

Occurrence and Health Effects of Arsenic in China

EHP mini-monograph, 2007, 115:636-662

Zheng, Y.^{1,2}, D.-J. Sun³, G.-F. Sun⁴, G.-Q. Yu³, S-X. Wang⁵, A.-H. Zhang⁶, D. An⁷, D.-S. Li⁷ and O. Odediran⁸

¹Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964, USA

²Queens College, City University of New York, Flushing, NY 11367, USA

³The Center for Endemic Disease Control, Chinese Center for Disease Control and Prevention, Harbin Medical University, Harbin, Heilongjiang 150081, P.R.China.

⁴Department of Environmental and Occupational Health, College of Public Health, China Medical University, Shenyang, Liaoning, PR China

⁵ Shanxi Institute for Prevention and Treatment of Endemic Disease, Linfen, Shanxi 041000, China

⁶Department of Toxicology, School of Public Health, Guiyang Medical University, Guizhou, 550004, PR China

⁷Guizhou Center for Disease Control and Prevention, 73 Bageyan Road, Guiyang 550004, Guizhou, China

⁸UNICEF, Water and Environment, New York, USA

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*Yu et al., 2007,
EHP 115:636-
642*

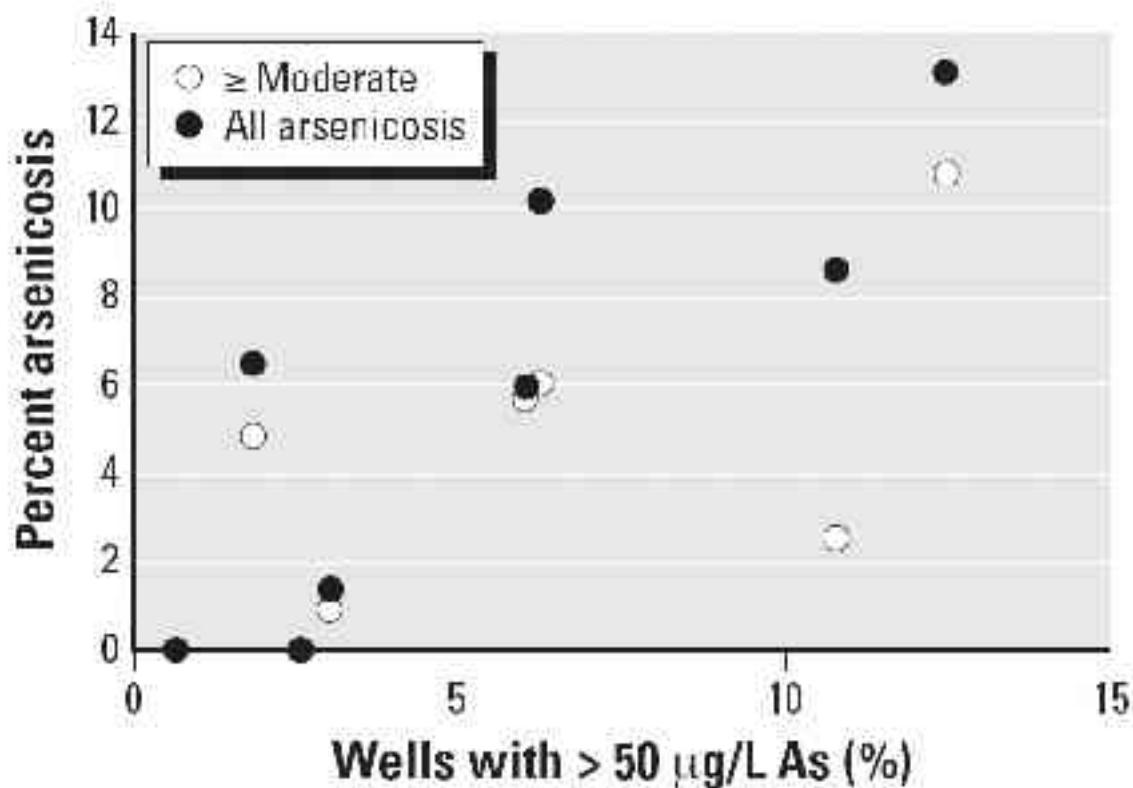
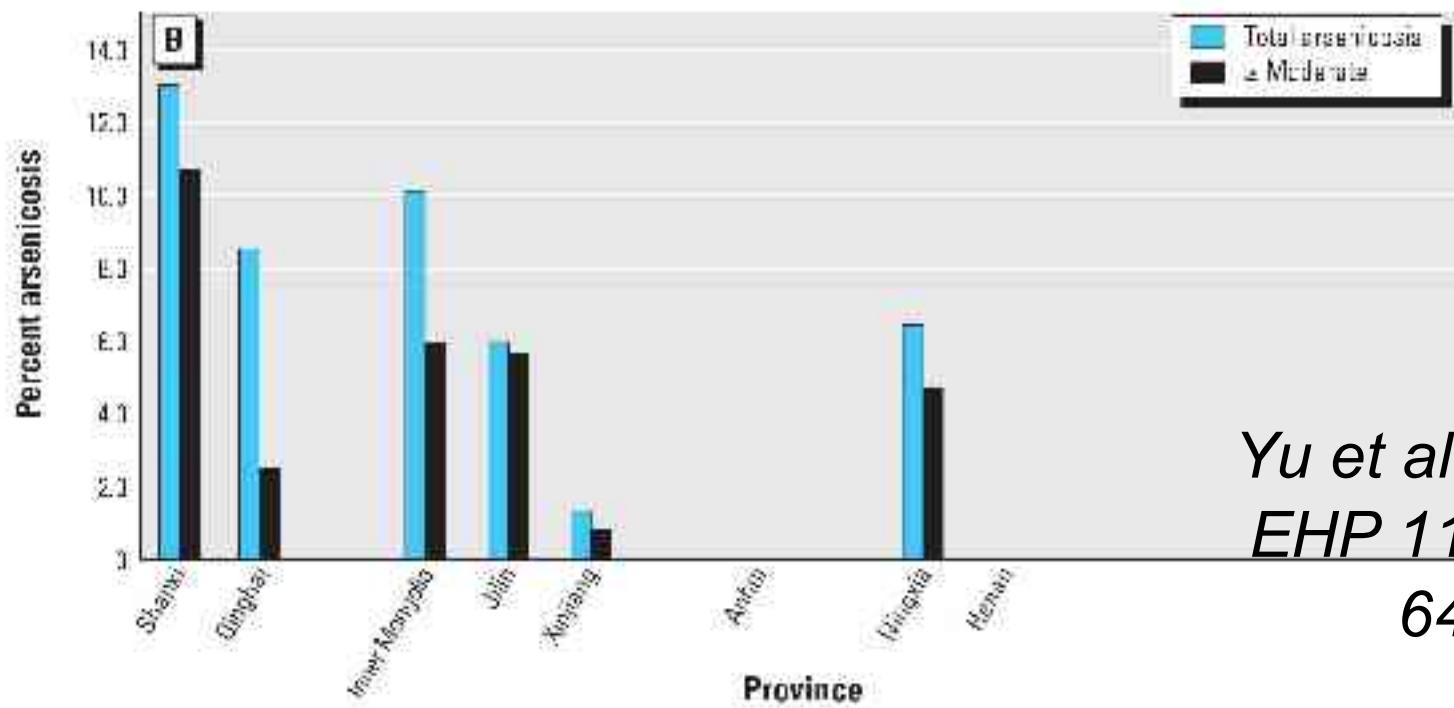
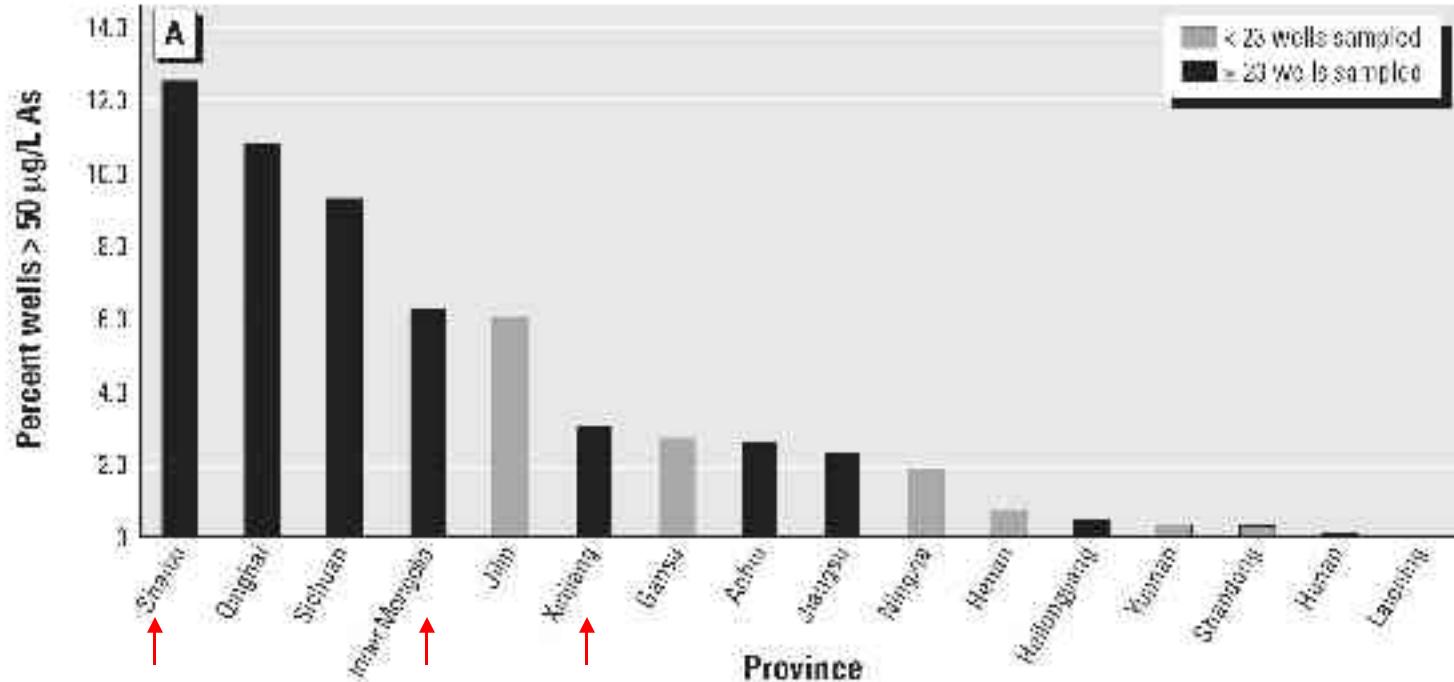


Figure 3. The correlation between the percentage of wells containing high concentrations of As ($> 50 \mu\text{g/L}$) with the percentage of arsenicosis in each province.

#provinces	#wells	#wells>50 ug/L	% wells>50 ug/L
16	445,638	21,155	5
#provinces	population	population>50 ug/L	%arsenicosis
16	21,044,733	587,696	7.5 (10096/135492)

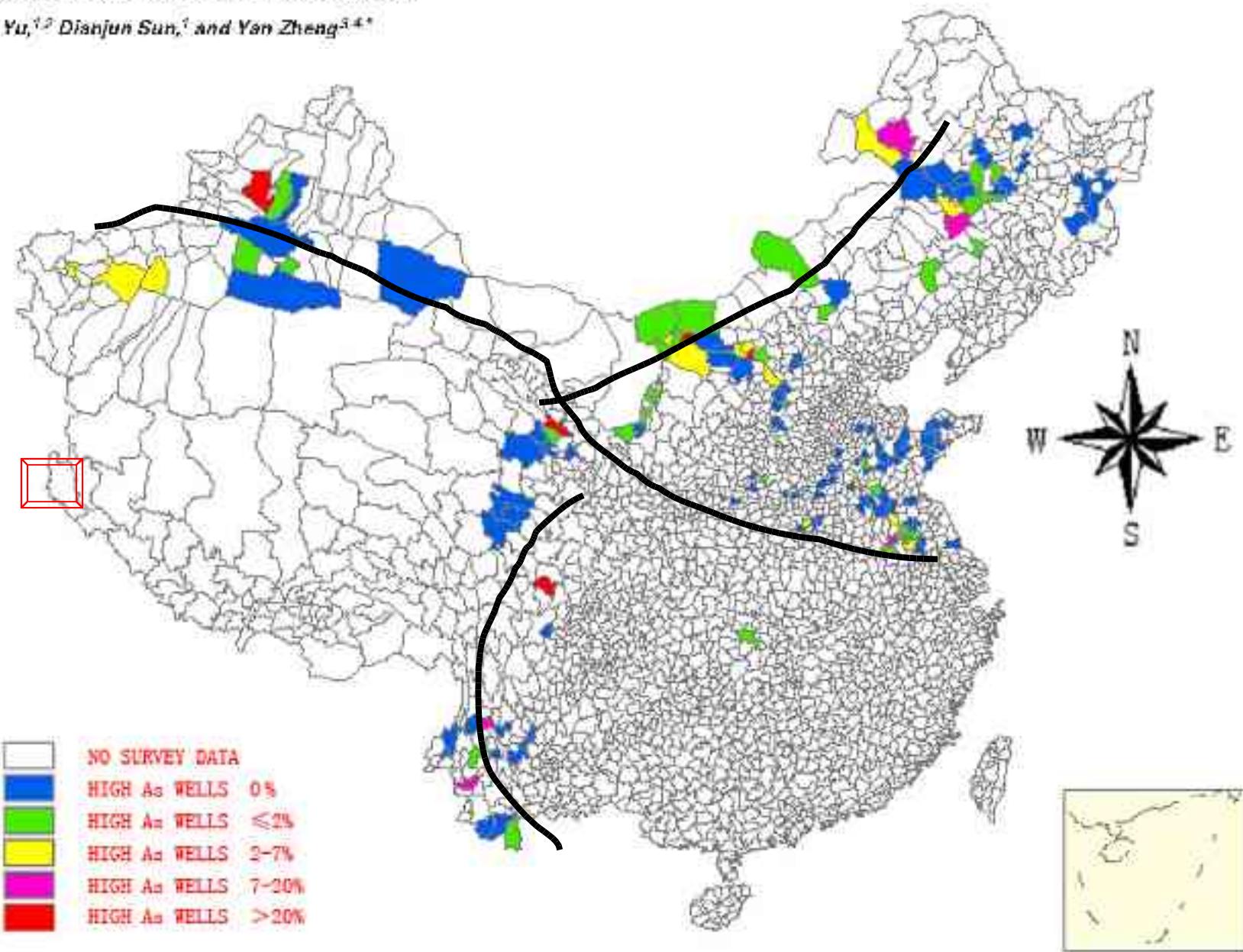


Yu et al., 2007,
EHP 115:636-
642

Health Effects of Exposure to Natural Arsenic in Groundwater and Coal in China: An Overview of Occurrence

Yu et al., 2007, EHP
115:636-642

Guangqian Yu,^{1,2} Dianjun Sun,¹ and Yan Zheng^{3,4,*}



Arsenic and Fluoride Exposure in Drinking Water: Children's IQ and Growth in Shanyin County, Shanxi Province, China

San-Xiang Wang,¹ Zheng-Hui Wang,¹ Xiao-Tian Cheng,¹ Jun Li,¹ Zhi-Ping Sang,¹ Xiang-Dong Zhang,¹ Ling-Ling Han,¹ Xiao-Yan Qiao,¹ Zhao-Ming Wu,¹ and Zhi-Quan Wang²

¹Shanxi Institute for Prevention and Treatment of Endemic Disease, Linfen, Shanxi Province, People's Republic of China; ²Shanyin Center for Disease Control and Prevention, Shanyin, Shanxi Province, People's Republic of China

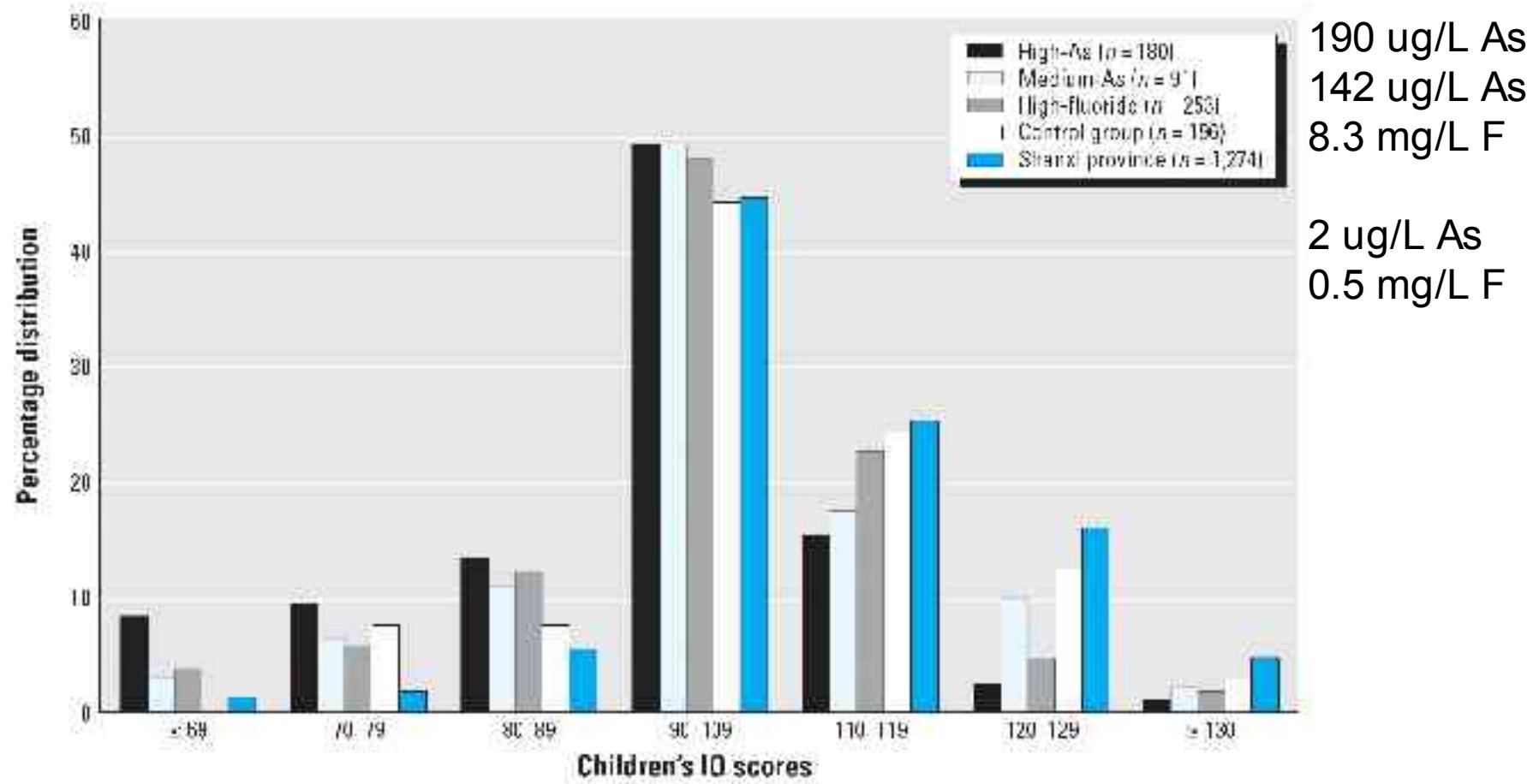


Figure 1. Frequency distribution of IQ in 10-year-old children from Shanyi county, Shanxi, China, who were exposed to high-As water, medium-As water, and high fluoride compared with control group with low-As and low-fluoride, as well as children residing in Shanxi province, China.

Urinary Arsenic Metabolites in Children and Adults Exposed to Arsenic in Drinking Water in Inner Mongolia, China

Guifan Sun, Yuanyuan Xu, Xin Li, Yaping Jin, Bing Li, and Xiancè Sun

Department of Environmental and Occupational Health, College of Public Health, China Medical University, Shenyang, Liaoning, People's Republic of China

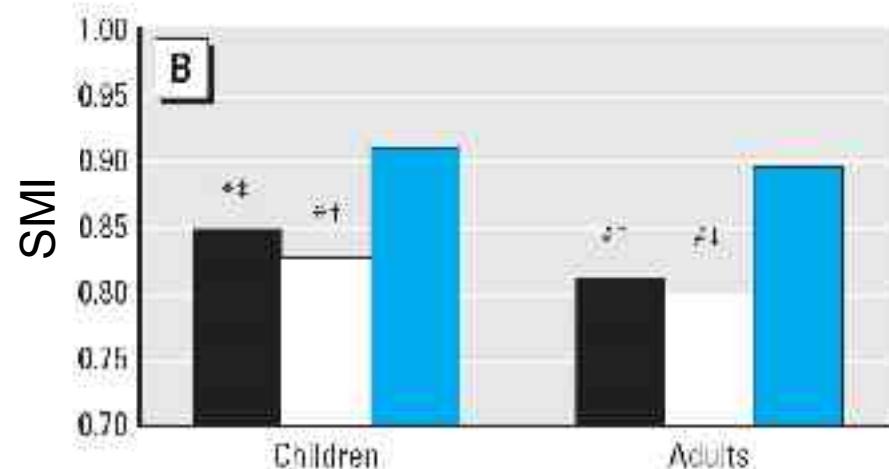
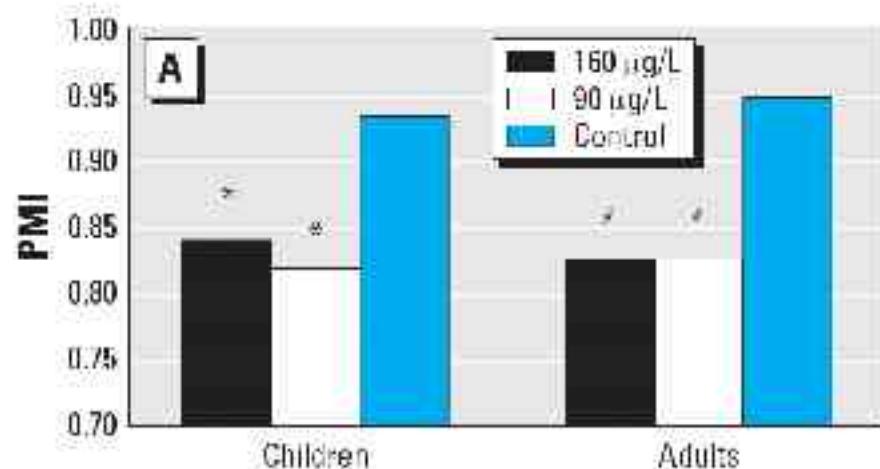


Figure 1. (A) Comparison of PMI in children and adults exposed to different levels of As in drinking water. Data are shown as geometric mean. (B) Comparison of SMI in children and adults exposed to different levels of As. Data are shown as geometric mean.

Statistical significance: * $p < 0.05$, compared with children's control group; # $p < 0.05$, compared with adult control group; † $p < 0.05$, compared with children in 160-µg/L exposed group; ‡ $p < 0.05$, compared with children in 90-µg/L exposed group.

CONCLUSIONS: Children had higher a capacity for secondary methylation of As than adults when exposed to the same concentrations of iAs in drinking water. Exposure to As may increase the capacity for methylation in children to some extent.

Unventilated Indoor Coal-Fired Stoves in Guizhou Province, China: Reduction of Arsenic Exposure through Behavior Changes Resulting from Mitigation and Health Education in Populations with Arsenicosis

Dong An, Dasheng Li, Yin Liang, and Zhengjin Jing

Guizhou Center for Disease Control and Prevention, Guiyang, Guizhou Province, People's Republic of China

Table 1. Occurrence of arsenicosis in three counties in Guizhou, China, in 1994 and 2004.

Endemic county	No. of endemic towns		No. of endemic villages		Population (n) in endemic villages		No. of arsenicosis patients	
	1994	2004	1994	2004	1994	2004	1994	2004
Xingyi	2	2	5	5	2,381	4,153	214	177
Xingren	1	3	9	13	14,685	20,747	1,555	2,250
Anlong	2	3	11	13	12,969	14,415	426	384
Total	5	8	25	31	30,535	39,315	2,205	2,811

Table 6. Urinary arsenic concentrations (mg/L) in exposed population before and after mitigation in 2005 in Guizhou, China.

Subject	No. of cases	2004 baseline survey			2005 survey		
		Mean \pm SD	Range	No. of cases	Mean \pm SD	Range	
Control	40	0.045 \pm 0.046	0–0.16	10	0.017 ^c \pm 0.007	0–0.05	
Patient	144	0.198 ^a \pm 0.300	0.001–1.73	50	0.019 ^b \pm 0.009	0.001–0.326	

^at = 3.21, p < 0.01 (compared with controls). ^bt = 3.51, p < 0.001 (compared with the group of arsenicosis patients before intervention). ^ct = 1.90, p > 0.05 (compared with the controls surveyed in 2004).

Unventilated Indoor Coal-Fired Stoves in Guizhou Province, China: Cellular and Genetic Damage in Villagers Exposed to Arsenic in Food and Air

Aihua Zhang,¹ Hong Feng,¹ Guanghong Yang,¹ Xueli Pan,¹ Xianyao Jiang,¹ Xiaoxin Huang,² Xuexin Dong,² Daping Yang,² Yaxiong Xie,¹ Luo Peng,¹ Li Jun,¹ Changjun Hu,¹ Li Jian,¹ and Xilan Wang¹

¹Department of Toxicology, School of Public Health, Guiyang Medical University, Guizhou, People's Republic of China;

²The 44th Hospital of People's Liberation Army, Guizhou, People's Republic of China

Table 1. Chromosome and DNA damage [mean ± SD (*n*)] in 184 villagers from Jiapu township (internal control and exposed groups) compared with 53 villagers from Ma Jiatun township (external control).

Group	As concentration [mean ± SD]		Chromosome damage			DNA damage			
	Dust (μg/g)	Hair (μg/g)	SCE	CA (%)	MN (μm)	DS fcpm	DPG cpm/μg DNA	UDS fcpm	DNA length (μm)
External control	45.0 ± 15.7 (53)	1.0 ± 1.2 (5)	3.0 ± 0.6 (25)	9.1 ± 2.3 (15)	15 ± 0.3 (25)	1,163 ± 710 (36)	9.3 ± 18 (40)	515 ± 193 (35)	80 ± 4 (41)
Internal control	76.3 ± 21.8* (15)	5.4 ± 4.3* (5)	3.8 ± 0.8* (10)	10.8 ± 5.0 (13)	18 ± 1.1 (12)	254 ± 113* (12)	1,229 ± 338* (11)	631 ± 382 (12)	138 ± 82* (9)
Mild	121.1 ± 110.3** (45)	5.7 ± 6.1* (6)	4.1 ± 1.2* (10)	5.1 ± 3.8* (15)	19 ± 13 (44)	315 ± 197* (16)	1611 ± 470* (21)	687 ± 387* (12)	95 ± 67* (10)
Intermediate	140.9 ± 135.5*** (55)	7.5 ± 7.0* (20)	4.8 ± 1.0* (47)	7.8 ± 3.1* (35)	18 ± 11 (49)	288.2 ± 355.2* (31)	2,130 ± 1,764* (25)	744 ± 517* (35)	30.1 ± 17.8** (54)
Severe	140.2 ± 128.5* (55)	7.9 ± 7.3* (32)	4.8 ± 1.2* (30)	7.2 ± 12.4* (30)	24 ± 14.2* (32)	213 ± 132* (36)	2,737 ± 1,074** (30)	782 ± 440* (36)	38.2 ± 14.7* (62)

Abbreviations: CA, chromosome aberration; DPG, DNA-protein cross-link; DS, spontaneous DNA synthesis; MN, micronucleus; *n* = number of subjects in each group; SCE, sister chromatid exchange; UDS, unscheduled DNA synthesis.

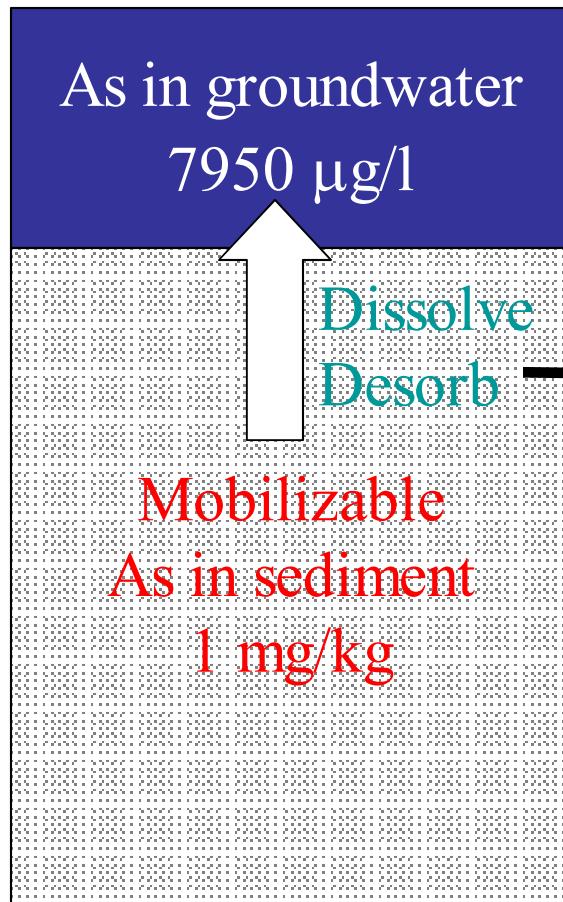
*Significantly different compared with the external control group ($p < 0.01$ using ANOVA). **Significantly different compared with the external control group ($p < 0.05$ using ANOVA). ***Significantly different compared to the internal control group ($p < 0.01$ using ANOVA). **Significantly different compared with the internal control group ($p < 0.05$ using ANOVA). *Significantly different compared with the mild group ($p < 0.01$ using ANOVA). **Significantly different compared with the mild group ($p < 0.05$ using ANOVA). ***Significantly different compared with the intermediate group ($p < 0.05$ using ANOVA).

CONCLUSIONS: The results showed that long-term As exposure may be associated with damage of chromosomes and DNA, gene mutations, gene deletions, and alterations of DNA synthesis and repair ability.

Crustal Level of As is sufficient to increase groundwater As to > 10 µg/L

groundwater
25% volume

Solid
75% volume

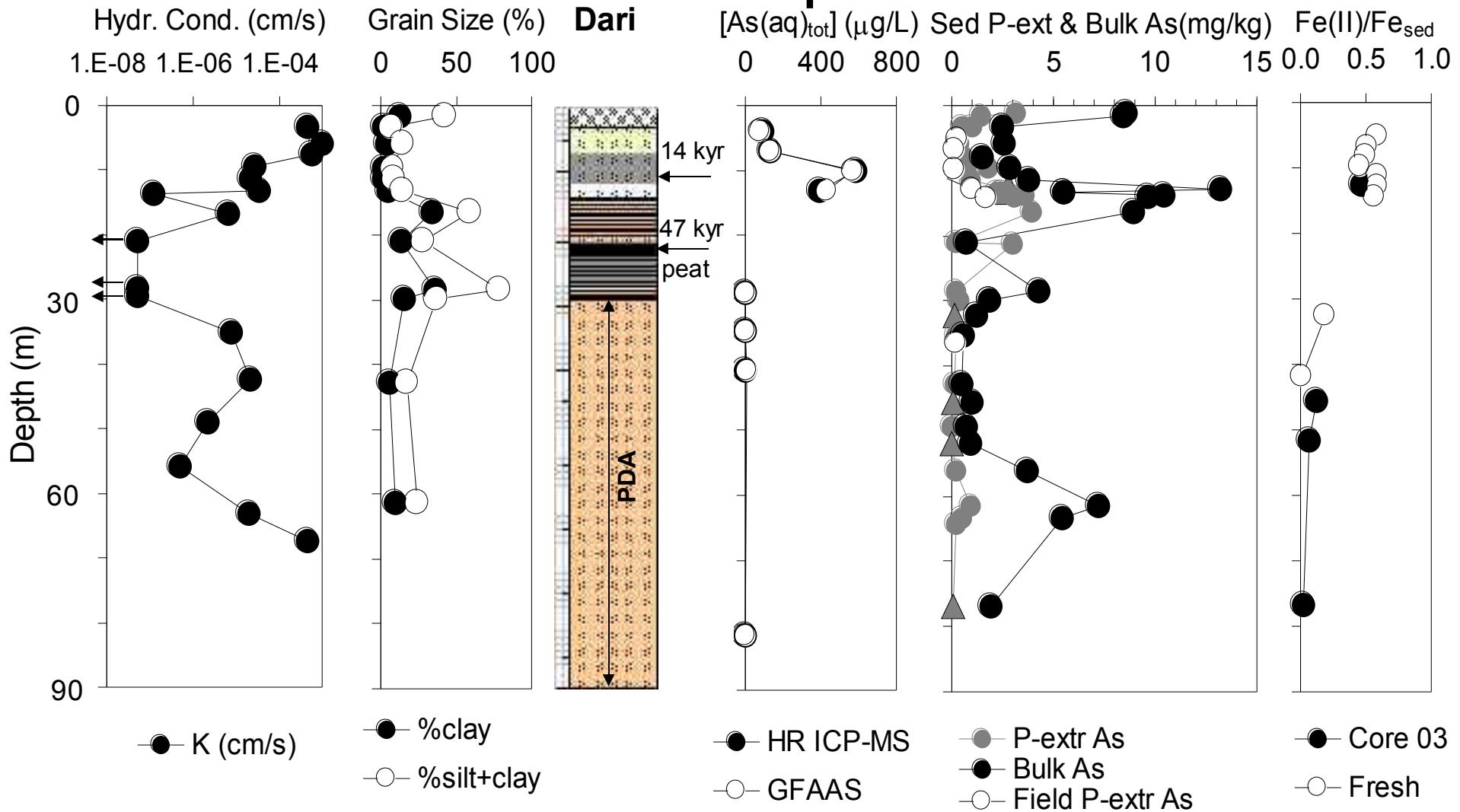


Reducing Conditions

Numerous studies including
Zheng et al. Appl. Geochem (2004)

Does 1 mg/kg mobilizable As reflect crustal level of As?

Mobilizable As in Bangladesh Aquifers: Holocene vs. Deep Pleistocene



As & Au in Carlin Type of Au Ore

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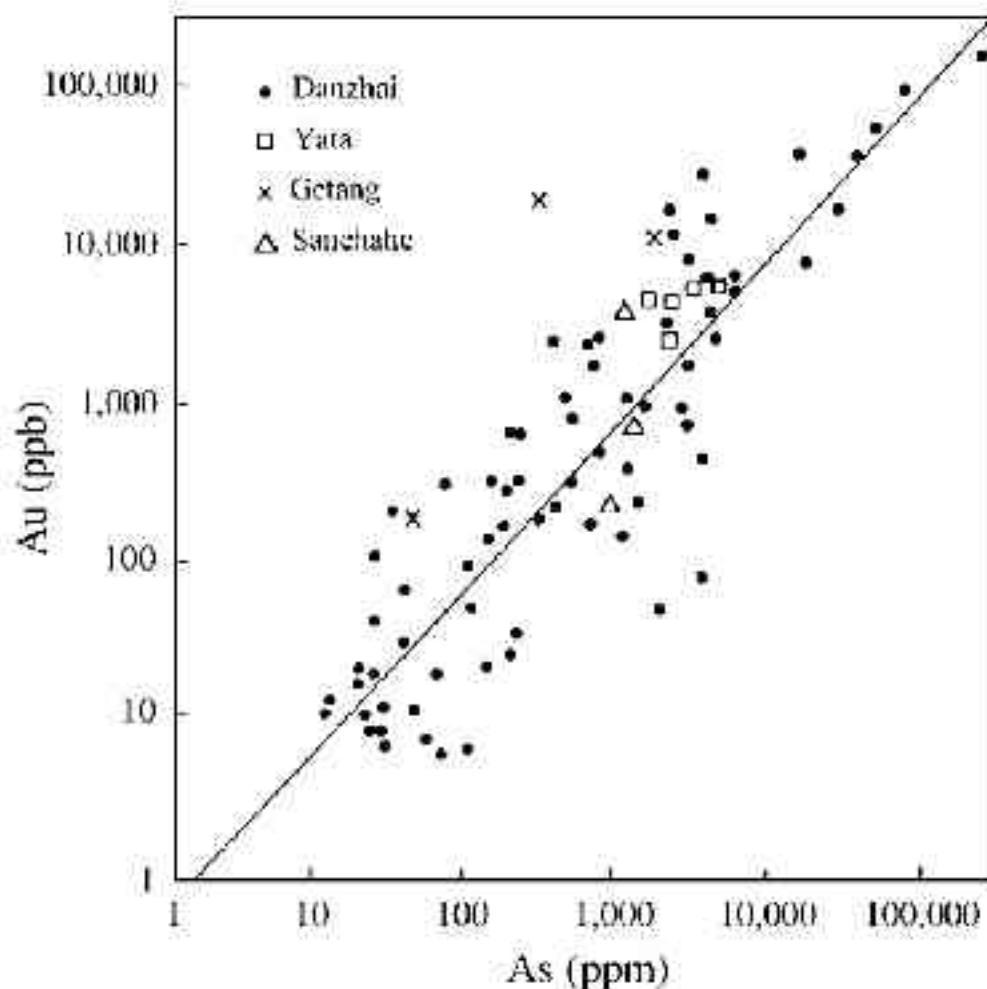
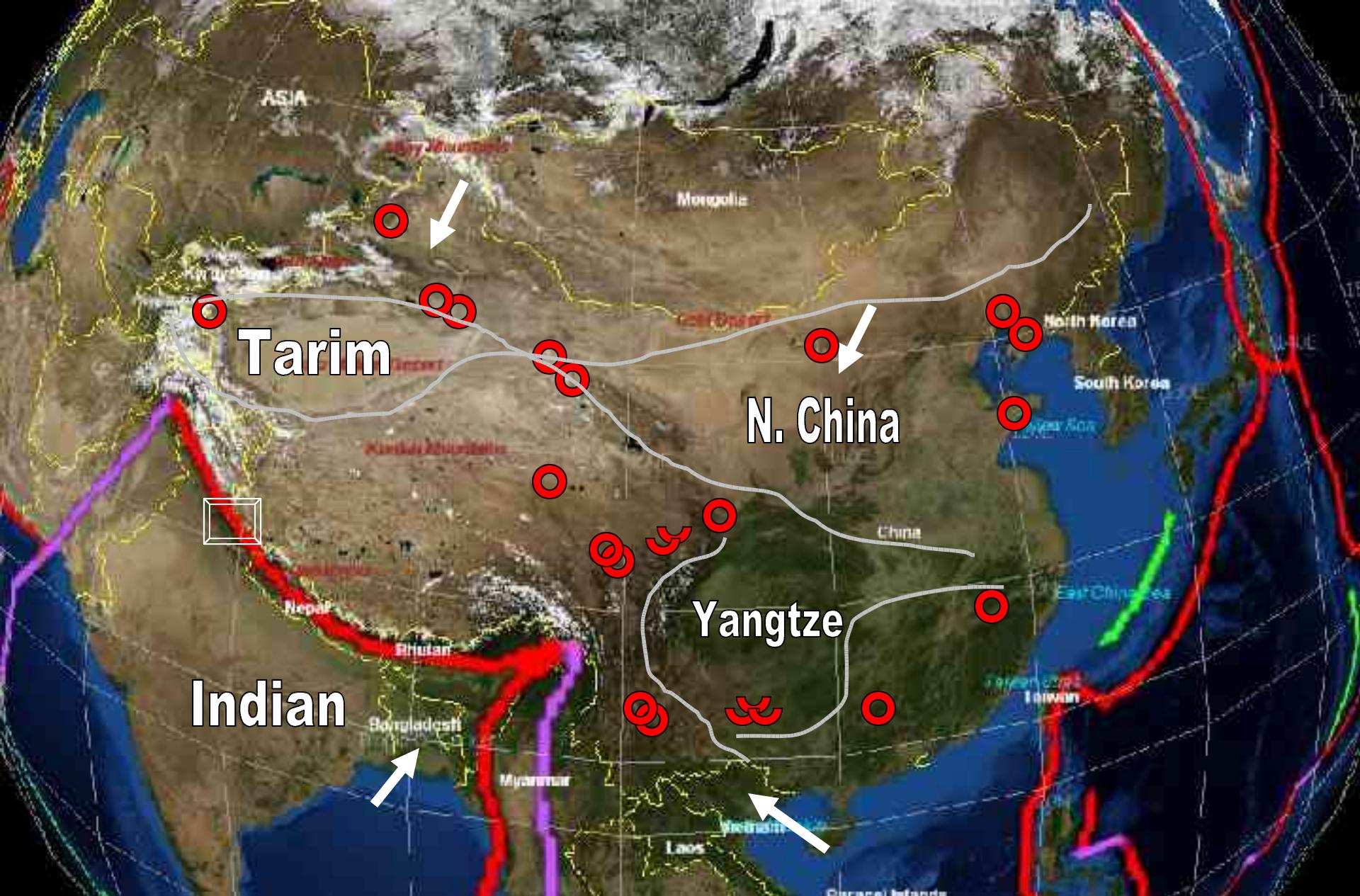


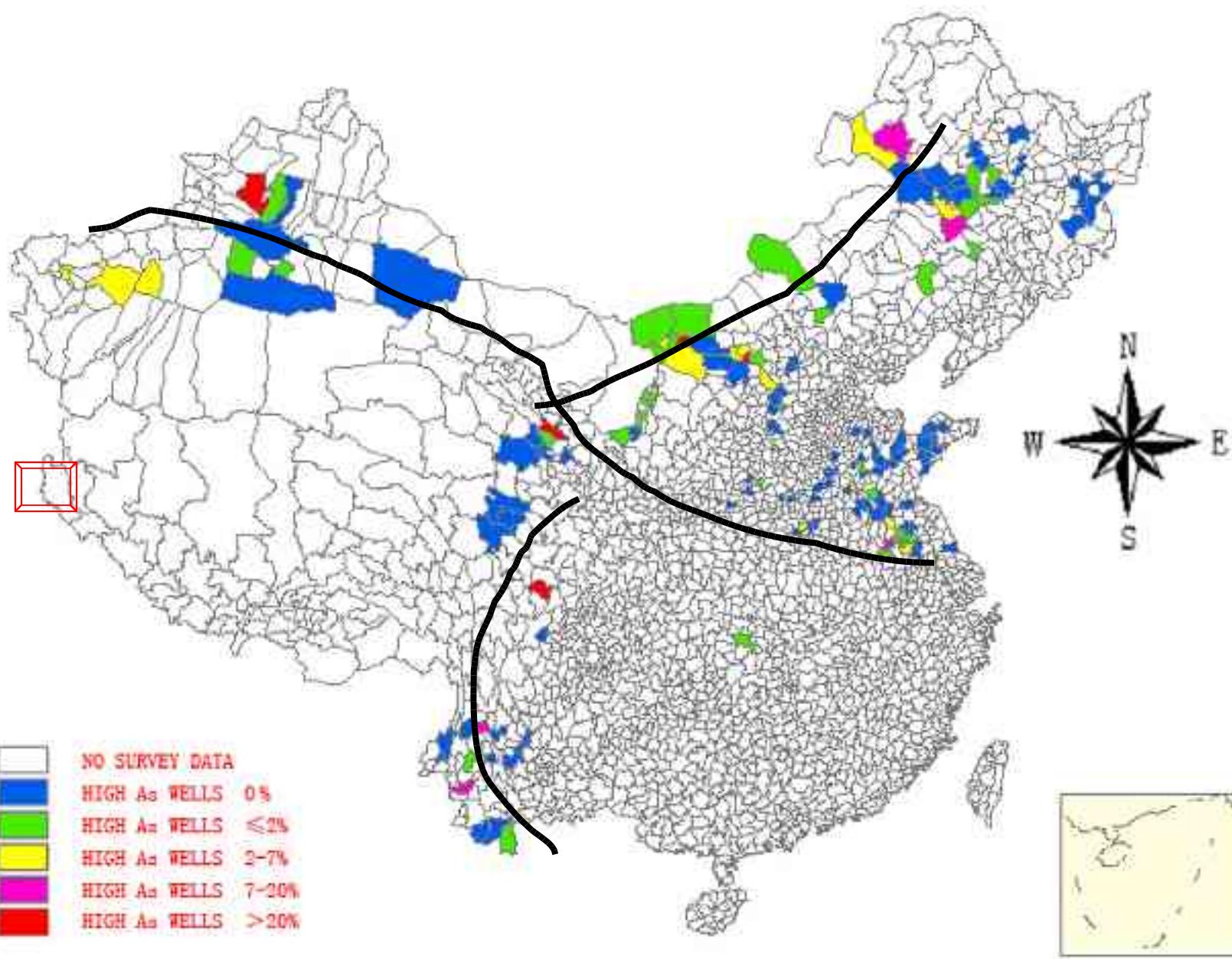
Fig. 6. Au and As composition of mineralized rocks from the Danzhai, Yata, Getang, and Sanchahe deposits based on data in Tu (1994) and Ashley et al. (1991)

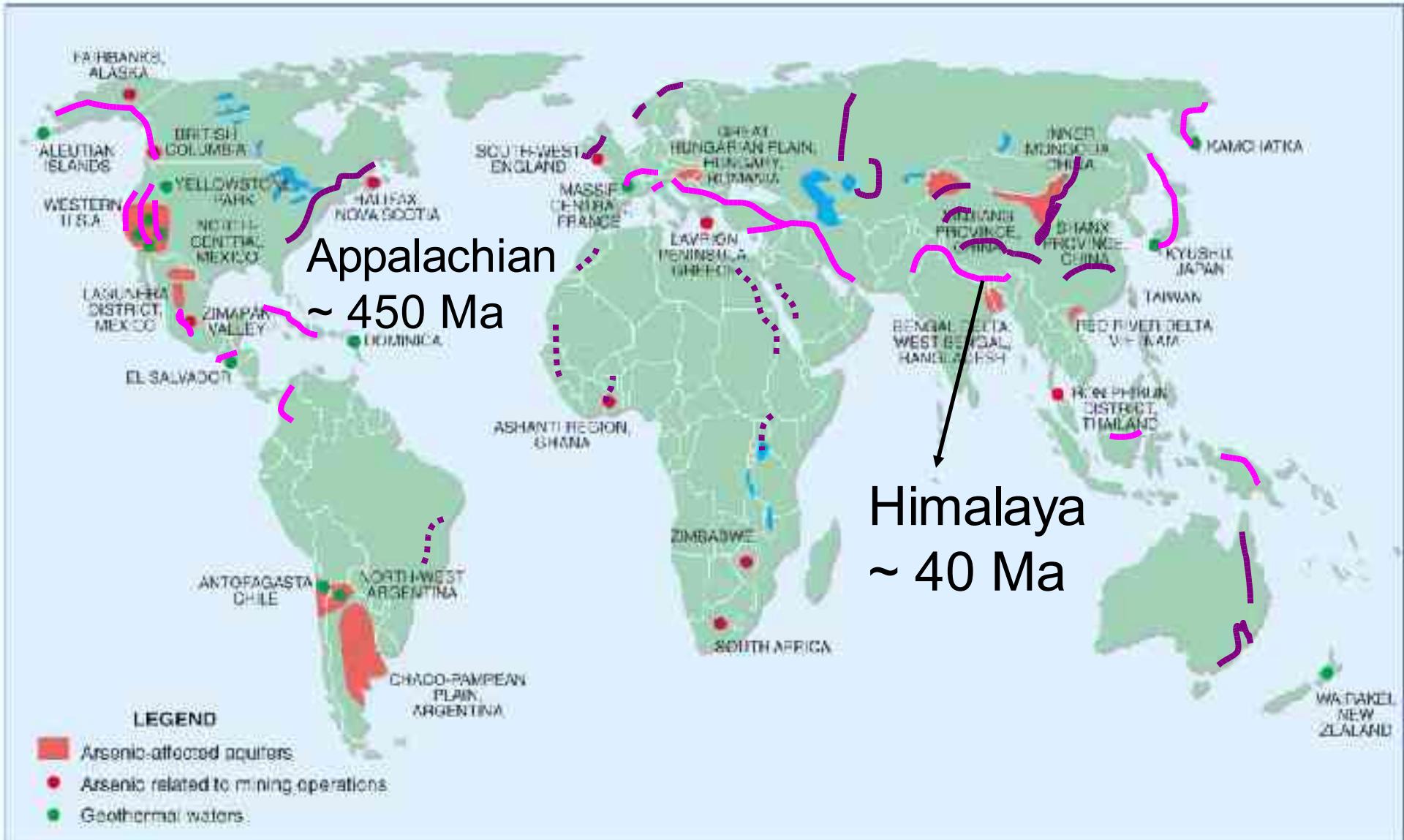
Hu et al., *Mineral. Dep.* (2002)



Zheng, Quartnary Sciences, 2007.
27(1):1-15

Zhou et al., Min. Dep. (2002)





Distribution of documented problems with $> 100 \mu\text{g/L}$ As in groundwater in major aquifers (red). Green dots indicate As from geothermal source. Areas in blue are lakes (adopted from Smedley and Kinniburgh, 2002). Lines indicate locations of ophiolite (may contain serpentinites) at convergent plate margins: hot pink < 200 Ma BP (Himalaya); dark purple solid: 200 Ma BP – 540 Ma BP (New England); and dotted > 540 Ma BP (After map 4, Dann, 1988).

Summary

- Enrichment of As in obducted ophiolitic complexes (e.g. ultramafic rocks) has been attributed to As-rich marine sediments.
- More research is needed to ascertain whether the heterogeneity of As in the crust implies:
 - 1) sedimentary aquifer down gradient from As-enriched source rock is more prone to develop groundwater As problem
 - 2) heterogeneity of groundwater As in bedrock aquifers is directly related to As distribution in rocks

The Heterogeneity of Arsenic in the Crust: A Linkage to Occurrence in Groundwater?

Yan Zheng

School of Earth and Environmental Sciences, Queens College, City University of New York, 65-30 Kissena Blvd., Flushing, NY 11367, USA.

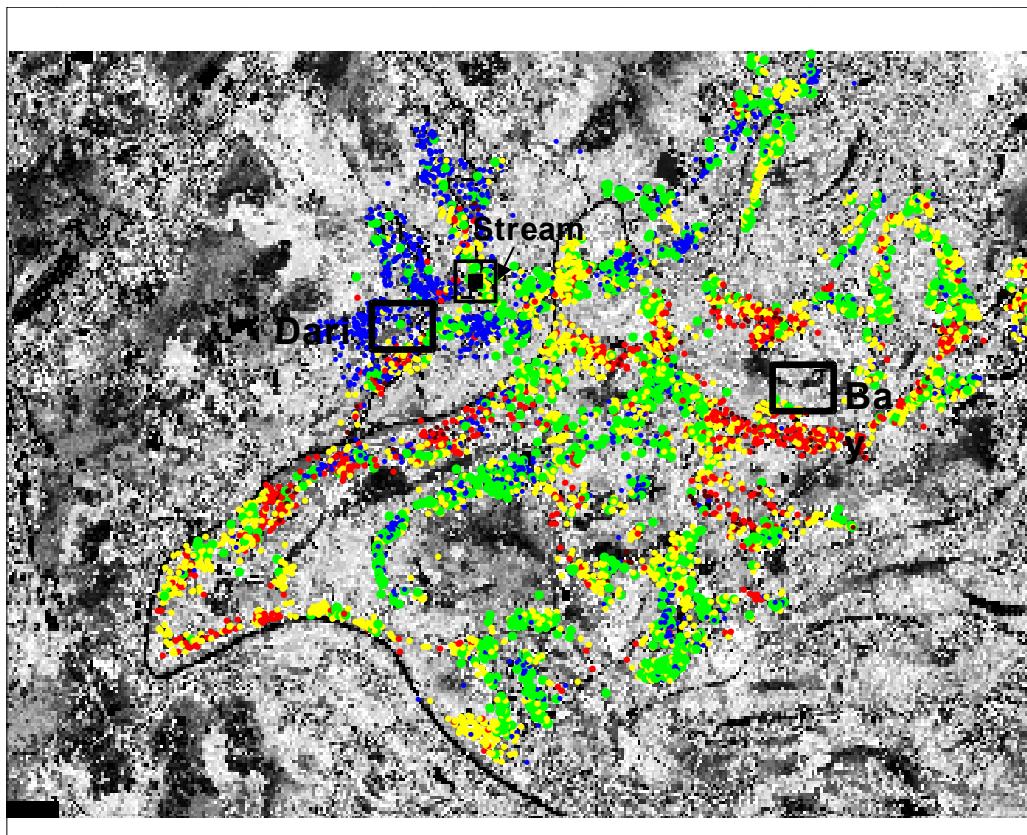
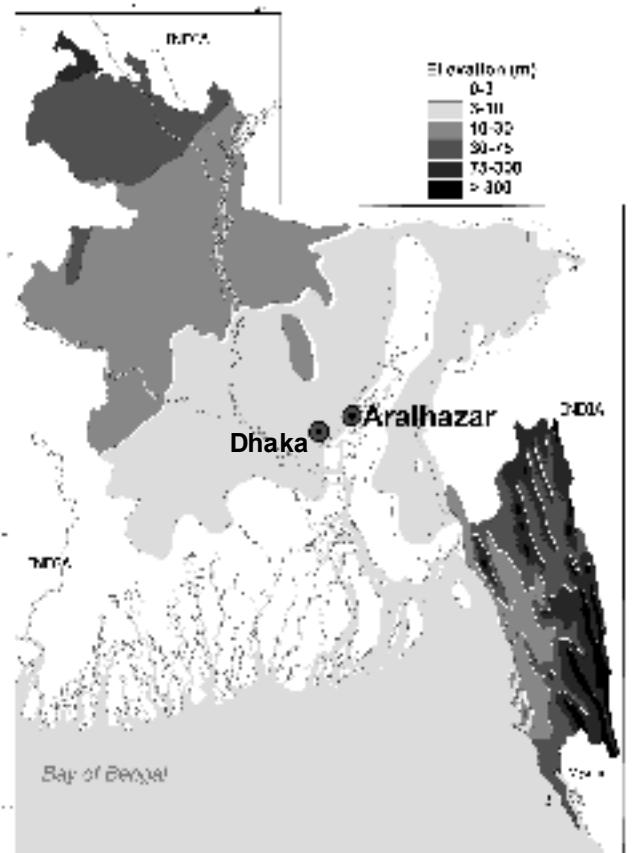
Lamont-Doherty Earth Observatory of Columbia University, 61 Rt. 9W, Palisades, NY 10964, USA.

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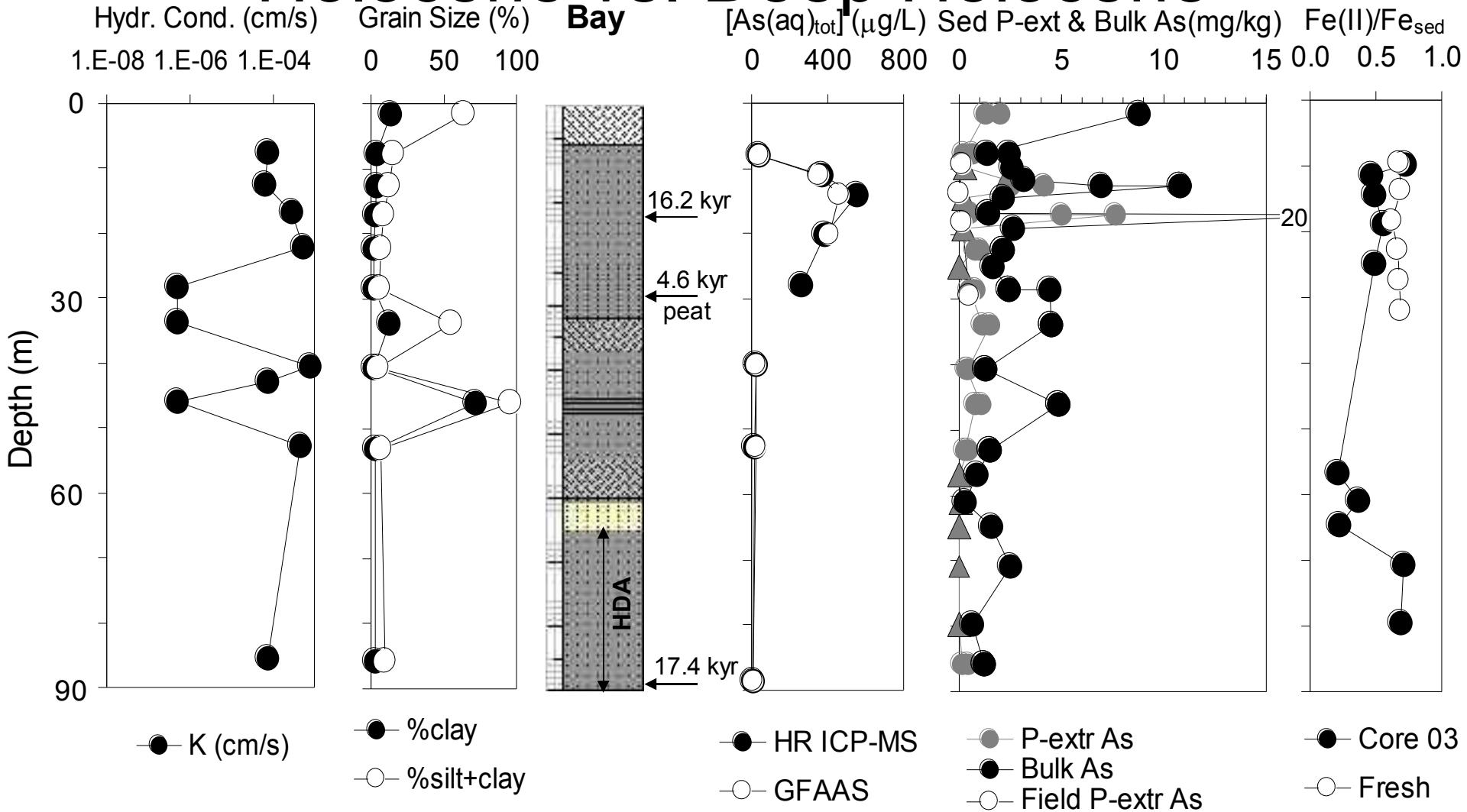
- The Earth Institute of Columbia University
- GSUC of City University of New York
- Dhaka University

Mobilizable As in Bangladesh Aquifers: Groundwater As in Araihazar



Mobilizable As in Bangladesh Aquifers:

Holocene vs. Deep Holocene



Zheng et al. GCA, 2005, 69:5203-5218

Anaerobic P-ext As method:

Jung & Zheng, Wat. Res., 2006, 40:2168

Mobilizable As in Bangladesh Aquifers: 1-2 mg/kg vs. 0.1-0.2 mg/kg

Table 3. Arsenic content of aquifer sediments from Bangladesh

Sample Description	Stratigraphy	Avg. groundwater As ¹ µg/l	Avg bulk sed As mg/kg	Avg sed ext-As ² mg/kg	Ref
<i>Aquifers with low groundwater As</i>					
Nayanganj, Araihaazar, Dari deeper	Dupi Tila	<1	2.3±2.2 (n=11)	0.2±0.3 (n=12)	this study
Nayanganj, Araihaazar, Bay deeper	older Holocene	10	1.2±0.9 (n=5)	0.1±0.1 (n=5)	this study
Munshiganj, deep ³	Dupi Tila	4	~ 1 (n=3)	<0.1 (n=3)	Swartz
West Bilat Haripur	Holocene?	<5		0.17 (n=7)	BGS,01
Dhaka	Dupi Tila	<5		0.17 (n=3)	BGS,01
Thakurgaon	Holocene alluvial fan	<5		0.15 (n=2)	BGS,01
Khittra	Dupi Tila	<5		0.13 (n=8)	BGS,01
Purba Fargilpur	Dupi Tila	<5		0.06 (n=7)	BGS,01
<i>Aquifers with elevated groundwater As</i>					
Nayanganj, Araihaazar, Dari shallow	Holocene	135	5.8±4.2 (n=9)	1.7±1.2 (n=9)	this study
Nayanganj, Araihaazar, Bay shallow	Holocene	234	4.4±5.0 (n=11)	1.4±2.0 (n=11)	this study
Munshiganj, shallow ³	Holocene	250	~ 2 (n=27)	<0.1 (n=27)	Swartz
Chanlai DW2	Holocene			2.53 (n=8)	BGS,01
Lakshmipur piez ⁴	Holocene	425	2.3±1.0 (n=6)	2.13 (n=49)	BGS,01
West Latifpur	Holocene			1.7 (n=5)	BGS,01
Ch. Nawabganj piez ⁴	Holocene	268	5.8±5.0 (n=4)	1.57 (n=19)	BGS,01
Bhimpur	Holocene			1.38 (n=6)	BGS,01
Rajarampur DW1	Holocene			1.07 (n=16)	BGS,01
Pirgacha	Holocene			0.85 (n=3)	BGS,01
Faridpur piez ⁴	Holocene	231	1.3±0.5 (n=5)	0.48 (n=43)	BGS,01

¹ Average groundwater As concentrations from existing tube wells in the area

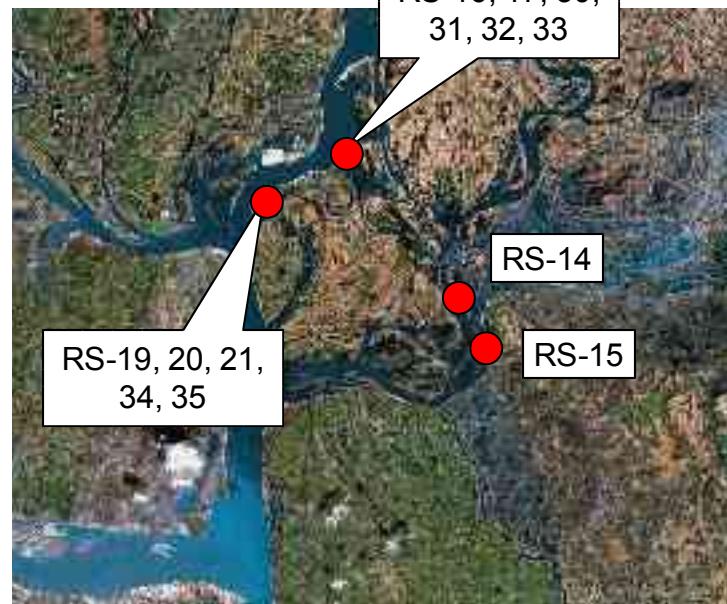
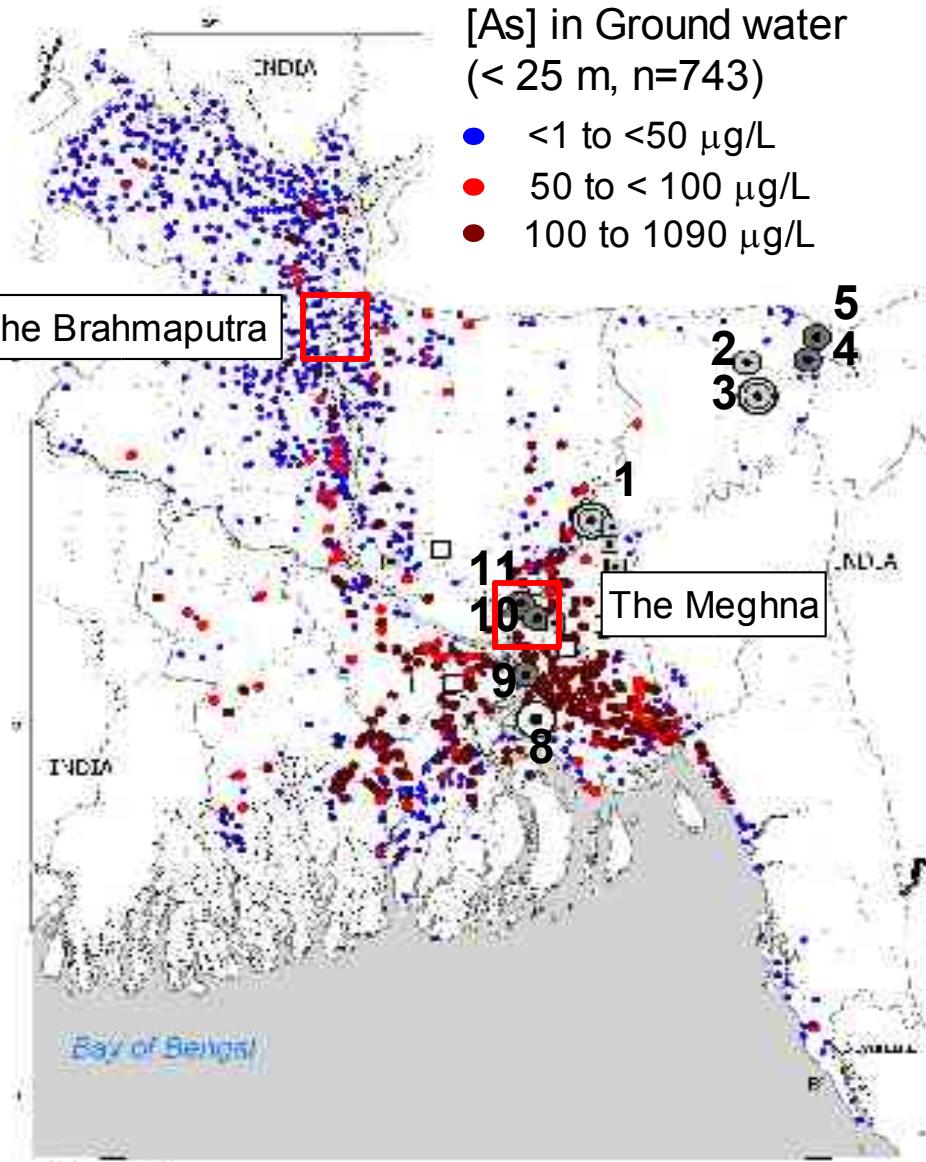
² Average extractable As from sediment by phosphate (this study and Swartz) and by oxalate (BGS and DPHE, 2001)

³ Average for data in Munshiganj was based on depth profile only

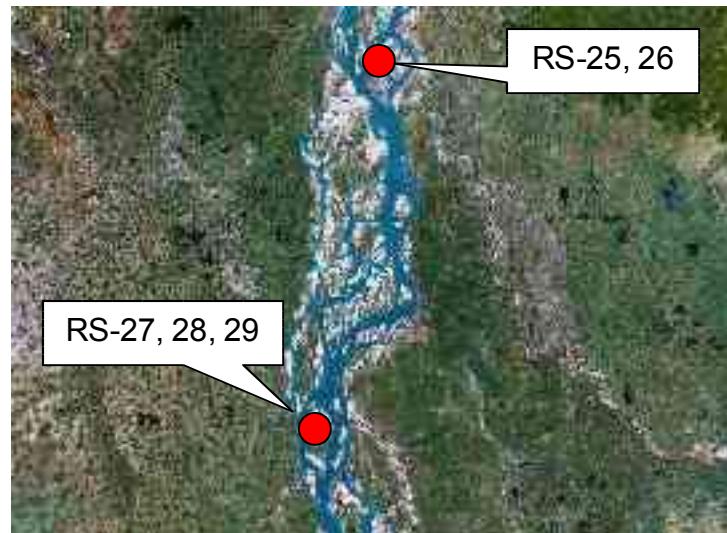
⁴ The three special study area reported by BGS and DPHE, 2001 where wells were installed and cores were taken

1000 mg/kg As in Meghna River Bank Sediment

A. The Meghna

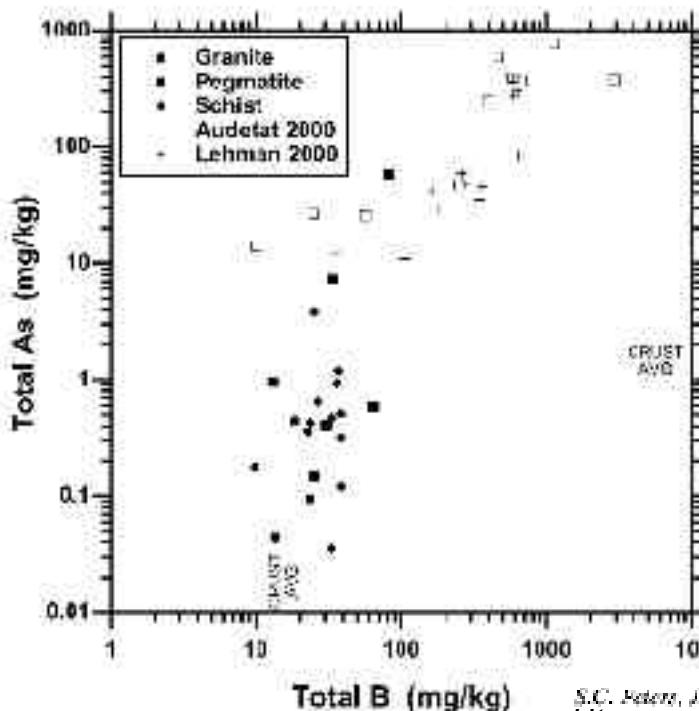
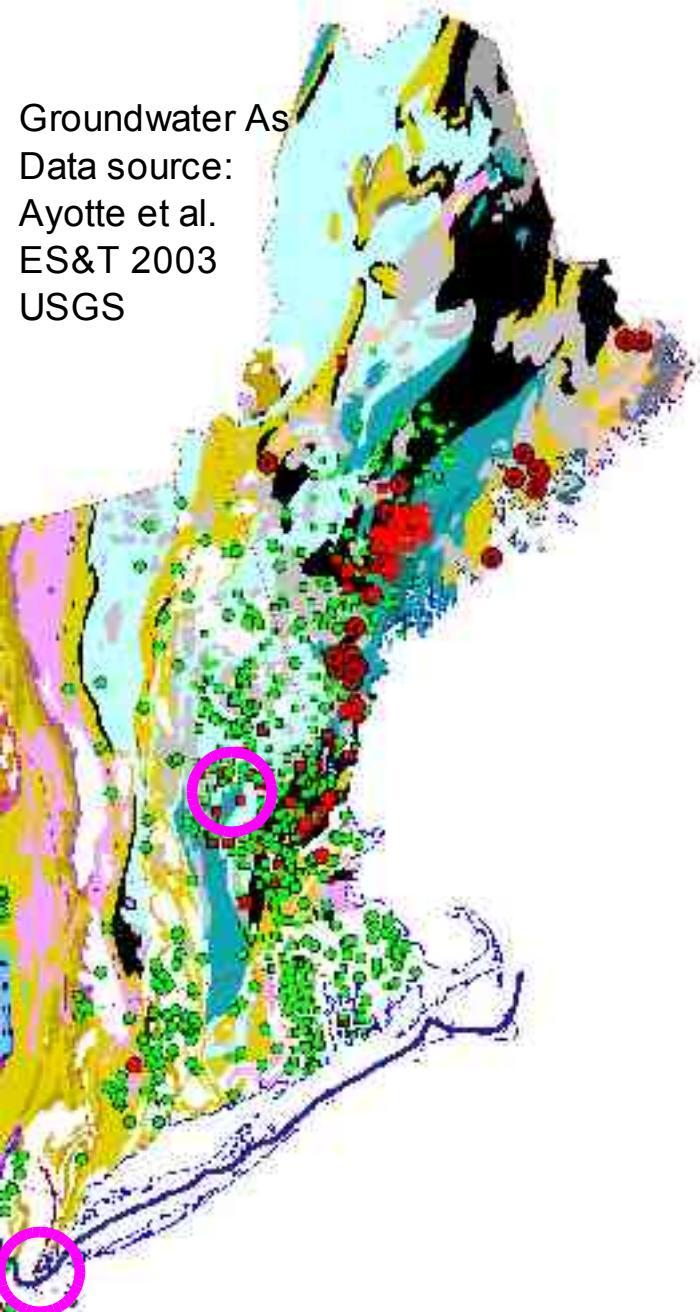


B. The Brahmaputra

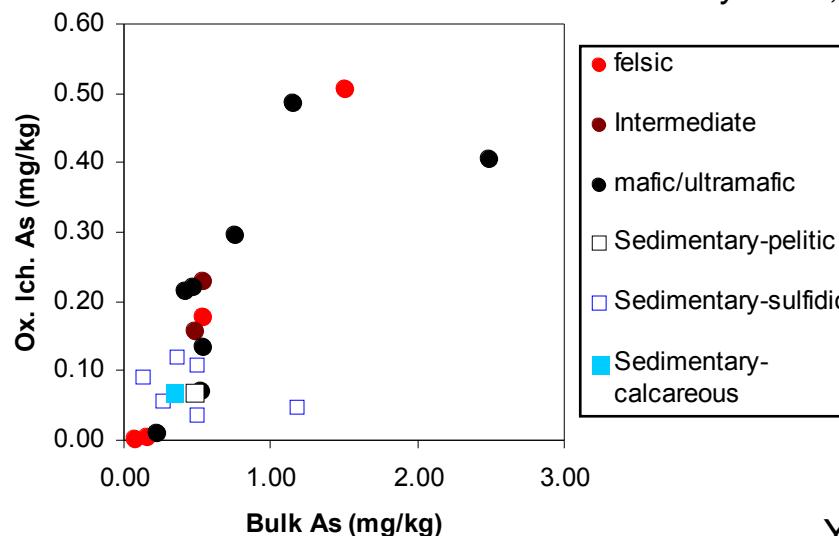


As in Rocks from New England, USA

Groundwater As
Data source:
Ayotte et al.
ES&T 2003
USGS



S.C. Peters, J.B. Blum / Applied Geochimistry 18 (2003) 1773–1797
Utsunomiya et al., Am. Mineral. 2003



Ypsilantis, 2005, M.A.

Arsenopyrite
(FeAsS)

Westerveldite
(FeAs)

Scorodite ring
($\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$)

Basic Rocks

Handbook of Geochemistry,
Wedepohl (ed.), 1969-1978

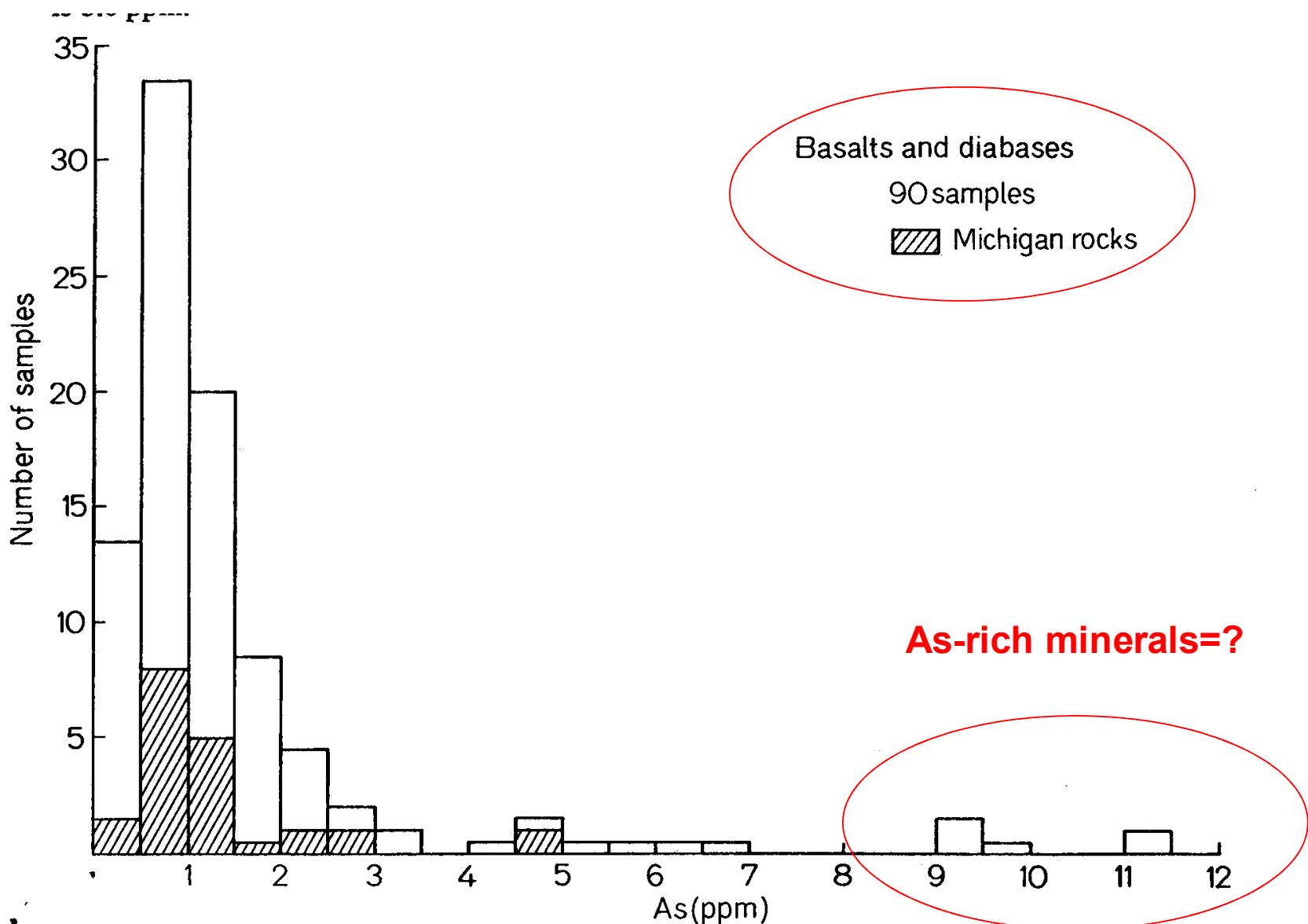


Fig. 33-E-1. Frequency distribution of arsenic in basalts and diabases. Based on the data of ONISHI and SANDELL [1955] and BARTEL *et al.*, (1963)

Acidic Rocks

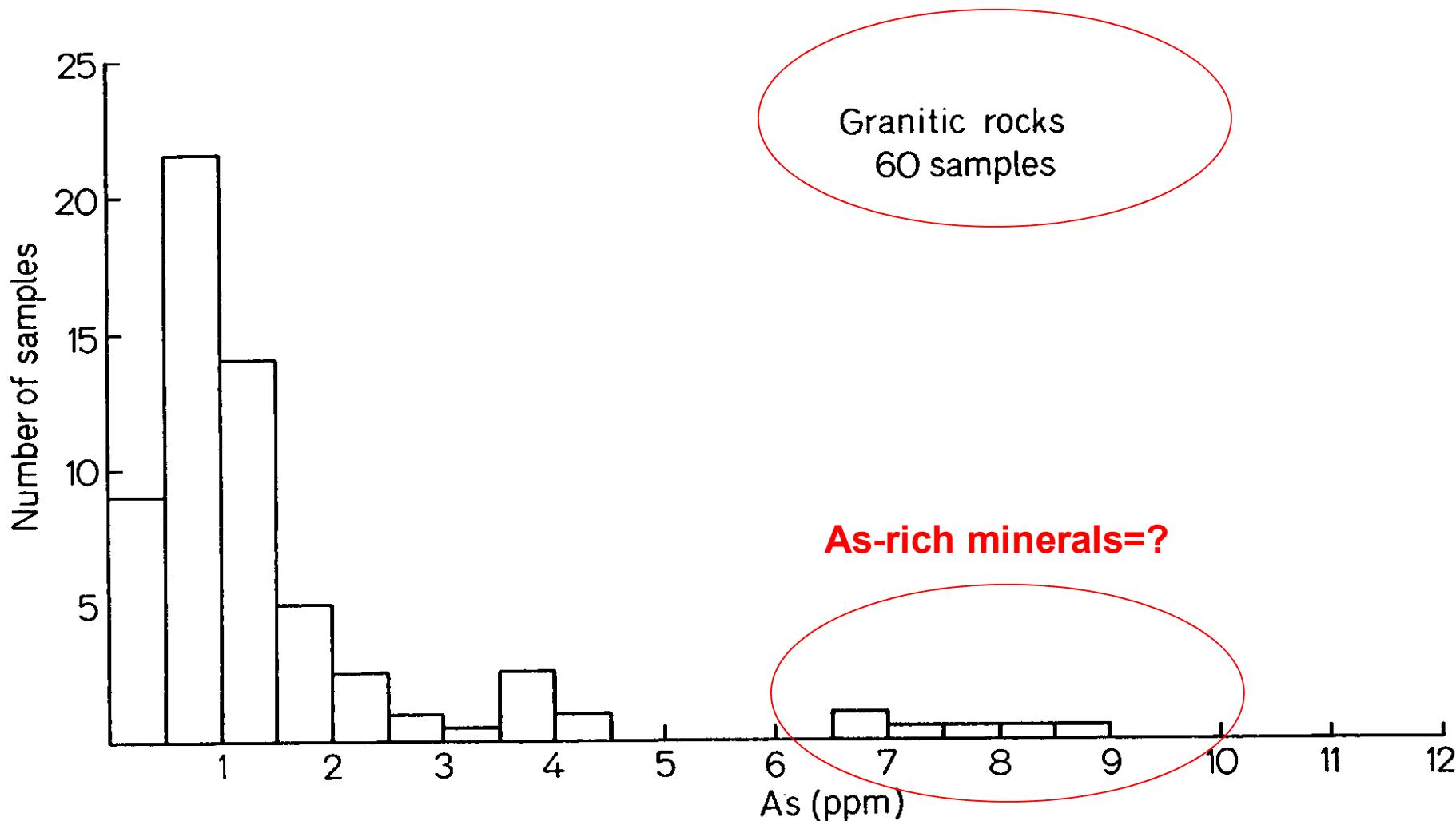
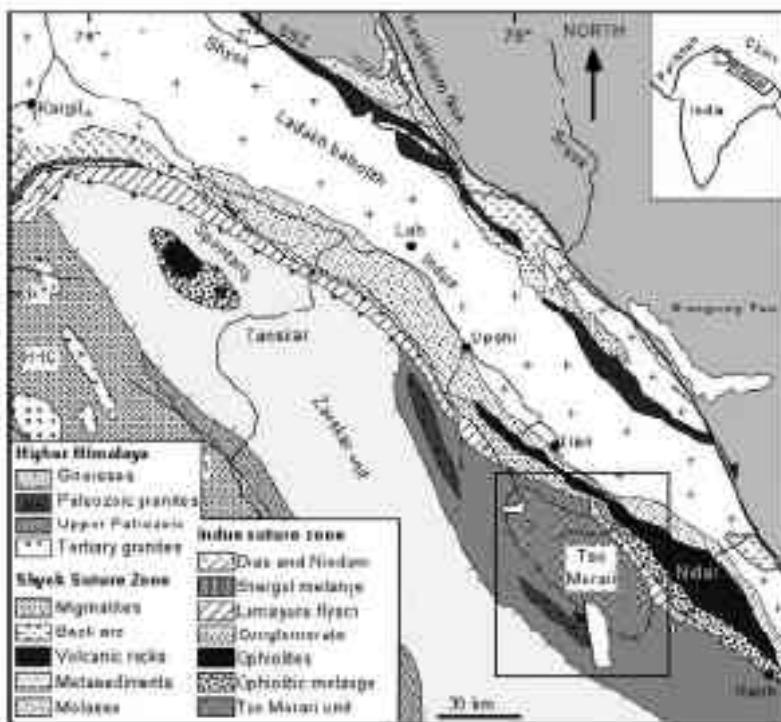


Fig. 33-E-2. Frequency distribution of arsenic in granitic rocks. Based on the data of ONISHI and SANDELL (1955) and ESSON, STEVENS, and VINCENT (1965)

~ 100 mg/kg As in Ultramafic Rocks with < 51 mg/kg S

5586

K. Hattori, Y. Takahashi, S. Guillot, and B. Johanson GCA, 2005



Substitute Si(IV) in antigorite
 $(\text{Mg}, \text{Fe})_{3\text{Si}2\text{O}_5}(\text{OH})_4$



Sorbed on magnetite and serpentine

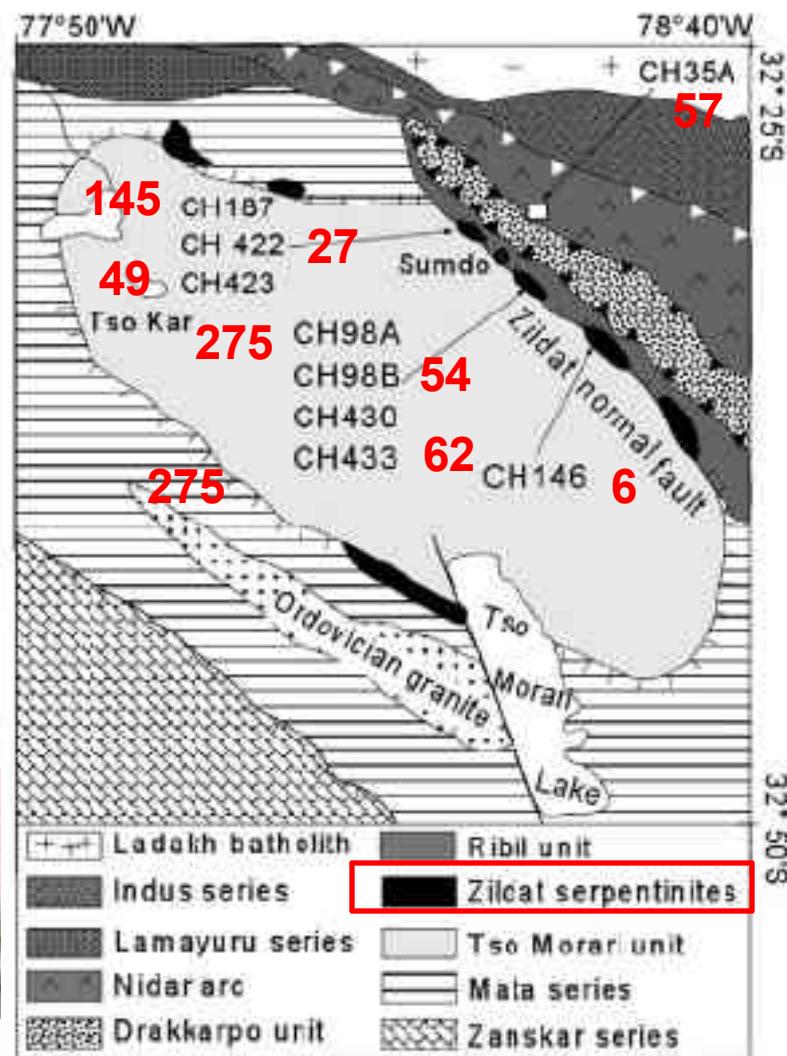


Fig. 1. Geological map of Lakakh area in northwestern India, showing sample locations in Indus suture zone. Map modified after Guillot et al. (2001).

Ophiolite: Obducted oceanic crust and the subjacent upper mantle.

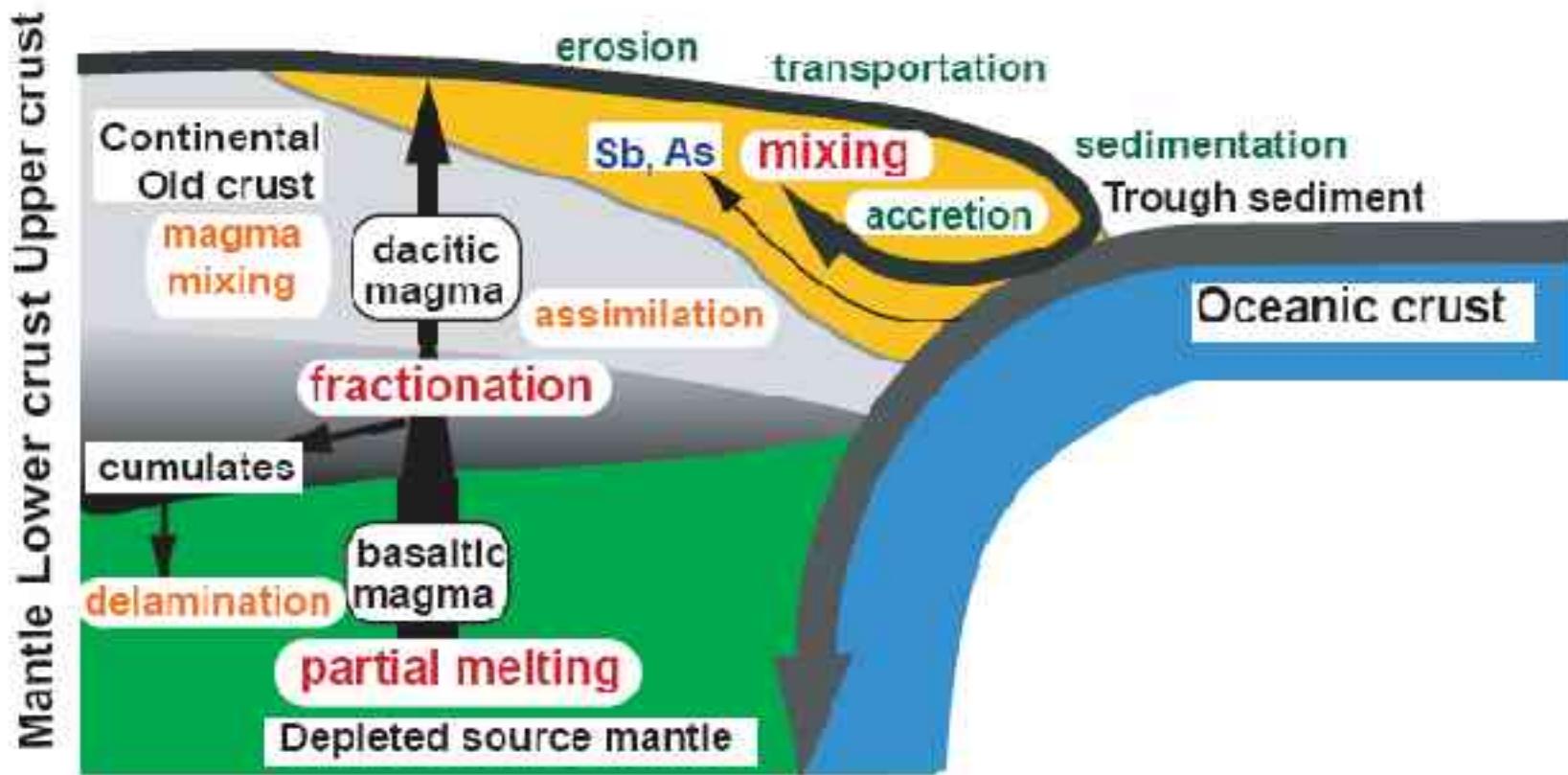


Figure 12. Schematic summary of crustal formation at an active arc. Mode of migration of accretionary complex has been adopted from [Tagami *et al.*, 1995]. A recycling of the upper crustal materials during subduction process does not change the bulk upper crustal composition of active continental margin, because accretionary complex rocks and metamorphic rocks are mostly arc-derived rocks. Alternatively, influx of magma could control the composition of the upper crust. No general temporal chemical changes in the compositions of the magma should result in the observed homogeneity in chemical compositions of the young Japan upper crust.