However, earlier experiments designed to investigate the mechanisms of microbial mercury uptake were performed using non-methylating microorganisms (*Vibrio anguillarum* and *Escherichia coli*)[5,6], and therefore may or may not provide insight into mercury uptake in mercury-methylating organisms. Experiments with the sulphate-reducing bacterium *Desulfobulbus propionicus* (a methylating microorganism) have shown that mercury methylation is enhanced in the presence of mercury sulphide[7], indicating that mercury uptake occurs passively in this organism. Thus, the jury is still out on the precise and potentially species-specific mechanism of mercury uptake.

Now, in a series of laboratory experiments, Schaefer and Morel[1] investigate mercury uptake and methylation in the iron-reducing, mercury-methylating bacterium *G. sulfurreducens*. They show that the amount of inorganic mercury taken up by these bacteria, together with their rate of mercury methylation, is higher in the presence of the amino acid cysteine, and suggest that the formation of a mercury–cysteine complex (a hydrophilic organothiol complex) facilitates mercury uptake in these methylators. They go on to show that methylation is not enhanced in the presence of other, similar-sized hydrophilic organothiols, such as glutathione, dithioerythritol or penicillanime, suggesting that other hydrophilic mercury–organothiol complexes do not have the same effect. Such a compound-specific response is characteristic of a protein-mediated uptake system, as they are expected to be highly substrate-specific. Thus, the results indicate that *G. sulfurreducens* may be actively taking up the mercury–cysteine complex. In contrast to the results obtained with *D. propionicus*[7], mercury methylation in *G. sulfurreducens* was not enhanced in the presence of mercury sulphide, indicating that the principal mechanism of mercury uptake differs in these two organisms.

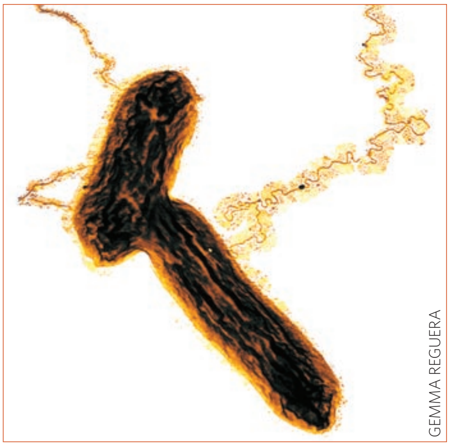
GEMMA REGUERA

Figure 1 | *Geobacter sulfurreducens*; mercury uptake and methylation by this bacterium are significantly increased in the presence of the amino acid cysteine, according to Schaefer and Morel[1].

The genome of *G. sulfurreducens* has been sequenced[8] and is amenable to genetic manipulation[9]. As a next step, one may be able to confirm genetically whether specific transport proteins are indeed important for the uptake of inorganic mercury under specific growth conditions in this organism.

For now, the results of Schaefer and Morel[1] suggest that the mechanisms of mercury uptake are highly diverse and under tighter biological control than previously thought. A more precise understanding of the specific mechanisms involved in mercury uptake may lead to novel approaches when it comes to the mitigation of mercury methylation in the environment. ❐

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References

1. Schaefer, J. K. & Morel, F. M. M. *Nature Geosci.* 2, 122–126 (2009).
2. Morel, F. M. M., Kraepiel, A. M. L. & Amyot, M. *Ann. Rev. Ecol. Syst.* **29,** 543–566 (1998).
3. Compeau, G. C. & Bartha, R. *Appl. Env. Microbiol.* **50,** 498–502 (1985).
4. Kerin, E. J. *et al. Appl. Environ. Microbiol.* **72,** 7919–7921 (2006).
5. Golding G. R. *et al. Environ. Sci. Technol.* **41,** 5685–5692 (2007).
6. Golding, G. R., Sparling, R. & Kelly, C. A. *Appl. Environ. Microbiol.* **74,** 667–675 (2008).
7. Benoit, J. M., Gilmour, C. C. & Mason, R. P. *Appl. Environ. Microbiol.* **67,** 51–58 (2001).
8. Mathé, B. A. *et al. Science* **302,** 1967–1969 (2003).
9. Coppi, M. D. *et al. Appl. Environ. Microbiol.* **67,** 3180–3187 (2001).

GLACIOLOGY

From the front

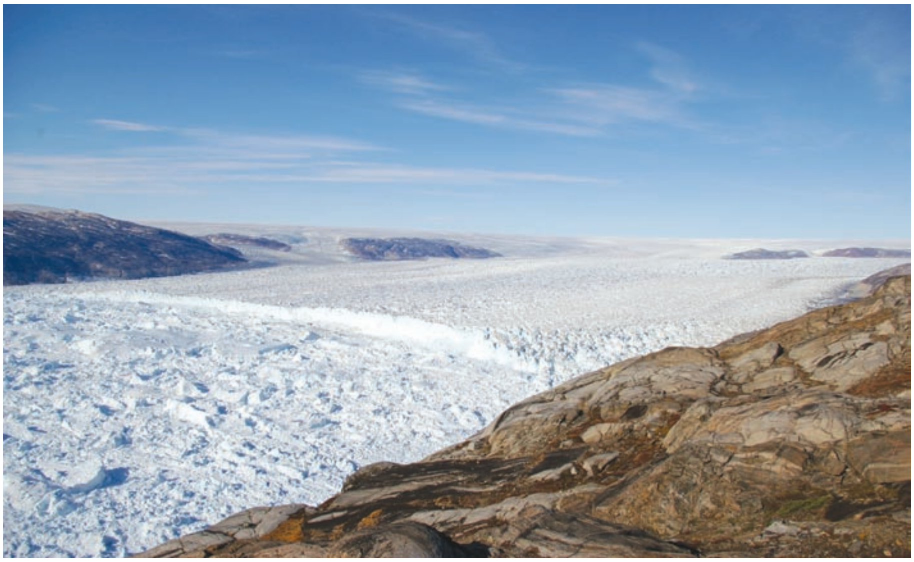
The causes of recent dynamic thinning of Greenland's outlet glaciers have been debated. Realistic simulations suggest that changes at the marine fronts of these glaciers are to blame, implying that dynamic thinning will cease once the glaciers retreat to higher ground.

Stephen Price

For the past decade, many outlet glaciers in Greenland that terminate in the ocean have accelerated, thinned and retreated. To explain these dynamic changes, two hypotheses have been discussed. Atmospheric warming has increased surface melting and may have also increased the amount of meltwater reaching the glacier bed, increasing lubrication at the base and hence the rate of glacier sliding[1]. Alternatively, a change in the delicate balance of forces where the glacier fronts meet the ocean could trigger the changes[2-4]. On page 110 of this issue, Faezeh Nick and colleagues[5] present ice-sheet modelling experiments that mimic the observations on Helheim glacier, East Greenland, indicating that the dynamic behaviour of outlet glaciers follows from perturbations at their marine fronts.

Greenland's ice sheet loses mass partly through surface melting and partly through fast-flowing outlet glaciers that connect the vast plateau of inland ice with the ocean. As the outlet glaciers flow into the sea, icebergs calve from their fronts. As highlighted in the fourth assessment report of the Intergovernmental Panel on Climate Change[6], earlier ice-sheet models have failed to reproduce the dynamic variability shown by ice sheets over time. It has therefore not been possible to distinguish with confidence between basal lubrication from surface meltwater and changes at the glaciers' marine fronts as causes for the observed changes on Greenland's outlet glaciers.

The distinction bears directly on sea- level rise — the motivation for much of modern-day glaciology. If the recent dynamic mass loss from Greenland's outlet glaciers is linked to changing atmospheric temperatures, it may persist for as long as



GORDON HAMILTON

Figure 1 | The calving front of Helheim Glacier, East Greenland. Numerical modelling by Nick *et al.*[5] successfully mimics the pattern of acceleration, thinning, retreat and stabilization observed on this large outlet glacier from ~2002–2006, providing strong support for the contention that perturbations at the marine calving front were responsible for its behaviour over that period of time.

temperatures continue to increase. However, if the source of the dynamic mass loss is a perturbation at the ice–ocean boundary, these glaciers will lose contact with that perturbation after a finite amount of thinning and retreat. Therefore, the first hypothesis predicts continued retreat of outlet glaciers into the foreseeable future, whereas the second does not — provided the bedrock topography prohibits a connection between the retreating glacier and the ocean.

Nick and colleagues[5] tested the physical mechanisms of each hypothesis in an innovative ice-flow model, and used that model to match a time series of observations from Helheim glacier, one of Greenland's three largest outlet glaciers (Fig. 1). They found that a reduction in resistance at the glacier front — which might result, for example, from the loss of a floating ice-tongue or a change in calving rate — triggers glacier behaviour in the model that is in broad agreement with observations[7] from 2001–2006. Importantly, the model captures the observed pattern of a relatively minor initial acceleration, followed by more rapid acceleration and thinning as the glacier terminus retreats into deeper water across a bedrock low, and subsequent deceleration and stabilization as the glacier retreats into shallower water. In contrast, for experiments where basal lubrication was altered to simulate increased sliding from meltwater input, the modelled velocity and geometry show little similarity to the observations.

Along with many observations[2–4,7–10], Nick and colleagues' simulations strongly support the contention that the recent retreat of Greenland's outlet glaciers is the result of changes at their marine fronts. Furthermore, the simulations confirm the earlier hypothesis[7] that bedrock topography largely controlled Helheim glacier's rapid acceleration and retreat in 2004 and 2005, and its deceleration and stabilization in 2006. Finally, the current work indicates that, if requirements of observational data (high-resolution bedrock topography) and computational resources (fine computational grid resolution) can be met, improved predictive capability for ice-sheet models is attainable. With respect to the concerns raised by the Intergovernmental Panel on Climate Change, this study signals progress.

Regarding ice-sheet stability and sea-level rise, two important conclusions can be drawn from the simulations. First, peak discharge rates associated with the acceleration of Greenland's outlet glaciers could be short-lived. As these glaciers adjust quickly, 'snapshots' of Greenland's mass balance[11] that include these transient peaks are not necessarily indicative of Greenland's long-term contribution to sea level. The authors suggest that the competition between accumulation and melting, and not the dynamics of outlet glaciers, may be the primary control on Greenland's future state of balance.

Perhaps more importantly, the simulations confirm the validity of the so-called marine ice-sheet instability[12,13] — a long-standing concern in glaciology. According to this hypothesis, if a glacier rests on bedrock below sea level that slopes downwards inland, its retreat into deeper water will be reinforced by acceleration and thinning until the bedrock slope reverses (and the glacier encounters shallower water) or until some other 'braking' mechanism halts its retreat. In the case of Helheim glacier, retreat was halted in 2006 by a combination of shallower water and the re-establishment of a floating ice-tongue that provides some resistance to flow[5,7]. If this had not occurred, Nick and colleagues show that shoaling bedrock topography would have stopped the retreat several tens of kilometres farther inland.

In Greenland, there are only a few places where the bedrock topography remains below sea level far inland from the coast. Therefore, according to the work by Nick and colleagues, for most of Greenland's outlet glaciers, dynamic mass losses are expected to be short-lived. One exception is beneath Jakobshavn Isbræ, Greenland's largest outlet glacier, where a deep bedrock trough extends far into the ice-sheet interior. Interestingly, and perhaps not coincidentally, Jakobshavn Isbræ continues to accelerate, thin and retreat to this day[14].

In Antarctica, the story is quite different. Here, many hundreds of thousands of square kilometres of the ice sheet rest on bedrock below sea level. The combination of the observations in Greenland and the matching model simulations by Nick and colleagues[5] indicate that the potential for large-scale ice-sheet instability in Antarctica is indeed real. ❐

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References

1. Zwally, H. J. *et al. Science* **297,** 218–222 (2002).
2. Thomas, R. H. *et al. J. Glaciol.* **49,** 231–239 (2003).
3. Thomas, R. H. *J. Glaciol.* **50,** 57–66 (2004).
4. Joughin, I., Abdalati, W. & Fahnestock, M. *Nature* **432,** 608–610 (2004).
5. Nick, F. M., Vieli, A., Howat, I. M. & Joughin, I. *Nature Geosci.* **2,** 110–114 (2009).
6. IPCC. *Climate Change 2007: The Physical Basis* (Cambridge Univ. Press, 2007).
7. Howat, I. M., Jougin, I. & Scambos, T. A. *Science* **315,** 1559–1561 (2007).
8. Joughin, I. *et al. Science* **320,** 781–783 (2008).
9. Holland, D. M., Thomas, R. H, Young, B. D., Ribergaard, M. H. & Lyberth, B. *Nature Geosci.* **1,** 659–664 (2008).
10. Sole, A., Payne, A., Bamber, J., Nienow, P. & Krabill. W. *Cryosphere* **2,** 205–218 (2008).
11. Rignot, E. & Kanagaratnum, P. *Science* **311,** 986–990 (2006).
12. Weertman, J. *J. Glaciol.* **13,** 3–13 (1974).
13. Schoof, C. *J. Geophys. Res.* **112,** F03S28 (2007).
14. Joughin, I. *et al. J. Geophys. Res.* **113,** F04006 (2008).