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CLIMATE SCIENCE

Ice streams waned as ice sheets shrank

It emerges that ice discharge from a major ice sheet did not increase rapidly at the end of the most recent ice age. The finding points to steady, not catastrophic, ice-sheet loss and sea-level rise on millennial timescales. SEE LETTER P.322

JASON P. BRINER

Ice sheets and the global sea are locked in a tug of war for water in which climate change dictates which side gains or loses ground. Mindful that tug-of-war contests often end with the catastrophic collapse of one side, climate scientists are deeply concerned about the manner in which ice sheets are currently declining[1]. This concern is largely focused on mechanisms that amplify ice loss, such as the acceleration of ice streams — massive rivers of ice that drain a disproportionately large amount of ice from ice sheets[2] (Fig. 1). On page 322 of this issue, Stokes *et al.*[3] present the first complete reconstruction of ice-stream activity throughout the disintegration of an ice sheet.

A fleet of geoscientists scattered across the poles, along with satellites in space, watches every move that ice streams make in Greenland and the Antarctic[4]. This work matters because ice streams are the valves that control the enormous volumes of ice poised to spill into the oceans and cause a rapid jump in sea level. But the duration of these observations (tens of years) has been short compared with the time that it takes for substantial ice-sheet changes to occur (hundreds to thousands of years).

One way to gauge ice-stream activity on longer timescales is to use the geological record — in sediments and landforms — of past ice streams that left their imprint on formerly glaciated landscapes. Over the past two decades, Stokes and his co-workers have greatly advanced the methods used to assemble scraps of evidence left behind by extinct ice streams and to generate histories of ice-stream activity[5]. The present study builds on this foundation and on the established chronology of ice-sheet positions through time[6].

Stokes *et al.* evaluate the importance of ice streams at the end of the most recent ice age, when a tug of war also played out between ice sheets and the ocean. Their evidence shows that ice streams turned on and off, and shifted from place to place, during the disappearance of the Laurentide Ice Sheet — the Antarctic-sized ice sheet that occupied Canada and the northern United States at that time. Perhaps most notably, Stokes and colleagues find that ice-stream activity decreased as the planet warmed: the number of ice streams fell, the amount of ice expunged by them decreased and ice streams occupied a progressively smaller percentage of the ice-sheet edge.

The authors' findings represent a leap forward in our view of ice-stream activity on timescales longer than a few decades. Until now, we were in the dark about how ice streams respond to ice-sheet decay. Would excessive ice streaming lower the elevation of ice sheets, thus robbing ice-accumulation centres of their elevated positions (which are good for gathering snow that compresses to form ice), and

CANADIAN SPACE AGENCY, 1997, PROCESSED BY ASF DAAC & OSU

Figure 1 | An Antarctic ice stream. Fast-moving rivers of ice, such as the Byrd Glacier (pictured) are known as ice streams, and drain a disproportionately large amount of ice from ice sheets. Stokes *et al.*[3] report a complete reconstruction of ice-stream activity throughout the disintegration of the ancient Laurentide Ice Sheet.

triggering catastrophic ice-sheet collapse? Does the additional meltwater that forms during periods of warming lubricate ice streams, causing them to discharge ice faster for prolonged periods? Stokes and co-workers' results suggest not.

However, the relevance of these findings to future ice-sheet behaviour is not totally clear, because the Laurentide Ice Sheet is not an exact analogue of today's ice sheets. For example, much of the Laurentide (including the ice streams embedded in it) terminated on land, whereas ice streams within the Greenland and Antarctic ice sheets terminate in the sea. Furthermore, present-day ice streams are largely 'fixed' in space by the mountains through which they pass[7], and therefore could flow for thousands of years. This differs from the many Laurentide ice streams that were not confined by the underlying landscape, and thus were typically more ephemeral.

Predicting the pace of future ice loss and sea-level rise is an enormous challenge. With their improved sophistication, numerical ice-sheet models have led to great strides in our understanding of how quickly ice sheets may vanish in the future, particularly marine-based ice sheets such as the West Antarctic Ice Sheet[8,9]. Stokes and co-workers' strategy of extracting data from relict ice-age landscapes provides a new viewpoint. As the Greenland Ice Sheet, and particularly the East Antarctic Ice Sheet, eventually retreat from the ocean, the Laurentide Ice Sheet becomes more closely analogous to them. Continued effort is needed to discover other secrets hidden in the palaeo-record of ice-sheet response to past climate change.

The current findings may not provide guidance about ice-stream changes during this century, but they will help us to predict the pace of long-term ice-sheet disappearance. And although ice sheets will inevitably lose the current tug of war, it is reassuring to know that the competition might not end catastrophically. ■

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CELL BIOLOGY

Form follows function for mitochondria

The fission of organelles called mitochondria has now been linked to the stress-sensor protein AMPK. When activated by stress, this protein phosphorylates the mitochondrial receptor protein MFF, which recruits the fission machinery.

CHUNXIN WANG & RICHARD YOULE

The architect Louis Sullivan wrote that, for all things, "form ever follows function". In keeping with this rule, energy-producing organelles called mitochondria exist in different forms in different cell types[1,2] and under different conditions[3]. Long, contiguous assemblies of mitochondria promote energy production, whereas stress causes their fragmentation into small, round, disconnected units. Mitochondria switch between these two forms through rounds of fission and fusion[4]. Writing in *Science*, Toyama *et al.*[5] identify a signalling pathway that triggers the fission of long mitochondrial assemblies in response to stress.

The energy status of a cell can be measured by the ratio of AMP molecules (an end product of chemical-energy expenditure) to energy-carrying ATP molecules in the cytoplasm. Mitochondria produce ATP in response to energy depletion. One sensor of energy depletion is an evolutionarily conserved protein known as AMP-activated protein kinase (AMPK). This protein is activated by binding AMP or by stresses that deplete ATP and increase the AMP:ATP ratio, such as glucose deprivation, inadequate blood supply and lack of oxygen[6].

Activation of AMPK enhances the production of mitochondria and improves endurance — indeed, the use of drugs that activate AMPK, such as AICAR, is banned from competitive sports by the World Anti-Doping Agency. AMPK phosphorylates several substrates[6], thereby regulating metabolism, mitochondrial proliferation and an intracellular degradation process called autophagy. However, previous studies have not demonstrated whether AMPK directly regulates mitochondrial form.

Researchers have known for years[7] that mitochondria undergo fission and become fragmented in response to poisons such as cyanide, which damage the organelles by inhibiting the electron transport chain (ETC) that drives ATP synthesis. But how such mitochondrial dysfunction is sensed, and how it triggers a rapid fission response, has remained unclear.

Toyama *et al.* found that AMPK is rapidly activated in response to the ETC-inhibiting drugs rotenone and antimycin A, presumably as a consequence of an increased AMP:ATP ratio. Mitochondria became fragmented in drug-treated cells, but this response was prevented by deletion of the gene that encodes AMPK. By contrast, pharmacological activation of AMPK with AICAR was sufficient

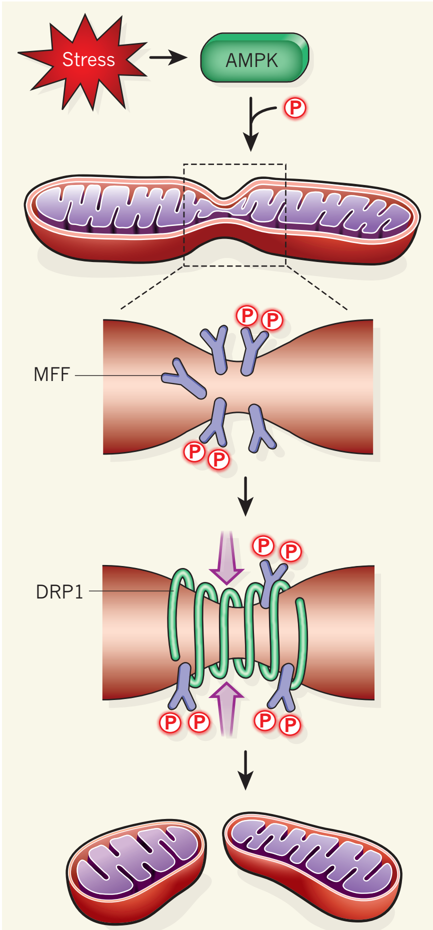

Figure 1 | The stress of separation. Mitochondria, which are the cell's energy centres, sometimes exist in fused assemblies that can be fragmented in response to stress. The receptor protein MFF is located on the outer membrane of such assemblies, at putative separation sites. Toyama *et al.*[5] report that, when activated in response to stress, the enzyme AMP-activated protein kinase (AMPK) phosphorylates (P) MFF, which then recruits the protein Dynamin-related protein 1 (DRP1) to the membrane. DRP1 forms constricting spiral complexes around the mitochondria, mediating fission.