

~10 μatm from their original values after 4 days (K. Van Scoy, University of East Anglia; F. Millero, University of Miami). The decreases are about a tenth of those expected if photosynthesis had used up all the available nitrate.

Not surprisingly, the debate continues on the causes for the difference between bottle-scale and mesoscale iron enrichments. Although we shall learn more when the final results become available, it probably will not be possible to solve this puzzle without repeating the experiment. Two loss terms were not well characterized: the loss of phytoplankton through zooplankton feeding within the patch, and the time-dependent loss of available iron in surface waters. In defence of the planners, however, no more equipment could have been brought on board without risk of capsizing the vessel.

The grazing question is a tricky one. Based on bottle experiments, the prevailing wisdom has been that stocks of the smaller picophytoplankton are limited by the tiny marine animals that 'graze' on them, and the larger phytoplankton are iron-limited. So the apparent increase in picophytoplankton within the patch came as a surprise.

Part of the explanation for the low response from larger phytoplankton may be increased grazing by zooplankton normally excluded or damaged in most bottle experiments. Microscopic examination of seawater samples during IronEx showed about a 50 per cent increase in microzooplankton (Barber), and net tows indicated that mesozooplankton which normally migrate daily to the ocean surface from deeper waters were remaining there to profit from the extra food supply (Coale) — at the meeting, Bill Sunda (National Marine Fisheries Service, NOAA) likened this behaviour to that of seagulls flocking in to feed.

So consumption by mesozooplankton could be reducing the concentration of phytoplankton below what is expected from bottle experiments. It may be that these larger zooplankton also feed on the smaller grazers and that the lifting of grazing pressure allows the picophytoplankton to capitalize on the higher iron availability.

Understanding the rate at which available iron is lost from the patch is crucial for explaining the extent of the ecosystem response. In contrast to what occurs in 'contained' experiments, total iron concentrations within the patch decreased by about 90 per cent by the fifth day of the open-ocean experiment (Johnson). Even then, we cannot quantify iron availability rigorously because current iron analysis techniques probably overestimate the biologically available fraction⁶. Repetitive fertilization will probably be necessary before direct comparisons to bottle incubations become meaningful. The

pulse of iron input appears to have been sufficient to 'kick-start' the ecosystem, only for it to stall as the iron ran out.

Although grazing effects and diminishing iron availability probably contributed to differences between the bottle-scale and mesoscale iron enrichments, several alternative hypotheses were raised at the meeting (F. Morel, Massachusetts Institute of Technology). These included indirect effects arising from reactive photochemical products created by iron photolysis, and adsorption of other metals onto the colloidal iron oxides formed upon iron enrichment, which then aggregated and sank from surface waters. Finally, bottle incubation results can differ from site to site (M. Wells, University of California, Santa Cruz), and the Galapagos region is several thousand kilometres from where most of the bottle experiments were conducted.

Has the 'iron hypothesis' been verified? So far, the answer is a qualified yes. Phytoplankton production and biomass did increase upon iron enrichment, although the results differed from those of bottle experiments. Nonetheless, oceanographers should not neglect bottle experiments in future work, as they provide perhaps the best way to probe the specific response of individual members of the plankton community⁷. On the other hand, mesoscale enrichments offer the chance to test the whole ecosystem response, but they are difficult to interpret because of unexpected or unquantifiable factors. Spin-offs of the 'iron hypothesis' — namely the depletion of important nutrients and carbon dioxide in surface waters — cannot be properly evaluated from the current results. The effects may be understood better after the follow-up iron fertilization experiments scheduled for next year.

The most resounding success of this complex experiment was to prove that it is possible to modify and then track a patch of open ocean surface water while measuring the ecosystem response. The experiment could hardly have been undertaken without the tireless effort and tenacity of John Martin. Regardless of the final judgement on the 'iron hypothesis', establishing the feasibility of such experiments may well turn out to be John's most enduring legacy. □

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1. Martin, J. H. *Paleoceanography* **5**, 1–13 (1990).
2. Hart, T. J. *Discovery Rep.* **8**, 1–268 (1934).
3. Martin, J. H. & Fitzwater, S. E. *Nature* **331**, 341–343 (1988).
4. Martin, J. H., Gordon, R. M. & Fitzwater, S. E. *Nature* **345**, 156–158 (1990).
5. Ledwell, J. R., Watson, A. J. & Law, C. S. *Nature* **364**, 701–703 (1993).
6. Wells, M. L. *Biol. Oceanogr.* **6**, 463–476 (1988).
7. Price, N. M., Ahner, B. A. & Morel, F. M. M. *Limnol. Oceanogr.* (in the press).

Superficial gain

In the noble army of solids, metals form a regiment of their own. They owe their unique ductility, shine and conductivity to their special lattice of positive metal ions in a sea of negative electrons. Daedalus points out that many non-metallic molecules, such as ammonium and the related alkylammoniums, also exist as stable positive ions. They might fit rather well into a metallic lattice. Indeed, ammonium forms an alloy with mercury. So Daedalus now plans to infiltrate various alien ions into the metallic lattice. By inserting ionic relatives of ammonium, ideally polymer ones, he hopes to create a whole new class of organometallic 'hybrid alloys'.

His scheme is to electroplate the ions onto the metal from a suitable molten salt. Very high pressure may be needed to collapse the deposited ions into the dense metallic state so that they can alloy with the metal cathode and diffuse into it. The cathode will acquire a subtly graded composition: pure metal in the interior, but with a steadily increasing proportion of alloyed non-metallic ions towards the surface. Metal plated in this way should transform engineering.

Thanks to its loading of organic ions, a hybrid-alloy surface will be rust-proof, and will bind to paint and glue tenaciously. Its organic content will give it a degree of flexibility, making the surface layer slightly softer than the underlying metal. The resulting 'case softening', claims Daedalus, should make the metal extremely tough. For a loaded component usually fails from the surface inwards: the stress is greatest there, and small surface irregularities invite cracks to start. A case-softened surface would yield more easily, reducing the surface stresses. The stresses inside would be higher, of course; but the smooth inward gradation from surface alloy to pure bulk metal would give no sharp discontinuity from which a crack could begin. So, paradoxically, by softening its surface you would strengthen the whole component. It could be stressed right up to the elastic limit of the underlying metal without fear of brittle failure.

Daedalus also hopes to make homogeneous metal-organic hybrid alloys in bulk form, thus bridging the gap between metals and non-metals. Far lighter than most alloys, they should still retain that special metallic ability to be bashed and deformed enormously without breaking or losing strength. They might not be magnetic, but they should conduct electricity in intriguing ways. Indeed, they could even form a whole new range of cunning semiconductors.

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