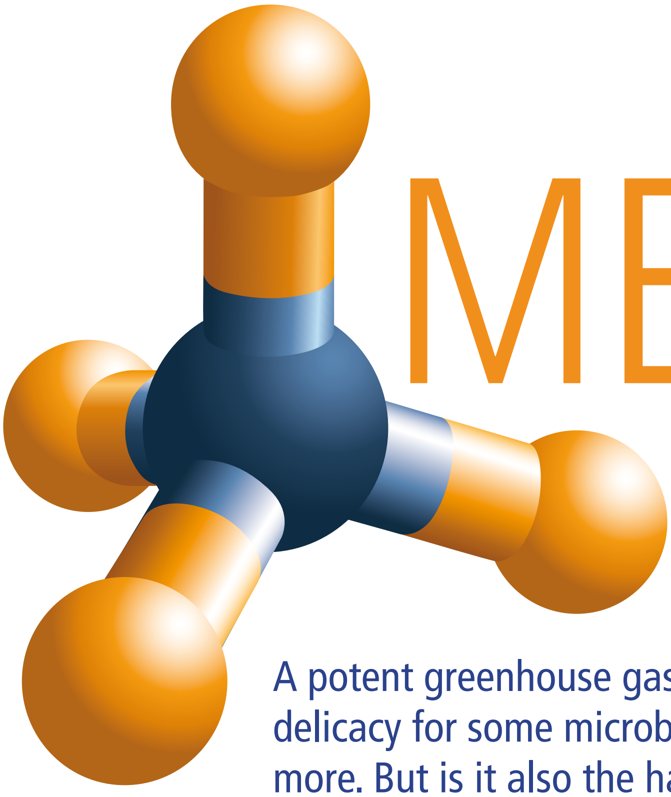

METHANE

NOT A DAMP SQUIB, NOT YET A TIME BOMB

A potent greenhouse gas, an energy source, a culinary delicacy for some microbes – methane is all of these and more. But is it also the harbinger of impending catastrophe? There's no smoking gun, finds **Ninad Bondre.**

About 55 million years ago, at the beginning of the Eocene epoch, the planet experienced a hot flash that was to last for over 100 millennia. The finger of suspicion points to a dramatic perturbation of Earth's carbon cycle. What sustained the warming, many researchers say, were massive methane emissions from ice-like compounds called methane hydrates (or clathrates). Such compounds are normally stabilised in marine sediments or beneath frozen ground onshore. During the earliest Eocene, something – and we don't know what exactly – destabilised the hydrates, releasing prodigious quantities of methane.

As a greenhouse gas, methane is rather potent, but it lasts in the atmosphere for only about a decade before oxidising to carbon dioxide. A sudden large release or a more subdued but continuous release of methane would strengthen the greenhouse effect and warm the Earth's surface. This could, in turn, put in motion processes that reinforce the warming (Figure 1). As the saga of the Anthropocene unfolds, the stability of methane hydrates and other methane sources is back in focus, as is the potential for a giant methane outburst. Unlike the earliest Eocene, we know well what the modern trigger might be: Arctic warming.

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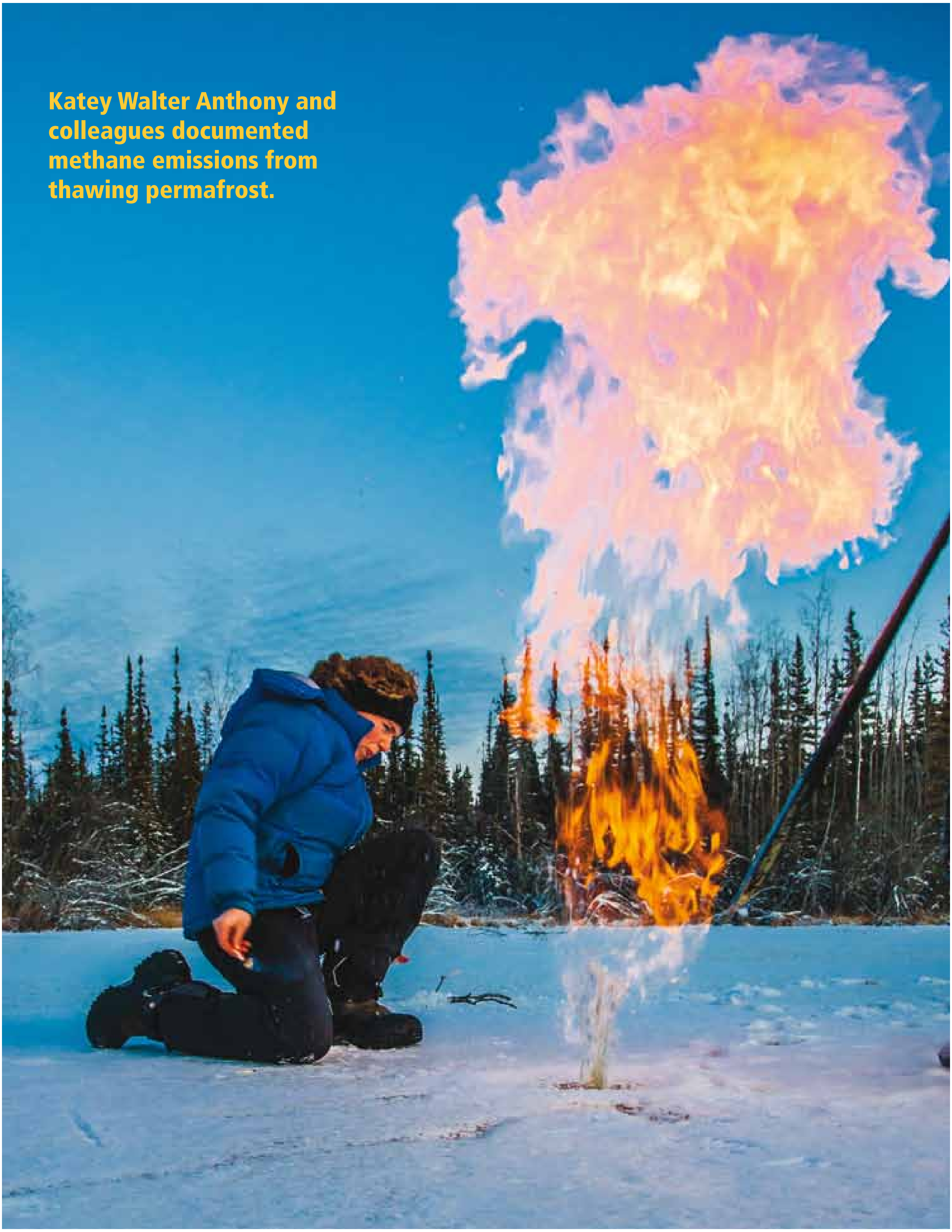
In recent years, a number of scientific and popular articles and blogs have explored the consequences of catastrophic methane release. Attempts to calm the nerves have so far done little to quell the unease. Arctic sea-ice extent this summer was the lowest in the satellite era, a fact that will only add to the unease. The Arctic Methane Emergency Group, for example, perceives the situation to be dire enough to call for urgent measures to cool the Arctic. A slew of possible geoengineering solutions – from cloud removal to injecting aerosols into the atmosphere – have been proposed as candidates to deal with an emergency.

The Arctic connection

Hydrates form when methane gas and water combine at low temperature and moderate pressure, conditions most likely to occur several hundred metres beneath water and/or sediments. The methane itself results from the microbial decomposition or deep burial and/or heating of organic matter. The amount of hydrates stored in the Arctic region is not well constrained but is estimated to be on the order of several hundred billion tons of carbon and possibly more. These occur in deep marine sediments, on the continental slopes and beneath the permafrost on land. They also occur beneath the remnant permafrost on shallow continental shelves that have been flooded during the past 15,000 years of sea-level rise. Hydrates in the deep marine sediments are not considered to pose a risk for at least the coming hundreds of years.

Until recently, the permafrost onshore and on continental shelves was thought to serve as a fairly effective seal. So much so



University of Alaska Fairbanks/Todd Paris.

that hydrates in the underlying sediments received little attention in discussions of the modern methane cycle. Indeed, methane from hydrates probably makes up a very small fraction of the current atmospheric concentration of about 1800 parts per billion of methane. But recent observations from the remote East Siberian Arctic Shelf (ESAS) by Irina Shakhova and colleagues point to perforations in the seal. In a 2010 *Science* paper, the researchers reported the widespread release of methane from marine sediments to the overlying ocean water and atmosphere. More recently, Shakhova's research group presented the findings of its latest fieldwork at two major conferences, drawing attention to even more extensive releases.

The ESAS was once a frozen tundra landscape that was gradually submerged as sea levels rose at the end of the last ice age. For thousands of years, it has been exposed to conditions very different from those under which it formed. Shakhova and colleagues contend that this has made it more susceptible to recent warming; it is now beginning to thaw. The warming would probably accelerate if the relentless decline of summer sea ice were to continue (see page 8 of this issue). At the moment, though, it remains unclear how long the region has been emitting methane at the rates reported recently. The link between Arctic warming and the observed release is yet to be firmly established. We also do not have a good handle on how the emissions will respond to future climate change.

Hydrates are not the only source of methane in the region. Walter Anthony *et al.* reported in *Nature Geoscience* this year that methane is leaking out of thawing permafrost and regions of glacial retreat throughout Alaska. Unlike the ESAS, this is gas that had accumulated over time – originating from a range of sources including decomposing organic matter, hydrocarbons and perhaps hydrates – but had hitherto been corked by ice or frozen soil. The scientists noted that the most active sites emitting old methane occur in areas of continuous permafrost with locally increased permeability or in areas that have only recently lost their capping ice. Continued warming could pop the cork, leading to a relatively rapid but transient pulse of methane emission to the atmosphere.

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It is useful to compare the methane emissions from these recent studies with global emissions (from all sources). Shakhova *et al.* reported an annual value of about 8 million tons for the ESAS. Walter Anthony's group estimated an annual value of up to 2 million tons for the circumpolar permafrost based on their observations in Alaska. Together, the emissions are a significant but small fraction of the annual global value, which is on the order of 500 million tons (of which the anthropogenic component is approximately 60 percent). Tropical wetlands, agriculture and fossil-fuel production and consumption are much bigger players. The contribution from the Arctic region could conceivably increase as the region warms, but does the warming constitute a clear and present danger?

Assessing the risk

Shakhova and colleagues find the formation of large pockets of free methane gas in the ESAS region feasible; these could conceivably lead to near-instantaneous methane release. Oxidation by anaerobic microbes within sea water can consume a lot of methane that does bubble out, although this process would be rather inefficient in the shallow water depths associated with the ESAS. But Carolyn Ruppel, who heads the United States Geological Survey's Gas Hydrates Project, cautions against inferring massive methane escape to the atmosphere based on seawater methane concentrations collected at different times. She also notes that researchers currently lack a technique that can distinguish between methane recently released from gas hydrate and other methane sources. Thus, it is not yet possible to discern whether the elevated methane levels detected on the ESAS imply methane hydrate dissociation.

Ruppel's calculations show that an instantaneous methane release equivalent to about 2 billion tons of carbon could bump up the atmospheric concentrations of the gas by over 55 percent of its current value. But such a release requires a major destabilisation, for example that triggered by a submarine landslide. Even if a billion tons of carbon were to be released suddenly as methane, David Archer notes on the RealClimate blog that the effect on temperature would be akin to that of a major volcanic eruption – except, of course, that a methane release would cause warming instead of cooling. Assuming that this would be an isolated incident, the warming would be relatively short-lived given the atmospheric residence time of about a decade for methane. The risk of crossing a dangerous threshold was the subject of an extended discussion on Andy Revkin's Dot Earth blog on The New York Times site last year. Several scientists expressed the view that a catastrophic methane outburst arising from hydrate instability in the Arctic was rather unlikely in the near term.

Many researchers do agree that the northern latitudes will witness smaller but regular releases of methane as the region warms. As methane ultimately oxidises to CO_2 in the atmosphere, it will add to the atmospheric CO_2 concentrations and thus amplify the greenhouse effect in the long term. What this will do to the huge pool of carbon in the permafrost – currently

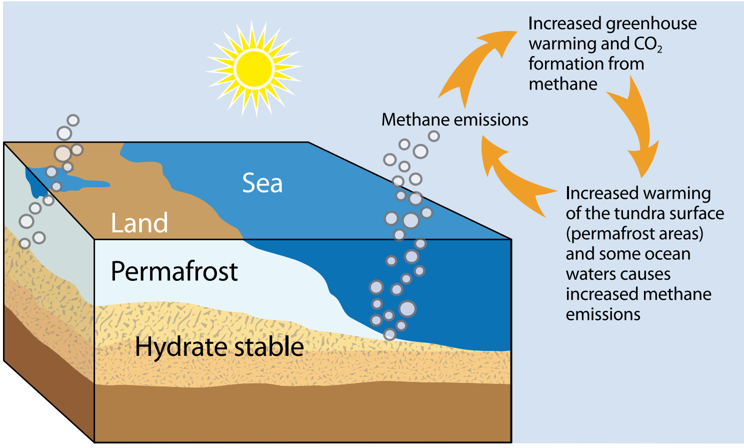

Figure 1. Schematic sketch (not to scale) depicting the Arctic methane feedback. Pronounced regional warming increases methane emissions, which strengthen the greenhouse effect and warm the surface. The warming, in turn, triggers additional emissions.
Modified after Figure 4 from Ruppel C and Noserale D (2012).

www.usgs.gov/blogs/features/usgs_science_pick/gas-hydrates-and-climate-warming/ (Accessed on 15 September 2012.)

sequestered as frozen organic matter – is another story.

Despite what appears to be a consensus against catastrophe, at least in the short term, the fascination with methane in the popular media and blogs suggest undercurrents of concern. The perceived vulnerability of the large ESAS methane hydrate deposits and the potential for unanticipated disturbances seem to be a big factor behind the unease. Does the recent geological past – the last million years or so – tell any tales that could help steer this discussion? I put this question to Hubertus Fischer, a palaeoclimate researcher at the University of Bern and a co-chair of IGBP's Past Global Changes project. Fischer says it is instructive to look at methane variations during the last glacial period as well as the overall variation during the last eight interglacials.

The last glacial period was marked by several abrupt temperature increases – the Dansgaard-Oeschger (DO) events – during which the atmospheric concentrations of methane spiked. Previous work shows that the hydrogen-isotopic signature of this methane is unlike that expected for deep marine hydrates (for example, Bock *et al.* 2010). There could be a contribution of such hydrates towards the end of the DO events, but no indication of a catastrophic release. Fischer notes that methane released from shallower hydrates, such as those on the ESAS, would not have a unique hydrogen isotopic signature. As discussed earlier such hydrates underlie permafrost that is flooded during interglacial sea-level rise. But the sea level was low at the beginning of the DO events and rose by only 20 metres or so during the events, not sufficient to flood large areas of permafrost and prime them for methane release during future events.

Interglacials refer to the geologically brief, warmer periods between ice ages. They are characterised by high atmospheric concentrations of greenhouse gases. Two of the last eight interglacials were significantly warmer than the Holocene and also about 2°C warmer than the present. In the Arctic the temperature was likely even higher. Nevertheless, Fischer points out, the methane concentrations reconstructed for the past interglacials are remarkably similar. This suggests that although methane sources (organic carbon in permafrost and methane hydrates, for example) respond during transitions to the warmer periods, emissions quickly stabilise. Thus, the rate of warming is more important than the overall temperature increase to assess future methane release from permafrost. It should be noted that many of the future warming scenarios easily exceed the amplitude – but more importantly also the rate – of warming leading up to and during the last interglacial.

The lessons that the past offers us are instructive but incomplete, and it is to models we must turn to project and predict future changes. Fischer emphasises that such models are still at an early stage, not least because there are too few observations and limited understanding of methane emissions at the ecosystem scale. Slowly but surely, though, the observations are beginning to build up. The field campaigns undertaken by the teams of Shakhova, Walter Anthony and others, coupled with remote sensing studies as discussed on page 26 of this issue, are steps in the right direction.

The scientific information at hand gives no indication of a catastrophe waiting to happen. But it does highlight gaps in our understanding and points to the need for continuous monitoring of changes to the methane cycle as the Arctic region warms.

The lessons that the past offers us are instructive but incomplete.

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