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GLACIOLOGY

Lubricating lakes

Jack Kohler

More than 150 subglacial lakes have been discovered beneath the Antarctic ice sheet. The four most recent additions, found right at the start of fast flow in a large ice stream, suggest that the lakes influence ice dynamics.

Antarctica is well known as the coldest place on Earth, but it is also surprisingly wet. Whereas the upper part of the ice is cold, geothermal heat and the insulating effect of the overlying ice combine towards its base to bring extensive areas of ice at the bed to its melting point. In the most extreme cases, lakes form beneath the ice sheet. In the past 20 years more than 150 such subglacial lakes have been discovered; Lake Vostok, at 15,690 km^2 about three-quarters the size of Wales, is the largest and best known[1]. As satellites provide better coverage and higher-resolution imagery of the Antarctic ice sheet, more and more such lakes are being found. On page 904 of this issue, Bell *et al.*[2] present satellite and ground data that reveal four additional lakes in Dronning Maud Land (sometimes referred to in English as Queen Maud Land), East Antarctica. These lakes are remarkable not only for their size, but also for their location, which is just where the flow of the ice sheet begins to accelerate.

Investigations of the base of the Antarctic ice sheet began in the 1960s, when glaciologists used ground-based and airborne radars to map the ice's thickness. Ice is transparent to radar over a wide range of frequencies, so the boundary between ice and bedrock is readily detected, even through several kilometres of ice. Water reflects radar energy more strongly than rock, making it easy to identify those parts of the bed that are wet. Early on, very bright radar reflections delineating a relatively flat boundary were recognized as the distinctive signature of subglacial lakes. The largest subglacial lakes can also be detected using remote sensing: the surface topography above lakes is unusually flat (Fig. 1).

Subglacial lakes were initially thought to be essentially stagnant, with water moving into or out of them at a trickle. But our view of the Antarctic basal drainage system has changed profoundly in light of recent observations. First, satellite radar altimetry data from East Antarctica revealed that the ice surface had dropped suddenly in one area while simultaneously rising at another location hundreds of kilometres away[3,4]. This drainage event, in which large amounts of water had flowed from one subglacial lake to another, occurred over the relatively short period of about 16 months. Laser altimetry data from the West Antarctic ice streams have since exposed a rich variety of lake drainage events, a veritable roiling of the ice surface up and down as water is squeezed from one part of the ice stream to another[5].

Bell *et al.*[2] supply the latest evidence for a link between subglacial water and the dynamics of the ice sheet above. The four subglacial lakes that they have discovered are in the drainage basin of the Recovery Glacier ice stream, which empties into the Filchner Ice Shelf off Antarctica at a longitude of about 30° W. These Recovery lakes are not only located in a part of the continent with relatively few known lakes, but they are also very large; two are exceeded in size only by Lake Vostok. What is most interesting about the Recovery lakes, however, is that they sit at the upstream end of one of the largest of the ice streams that drain the interior ice of the high polar plateau, just where ice velocities start to increase. Upstream of the lakes, the ice sheet moves at a leisurely 2–3 metres per year; downstream of the lakes it suddenly flows at about 50 m yr^{-1} towards the Filchner Ice Shelf, and eventually into the Weddell Sea.

So how exactly does water underneath an ice sheet affect ice dynamics? As ice flows over a lake, the friction at its base vanishes and its speed increases (see Fig. 1). Furthermore, the freezing of lake water on the underside of the ice sheet adds thermal energy to the basal ice. This prevents the ice from freezing onto the bedrock when it hits the ground again, and also allows faster flow, as warm ice is much softer than cold ice. Nevertheless, for most of the subglacial lakes discovered so far, the surrounding ice apparently buttresses the ice over the lake and prevents faster flow. Bell *et al.* suggest that the location of the Recovery lakes at the onset of a fast-flowing ice stream provides the first evidence that subglacial hydrology could be responsible for the initiation of an ice stream,

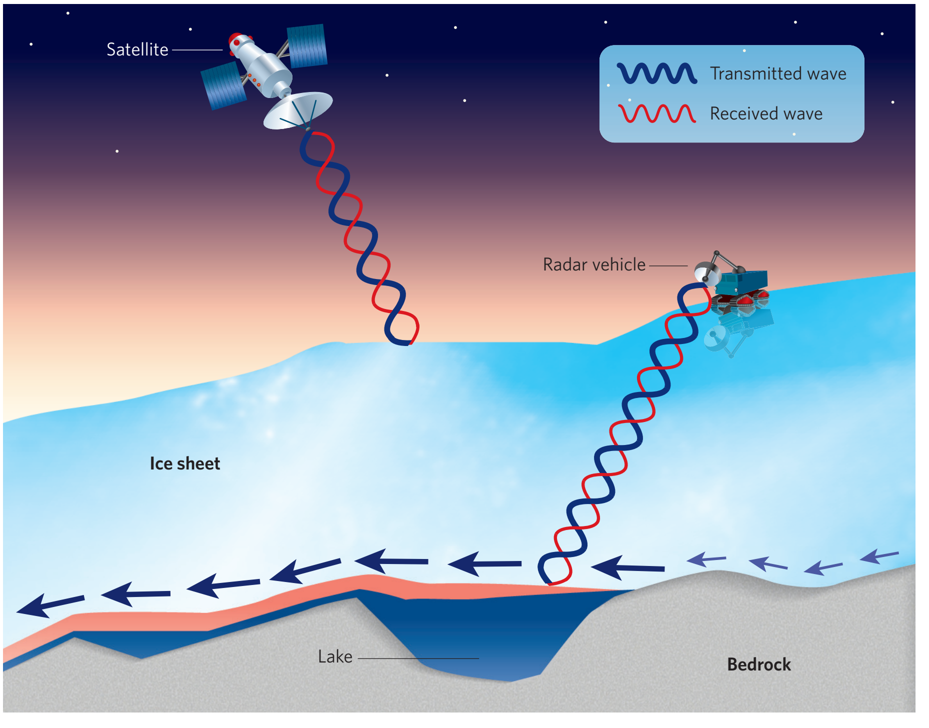

Figure 1 | Slippery slope. The relative strength of reflection of ground-based radar distinguishes between bedrock and water at the base of an ice sheet, and the characteristic flat area in the ice surface above a subglacial lake can be detected by satellite-based surface observations. Using satellite measurements, Bell *et al.*[2] find four subglacial lakes right at the onset of fast ice flow at the Recovery Glacier ice stream in Dronning Maud Land, Antarctica. They propose that the freezing of lake water to the base of the ice sheet (pink area), together with water spilling over from the lake and scouring the bedrock, could reduce friction and help speed up ice flow towards the sea.

either by changing the ice sheet's basal thermal regime or by introducing water into the path of the ice stream through periodic drainage events.

If this proves to be the case, it would substantially change our understanding of the effect of subglacial lakes on ice-sheet stability. It indicates that basal hydrology needs to be accounted for in numerical models of ice-sheet motion because it has the potential to rapidly induce fast flow. The recent sudden acceleration of ice streams in Greenland[6,7], and its resultant effect on the mass balance of the Greenland ice sheet[8], underscores the importance of understanding the dynamics of ice-sheet response to climatic change.

Might the geographical coincidence of the Recovery lakes and the start of fast flow be just that, a coincidence? So far we have not seen any other large subglacial lakes at the heads of ice streams. But Antarctica remains one of the most poorly mapped parts of our planet — we know more about the surface of the dark side of the Moon than we do about the bedrock or even the surface topography of Antarctica. Antarctica's surface is being mapped at ever higher resolution with remote-sensing satellites such as NASA's ICESat or the planned European Space Agency mission CryoSat-2, but radar imaging of the bedrock is not keeping pace. Proposed missions to put ice-sounding radar instruments on board a satellite, with the goal of mapping the bed in Greenland and Antarctica, have yet to be approved. For now, continued airborne and ground-based geophysical exploration is the only way forward for imaging the ice sheet's base.

During the forthcoming International Polar Year, a number of land traverses and aerial campaigns are planned for Antarctica. In 2008, a Norwegian–US traverse will survey the Recovery lakes area. This was last visited by the US–UK traverse from the South Pole to Dronning Maud Land in 1965–66. Interestingly, that early expedition, which was equipped with one of the first radars, also crossed over the lakes discovered by Bell and colleagues (Fig. 2). The radar equipment was relatively primitive and used only intermittently, so the lakes were not identified in the field. But a logbook duly noted that Gordon de Q. Robin, then head of the Scott Polar Research Institute in Cambridge, UK, and one of the pioneers of radar glaciology, had suggested the existence of a "…possible melt-layer at the bottom of ice cap".

The implications of this early prediction for ice flow are just starting to be appreciated, as Bell *et al.*[2] make the link between subglacial lakes and the onset of one of the largest ice streams in Antarctica. ■

W. ISHERWOOD

Figure 2 | Scenes from above the shores of the Recovery lakes. **The 1965–66 US–UK South Pole–Queen Maud Land traverse, showing a Sno-Cat tractor and, in the background, a 'rolly' tyre set containing fuel, and the ice-sounding radar antennae. The tractor is just crossing a crevasse at the edge of the Recovery ice stream, near where Bell *et al.*[2] have now discovered four subglacial lakes.**

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PHYSICAL CHEMISTRY

Oil on troubled waters

David Chandler

The nature of the boundary between water and oil is crucial to many nanometre-scale assembly processes, including protein folding. But until now, what the interface really looks like remained in dispute.

At the boundary between liquid water and water vapour, an interface forms that is marked by an area of lower-than-average density. The same sort of 'depletion layer' also occurs when water comes into contact with a sufficiently large hydrophobic surface — oil, in the most notorious instance, and various other organic molecules. According to theory, this happens because hydrophobic surfaces provide no opportunity for water molecules to establish their usual hydrogen bonds. Without this adhesive force, the molecules move away from the surface to seek such bonds in the bulk of the liquid.

As lucid as this explanation might seem, experimental confirmation has so far been surprisingly elusive. But at last two independent groups of researchers — Poynor *et al.*[1], writing in *Physical Review Letters*, and Mezger *et al.*[2], writing in *Proceedings of the National Academy of Sciences* — provide experimental confirmation of a depletion layer at the interface between water and a hydrophobic surface. And calculations of the molecular dynamics of water confined by two surfaces with nanometre-scale patterns of hydrophobic and hydrophilic regions, described by Giovambattista *et al.*[3] in the *Journal of Physical Chemistry C*, provide further grist to the mill.

The prediction that liquid water borders with oil in the same way it does with vapour was first made more than 30 years ago[4]. Since then, the idea has been bolstered by further theoretical analysis[5], and has helped in understanding the forces that stabilize the assembly of hydrophobic molecules, among them the