for a particular correspondence between the lattice spacing in the *c*-direction and the period of the pair wavefunction. In the extreme high-field limit, the superconducting phase should return with a critical temperature increasing, instead of decreasing, with the magnetic field. This spectacular high-field 're-entrance' mostly involves electrons pairing with parallel instead of antiparallel spins.

Lee *et al.*[1] have stressed that the survival of superconductivity at magnetic fields exceeding by a large amount the paramagnetic limit suggests parallel spin pairing. In fact, by measuring the temperature at which the resistivity reaches zero under a magnetic field, they are detecting the melting of a lattice of magnetic vortices, rather than the temperature dependence of H_{c2}. But their conclusion that $H_{c2} >> H_{\mathrm{p}}$ is still valid.

A lot of work must be done before we can unambiguously claim that these materials show the re-entrance of superconductivity predicted for the high-field regime. In particular, higher fields (above 20 tesla) and lower-temperature experiments with accurate field alignment should be feasible in the near future.

We do not foresee very high critical temperatures in quasi-one-dimensional superconductors, so it isn't clear what applications they might have. But they are important materials for testing our models of superconductivity and, more generally, the theory of electrons in low-dimensional spaces. ☐

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Oceanography

The limits to growth

Louis A. Codispoti

That the availability of nutrients and light controls carbon fixation by oceanic plants is a proposition that attracts little debate. But there has been hot discussion over just what nutrients limit this process and the applicable timescales. The traditional argument has centred around the relative importance of phosphorus and nitrogen[1]. More recently, iron and other trace metals have received considerable attention, and experiments[2] have shown that carbon fixation in some parts of the ocean can be limited by iron.

Most investigators agree that fixed nitrogen can be limiting over shorter time intervals, but those who favour phosphorus as the ultimate controlling nutrient over periods of more than 10,000 years may feel their hackles rise when they read Paul Falkowski's latest paper on page 272 of this issue[3]. Falkowski asserts that it is nitrogen, not phosphorus, that limits primary productivity on geological timescales. He bases his arguments, in part, on a discussion of the evolutionary history of the enzyme systems involved in nitrogen fixation and denitrification which seem to be the main source and sink, respectively, for oceanic fixed nitrogen.

Denitrification seems to have evolved independently several times, leading to diversity in the enzymes and microbes responsible. This is not so for nitrogen fixation and, to quote Falkowski, "...the sequence of the genes encoding the catalytic subunits for nitrogenase [the nitrogen-fixing enzyme] is highly conserved in cyanobacteria and other eubacteria, strongly suggesting an ancient, common ancestral origin".

A key point is that nitrogenase, which seems to have originated before the atmosphere was well oxygenated, has requirements for iron and for anoxia that are not well-matched to present-day oceanic conditions. Falkowski points out that the iron requirement for nitrogenase is about 100 times higher than for the enzymes involved in the uptake of fixed nitrogen during carbon fixation. He suggests that, once the Earth's atmosphere and most oceanic waters became oxidizing, nitrogen fixation in oceanic waters was inhibited because Fe(III), the stable form of iron under these conditions, has a low solubility. This, and the locus of nitrogen fixation in oxygenated surface waters, where turbulence can make it difficult to maintain anoxic microzones and also produces sub-optimal light conditions, restrain oceanic nitrogen fixation[4,5], and help to explain how nitrogen can be limiting even though free nitrogen gas is abundant. By drawing attention to the evolutionary history of the enzyme systems, and with his incisive review of the literature, Falkowski has presented a good case for nitrogen limitation on geological timescales, even though I am not yet ready to completely dismiss the idea that phosphorus may have been limiting at times[1,6].

Given the recent interest in iron limitation[2], the reader may come away with the impression that the main point is the link between iron and nitrogen fixation on the supply side, but Falkowski recognizes that the demand side, denitrification, is also important. Denitrification requires a flux of organic material, fixed nitrogen (mainly nitrate and nitrite) and low oxygen concentrations to become a dominant respiratory pathway. Such conditions are met in most shallow and

Jupiter's moons

Virgin Callisto

The nymph Callisto wanted to remain a virgin, like her hunting companion Artemis. Inevitably, she was seduced by Zeus (or Jupiter), and then got turned into a bear for her pains by the jealous Hera. But sometimes the real world is kinder than myth: the Galileo spacecraft has discovered that Jupiter's outermost large moon (right) is a virgin aggregate of rock and ice.

The difference between Callisto and its siblings is striking. Unlike Io, Europa and Ganymede, Callisto shows no evidence of an internal magnetic field (D. A. Gurnet *et al.* and K. K. Khurana *et al. Nature* 387, 261 and 262; 1997). In the other moons, the field probably comes from a molten iron core, which formed when the moon got hot enough for ice, rock and metal to melt and separate. And indeed, Callisto's gravitational field shows that, unlike the other moons, it has a fairly uniform density, with maybe just a thin surface ice layer (J. D. Anderson *et al. Nature* 387, 264; 1997).

Why is Callisto so different from Ganymede, which is almost the same size? Early heating of the two moons, from accretion and internal radioactivity, would have been about the same. But Ganymede may once have passed through an orbital resonance, where it was melted by tidal heating from Jupiter; Callisto, unlike her namesake, appears to have avoided such warm embraces.

Stephen Battersby