

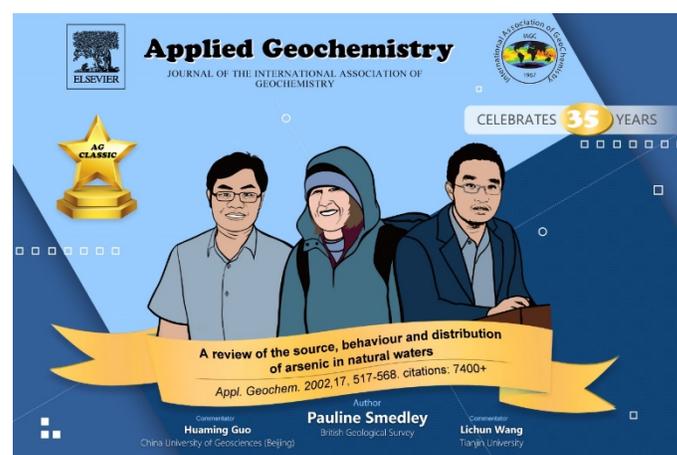
# AG Classics

## International Association of Geochemistry (IAGC)

Smedley and Kinniburgh (2002) A review of the source, behaviour and distribution of arsenic in natural waters, *AG* 17(5) 517-568.

### About AG Classics

The celebration of 35 years is a great moment to reflect on *Applied Geochemistry's* publication milestones, which often shaped their respective research areas. In our special program "AG Classics," we select and highlight those key publications. When possible, the journal will invite authors and a few commentators, who work in the same area and might have been influenced by the paper, to create a virtual panel discussion to present their perspectives on the evolution of the topic and identify the current frontiers, knowledge gaps, and research needs. We anticipate that this initiative will engage researchers all over the world with various backgrounds and eventually present valuable documentation of the journal's history and the discipline of geochemistry at large.



*Q1. This review article was published in 2002, how did people perceive arsenic contamination back then? What were the initial motivation and appropriate opportunity for writing this article?*

**Pauline:** Health problems related to arsenic in groundwater had been discovered in the alluvial aquifers of West Bengal and Bangladesh in the decade before, but international awareness of the problem and its scale only started to become recognised in the late 1990s. Large testing programmes of groundwater sources in the Bengal Basin were underway at that time. By 2002, governments, water suppliers, NGOs and researchers had begun testing in several analogous hydrogeological conditions. Research in all aspects of arsenic contamination was expanding rapidly, especially in relation to the Bengal Basin. The map in the review article highlights the areas recognized as being affected at the time and can be compared with the greatly increased knowledge that has been acquired subsequently. The motivation to write

In the first issue of *AG Classics*, Huaming Guo (China University of Geosciences), Lichun Wang (Tianjin University) and Pauline Smedley (British Geological Survey) discuss her 2002 classic paper "A review of the source, behaviour and distribution of arsenic in natural waters." This is the most highly cited paper on arsenic geochemistry, with over 7400 citations since its publication in 2002. Here, Pauline, Huaming, and Lichun discuss the paper and arsenic geochemistry in natural waters.

the article followed our completion of a DFID-funded BGS/Bangladesh Government project led by David, my co-author, on the nature and scale of arsenic contamination in Bangladesh. It also followed several other arsenic studies I had been involved with in Ghana, Argentina, China and the UK, which contrasted nicely with the situation in Bangladesh and provided a broader perspective.



Mine effluent pumped to a tailings dam, Ashanti, Ghana (1993); the author's first experience with arsenic in the environment

was quite falling behind the developed country, most scholars in China had no choice but to go to the library to read the hard-copies of journals. Although this review article was published ahead of my PhD defense, I did not have a chance to read it; after I came across it by chance, I for the first time systematically understood the distribution, source, and transport fate of arsenic in the natural environment, especially in the subsurface settings. This article indeed consolidated my confidence on continuing my research on the high arsenic groundwater issues. My research focused on the removal of arsenic in the groundwater system using natural minerals when I was working as Humboldt Research Fellow in Germany. This was actually the first milestone I've achieved in my academic career, i.e., the first time I worked on arsenic-related problems after I studied abroad with international perspectives.

In 2005 when the investigation of the high arsenic groundwater issues just emerged in China, I submitted a NSFC proposal on the arsenic problem. Due to

*Q2. At what stage were you in your professional career when you wrote/read this article? How do your professional develop and what are the milestones that you have achieved afterwards?*

**Pauline:** I was a Principal Hydrogeochemist at the British Geological Survey (BGS) and, in terms of time, was at mid-stage in my professional career. I was on maternity leave when the article was published. I still work at BGS and lead a small team of groundwater scientists.

**Huaming:** I was a post-doctoral researcher at Tsinghua University at that time. Frankly speaking, my research did not touch on the topic of high arsenic groundwater issues. However, since my dissertation was to some degree related to the arsenic problem, I have been always keeping track of the updated arsenic researches. Meanwhile, it was really difficult and inefficient to catch up with the new documented knowledge, because the literature retrieval technique



Artesian well, Huhhot Basin, Inner Mongolia

its novelty and high innovation, the proposal was financially supported after the peer-review process, which was actually my first proposal ever. Words cannot express my joy, and nothing cannot be better than my research's results and perspective were recognized and positively assessed.



Measuring groundwater quality at Hetao Basin

**Lichun:** I was near the end of my PhD life at The University of Texas at Austin. Honestly, I had little knowledge on the fate and transport of arsenic although I know quite well about the transport phenomenon, since my dissertation was on the flow and transport mechanisms in fractured rocks. Back then and coincidentally, Peter S. Knappett at Texas A&M University and my supervisor M. Bayani Cardenas planned to collaborate on the topic of arsenic transport at riparian zone, focusing on the effects of fluctuating river stage on the fate of arsenic at Bangladesh. I was attracted by its scientific and societal impacts, and thereby volunteered to build a conceptual reactive model.

This paper greatly helped me thoroughly understand the source and transport behavior of arsenic in the

aquatic systems. More importantly, it opened up the opportunities on deeply understanding why and how arsenic might be absorbed to or released from riparian sediment by spending time on sourcing its citing articles. Meanwhile, with the help of Pin Shuai who is now a scientist at Pacific Northwest National Laboratory, I eventually built a reactive model, upon which Peter and Bayani succeeded in obtaining funding from NSF.

In January 2020, after I came back to China joining Tianjin University, the whole team including folks from Texas A&M University, The University of Texas at Austin, The University of Texas at San Antonio and me arrived at Bangladesh, investigating on physical and geochemical properties of water and riparian sediment. About ~3 weeks field work was overwhelmed with digging wells, sampling water and sediments, etc. Although it was tough and just prior to the outbreak of COVID-19, we were all glad that we made this field work happen, which will be continued with many exciting results.



Using electrical resistivity method to decipher sediment properties at the bank of Meghna river, Bangladesh on Jan 8<sup>th</sup>, 2020. Back to front: Micaela Pedrazas, Alamgir Hosain, and Lichun Wang.

*Q3. How did the knowledge learned from this article shape your professional career afterwards, e.g., Do you hold the momentum to continue working on arsenic contamination problem?*

**Pauline:** I think it had little impact on the direction of my research. As I work for a government organization, the focus of my work has changed over the years according to the priorities of my employer.

*Q4. As far as we know, this review article is the most cited reference on the problem of arsenic contamination, which also deserves a prestigious place in the historical literature of environmental geochemistry or groundwater science. What are the possible reasons you think why this article is highly cited?*

**Pauline:** It was timely as the scale of the arsenic problem internationally was only just becoming apparent, and it resonated because arsenic in drinking water has become such a prominent public health issue. We also did our best to be thorough and useful. The groundwater arsenic issue makes it onto the curriculum of many undergraduate geoscience courses and the article may well get a plug on associated reading lists.

**Huaming:** I think there might be two reasons. First, this review article systematically summarized the distribution and source of arsenic in natural waters, water-rock interactions, and common characteristics of high arsenic groundwater (including geothermal water) in a variety of environments (especially in a redox environment). It provided a framework that the knowledge of environmental arsenic research can be subsequently enriched and improved, the audiences with diverse research background can be more or less inspired. Second, arsenic problem is a global issue, e.g., high arsenic groundwater was globally distributed in 6 continents with over 70 countries and 230 regions. Moreover, a long-term consumption of high-arsenic water ( $\text{As} > 10 \mu\text{g/L}$ ) can lead to arseniasis, such as cornification, skin pigmentation disorder, skin cancer, lung cancer, and other potential illness. Therefore, researches on environmental arsenic are

the global hot topics due to the above-mentioned aspects. Of course, this review article was the pilot research that led to blooming results on arsenic problems.

*Q5. Are there hidden interesting stories behind this article? For instance, what were the agencies supporting this kind of (or a series of similar) work? How long did it take you to write this review article? Were there struggling issues or troubles encountered when you wrote it?*

**Pauline:** An initial draft of this article was intended as a chapter for a UN multidisciplinary report. When it became apparent that that report might not be finalized, we decided to try to get it published in a journal rather than lose it. How long did it take to write? Including the time spent researching the various studies that contributed, about 8 years. It was a long time ago, but I think we wrote the article itself in a few weeks.

*Q6. Do you still remember the circumstances the first time you read this review article?*

**Huaming:** It was my first time that I learned to how to download electronic copies of papers, including this review article. I clearly remembered that I was about to write the application materials for the Humboldt Research Fellow, including my study plan that was to use natural minerals to remove arsenic in groundwater. Fortunately, this review article provided plenty of useful research background to support the necessity and urgency of removing arsenic in high arsenic groundwater settings.

**Lichun:** Being deeply attracted by the topic of fate and transport of arsenic in aquatic environments, I quietly sat down in my office searching for relevant articles with coffee in the early morning. What shocked me was that this review paper popped out on the top list for the first time when I googled it by using keywords: “review, arsenic, natural water”, although it was published over one decade earlier. I was surely impressed by the depth and breadth of

knowledge in this review article, no wonder why it has a great number of citations! Indeed, it took me about one more week to further dig into its citing articles, upon which I gradually grasped the essence of arsenic transport mechanisms in natural environments.

*Q7. Are you still recommending this review article to the new students in your research group? Are there any impacts on your teaching process in class?*

**Huaming:** Yes, I am always recommending this review article to the new students. As a piloting research article for environmental arsenic study, it can not only help students better acquire the fundamental knowledge, but also let them recognize how scientists perceived and studied the arsenic-related problems about 20 years ago.

Additionally, I often times cite figures and tables from this article when I teach in class. Particularly, I never forget to mention some cases in this article when I discuss the effects of oxidation-reduction and adsorption-desorption processes on chemical component behaviors in groundwater system. The students are benefiting from by doing so, since they can not only better digest the knowledge taught in class, but



Part of the research group sampling high arsenic groundwater at Inner Mongolia. Left to right: Song Yan, Shiping Xing, Zhuo Zhang, Huaming Guo, Chen Yu, Shujun Hui, Ao Wang, Chaoran Zhang.

also essentially understand the practical values for the application of theoretical knowledge.

*Q8. This review paper was published eighteen years ago, numerous scientists around the world are devoted to solving the global arsenic problem. As a prestigious and knowledgeable expert, could you briefly summarize and envision the hot research topics on the arsenic contamination in the near future, as well as describe your personal research interests related to it?*

**Pauline:** Although a huge amount of research has been carried out internationally on the mechanisms involved in arsenic mobility and transport, the question of the source(s) of organic carbon to drive the redox reactions has to my mind not been fully resolved. The relative roles of naturally-occurring versus recent pollutant sources remains an area of uncertainty and this impacts the conceptual model of how arsenic is mobilized, and how aquifers are managed. There are still parts of the world where water testing has been comparatively limited (e.g. parts of Africa) and still large populations unserved with safe drinking water, especially in South Asia. Geoscience has played an important role in understanding these problems over the years but can only go so far in contributing towards their mitigation. My own research interests encompass broader aspects of drinking-water chemistry and the many compounds in groundwater that can impact on human health. Trace elements such as uranium, radon, fluoride, molybdenum and nickel have been of increasing interest in recent years, driven by international drinking-water regulations and guidelines.

**Huaming:** Thanks. I am not yet a prestigious expert, but I can briefly talk about hot research topics on arsenic problems based on my personal experiences, which can be categorized into three aspects: (1) The ultimate source of arsenic in groundwater settings. To my knowledge, this aspect remains poorly understood. At the field scale, tectonics might be the driving force that transports arsenic from deep crust to the supergene environment, but many questions are still

unknown, e.g., how is arsenic transported? What is the pathway does it transport and become the water-bearing formations? How do these formations evolve due to water-rock interactions? (2) The interactions between organic matter and microorganisms in high arsenic groundwater systems. Previous studies suggested that both of organic matter and microorganisms can boost the enrichment of arsenic in groundwater. However, we still know little about them in high arsenic groundwater systems. It is urgent to address the key scientific question: How to combine in-situ and laboratory experiments to reveal these interactions and the subsequent effects of biogeochemical processes leading to the enrichment of arsenic. (3) The highly efficient and low-cost groundwater arsenic-removal techniques. Numerous studies demonstrated that iron-based and carbon-based functional materials (including nano-materials) might be promising for removing arsenic, but there are still some practical problems regarding high-arsenic groundwater. For example, the reduction of removing capacity and hardening of materials, as well as high maintenance cost, etc. Development of new materials and techniques can help to solve above-mentioned problems. Moreover, development of techniques for in-situ high arsenic groundwater remediation with a high efficiency would be another hot research direction.

*Q9. Do you have any personal suggestions for the next generation to succeed in pursuing and practically solving arsenic-related problem?*

**Pauline:** There exists no panacea for solving the arsenic problems internationally, but while the issue continues to affect the health of millions, it will be important to maintain it high on the agenda.

*Q10. Based on your enriched experiences, what are the impacting factors for a young scholar to be able to publish a far-reaching work?*

**Pauline:** I think the scholar will need an important research topic, a thorough and methodical approach, and some luck.

*Q11. Could you talk about the situations of your international research collaborations? Any comments on these collaborations based on your experiences, especially under the current stressful international circumstance along with COVID pandemic.*

**Pauline:** The challenges of fostering good international collaborations have become ever greater over the years as funding streams for international research have diminished, security problems in many parts of the world have increased and now coronavirus has rendered international travel impossible or very difficult. Added to that, though our European collaborations have been strong over the years, there is considerable uncertainty over the potential impacts of Brexit in terms of future funding, research exchanges/employment and collaborations. On the plus side, coronavirus has forced a rethink on the need for international flights and the face-to-face, and has normalized the virtual workshop or conference. I suspect that science will resolve the immediate coronavirus problems quite soon, but that the virus will have inadvertently changed the way we work and interact in the future. Reduced travel would be a positive for the environment.

**Huaming:** We are always putting a high value on our international exchange and collaboration, which in my opinion should not be affected by the politics (or international relationships). I am now taking in charge of the Program of Introducing Talents of Discipline to Universities, titled "Groundwater evolution and aquifer restoration". This program is carried out in order with international participants from China, USA, UK, Germany, France, Sweden, Australia, Denmark, South Korea, etc, which aims to address many common concerns for groundwater. This program however slows down due to tight international situations along with COVID pandemic. Particularly, the physical visit and joint research study between us and scientists from abroad are greatly hampered. We are now trying our best to overcome the encountered issues via many virtual alternatives, including online discussion, teaching, and international meeting, as well as exchange via Email. Upon

which we can freely discuss and interact with each other, and revise the collaborative papers. Above-mentioned activities to some degree enhance our collaborations, which might be a valuable experience if some similar research tasks have to be done.

*Q12. In your opinion, what are roles for the governors, scholars and ordinary populace to play respectively in solving a global and hidden arsenic contamination problem?*

**Pauline:** Researchers have a role in investigating and providing scientific evidence to inform decisions but different mitigation options have differing costs and consequences and so the decisions are a matter for policy makers to determine on the basis of local needs and priorities. Both roles can contribute to raising and maintaining awareness among the population of arsenic problems and their health consequences.

**Huaming:** We should attempt to unravel the key underlying mechanisms behind the phenomena of arsenic contamination as well as the existing and emerging treatment and remediation techniques. The ultimate goal is to enable economical, efficient and environmentally-friendly solutions to the As problems, which can be used by policy makers and enterprises. The governments and researchers should also disseminate the knowledges to the public regarding the distribution, hazards and preventions of As issues,

and minimize the chance of the exposure of the populations. In a word, it has to be coherent effort leveraging the resources from the government, academia and the general public to address the global challenges of As contamination.



## Applied Geochemistry

Volume 17, Issue 5, May 2002, Pages 517-568



Review

# A review of the source, behaviour and distribution of arsenic in natural waters

P.L. Smedley , D.G. Kinniburgh