Freeze, thaw, fracture?

Article (Unspecified)

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By cycles of freeze and thaw, ice can split apart rock. We thought we knew why. Julian Murton says we need to think again, and think 'permafrost'.

Why does freezing break up rock? Everybody knows that when water freezes it expands – by nine percent to be precise. If it seeps into rocks and then freezes, the rocks can fracture and split apart, a process known as frost weathering. So far so logical. But this long-held explanation is probably not very significant in nature because it requires some pretty unusual conditions. The rock must essentially be water-saturated and frozen from all sides, to prevent the piston-like effect of freezing water driving the remaining liquid water into empty spaces or out of the rock through an unfrozen side or crack. So we need to look for another explanation.

Last year we reported in the American journal *Science* the results of our experiments of growing permafrost in the laboratory. We showed that rock fracture under realistic conditions is not caused by the expansion of freezing water, as previously thought, but by the growth of ice lenses. This process forms an icy layer of fractured rock that pulsates to the climate beat, generates rock debris and sculpts landscapes above the permafrost.

Ground that stays at sub-zero temperatures from one winter to the next is called permafrost. Each summer the surface metre or so of ground thaws, and each winter it freezes, while the ground beneath – the permafrost – remains below zero degrees and usually frozen. The seasonal temperature changes drive water down into the upper metres of permafrost, where it freezes and forms an ice-rich layer beneath the Arctic tundra. Yet how does an icy layer of soil tell us about the fracture of rock? The answer lies in the movement of water through porous frozen ground.

You might think that all water in permafrost is frozen and immobile. But small amounts of liquid water do exist at sub-zero temperatures and move slowly through permafrost, driven by differences in soil temperature. The water heads towards local sites of freezing, where it forms lenses or layers of ice, typically a few millimetres thick. The result looks like the black and white stripes of a zebra, with the white representing the ice lenses and the black representing the soil between them. As the ice lenses grow, they force apart the soil and heave up the ground surface, often helping to produce striking geometrical patterns on the tundra surface. The same process should also happen in porous bedrock.

To test this idea, we grew permafrost in large blocks of limestone. The lower half of each block remained below zero (permafrost) while the upper half cycled above and below this freezing point, simulating about twenty Arctic winters and summers.

During the experiments ice lenses grew in the permafrost. Paradoxically, the ice grew most in summer, as the upper layer of rock thawed, releasing meltwater that moved down into the underlying permafrost, where it supplied ice lenses that fractured the rock and heaved up the surface. But then came the European heatwave of summer 2003. This was bad news for ice lenses. As temperatures in our cold rooms soared, we measured the rock surface collapse by about ten millimetres as ice lenses melted in the upper layer of permafrost. Thankfully, the permafrost recovered during the next few winters, and the ice lenses quickly started to grow again.

By the end of the experiments the permafrost had become fractured and rich in ice lenses. The ice and fractures resembled those in limestones, shales and sandstones in Arctic permafrost of Canada and Svalbard, a group of islands off the northern coast of Norway (NERC has a research base on Spitsbergen). The fractures also resembled those in ancient weathering profiles from places where ice age permafrost previously existed, for example beneath the chalklands of southern England and northern France.

Overall, our experiments showed that ice lenses fracture permafrost bedrock, and hot summers melt some of the ice, triggering rock subsidence. Melting releases rock fragments to hillslopes, rivers and glaciers in Arctic and alpine regions. We can imagine permafrost thaw on a much bigger scale, say at the end of ice ages. As climate warms and permafrost disappears, this would cause major disturbances to the upper metres of icy fractured bedrock. We can see the evidence for this disturbance all over the chalklands, in the form of thick rocky, slope deposits, contorted weathering profiles and myriads of soil deformation structures.

Now plan for the future: the predicted warming of Arctic and alpine climates will thaw ice-rich bedrock, destabilising rocks beneath the surface that have been fractured and heaved by ice lenses. Rockfalls and landslides will become more common in mountain permafrost, and many rocky surfaces will subside in the Arctic. So the next stage of our research must be to monitor rock fracture and stability in Arctic permafrost on Svalbard and mountain permafrost in the European Alps.

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More information: Why do freezing rocks break? *Science*, **314**, 1092–1093. Hallet B. 2006.
Bedrock fracture by ice segregation in cold regions. Murton JB, Peterson R, Ozouf J-C. 2006. *Science*, **314**, 1127–1129.

Photos:

1. Ice lenses in natural permafrost soil, Svalbard
2. Ice lenses and rock fractures in artificial permafrost
3. Rock fragments, Svalbard
4. The author on Arctic fieldwork, Canada