Techniques and methods of arsenic contaminated groundwater exploration in the Hetao plain of Inner Mongolia, China

Toshiaki ITO[1], Fumio KANAI[2], Kazuro BANDO[3]
Research group for arsenic contamination of groundwater in Inner Mongolia[4] ,
Asia Arsenic Network[5], Research Group for Applied Geology[6]

(1.KOKUSAIKOUGYO Co., Ltd., 2−24−1, Harumi−chou, Fucyuu−shi, , Tokyo 183−0057, Japan; 2.Kanai Consulting engineer office,2−35,Kouyoudai,Uchinada−machi,Kahoku−gun,Ishikawa,920−0272, Japan; 3.KOWA Co., Ltd., 6−1, Shinkou−chou, Chuou−ku, Niigata−shi, Niigata 950−8565, Japan; 4.c/o Kouichi TERASAKI, 6379−72, Igarasi Ichino−chou, Nishi−ku, Niigata−shi, Niigata 950−2101, Japan; 5.c/o Hidenori YOKOI, 2−9−6−208, Tsurunoshima, Miyazaki−shi, Miyazaki 880−0014, Japan; 6.c/o Kazuyuki SUENAGA, 1−15−31−202, Hon−chou, Asaka−shi, Saitama 351−0011, Japan)

Abstract: In 1990, the chronic arsenicosis patients due to drinking contaminated groundwater were reported in the Hetao plain of Inner Mongolia, China. At present, it is estimated that more than 410,000 of inhabitants are damaged by arsenic poisoning in Inner Mongolia. We carried out hydrogeological survey, geological survey, medical survey and installation of piped water supply systems for an 8-year period from 1997 to 2004. These surveys revealed the mechanism of the groundwater contamination by arsenic in the Hetao plain as follows: Fe-oxyhydroxide is dissolved by intensifying reducing condition in the aquifers as a result the adsorbed arsenic is released into groundwater. In order to prevent further increase of arsenicosis patients, it is important to stop ingesting contaminated water, and to supply safe drinking water. For that purpose we need to understand the mechanism of arsenic contamination based on geological and hydrogeological conditions of the field.

Key words: arsenic; groundwater; contamination; Hetao plain; Inner Mongolia; China
CLC number: P641.72 **Article Character**: A **Article ID**: 1000-3657(2010)-03-0730-11

1 Introduction

In the Hetao plain, natural high arsenic groundwater has affected wells in 662 villages and more than 180,000 of peoples. We carried out hydrogeological and medical investigations to grasp the outline of arsenic contamination throughout the Hetao plain and the details of the contamination at Wuyuan County of the central area of the plain.

2 Occurrence of the chronic arsenic poisoning

The first patient of chronic arsenic poisoning was reported in 1990 at the Hetao plain. The groundwater

Received date: 2010−03−20; **Revised date**: 2010−04−10
Fundation item: This study was financially supported by the Environmental Restoration and Conservation Agency of Japan, The Toyota Foundation, The Niigata International Cooperation Friendship Fund, Tokyo Geographical Society.
Biography: Toshiaki ITO, male, professor, born in 1961, main study field: groundwater and geo-environment sciences; E-mail: toshiaki_ito@kkc.co.jp.

use conditions had changed in the 1980's; the residents had used common dug wells at depths from 3 to 5 m, but since the 1980's they started to use private tube wells at depths from 15 to 30 m by the reasons of convenience and better sanitary conditions. As a result, the deeper groundwater with high concentrations of arsenic was used for drinking so that the health hazard was generated in the residents. The first patient had keratosis (Fig.2) with skin cancer and elevated arsenic concentration was detected from the groundwater which the patient used for drinking. Therefore, the groundwater contamination by arsenic was confirmed[1].

According to the latest data obtained by the Inner Mongolia Center for Endemic Disease Control and Research, arsenic contamination areas are found at 776 villages of 13 counties in Inner Mongolia. The maximum concentration of arsenic in the groundwater was 1.86 mg/L, and it is estimated that more than 410,000 people have health problems by arsenic exposure.

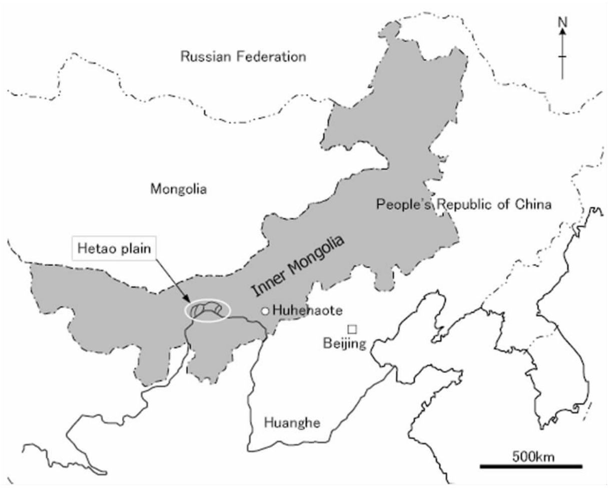

Fig.1 Location of the Hetao plain in Inner Mongolia, China

3 Geology of the Hetao plain

The Hetao plain is an inland collapsed basin caused by faults in Eocene age. The subsiding movement has continued to Holocene and thick Tertiary and Quaternary sediments have been deposited in the basin. The Tertiary strata are mainly composed of reddish brown colored muddy sediments and the Quaternary consisting of sandy beds with intercalated mud layers. The alluvial fan extends near the foot of mountain. The fun deposits consist of coarse sediments such as gravels and sands. Most of the Quaternary sediments in the Hetao plain are derived from detritus of the Huanghe (Yellow) River.

4 Distribution of contaminated areas

We carried out field investigations 3 times during the period from 1997 to 1998, to grasp the conditions of arsenic contamination in the Hetao plain. In the first field investigations we analysed quality of groundwater. And next we did a drilling operation. We installed an observation well(Fig.4).

Fig.2 Symptoms of arsenic patients (left: pigmentation, right: keratosis)

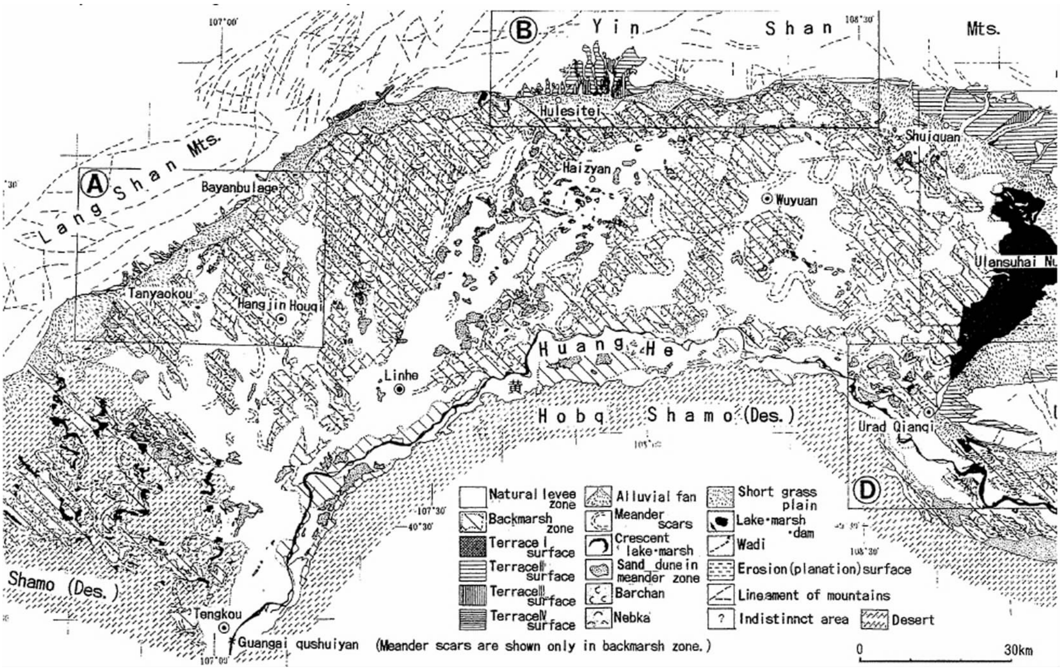

Fig.3 Geomorphological map of the Hetao Plain
(Research Group for Arsenic Contamination of Groundwater in Inner Mongolia, 2007)[2]

(Water quality survey Drilling operation Installation of observation well)

Fig.4 Groundwater survey in Hetao plain (1997−1998)

As a result of these investigations, natural high arsenic groundwater is not found in the area where the Tertiary reddish brown clay bed is exposed at and near the surface. Also, groundwater in alluvial fan deposits is safe drinking water and is used as the source of water supply. Although the contaminated areas are located in the lowland of the central part of the basin, the distribution pattern is not uniform and the areas are distributed locally and irregularly. The contaminated areas are found along the ancient stream channels and appear to be reflected by the differences of sedimentary facies caused by the changes in sedimentary environment and channels of geologic age [3]. As a result, the arsenic concentration of groundwater tends to be higher in the areas where the aquifers are overlain by thick fine-grained sediments such as clayey

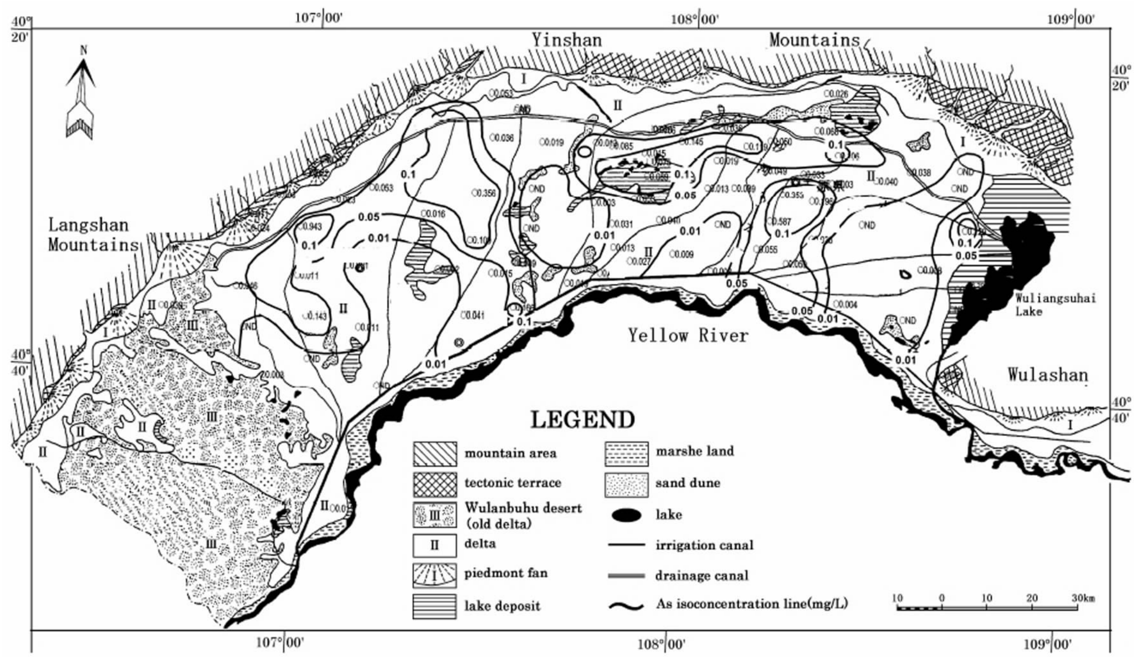

Fig.5　Map showing As concentration in groundwater of the Hetao plain in Oct. 1998
(Research Group for Arsenic Contamination of Groundwater in Inner Mongolia, 2007)[2]

aquicludes.

5　Color of aquifer sediments in the contaminated area and subsurface geology

5.1　Detailed survey in model villages

We carried out detailed investigations at Ershe-Jianshe village and Qishe-Fengle village in Wuyuan county in the central part of the Hetao plain. (Fig.6) The distance between the two villages is about 4 km. Ershe-Jianshe village is severely affected by groundwater contamination by arsenic where many chronic arsenicosis patients have been found, whereas in Qishe-Fengle village any contaminations by arsenic and arsenicosis patients have not been found. Therefore, we selected these two villages to make comparison of subsurface geologic conditions and to find the mechanism of the groundwater contamination by arsenic.

5.2 Subsurface geology of contaminated village

According to the boring survey, the subsurface geology at Ershe-Jianshe village up to 30 m in depth

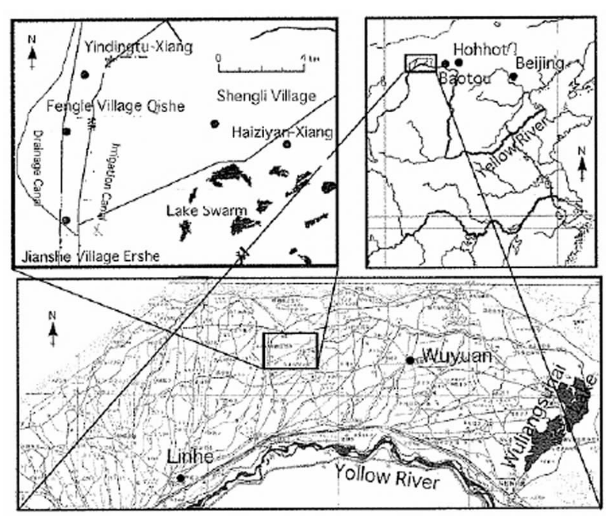

Fig.6　Location of detail survey areas

consists of upper sandy layer, muddy layer, and lower sandy layer in descending order.

The upper sandy layer is composed of very fine to fine sand. The thickness is 1-2 m, and affected by harming. The muddy layer is mainly composed of clay with thin layers of very fine sand, partially containing organic matters. The thickness of muddy layer is 8-12 m, and the layer occurs at depths of 10-14 m. The lower sandy layer is composed of fine to medium sand, having thickness more than 12 m. The lower sandy layer could be a main aquifer for tube wells. That arsenic concentration ranges between 0.13-0.56 mg/L (Fig.7).

The sediments are characterized by different color zones; brown colored zone, gray colored zone, and dark gray colored zone in descending order. The gray colored zone at depths between 10-14 m is overlain by the muddy layer (the brown colored zone). The dark gray zone occurs below 15-20 m in depth. Thus, the sediments show darker colors with depth.

5.3 Subsurface geology of non –contaminated village

The subsurface geology at Qishe-Fengle village mainly consists of medium sand from the surface to adepth of 30 m. The grain size seems coarser than that of Ershe-Jianshe village, and there is no thick muddy layer distributed in Qishe-Fengle village. The tube wells are installed at depths of 8-13 m. The arsenic concentrations range between ND-0.04 mg/L (Fig.8). The colors of the sediments are divided into 3 zones; brown colored zone, brown-gray colored zone, and gray colored zone in descending order. The brown-gray colored zone occurs at depths of 11-13 m, and the gray zone underlies below 14-18m in depth. In contrast to Ershe-Jianshe village, the dark gray colored zone is not found in the non-contaminated village.

5.4 Color of aquifer sediments in the contaminated area and subsurface geology

The sediments in the contaminated area are divided into three zones on the basis of lithology and color; brown, gray and dark gray zones. The groundwater from the brownish colored aquifer sediments is free from arsenic, whereas the groundwater from the gray to dark gray aquifers has high arsenic concentration. The color of sediments shows the change in Fe-oxyhydroxide from oxidative to reductive environment. In the brown sediments, Fe-oxyhyroxides are principal minerals, while in the gray and dark gray zones iron could be reduced from Fe(Ⅲ) to Fe(Ⅱ) and the minerals turn to be unstable; as a result the adsorbed arsenic is released into groundwater.

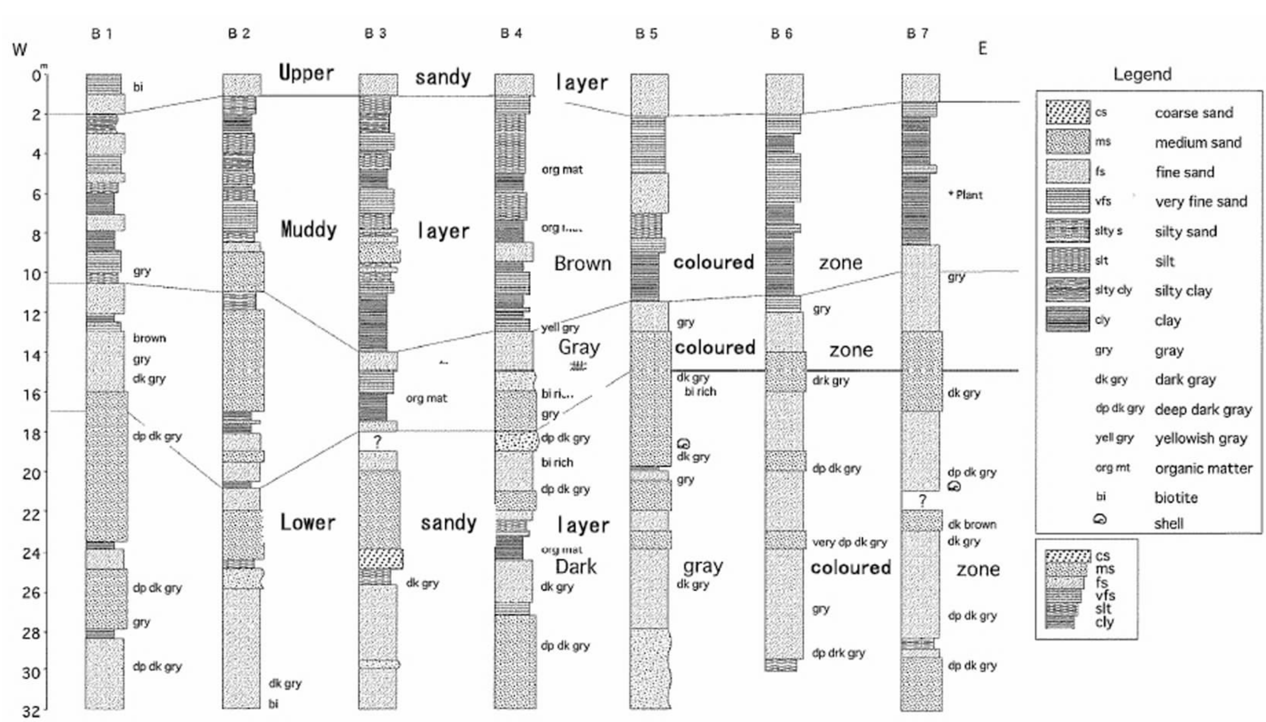

Fig.7 Geological columns obtained by drilling in Ershe–Jianshe village

(Research Group for Arsenic Contamination of Groundwater in Inner Mongolia, 2007)[2]

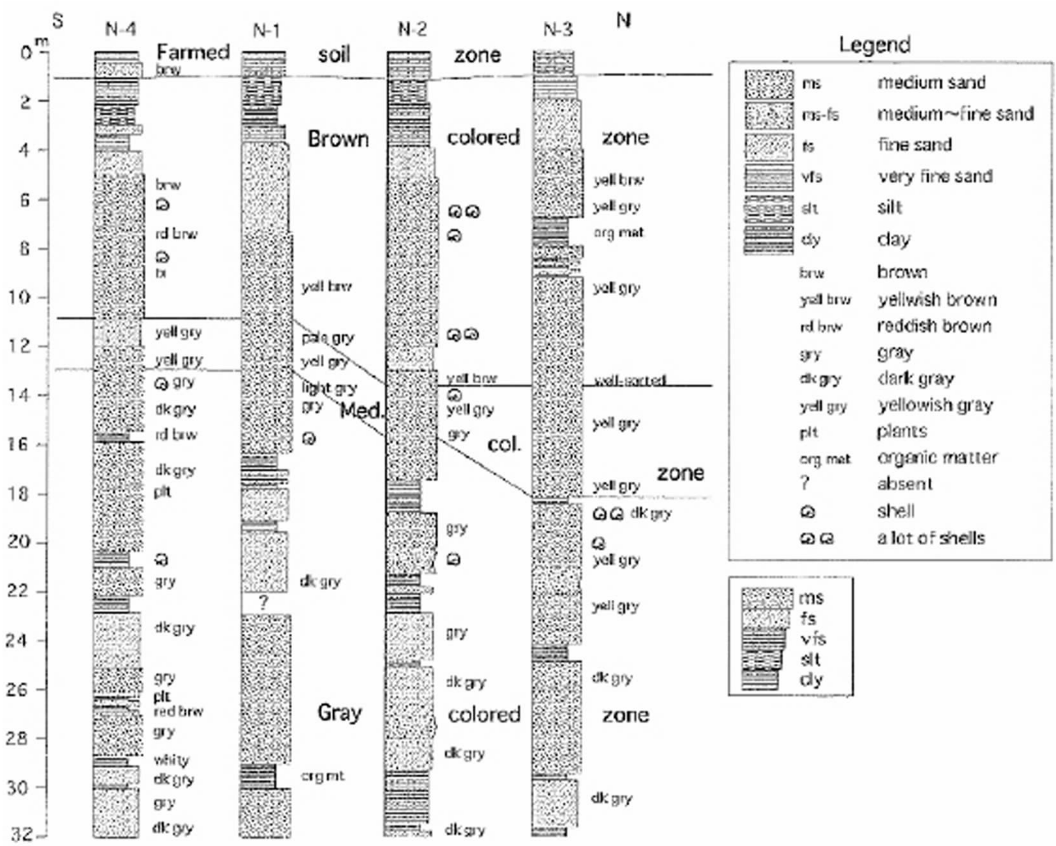

Fig.8 Geological columns obtained by drilling in Qishe-Fengle village
(Research Group for Arsenic Contamination of Groundwater in Inner Mongolia, 2007)[2]

6 Mechanism of groundwater contamination by arsenic

6.1 Characteristics of groundwater and arsenic concentration

The maximum arsenic concentration in groundwater of the Hetao plain is 1.35 mg/L. The arsenic concentration of the investigated 38 wells in Ershe, Jianshe village, Wuyuan county show more than 0.13 mg/L (the maximum is 0.65 mg/L). The pH values are higher than 8.5 in the contaminated areas due to intensive evaporation (Fig.9). High pH values are known to contribute releasing arsenic into groundwater, owing to lowering in ability of arsenic adsorption by hydrous ferric oxide. Also release of arsenic from hydrous ferric oxide into groundwater should be enhanced, because the oxidation-reduction potential (ORP) decreases with water depth.

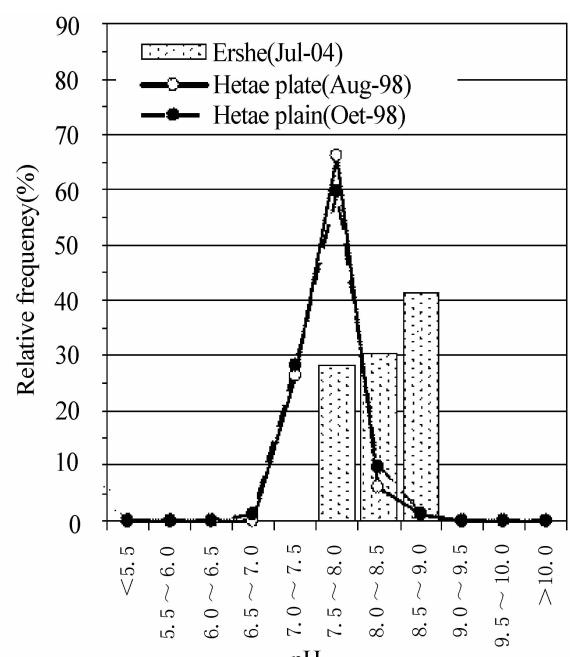

Fig.9 Relative frequency of pH in Hetao Plain

SO_4^{2-} concentration in groundwater decreases by the action of sulfate-reducing bacteria with increasing depth and decreasing ORP, although the concentration is more than 300 mg/L in shallow depth. SO_4^{2-}/HCO_3^- molarity ratio shows negative correlation with arsenic. SO_4^{2-} is reduced and changes into HS^- and H_2S, resulting in the formation of iron sulfide.

6.2 Characteristics of sediments and source material of arsenic

We carried out analyses of mineral composition, chemical composition, and selective sequential extraction (SSE; Goh[4] and Lim, 2005) using boring samples from Ershe-Jianshe village and Qishe-Fengle village. Alluvial aquifer sediments consist of sand with intercalated clay and silt layers. The mineralogical composition of the sediments is not significantly different from that of normal terrigenous deposits. Chemical composition is also not specific as compared to normal sediments. Fine-grained sediments are rich in arsenic. The mean arsenic content of clay beds is 20 mg/kg (the maximum is 38 mg/kg) and that of sand is 8.0 mg/kg (Fig.11).

Those values are slightly higher than the clastic sediments in other arsenic affected areas, but not so extremely high. Arsenic content shows positive

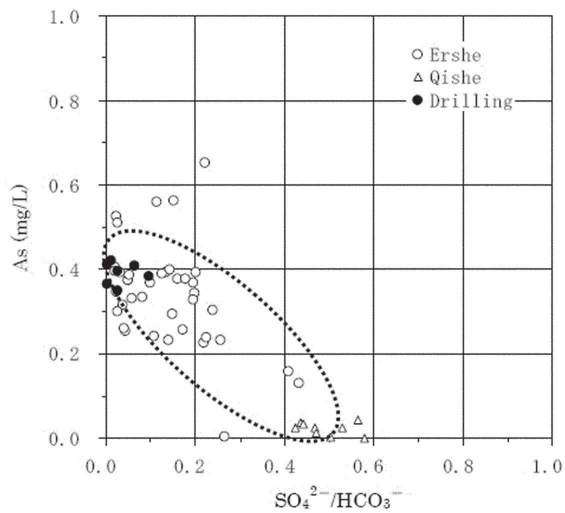

Fig.10 Relation between SO_4^{2-}/HCO_3^- molarity ratio and As concentration in groundwater
(Research Group for Arsenic Contamination of Groundwater in Inner Mongolia, 2007)[2]

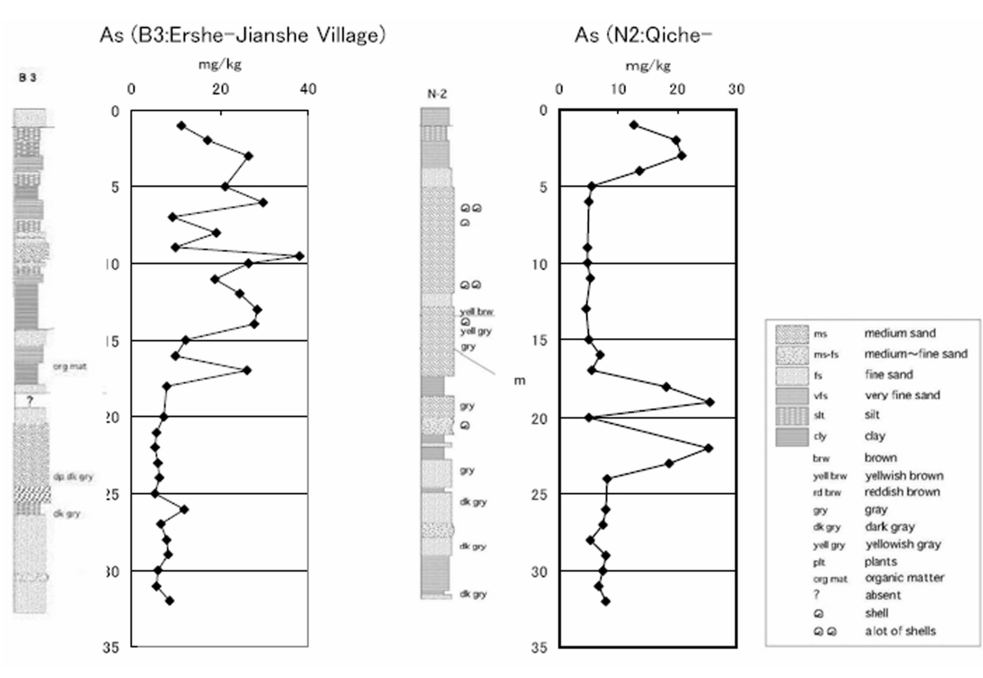

Fig.11 Minor elemental composition changes of B3 drilling core samples in Ershe–Jianshe Village, and N2 drilling core samples in Qiche–Fengle village by XRF. Composition changes are expressed by X–ray intensity
(Research Group for Arsenic Contamination of Groundwater in Inner Mongolia, 2007)[2]

correlation with total Fe_2O_3, V and loss of ignition (LOI). (Fig.12) Arsenic in sand bed seems to be contained in Fe-oxyhydroxide film coating the sand grains. The experiment of selective sequential extraction of sediments reveals that most arsenic is adsorbed by amorphous and low crystalline Fe-oxyhydroxide(Fig.13).

6.3 Origin of arsenic source material

As previously described, the sediments of the Hetao plain are mainly derived from detritus transported by the Yellow River. Arsenic content of suspended materials in the Yellow River generally exceeds 20 mg/kg (Zhang[5] 1996, Kubota et al[6]2003). This content is close to that of alluvial clay bed in the plain. The main source of arsenic is regarded as fine-grained detritus and colloidal suspended materials supplied by the Yellow River, though near the foot of mountain, influx of arsenic from metal sulfide mine in the mountain can not be denied. The Fe-oxyhydroxide film coating sand grains is also a source of arsenic.

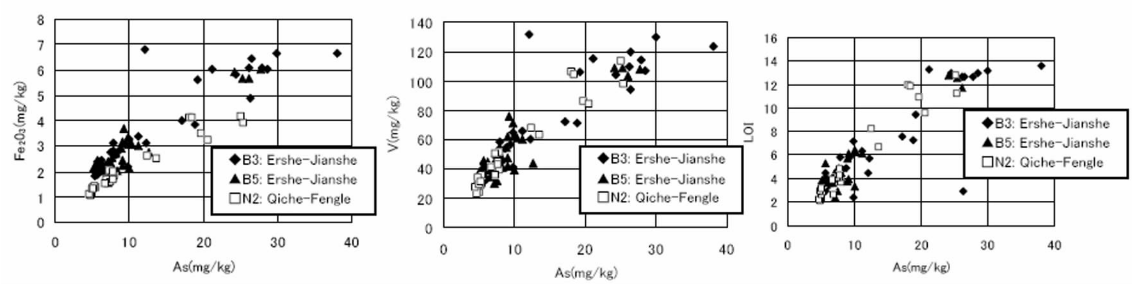

Fig.12 Correlation of As with Fe_2O_3, V and LOI in Ershe and Qishe–Fengle village sediments
(Research Group for Arsenic Contamination of Groundwater in Inner Mongolia, 2007)[2]

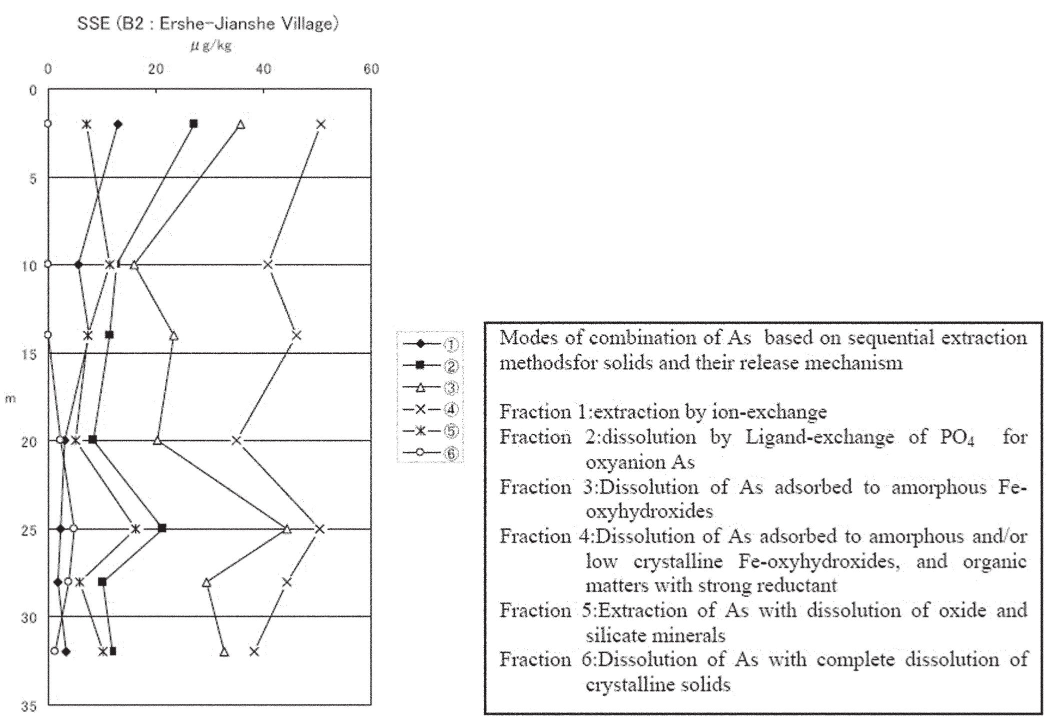

Fig.13 Result of SSE experiment of B2 drilling slime samples in Ershe–Jianshe village
(Research Group for Arsenic Contamination of Groundwater in Inner Mongolia, 2007)[2]

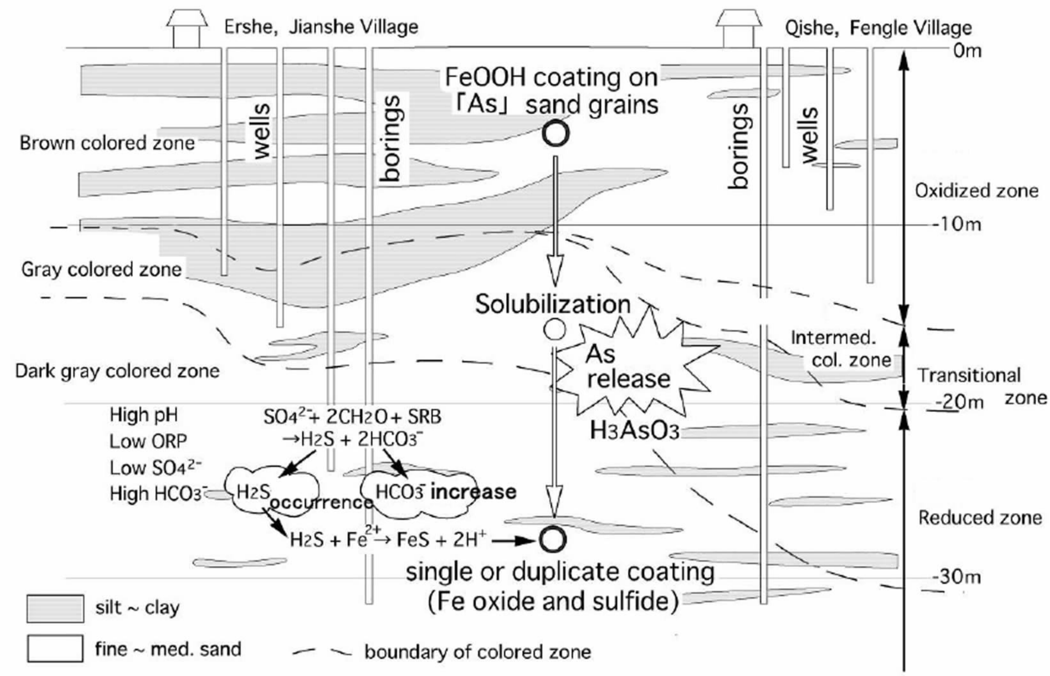

Fig.14 Schematical geologic profile of Ershe–Jianshe and Qishe–Fengle, and arsenic release mechanism (Research Group for Arsenic Contamination of Groundwater in Inner Mongolia, 2007)[2]

6.4 Release mechanism of arsenic into groundwater

ORP values of the groundwater decrease with depth. The water in the dark gray aquifer sediments shows reducing environment with less than-160 mV by the ORP meter with Pt electrode. Hence arsenic adsorbed on Fe-oxyhydroxide has been released into groundwater under such strong reducing condition caused by decomposition of buried organic matter and bacterial activity. Above mentioned reduction of sulfate to hydrogen sulfide by sulfate-reducing bacteria also promots arsenic release from solid phase into groundwater(Fig.14).

7 Improved drinking water

It is very important for the arsenic patients to take at Shengli village arsenic free safe drinking water as soon as possible to mitigate their health problems. If the arsenic contamination is found in a village, arsenic safe drinking water should be supplied to the village. We implemented a project of supplying safe drinking water to villages by the request from the local government.

In the period from 1998 to 1999, we installed piped water supply systems for 355 of households, 2 of primary schools, and 5,800 of livestock at Shengli village. This system consists of 2 wells and 37 km of pipeline (Fig.15,16). On the other hand, in 2004, we

Fig.15 Completion of piped water supply system

cooperated to install piped water supply systems at Jianshe village.

8 The background of disaster and the role of hydrogeology

The natural high arsenic groundwater in the Hetao plain is due to natural origin. Inhabitants have been drinking the groundwater without knowledge of its contamination by arsenic. There are several background conditions including microbe contamination of shallow wells at depths from 3 to 5 m, technical development of drilling well to reach deeper aquifers, expansion of cultivated land, etc. However, the groundwater of deep aquifers is contaminated by arsenic.

But, our investigations showed that there are limited numbers of wells which are contaminated by arsenic in the Hetao plain. The arsenic contamination is controlled by the redox conditions of groundwater reflecting the depositional conditions of aquifer materials. It should be noted that there are safe groundwater sources still existing in the Hetao plain.

There are many methods/techniques to remove arsenic from contaminated water, however, it is not easy to install those devices due to the cost, operation and maintenance points of view, and considering the actual socio-economic conditions of the residents.

Therefore, it should be emphasized that understanding of the mechanism on arsenic groundwater contamination is the best and the fastest way to solve the contamination problems in the study area. The knowledge of hydrogeology could provide possible locations of obtaining safe drinking water and future extent of arsenic contamination. The approaches based on the hydrogeology could help mitigation activities against the arsenic problems.

Acknowledgements: During the field investigations, we received kind assistance from the Institute of Endemic Disease for Prevention and Treatment in Inner Mongolia, Nature Dialectics Research Association of Inner Mongolia, Wuyuan County government, Haiziyan-Xiang and Yindingtu-Xiang town governments.

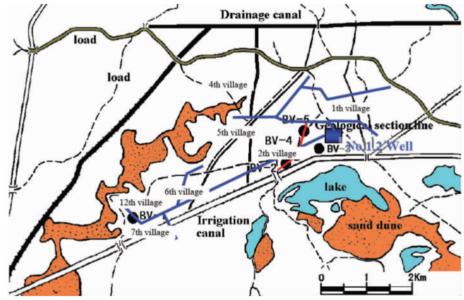

Fig.16 Water supply system in Shengli village

References:

[1] Guo Xiaojuan , Sun Zhiming, YOKOI Hidenori, et al. Arsenic contamination in Inner Mongolia, China [C]//6th Forum in the Arsenic Contamination of Groundwater in Asia, 2001：99-110.

[2] Research Group for Arsenic Contamination of Groundwater in Inner Mongolia. Arsenic contamination of groundwater in the hetao plain of Inner Mongolia, China. Monograph 2007, 58：125, The Association for the Geological Collaboration in Japan.

[3] Gao Cunrong, Research Group for Applied Geology, Inner Mongolia Groundwater Research Sub-Group. Arsenic pollution of groundwater in the Hetao plain of Inner Mongolia, China [J]. Earth Science (Chikyu Kagaku), (1999), 53：434-451(in Japan).

[4] Goh, Kok-Hui and Lim, Teik-Thye. Arsenic fraction in a fine soil fraction and influence of various anions on its mobility in the subsurface environment [J]. Applied Geochemistry, 2005, 20：229-239.

[5] Zhang, Jing. Geochemistry of arsenic in the Huanghe (Yellow Eiver) and its delta region——A review of available data [J]. Aquatic Geochem., 1996, 1：241-275.

[6] KUBOTA Yoshihiro, YOKOTA Daiki, KUBOTA Sayaka. Arsenic contents of recent surface sediments in the Hetao plain of Inner Mongolia, China [C]//The 4th Forum on Arsenic Contamination of groundwater in Asia Lecture Overviews, 1999：65-67.

中国内蒙古河套平原砷污染地下水勘探技术方法

Toshiaki ITO[1], Fumio KANAI[2], Kazuro BANDO[3]
Research group for arsenic contamination of groundwater in Inner Mongolia[4] , Asia Arsenic Network[5], Research Group for Applied Geology[6]

(1.*KOKUSAIKOUGYO Co., Ltd.*, 2–24–1, *Harumi–chou, Fucyuu–shi, , Tokyo* 183–0057, *Japan*；2.*Kanai Consulting engineer office*,2–35, *Kouyoudai,Uchinada–machi,Kahoku–gun,Ishikawa*,920–0272, *Japan*；3.*KOWA Co., Ltd.*, 6–1, *Shinkou–chou, Chuou–ku, Niigata–shi, Niigata* 950–8565, *Japan*；4.*c/o Kouichi TERASAKI*, 6379–72, *Igarasi Ichino–chou, Nishi–ku, Niigata–shi, Niigata* 950–2101, *Japan*；5.*c/o Hidenori YOKOI*, 2–9–6–208, *Tsurunoshima, Miyazaki–shi, Miyazaki* 880–0014, *Japan*；6.*c/o Kazuyuki SUENAGA*, 1–15–31–202, *Hon–chou, Asaka–shi, Saitama* 351–0011, *Japan*)

提要：1990 年报道了在中国内蒙古河套平原由于饮用污染的地下水而患砷中毒的病例。估计目前内蒙受到砷中毒影响的居民已超过 41 万人。从 1997 年至 2004 年, 在长达 8 年的时间里, 我们进行了水文地质调查、地质调查和医学调查, 并装置了管道输送的供水系统。这些调查揭示了河套平原地下水受砷污染的机理: 由于被吸收的砷释放进入地下水, 蓄水层中不断加强的还原环境造成铁氢氧化物的溶解。为了防止砷中毒病人数量的进一步增加, 停止饮用污染过的水和供应安全的饮用水是重要的。我们需要根据当地的地质和水文地质条件来了解砷污染的机理。

关键词：砷；地下水；污染；河套平原；内蒙古；中国

作者简介：Toshiaki ITO, 男 ,1961 年生 , 教授 , 主要研究领域 : 地下水和地质环境科学 ;E-mail: toshiaki_ito@kkc.co.jp。