nitrogen limitations on plant growth. Thus carbon uptake during plant growth exceeds carbon loss from soils, and terrestrial carbon accumulates with warming (Fig. 1b). In contrast, carbon-only models predict a decrease in terrestrial carbon with warming. Overall, although net terrestrial carbon sequestration is reduced when nitrogen is accounted for, climate warming increases carbon sequestration in a negative, rather than a positive feedback. However, with strong warming, respiratory losses win out and terrestrial ecosystems become a source of carbon despite the beneficial effects of nitrogen.

The results of Sokolov and co-workers not only raise doubts about the reliability of carbon cycle–climate models that do not simulate the nitrogen cycle, but raise new uncertainties regarding the influence of additional atmospheric pollutants and ecological processes on the size of the terrestrial carbon sink. For example, anthropogenic nitrogen deposition, which is not considered in their model, could further stimulate plant growth[11], although progressive nitrogen limitations as nitrogen becomes increasingly bound up in larger biomass pools may diminish productivity[5]. Furthermore, biological nitrogen fixation, reallocation of nitrogen between vegetation and soils, and between labile and recalcitrant pools, together with redistribution of plant species in response to disturbance or climate change, must be considered.

The current generation of carbon cycle–climate models are based on the premise that CO_2-induced increases in plant productivity are offset by warming-induced increases in carbon loss[2,12]. The results of Sokolov and co- workers will undoubtedly motivate modellers to expand their biogeochemistry to include the nitrogen cycle, as well as other elements. Phosphorus, for example, is an important plant macronutrient, and nitrogen–phosphorus interactions influence ecosystem functioning[13].

However, better understanding of the carbon cycle–climate feedback will ultimately require a more comprehensive shift in model capabilities. Land–atmosphere interactions in climate models have expanded from their initial biogeophysical focus on energy and water to include biogeochemical cycles[14]. The models must now be expanded to include biogeographical processes such as land use, fire and post- disturbance vegetation succession, which greatly affect carbon fluxes. Interactions among biogeophysical, biogeochemical, and biogeographical processes, especially in response to human modification of the landscape, will probably produce a rich array of climate forcings and feedbacks.

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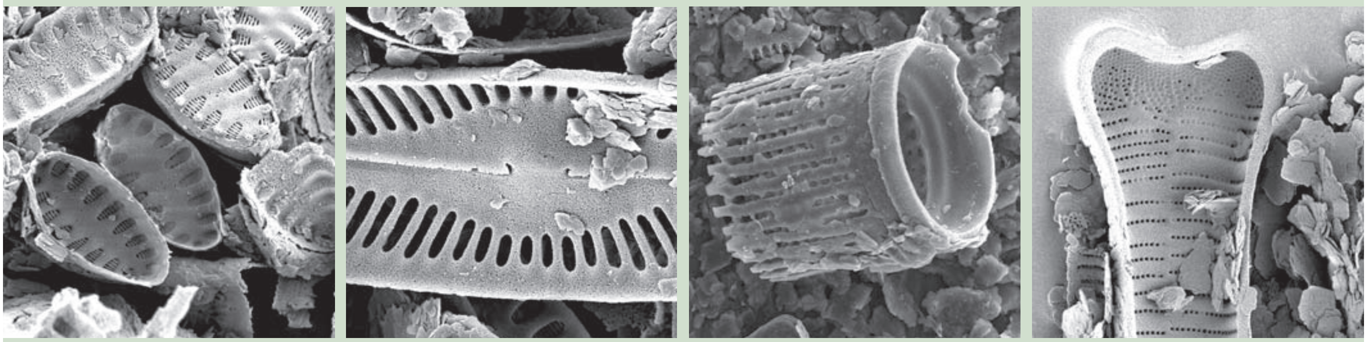
PALAEONTOLOGY

A long-lost tundra



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Hidden deep beneath vast ice sheets and in foreboding desert valleys lie the remnants of Antarctica's warmer past. Before the dawn of the southern ice sheets, Antarctica was covered by plants, lakes and rivers — a landscape that would be quite unfamiliar to the penguins and seals that call the continent their home today.

Beginning about 50 million years ago, the Earth's climate started to cool, and by 34 million years ago ice sheets slowly marched across the southernmost continent. Although this cooling marked the end of the reign of many temperature-sensitive plants, little is known about the survival of the more rugged shrub tundra community. Now Adam Lewis of Boston University and colleagues have discovered a wealth of fossils in the McMurdo Dry Valleys that chronicle the final demise of the tundra (*Proc. Natl Acad. Sci. USA* **105,** 10676–1068; 2008).

The team found spectacularly preserved fossils among the sediments of ancient alpine lakes from about 14 million years ago. The deposits revealed a number of diatoms and ostracods that colonized the lake surface and the bottom sediments. The researchers also found a number of semi-aquatic mosses from the lake shore and other mosses blown or carried in from further away. In addition, the sediments were rife with pollen from a number of plants, including beech trees, as well as the occasional beetle.

This fossil assemblage suggests that the lakes in question were permanent, and largely free of ice throughout the year. However, the lakes of that area, and their denizens, were gone 200,000 years later. The team used glacier modelling to conclude that air temperatures rapidly decreased by 8 °C from 14 to 13.8 million years ago. The overlying sediments suggest that the temperatures, and the tundra, never recovered.

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