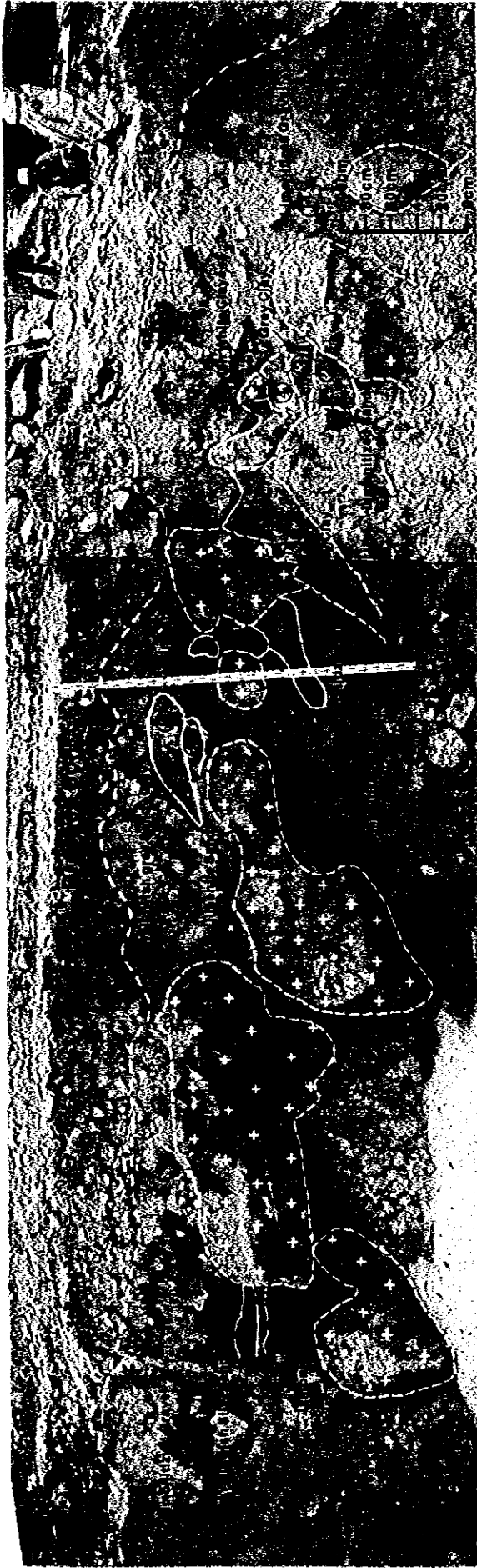
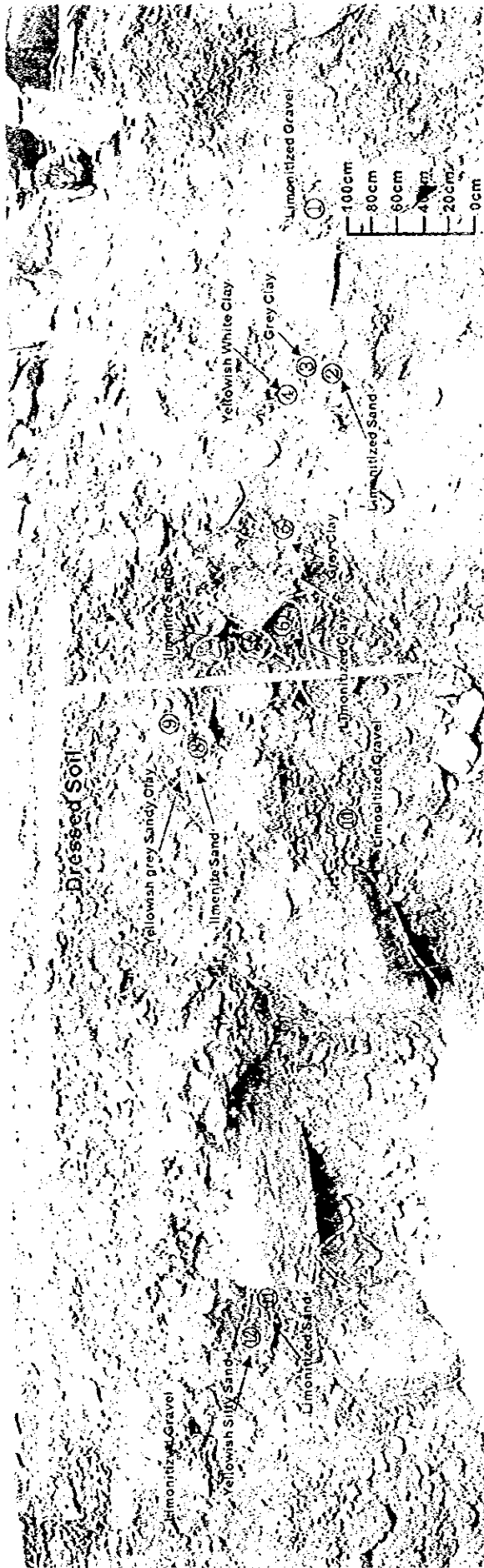


Fig 3.11 Location of Trench Survey



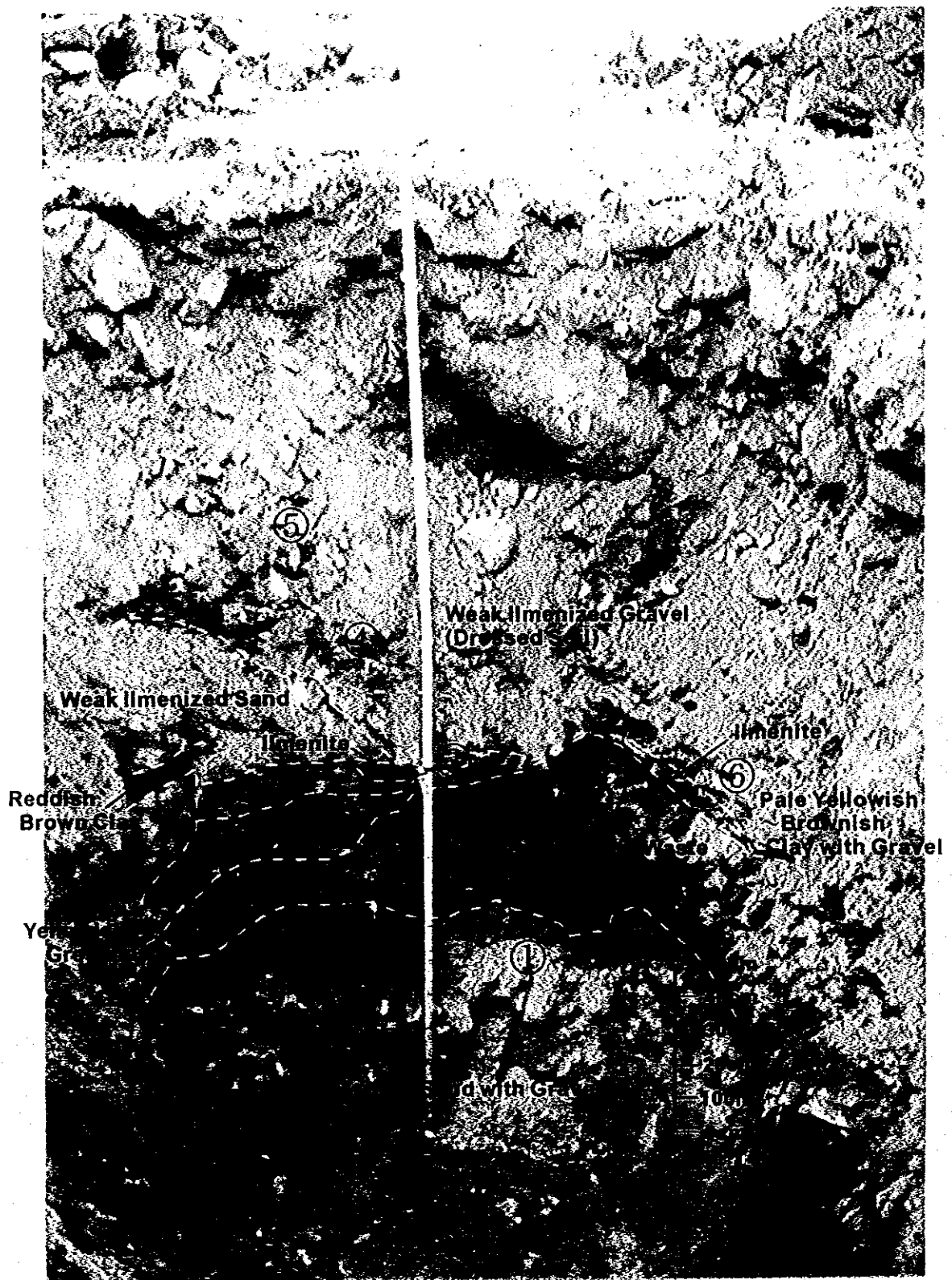
No.	Elution Result		
	Code	As (mg/l)	No.
①	T-1-1	0.4	T-1-7
②	T-1-2	0.2	T-1-8
③	T-1-3	0.6	T-1-9
④	T-1-4	1.0	T-1-10
⑤	T-1-5	1.6	T-1-11
⑥	T-1-6	3.8	T-1-12

Fig 3.12 Cross Section of Trench T-1 Site



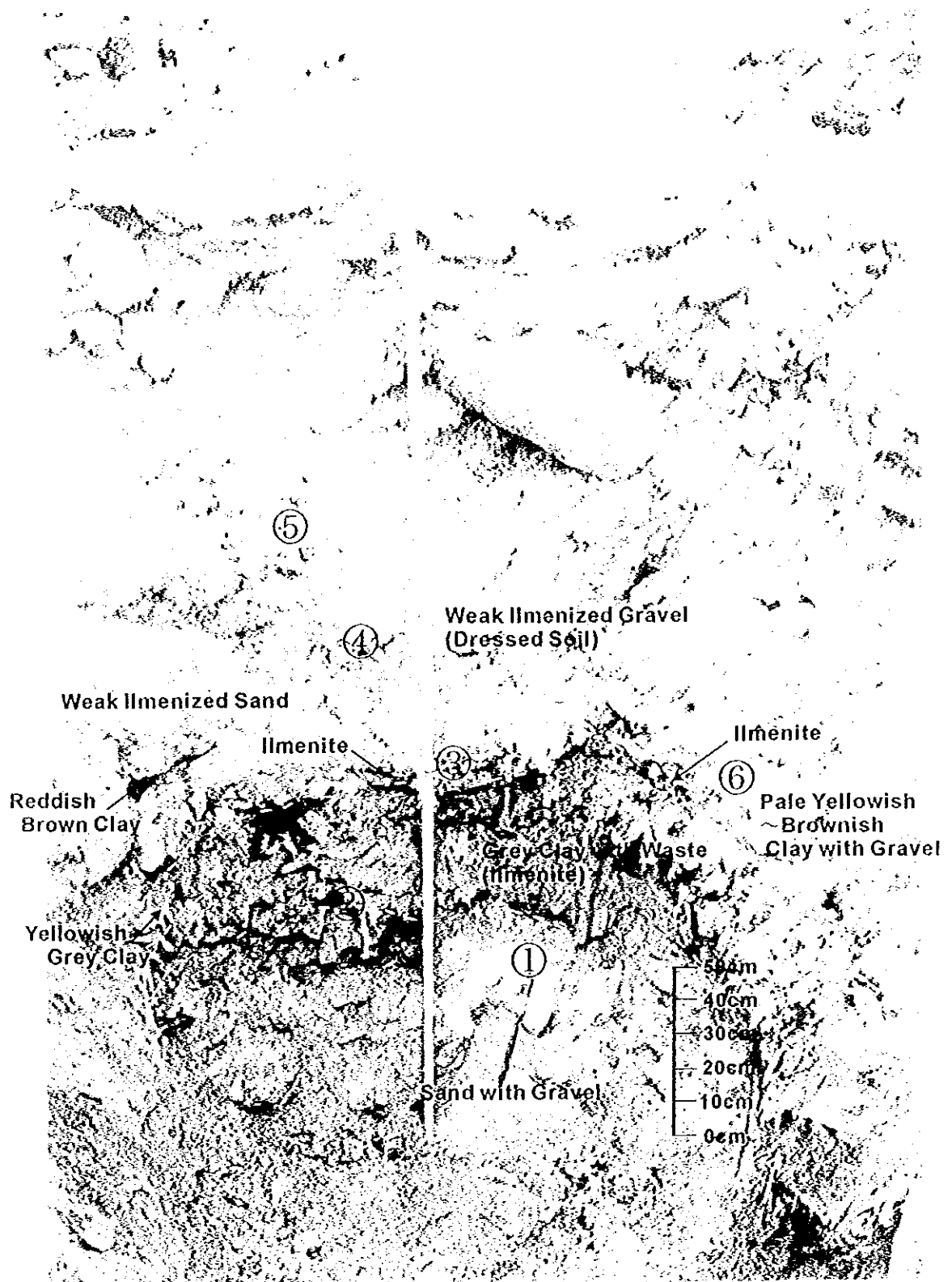
No.	Fluoride Result		Code	As (mg/l)
	Code	As (mg/l)		
(1)	T-1-1	0.4	T-1-7	72
(2)	T-1-2	0.2	T-1-8	380
(3)	T-1-3	0.6	T-1-9	6.9
(4)	T-1-4	1.0	T-1-10	3.1
(5)	T-1-5	1.6	T-1-11	1.0
(6)	T-1-6	3.8	T-1-12	0.4

Fig 3.12 Cross Section of Trench T-1 Site



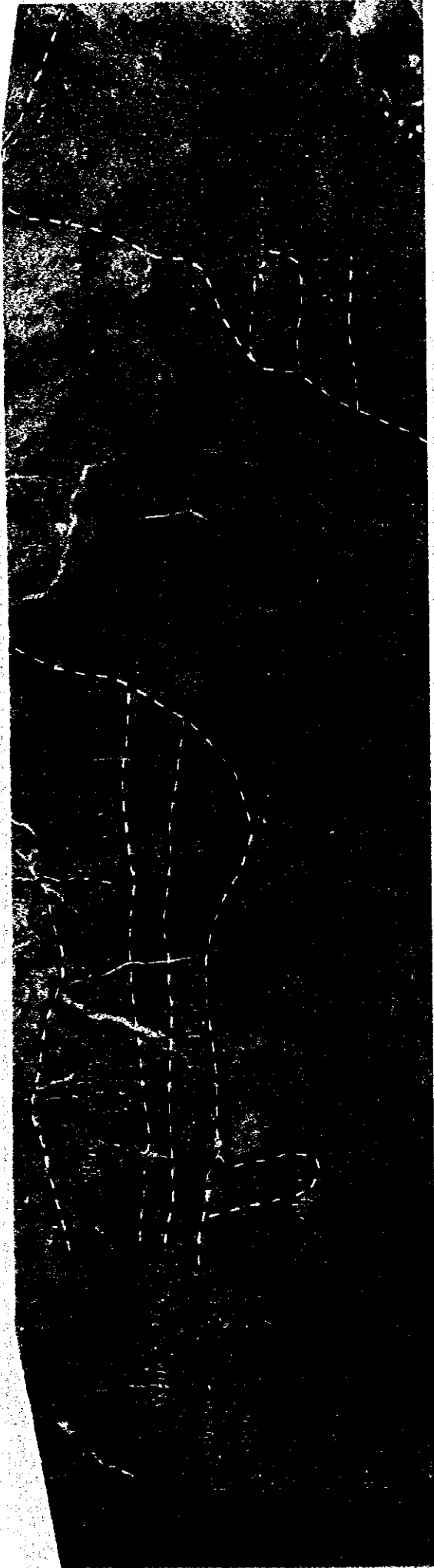
Elution Result		
No.	Code	As (mg/l)
①	T-2-1	0.2
②	T-2-2	110
③	T-2-3	1.0
④	T-2-4	0.9
⑤	T-2-5	0.1
⑥	T-2-6	0.3

Fig 3.13 Cross Section of Trench T-2 Site



Elution Result		
No.	Code	As (mg/l)
①	T-2-1	0.2
②	T-2-2	110
③	T-2-3	1.0
④	T-2-4	0.9
⑤	T-2-5	0.1
⑥	T-2-6	0.3

Fig 3.13 Cross Section of Trench T-2 Site



Elution Result		
No.	Code	As.(mg/l)
①	T-3-1	0.2
②	T-3-2	0.2
③	T-3-3	0.6
④	T-3-4	0.4
⑤	T-3-5	0.4
⑥	T-3-6	nd
⑦	T-3-7	0.5

Fig 3.14 Cross Section of Trench T-3 Site



Elution Result		
No.	Code	As (mg/l)
①	T-3-1	0.2
②	T-3-2	0.2
③	T-3-3	0.6
④	T-3-4	0.4
⑤	T-3-5	0.4
⑥	T-3-6	nd
⑦	T-3-7	0.5

Fig 3.14 Cross Section of Trench T-3 Site



Elution Result		
No.	Code	As (mg/l)
①	T-4-1	0.4
②	T-4-2	0.5
③	T-4-3	0.1

Fig 3.15 Cross Section of Trench T-4 Site



Elution Result	
No.	Code
(1)	T-4-1
(2)	T-4-2
(3)	T-4-3

Fig 3.15 Cross Section of Trench T-4 Site

3.3.2.2 The town concentrator and vicinity

Fig. 3.16 shows the enlarged map of the area. Arsenic concentration in the auger water is expressed by color of the points, while dissolved iron (Fe(II)) concentration is shown by red numbers below the points. The contour line shows a reducing environment by the ORP data. Cross section line for the model (to be discussed at later in the section) is also shown. Auger sampling locations were set at 50-m interval around 21 g and 22 g, which were high in arsenic at reconnaissance survey and supplemented some locations. Arsenic content in the auger waters was at the range of 0.5 to 1.0 mg/l, but high concentration considered as a contamination source was not detected. The highest arsenic concentration of 1.7 mg/l was detected at the point 35, which is near the outflow of the dredging pond at the western edge of the area. Except at this point, there is not a sharp contrast in the arsenic concentration. It is unlikely that small-contaminated sources were scattered. Fig. 3.17 shows the correlation of the arsenic content of the auger water and that of the soil elution test. As for the soil elution test, the highest value was used if there were multiple samples from the same hole. Most of the samples, except some (inside the concentrator and near the dredging pond), have arsenic concentration in the water at around 0.5 mg/l and do not correlate with the soil elution results. This may suggest that arsenic pollution around the town concentrator came from single, large source rather than scattered, small sources. From this viewpoint, this dredging pond received attention as a possible source from its location and size.

Arsenic content of discharged water from the dredging pond was measured in the field and high arsenic concentration at 1.1mg/l was recorded. Therefore, a detailed investigation of the pond was carried out. Fig. 3.18 shows the detailed map of the pond. The investigation included depth, water sampling, field measurement and sediment sampling. Fig. 3.18 also shows the depth profile as well as the sampling locations and arsenic content of the water and sediment. As a result, 3.2 mg/l of arsenic was detected at the deepest site in southeastern part of the pond. The water level of the pond is higher than the groundwater level around the town concentrator. Thus it is thought that the groundwater flow is from the pond to east through the town. This hypothesis is in agreement with the observed distribution of arsenic content in groundwater.

The soil elution test at point 36 inside the town concentrator detected arsenic at 1.6 mg/l. This suggests the concentration waste by roasting process be dumped inside the facility. The waste is subject to arsenic release by rainwater percolation. However since the roof of the concentrator building covers the site, little rainwater was percolated into the soil. Fig. 3.17 as noted above indicates that arsenic in water at this

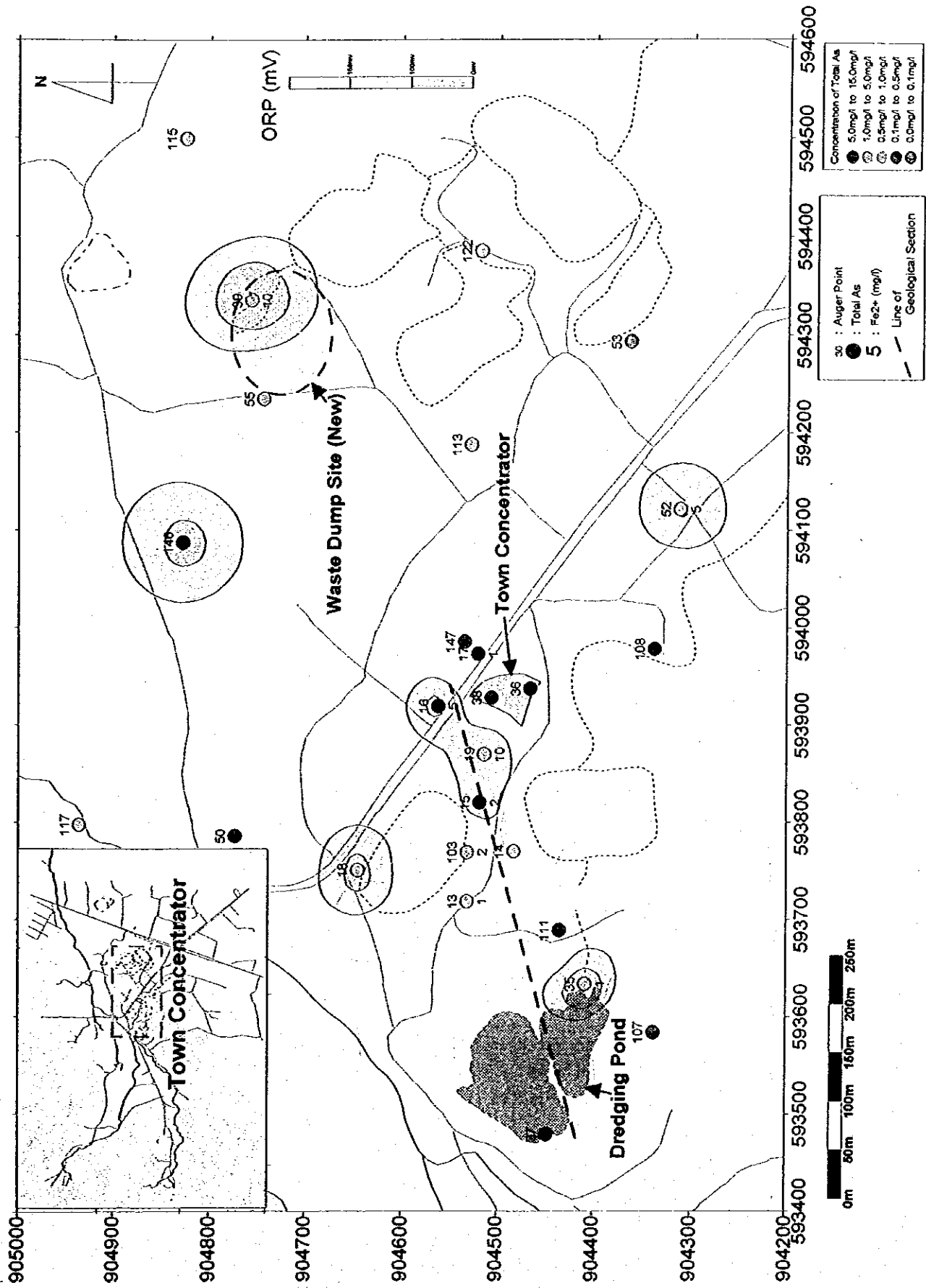


Fig 3.16 Survey Map around the Town Concentrator

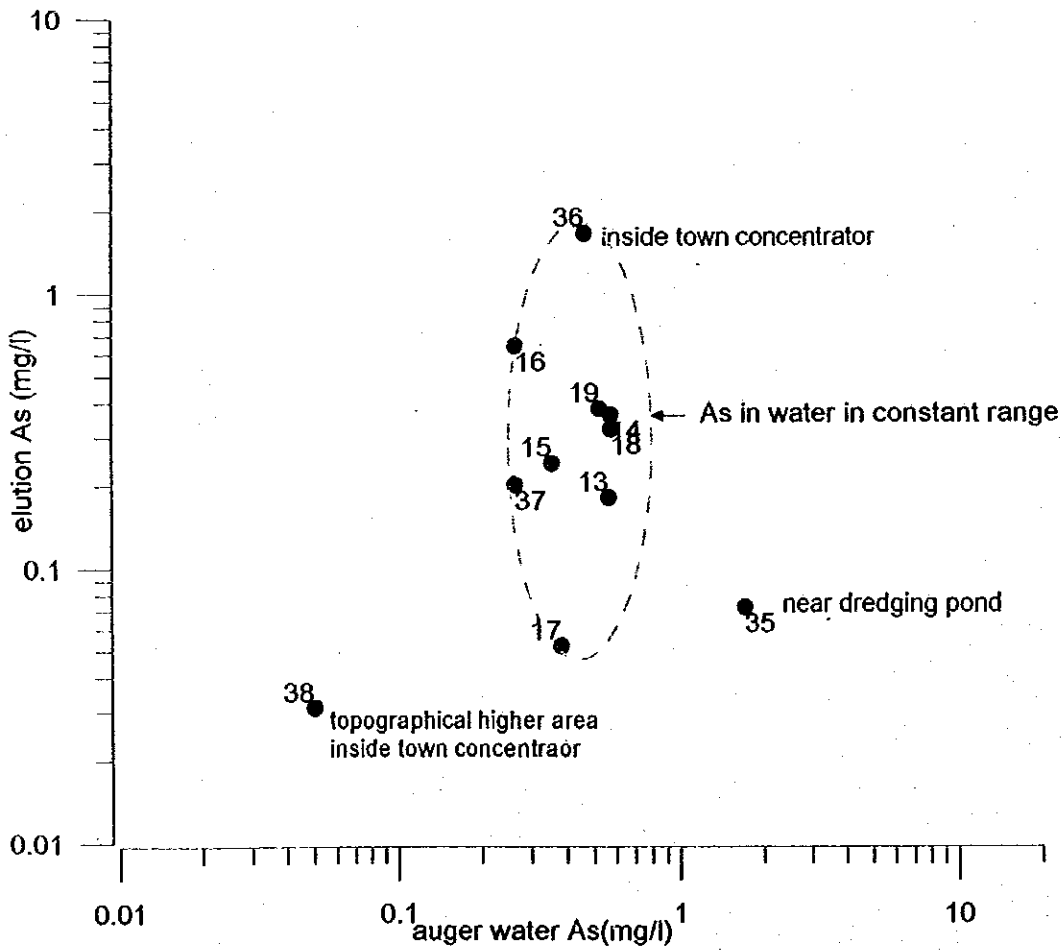
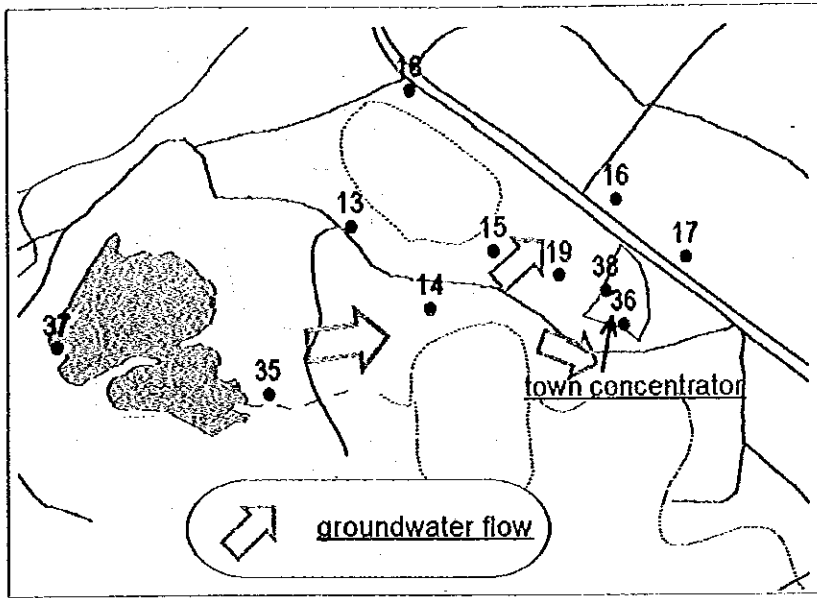


Fig 3.17 Comparison of Arsenic in Soil Elution and Auger Water

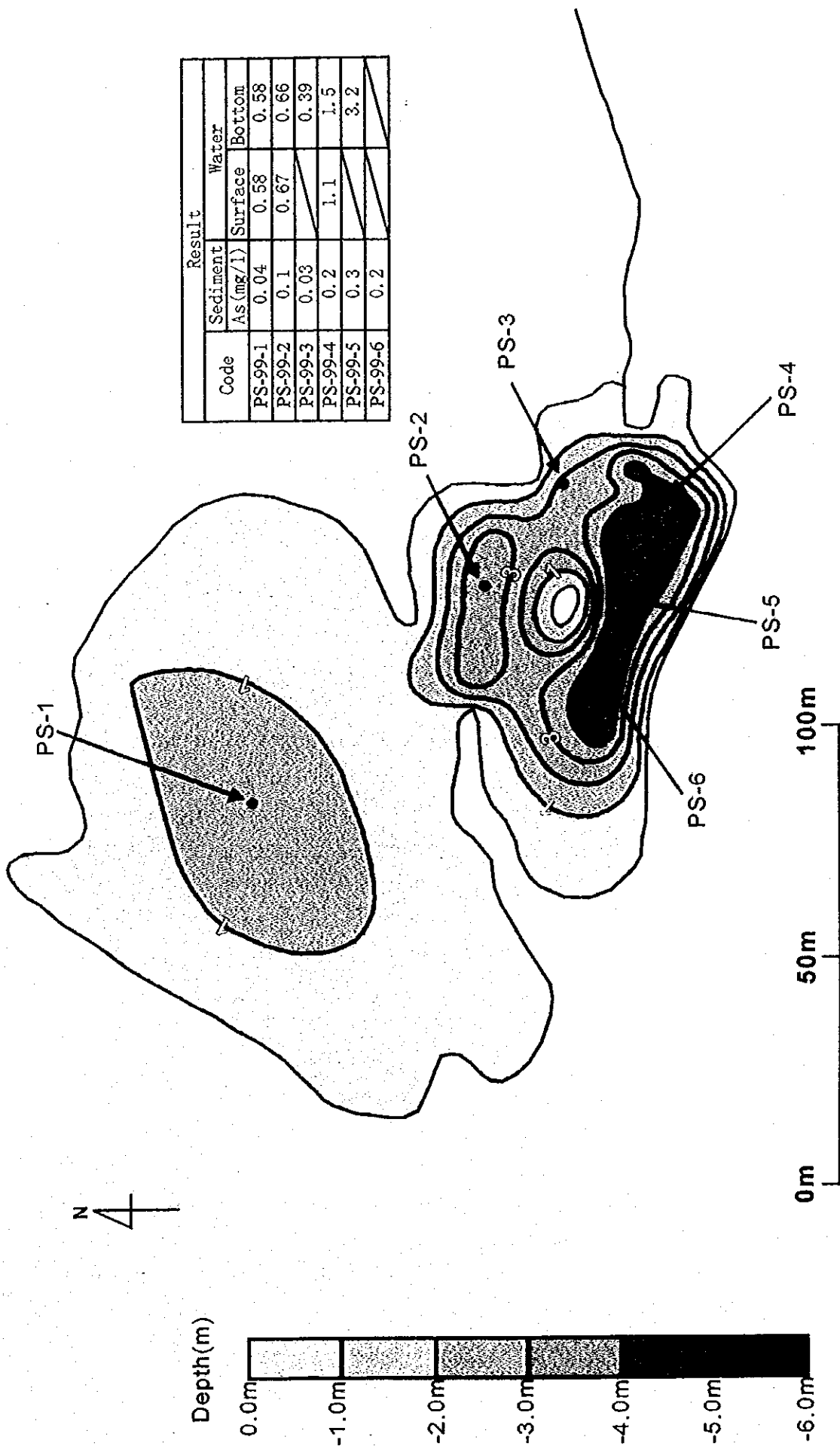


Fig 3.18 Survey Map of the Dredging Pond

point is nearly the same level as other points in the area, in spite of the higher arsenic value by the elution test. This supports the above interpretation. Another point, 38, inside the concentrator showed low arsenic content in both water and soil elution test. This may be due to its location on the outer edge of the concentrator site.

The auger survey, point 39, at the waste dumpsite (new) showed high arsenic of 2.8 mg/l in the water. However, the soil elution data is only 0.14 mg/l. ORP shows a reducing condition of the site.

3.3.2.3 Around site 32C

Fig. 3.19 shows the enlarged map of the site. The arsenic concentration in the auger water is expressed by color of the points, while dissolved iron (Fe(II)) concentration is shown by red numbers below the points. The contour line shows a reducing environment by the ORP data. Cross section line for the model (to be discussed in a later section) is also shown. The location of trench is shown in the partial enlarged map. The auger point was set around the site 32C where the high arsenic had been detected during the reconnaissance survey

The zone with high arsenic content over 1 mg/l is well correlated with the low ORP zone. The arsenic content decreases toward away from the central high point. This confirmed that the zone is the contaminated source.

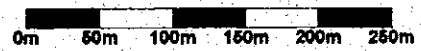
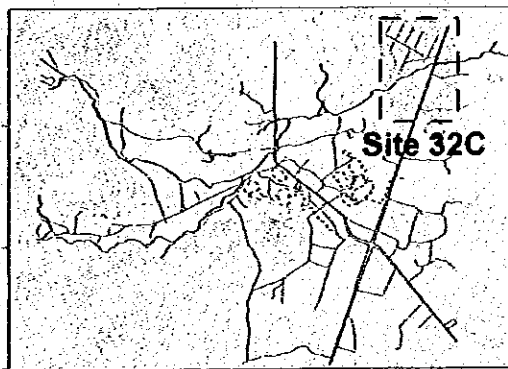
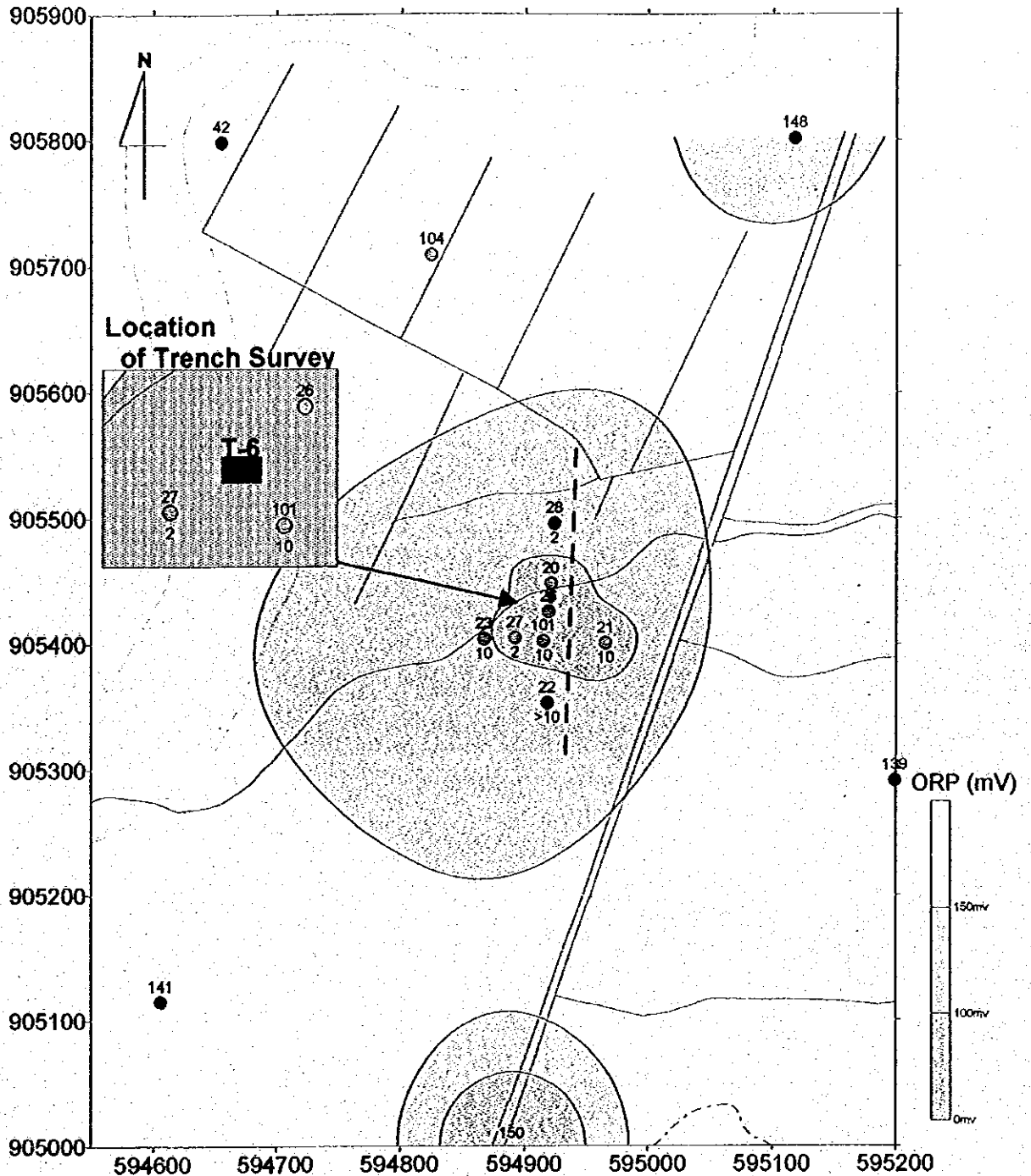
Fig. 3.20 shows the cross section photograph of the trench. Approximately 1 m from the ground surface is covered by a layer, which contained white clay. The layer is considered to be soil brought in from outside. The layer contains swelling clay, which adsorbs water and becomes extremely sticky. As noted before, the air sealing by this clay can explain the low ORP. Soil elution test did not detect high arsenic. Below the surface layer is a reddish soil rich in Fe oxide. This soil is the same as the lateritic soil that is widely distributed in the shooting range northwest of the site.

3.3.2.4 Around site 32L

Fig. 3.21 shows the enlarged map of the area. In the middle of the area, there is dressed soil with dimensions of 2 m thick, 20 to 30 m wide and 150 m long.

High arsenic in the auger water is distributed along this dressed soil zone. The highest arsenic of over 10 mg/l was detected. The soil elution test also detected high arsenic. There are also points high in dissolved Fe(II) ions with low ORP, but their location did not correlate well with the high arsenic zone.

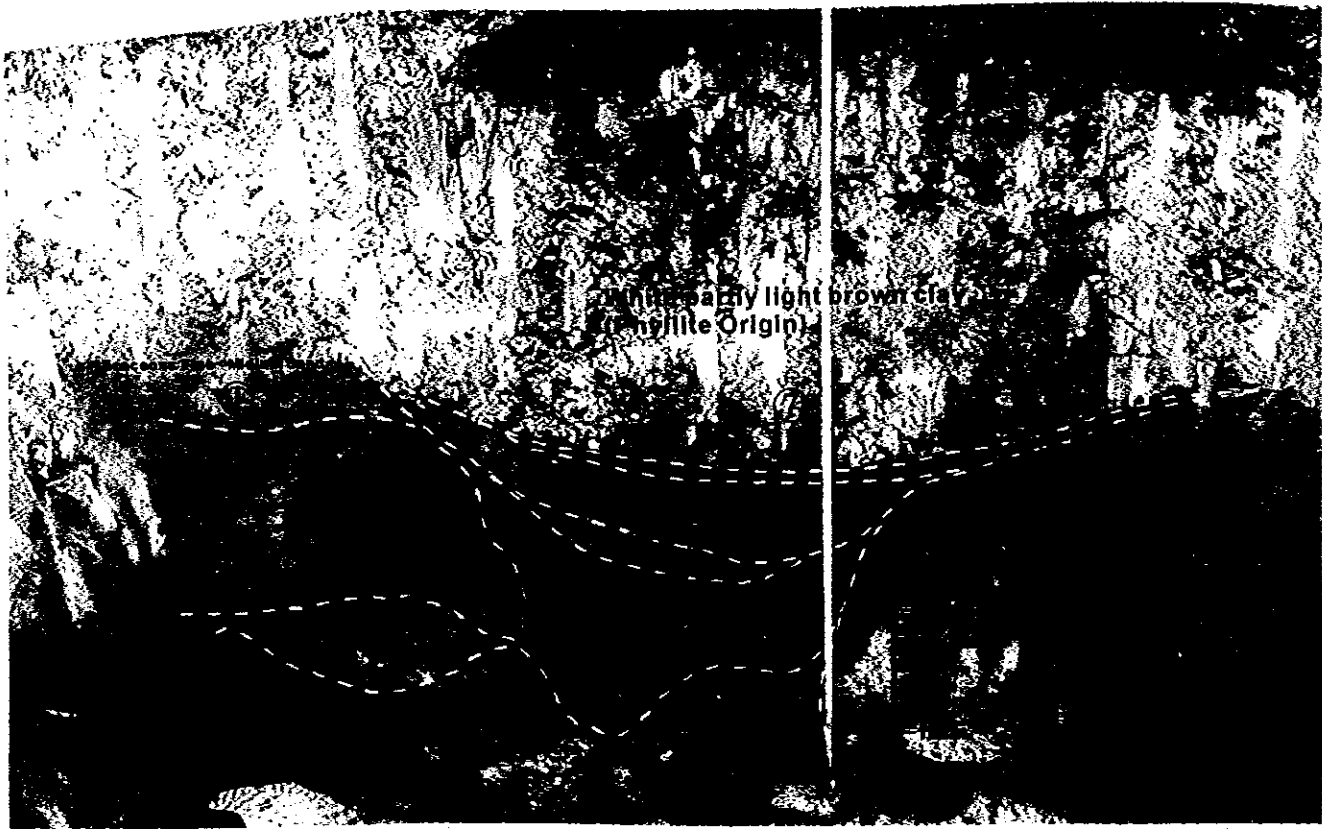
The dressed soil contains much gravel and is considered to be brought in from outside. It is estimated that the contaminated waste was included in the soil brought in



- 30 : Auger Point
- : Total As
- 5 : Fe²⁺ (mg/l)
- - - : Line of Geological Section

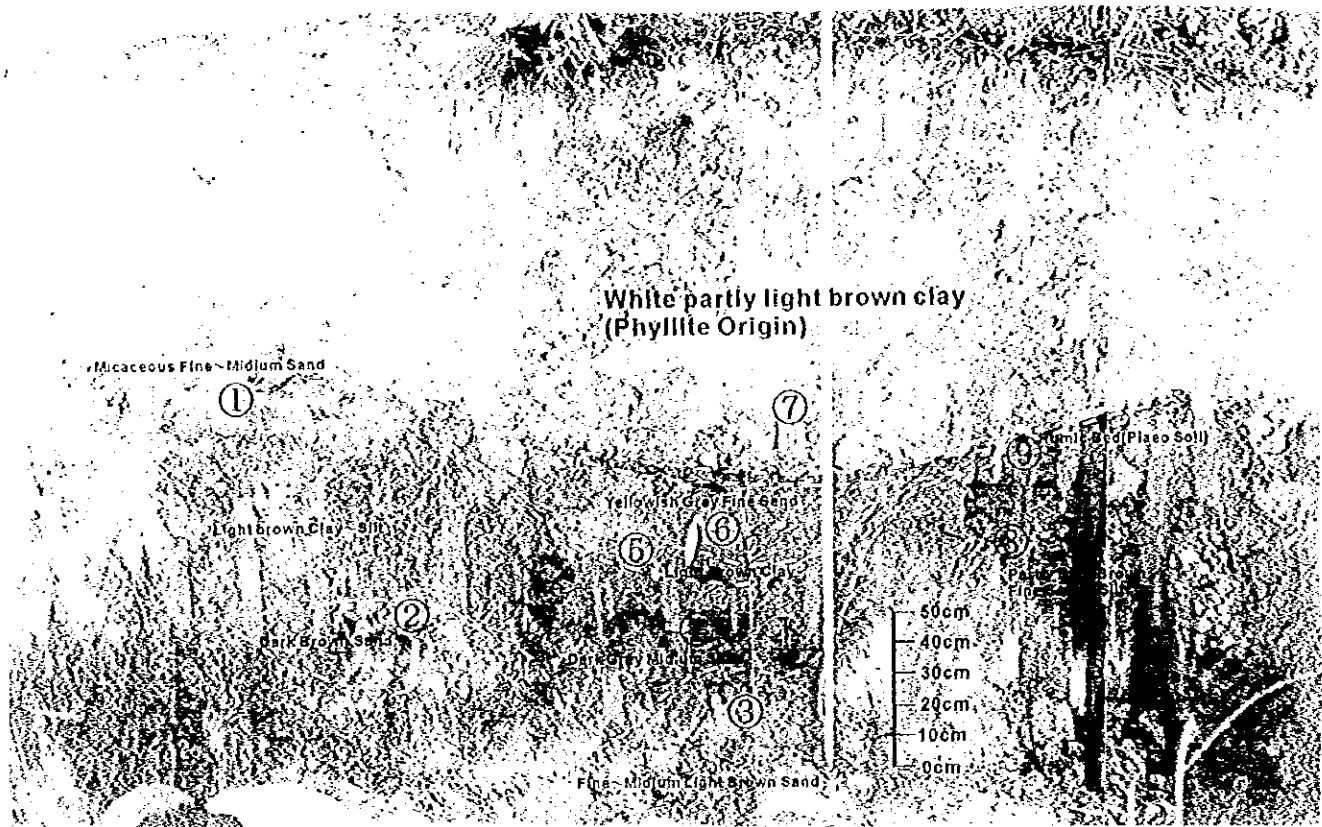
- Concentration of Total As
- : 5.0mg/l to 15.0mg/l
 - ⊙ : 1.0mg/l to 5.0mg/l
 - ⊗ : 0.5mg/l to 1.0mg/l
 - : 0.1mg/l to 0.5mg/l
 - : 0.0mg/l to 0.1mg/l

Fig 3.19 Survey Map around the site 32C



Elution Result					
No.	Code	As (mg/l)	No.	Code	As (mg/l)
①	T-6-1	3.3	⑥	T-6-6	0.1
②	T-6-2	0.4	⑦	T-6-7	0.0
③	T-6-3	0.7	⑧	T-6-8	0.2
④	T-6-4	0.2	⑨	T-6-9	0.3
⑤	T-6-5	0.1	-	-	-

Fig 3.20 Cross Section of Trench T-6 Site



Elution Result					
No.	Code	As (mg/l)	No.	Code	As (mg/l)
1	1-6-1	3.3	6	1-6-6	0.1
2	1-6-2	0.1	7	1-6-7	0.0
3	1-6-3	0.7	8	1-6-8	0.2
4	1-6-4	0.2	9	1-6-9	0.3
5	1-6-5	0.1			

Fig 3.20 Cross Section of Trench T-6 Site

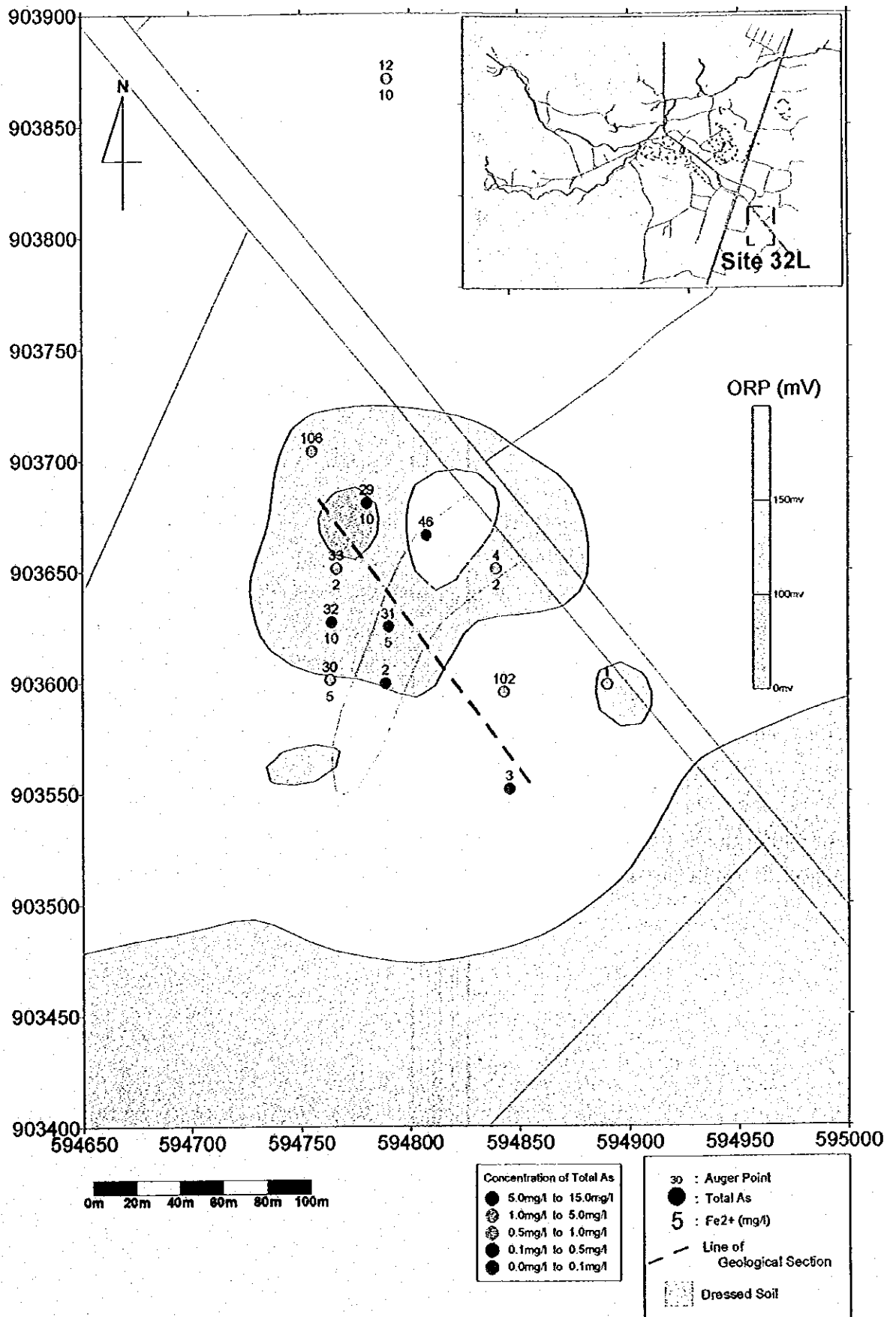


Fig 3.21 Survey Map around the Site 32L

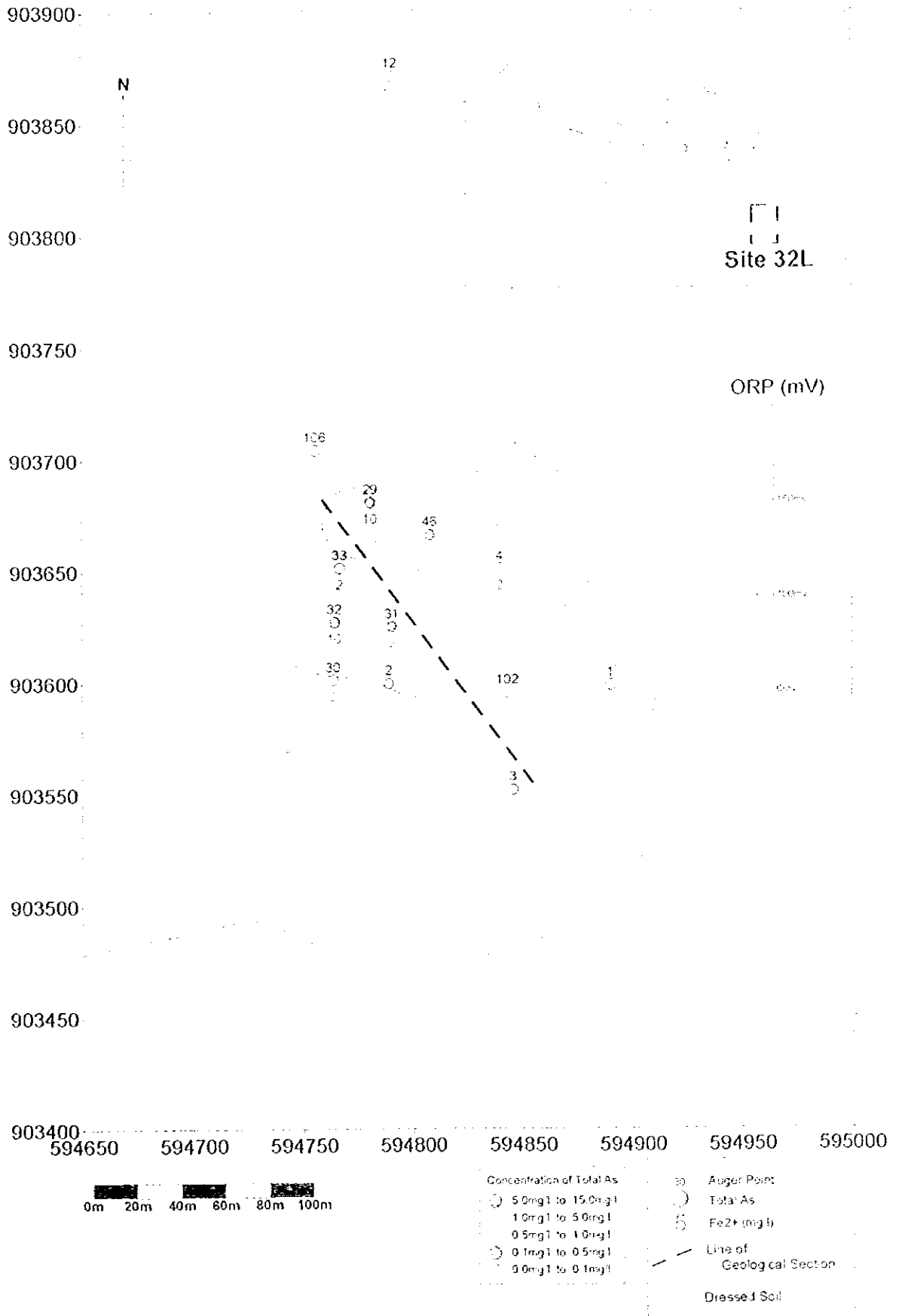


Fig 3.21 Survey Map around the Site 32L

from outside.

3.3.2.5 Others

Arsenic contents of the water in other dredging ponds in the area were measured. Locations of the sampled ponds are shown in Fig. 3.22. For reference purposes, the water of the dredging pond outside of the survey area at Ban Thing Kha in the north and Nongphet in the south were also sampled. Water was sampled at near the outflow of the ponds at the depth of 1 to 2 m. The table below shows the result.

Table 3.3 Arsenic in dredging ponds

POND	1	2	3	4	5	6	7
As (mg/l)	1.1	0.37	0.29	0.14	0.041	0.081	0.055

The dredging pond 2 showed relatively high arsenic at 0.37 mg/l but it can not be considered as a contaminated source, because it is downstream of the dredging pond 1 and directly receives the high arsenic water from the pond 1. The dredging pond 3 with 0.29 mg/l of arsenic is located near the waste dumpsite (new), which is considered as a contamination source and is also downstream of the contaminated groundwater. Therefore, the new waste dumpsite is likely to be a contamination source of the pond 3. Other ponds were relatively low in arsenic content and thus they can not be considered as an arsenic source.

High arsenic in auger water was observed along the highway near the southern edge of the survey area. The map showing survey results are in Fig. 3.23. There is a pig farm and swamp upstream. High arsenic concentration starts at this zone.

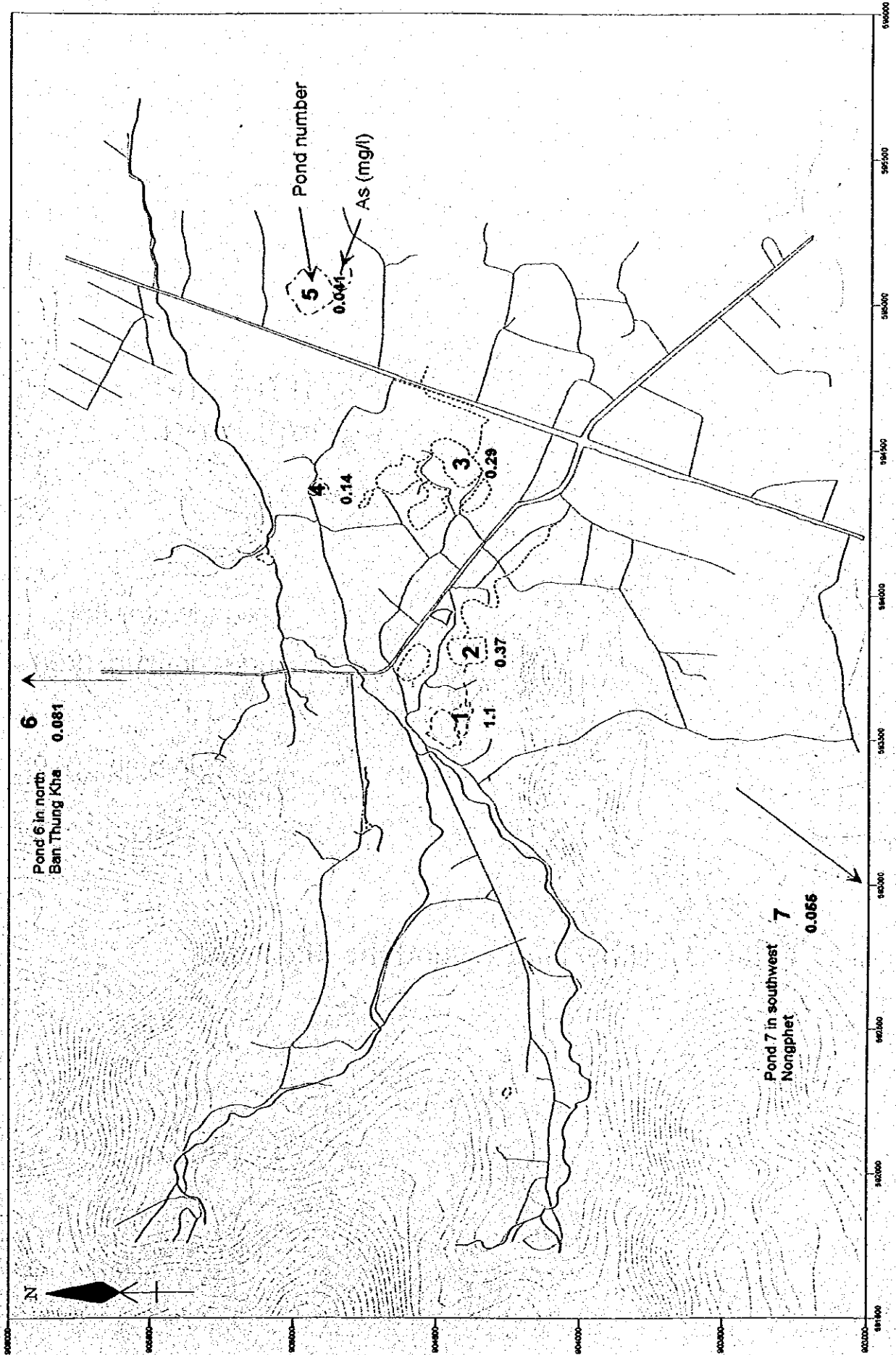


Fig 3.22 Arsenic Concentration in Dredging Ponds

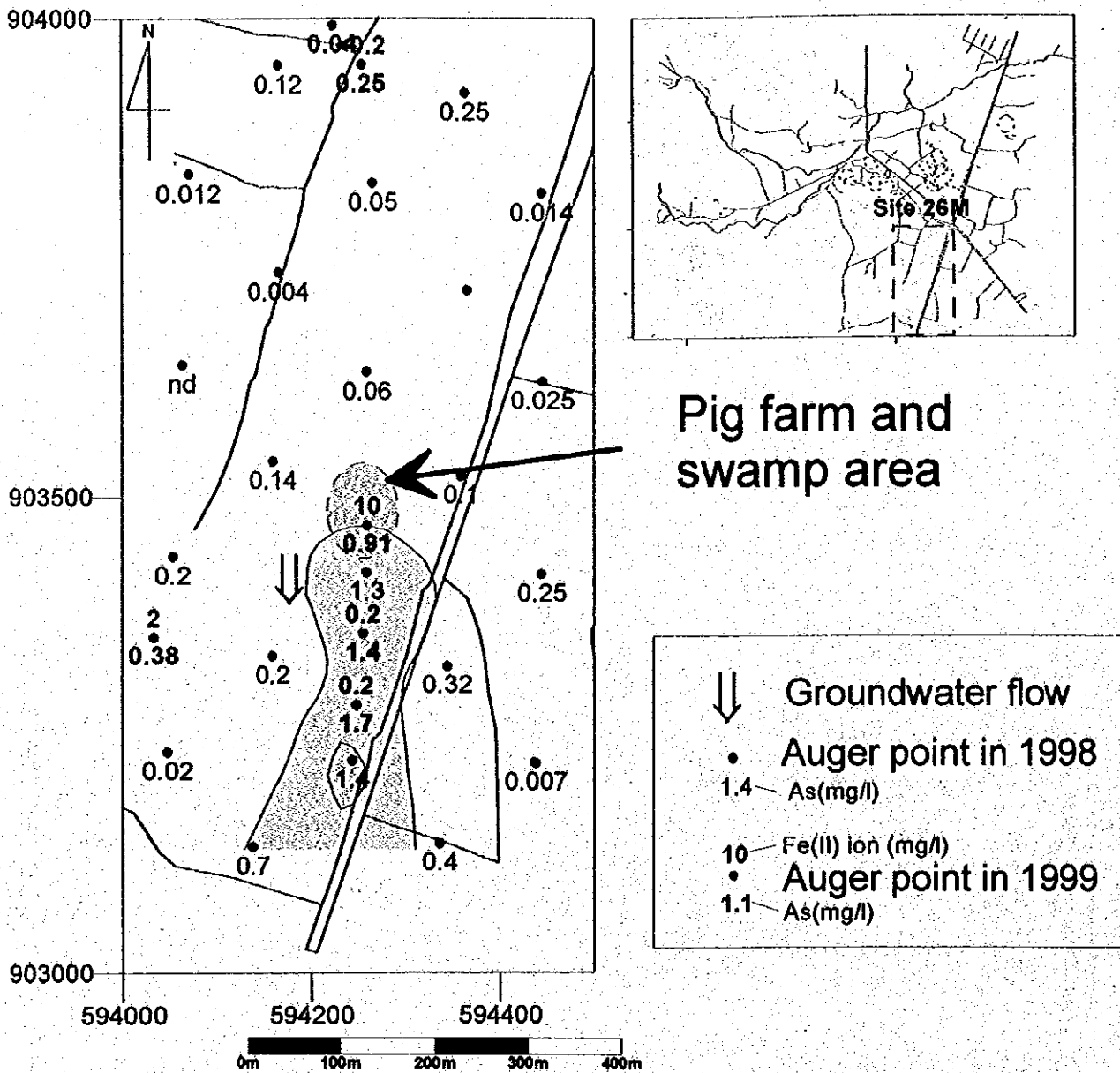


Fig 3.23 Survey Map around the Site 26M

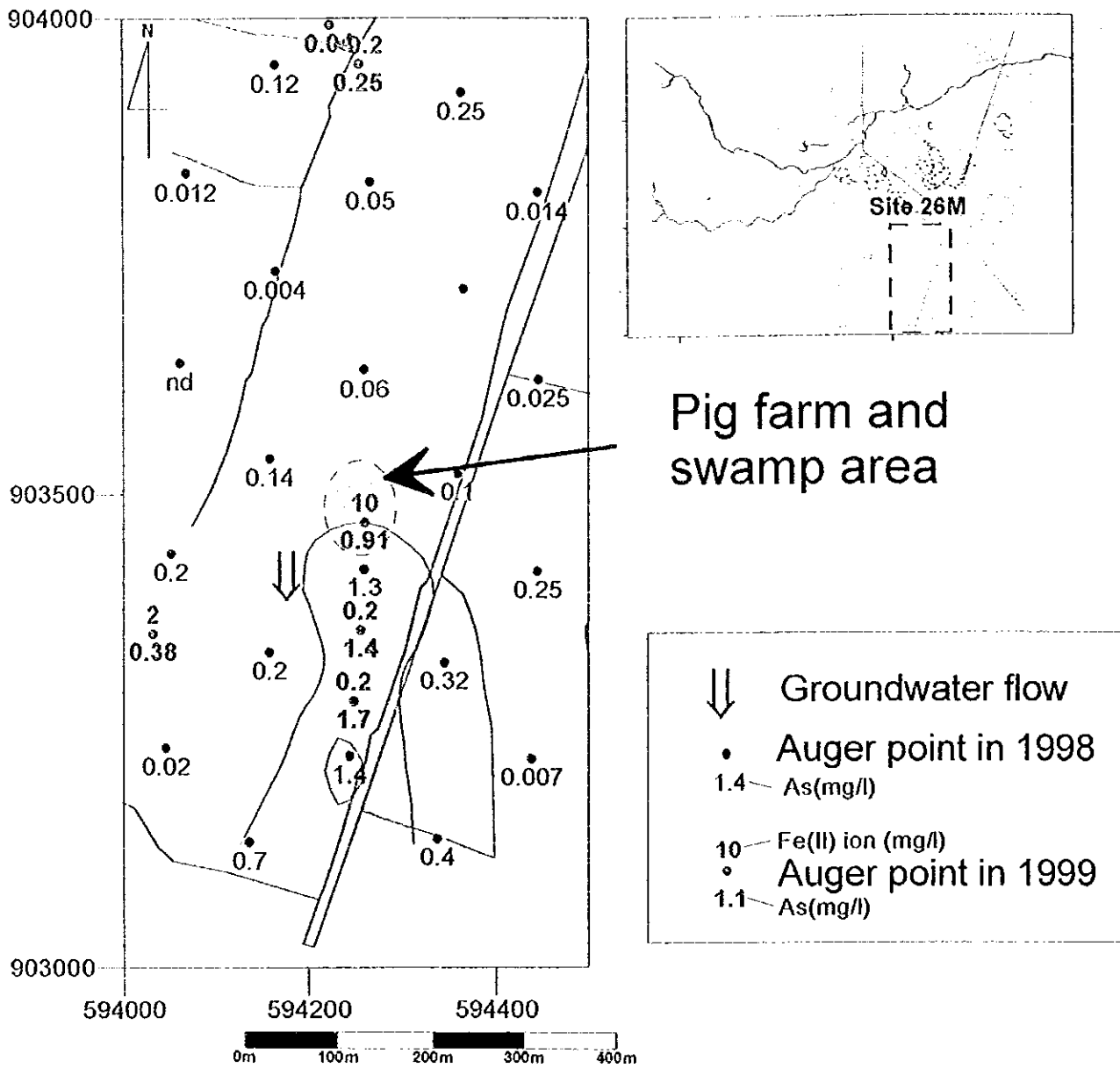


Fig 3.23 Survey Map around the Site 26M

4. Mechanism of arsenic release from a contaminant source

4. Mechanism of arsenic release from a contaminant source

Fig. 4.1 summarizes the study flow and resulting maps.

4.1 Sequential extraction of soil and geochemical phase of arsenic

When arsenic is concentrated in the sedimentary strata, generally it is in the form of sulfide such as arsenopyrite, or co-precipitated with or adsorbed onto oxide/hydroxide of Fe and Mn. Conventional elution test of the soil can detect As_2O_3 included in the roasting waste but it can not easily detect arsenic in sulfide or in oxide/hydroxide of Fe and Mn. That means the elution test alone may not be able to identify the contamination source and even if it could, it is difficult to clarify mechanism of the arsenic release. From this viewpoint, sequential extraction of soil sample was carried out to find the geochemical phase of arsenic to identify the contamination source and clarify the arsenic release mechanism. Sequential extraction was done for the following five steps. That is,

- step 1 Water soluble
- step 2 Ion exchangeable
- step 3 Sorbed and organic
- step 4 Sulfide
- step 5 Fe and Mn oxide

step 1 is the elution test. The following treatment was done after step 2

step 2 1 M ammonium acetate. Shake one hour at pH=7.

step 3 0.1 M sodium pyrophosphate. Adjust to pH=7 by orthophosphoric acid.
Shake 15 hours.

step 4 1 M sodium hypochlorite. Adjust to pH=9.5 by 6 M HCl.

Shake 10 hours. Repeat. Adjust to pH=3 by 1.5 M HCl and wash by distilled water

step 5 1M Hydroxylamine hydrochloride. Adjust to pH=5 by sodium citrate.
Shake 1 hour. Repeat.

The above sequential extraction procedure can not assure that the 100% extraction of the target phase. This survey focused on sulfide and Fe and Mn oxide phases. Fe and Mn oxide phases can be considered for two portions. The portions are arsenic that is co-precipitated with Fe and Mn oxides and included in the structure, and arsenic that is adsorbed onto the surface of Fe and Mn oxide. The former will be detected in step 5, while the latter will be detected in step 3.

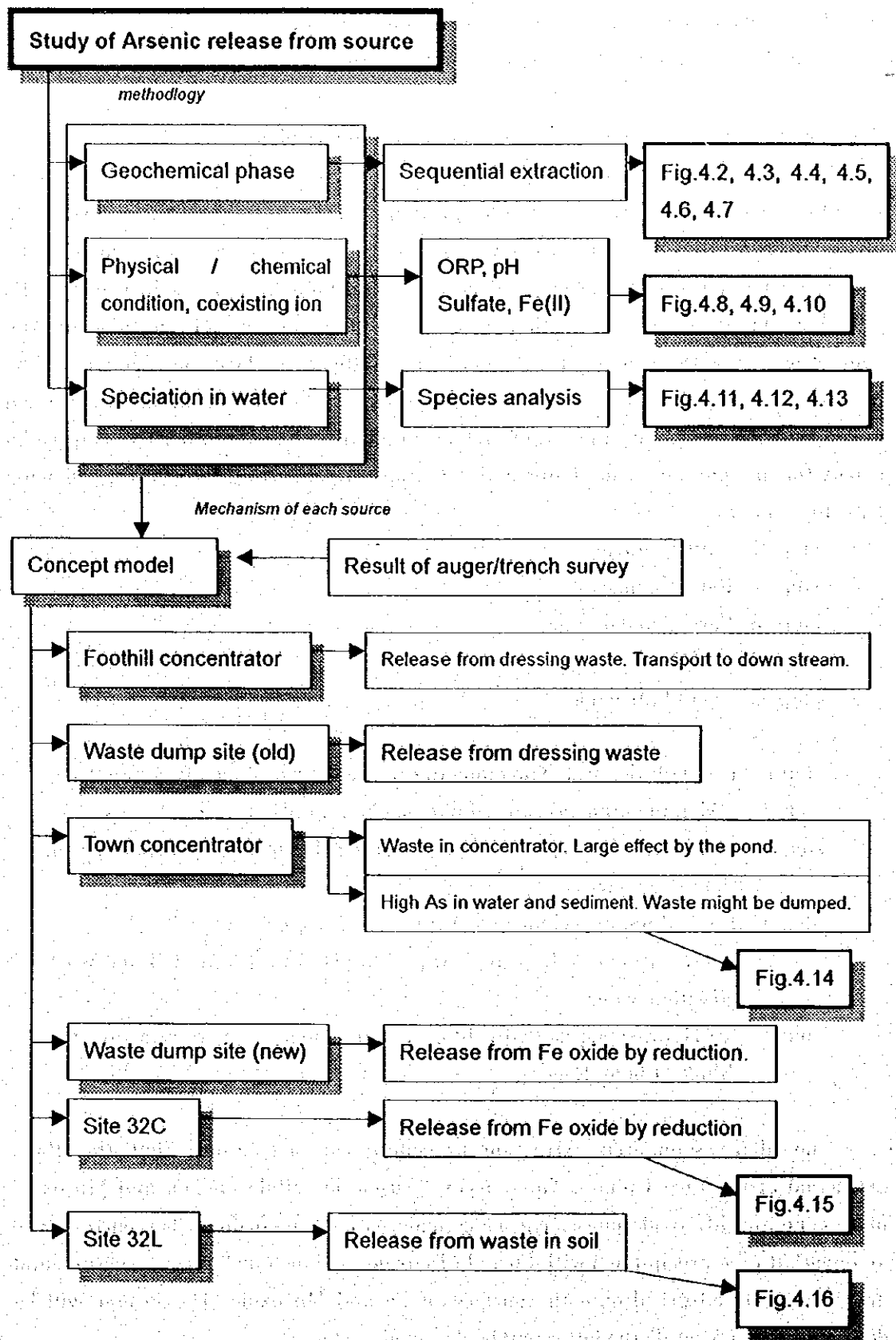


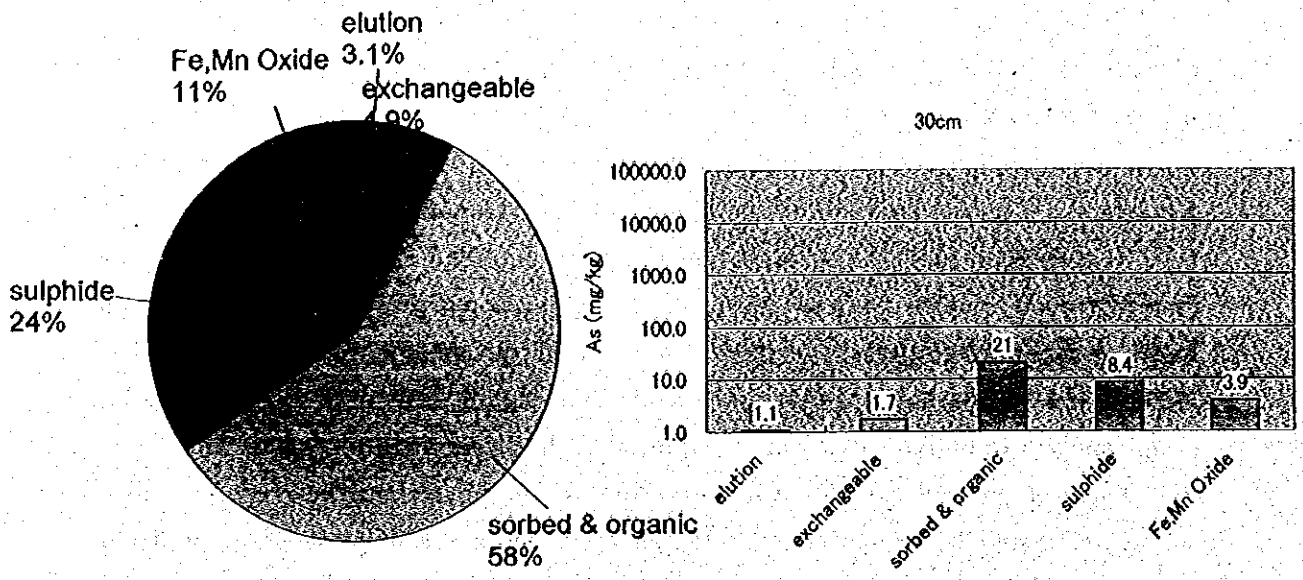
Fig.4.1 Survey Flow of Arsenic Release Mechanism Study

Simplified interpretation is dangerous except for the first step. A high composition of water-soluble and ion exchangeable phase can be considered as the contribution of As_2O_3 from the roasting process waste. While the high composition of the sulfide phase can be considered as the contribution from mining and concentration waste. Sorbed and organic phase, and Fe and Mn oxide phase can be considered as the contribution of the natural concentration process in sedimentary strata. The sequential extraction as described above was tested in the laboratory for replication precision and was confirmed its level of data quality. The data can be used to compare individual samples. Therefore, if the geochemical phase of the soil varied significantly in the nearby samples, it may suggest the mixing of the artificial input such as concentration waste.

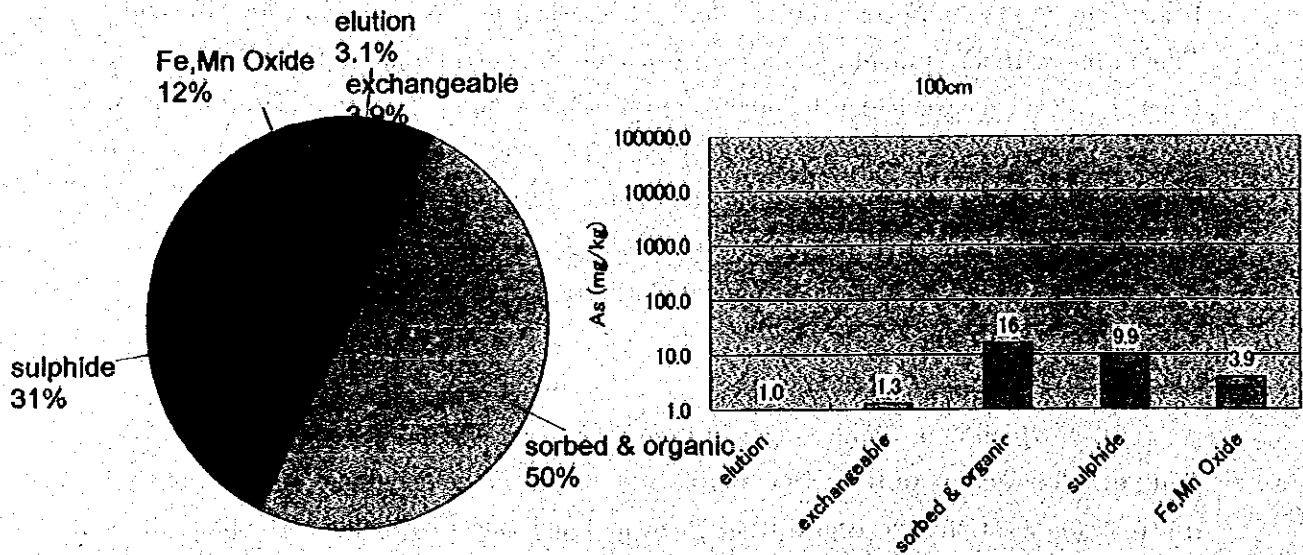
Forty of the soil samples were used for the elution test in the reconnaissance survey and tested for sequential extraction. Average geochemical phases of soil at 30 cm and 100-cm depths are shown as a pie graph in Fig. 4.2. The absolute concentration level was also shown as a bar graph beside the pie graph. For both the 30-cm and 100 cm depth cases, arsenic in water-soluble phase (elution) is only 3% of the total. The absolute concentration is around 1 mg/kg. On the other hand, sorbed and organic phase in step 3 reaches 59% at the 30-cm depth and 51% at the 100-cm depth. As discussed before, this phase may come largely from the sorbed portion onto Fe and Mn oxide. Combining with Fe and Mn oxide phase in step 5, contribution of Fe and Mn oxide reaches 70% at the 30-cm depth and 63% at the 100-cm depth. This means that it is over 20 times more than the water-soluble phase. The fact confirmed that studying soil pollution by arsenic only by the elution test is not sufficient. The sulfide phase is 24% at the 30-cm depth and 31% at the 100-cm depth.

Typical examples of the geochemical phase from contaminated sources surveyed at the detailed investigation are shown in Fig. 4.3, 4.4, 4.5 and 4.6. The locations of the samples were also shown in Fig. 4.7.

T-1-7, which is a sample collected from trench at the foothill concentrator, shows that 90% of arsenic is in the water-soluble and ion exchangeable phase suggesting that it is roasting waste from concentration. The combined concentration of both phases high at 1,180 mg/kg. Similarly T-1-10 shows 98% of arsenic in sorbed and organic phase at extremely high concentration at 35,000 mg/kg. These facts, varying geochemical phase and very high arsenic indicates various concentration wastes were mixed and dumped at the site. Samples from another trench in front of the foothill concentrator, T-2-2 and T-2-4 gave similar result. Trench sample T-3-6 at the downstream shows 90% of arsenic in sorbed and organic phase and Fe and Mn oxide phase at high concentration of 1,000 mg/kg. Arsenic is considered to be diffused or transported from concentrator waste.

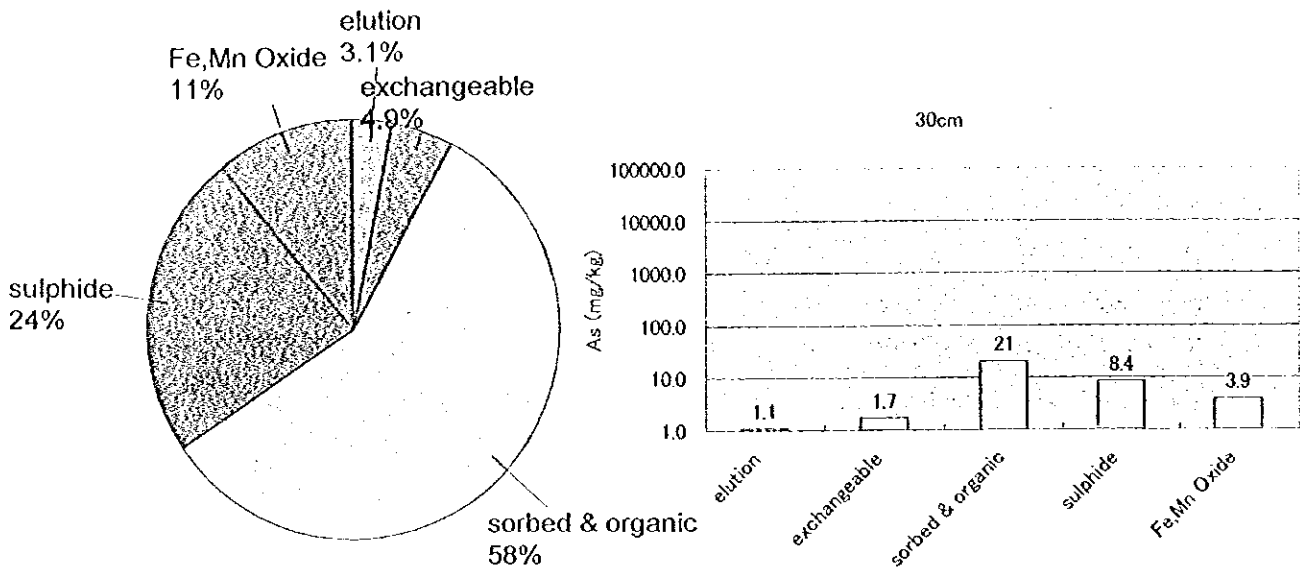


average of 30cm depth

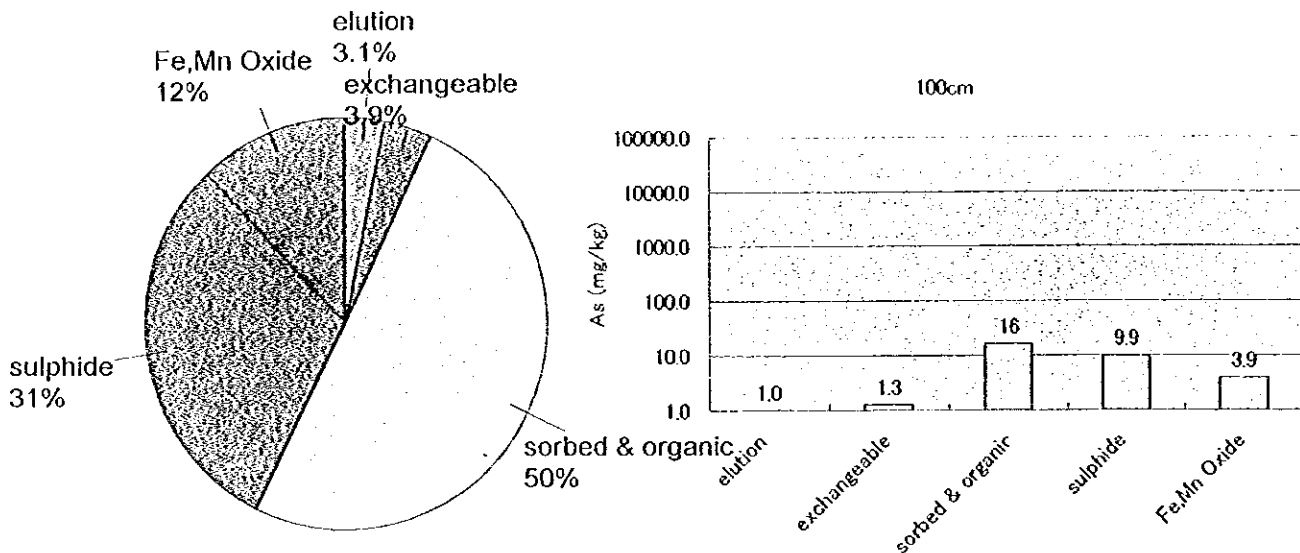


average of 100cm depth

Fig 4.2 Geochemical Phase of Soil Samples (1998)

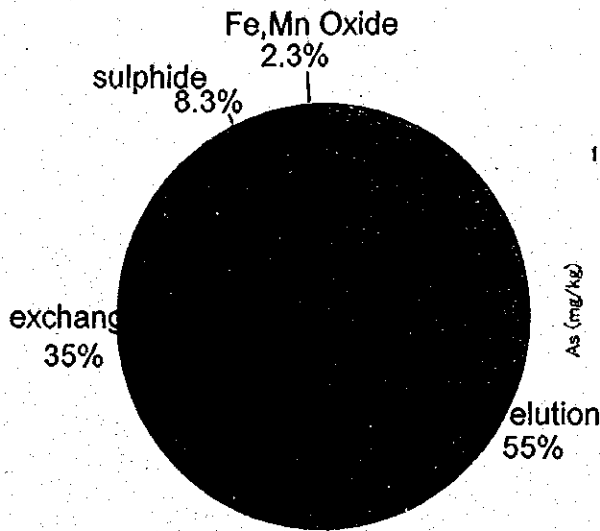


average of 30cm depth



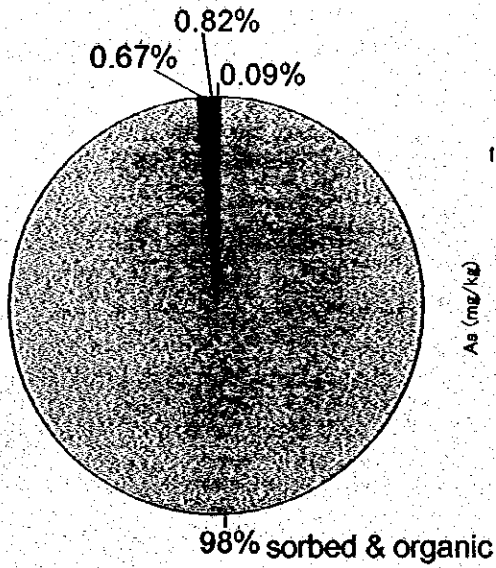
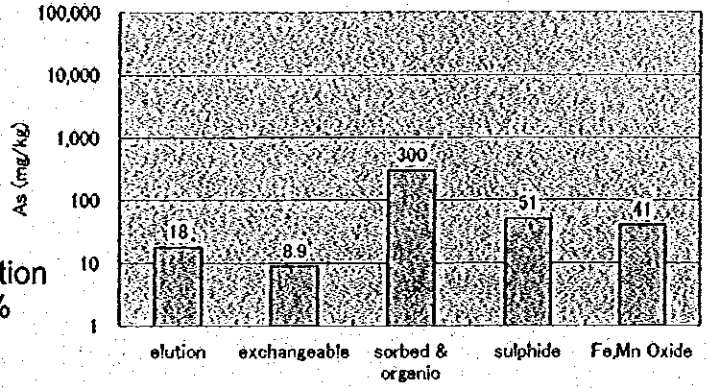
average of 100cm depth

Fig 4.2 Geochemical Phase of Soil Samples (1998)



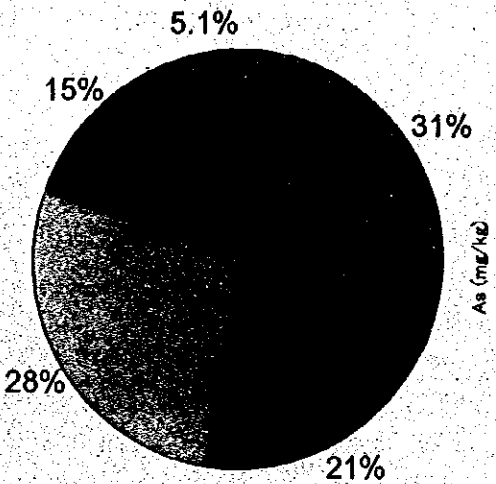
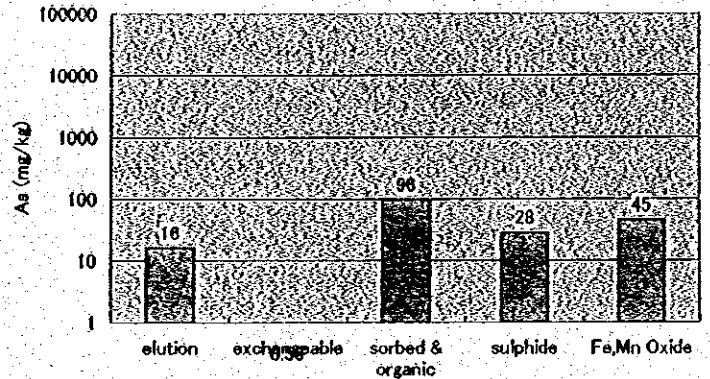
Foothill Concentrator

AS-99-34-1



Foothill Concentrator

AS-99-36-2



Foothill Concentrator

PS-99-5

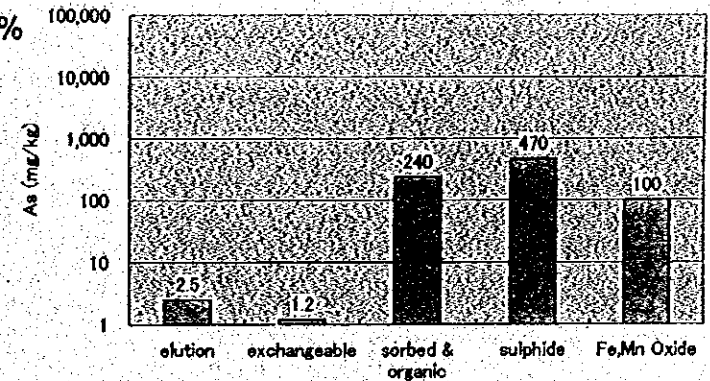
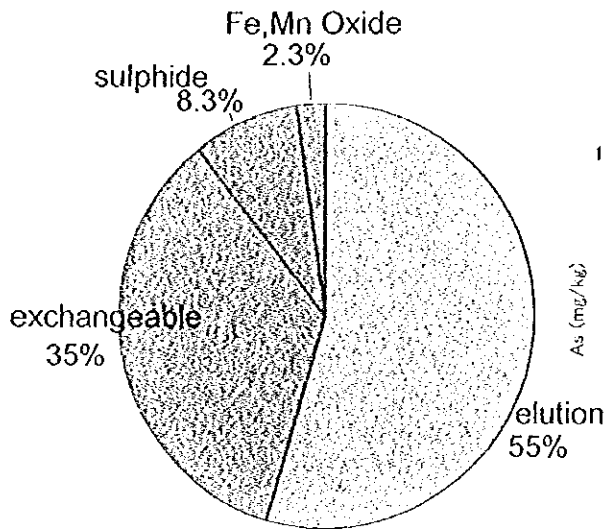
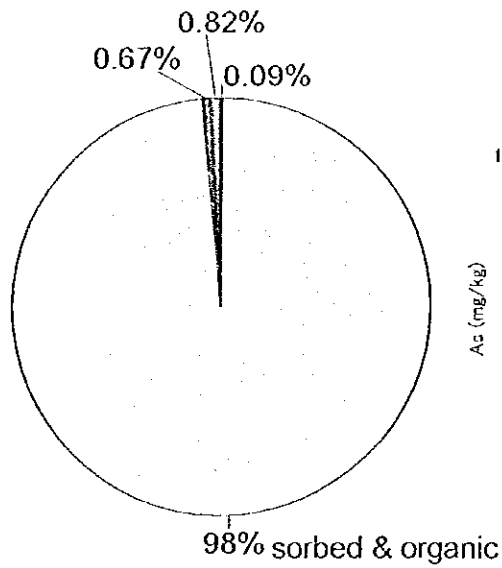
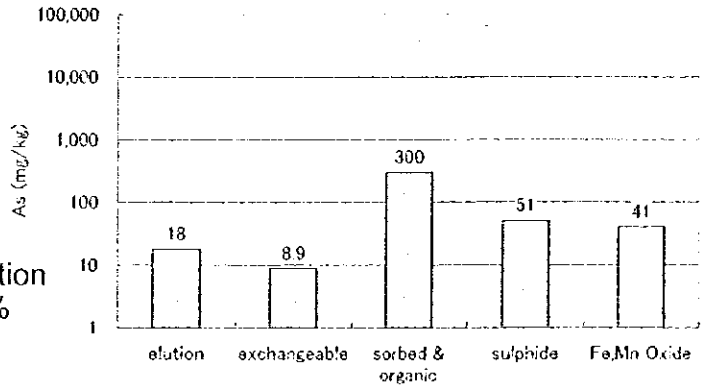


Fig 4.3 Geochemical Phase of Soil at Source Sites (1)



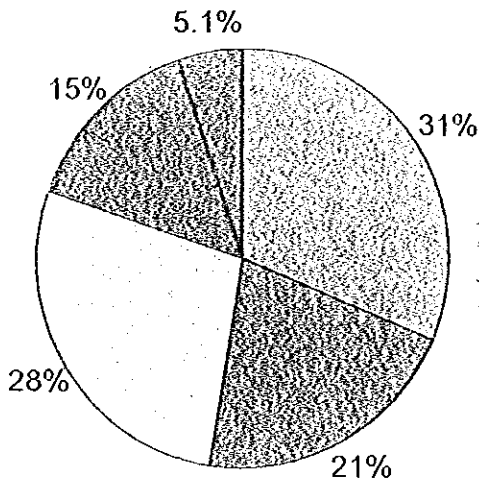
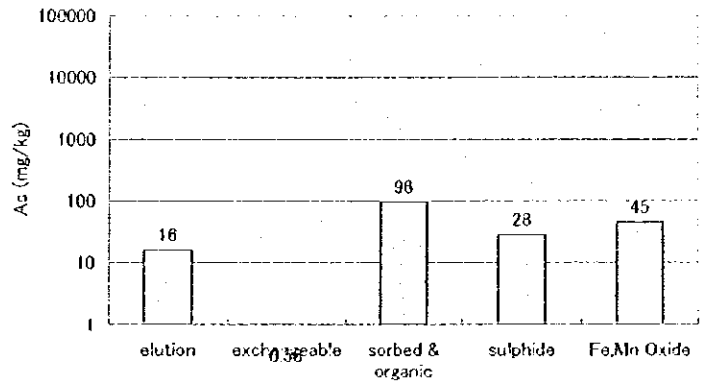
Foothill Concentrator

AS-99-34-1



Foothill Concentrator

AS-99-36-2



Foothill Concentrator

PS-99-5

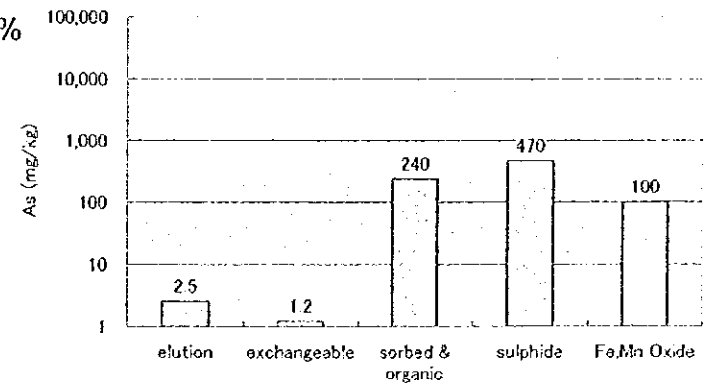
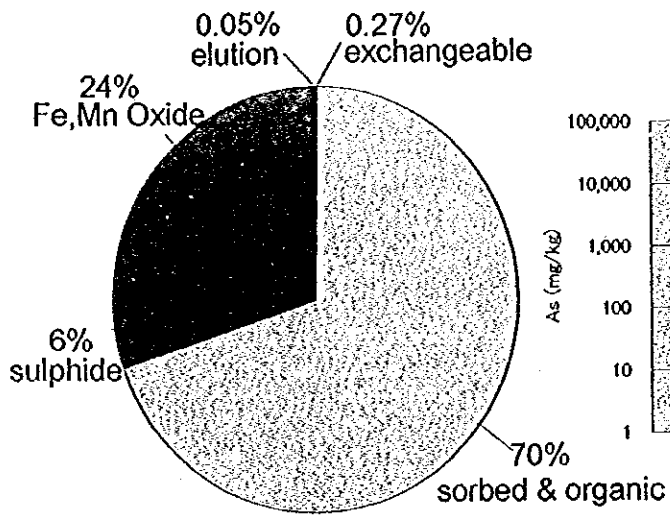
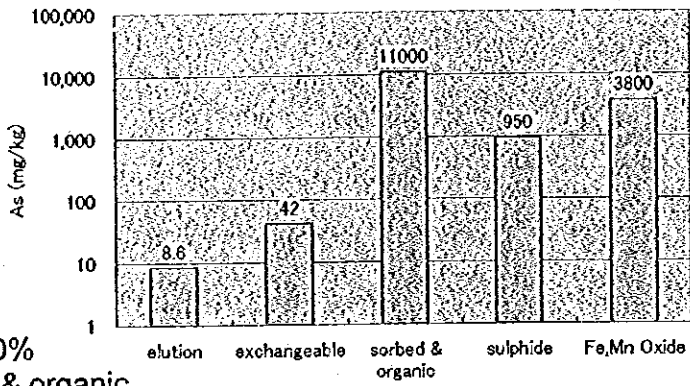


Fig 4.3 Geochemical Phase of Soil at Source Sites (1)



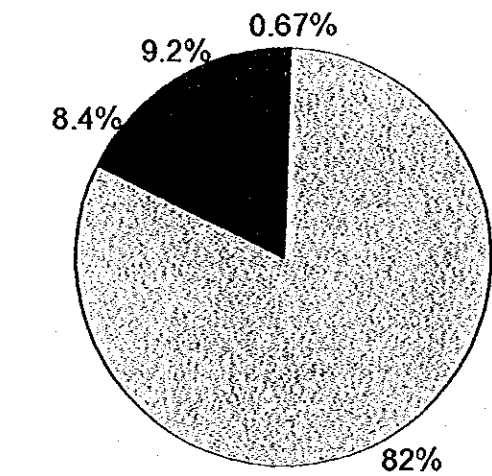
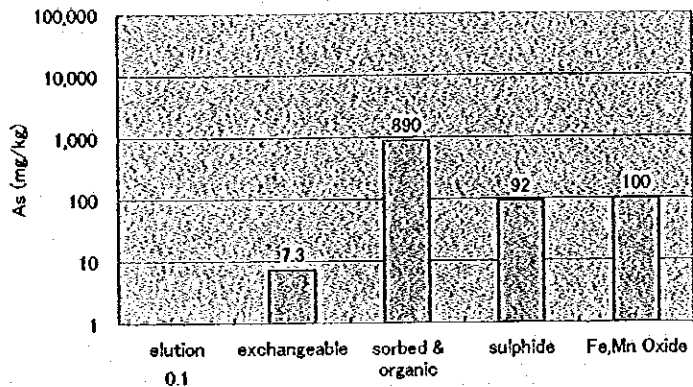
Foothill Concentrator

T-2-4



Downstream of Foothill Concentrator

T-3-6



Around the site 32C

T-8-2

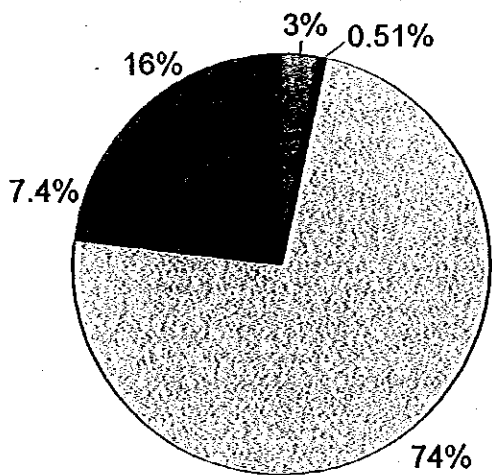
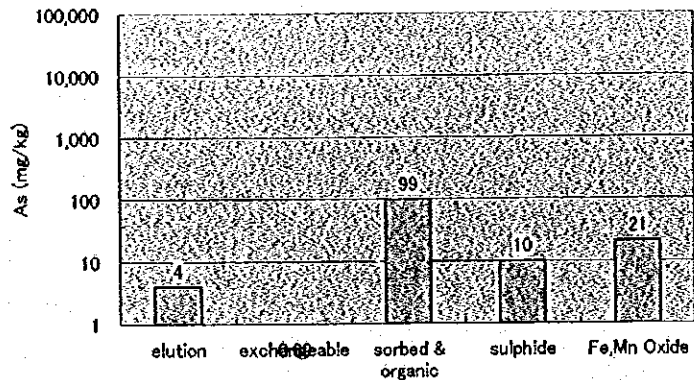


Fig 4.4 Geochemical Phase of Soil at Source Sites (2)

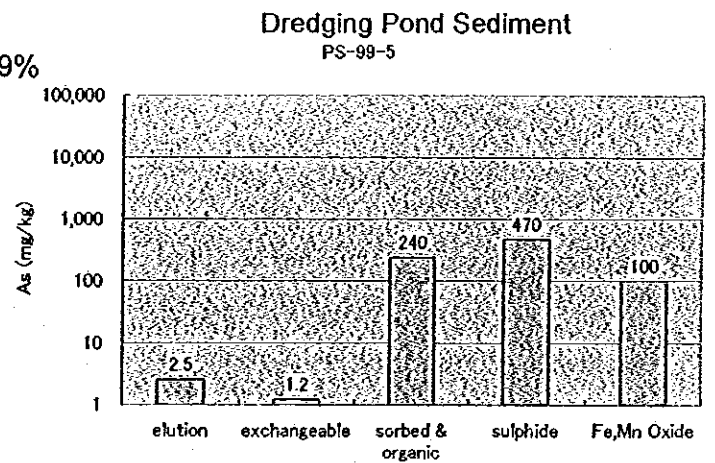
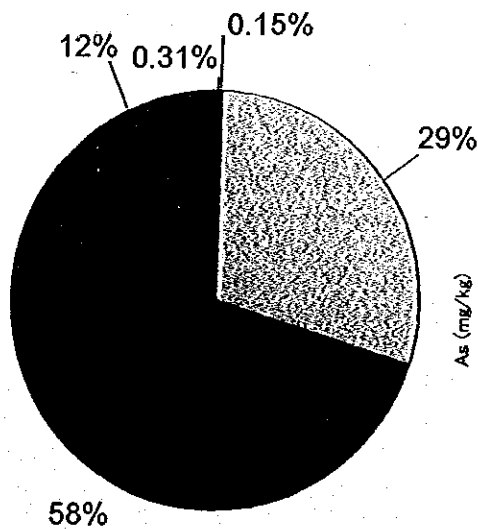
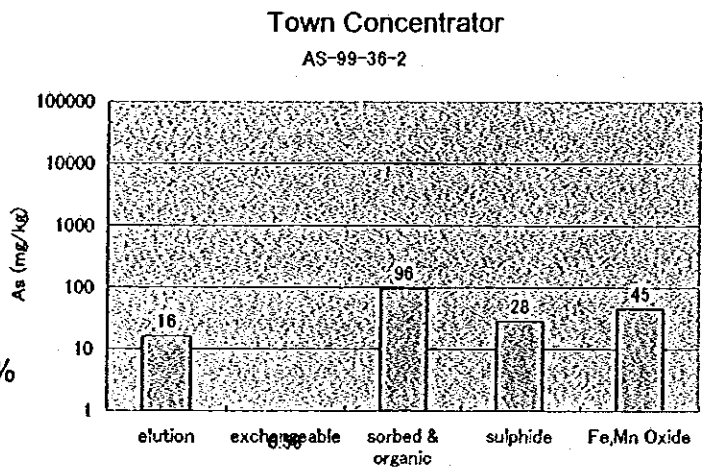
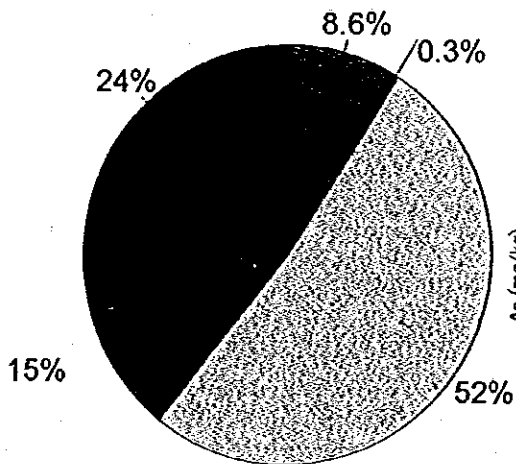
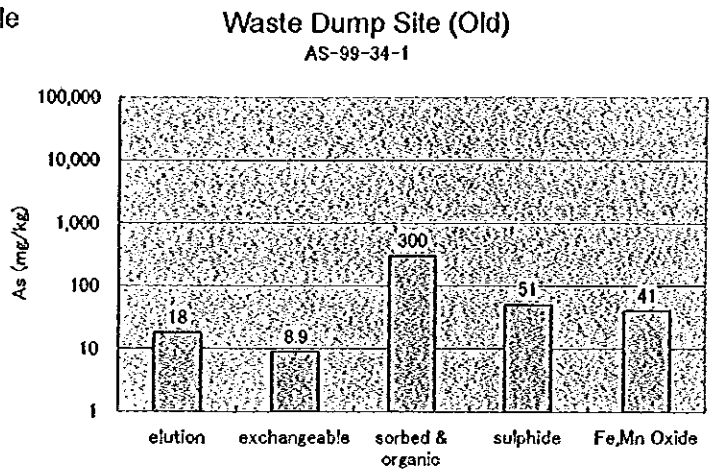
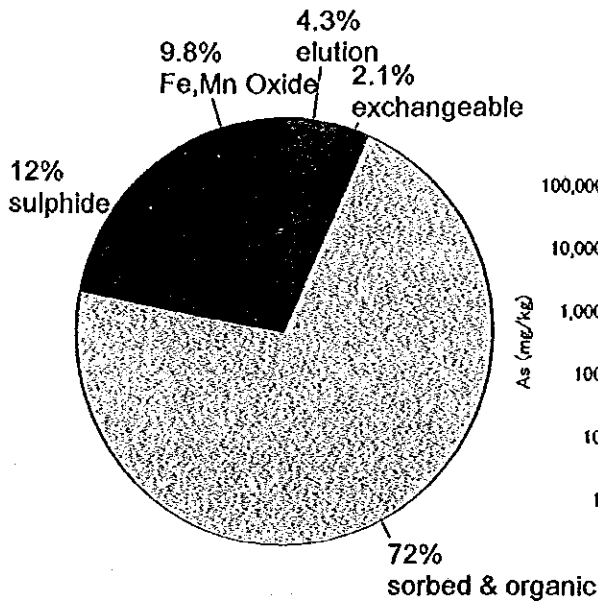
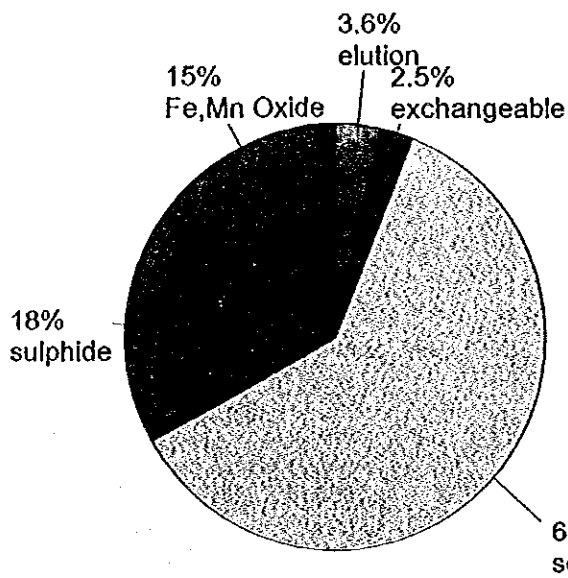
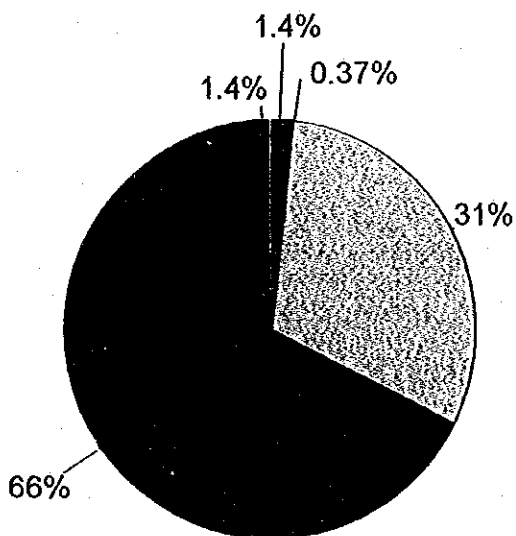
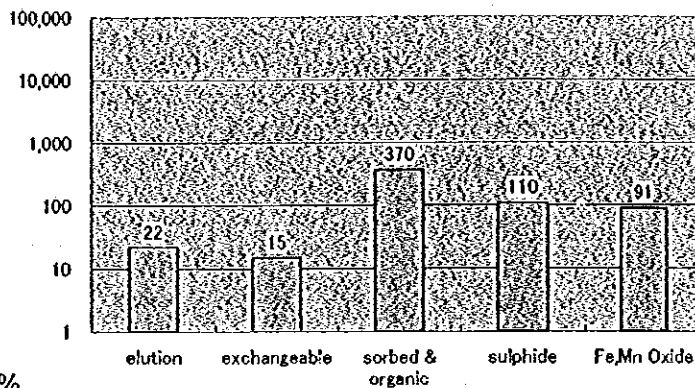


Fig 4.5 Geochemical Phase of Soil at Source Sites (3)



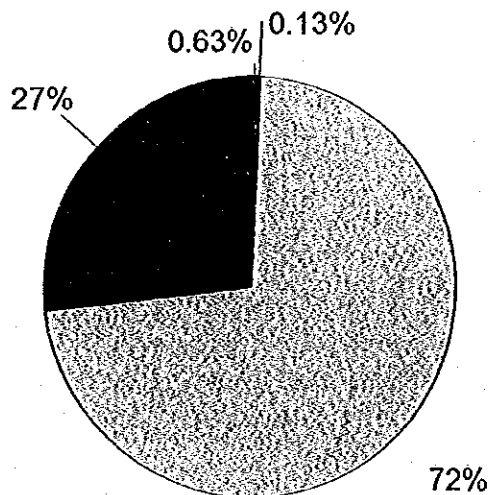
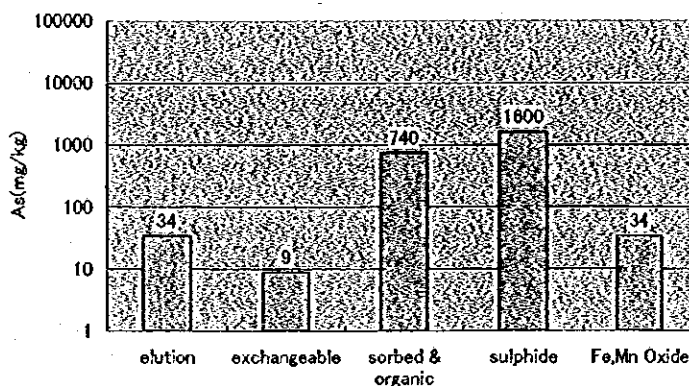
Around the site 32L

AS-99-2-4



Around the site 32L

AS-99-31-4



Waste Dump Site (New)

AS-99-39-2

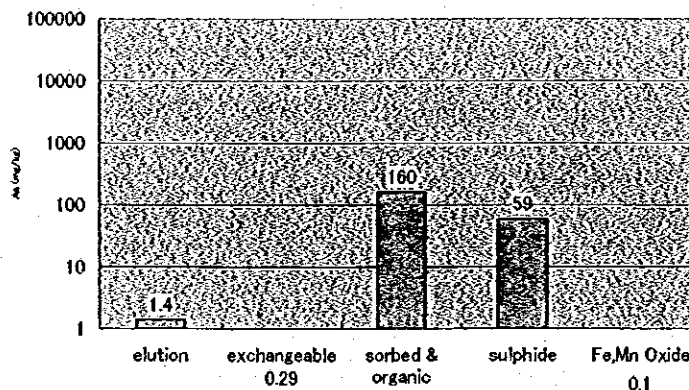


Fig 4.6 Geochemical Phase of Soil at Source Sites (4)

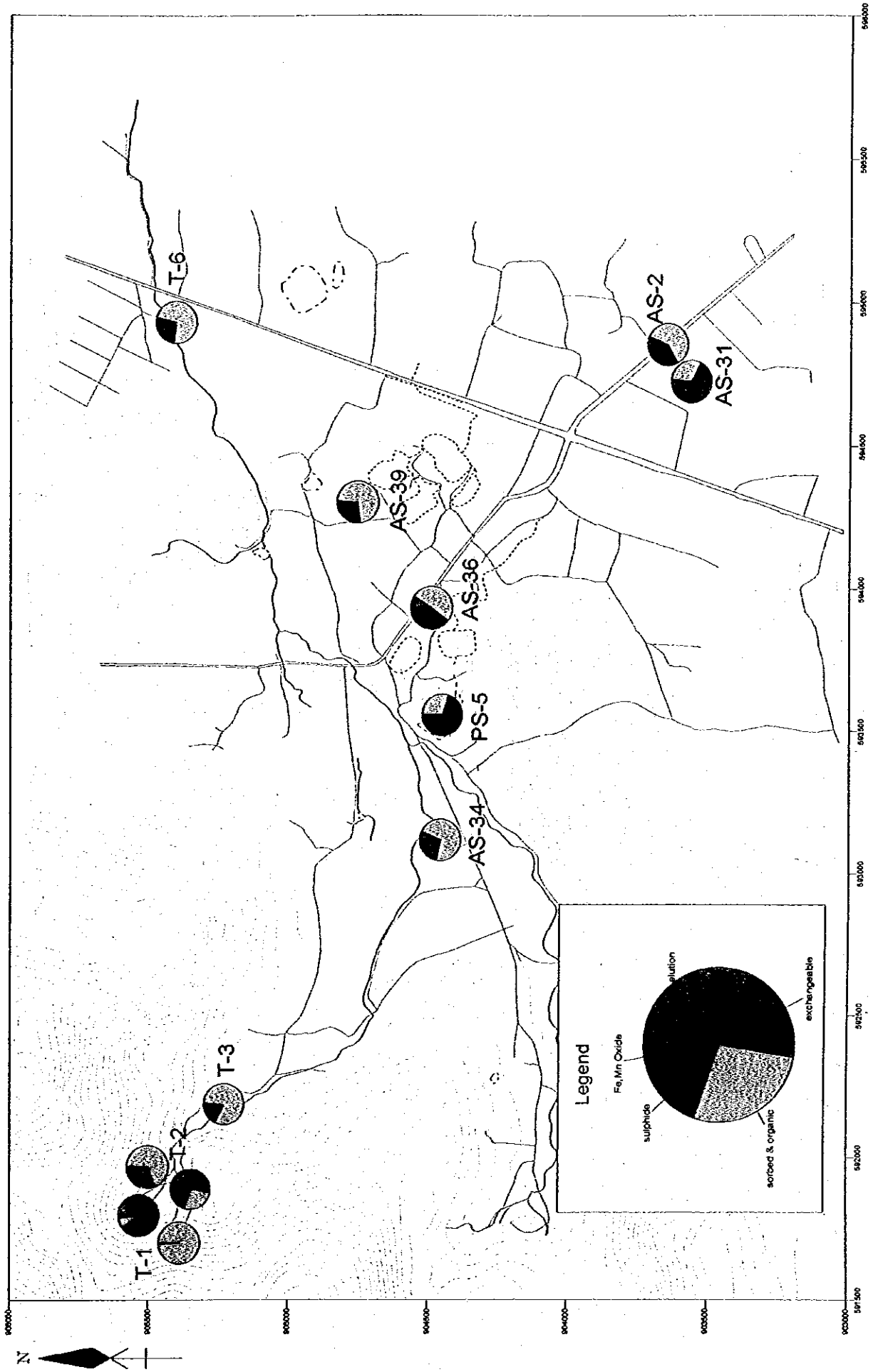


Fig 4.7 Geochemical Phase and Sampling Location