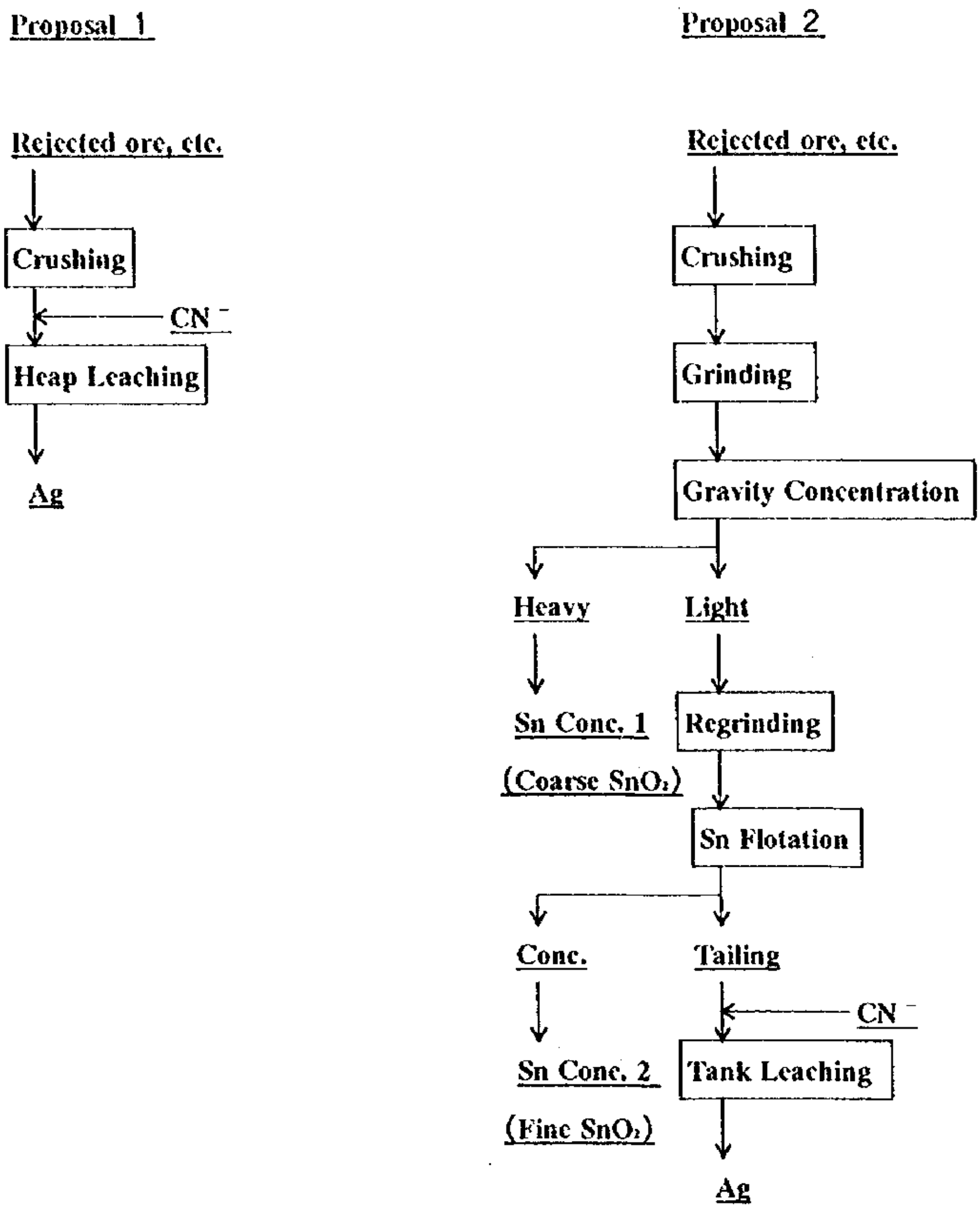


Figure 6-1-7 Recovery of Valuable Metal or/and Minerals from Rejected Ores, etc.(Concept)