Heavy Metal Contamination around the Abandoned Metal Mine Sites in Korea

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Heavy Metals (trace metals)

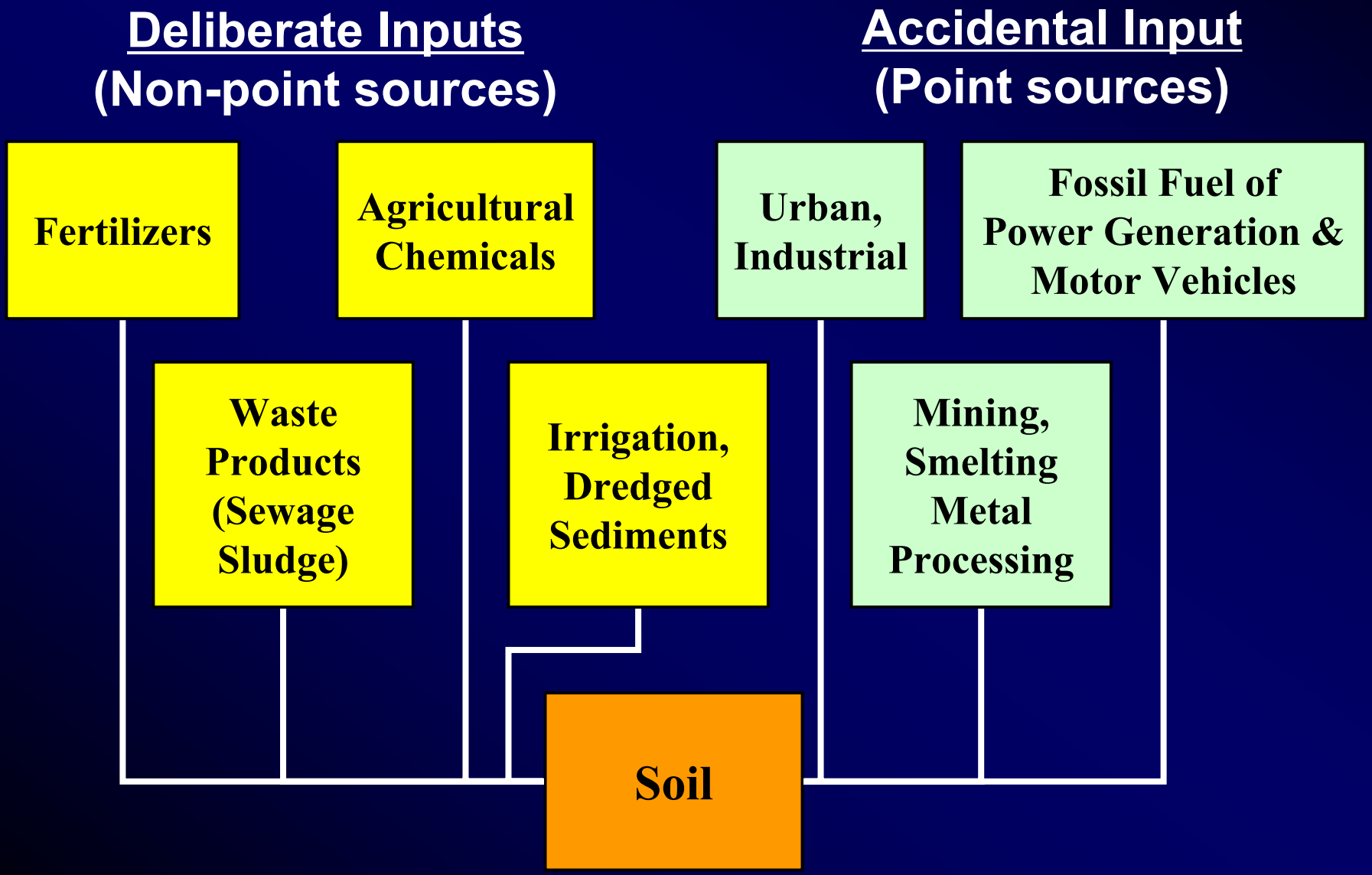
- A large group of trace elements which are both industrially and biologically important (Alloway, 1995)
- atomic density > 6 g/cm^3
- As, Cd, Cr, Ni, Cu, Pb, Mn, Co, Hg, Se, Zn (Sb, Au, Mo, Ag, Tl, Sn, U, V)
- ( ) : less important

Metal Pollution in Soil

- Natural condition
  - High background source rocks
  - Enrichment

- Anthropogenic pollution
  - Contamination

Anthropogenic Soil Contamination (Tiller, 1989)



Our Lab.

Assessment of Metal Pollution in Soils

1. Analysis of soils and metal speciation

2. Analysis of plant organ

3. Regional geochemical mapping
   - Regional background

4. Pollution Index(= P.I.)
   - Enrichment Index

5. Human risk assessment

Pollution Index (P.I.)

Pollution Index

$$= \frac{\sum (\text{element contents in soil / tolerable level})}{\text{No. of analysed elements}}$$

Pollution Index

$$= \frac{1}{10}\left(\frac{As}{20} + \frac{Cd}{3} + \frac{Cu}{100} + \frac{Hg}{2} + \frac{Pb}{100} + \frac{Mo}{5} + \frac{Sb}{5} + \frac{Se}{10} + \frac{Tl}{1} + \frac{Zn}{300}\right)$$

Tolerable Level to Soil Pollution

Element	Tolerable level (ppm)			
	Linzon (1978)	Kabata-Pendias (1979)	Kloke (1979)	KOREA
As	25	30	20	6
Cd	8	5	3	1.5
Cr	75	100	100	4(+6)
Cu	100	100	100	50
Hg	0.3	5	2	4
Mo	2	10	5	-
Ni	100	100	50	40
Pb	200	100	100	100
Sb	-	10	5	-
Se	5	10	10	-
Zn	400	300	300	300

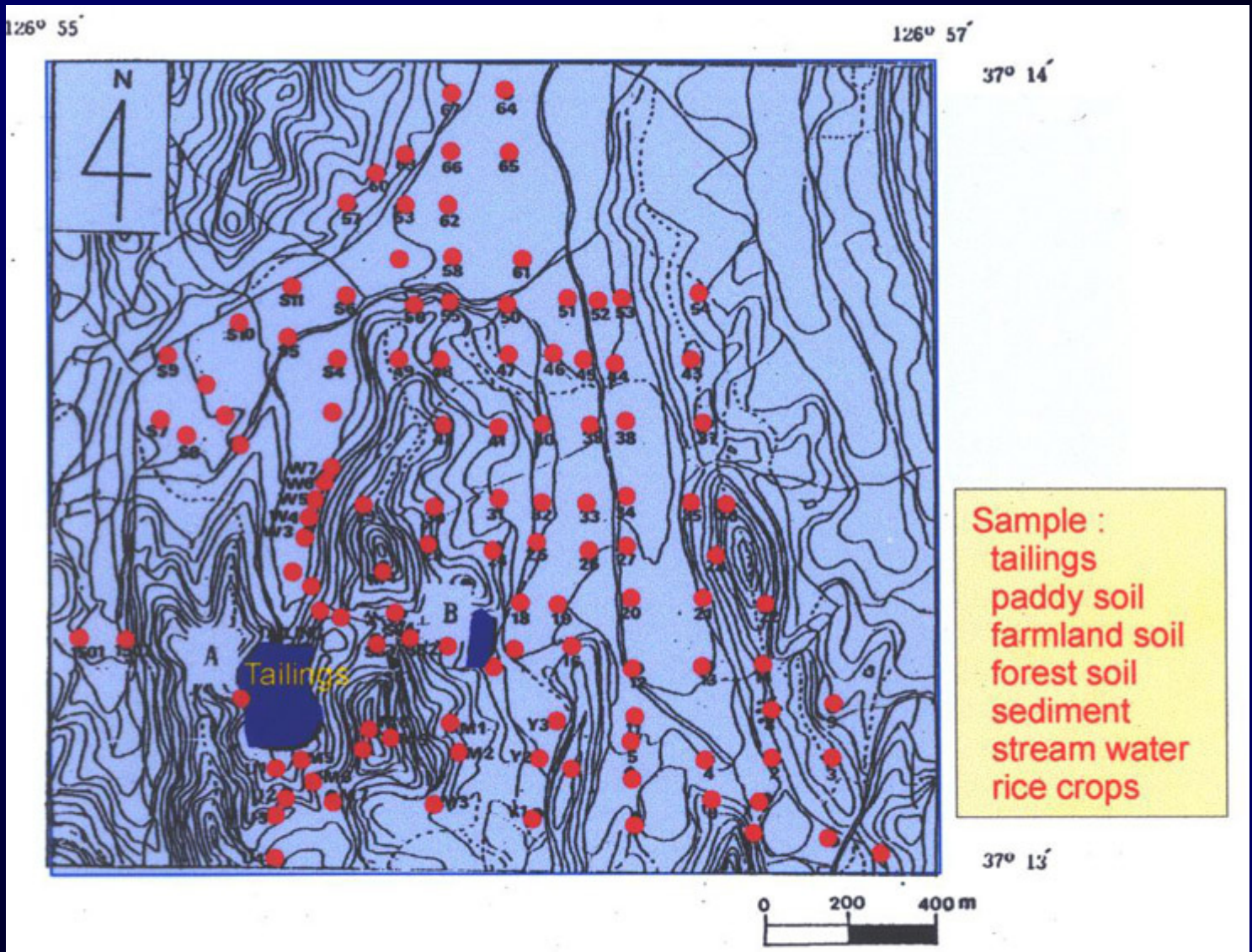
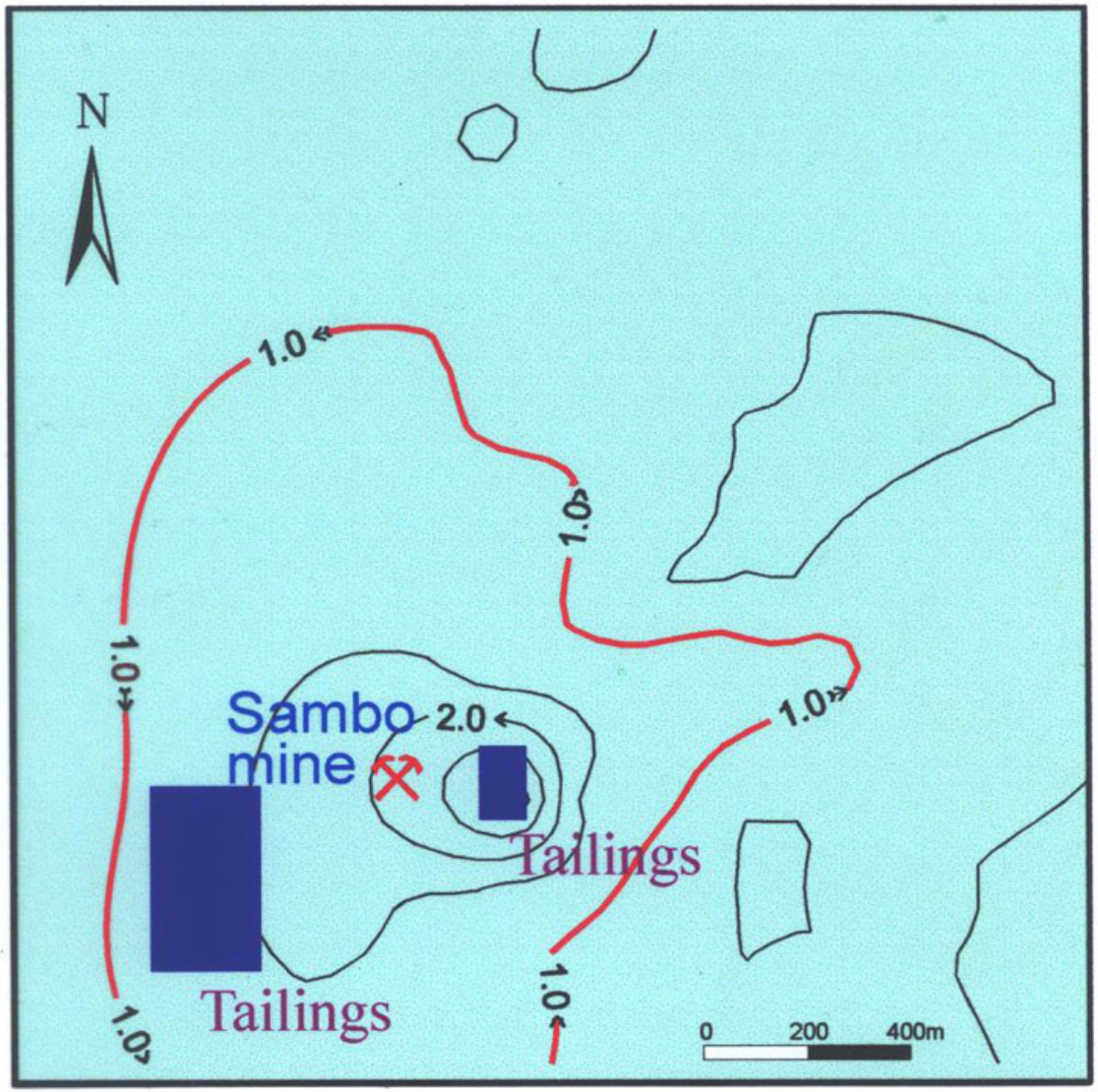


Fig. Sampling locations around the Sambo Pb-Zn barite mine.



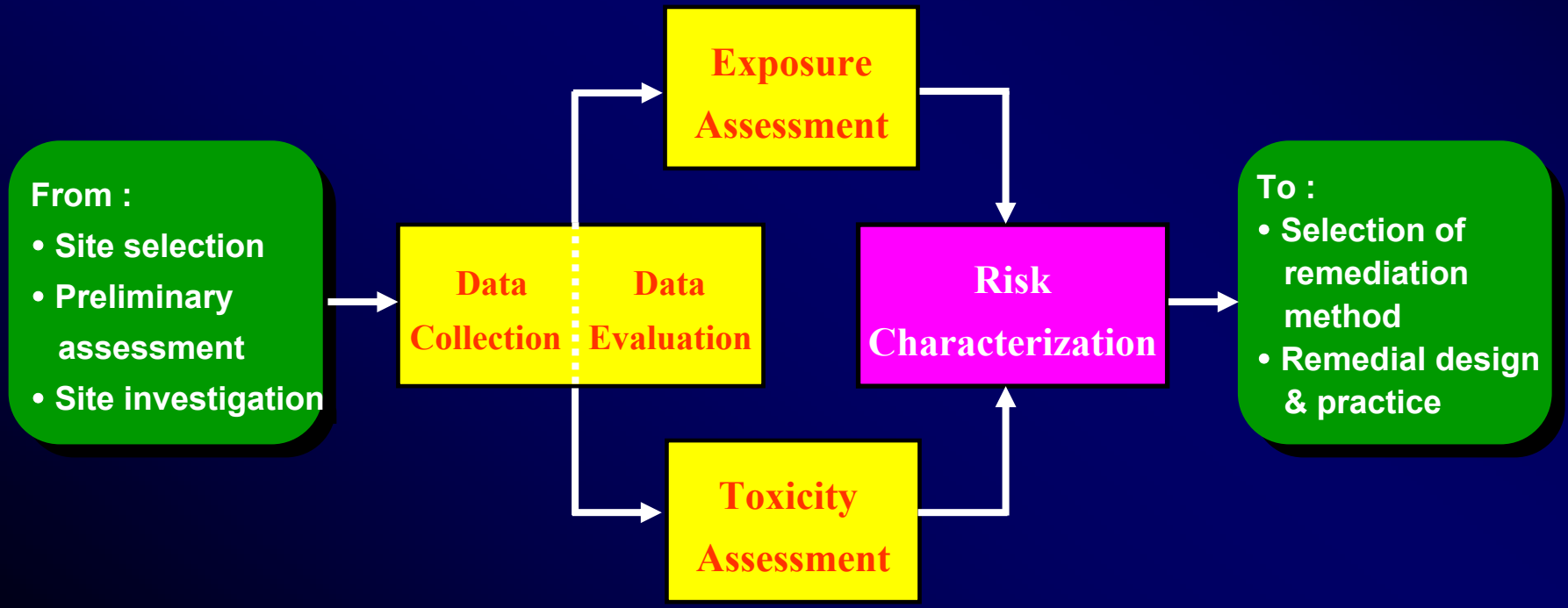
PI = [Cd/3+Cu/100+Pb/100+Zn/300]/4

Fig. Pollution index in soils around the Sambo Pb-Zn barite mine

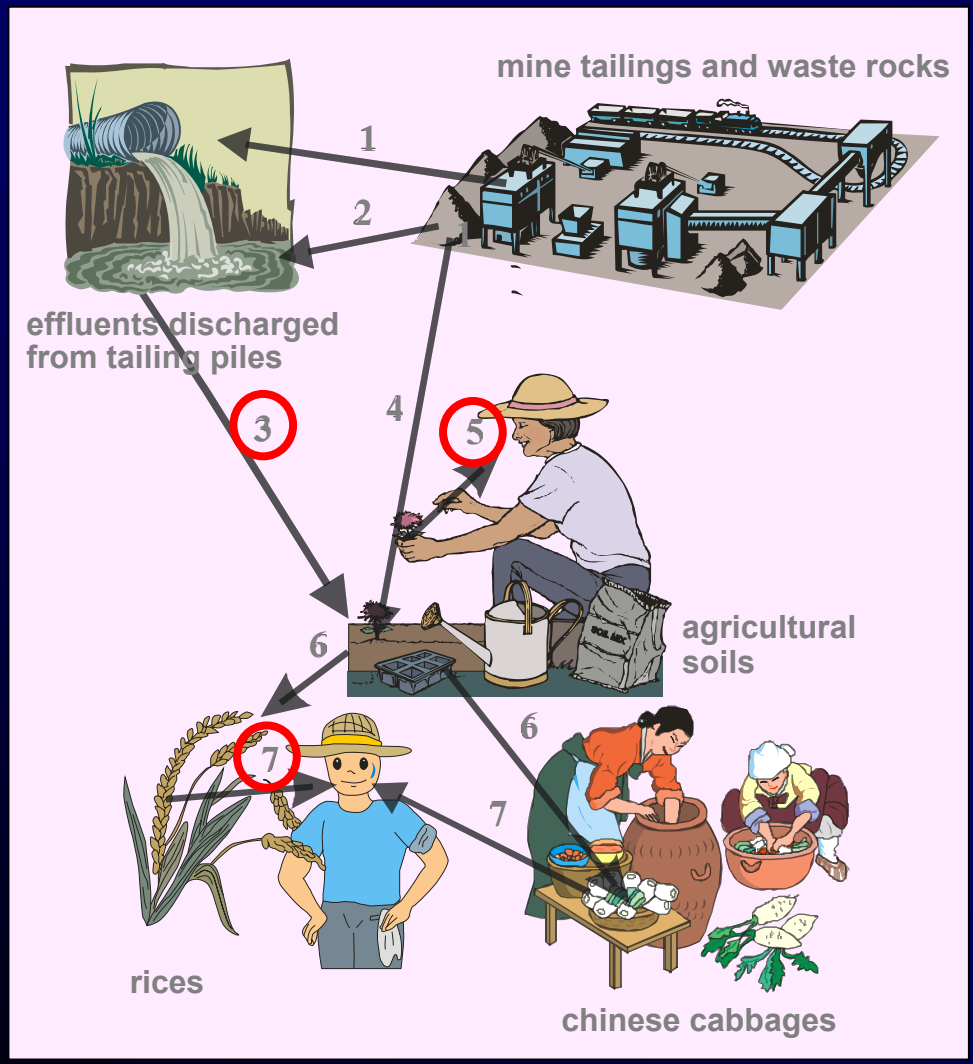
Risk Assessment Process

- **Risk assessment :**

Characterize the current and potential threats to human health and the environment that may be posed by contaminants migrating to groundwater and surface water, releasing air, leaching through soil, remaining in the soil, and bioaccumulating in the food chain



Exposure Pathway



Multiple pathways of exposure

1. Aqueous effluents entering surface and groundwater systems
2. Contaminated dust entering surface water bodies
3. Contaminated surface and groundwater used for irrigation and drinking
4. Disposal of contaminated particulate matter onto agricultural soils
5. Soil ingestion (through bad hygiene)
6. Plant uptake from soils
7. Ingestion of contaminated plants

Result of Risk Assessment for heavy metals

∗ Hazard indices (HI) for As, Cd and Zn - toxic risk

Mine	HI for As	HI for Cd	HI for Zn	HI
Dongil	5.76	2.56	0.80	9.1
Okdong	8.88	1.11	0.44	10.4
Songcheon	26.32	10.74	0.42	37.5
Dongjung	1.00	0.13	0.02	1.2
Dokok	0.11	3.45	0.03	3.6
Hwacheon	5.38	0.97	0.57	6.9

∗ Cancer risk for As with exposure pathways

Mine	Soil pathway	Groundwater pathway	Rice grain pathway
Dongil	3.1×10^{-6}	6.6×10^{-4}	3.6×10^{-4}
Okdong	1.2×10^{-6}	7.2×10^{-4}	8.5×10^{-4}
Songcheon	2.0×10^{-5}	4.6×10^{-3}	-
Dongjung	8.0×10^{-6}	1.7×10^{-4}	-
Dokok	6.8×10^{-7}	1.9×10^{-5}	-
Hwacheon	1.7×10^{-6}	1.3×10^{-4}	8.2×10^{-4}

Objectives

1. Environmental geochemical survey around abandoned metal mines in Korea
2. Characteristics of contamination according to the type of metal mine
3. Impacts on food crops and human health
4. Proper reclamation plan

光明시 가학동 폐광일대 주민

카드뮴 집단 검출

30년이상 거주 노동부기준치 2~3배 나

「이타이이타이病」 기

농작물·지하수 통해

중앙대의대 2년간 역학조사결과

경기 광명시 가학동 가학광산 주민 주민들 체내에서 일본의 「이타이 이타이병」을 일으키는 유독 중금속 카드뮴이 집단적으로 다량 검출됐다.

이같은 사실은 중앙대 의대 예방의학교실 ㅍㅌㅎ교수팀이 광명시의 의뢰로 지난 2년간 주민들을 대상으로 벌인 역학조사를 바탕으로 작성한 최종보고서에서 15일 밝혀졌다.

조사에 따르면 주민 4명의 신장에서 카드뮴이 노동부의 카드뮴취급작업장의 근로자 건강관리기준치(10㎍)를 2~3배 초과해 검출된 것으로 소변분석 결과 드러났다.

이 수치는 카드뮴 취급 무관한 일반인에게서 검출되는 농도(2㎍ 이하)보다 10배이상 높은 것이다.

또 3명의 혈액에서 근자기준치 10㎍가 넘는 카드뮴이 나왔으며 특히 1명

카드뮴중독症…칼슘대사 장애 유발

이타이 이타이病이란

이타이 이타이병은 1955년 일본 도야마(富山)현 진즈가와(神通川)유역 주민들이 뼈가 연화돼 걸을 수 없는 괴질을 집단으로 앓게 되자 「아프다 아프다」는 뜻으로 이름 붙여진 병이다. 그 오사카시 등 일본 국내 곳곳에서 똑같은 증세의 환자가 발견됐으며 처음 학계에 보고된지 13년만인 68년 후생성은 병의 원인을 미쓰이

16 March, 1996

경향 사회 1996년5월7일 화요일

폐광지역 중금속 오염 환경부 실태파악 착수

本紙보도따라…예산지원 긴급요청

7 MAY, 1996

光明가학동 벼농사 금지

환경연합 전국2백50곳 별도조사

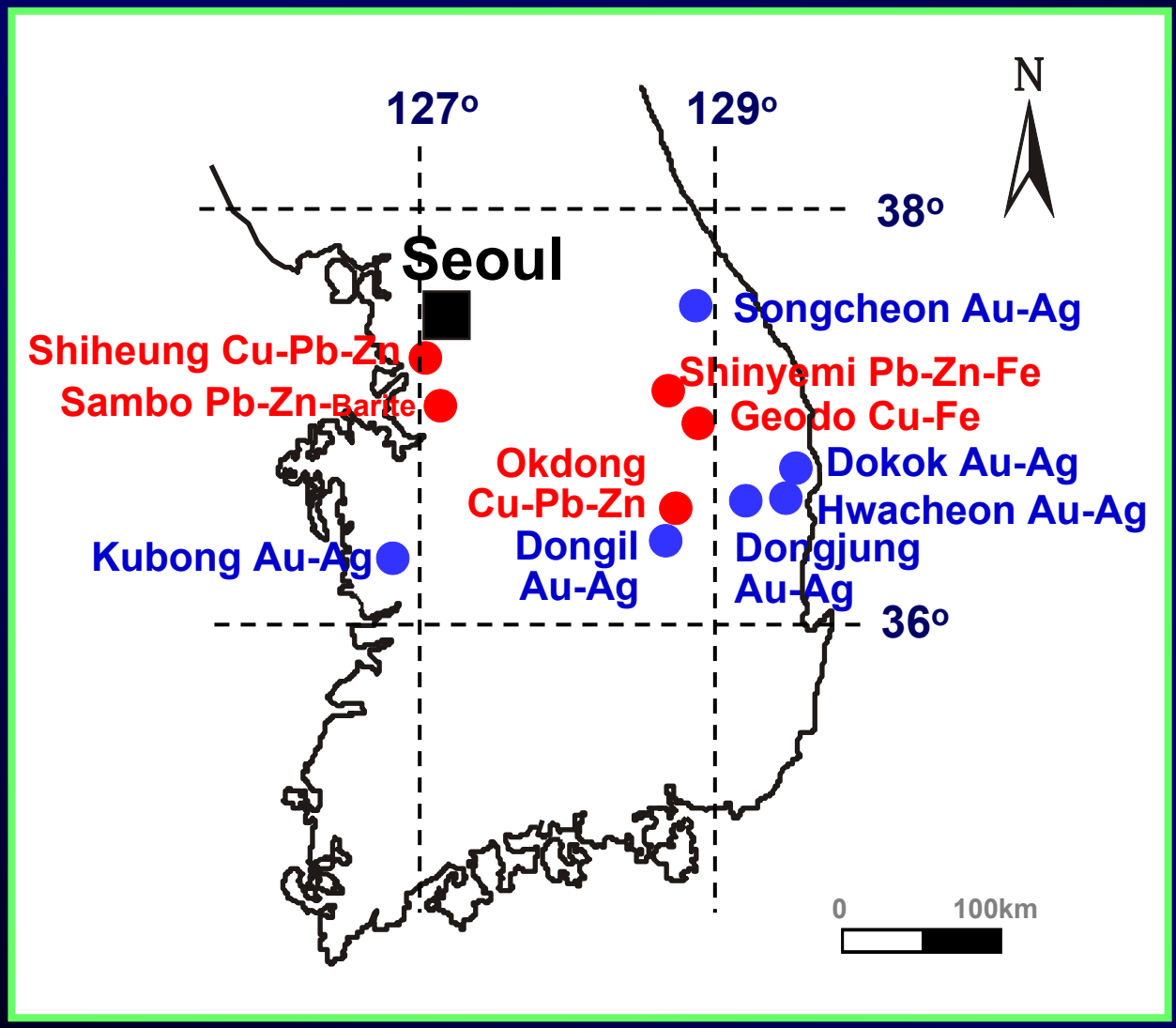
Metal Mines in Korea (MOCIE, 1999)

Total	906
Au, Ag	487
Cu, Pb, Zn	369
Fe	10
W	21
Mo	5
Mn	2
Bi	2
Ni	6
Sn	3
Co	1

Abandoned metal mines :
894 mines (98.7%)

Working metal mines :
12 mines

Location of the Study Mines



Geology and Site Description for the Base-metal Mines

Mine	Type of ore deposits	Major metals	Main geology	Sulfide minerals	Woking period
Sambo (SB)	Hydrothermal vein type	Pb, Zn, Barite	Muscovite Schist, granite gneiss, two-mica granite	Galena, Barite, Sphalerite	1945 - 1991
Shiheung (SH)	Skarn	Pb, Zn, Cu	Biotite banded gneiss, schist lime-silicate	Sphalerite, Galena, Chalcopyrite, Pyrite	1912 - 1973
Okdong (OD)	Hydrothermal vein type	Cu, Pb, Zn	Shale, sandstone	Chalcopyrite, Galena, Sphalerite, Pyrite	1936 - 1988
Shinyemi (SY)	Lens or pipe skarn	Pb, Zn, Cu, Mo, Fe	Limestone	Sphalerite, Galena, Chalcopyrite, Pyrite, Pyrrhotite	1941 - 2003
Geodo (GD)	Skarn	Fe, Cu, Au	Limestone, diorite porphyry	Chalcopyrite, Arsenopyrite, Pyrite	1921 - 1988

Geology and Site Description for the Au-Ag Mines

Mine	Type of ore deposits	Major metals	Main geology	Sulfide minerals	Woking period
Kubong (KB)	Hydrothermal vein type	Au, Ag (Cu,Pb,Zn)	Granitic gneiss lime-silicate	Pyrite, Galena, Sphalerite, Pyrite, Arsenopyrite	1908 - 1970
Dongil (DI)	Hydrothermal vein type	Au, Ag (Cu,Pb,Zn)	Sedimentary rock	Chalcopyrite, Galena,Sphalerite, Pyrite, Arsenopyrite	1975 - 1992
Songcheon (SC)	Hydrothermal vein type	Au, Ag (Mo)	Metamorphic rock	Arsenopyrite, Sphalerite, Galena	1962 - 1977
Dongjung (DJ)	Hydrothermal vein type	Au, Ag (Pb,Zn)	Biotite granite	Galena, Sphalerite, Pyrite, Arsenopyrite	1933 - 1976
Dokok (DK)	Hydrothermal vein type	Au, Ag (Cu)	Sedimentary rock & Quartz porphyry	Chalcopyrite, Sphalerite, Galena, Pyrite	1936 - 1989
Hwacheon (HC)	Hydrothermal vein type	Au, Ag (Pb,Zn)	Conglomerate, sandstone, shale	Arsenopyrite, Galena, Pyrite	1933 - 1977

Shiheung Cu-Pb-Zn mine

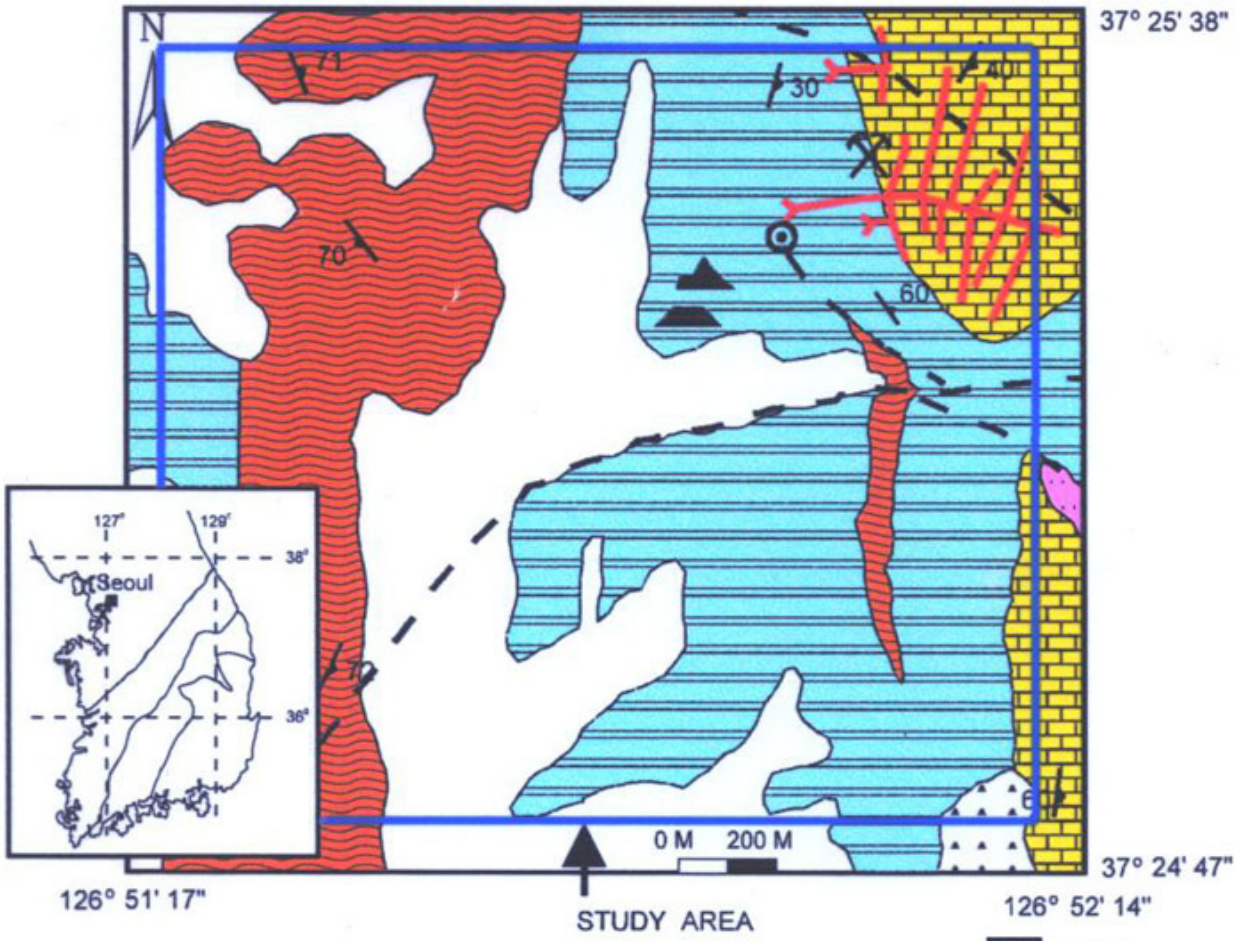
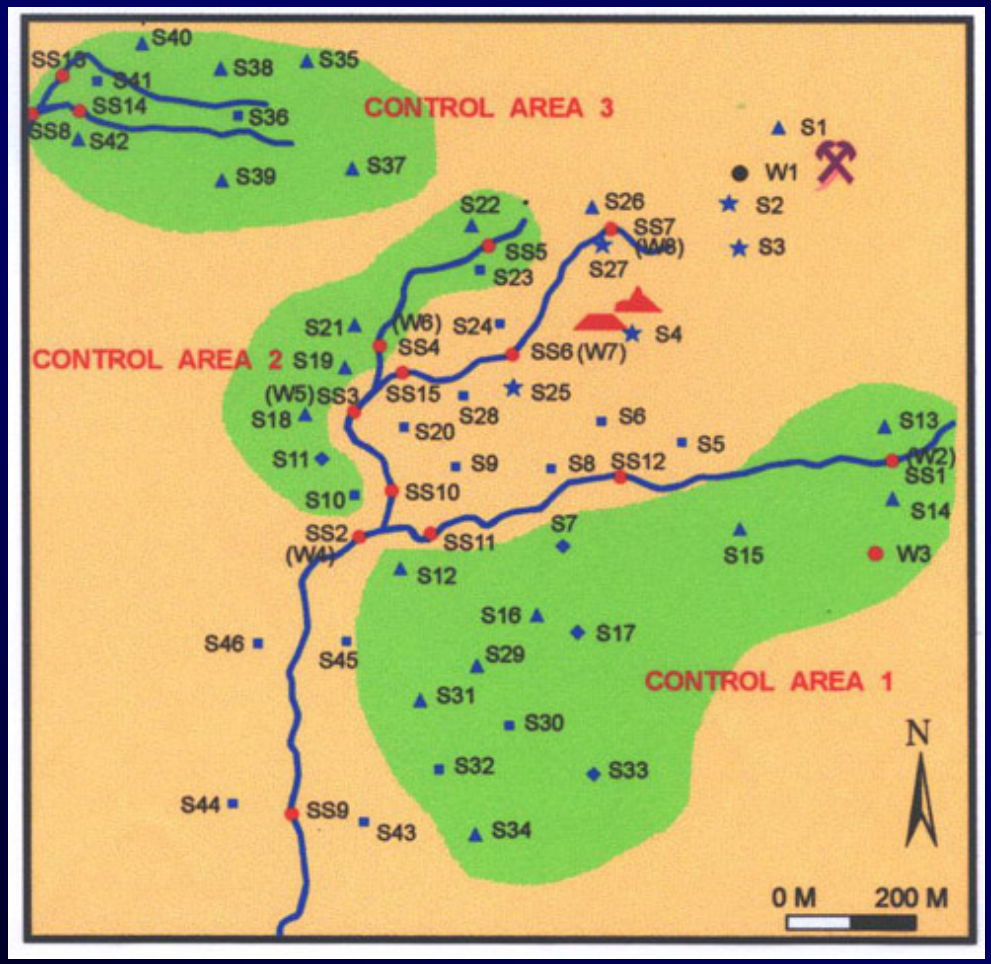


Fig.1 Geologic Map in the vicinity of the Shi-heung Cu-Pb-Zn Mine (from Chi, 1970).



MINE
TAILINGS
WASTE LANDFILL SITE
CONTROL AREAS
OBJECT AREA

PADDY SOIL
FARMLAND SOIL
FORREST SOIL
TAILING SOIL, DRESSING SOIL
STREAM SEDIMENT
(AND / OR WATER)

Fig. Sampling Location Map in the vicinity of the Shi-Heung Cu-Pb-Zn Mine.

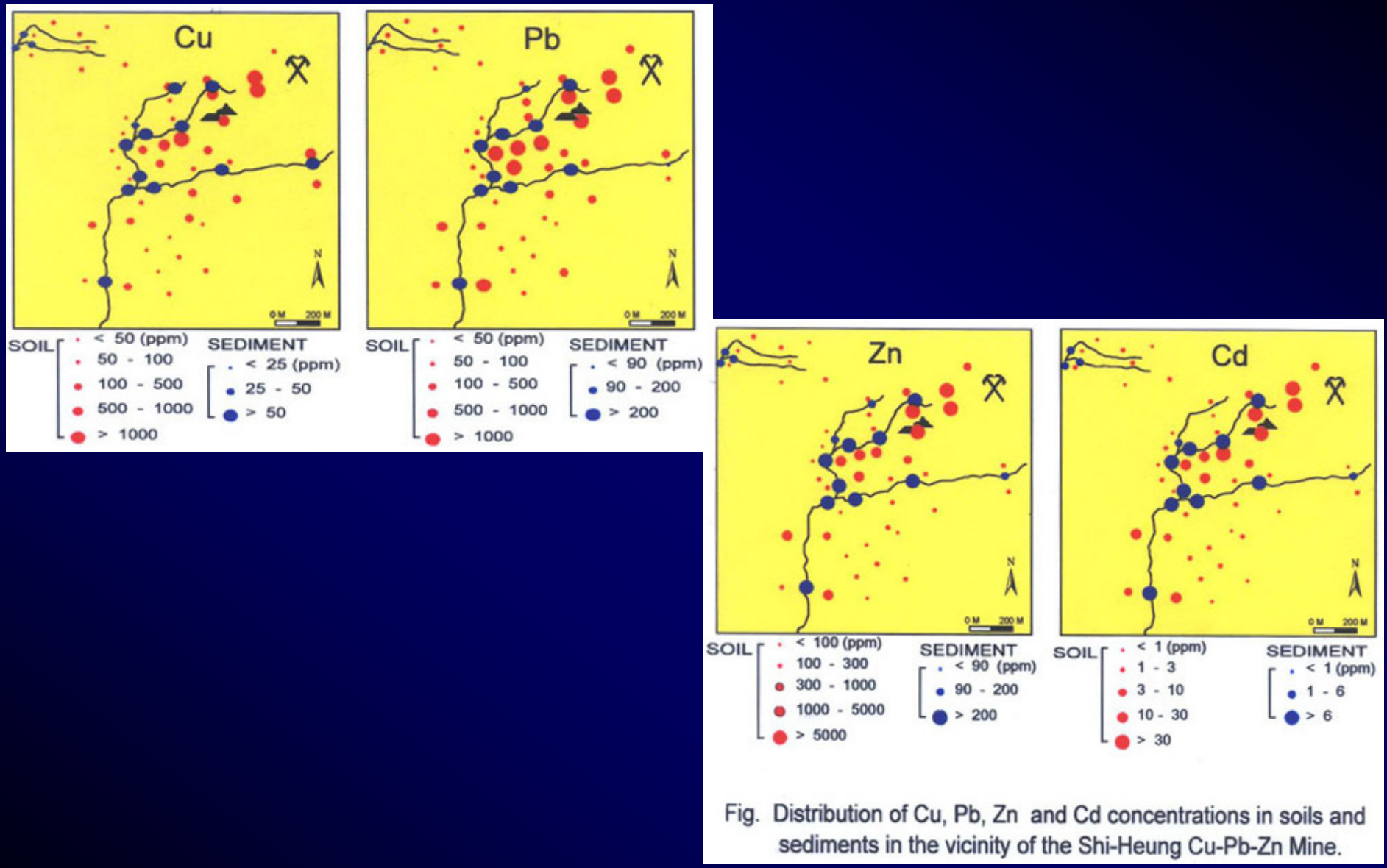


Fig. Distribution of Cu, Pb, Zn and Cd concentrations in soils and sediments in the vicinity of the Shi-Heung Cu-Pb-Zn Mine.

Table Pollution index of heavy metals in soils and sediments around the Shiheung Cu-Pb-Zn mine.

Area	Sample	P.I.
Object area	Paddy soil (11)	3.4 0.8 - 9.1
	Forest soil (2)	1.8 1.7 - 2.0
	Stream sediments (9)	13.8 5.4 - 22.5
	others (5)	61.1 17.0 - 103
Control area 1	Paddy soil (2)	0.6 0.5 - 0.6
	Farmland soil (3)	0.7 0.4 - 1.2
	Forest soil (8)	0.8 0.4 - 2.1
	Stream sediments (1)	0.6
Control area 2	Paddy soil (2)	0.7 0.4 - 1.0
	Farmland soil (1)	0.5
	Forest soil (4)	0.5 0.3 - 0.7
	Stream sediments (2)	0.6 0.6 - 0.7
Control area 3	Paddy soil (2)	0.4
	Forest soil (6)	0.5 0.4 - 0.6
	Stream sediments (3)	0.5 0.4 - 0.6

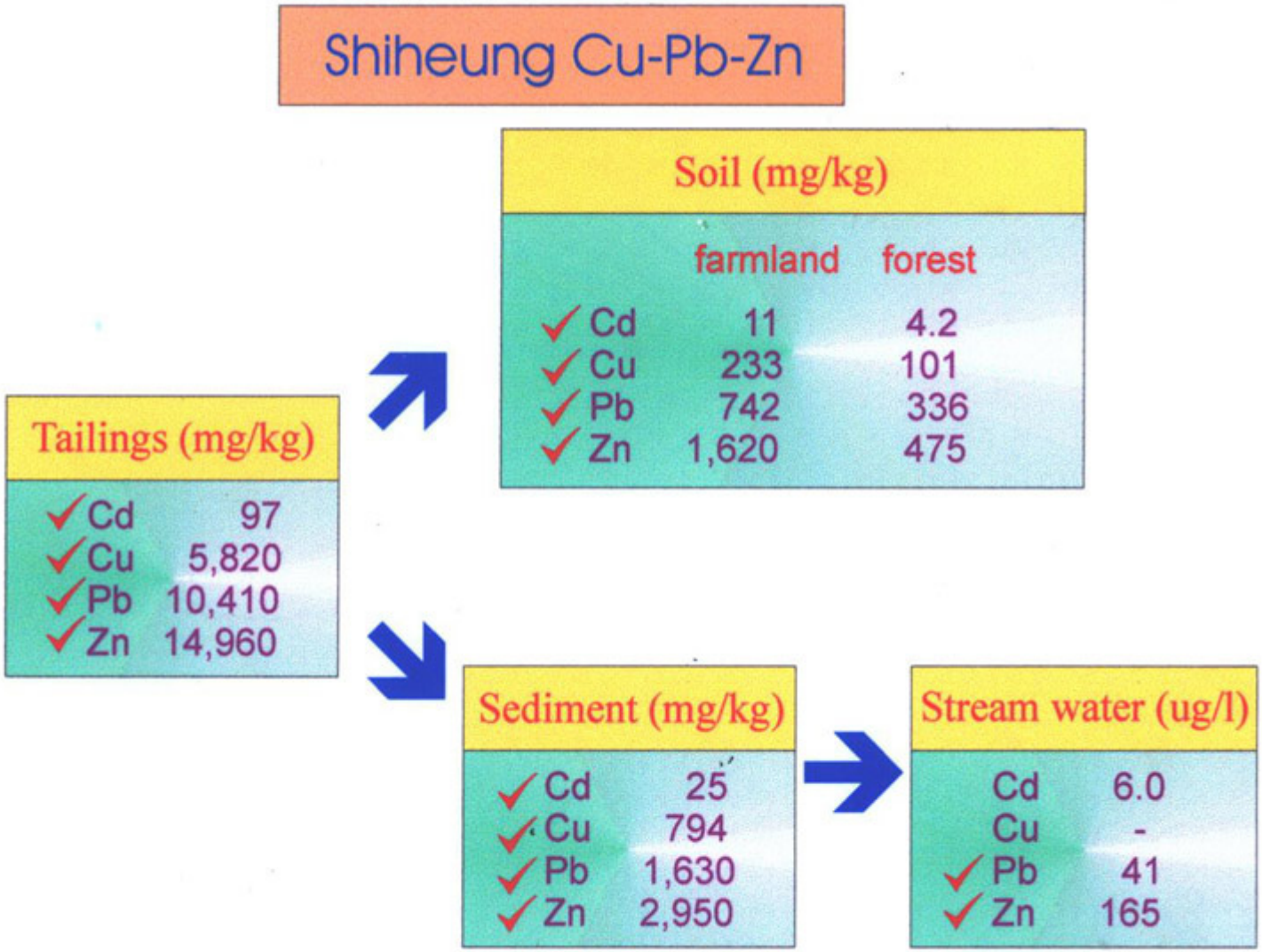


Fig. Heavy metal concentrations around an abandoned mine.

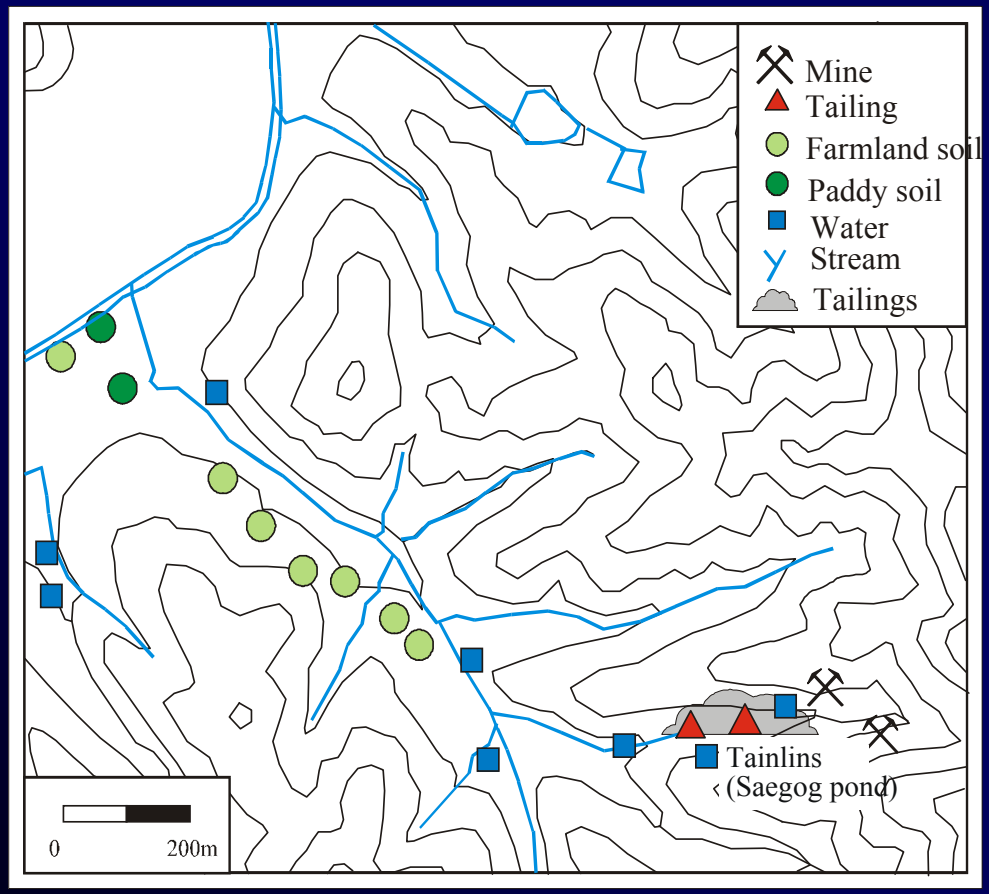

8 8'96


8 8'96

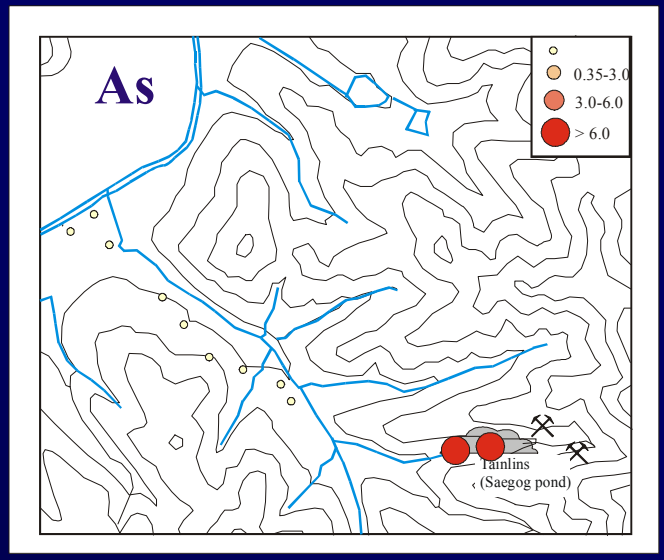

8 8'96

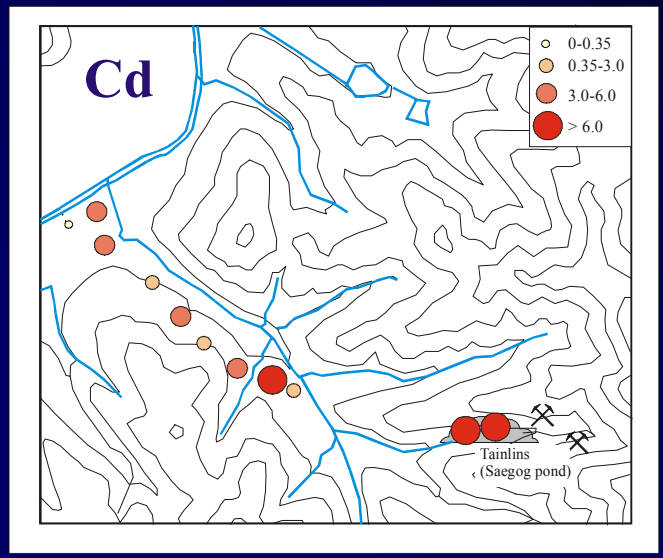
Okdong Cu-Pb-Zn mine

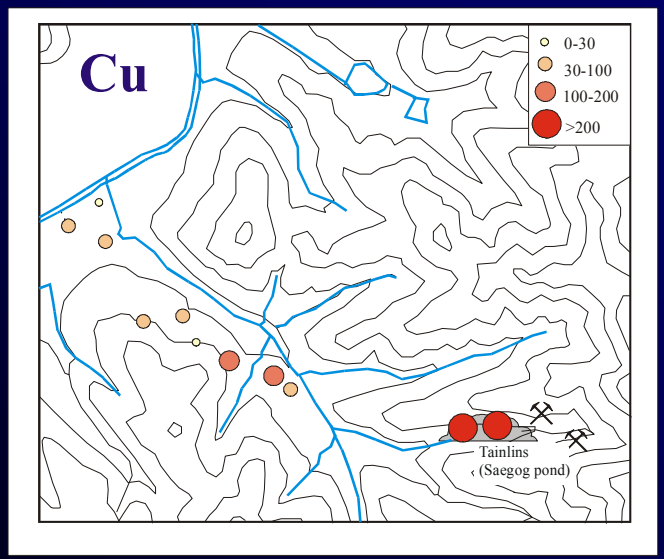
Sampling Location Map for the Okdong mine

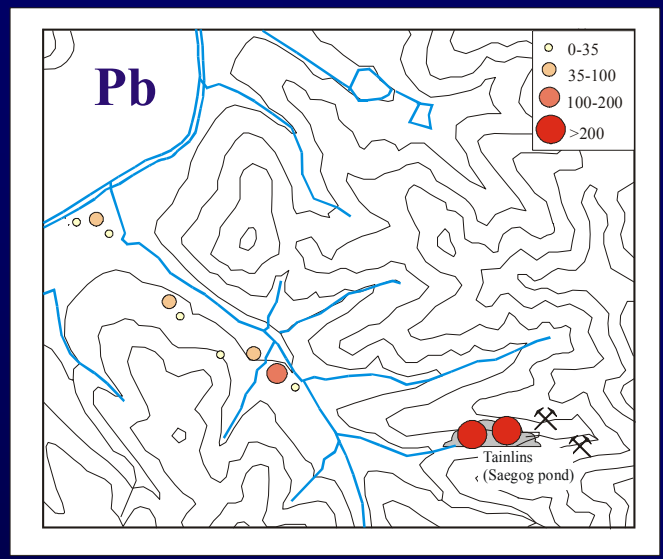


Distribution of As, Cd, Cu and Pb in Soils (OD)

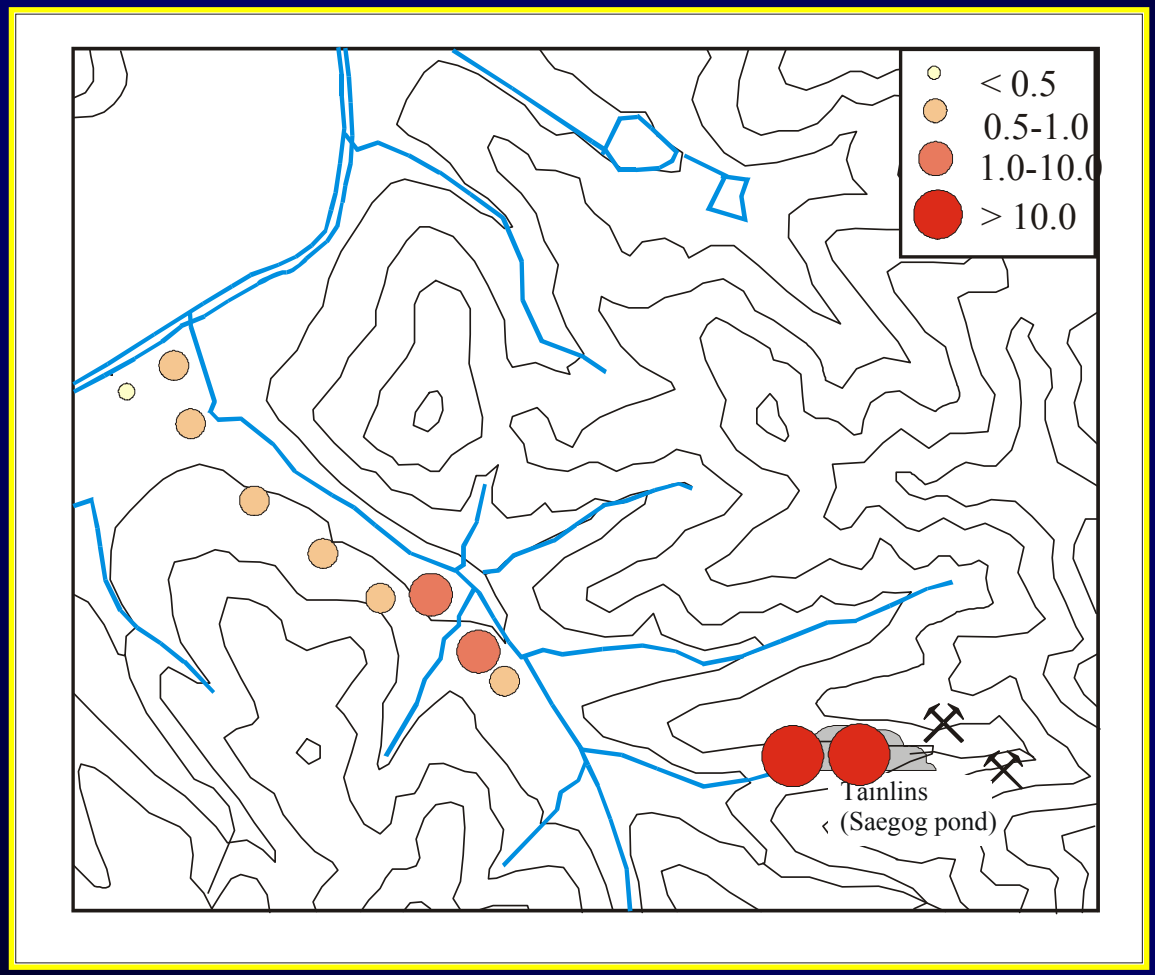




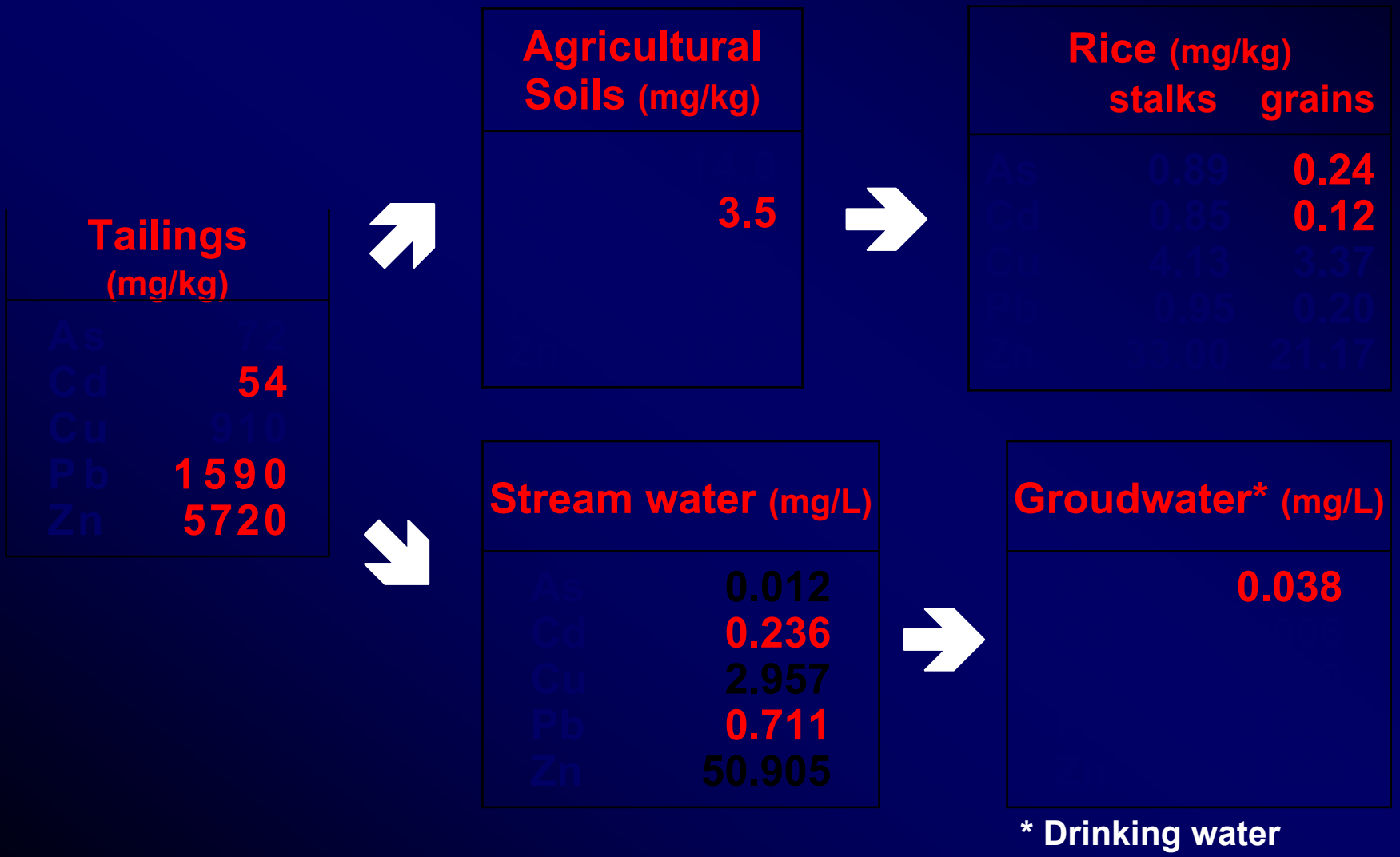


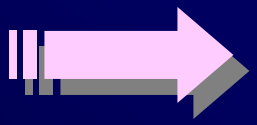


Pollution Index of soils from the Okdong mine



Heavy Metal Contamination of the Okdong mine





Kubong Au-Ag mine

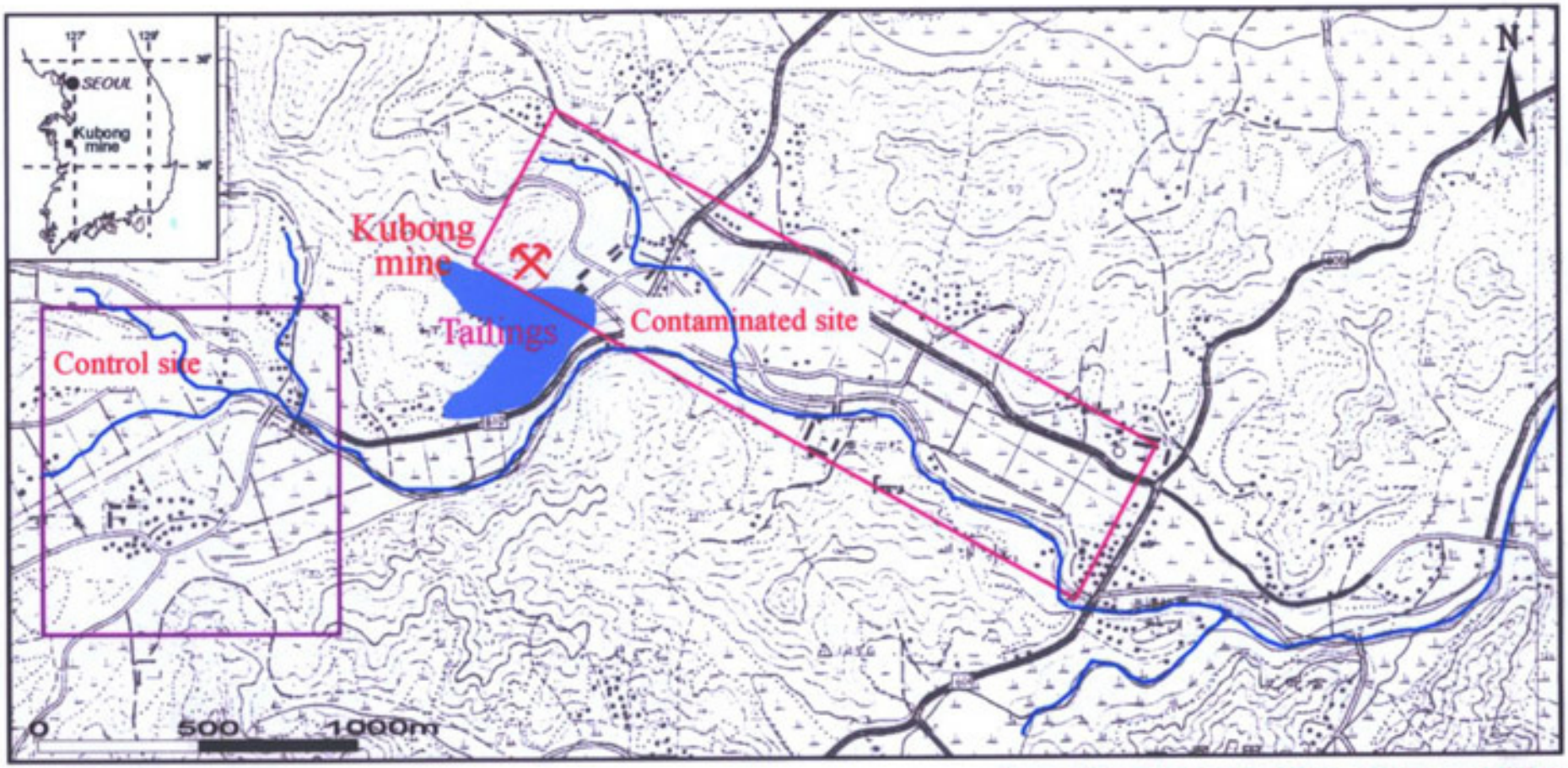
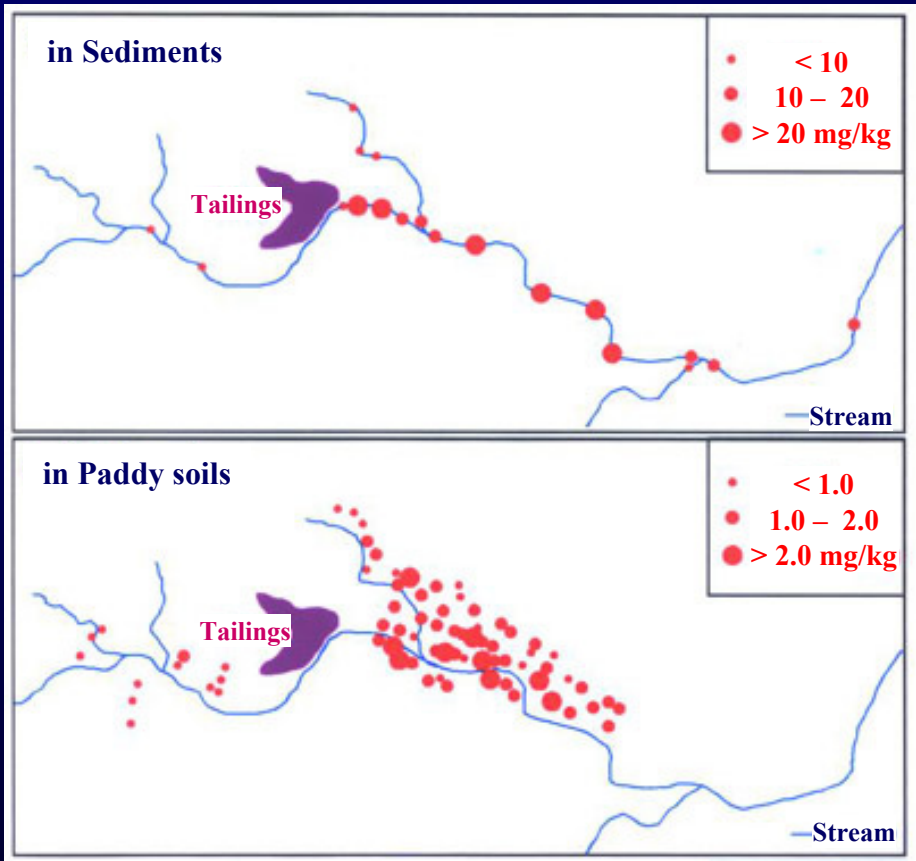


Fig. Sampling sites in the Kubong Au-Ag mine area.



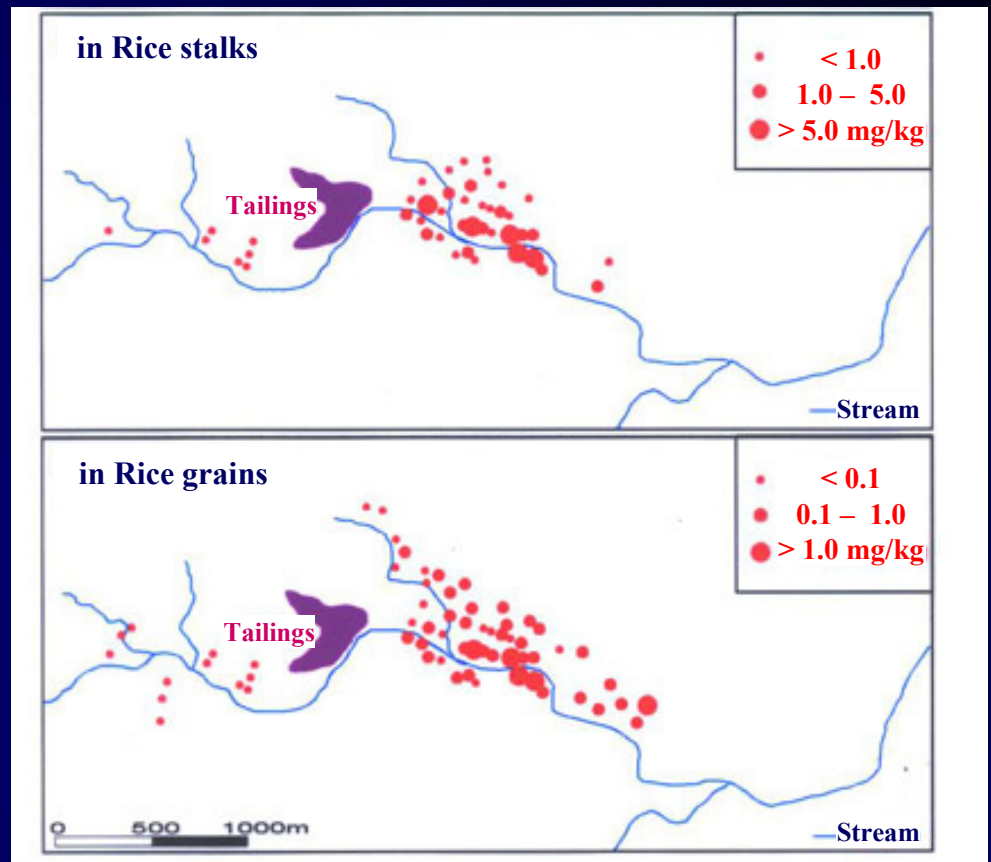
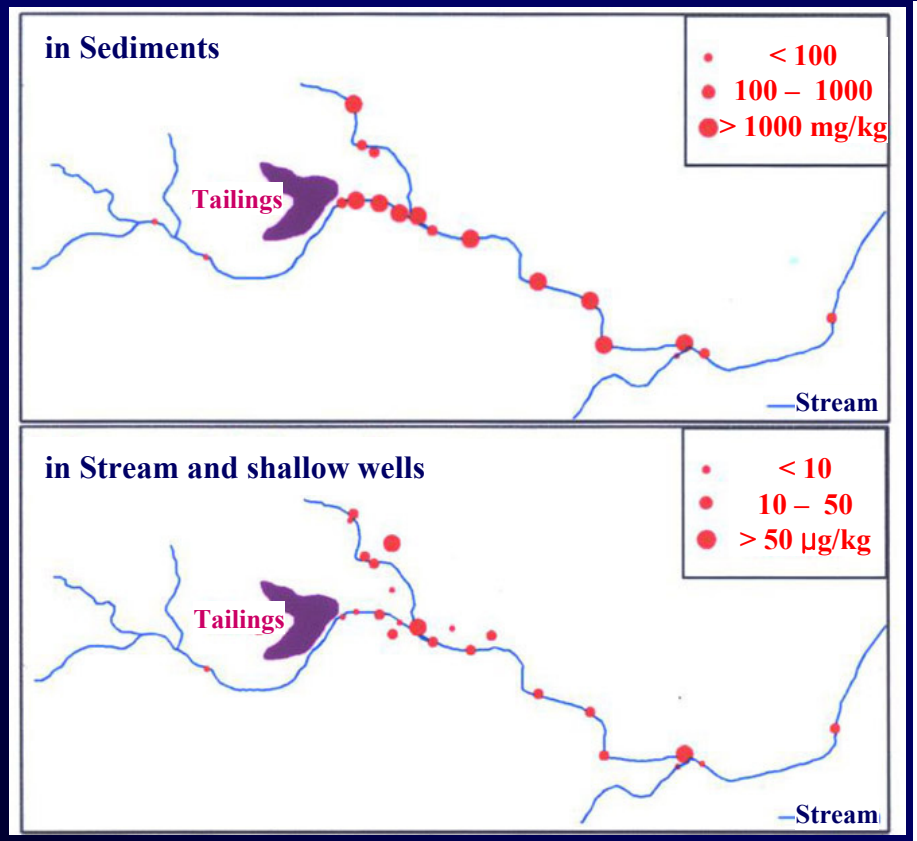


Fig. Distribution of Cd in stream sediments, paddy soil, rice stalks and grains from the Kubong Au-Ag mine area.



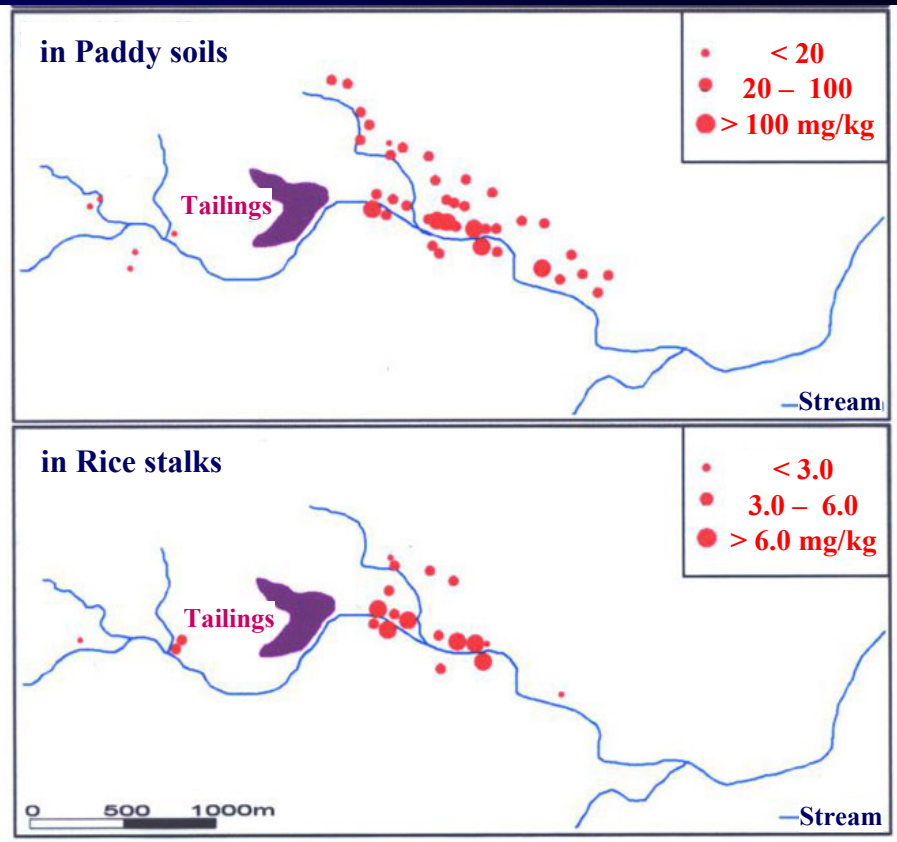
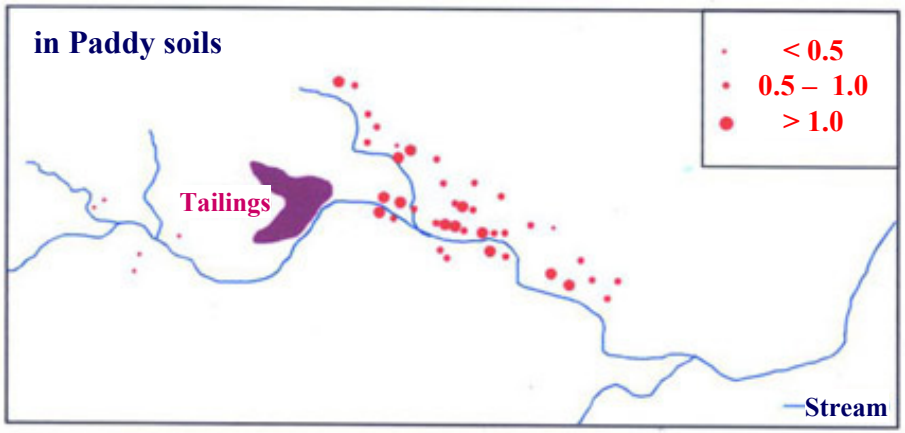
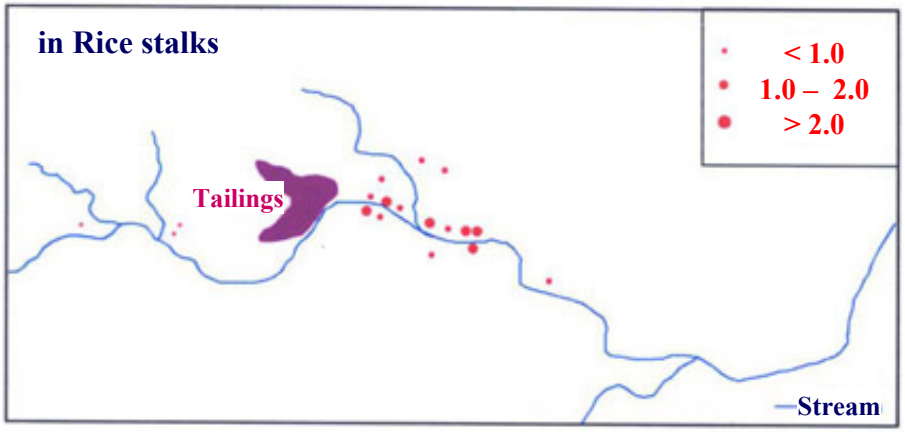


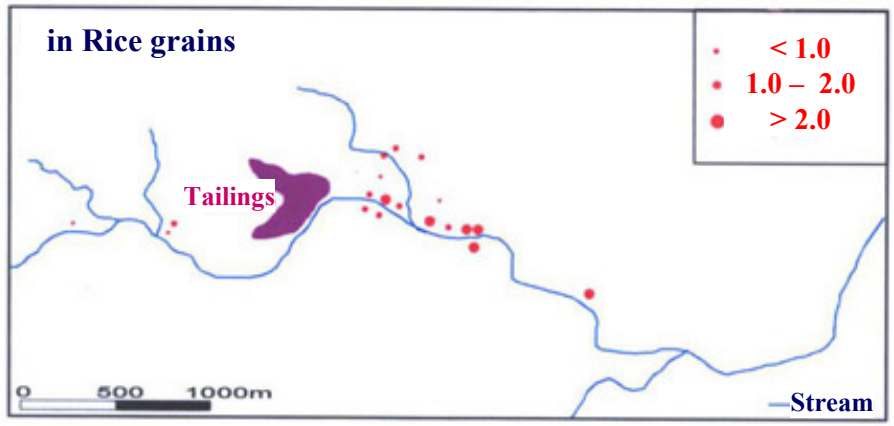
Fig. Distribution of As in stream sediments, stream and shallow wells, paddy soils and rice stalks from the Kubong Au-Ag mine area.



P.I. = [As/20 + Cd/3 + Cu/100 + Pb/100 + Zn/300] / 5



P.I. = [As/1.7 + Cd/0.2 + Cu/30 + Pb/10 + Zn/150] / 5



P.I. = [As/0.15 + Cd/0.091 + Cu/4.5 + Pb/0.8 + Zn/21.5] / 5

Fig. Pollution Index of paddy soil, rice stalks and grains from the Kubong Au-Ag mine area.

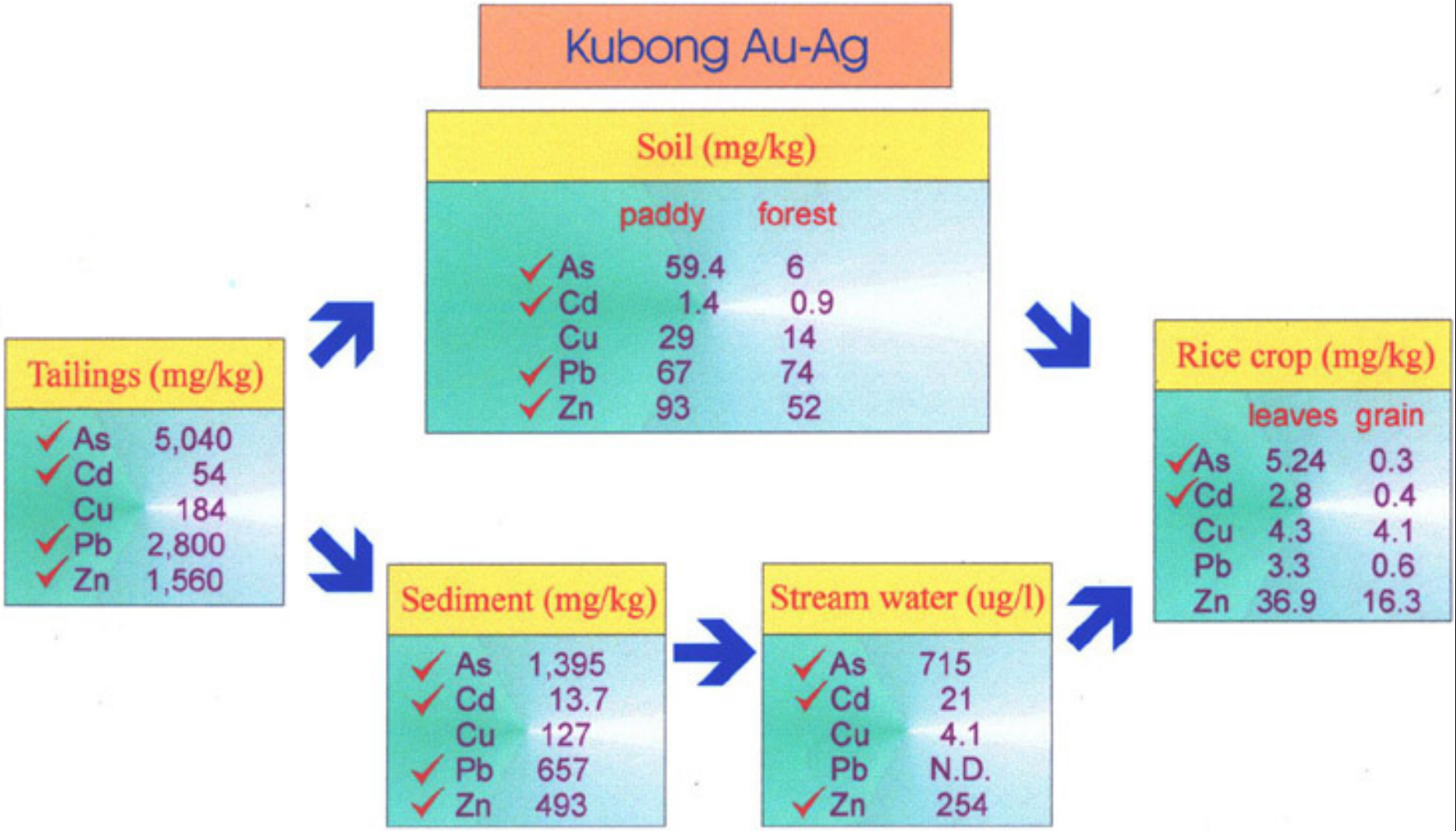
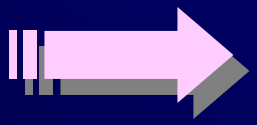
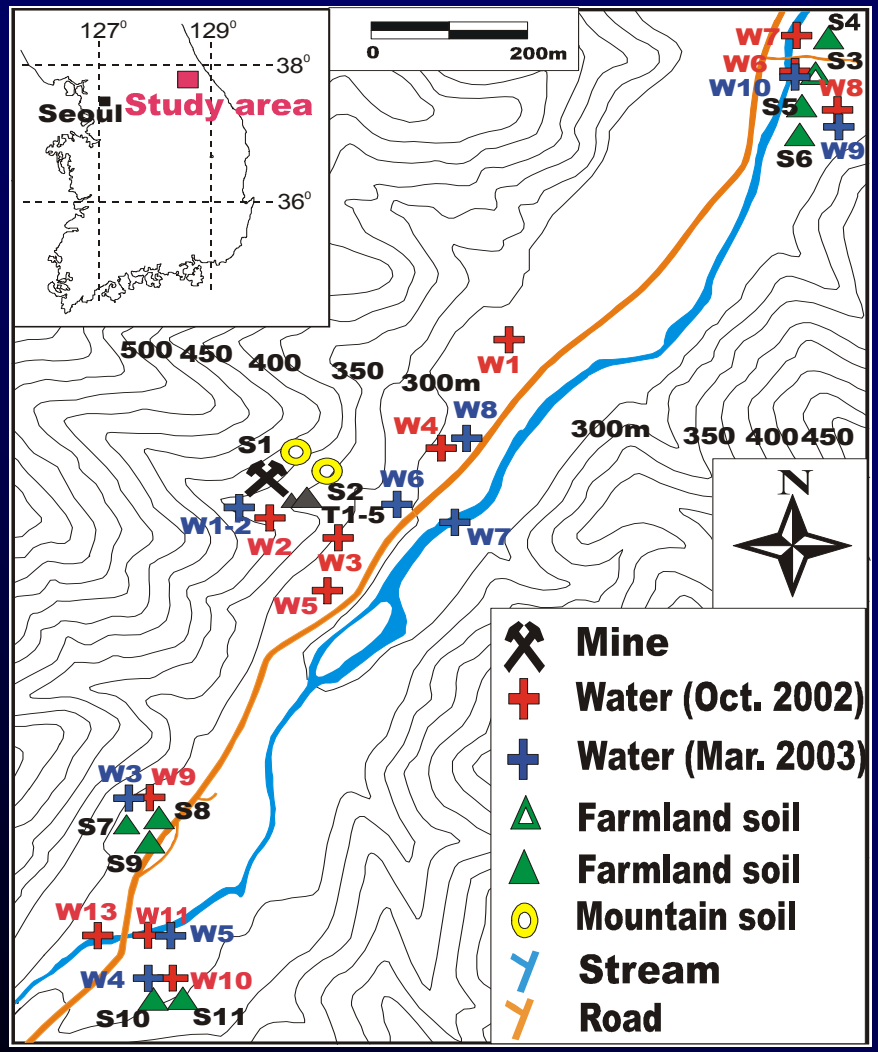


Fig. Heavy metal concentrations around an abandoned mine.

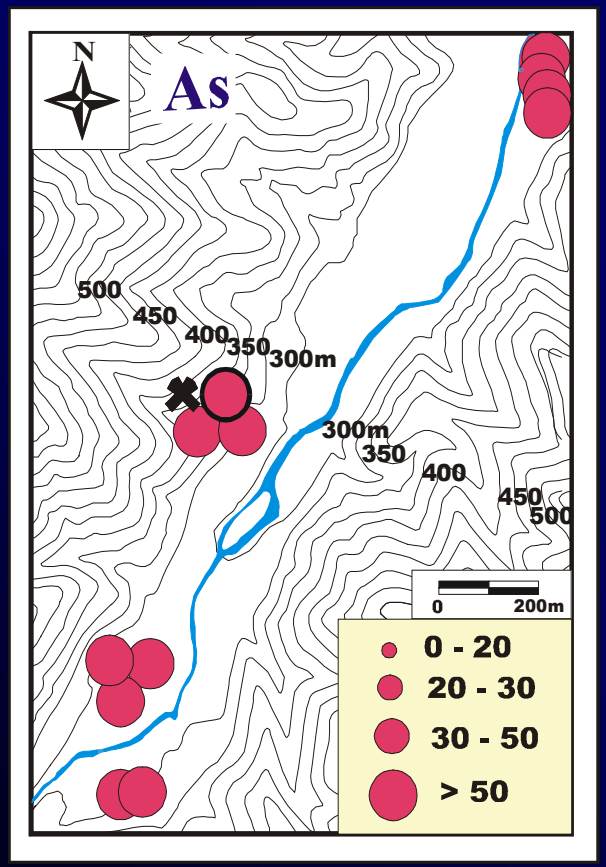


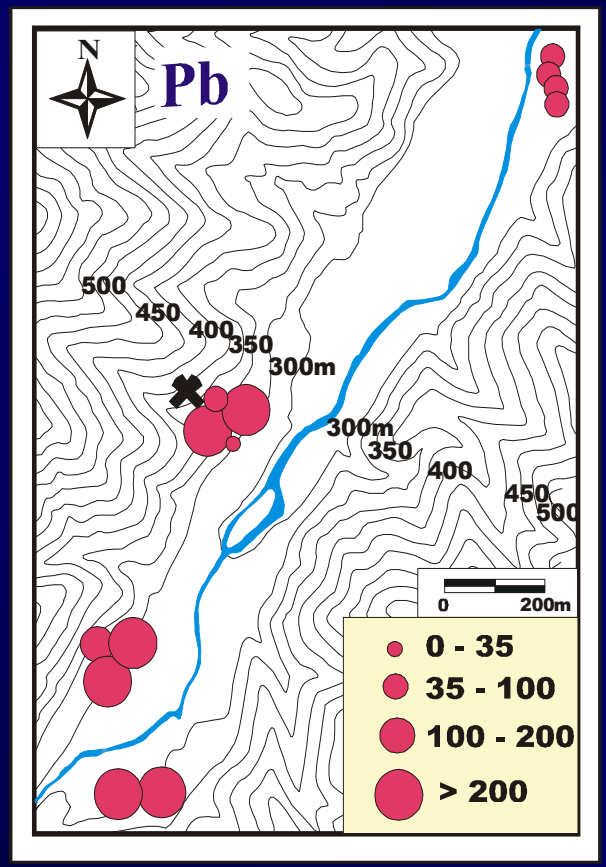
Songcheon Au-Ag mine

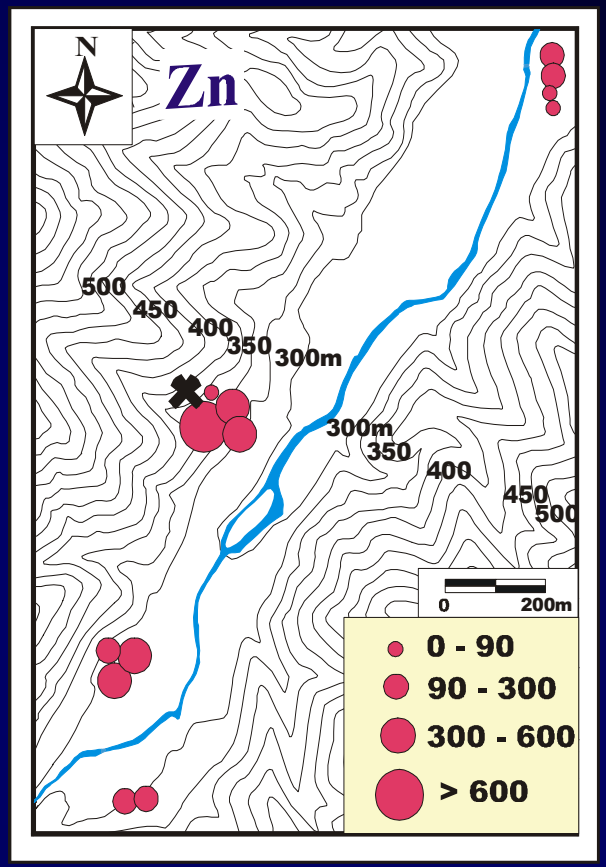
Sampling Location Map for the Songcheon mine



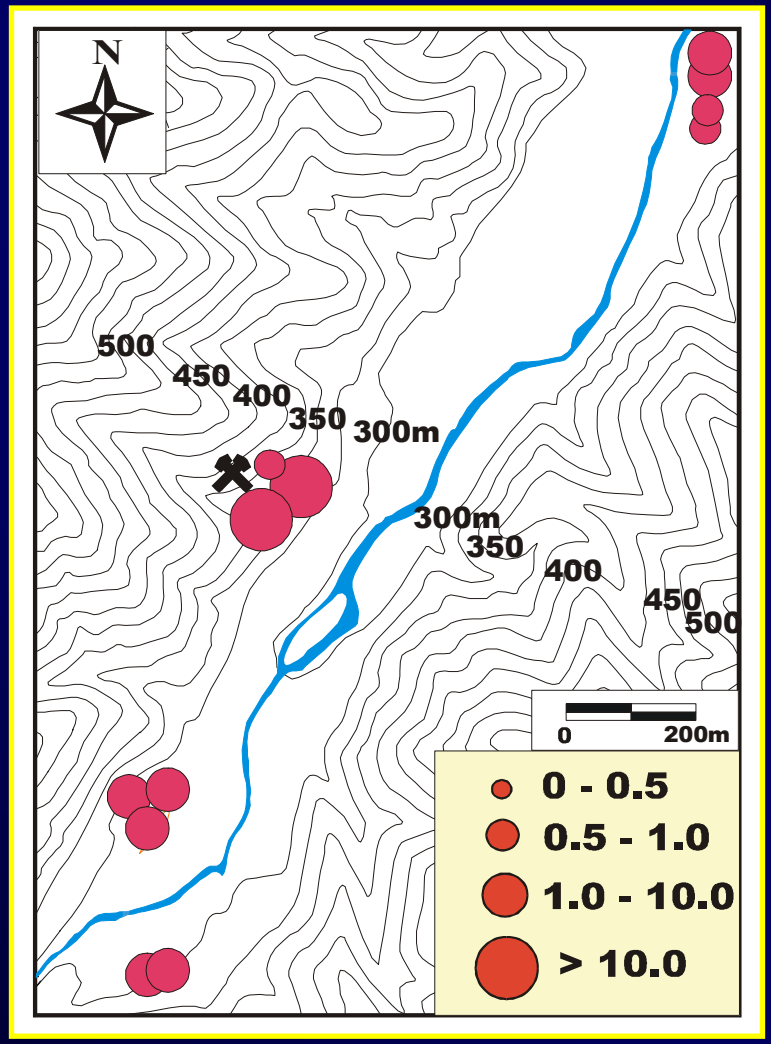
Distribution of As, Pb and Zn in Soils (SC)



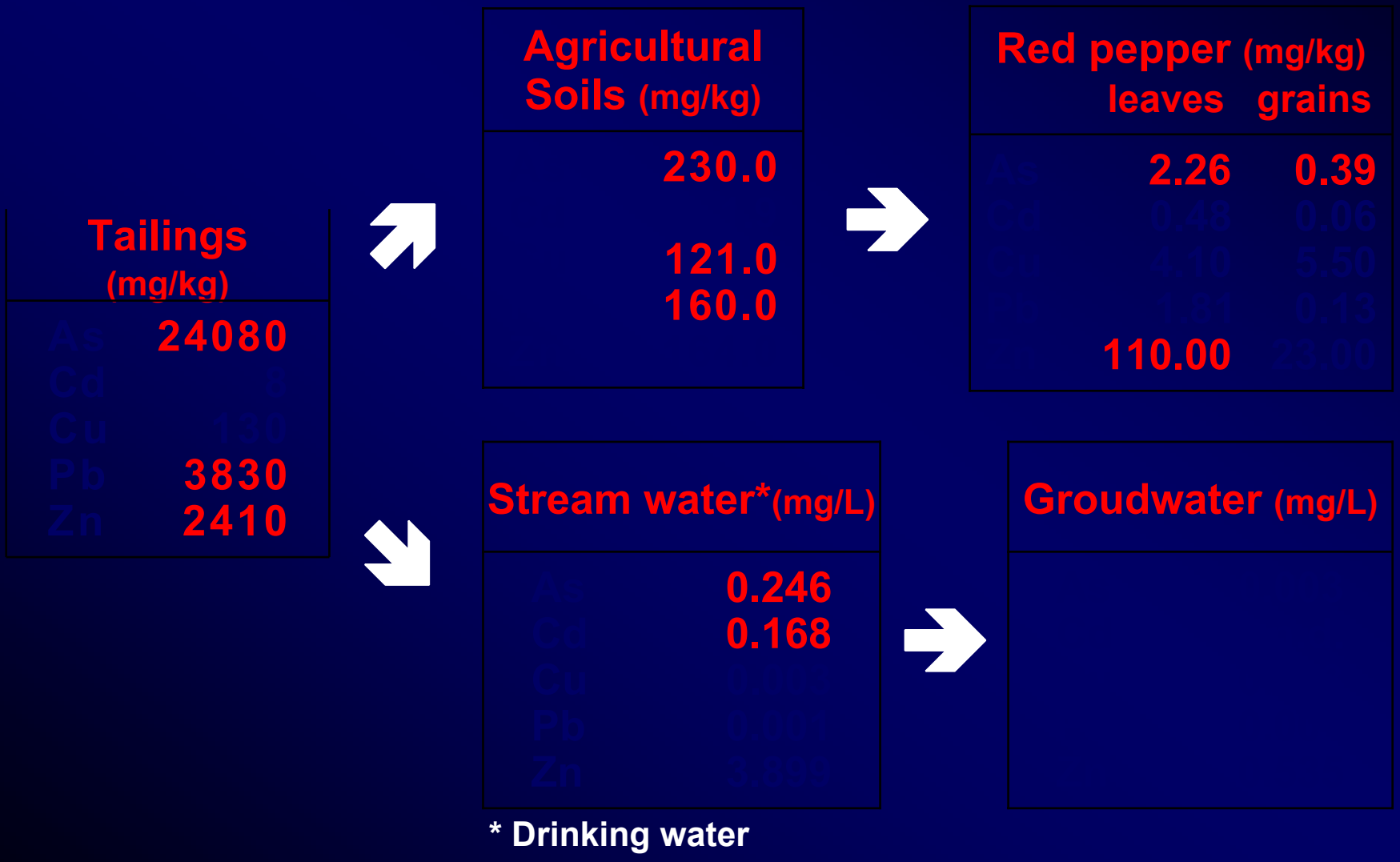




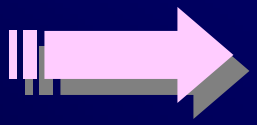
Pollution Index of soils from the Songcheon mine



Heavy Metal Contamination of the Songcheon mine



* Drinking water



Chemical Speciation of Heavy Metals

Table Extractants used in sequential extraction and nominal phases dissolved (modified from Davidson et al.,1994).

Extraction step	Reagent	Phase(s)
I	$MgCl_2$ (1M)	Exchangeable
II	CH_3COOH (0.16M)	Carbonate-bound
III	$NH_2OH \cdot HCl$ (0.1M) at pH 2.0	Reducible
IV	H_2O_2 (8.8M), CH_3COONH_4 (1M) at pH 2.0	Oxidizable
V	HCl (36%), HNO_3 (62%)	Residual

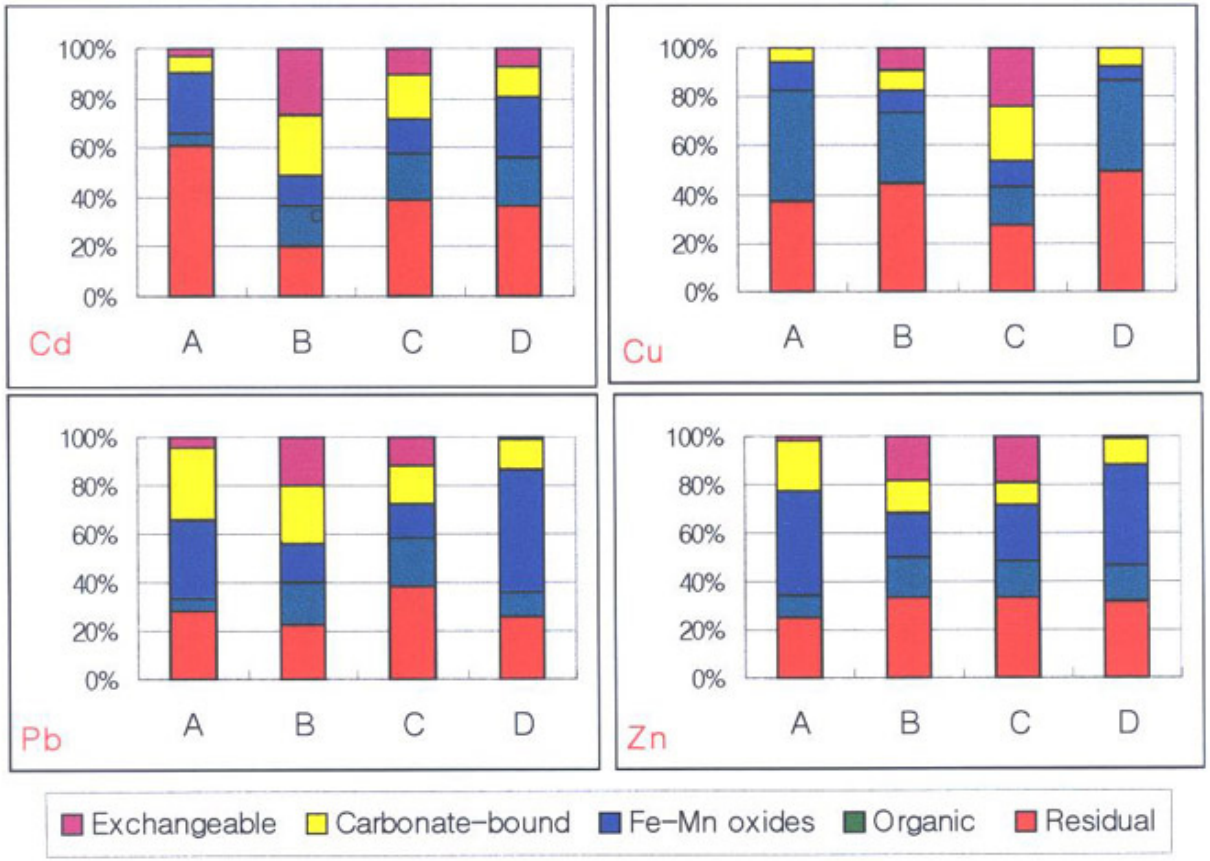


Fig. Mean chemical partitionings of Cd, Cu, Pb and Zn.
In stream sediment
A: Sambo Pb-Zn-barite
B: Shinyemi Pb-Zn-Fe
C: Geodo Cu-Fe
In soils
D: Shiheung Cu-Pb-Zn

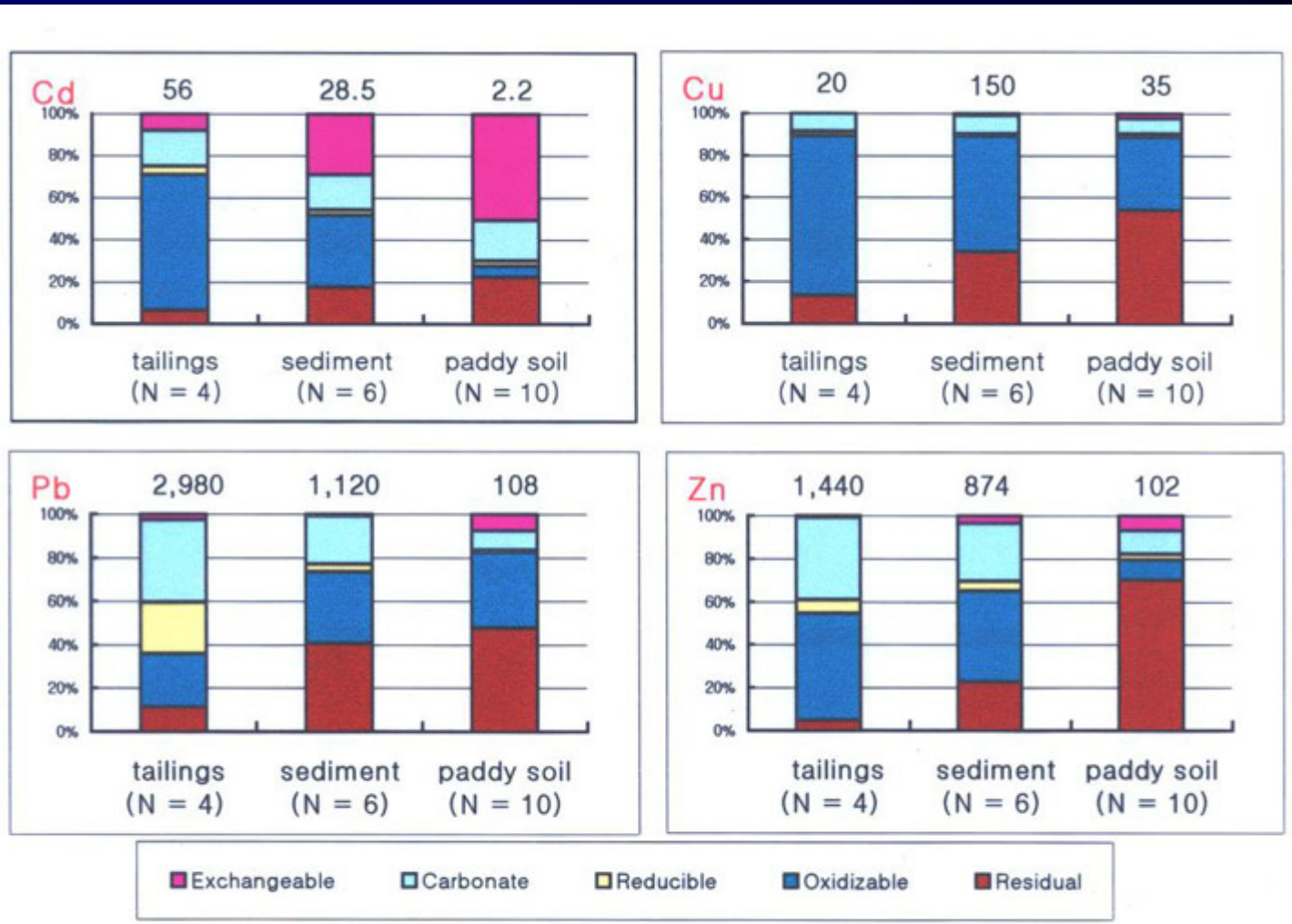


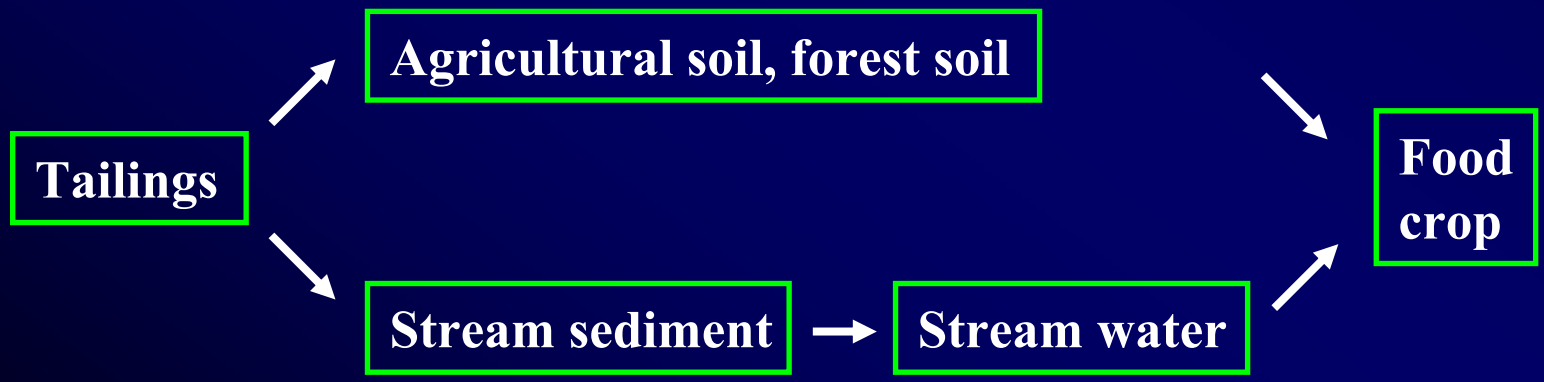
Fig. Mean chemical partitioning of heavy metals in tailings, stream sediment and paddy soil around the Kubong Au-Ag mine.

Conclusions

1. Dominant contaminating source in the study mines :
   Tailings and its effluent (acid mine drainage)

2. Contaminating elements of the nearby environment :
   As, Cd, Cu, Pb and Zn according to ore or gangue mineralogy

3. Pathways of contaminants :



4. Pollution index of multi-contaminants :

Not a single but a number of elements in soil contamination

Convenient to treat and interpret multi-elements data

5. Chemical forms of heavy metals :

Non-residual fractions : susceptible to the change of ambient conditions high potential of bioavailability

Cd and Zn : large fractions in exchangeable form

→ high mobility in soils or sediments

6. Food crops : significant levels of metals in rice grain

→ large amount of intake by residents relatively higher contents in crops under oxidizing conditions reducing