OCEAN SCIENCES

Iron findings

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A huge phytoplankton bloom in the Southern Ocean yields estimates of how a continuous supply of iron affects oceanic carbon sequestration. But iron is not the only factor — nutrient supply is crucial too.

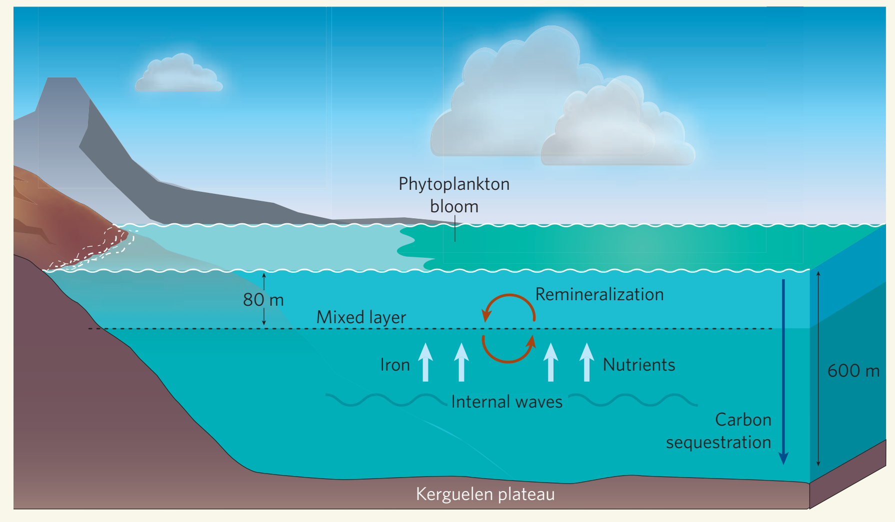

Figure 1 | Kerguelen blooming. The Kerguelen plateau is about 600 m under the ocean surface; in this region, internal waves enhance the vertical mixing of the deep waters above the plateau, which have higher iron and nutrient concentrations, with those in the 80-m-thick surface mixed layer. Up to half of the particulate iron and other nutrient elements were broken down (remineralized) to dissolved forms in the upper ocean. Both of these processes supplied continual nourishment to the phytoplankton studied by Blain *et al.*[3], which — through photosynthesis and the subsequent sinking of organic carbon into the deep ocean over several months — contribute to higher than previously reported[2] sequestration of atmospheric CO$_2$ per unit iron supplied.

The ocean is a daunting place to study, where investigations must contend with a wide range of scales — from intracellular to ocean basins, from nanoseconds to seasons[1]. The difficulties are evident in the variety of approaches used to study the ecological productivity of its microscopic algae, or phytoplankton. Small-scale perturbation experiments, for example incubating seawater samples in small bottles with added elements such as iron, provide useful information on phytoplankton physiology and other intrinsic processes. They cannot, however, represent processes occurring across entire ecosystems, as the sampled phytoplankton are enclosed and isolated. In contrast, 'mesoscale' *in situ* studies, which perturb patches of ocean on the scale of hundreds of square kilometres, can address ecosystem-scale questions[2]. But even month-long experiments at this scale have flaws, such as pronounced mixing of the enriched patch with surrounding waters, altering its properties.

In a recent paper in *Nature*, Blain *et al.* (page 1070, Vol 466, 2007)[3] overcame these scaling issues by investigating a naturally occurring phytoplankton bloom covering an area of 45,000 km^2. Such large blooms photosynthetically convert so much carbon into an organic form that they have a marked effect on the atmospheric carbon dioxide concentration, and hence the global climate: a significant proportion of the carbon thus 'fixed', known as particulate organic carbon, is sequestered in the ocean depths. Iron is now recognized to be of equal importance to nutrients such as nitrate[4] in stimulating the development of these blooms. A larger supply of iron to the surface ocean — from dust deposition, for instance, as recorded from the geological past[5] — can increase phytoplankton productivity and thus carbon sequestration and CO$_2$ drawdown[6].

Blain and colleagues[3] used satellite images to pinpoint an annually recurring bloom near Kerguelen, an island archipelago in the Southern Ocean south of, and at a longitude about equidistant from, South Africa and Australia. This 'natural laboratory' was sustained for months through constant iron and nutrient enrichment from below (Fig. 1, overleaf). The larger spatial and temporal scales of the bloom permitted Blain and colleagues to address questions inconclusively covered by previous mesoscale iron-enrichment studies in polar regions (see ref. 2 for a review). Chief among these was how much of the carbon fixed by the bloom was sequestered into the ocean depths.

The determinant of whether iron enrichment can alter global climate is the magnitude of carbon sequestration per unit of iron added. During their 30-day study, Blain *et al.* report 10 to 100 times more carbon export per unit of iron supplied than was estimated during the previous studies. These higher ratios are particularly significant, because they indicate that the higher iron supply evident during glaciation maxima[5] had a greater impact on atmospheric CO$_2$ drawdown than has generally been assumed. The contribution of iron enrichment to the total glacial–interglacial shift of 80 parts per million (p.p.m.) in atmospheric CO$_2$ might therefore approach the upper bound of 24 p.p.m. cited recently[6].

What are the reasons for this discrepancy[2,3]? Blain *et al.*[3] provide two explanations. First, the polar mesoscale iron-enrichment measurements[2] underestimated carbon export, because they were too short-term (lasting just weeks) to observe its full extent. Second, they overestimated iron supply: pulses of extra iron into the surface ocean are prone to rapid removal, for example by sticking to sinking particles.

The ratios of carbon export to iron supply estimated by Blain *et al.* for particles sinking from the Kerguelen bloom are very similar to carbon–iron ratios in phytoplankton in high-iron laboratory cultures[7], pointing to little biological modification of these ratios between photosynthesis and subsequent sequestration. The similarity of the ratios is difficult to reconcile with recent reports that the organic carbon on sinking particles is broken down into dissolved forms, or remineralized, more rapidly than is iron[8]. The authors also report high stocks of zooplankton grazing on the Kerguelen blooms that would be absent from the laboratory cultures. The presence of zooplankton aids the remineralization of both iron and carbon, and thus reduces carbon export while resupplying iron to the phytoplankton.

The phytoplankton bloom at Kerguelen, fuelled by a sustained supply of iron and nutrients, was of exceptional duration, lasting some months. Although it used up virtually all of the iron and silicic acid in surface waters, it did not deplete its nitrate stock. Under high-iron conditions, a bloom should use equal amounts of nitrate and silicic acid[9]. The implication is that, despite the continuous vertical supply of nutrients characteristic of the Kerguelen site, the growth rate of the resident bloom is probably suboptimal owing to insufficient iron.

Together with other measurements[2], Blain and colleagues' results provide a powerful tool for modellers investigating the effects of the mode of iron supply on ocean biogeochemistry. The main modes, in the geological past, have been episodic iron enrichment of the uppermost ocean through dust deposition and/or sustained enrichment of overlying waters through the upwelling of deep waters. The sustained iron and nutrient supply through internal wave activity at Kerguelen means that the intensity — and, more importantly, the ratio of its iron and nutrient supplies — may differ from those of polar upwellings. A quantification of the effects of upwelling and internal waves on this ratio is needed to determine whether the Kerguelen data are a proxy for the polar ocean during the glacial maxima.

But does Blain and colleagues' evidence[3] of more carbon export per unit iron supply mean that iron enrichment is a viable short-term climate-mitigation strategy? The authors say no: the enhanced export resulted from bloom longevity that was driven not just by sustained iron enrichment, but also by continuous nutrient enrichment. Moreover, the ratio of carbon export to iron supply is notoriously difficult to measure, and only a fifth of the phytoplankton's requirements were accounted for in the study's iron budget.

Nevertheless, the work is a novel and valuable addition to the library of phytoplankton-biogeochemistry studies. A final testament to the challenges of marine research, and the technical difficulties in assessing the efficacy of iron enrichment as a climate-mitigation strategy, is given by the story of Blain and colleagues' sediment traps, particle interceptors used to measure carbon sequestration at great depth. These could not in the first instance be recovered, but have just finally been salvaged — one year on. ☐

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