Japan International Cooperation Agency (JICA)

The Kingdom of Thailand
Ministry of Science,Technology and Environment

FINAL REPORT

ON

THE ENVIRONMENTAL MANAGEMENT PLANNING SURVEY FOR ARSENIC CONTAMINATED AREA OF THE NAKHON SI THAMMARAT PROVINCE

IN

THE KINGDOM OF THAILAND

MARCH,2000

MITSUI MINERAL DEVELOPMENT ENGINEERING CO., LTD.
KOKUSAI KOGYO CO.,LTD.

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PREFACE

In response to a request from the Government of Kingdom of Thailand, the Government of Japan decided to conduct and entrusted "The Environmental Management Planning Survey for Arsenic Contaminated Area of the Nakhon Si Thammarat Province in The Kingdom of Thailand" to Japan International Cooperation Agency (JICA).

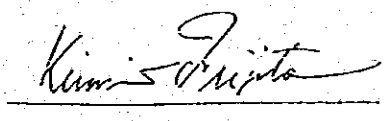
JICA sent a study team led by Dr. Takashi Ohya of Mitsui Mineral Development Engineering Co., Ltd.(MINDECO) and organized by MINDECO and Kokusai Kogyo Co., Ltd. to Kingdom of Thailand from September 1998 to March 2000.

The team held discussions with the officials concerned to the Government of Kingdom of Thailand, and conducted related field surveys. After returning to Japan, the team conducted further studies and complied the final results in this report.

I hope this report will contribute to the improvement of the situation of arsenic contamination in Nakhon Si Thammarat Province and to enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of Kingdom of Thailand for their close cooperation throughout the study.

March 2000



Kimio FUJITA
President
Japan International Cooperation Agency

March 2000

Mr. Kimio FUJITA
President
Japan International Cooperation Agency

Dear Mr. Fujita,

Letter of Transmittal

We are pleased to submit the report of The Environmental Management Planning Survey for Arsenic Contaminated Area of the Nakhon Si Thammarat Province in the Kingdom of Thailand.

The report contains results of the survey, which are identification of arsenic contaminated areas, mechanism of arsenic dissolution in groundwater, prediction of change in arsenic contamination and possible countermeasures based on the survey result. The contents of the report were discussed with and reflected opinion of Japanese government and JICA.

The report has compiled after discussion with Thai counterpart officials of Environmental Research and Training Centre, Department of Environmental Quality Promotion, Ministry of Science, Technology and Environment, Department of Mineral Resources, Ministry of Industry and Nakhon Si Thammarat Provincial Government in Bangkok and Nakhon Si Thammarat.

The survey revealed the specific areas with high arsenic contamination and contamination mechanism and presents a general idea of countermeasure.

Thai government decided to draft a master plan to cope with problem in the area including countermeasures, alternative water resources and improvement of health condition. The survey team strongly recommends studying feasibility of countermeasures against contamination sources because of their necessity, importance and convenience.

It becomes clear that many people in the world are suffering from arsenic poisoning by using arsenic contaminated water. We believe that the methodology of the survey and the interpretation used for this survey can be applied for the similar arsenic problems in the world.

The survey team thanks Japan International Cooperation Agency, Ministry of

Foreign Affair, and Ministry of International Trade and Industry of Japan, which have given us an opportunity to execute such an important and challenging project.

The team appreciates keen cooperation of Environmental Research and Training Centre, Department of Environmental Quality Promotion, Ministry of Science, Technology and Environment, Department of Mineral Resources, Ministry of Industry and many institutions associated with the project.

Takashi OHYA
Leader of the Study Team
The Environmental Management Planning Survey
for Arsenic Contaminated Area of
the Nakhon Si Thammarat Province in The Kingdom of Thailand

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List of Abbreviation and Term　略号・用語表

	Englsih	Japanese
JICA	Japan International Cooperation Agenecy	国際協力事業団
MITI	Ministry of International Trade and Industry	通商産業省
GoT	Government of Thailand	タイ国政府
NEB	National Environmental Board	国家環境会議
ONEB	Office of National Environemtal Board	国家環境会議事務局
MOSTE	Ministry of Science,Technology and Environment	科学技術環境省
PCD	Pollution Control Department	環境汚染管理局
OEPP	Office of Environmental Policy Planning	環境政策計画室
DEQP	Department of Environmental Quality Promotion	環境質促進局
ERTC	Environmental Research and Training Centre	環境研究研修センター
DMR	Department of Mineral Resources	工業省鉱物資源局
DMRNST	Department of Mineral Resources Local Office in Nakhon Si Thammarat	鉱物資源局ナコンシタマラート地方事務所
MOH	Ministry of Health	保健省
DTEC	Department of Technical and Economic	経済協力局
RID	Royal Irigation Department	王室灌漑局
DIW	Department of Industrial Works	工場局
PWD	Public Works Department	タイ公共事業局
PWA	Provincial Waterworks Authority	地方水道庁（公社）
ARD	Accelerated Rural Development Office	農村開発促進庁（地方開発振興局）
Eighth Plan	Eighth Economic and Social Development Plan	第八次経済社会発展計画
LGoNST	Local Government Office of Nakhon Si	ナコンシタマラート県政府
RPO	Ron Phibun District Office	ロンピブン郡政府
HORP	Health Office of Ron Phibun District	ロンピブン郡保健局
BGS	British Geological Survey	英国地質調査所
PSU	Prince of Songkla University	ソンクラ大学
AAN	Asia Arsenic Network	アジアヒ素ネットワーク
AAS	Atomic Absorption Spectrophotometry	原子吸光分析機
IC	Ion Chromatograph	イオンクロマトグラフ
EC	Elctric conductivity	導電率
ORP	Oxidation Reduction Potential	酸化還元電位
T-As(AAS)	Total arsenic by Atomic absorption Spectrophotometry	原子吸光分析機による全ヒ素分析値
T-As(Hironaka)	Total arsenic by Hironaka mthod	広中式による全ヒ素分析値
As(III)	Trivalent arsenic	3価ヒ素
As(V)	Peantavalent arsenic	5価ヒ素
Changwat	Province	県(Province)
Amphoe	District	郡(District)
Tambol	Sub-district	行政区(Sub-district)
Mubaan	Village	村(Village)
Siam Tone	Siam Tone Co.,Ltd	サイアム利根株式会社
IPT	Integrated Promotion Technology Co.,ltd.	

1. Outline

1. Outline

1.1 Background of the survey

It has been known a long time that the endemic disease called "Kai-dam" exists in Ron Phibun, Nakhon Si Thammarat, in Southern Thailand. Kai-dam has a dermatological symptom of creating dark dots on the sufferer's skin. In the 1980s, the disease was understood to be caused by arsenic consumption.

In the area, over 1000 chronic patients were counted in 1992. Institutes of Thai government and foreign governments studied the skin disease and concluded that arsenic contamination of the groundwater by the activities of the mineral industry caused the disease.

Ron Phibun is at the center of a tin mineralized zone, about 800 km south of Bangkok on the Malay Peninsula. Primary Sn-W-As deposits and secondary placer tin deposits have been mined 100 years ago.

Arsenic content in the groundwater from some wells in the area is about fifty to one hundred times of The World Health Organization (WHO) potable water standard (10 micro g / liter). In the past, arsenic analyses of the groundwater and study of arsenic contamination were carried out in the area. Because of a lack of finance and experience, arsenic contamination source and contamination mechanism have not been well studied.

As a temporary measure, the Thai government has transported potable water from outside of the area and distributed water jugs to local residents for collecting rainwater. Recently the government has constructed simple water pipelines. Because residents have used groundwater for a long time, they are neither accustomed to nor able to pay for potable water. Tap water is not extensively used and simple water pipelines do not drastically improve the hygienic condition of the area.

Contaminated water is transported downstream with the groundwater flow and residents living downstream will be exposed to contamination. In order not to jeopardize the downstream residents, it is urgent to make clear the contamination mechanism and study countermeasures against contamination.

The Thai government requested the Japanese government to study groundwater contamination, identify contamination sources and draft feasible countermeasures. In turn, the Japanese government accepted the request and started the project.

1.2 Outline of the survey area

Ron Phibun District (Amphoe) is in Nakhon Si Thammarat Province, 32 km south of and about a 40-minutes drive from Nakhon Si Thammarat City, the Provincial

Capital. Ron Phibun district is 504.76 km^2 and divided to six sub-districts (Tambol), Hintok, Saothong, Ron Phibun, Kuanchum, Kuanphang, and Khuankoey. The Ron Phibun sub-district consists of 16 villages. In this report, Ron Phibun is used for the name of sub-district, unless mentioned otherwise.

Table 1.1 shows the number of arsenic chronic patients by villages in Ron Phibun sub-district. A high percentage of sufferers lives in villages No. 12 and No. 13 in the city center and No. 2 in Ron Phibun Basin, west side of the city. Over 50 per cent of the sufferers lives in villages No. 12 and No. 13.

Village No.	No. of Patients	Percentage	Village No.	No. of Patients	Percentage
1	29	8.7	9	11	3.3
2	31	9.3	10	5	1.5
3	0	0.0	11	0	0.0
4	27	8.1	12	104	31.1
5	21	6.3	13	72	21.6
6	7	2.1	14	7	2.1
7	13	3.9	15	4	1.2
8	2	0.6	16	1	0.3

Table 1.1 Arsenic chronic patients by village of residence in 1997

Ron Phibun is at the foothill of the Khao Ron Na and Khao Suan Chan Mountains, which form the central ridge of the Malay Peninsula. Khao Ron Na and Khao Suan Chan Mountains are a part of the Khao Luang Mountains. In the western part of the survey area, there are mountains with the highest peak being the Khao Huai Mut Mountain, 925 m in elevation. The area over 50 m above sea level is steep and mountainous. Peaks of mountain range are in the east-west to northeast-southwest direction. The area drainage patterns have many branches, which usually are developed in relatively homogeneous rocks.

In the eastern part of the survey area, it is relatively flat with some undulations. In the center of the survey area, there is a basin, called Ron Phibun basin, extending 2 km in the east-west and 1 km in north-south.

Climate of the area is tropical monsoon. Hot and dry season is between February and April, and rainy season otherwise. Average annual precipitation is 2,381.8 mm. Wind direction is predominantly to the southwest from May to October and northeast from November to January. Monthly average temperature varies from 25.8 to 28.5° C.

The temperature variation is very small.

Tin veins develop in granite bodies in the western part of the survey area and some of them were mined until recently. The mined ore was transported to the foothill concentrator and the town concentrator. The concentrated minerals were shipped out of the area. The both concentrators were operated until recently.

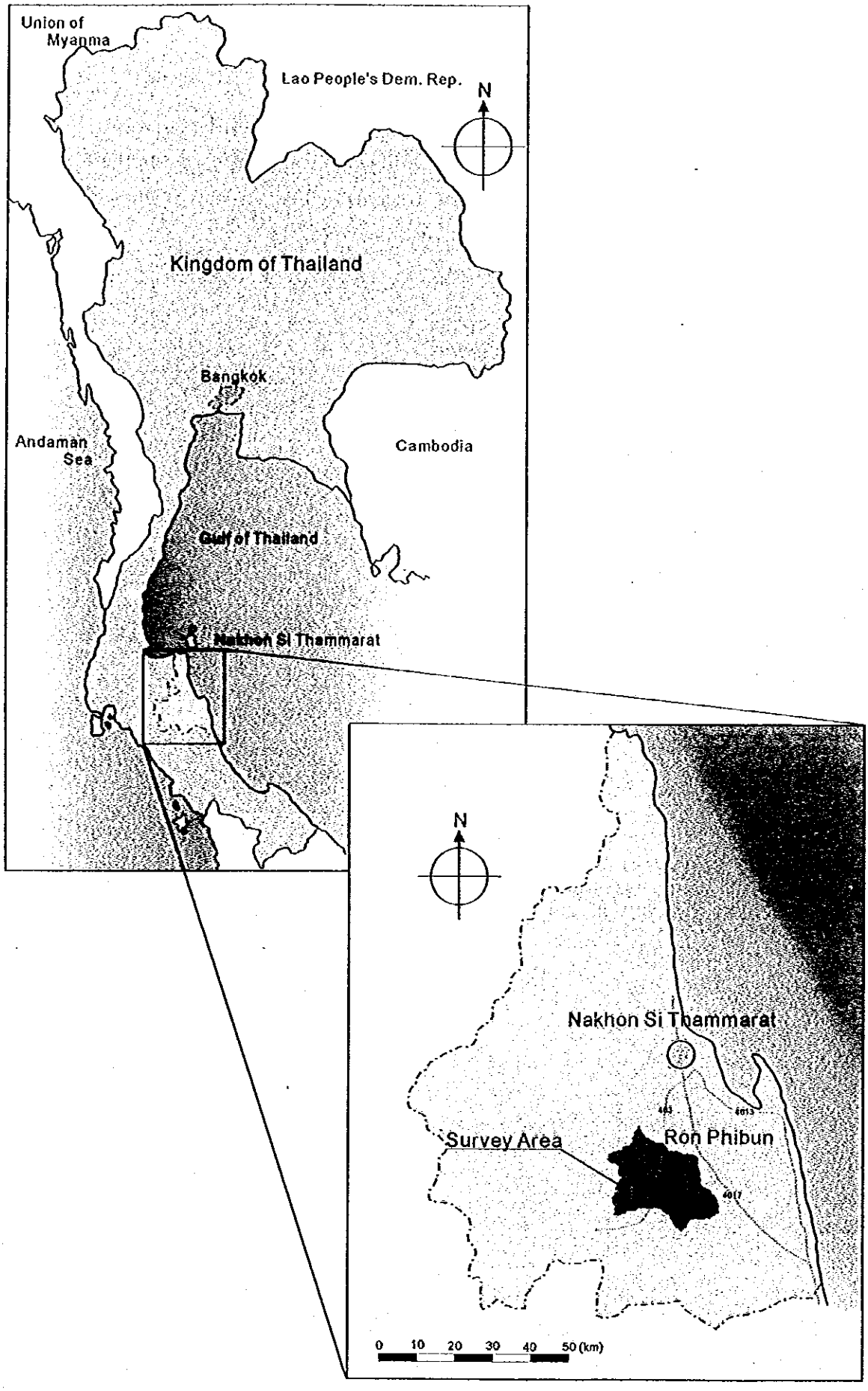

Fig 1.1 Location of the Survey Area

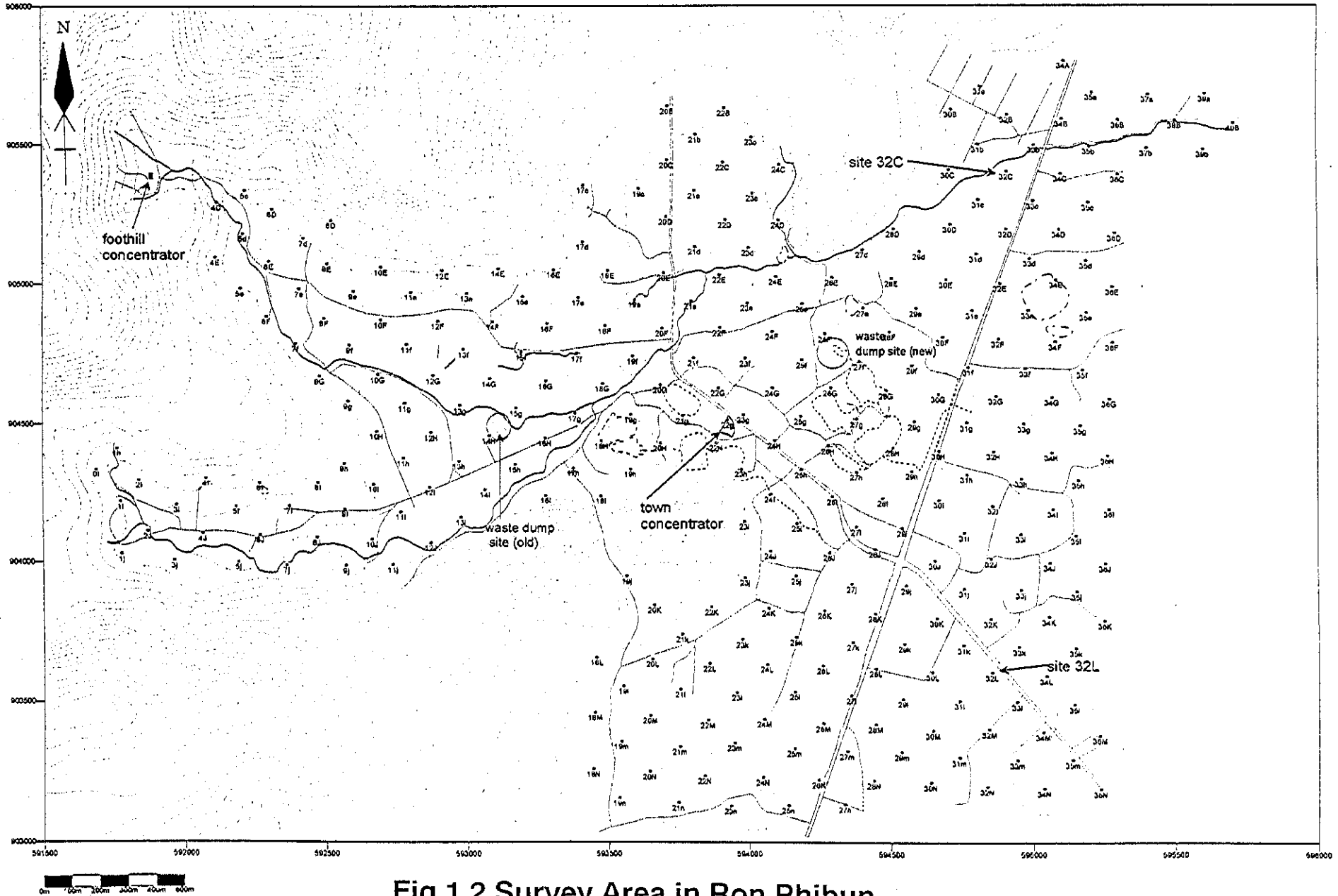

Fig 1.2 Survey Area in Ron Phibun

2. Principle of the survey

2. Principle of the survey

2.1 Principle of the Survey

2.1.1 Objectives of the Survey

The objectives of the survey are to delineate the source of contamination in the survey area, to clarify contamination mechanism, and to draw countermeasures against arsenic contamination in groundwater and transportation of the contamination downstream. Technology used for the survey was transferred to the counterpart organization, Environmental Research and Training Center, Department of Environmental Quality Promotion, Ministry of Science, Technology and Environment.

2.1.2 Principle of the Survey

The survey was carried out with the hypothesis that concentrated arsenic was brought into the area with tin mineralization, arsenic was distributed by mining activities, arsenic absorbed by soil and clay was dissolved into water and transported with the groundwater.

1. We studied the followings for identifying the source(s), distribution and mechanism of arsenic contamination.
   - Mining geologic study on tin veins in granite as a source of arsenic in the area.
   - Chemical behavior of arsenic minerals by mining activity and mineral concentration.
   - Arsenic concentration in shallow groundwater in plain sediments.
   - Behavior of soluble arsenic in soil.
   - Concentrator waste.
2. The followings were studied for understanding the dissolution mechanism of arsenic.
   - Chemical phase of arsenic dissolution by sequential extraction test of soil samples.
   - Physical chemistry of sediments.
3. The followings were studied for understanding the movement of surface and underground water.
   - Recharge and discharge of groundwater.
   - Computer modeling of groundwater flow.
4. Social impact of arsenic contamination and organization for executing the countermeasures were studied.
5. Countermeasures were discussed based on the integrated analysis of data.

2.2 Members

Members of the JICA survey team are as follows:

Dr. Takashi OHYA	Leader
Mr. Yoshihiro NAGUMO	Mining Geologist
Mr. Hiroshi HAMA	Geologist
Mr. Shoji NAKAMURA	Geologist / Mineral Dressing Engineer
Dr. Akira KAMATA	Hydrologist
Dr. Peifeng LEI	Hydrologist
Ms. Shoko OSHIKAWA	Chemist
Mr. Munehiro FUKUDA	Chemist
Dr. Akira TAKATA	Civil Engineer / Environmental Engineer
Mr. Yoshiaki ISHIZUKA	Drilling Engineer
Mr. Shoji MASUMURA	Sociologist / Economist
Mr. Tomohiro KATO	Coordinator

Field surveys were carried out as follows:

First Phase	September 9, 1998	-	December 10, 1998
Second Phase	January 20, 1999	-	March 3,1999
Third Phase	May 17,1999	-	August 27, 1999
Fourth Phase	August 23, 1999	-	August 28,1999
Fifth Phase	December 12, 1999	-	December 21, 1999
Sixth Phase	March 12, 2000	-	March 21, 2000

2.3 General of the survey

2.3.1 Mining geology

Four old mines, which mined vein-type tin in granite, were studied in detail. Forty soil samples were collected from the area of the mines and examined under EPMA and chemical analysis. Twenty-four ore and rock samples were collected and examined for their mineralogical constituents under the microscope and X-ray diffraction analysis.

2.3.2 Geology / Auger drilling

The survey team drilled 364 auger holes. Out of 364 holes, 306 auger holes were drilled in a reconnaissance survey to study the distribution of arsenic in shallow groundwater and arsenic solubility in the soil. For reconnaissance, auger holes were drilled every 140 m and 5 m deep or 30 cm under groundwater level.

In three highly contaminated areas found by the reconnaissance auger survey,

auger holes were drilled every 50 m or less for a detailed survey. In order to study water transmission between river flow and groundwater, auger holes were drilled along lines crossing the rivers. There were 56 auger holes drilled in the detail survey.

Groundwater was sampled from all auger holes, tested for its arsenic content, pH, ORP (oxidation reduction potential) and EC (electric conductivity) by a portable analysis kit in the field and sent to the ERTC laboratory for an accurate analysis of its arsenic content.

From the auger hole, soil samples were collected at depths of 30 cm and 1 m for elution and sequential extraction tests at the ERTC laboratory.

Dust fall and rain water samples were collected at 12 stations.

Mine waste, mining method and mineral concentration method used were studied.

2.3.3 Hydrology

The survey team measured river flow twice during rainy season and twice during dry season.

The survey team made an inventory of 93 shallow wells, 87 deep wells, 30 wells drilled for this survey and auger holes completed as observation hole. The inventory list describes the location, owner, depth, usage, physical and chemical properties, and other specifications of the wells.

Two automated weather stations were established in the foothills and plains. Each station records temperature, humidity, wind velocity, wind direction and precipitation.

Water table was measured at many wells four times a day. Automatic water-table-recording meter was set on a well.

Aquifer was tested by pumping at all newly drilled wells.

Based on the data, a hydrological computer model was made.

2.3.4 Sociological and economical study

The team studied the sociological and economical situation of the survey area.

2.3.5 Chemical analysis

The survey team investigated the Ion-Chromatograph-Atomic Absorption system for arsenic species analysis. The survey team trained counterpart personnel on the operation of the system.

This survey required to analyze numerous samples, so that the team made operational guidelines for the counterpart and trained the counterpart to carry out the laboratory analysis.

2.3.6 Civil engineering

Countermeasures against arsenic contamination were drafted.

2.3.7 Video production

Educational video tape was produced to explain the toxicity of arsenic, arsenic contamination and this survey.

2.3.8 Pamphlet Production

For education of local residents, Pamphlet was produced to explain basic consideration for land use not to enhance arsenic contamination, the toxicity of arsenic, arsenic contamination and this survey.

Table 2.1 Outline of the survey

Area	Item	Details
Mining Geology	Reconnaissance	
	Ore deposit	
	Rock and ore sampling	
	Soil sampling	40 samples
Geology, Mineral Dressing and Drilling	Auger drilling	306 holes: reconnaissance survey 141m interval
	Well drilling	57 hole: detailed survey
		16 deep wells (total length: 407 m)
		14 shallow wells (total length: 109 m)
	Trenching	6 ditches
	Dust fall sampling	12 stations
Hydrology	River flow	Twice at over 40 stations (Oct. and Nov. 1998)
		Twice at over 40 stations (May and June, 1999)
	Well inventory	
	Weather recording	At automated stations in the plains and foothills
	Water table	
Chemical Analysis	In situ measurement	4,242 water samples (Temp., ORP, EC, pH, As)
	Laboratory measurement at ERTC	5,386 water samples (Na, K, Ca Mg, Mn, As, etc.)
		3,205 soil samples
		Elution tests: 1,867 samples
		Sequential extraction tests: 1,338 samples
Video Production		Narrated in Thai and English
Pamphlet Production		10,000 copies in thai language

3. Identification of contamination source

3. Identification of contamination source

The general flow of the survey for identifying the contamination is illustrated in Fig 3.1. For identifying the contamination source, we studied amount and chemical form of arsenic in 1) tin veins and mining waste and 2) waste from the concentrators. We also studied arsenic in sediments and dumped waste.

3.1 Tin veins and mining waste

3.1.1 Mining geology

The survey area is a well-known tin mining area. Only one secondary placer tin mine remains in operation. We studied the primary vein-type tin deposits and closed mines for clarifying the relationship of arsenic contamination in the sediment of the hinterland.

Major vein-type tin deposits were mapped with a portable compass and chain. Old mines in the bush were located by GPS. The host rock, occurrence of veins, scale of mining activity and remaining mine waste were noted at each deposit.

Forty soil samples were collected along the survey routes and provided for elution and sequential extraction tests.

3.1.2 Primary tin deposit and mining waste

Basement rock in the survey area is Cambrian-Ordovician sedimentary rocks. The sedimentary rocks generally strike NNE-SSW and dip 30° SE. It consists of an alteration of fine-grained sandstone, siltstone and mudstone at the bottom, limestone parting which becomes dominant in the upper layer, and massive limestone at the top of the sedimentary rocks. Change of lithofacies is thought to be transitional but not confirmed. Granite intruded through the sedimentary rock during the Cretaceous period. Quartz veins and greisen were formed by pneumatolysis and hydrothermal processes at the last stage of the granite-forming activity. Both pneumatolysis and hydrothermal processes are thought to have brought tin mineralization.

Hydrothermal tin veins tend to extend east-west in the Ron Phibun area.

Hydrothermal process skarnized limestone of the sedimentary rocks. We identified skarn minerals, like chlorite, epidote, vesuvianite, garnet and magnetite by the naked eye. Under the microscope, a fair amount of garnet, epidote and vesuvianite are seen in the drilled core sample. There exists a possibility that large skarn zones have been formed over granite. Tin mineralization has not been confirmed in the skarn zone.

We have visited ten old mines, which are shown in Fig. 3.2. Mining waste at the

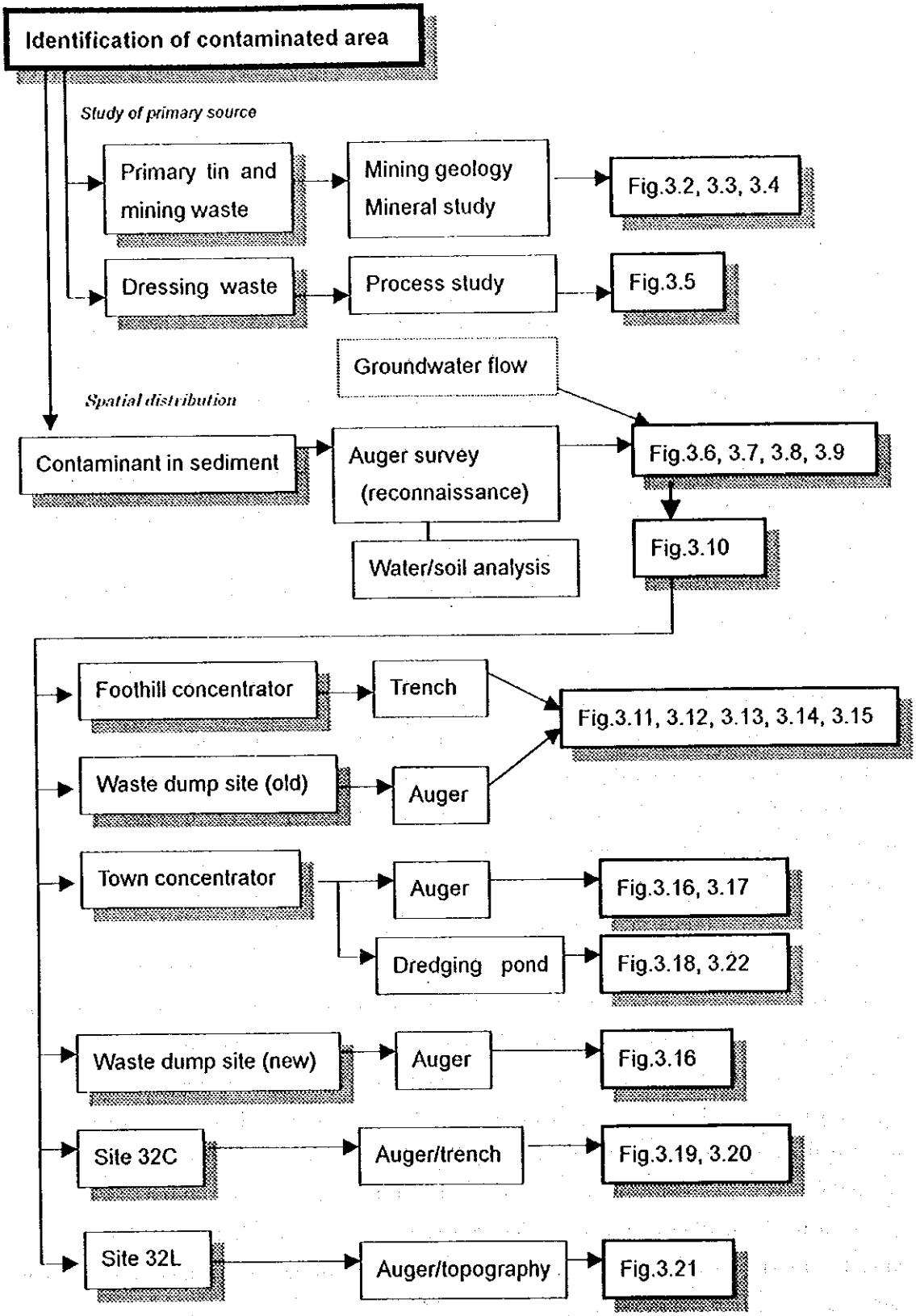

Fig.3.1 Survey Flow of Contaminated Area Identification

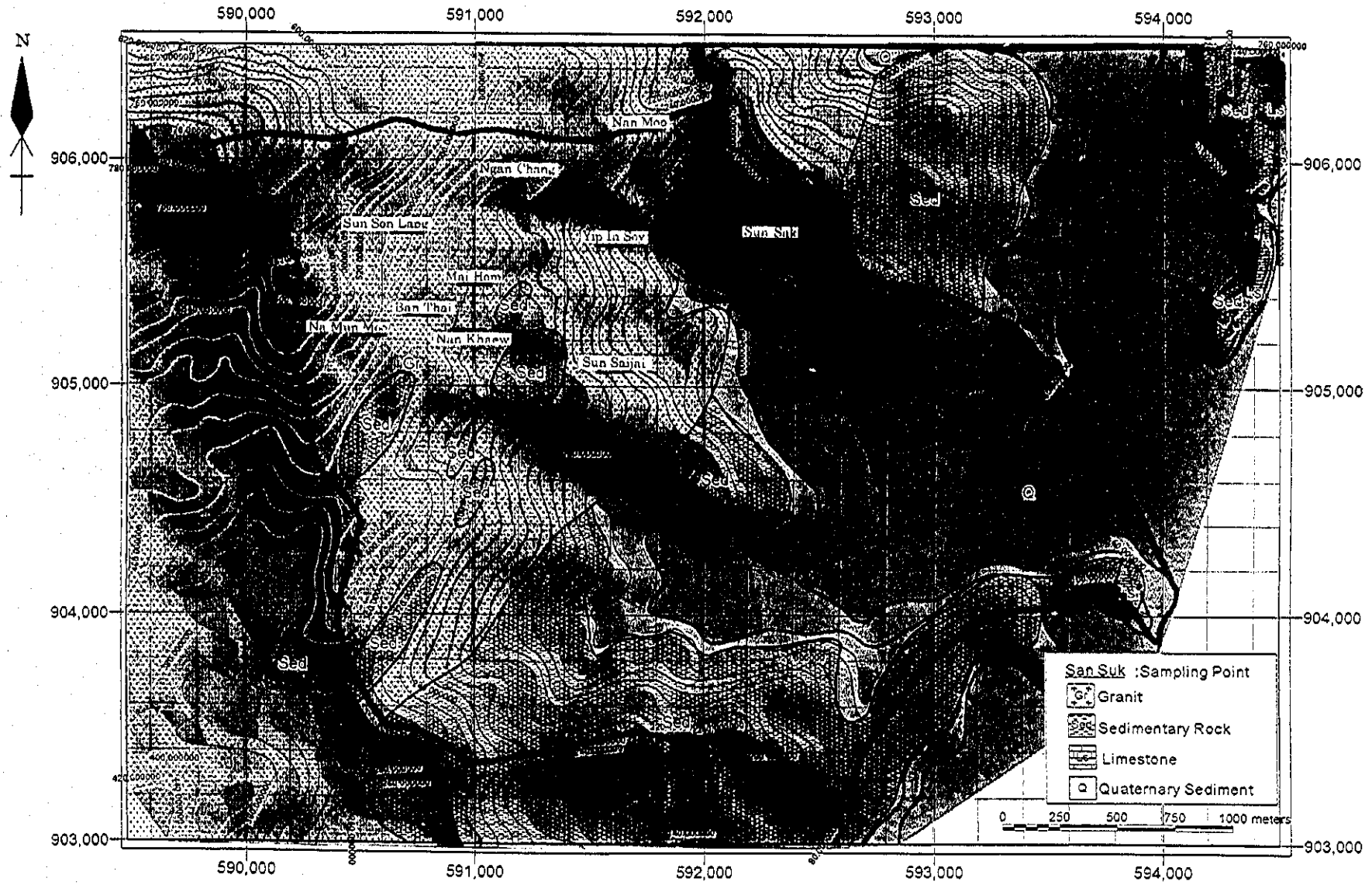

Fig 3.2 Mining Geological Map

old mines are mainly brownish altered greisenized granite, some quartz veins and greisen vein. We could not find cassiterite, which was the major target of the mines. However we could easily find arsenic minerals, arsenopyrite and scorodite, which was formed by the alteration of arsenopyrite. The shape of the primary deposits, which is guessed from the shape of open pit trenches and entrance of tunnels, extends east west and vertically. Their extension is about 100 m long and thickness of the veins is on the order of 10 cm. One mineralized zone consists of several veins running in parallel. Ore minerals were not found but are documented to be cassiterite with associated wolframite. Gangue minerals are granite forming minerals, namely, quartz, feldspar, muscovite, and phlogopite and tourmaline, which were formed by greisenization. A few percent of arsenopyrite are seen in the mineralized zone. Arsenopyrite is stable and not easily dissolved, but it becomes unstable and easily dissolved only in an acidic atmosphere. When arsenopyrite is exposed to acid, it becomes easily soluble.

Results of the chemical analysis on 40 soil samples around the mineralized zones are listed on Table 3.1 and Fig. 3.3. The amount of dissolved arsenic is estimated based on the table. Elution test shows that extracted arsenic by water from 19 decomposed granite samples is between 4.4 and 610 micro g / liter and their average value is 69.2 micro g / liter. Arsenic from 11 soil samples of granite origin is between 5.3 and 270 micro g / liter. Arsenic was not detected from eight out of a total of nine soil samples of sedimentary rock origin. In only one sample of sedimentary rock origin, arsenic was 28 micro g / liter. Therefore we assume that sedimentary rock does not contribute to adding any arsenic to the environment. Soluble arsenic from soil samples collected in vicinity of ore deposits is in the order of one hundred micro g / liter (maximum being 610 micro g / liter), but arsenic was collected a distance away from ore deposits is about 10 micro g / liter. Amount of extractable arsenic from soil in vicinity of ore deposits is about ten times larger than from soil a distance away from ore deposits. This fact implies that the difference in amount of arsenic minerals is by distance from the mineralization. A few per cents of arsenopyrite were found in mineralized zone, so that a few tenths of a per cent of arsenopyrite must be in granite away from mineralization. This assumption implies that greisenization with arsenopyrite extended over the entire granite in the area.

	Extractable arsenic	Amount of arsenopyrite
Granite in mineralized zone	100 micro g / liter	few %
Granite out of mineralization	10 micro g / liter	few tenths %
Sedimentary rock	none	none

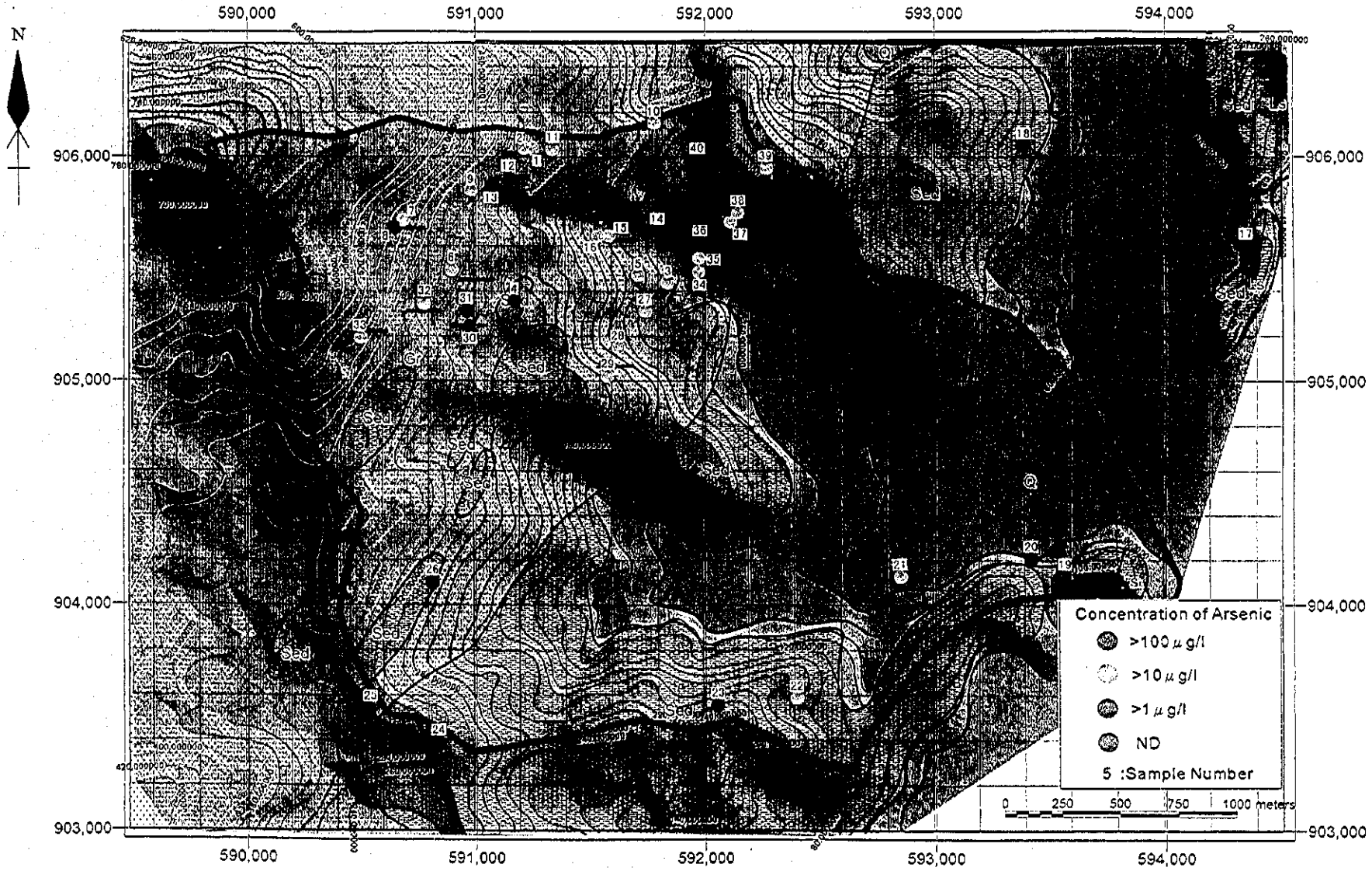

Fig 3.3 Location of Soil Samples at Primary Mining Area

		UTM coordination		Analysis		
Sr.No	sample No	east	north	As(ppb)	SO4(mg/l)	note
1	SS98-1	591,210	906,030	14	5.7	BC white,sandy decomposed-granite
2	SS98-2	591,210	906,030	34	6.3	BC brownish-white decomposed granite
3	SS98-3	591,830	905,430	11	6.9	BC limonite-stained dec. granite
4	SS98-4	591,170	905,360	n.d.	4.9	B reddish soil
5	SS98-5	591,730	905,480	19		BC white dec. granite
6	SS98-6	590,890	905,480	10	7.6	BC brownish dec.granite
7	SS98-7	590,700	905,690	31		ditto
8	SS98-8	590,680	905,660	610	7.3	ditto
9	SS98-9	590,980	905,860	11	4.9	ditto
10	SS98-10	591,770	906,160	23	5.5	ditto
11	SS98-11	591,310	906,050	24	3.3	ditto
12	SS98-12	591,150	905,900	190	9.8	BC light brownish dec.granite
13	SS98-13	591,050	905,870	7.8	5.1	BC brownish dec.granite
14	SS98-14	591,750	905,650	4.4	14.4	BC brownish dec.granite
15	SS98-15	591,570	905,630	28	9.1	BC brownish dec.granite
16	SS98-16	591,560	905,620	11	6.5	BC slightly brownish dec.granite
17	SS98-17	594,370	905,600	n.d.	4.7	B brown soil
18	SS98-18	593,370	906,070	n.d.	13.3	B grey soil
19	SS98-19	593,580	904,150	n.d.	6.7	B grey clayey
20	SS98-20	593,430	904,220	n.d.	6.5	B brownish soil
21	SS98-21	592,830	904,130	10		B yellowish clay
22	SS98-22	592,460	903,580	28	5.1	B reddish brown clay
23	SS98-23	592,060	903,550	n.d.	12.0	B reddish brown clay
24	SS98-24	590,820	903,390	n.d.	4.5	B brown sand
25	SS98-25	590,520	903,560	5.3	10.8	AB grey soil with plant root
26	SS98-26	590,800	904,090	n.d.	3.9	AB grey soil with plant root
27	SS98-27	591,740	905,320	29	4.6	AB grey soil with plant root
28	SS98-28	591,600	905,130	40	6.3	AB grey soil with plant root
29	SS98-29	591,550	905,050	23	10.0	AB grey soil with plant root
30	SS98-30	590,970	905,240	200	5.7	BC brownish dec.granite
31	SS98-31	590,950	905,300	9.1	6.7	BC brownish dec.granite
32	SS98-32	590,780	905,350	56	6.9	BC brownish dec.granite
33	SS98-33	590,540	905,320	22	10.4	BC brownish dec.granite
34	SS98-34	591,980	905,510	43		AB grey soil with plant roots
35	SS98-35	591,980	905,570	30	12.3	AB grey soil with plant roots
36	SS98-36	592,000	905,620	270		AB grey soil with plant roots
37	SS98-37	592,110	905,700	48		B light brown clay
38	SS98-38	592,150	905,750	54	3.3	B grey soil
39	SS98-39	592,260	905,950	22	6.9	B light brown clay
40	SS98-40	591,990	905,970	170	5.3	B grey sandy

Table 3.1 Analytical Result of Soil Samples

Amount of extractable arsenic is about one hundred thousandth of the amount of arsenopyrite.

Based on the table above, amount of arsenic supplied to the Ron Phibun basin was estimated. On Fig. 3.2, a red line surrounds the area that supplies materials to the Ron Phibun basin. The area is 3,800,000 m^2. We assume the mineralized zone is 150 m long and 50 m wide and is 7,500 m^2. We assume that there are ten mineralized zones in the area. Total area of mineralized zones is 75,000 m^2. Density of granite is assumed to be 2.6 g / m^3. Amount of extractable arsenic from the mineralized zones within a 1-m depth is 19 kg and from the fresh granite area is 97 kg. Existence of a mineralized zone added about 17% of extra arsenic in the area.

The dip of sedimentary rocks, left as roof pendant on granite, is 30° SE as sedimentary rocks are distributed east of the survey area. When we make a summit level map and reconstruct the old topography of the area, sedimentary rocks of the roof-pendant can be connected to sedimentary rocks in the east. The summit level map is shown in Fig. 3.4. We assumed that vertical distance of the eroded material is 35 m, which is elevation difference of the present topography and reconstructed summit level topography. The amount of eroded granite is about 166,000,000 m^3. By assuming a ratio of mineralized zone in granite to the eroded zone as being the same as the present, the total amount of extractable arsenic from the eroded granite is 5,100 kg. By assuming no arsenopyrite has been altered and dissolved, amount of arsenopyrite is estimated to be about 5,100 tons. Under the microscope, arsenopyrite is seen in the sediment core samples from the drilled holes in the plain for this study. It indicates that some arsenopyrite was crushed during transportation process and transported as arsenopyrite crystals.

The total amount of sedimentary rocks eroded is estimated to be 279,000,000 m^3 or 726,000,000 tons by assuming a density of 2.6 g / m^3.

From the basement map derived from the drilling results, the amount of unconsolidated sediments filling between the present surface and basement rock is estimated as 12,000,000 m^3 or 21,000,000 tons by assuming a density of 1.8 g / m^3. If all the arsenopyrite, 5,100 tons, eroded from the granite mountain remained in unconsolidated sediments in the plain, the concentration of arsenopyrite can be 2.3% of mineral content. If arsenopyrite remained in the unconsolidated sediment at the same ratio as amount of remained sediment, the concentration of arsenopyrite would be 0.07% in mineral content. The soil test shows that the amount of extractable arsenic is one hundred thousandth of the amount of arsenopyrite. The amount of extractable

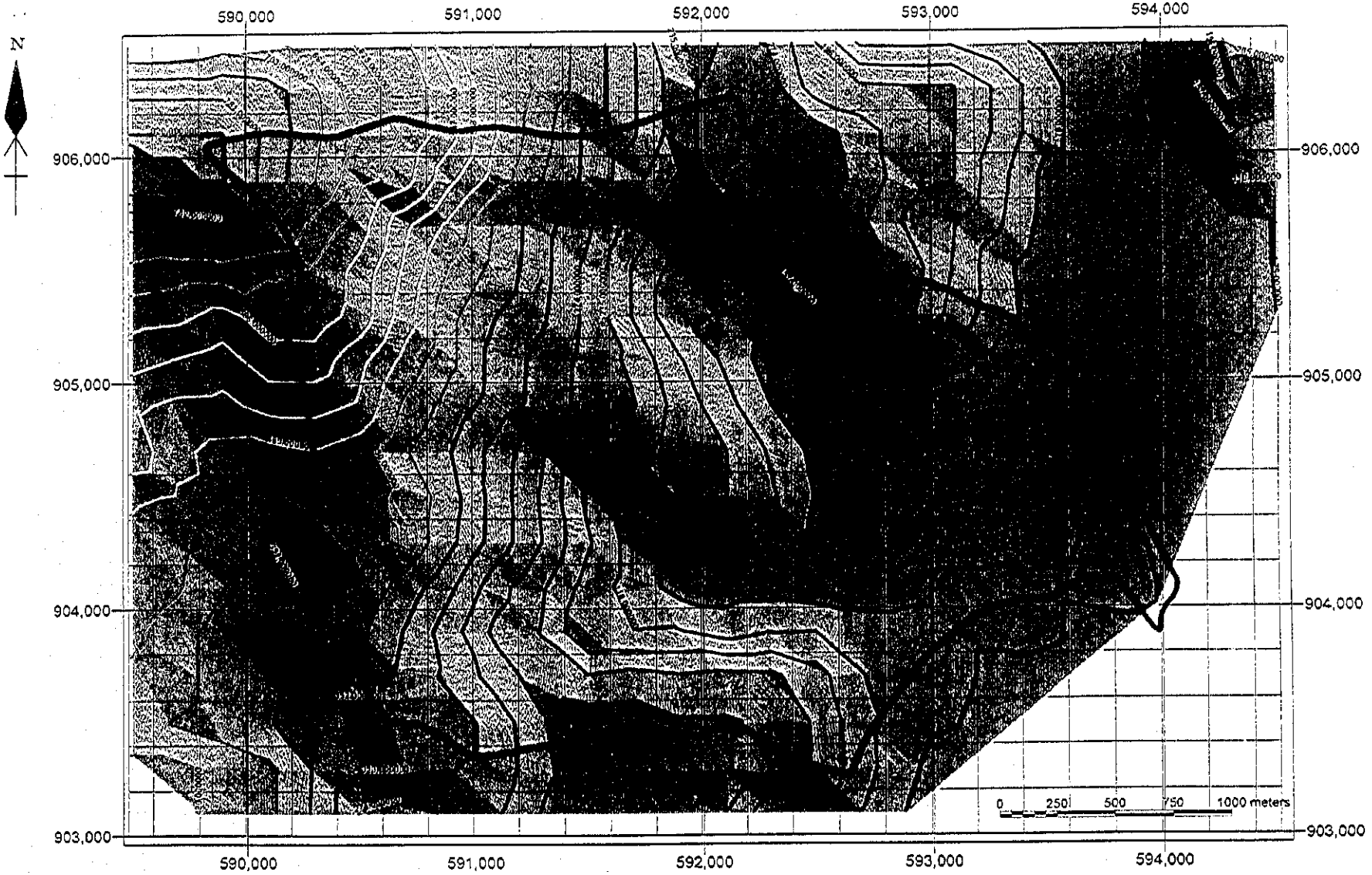

Fig 3.4 Summit Level Map

arsenic is estimated to be about 153 kg.

If all extractable arsenic from the granite area and unconsolidated sediment, 116 kg and 152 kg, respectively are dissolved in the annual rainfall of 2,300 mm, the average arsenic concentration in rainwater is 14 micro g / liter. The contribution of the mineralized zone for arsenic release to the environment is about 18%. Therefore, it contributes only 1 micro g / liter.

As a conclusion of the section, a primary ore deposit or mineralized zone, in nature, contributes very little to the arsenic contamination of the area. On the other hand, under the microscope, we found that most core samples from a shallow depth in unconsolidated sediments contain metal iron, bronze and metal tin which are supposed to be waste from the concentrator.

3.2 Concentration waste

3.2.1 Mineral concentration flow

There are three mineral concentration facilities in Ron Phibun district. Two of them are past facilities, which are not in operation now. They concentrated primary tin ore formed by granite intrusion and following mineralization. Primary tin mineral contains sulfide of Cu,Zn,Fe, etc.. Purity of tin was improved by concentration process such as floatation and physical dressing. To remove arsenic, roasting process is necessary. Another facility is still in operation and process secondary tin deposit (sedimentary), which was formed at shallow bottom, shore of the rivers by weathering of primary tin and subsequent flushing by rain and concentration by gravity. Both cases, product is SnO_2. There was not facility which process SnO_2 to Sn. However, in mineral study, tin and arsenic rich silicate mineral, which is considered as slug of tin concentration, was found. This suggests the possibility of small scale or testing of dry mineral concentration process.

3.2.2 Field study

(1) Analytical result

Result of contaminated site reconnaissance study was shown in Table 3.2. In this table, value for elution test is multiplied by ten to get the arsenic content per original soil weight. Data for elution test shown in mg/l is the concentration of arsenic in water which is 10 times of original soil weight. In this way, the data of elution test and sequential extraction can be compared.

CS98-1～5 are the samples of primary tin deposit containing arsenic from eastern Kao Suan Chan in Ron Phibun. These rock samples were crushed by vibration

Sample Code	Elution							Sequential Extraction				Sample Description
	Cd	Cu	Mn	Pb	As	Zn	Fe	Phase 2	Phase 3	Phase 4	Phase 5	
	(μg/kg)				(mg/kg)			As (mg/kg)	As (mg/kg)	As (mg/kg)	As (mg/kg)	
CS-98- 1	14	48	23	200	0.47	<0.5	29	-	-	-	-	Ore of Ganchan Mine
CS-98- 2	5.8	170	57	120	0.1	<0.5	9.6	-	-	-	-	Ore of Maihom Mine,No.1 Vein
CS-98- 3	110	79	270	<5	0.69	10	71	-	-	-	-	Ore of Maihom Mine,No.2 Vein in the waste dump
CS-98- 4	37	93	41	740	0.36	0.7	35	-	-	-	-	Ore of an old Mine,on the way to the Ganchan Mine
CS-98- 5	12	49	100	<5	0.31	<0.5	0.9	-	-	-	-	Ore of Ton I Hong Mine,near Yi pin soi Mine
CS-98- 6	100	870	55	270	31.3	11	140	9.65	>1,400	3.68	7.92	Mining waste of Yi pin soi Concentrator(No.2)
CS-98- 7	-	-	-	-	0.21	-	-	-	-	-	-	Gutter sediment of Yi pin soi Concentrator (No.2)
CS-98- 8	-	-	-	-	0.79	-	-	9.59	1.23	1.71	7.46	Soil of Downtown concentrator(No.1)
CS-98- 9	-	-	-	-	0.15	-	-	-	-	-	-	Soil of Downtown concentrator(No.1)
CS-98- 10	88	610	90	5,100	6.22	68	38	-	-	-	-	Mining waste of Downtown Concentrator (No.1)
CS-98- 11	-	-	-	-	0.23	-	-	3.17	5.57	1.1	1.73	Mining waste of Downtown Concentrator (No.1)
CS-98- 12	-	-	-	-	1.22	-	-	4.86	2.15	4.64	3.47	Mining waste of Downtown Concentrator (No.1),Dust
CS-98- 13	-	-	-	-	0.29	-	-	-	-	-	-	Mining waste of Downtown Concentrator (No.1),Sludge in Flotator
CS-98- 14	-	-	-	-	0.11	-	-	4.55	4.2	5.07	9.98	Mining waste of abondoned Concentrator in Village No.2
CS-98- 15	-	-	-	-	0.05	-	-	-	-	-	-	Mining waste of abondoned Concentrator in Village No.2
CS-98- 16	-	-	-	-	N.D.	-	-	-	-	-	-	Feed ore of operating concentrator (No.3)
CS-98- 17	21	83	69	<5	0.33	<0.5	1.6	-	-	-	-	Mining waste of Yi pin soi Concentrator(No.2)
CS-98- 18	34	42	160	20	0.54	<0.5	30	-	-	-	-	Mining waste of Yi pin soi Concentrator(No.2)
CS-98- 19	27	65	250	<5	0.51	<0.5	30	-	-	-	-	Mining waste of Yi pin soi Concentrator(No.2)
CS-98- 20	36	12	140	5.5	0.25	<0.5	0.41	-	-	-	-	Mining waste of Yi pin soi Concentrator(No.2)

Parameter

Elution :As,Fe,Mn,Cd,Cu,Zn,Pb

Sequential Extraction :As

Sequential Extraction

Phase 2 Exchagable phase

Phase 3 Organic and Absorbed phase

Phase 4 Sulfide phase

Phase 5 Fe and Mn oxide phase

Elution

As analysis of elution is as same analysis procedure as Phase 1 of sequential extraction

Table 3.2 Analytical Result of Samples at Source Sites

mill and then used for elution test. arsenic concentration is in the range of 0.01~0.069 mg/l 0.1~0.69 mg/kg original soil) which is similar to soil in primary deposit area. This data is in agreement with geological study (Arsenic loading to downstream from primary deposit is not significant).

Samples, which considered containing concentration waste, were taken at and around the foothill and the town concentrators for sequential extraction test. Generally speaking, arsenic in other phases of sequential extraction test is 10 times higher than elution phase. Arsenic in ion exchangeable phase (step 2) of samples is 4 to 12 times higher than auger soil and drilling core samples. This indicates arsenic in more soluble phase is high.

A sample at the foothill concentrator showed nearly 100% composition of sorbed and organic phase at over 1400mg/kg concentration (CS-98-6). The sample by trench survey at the foothill concentrator (T-1-10) also showed 98% composition of sorbed and organic phase at over 35,000mg/kg concentration. This suggests these are similar types of waste. The waste around the concentrator was removed to controlled waste disposal site, which is built by DMR in 1998. It is considered that some of the waste could not be removed and left at the site.

At the town concentrator, following samples were collected. Two soil samples containing concentration waste (CS-98-8,9), one tin ore sample (including arsenopyrite, CS-98-10), sample considered as concentration waste (CS-98-11) , sample considered as dust at the top of roasting furnace (CS-98-12), and slime sample inside the pit of flotation process (CS-98-13). These samples generally have relatively low arsenic in elution test and in sequential extraction test. However, drilling survey detected high arsenic (0.44 to 0.84mg/l) in elution test at the soil samples, which are shallower than 3 - 4 m depth. In addition, groundwater samples from the auger well and the existing well showed high arsenic indicating presence of arsenic containing waste in the concentrator facility.

Arsenic content of the groundwater in the town concentrator

	Arsenic(mg/l) (by atomic adsorption spectroscopy)	
MW 1	2.0	outside of the concentrator building
MW 2	1.0	outside of the concentrator building
22g	12.0	outside of the concentrator building. Completed as observation well

(2) Estimation of waste volume containing arsenic in the town concentrator

Volume of arsenic containing waste from the town concentrator was estimated by questionnaire survey, etc. The town concentrator has processed maximum of 3 ton/day of tin ore while in operation and had processed total of 10 to 30,000 tons. Fig. 3.5 shows the estimated balance of ore processing. It is estimated that arsenic content in ore is 3 to 5% and total amount of arsenic is 900 to 1,500 tons. Upstream process before roasting generated waste containing arsenic in the form of sulfide. The amount is 5,400 to 9,000 tons at arsenic contents around 10%. At roasting process, arsenic becomes, in principles, oxide form (as As_2O_3). Depending on the roasting condition, sulfate salt or arsenate salt also might be generated. If combustion process is not well controlled, non-reacted sulfide also presented. In summary, amount of arsenic waste as oxide form is 1,000 to 1,800 tons at arsenic. These concentration waste is considered to be left inside the concentrator site. However, their amount is far less than the estimated volume. Hence, most of them might be dumped to some place within Ron Phibun district as detected by auger, drilling survey.

3.3 Exploration of contaminated source in sediment

3.3.1 Reconnaissance by auger survey

As a first step of exploration of contaminated source and delineation of polluted groundwater, auger survey of approximately 300 points in 141m spacing, which covered entire survey area, was carried out during August to November in 1998. Auger was driven manually down to 5m depth to sample soil and groundwater and to measure various physical/chemical condition (maximum depth depended on groundwater table. If water table is deeper than 5m, groundwater was not sampled). Sampling points is shown in Fig. 3.6. Soil was sampled at 30cm and 100cm depth. Samples were subject to elution test for arsenic and sulfate. Together with groundwater sampling (hereunder it will be called auger water to differentiate from well water). pH. ORP (Oxidation-Reduction potential). temperature. EC. arsenic is field measured. Arsenic was analyzed also by atomic adsorption at the laboratory.

Fig. 3.7 shows arsenic concentration contour of auger water. Arsenic concentration is laboratory data. Contour map is prepared by kriging of log converted value of original data. Therefore. there may be slight difference between actual data and contour. However contour is inferred from many data and hence the map shows generalized trend of arsenic distribution.

Following four areas were recognized as over 1mg/l concentration zone in the contour map. That is. 1) the foothill concentrator and its downstream, 2) around the

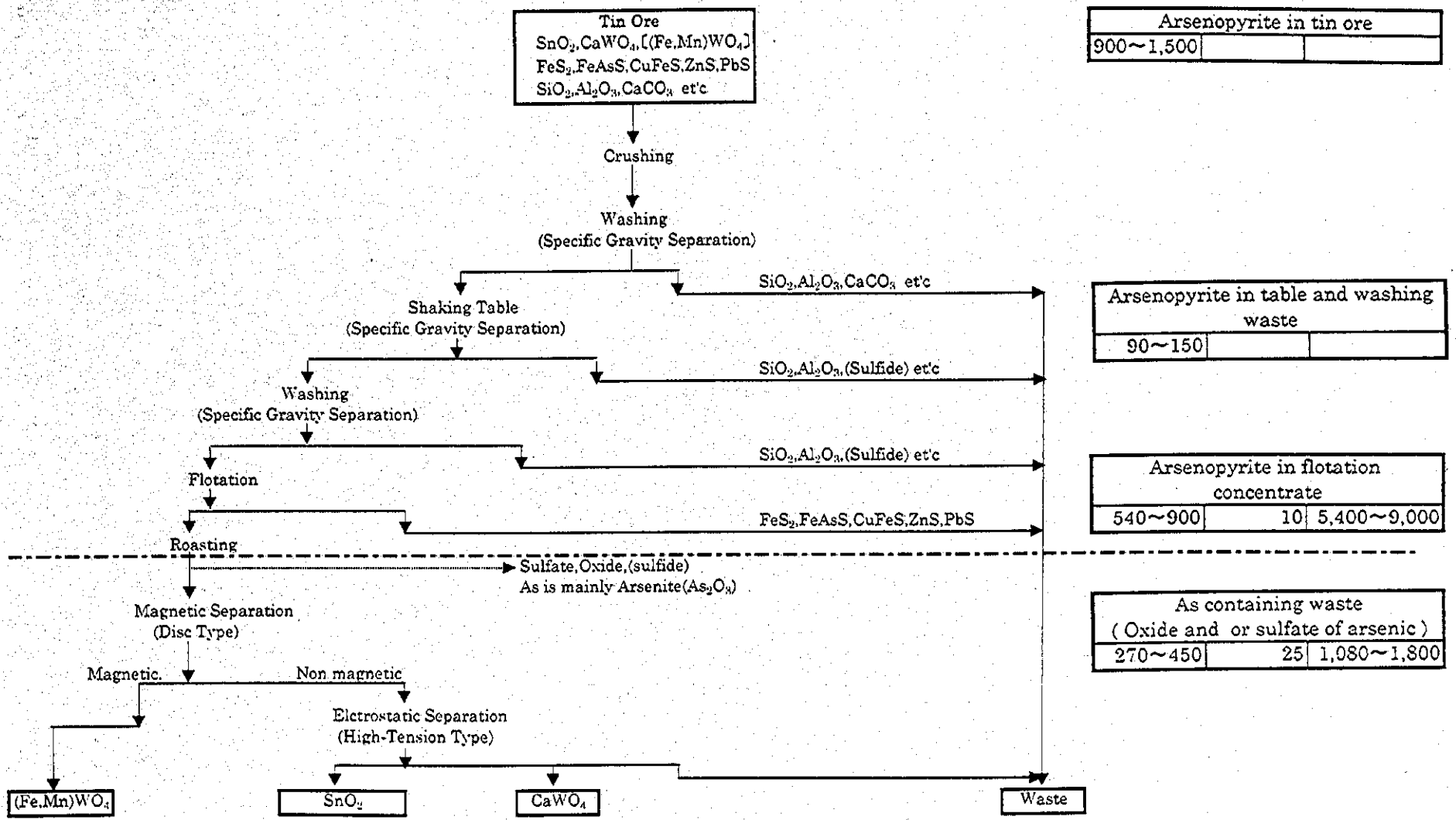

Fig.3.5 Material Balance of the Town Concentrator

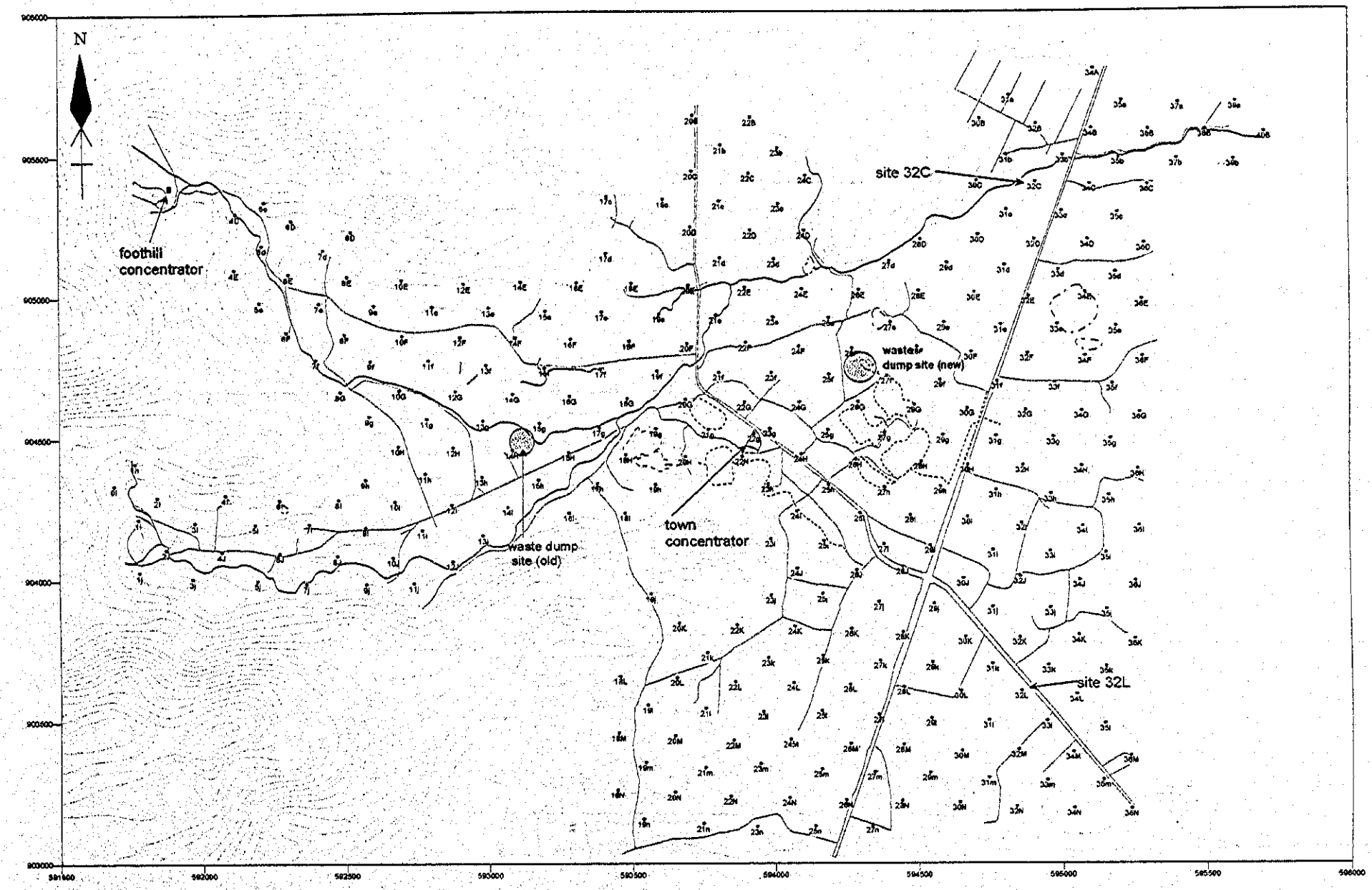

Fig 3.6 Location of Auger Survey Points (1998)

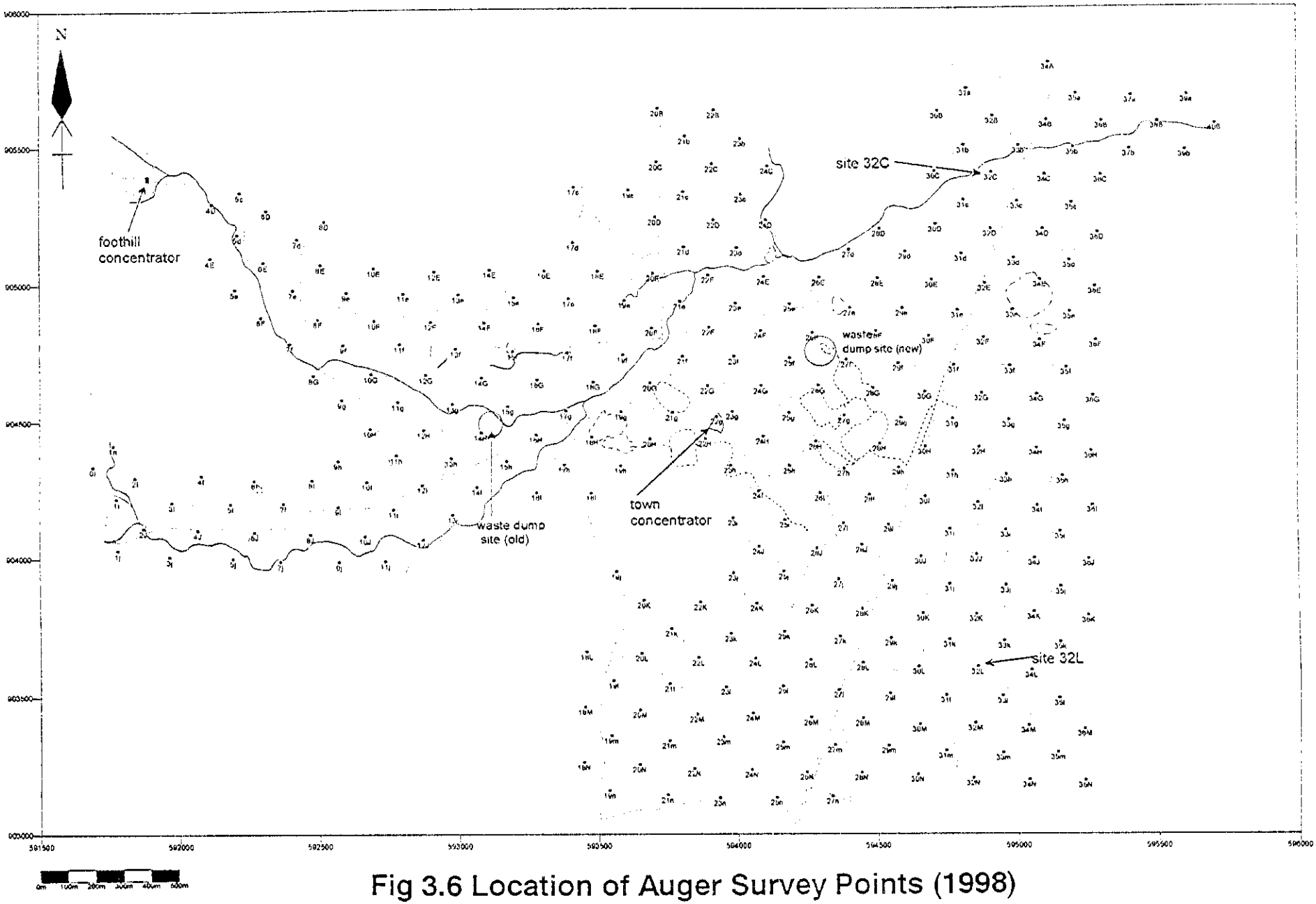

Fig 3.6 Location of Auger Survey Points (1998)

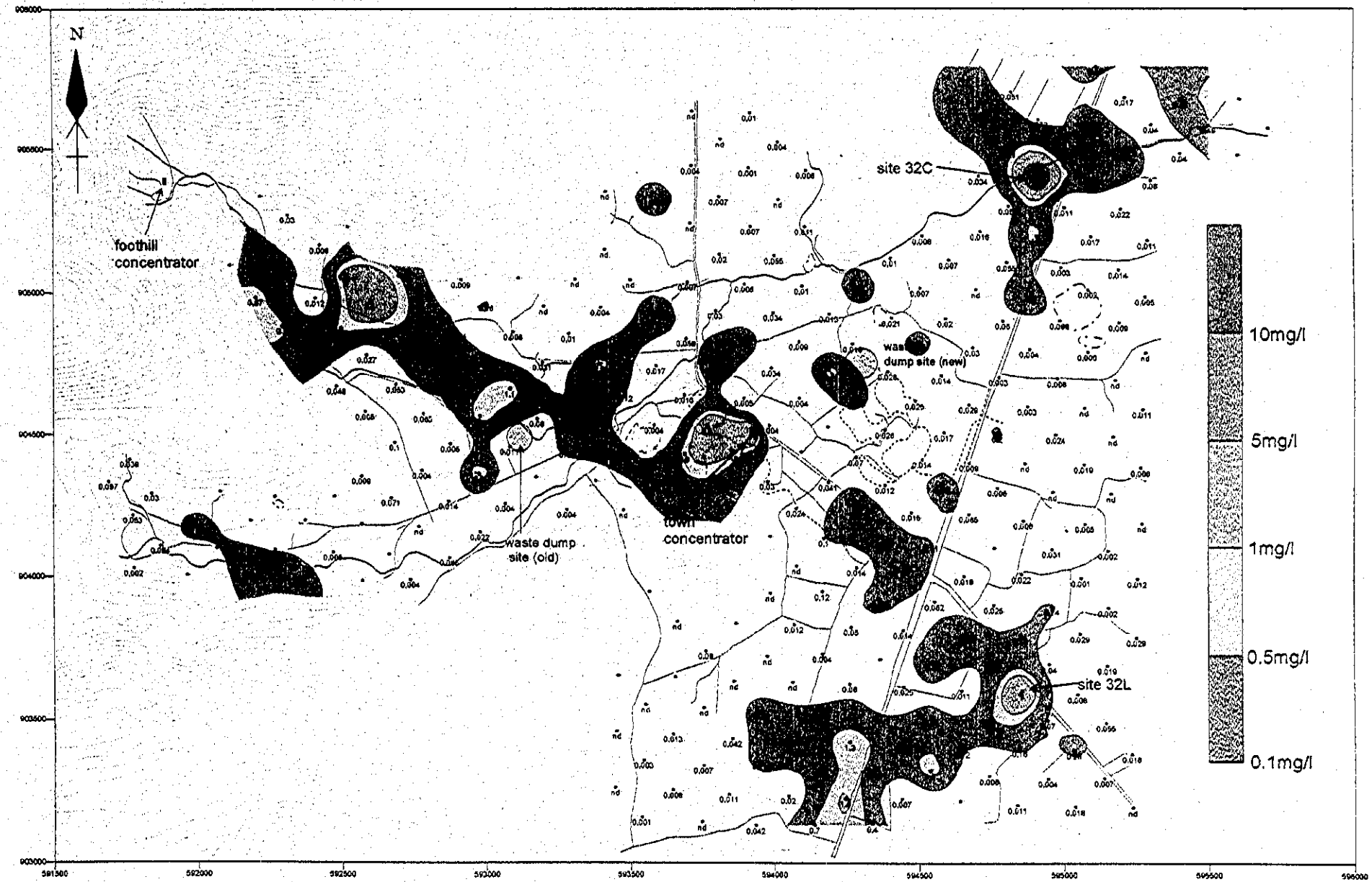

Fig 3.7 Arsenic Distribution of Auger Water (1998)

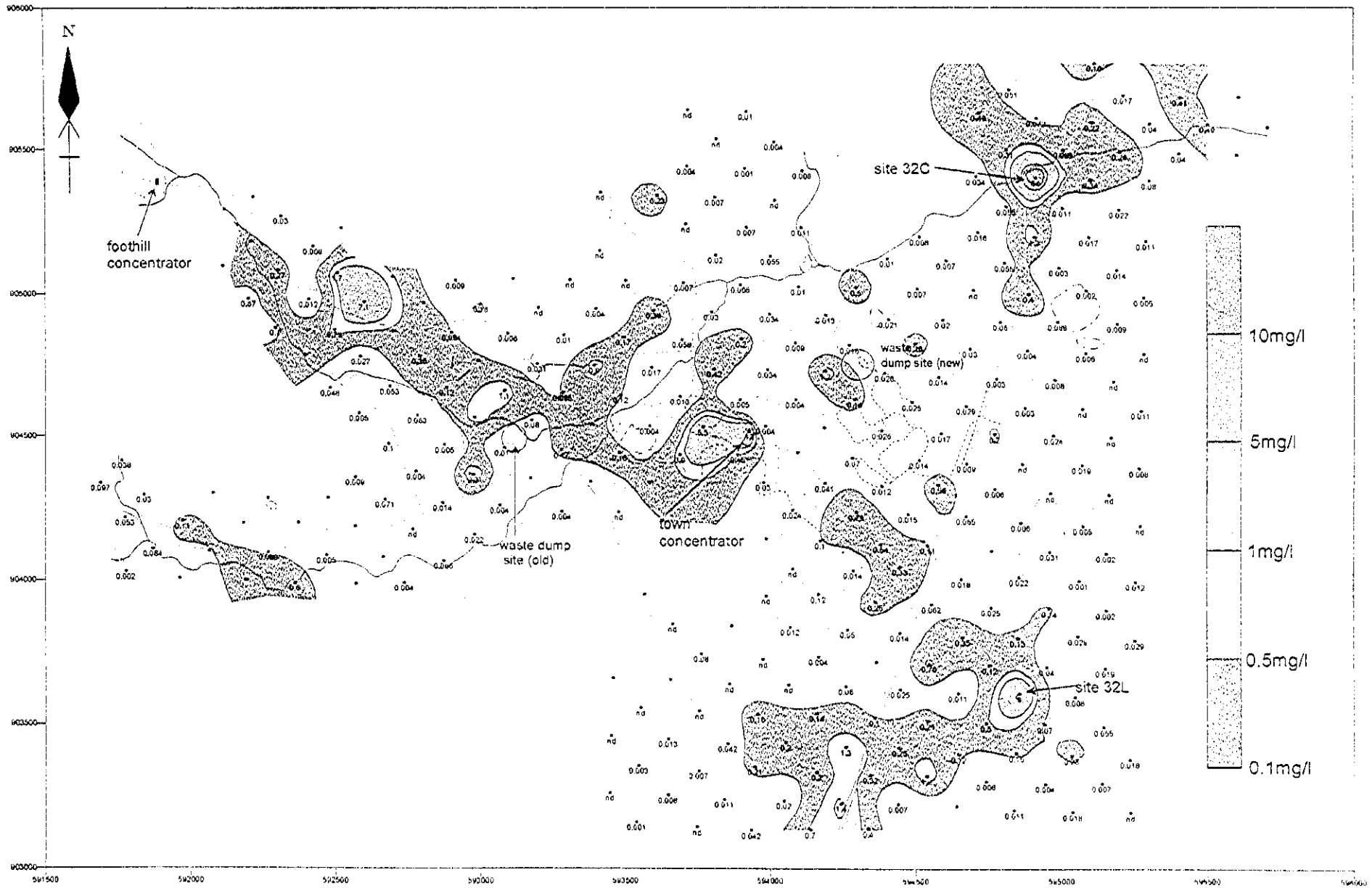

Fig 3.7 Arsenic Distribution of Auger Water (1998)

town concentrator, 3) around the site 32C, 4) around the site 32L. These areas does not have continuity each other in the contour map, and hence it is considered that there are separate sources.

Fig. 3.8 and 3.9 show arsenic concentration contour of soil elution test for 30cm and 100cm depth respectively. Zones above 0.1mg/l concentration were observed at the downstream of the foothill concentrator and around the town concentrator in Fig. 3.8. Some points in these zones exceed 1mg/l of arsenic. Other area, high points were scattered. Value of the elution test can not be compared directly with arsenic concentration of the auger water samples because 10 times of water weight was used for elution test. Fig. 3.9 shows other high zones above 0.1mg/l concentration in southeastern side of the town in addition to the two zones discussed in Fig. 3.8. However, there was no point above 1mg/l in these zones. Most of the points in these zones were less than 0.5mg/l.

Following conclusions can be drawn by comparing the arsenic distribution in auger water and in soil elution test. Out of high concentration zones of auger water, two zones, namely, 1) downstream of the foothill concentrator and 2) around the town concentrator, agreed with the high concentration area of soil elution test. On the other hand, remaining zones, namely, at 3) around the site 32C and 4) around the site 32L, do not have high concentration by the soil elution test.

3.3.2 Detail investigation by auger and trench survey

From the above discussion, areas for detailed investigation were selected as follows. Fig. 3.10 shows the areas. Reasons for choosing each area are described below.

1) The foothill concentrator and its downstream
   The concentrator was assumed as a major contaminated source. At the downstream, high arsenic content is observed in auger water as well as soil elution test. The area is difficult or impossible for auger sampling because of large gravel. Therefore, trench survey using a backhoe was planned. There was an old waste dumping site (hereunder it will be called waste dumpsite (old)) at the downstream outside of the area set in Fig. 3.10. An auger sampling was planned at the center of the dumping site.
2) The town concentrator and vicinity
   The concentrator was assumed as another major source. High arsenic is observed in auger water as well as soil elution test. Auger survey was planned. There is a new waste dumping site (hereunder it will be called waste dump site (new)) in the area.

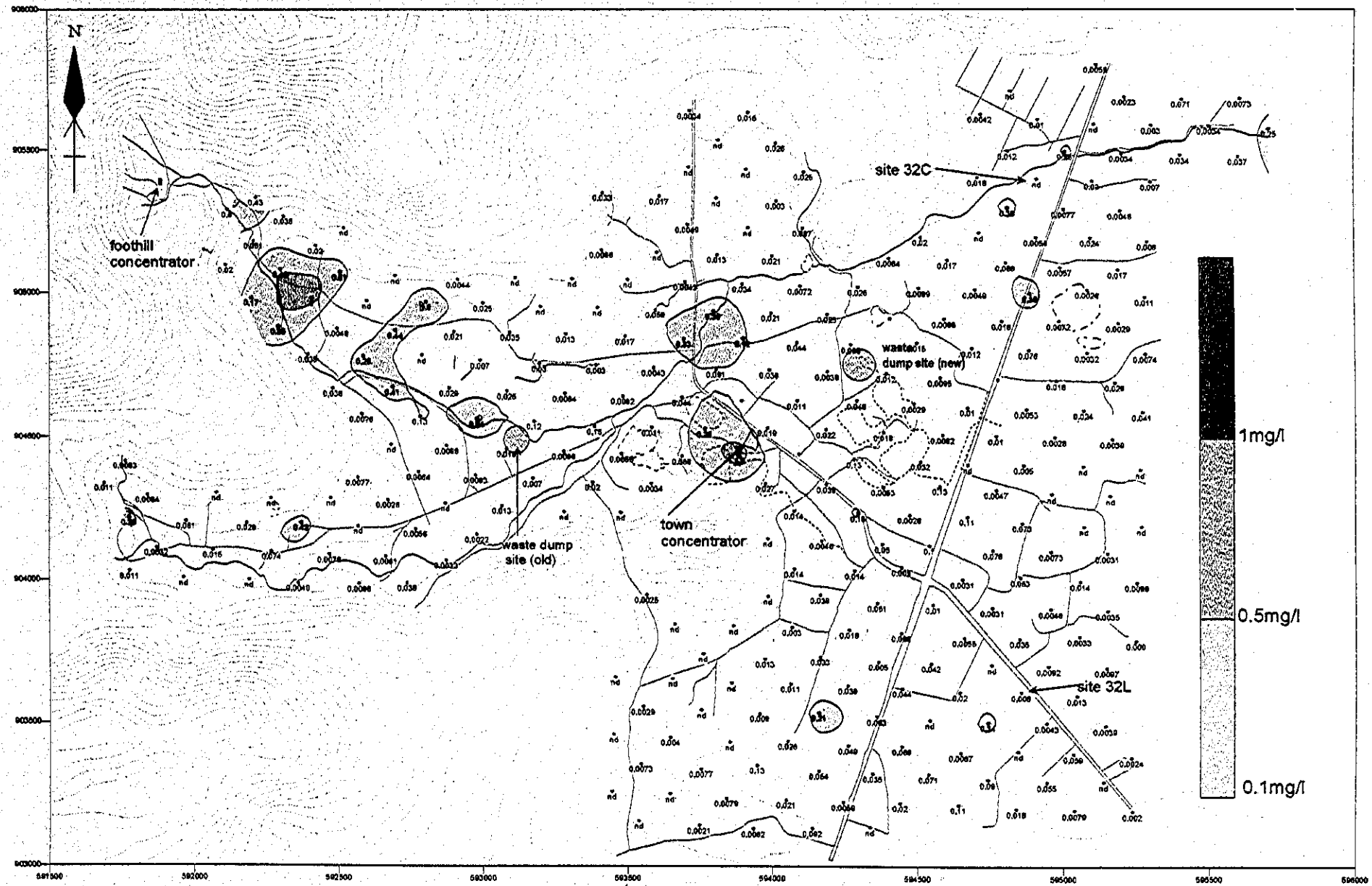

Fig 3.8 Arsenic Distribution of Soil Elution at 30cm Depth (1998)

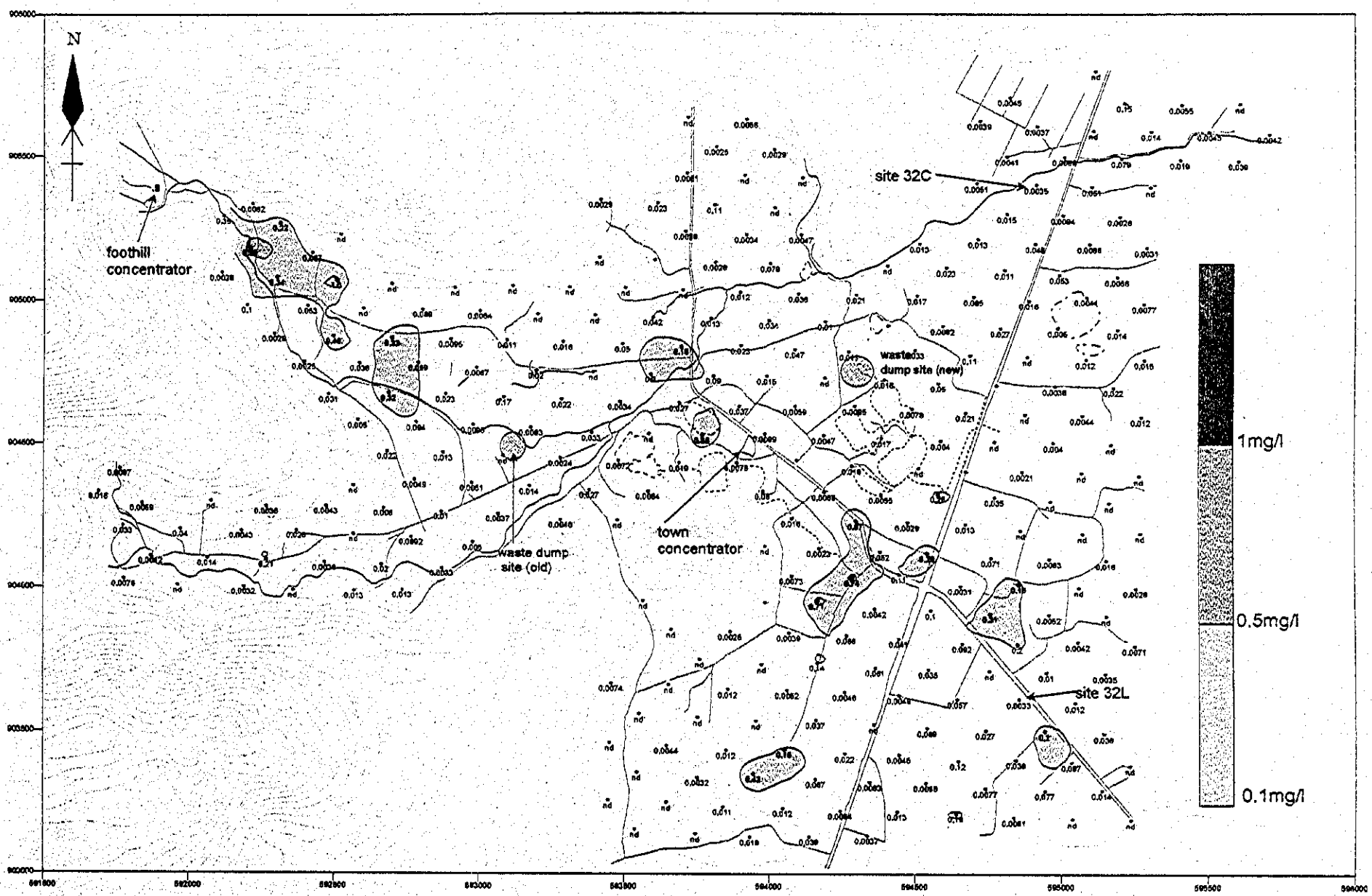

Fig 3.9 Arsenic Distribution of Soil Elution at 100cm Depth (1998)

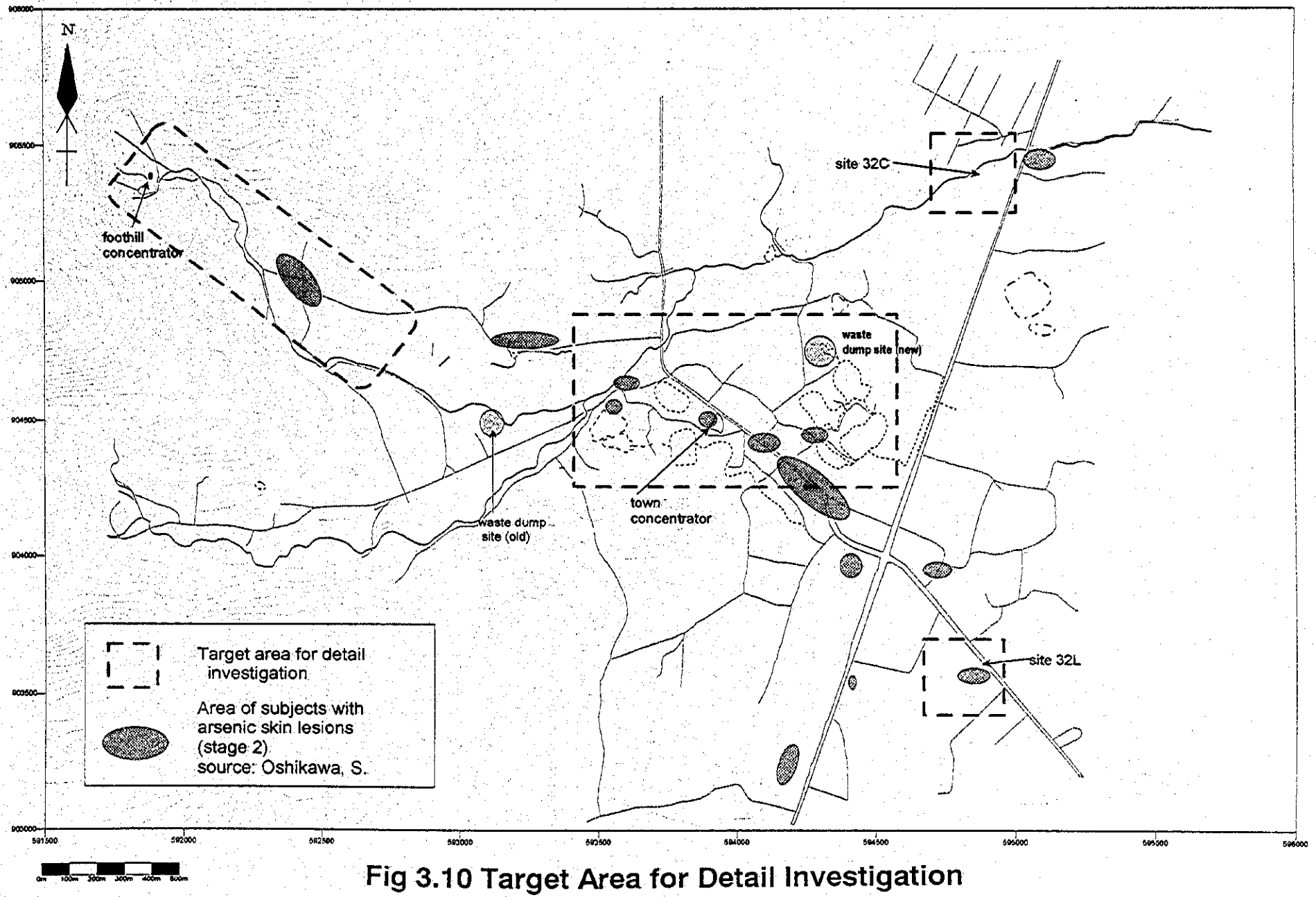

Fig 3.10 Target Area for Detail Investigation

An auger sampling was planned at the center of the dumping site.

3) Around the site 32C

High arsenic is observed in auger water. The soil elution test does not indicate high arsenic. Combined auger and trench survey is planned.

4) Around the site 32L

High arsenic is observed in auger water. The soil elution test does not indicate high arsenic. Auger survey is planned.

Fig. 3.10 also shows the distribution of the patients of arsenic poisoning whose skin lesions are above stage 2 (Oshikawa, 1998). The most of the patients are within the selected areas for detail investigation or its immediate downstream.

3.3.2.1 The foothill concentrator and its downstream

Fig. 3.11 shows the location of trench survey. The figure also shows the arsenic concentration of auger water and soil elution test. The trench locations were shown as T-1, T-2, T-3 and T-4 respectively. T-1 is located just beside the concentrator. It is assumed that mineral concentration facility was operated at this point. T-2 is in front of the concentrator. It is assumed previous effluent pond was located at this point. T-3 is located 300m downstream from the concentrator and in left shore of the stream. T-4 is approx. 400m southeast from T-3 and in the high arsenic zone of auger water.

Fig. 3.12 and 3.13 show the photographs of cross-section of T-1 and T-2. Geological observation, soil sampling points and their elution test result are also shown. Visual inspection identified various concentration wastes in several spots. Extremely high arsenic over 100mg/l in soil elution test was observed. This fact confirmed that these locations might be as contaminated source.

Fig. 3.14 and 3.15 show the photographs of cross-section of T-3 and T-4. There was no spot where extremely high arsenic is detected as T-1 and T-2. In average, around or below 0.5mg/l of arsenic was detected in soil elution test. It is considered that arsenic contamination at the foothill concentrator was diffused to the downstream.

Auger survey at the center of the waste dump site (old) (refer to Fig. 3.5 for location) revealed high arsenic both in auger water and in soil elution test (1.5mg/l and 1.8mg/l respectively) . ORP in water indicated oxidation condition. This oxidation status and high arsenic in soil elution test suggested the possibility of dumping of concentration waste in the site.