Although rock avalanches are ubiquitous in mountain terrains, the impacts of individual large rock slope failures on glacier dynamics are difficult to discern: the vast debris-covered snouts of the Himalayas and Andes[8] are the products of continuous rock avalanching. Similarly, the collapse of 14 million cubic metres of rock from the summit of Mount Cook onto the surface of the Tasman Glacier in New Zealand in 1991 merely added to an already well-developed surface debris cover[9]. The rock avalanche debris passed through the Hochstetter icefall on the east face of Mount Cook in less than three years, attesting to the high rates of mass transport in New Zealand's mountain glaciers (Fig. 1). This event clearly showed us that debris from a single rock avalanche can be transported away quickly through a glacier system with a high mass turnover rate, and so any impact it may have on glacier mass balance should be quickly registered by the construction of a moraine with rock avalanche debris at the glacier snout.

But could a single large rock avalanche result in a significant response from the margin of a mountain glacier, especially if the avalanche event did not fully cover the glacier surface in debris? Additionally, could glacier advance initiated by such a rock avalanche be discerned in the landform record from a climatically driven advance? Contemporary reports of glacier advances in response to individual large rock slope failures are not common. But they do suggest a potential for non-climatic, short-term responses by glacier mass balance to rock avalanche input[1,7,10–12].

Tovar and co-authors have taken a novel approach to assessing the origin of end moraines in the ancient landform record, using New Zealand's widely cited Waiho Loop. Building on previous notions that the moraine is probably not related to the well-recorded Northern Hemisphere climate cooling of the Younger Dryas[13], they investigated the detailed lithology of the Waiho Loop. They conclude that the moraine consists of only one rock type, and that the shape of the debris lacks the signature that would be expected from subglacial transport. Because these characteristics are unusual for traditional end moraines, they propose that the material was derived from a single rock slope failure from Mount Roon, located on the true left side of the formerly more expansive Franz Josef Glacier.

As the proposed rock avalanche material is now contained entirely in a single steep-sided moraine ridge — the Waiho Loop — it follows that the impact on the mass balance must have been substantial and the throughput rate was swift. Throughput of ice continued, driven by the significant snow accumulation in the upper reaches of the glacier, and less of that throughput was lost in the ablation zone owing to the transient debris cover. A slower throughput would have resulted in a wider distribution of the rock avalanche debris on the valley bottom and its formation into a wide band of hummocky moraine.

The work by Tovar and co-authors explains why the Waiho Loop is the only isolated moraine ridge that is located inside the end moraine complexes from the Last Glacial Maximum on the New Zealand west coastal plains. An unlikely palaeoclimatic anomaly would be required to explain the advance of only one west-coast glacier at the time of its construction.

The study also reveals that Quaternary geologists have significantly underestimated the impacts of rock slope failures on glacier dynamics and on the glacial landform record. The spatial and temporal occurrence of glacier advances in the Quaternary Period triggered by rock avalanches and climatic changes, respectively, can be achieved with the simple but effective techniques reported here. Tovar and co-authors have delivered a timely reminder that it is unwise to invoke widespread palaeoclimatic events from small numbers of dated geomorphic features.

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ENVIRONMENTAL SCIENCE

Arsenic meets dense populations

In the South Asian lowlands, high population density coincides with dangerous levels of arsenic in groundwater. Maps based on surface geology can help identify regions at risk of arsenic contamination.

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The floodplains of the Tigris and the Euphrates, the Nile and the Indus allowed major civilizations to blossom, thanks to riverine soil nutrients that sustained high levels of agricultural production. It is therefore not by chance that deltas and floodplains of several South Asian rivers draining the Himalayas coincide today with some of the world's densest rural populations (Fig. 1a). However, sanitation hasn't kept up with population growth, resulting in widespread contamination of streams and ponds with microbial pathogens. In an effort to reduce infant mortality, a large fraction of the rural population in the region has switched to drinking groundwater instead of untreated surface water as it is typically not contaminated with microbial pathogens. But over the past two decades, groundwater contamination with geogenic arsenic has been discovered in a growing number of countries in the region. On page 536 of this issue, Winkel and coauthors[1] provide a map of South Asia that allows an initial assessment of the risk of arsenic contamination in areas that have so far largely been ignored.

Across floodplains of the Bengal Basin, groundwater is pumped by millions of private tubewells from water-logged sand deposits. The first signs of trouble appeared in the 1980s when K. C. Saha of the Institute for Tropical Medicine in Kolkata was shown skin lesions by numerous villagers from the Indian state of West Bengal and linked these to the high arsenic content of groundwater from shallow aquifers[2]. It took another decade of heroic efforts before government and international organizations recognized that natural contamination of tubewells with arsenic was a problem of even greater magnitude in Bangladesh[3].

On the basis of past exposure to arsenic in well water alone, a doubling of the lifetime mortality risk caused by cancers of the liver, bladder and lung has been estimated for Bangladesh[4]. There is also growing concern that arsenic exposure inhibits the mental development of children and could therefore have additional long-term impacts[5]. Tubewells have also proliferated in other depositional environments across South Asia where groundwater is easily extracted with inexpensive hand pumps. Surveys of Cambodia, China, Nepal and Vietnam indicate that groundwater from a significant proportion of these wells contain excessive levels of arsenic.

Winkel and colleagues address the crucial question of where else in the region rural populations may unwittingly be exposed to arsenic contained in groundwater. In a first calibration step, the study makes good use of existing arsenic data for Bangladesh, Cambodia, and Vietnam and compares them through a regression model with available maps of surface topography, geology and soil texture. The reasonable assumption is that surface properties reflect the environment under which underlying aquifers sands were deposited. A subset of these characteristics should then influence whether arsenic is released to the groundwater. The model does a reasonably good job at delineating where groundwater is likely to exceed the World Health Organization guideline for arsenic in drinking water of 10 $\mu g\ l^{-1}$, although it is not always clear to what extent and why some of the model input parameters contribute to the arsenic risk predictions.

The most novel part of the paper is the use of the calibrated relationship between surface topography and arsenic contamination risk to make predictions for hitherto largely untested areas in Myanmar, Thailand and the island of Sumatra in Indonesia. In the region of Sumatra, the authors tested their model by sampling close to one hundred wells in predicted high- and low-risk areas. As it turns out, the depth of the wells sampled in Sumatra extends to deposits over 10,000 years old. Therefore the proportion of wells that are high in arsenic, though still significant, is smaller than predicted. Similarly, the proportion of wells high in arsenic in the Chao Phraya basin of central Thailand is lower than predicted because these wells probably extend to older deposits that are less likely to release arsenic.

Myanmar is by far the largest new area of concern in terms of exposure to arsenic raised by Winkel and colleagues' study. The Irrawaddy delta supports a dense rural population (Fig. 1a) whose reliance on shallow tubewells, by analogy to Bangladesh, may increase rapidly in the future. The thickness of sediment in the submarine fan of the Irrawaddy delta is also the only one in the region approaching that of the adjacent Bengal Basin (Fig. 1b), suggesting that extensive high-risk deposits less than 10,000 years old could be present in the area.

In Bangladesh, over ten years after the scale of the problem was recognized, millions of villagers still drink groundwater with elevated levels of arsenic[6]. Blanket testing of existing wells has been the most effective form of mitigation to date because it has encouraged villagers to share the subset of wells that are low in arsenic[6,7]. To reduce arsenic exposure further, a market-driven mitigation effort is currently under discussion, involving the government, mobile phone operators, insurance companies, well drillers and universities. The idea is to provide households with the option of paying a modest premium to ensure reimbursement if a new well that is installed to the depth prescribed by available

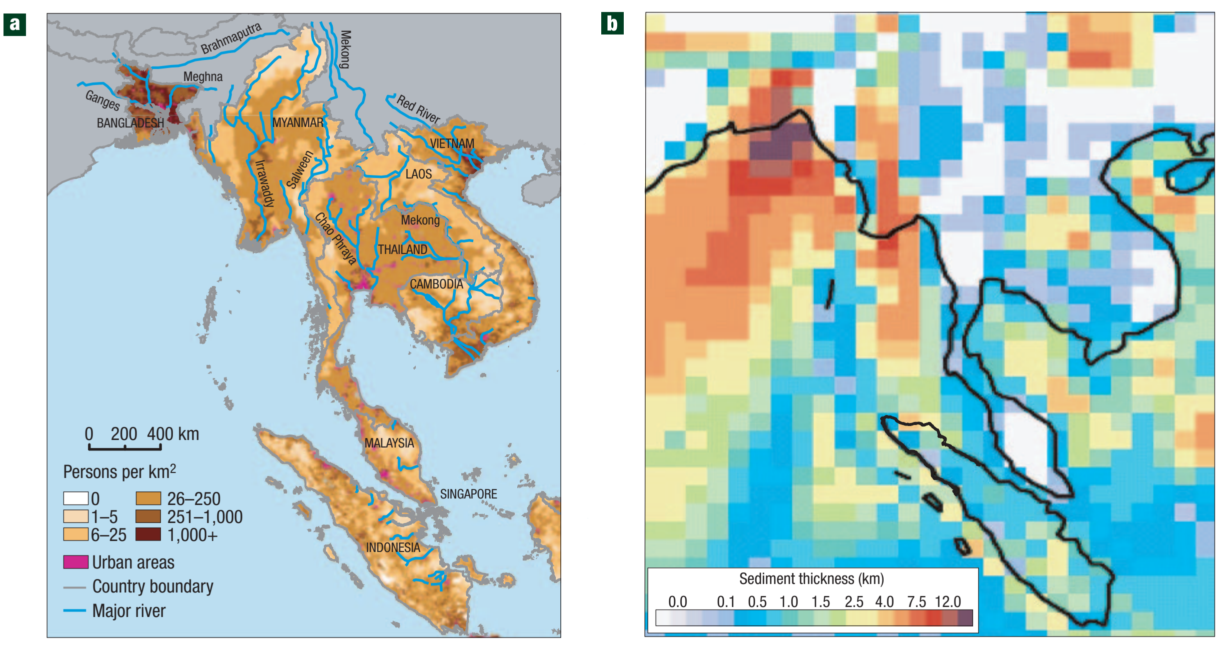

Figure 1 Population and arsenic risk in South Asia. **a**, Rural population density in the region studied by Winkel *et al.* Map created by Tricia Chai-Onn (CIESIN). Copyright 2008 The Trustees of Columbia University in the City of New York. Global Urban-Rural Mapping Project (GRUMP), Population Density and Urban Extents data sets are available at http//sedac.ciesin.columbia.edu/gpw/. **b**, Sediment thickness in the same region. Thick sedimentary layers on land and downstream on the sea floor suggest relatively young surface deposits, which are more likely to be contaminated with arsenic. In these regions, deeper drilling is likely to be needed to reach groundwater that is low in arsenic. Map prepared by Michael Steckler (LDEO) using data from http://mahi.ucsd.edu/Gabi/sediment.html (ref. 11).

data fails to yield low-arsenic groundwater. Dissemination of public health messages and exchange of arsenic data via mobile phones are key components of this approach.

Winkel *et al.* indicate, somewhat wistfully, that there is an urgent need to intervene and test shallow tubewells in the high-risk areas delineated by their map of Myanmar. But the recent response of the government of Myanmar to a natural hazard of a different nature, cyclone Nargis, suggests that a public information and testing campaign about arsenic in groundwater is unlikely to take off any time soon, even after more pressing issues are addressed in the Irrawaddy delta. And compared with the six mobile phone operators serving over 42 million mobile subscribers in Bangladesh, the single state-controlled mobile phone operator with a few hundred thousand subscribers in Myanmar provides nowhere near the same infrastructure for public information.

A modified approach worth exploring in Myanmar might be for non-governmental organizations to forge links with the numerous small teams of drillers who are contracted by households to install a well within a day. A key feature would be to widely distribute one of several suitable field kits for testing arsenic levels[8] to drillers and to train them to take advantage of patterns in the local depth-distribution of arsenic[9,10]. At the same time non-governmental organizations could inform households of the health hazards of arsenic exposure, creating an incentive for drillers to provide an improved service by offering the installation of low-arsenic wells.

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CLIMATE SCIENCE

Take the long view

STEVE AIREY

In the current crisis of credits and house prices, property owners with a mortgage may find a future commitment of over 25 years uncomfortably long. But a quarter of a century is nothing compared to our future commitment to climate change. Already on track to rising temperatures and sea levels, we need an idea of where we are heading.

Gian-Kasper Plattner and colleagues (*J. Clim.* **21,** 2721–2751; 2008) provide at least a broad sense of direction by simulating our commitment to future climate change with eight climate–carbon cycle models of intermediate complexity, assuming a number of different scenarios for future carbon dioxide emissions. In all the scenarios, atmospheric carbon dioxide concentrations are either constant or in decline after the end of the 21st century, providing us with an idea of how long the effects of carbon dioxide emissions will linger after atmospheric concentrations have stabilized.

Perhaps the most striking result is that the year AD 3000 — the time limit of the simulations — is apparently too close in time for a full assessment. Even in the highly unlikely event that anthropogenic emissions stop in the year 2100, 15–28% of the carbon dioxide emitted through human activity since the industrial revolution will still be airborne 900 years later. For a stabilization of atmospheric carbon dioxide concentrations at 750 p.p.m.v. — a goal that looks achievable if not desirable from today's point of view — temperatures start declining fairly soon after stabilization, but they do so very slowly. Even worse, the sea level rise resulting from thermal expansion alone (that is, not taking into account meltwater from the Greenland ice sheet or elsewhere) does not come to a halt by the year 3000 in some of the models.

These findings reflect the huge inertia of the climate system. The rapid change in the composition of the atmosphere over the past century has shaken the system out of equilibrium. The slower components, such as the oceans, will catch up only in the long run. Eventually, the global carbon cycle will redistribute the carbon (if the carbon dioxide doesn't keep coming faster than it can be mopped up), but it may take thousands if not tens of thousands of years.

Getting the carbon cycle right in the models is therefore crucial for investigating climate change on a long time horizon. Unfortunately, important details are still under debate. The uncertainties associated with different but equally plausible assumptions, for example regarding carbon cycle–climate feedbacks and terrestrial fertilization of plants by atmospheric carbon dioxide, significantly affect the quantitative outcomes of the simulations.

In addition, it is impossible to predict which way technological development will take us over the next century or so: who, in 1908, would have thought that carbon dioxide emissions from automobiles would present a problem in 2008?

It is therefore hard to say how long it will be until sea level rise means that the Thames Barrier (see image) cannot protect London from flooding any more. When the time comes, house owners in the lower reaches along the Thames will have to fear for the value of their property once more. The impacts in less wealthy parts of the world will be far more severe.

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