Ancient Permafrost and a Future, Warmer Arctic

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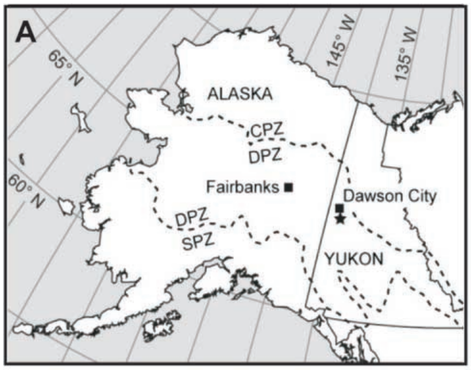
Areas of permafrost are subdivided into continuous (>90% frozen ground), discontinuous (>50%), and sporadic (<50%) permafrost zones (Fig. 1A). Permafrost outside the continuous permafrost zone is particularly vulnerable to future climate change because it is near the melting point and because the depth of frozen ground is typically thin (a few to tens of meters). Permafrost in northwest North America warmed in the late 20th century (*1*), and numerical models predict widespread and severe permafrost degradation under 21st-century climate-warming scenarios (*2*), with potential for concomitant release of stored carbon (*3*). However, our limited knowledge of the response of permafrost to past warming makes it difficult to evaluate the future response (*4*).

We investigated relict ground ice within the discontinuous permafrost zone of central Yukon Territory, Canada. Permafrost in this area is warm (>–2°C), up to a few tens of meters thick, and strongly controlled by local site conditions; permafrost is generally sparse or absent on south-facing slopes and in areas lacking insulating vegetation cover. At the Dominion Creek site, large vertically foliated ice bodies (ice wedges) are present within a few meters of the surface (*5*). The ice composing the wedge is distinctive because of the presence of vertical foliations with parallel air bubbles. These ice wedges formed at the former surface through thermal contraction cracking and infilling by surface water and freezing and would necessarily have had an overlying active layer (seasonally thawed horizon) when the ice wedge formed. Seasonal melting of the paleoactive layer truncated the top of the ice body, producing a flat upper surface, with some secondary wedge growth present at the ice wedge surface, indicating that the paleoactive layer is present (Fig. 1, B and C).

A volcanic ash called the Gold Run tephra was recovered from within the paleoactive layer and across the exposure at this level for 50 m laterally, where it overlies at least one additional ice wedge. Thus, the underlying ice wedges predate deposition of the tephra. Two independent age estimates for the tephra were made on glass by using the isothermal plateau and the diameter-corrected fission-track methods. These estimates provide a weighted-mean age of 740,000 ± 60,000 years before the present (yr B.P.) (table S1) and are consistent with faunal ages associated with this bed and the normal magnetic polarity of the surrounding sediments (*5*).



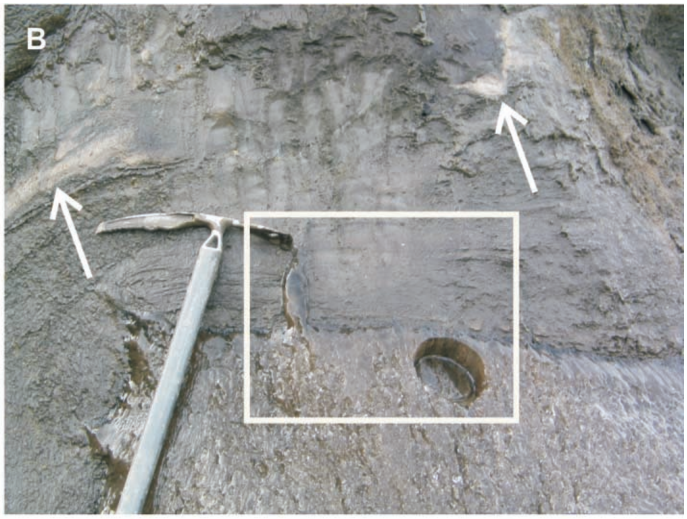


Fig. 1. (**A**) Permafrost zones of northwestern North America (continuous, discontinuous, and sporadic are CPZ, DPZ, and SPZ, respectively) and study site location (*). (**B**) Top of relict ice wedge with beds of Gold Run tephra (740,000 ± 60,000 yr B.P.) marked by arrows. (**C**) Close-up [box in (B)] of relict secondary wedge on ice wedge surface (scale bar = 10 cm).

The relict ice wedge overlain by the Gold Run tephra represents the oldest ice known in North America and is evidence that permafrost has been a long-term component of the North American cyrosphere. Importantly, this finding demonstrates that permafrost has survived within the discontinuous permafrost zone since at least the early-Middle Pleistocene. This age range includes several glacial-interglacial cycles, including marine isotope stages 5e and 11, both considered to be longer and warmer than the present interglaciation (*6*). The presence of relict Middle Pleistocene permafrost suggests that the controls on permafrost thickness and distribution, such as surface cover (which insulates permafrost), deeper ground ice (which cools shallow permafrost), and excess ice (which retards thaw due to latent heat effects), are still not adequately considered in numerical models of permafrost degradation (*7*). This study highlights the resilience of permafrost to past warmer climate and suggests that permafrost and associated carbon reservoirs that are more than a few meters below the surface may be more stable than previously thought.

References and Notes

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Supporting Online Material

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SOM Text
Table S1
References

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