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Arsenic levels lowered by adsorption onto soil sediment in the Bengal Basin

Study challenges existing ideas about arsenic in deep groundwater supplies

Naturally occurring arsenic contaminates water supplies in Bangladesh and other parts of Asia, leading to what the World Health Organization (WHO) describes as the "largest mass poisoning in history". A recent study reported in *Nature Geoscience* examined the dynamics of arsenic in soil, showing that adsorption of the element onto sediment particles reduces its presence in tapped water drawn from deep underground. This finding is important because it challenges existing beliefs about how arsenic enters water supplies and, therefore, has the potential to change water management procedures and drastically improve the supply of potable water to millions of people.

A challenge to current beliefs

The study, conducted by an international team of scientists from Columbia University, Queens College, the University of Delaware, Barnard College, and the University of Dhaka, is unique because it uses data obtained both from in situ field experiments at the Bengal Basin and from high throughput computer models to illustrate that arsenic adsorption onto deeper sediments significantly impedes arsenic migration from soil to groundwater. This contradicts the widely held belief that the element enters deep-water wells when they are replenished by arsenic-rich water from shallower sediments, drawn deeper in downwards seepage and replacing water removed for irrigation and large-scale domestic use. Rather, the authors argue, the quality of construction of individual wells and isolated, naturally occurring, groundwater arsenic, may be responsible for higher readings in some deep-water sources.

This research follows in the wake of alarmingly high arsenic readings in deep groundwater wells across Bangladesh, exceeding the WHO's drinking water guideline value (10μg/l) and threatening both private and large-scale public water supply systems. Deep-water, taken from at least 150m underground, is routinely drawn from more than 100,000 wells across Bangladesh and Western Bengal to avoid reliance on shallower aquifer systems that are widely contaminated with arsenic and microbial pathogens. In South and Southeast Asia, shallow water sources may contain arsenic concentrations in excess of 200μg/l and the resulting health problems have ravaged local populations.

Long-term exposure to soluble arsenic salts through contaminated drinking water or the products of arsenic-rich irrigation waters (rice, livestock, burning cattle dung for fuel) leads to a gradual poisoning of the body, including the development of pigment patches, scaly skin, swollen limbs and joints, tumorous growths, and ultimately, fatal bouts of cancer.

Multifaceted experimental design

In the *in situ* portion of the experiment, arsenic levels were measured after uncontaminated groundwater was extracted and enriched with approximately 200μg/l of two arsenic species (III and V) and conservative tracer bromide, before being injected back into a nearby well of the same depth. Measurements over nine days showed that arsenic levels of species III and V dropped to 31% and 14% of their initial levels, respectively, during the 48 hours following inoculation. Meanwhile, concentrations of bromide remained near the level of injection during the first two days, suggesting arsenic was being removed from the groundwater by adsorption onto aquifer sands. Similar results were achieved in sand and groundwater removed from the same aquifer and characterised in the laboratory setting.

These data provided background information for hydrological computer model simulations charting groundwater flow and transport throughout the entire Bengal Basin. As in the field study, the models suggest that adsorption significantly slows the spread and subsequently reduces the presence of arsenic in publicly accessible water systems under several present and future scenarios.

Simple solutions to a global problem

Lead author Kathleen Radloff and her colleagues suggest that, by showing that increased contamination of deep groundwater is unlikely to be triggered by water withdrawal for small-scale domestic use, their findings may have direct implications on local policy and behaviour. However, the authors urge caution, pointing out that their study only considers the large-scale use of hand-pumps and does not cover recently introduced water supplies that are piped to burgeoning human communities. Moreover, they are careful to point out that most of the Bengal Basin remains highly vulnerable to downward migration of high-arsenic groundwater in the event of large-scale withdrawal of deeper waters, despite the effects of adsorption to the sediment, and therefore they discourage the use of deep groundwater for irrigation. Rather, they suggest, farmers should find alternative methods of irrigation or consider growing less water-intensive crops.

Arsenic contamination of groundwater is a global phenomenon and this study captures the imagination of researchers worldwide. "This research carries a far-reaching public health significance, not just for the people of Bangladesh but for those affected globally from arsenic exposure, including Americans," explains William Suk of the US National Institute of Environmental Health Services, which funded the study. According to the US Geological Survey, up to 43

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million Americans depend on unregulated private wells and roughly a quarter of these having at least one contaminant exceeding levels considered safe by the Environmental Protection Agency.

Radloff herself is optimistic about the implications of her team's findings but remains careful not to overstate the meaning of what is largely a pilot study. "It is important to verify how adsorption changes across the Delta. We have specifically made very conservative assumptions in our modelling since it is likely that the different parts of the basin, with different sediment, will also have different responses," she explained to *Chemistry World*.

Dipankar Chakraborti of Jadaupur University, a globally renowned scholar in the field of arsenic contamination, reiterates Radloff's point. "This paper shows that deep aquifer sediment will adsorb arsenic resulting in safe water, but will this procedure work the same all over the Bengal Delta? Consideration must be given to differences in Bengal Delta sub-surface geology."

Nevertheless, with around a quarter of Bangladeshi and West Bengali wells contaminated with arsenic at above-WHO limits, this study's implications are a prime example of scientific discovery challenging existing knowledge, with the potential to directly improve the quality of human life with relatively simple planning and behavioural solutions.

Edvard Glücksman, EGU Science Communications Fellow

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More tsunamis for Aceh

New research shows the 2004 tsunami was the first in a new cycle of clustered earthquakes – Aceh is still in danger

Indonesia has everything seismologists could wish for, particularly the island of Sumatra in the western part of the country. Researchers have long wanted to study this region, but political unrest in Aceh, the northern tip of Sumatra, made that difficult and risky. Thus, the 2004 tsunami came as a surprise: nothing was previously known of tsunami recurrence patterns for that spot and no historical records existed.

The country, though, is rich with seismic history. Centuries of colonial records established Indonesia's proneness to frequent large earthquakes. No wonder: it is part of the Sunda megathrust, where the Indo–Australian plate subducts under the Sunda plate, and is one of the most tectonically active regions on Earth.

Megathrusts produce the most powerful of all earthquakes. The oblique alignment of their plates gives vastly greater surface area than plates contacting only along their edges. This means more friction, more strain, and much more energy finally released.

The Sunda megathrust runs 6,000km from near northern Australia, along the southern coasts of the islands of Java and Sumatra, and northward through the Andaman Sea into Myanmar. Being so long, it is broken into several segments, each with distinct earthquake recurrence patterns. Recent historical and paleoseismic studies of the Mentawai segment, adjacent to the site of the 2004 epicentre, indicate strong clustering: several large earthquakes occur in a relatively short time, followed by relatively longer calm periods.

After 2004, an urgent need arose to establish the earthquake history for that location too. The tsunami also changed the political situation in Aceh – the current Governor came to power because the tsunami allowed him to escape from political detention – meaning that the province opened to international researchers. So began an international study, spearheaded by Dr. Aron Meltzner, now of the Earth Observatory of Singapore.

Conventional paleoseismic methods, such as trenching combined with carbon dating, are notoriously inaccurate. With these techniques, it is normally difficult to differentiate a clustered group of earthquakes from regular periodic patterns. Coral reefs, on the other hand, offer a way of distinguishing between clustering and regular seismic patterns, at least in tropical waters where such marine life thrives.

Fortunately, the southern Sumatran islands are one of few places on Earth where corals grow over a locked megathrust fault segment. Corals there directly respond to, and record, relative sea-level changes caused by strain accumulation and earthquake release: virtually a seismic logbook which Dr. Meltzner and colleagues could access. Even better, Simeulue Island, off southern Aceh, straddles the boundary between the 2004 segment and the adjacent, historically active, segment of the megathrust. This site is, therefore, one of very few where it might be possible to distinguish close but unrelated earthquakes originating from neighbouring fault segments.

Earthquakes generally lift coral microatolls partly out of the water, killing the corals. Obtaining the date of coral death, via uranium-series radiometric dating, closely approximates the earthquake date. Living corals preferentially absorb uranium-234 from seawater; measuring accumulation of decay-product thorium-230 indicates time since death. Meltzner's study employed intense sampling, sufficient to obtain date-errors of only two to three years. The study team also surveyed the microatolls, giving precise 3D uplift and lateral movement vectors. The date and vector information,

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combined with coral's annual growth rings, can be used to accurately reconstruct and date land movements resulting from previous earthquakes and subsequent subsidence.

The 2004 megathrust segment, like its neighbour the Mentawai segment, revealed a rough earthquake clustering pattern. A trio of earthquakes seems to have occurred there for over 50 years starting in mid-1390. Uplift data shows the middle one, which occurred around 1430, was smaller and less well resolved, though the final earthquake of that series, in about 1450, was probably larger than the 2004 event. The corals also suggest a fourth historical earthquake around 950, although the date-error for this event is some five times larger than for the trio of earthquakes. The simplest conclusion, according to Dr. Meltzner, is that the 2004 segment had no activity from 1450 to 2004, and that 2004 marked the beginning of a new cycle. The 10th century earthquake was probably the tail of a previous cycle.

The earthquake cycle that finished in 1450 resulted in a cumulative fault slip of the 2004 segment of 20–25 metres. Yet, in 2004 the fault only slipped ten metres. Similarly, the total coral uplift of that period was also double that of 2004. These results indicate the 2004 fault segment should still hold considerable unreleased strain. The study authors concluded that in this area, after centuries of quiet, one large tsunami will be followed by others within decades, and then the site will quieten again. That means more tsunamis soon.

Huge tsunamis such as that of 2004, affecting the whole Indian Ocean, are unlikely in the region for several more centuries. However, the next rupture of the 2004 fault segment will almost certainly occur within decades, and probably within 200–400 kilometres of the 2004 epicentre. For Aceh, that means local effects similar to 2004. This suggests urgent preparation and mitigation priorities for the Aceh government.

Future studies will push back the dates to determine the 2004 segment's cycles beyond 1000 years. Ongoing research will also establish patterns for other megathrust segments and compare them as a whole, including how segments interact and the reasons large earthquakes do not cross the segment boundaries.

Wayne Deeker, freelance science writer

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What we know about catastrophic rockslides in the Alps

New and old dating methods are helping scientists understand what triggers large landslides

Very large rockslides, with a volume of more than one million cubic metres, are rare but can have disastrous effects on human settlements. A famous example of one of these 'catastrophic rockslides' happened in 1963, when a large volume of rocks fell into the artificial lake of Vajont, Italy causing a flood wave that destroyed several villages and killed 2,000 people.

To prevent similar disasters, it is important to understand the factors that can cause such large landslides. Early explanations involved only earthquakes, but since the mid-19th century, climate change has also been considered an important factor that can increase the occurrence of catastrophic rockslides.

According to this hypothesis, temperature oscillations increase the weathering rate of rock surfaces, causing the rock to become strongly cracked and fissured. During periods of more humid climate, water infiltrates the rocks trough these fissures. The water acts like a lubricant and causes huge blocks to slip off – a rockslide occurs.

To test this hypothesis, it is necessary to compare the occurrence of rockslides with past climatic variations. In the Alps, written records of rainfall or temperature span about 250 years, a period where only a few large landslides occurred, like in 1806 when a rockslide destroyed the Swiss village of Goldau and killed some 500 people. To improve this limited database, geologists reconstructed the climate of the last 10,000 years and dated as many fossil rockslides as possible.

The climate in the Alps can be reconstructed with various methods: the chemical composition and fossil content of sediments deposited in alpine lakes can be used to estimate the amount of rainfall during the period when these sediments formed. Fluctuations of glaciers, inferred from the preserved moraines, are used to reconstruct the oscillations of temperature in the same time period.

Until about 50 years ago, radiocarbon dating was the only applicable method to date fossil rockslides. One of the first catastrophic landslides investigated with this method was the rockslide of Köfels in Tyrol, Austria, where a piece of wood buried by the rocks was dated to more than 9,800 years. However, such findings are rare

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A large boulder of dolostone at the Tschirgant rockslide in the Tyrol region. Note the smaller pebbles at the basis of the boulder, which are hold together by the cement that formed after the rockslide occurred. (Credit: David Bressan)

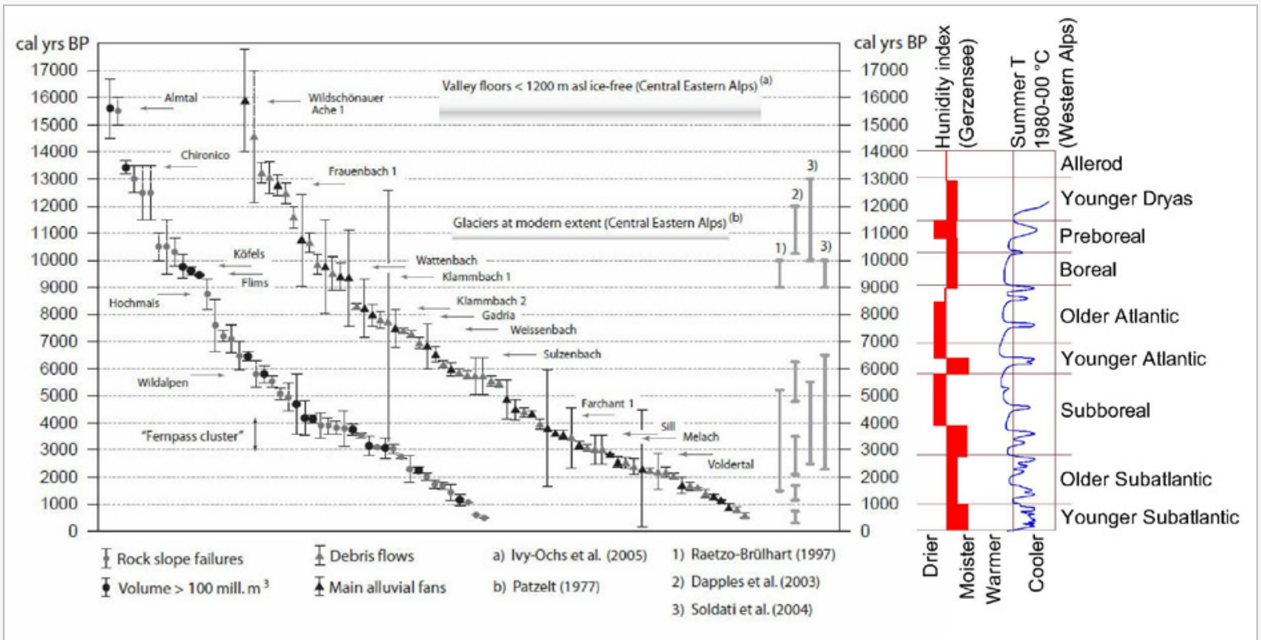
and the age of many fossil rockslides could not be measured until recently.

A new dating method, developed in the past few years by Marc Ostermann and colleagues at the University of Innsbruck in Austria, has significantly increased the number of datable deposits of old rockslides. Many landslides in the Alps occurred in regions characterised by carbonate rocks, like limestone or dolostone. Both these minerals, composed of calcium and magnesium, and with traces of uranium, are soluble in water. When a rockslide occurs, the superficial debris is rapidly dissolved by rainfall. The saturated water then percolates to the underground where it deposits a part of the dissolved elements, forming a new generation of minerals inside the cavities of the rockslide debris. This new formed ‘cement’ has almost the same age as the rockslide event.

The radioactive uranium incorporated into the cement slowly decays into thorium. By measuring the concentration of these two elements, it is possible to calculate the age of formation of the cement and therefore the age of the rockslide, as shown by the Innsbruck researchers.

With this method, the scientists dated various catastrophic rockslides of unknown age situated in the Austrian region of Tyrol, like the rockslide at the mountain pass of Fernpass or at the Tschirgant Mountain. Both fossil rockslides were dated to an age interval between 4,000 and 3,000 years.

In 2008, Prager and collaborators reviewed the available ages of these and other large fossil landslides and debris flows in the Central Alps. They found indications of a clustering of rockslides during the Subboreal – a period between 4,200 and 3,000 years ago. From the studied sediments deposited in the Swiss lake of Gerzen, and from the reconstructed fluctuations of the alpine glaciers, it is also known that the Subboreal was a period characterised by a humid climate, and with strong oscillations in temperature. However, Prager and his team note that the available data is still limited, and that



Temporal distribution of fossil landslides in the Tyrol and its surrounding areas compared to climatic variations (humidity and temperature). Note the cluster of events around 4,000 years ago (modified by David Bressan after Prager et al. 2008).

there are significant regional variations in the occurrence of landslides, possibly related to local variations in rainfall or temperature.

With a steadily growing database, using old and new dating methods, it will become clearer how rockslides are triggered by these environmental factors and how the occurrence of catastrophic events is controlled by climate change.

David Bressan, freelance geologist based in Italy

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Interview with Dr. Andy Smith, glaciologist who collaborated with BBC's Frozen Planet team

The British Antarctic Survey scientist talks about his research and the experience of working with a film crew

"Frozen Planet takes you on the ultimate polar expedition. This landmark series brings to the screen the frozen wildernesses of the Arctic and Antarctic as you have never seen them before, and may never see them again..." (BBC)

First of all, could you introduce yourself and talk a bit about your research work?

I have been working on the glaciers and ice sheets of Antarctica and the Arctic for over 28 years. I work as a glaciologist, using geophysical methods to study the ice and what lies beneath it. Changes in the ice sheets could have a significant impact on global sea level so we want to understand how the ice flow is controlled, what causes changes, and even what could mitigate change. We are currently working on Pine Island Glacier, part of the West Antarctic Ice Sheet. It is remote and difficult to get to, but it is the part of the ice sheet showing more change than anywhere else, so the logistical effort required to work there is well worth it. We hope to be in the field for nearly 3 months, living in tents and travelling by skidoo and sledge.

Where, when, and why did you team up with the Frozen Planet team?

The Frozen Planet team were at Rothera Station, our main station just off the west coast of the Antarctic Peninsula, in early 2010. This coincided with my return from a project on another large glacier, Rutford Ice Stream, where we were using seismic and radar surveys to study the material beneath the ice stream and, in particular, the subglacial hydrology. We had arranged in advance that our time at Rothera would overlap so we could work together. They were working with many people at Rothera and filming a whole range of the activities there. For their time with me, we specifically wanted to fly to Wilkins Ice Shelf and, if possible, land on one of the huge icebergs that have calved off it. Not long before, Wilkins Ice Shelf had suffered a major collapse in which a large proportion of the ice shelf very rapidly disintegrated into hundreds of pieces, some of which were easily big enough to land a plane on. When we flew over the ridge and first saw all the icebergs where the ice shelf had been, it really was an amazing sight. And then flying down and between the icebergs was some of the most exciting flying I've experienced. We also spent some time discussing and filming some of the geophysical methods we use, especially those where we use explosives as the energy source, to look beneath the ice.

How would you describe your experience accompanying the BBC crew and, in particular, the series-presenter David Attenborough?

The best way to describe my experience was immensely enjoyable and very stimulating, but David Attenborough himself was not part of the crew I worked with. Being able to work with them was a memorable experience. They combined being very professional and thorough, with at the same time being able to make me feel relaxed and comfortable. I'm sure this helped them to get the best out of people, which I think comes over well in the programmes. Being with them was hard work, but it was great fun too and I was impressed at how much they managed to fit into a relatively short visit. One thing everyone had to get used to was plans changing almost on a minute-by-minute basis, but I was expecting this and it clearly is the best way for them to fit so much in and to get the best footage possible.

What was a typical day like during that trip?

Busy! Early starts with a hurried breakfast normally followed by either hurriedly getting all the filming equipment to the aircraft if we were flying, or else an early morning drive to a snowfield a few kilometres away if we were doing 'ground work' that day. I would often go ahead to prepare the scientific equipment or, if we were using them, the explosives charges, before the crew arrived. The best way to describe the day once the crew arrived is 'full-on'. But there was a lot of variety – trying new ideas, taking new opportunities, and just staying very focused on getting all the right footage. Evenings back at the station were the time for checking the day's work and planning for the next one. I remember long conversations about my work and its relevance, about the things we would – and perhaps wouldn't – be able to film, about the different options for the next day and what things would affect decisions and dictate the plan; they were very thorough about getting a complete understanding of things. Then of course, the day's plan could easily change at a moment's notice if the lighting improved or whales were seen unexpectedly. It was a sign of how thorough the crew's preparation was that they were able to do this when conditions required it.

University of California scientists benefited from teaming up with the Frozen Planet team on a field trip since they couldn't afford the specially equipped boat the BBC team had access to. Did the collaboration help your research in a similar way?

The field project I was working on at the time was in a different location and couldn't really benefit from the crew in this way. However, I think it is excellent that other teams could gain in this way and improve the research being done thanks to the BBC. Where both sides can benefit, it can only be a good thing for everyone.

Do you think the programme, in particular the episode you feature in (number 7), shows a good balance between portraying good and correct science with the need to get interesting shots?

I have yet to see the full programme but what I have seen across the series so far has shown a good balance. I think the photography has been absolutely stunning; at the same time, as an environmental research scientist, I've been perfectly happy with the science that has been portrayed.

In your view, how important are programmes like Frozen Planet in raising public awareness of what's happening in polar regions?

They are very important. As my research is funded by the UK Government it is very important to show UK taxpayers how their money is being spent and why study of the Antarctic affects them. Being so far away, the public often wonders why there is such a big science effort at the polar regions – but they are vast and play an important role in our understanding of how the Earth works. My work on Pine Island Glacier, for instance, is important for scientists to be able to access how this glacier (the size of England) in Western Antarctica is contributing to sea level rise.

Email interview conducted by Bárbara T. Ferreira, Chief Editor of GeoQ

Dr. Andy Smith (centre) with polar guide Ian Hey (left), and fellow glaciologist Gabby Chevalier (right). Credit: British Antarctic Survey