cord blood. Although having a paternal DNA sample makes such analysis easier, Fan and colleagues' study shows that it is not necessary. Furthermore, comparing the father's DNA sequence with that of the fetus carries the risk of uncovering mistaken paternity, and this is avoided in Fan and colleagues' approach.

How will the ability to non-invasively sequence the fetal genome improve prenatal care? Fan *et al.* posit that it will enable treatment for genetic disorders to begin immediately after delivery. I argue that we could most effectively use the information to begin treatment while the fetus is still in the womb[7]. However, it is striking that before we have even considered all of the ramifications of complete genomic sequencing of a newborn's DNA, we now have three demonstrations of non-invasive sequencing of the fetal genome[2,6,8]. The situation is ethically and clinically more complex with a fetus than with a newborn for two reasons: one, the 'patient' is in the womb and cannot be fully examined, and two, prospective parents have the option of terminating the pregnancy.

These studies therefore raise many ethical and practical questions about how prospective parents and physicians might use this genomic information. For example, Kitzman and colleagues[6] detected 44 spontaneous point mutations in the fetal genome that they sequenced. One of these mutations creates an amino-acid substitution in the protein encoded by the gene *ACMSD*, which is implicated in Parkinson's disease, suggesting that this mutation might have clinical significance later in that unborn child's life. Will expectant couples want to know this sort of information? Now, multiply this point mutation by several hundred — a plausible quantity of 'noteworthy' genetic information that might typically be obtained from a whole-genome sequence — and imagine the time and resources needed to provide parents-to-be with genetic counselling regarding the implications of all of this data.

Although the concept of routine fetal-genome sequencing may still seem futuristic, non-invasive prenatal diagnosis of abnormal chromosome number is already offered to pregnant women in certain high-risk categories in the United States and China[9]. But before the vast amounts of information acquired from fetal-genome sequencing can be applied in a useful manner, the gap between technology and clinical interpretation must be narrowed. For parents to learn their fetal ACGTs, substantial investment is needed in teaching health-care providers about the human genome. ■

Diana W. Bianchi *is at the Mother Infant Research Institute, Tufts Medical Center, and in the Departments of Pediatrics, Obstetrics and Gynecology, Tufts University School of Medicine, Boston, Massachusetts 02111, USA.*
e-mail: dbianchi@tuftsmedicalcenter.org

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BIOGEOCHEMISTRY

The great iron dump

The discovery that marine algal blooms deposit organic carbon to the deep ocean answers some — but not all — of the questions about whether fertilizing such blooms is a viable strategy for mitigating climate change. SEE ARTICLE P.313

KEN O. BUESSELER

"Give me half a tanker of iron and I'll give you the next ice age," is perhaps the best-known quote in ocean science. It comes from the late John Martin[1], a leader in the study of iron and its role in sustaining productivity in the ocean. The quip refers to Martin's proposal that the addition of iron to the upper ocean could trigger algal blooms that would ultimately alter climate by sequestering atmospheric carbon dioxide as organic carbon in the deep ocean. Smetacek *et al.*[2] have taken on the challenge of proving Martin's hypothesis experimentally, and on page 313 of this issue they report that carbon formed from iron-fertilized algal blooms does indeed sink to the deep ocean — the first time that this has been convincingly observed.

Productivity in many parts of the global ocean is limited by iron levels, as demonstrated through several studies[3] in which the addition of iron to the upper ocean stimulated phytoplankton blooms and greatly increased CO_2 uptake into surface waters through photosynthesis. But for ocean iron fertilization (OIF) to have an impact on Earth's climate, organic carbon produced by the phytoplankton must be transported to the deep ocean where it cannot readily re-exchange with the atmosphere — this is the key event in Martin's ice-age-inducing scheme. Proving Martin's iron hypothesis therefore requires the fate of blooms to be followed.

This is what Smetacek *et al.* have done as part of the European Iron Fertilization Experiment (EIFEX). By tracking phytoplankton biomass using several methods, the authors demonstrated that at least half of the carbon captured by the algal bloom in their OIF experiment sank to depths well below 1,000 metres, some of which is likely to have reached the sea floor. Their findings help to inform us about how the oceans regulate atmospheric CO_2, and provide further input to the debate into whether the oceans can, or should, be deliberately modified using OIF to mitigate the effects of climate change — an example of a practice known broadly as geoengineering.

OIF experiments are challenging because the waters used in such studies cannot usually

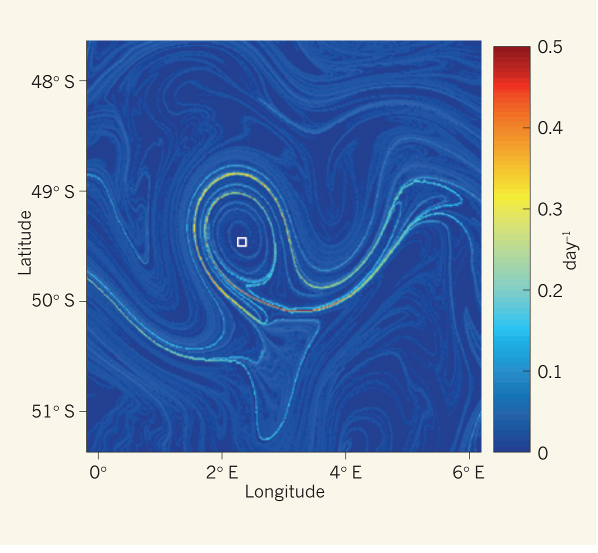

Figure 1 | Ocean eddy. Smetacek *et al.*[2] describe the results of an experiment in which they added iron salts to a patch of ocean within an eddy in the Southern Ocean, near Antarctica. The eddy is depicted here using Lyapunov exponents (reported as day^{-1}). Lines of maxima of Lyapunov exponent represent barriers to the transport of water in the ocean, and can be thought of as fronts between water masses of different origins. The white square corresponds to the centre of the ocean patch to which iron was added. The authors show that algal blooms triggered by the introduction of iron deposit organic carbon to the deep ocean.

be separated from the rest of the ocean in the way that laboratory experiments can be constrained by beakers. To overcome this problem, Smetacek *et al*. used an ocean eddy near Antarctica as a 'beaker' (Fig. 1). This solution seems to work well — the authors provide considerable evidence that the upper and lower layers of the eddy moved together coherently, and that the eddy had exchanged less than 10% of its content with the surrounding ocean by the end of the experiment.

The authors introduced dissolved iron(II) sulphate ($FeSO_4$) over a 167-km^2 patch in the eddy's core, so that the concentration of iron at the ocean's surface reached a level known to stimulate phytoplankton growth. The consequences were substantial: phytoplankton biomass more than doubled in 24 days, with 97% of the observed increase in chlorophyll associated with large diatoms, a class of phytoplankton that has high iron requirements. Along with this growth, the authors observed a reduction in levels of dissolved inorganic carbon (DIC) and of several nutrients (nitrogen, phosphorus and silicon). Data collected from stations outside the eddy, used as controls to monitor non-fertilized conditions, showed no such effects.

The scientists kept up their study for a full 37 days — longer than any other OIF experiment — and so were able to document the collapse of the diatom bloom through the formation of rapidly sinking aggregates of dead phytoplankton and zooplankton faecal pellets that carried carbon to the deep ocean. The last 13 days of observations were crucial to their success, because they enabled the authors to calculate the depletion of dissolved and particulate carbon at the surface and subsequent increases in particulate organic carbon at depth. Such 'budgets' are notoriously tricky to close in OIF studies, because of the difficulty in quantifying carbon losses that occur through air–sea gas exchange and physical mixing at the fertilized patch's boundaries, and because it is hard to account for variability in carbon levels within and outside the patch. In this case, however, the combination of evidence was clear: the iron-induced diatom bloom led to the export and sequestration of about one mole of carbon per square metre of ocean surface, from the uppermost 100 metres of ocean. In fact, one of the methods used by the authors suggested that, at its peak, carbon flux was the largest ever recorded in the Southern Ocean.

The implications of these findings are several-fold. First, a measure of the efficiency of carbon export in the experiments can be obtained by dividing the amount of DIC removed from the upper 100 metres of ocean by the amount of iron added. This measure — the carbon/iron molar ratio — is crucial for geoengineering proposals, which must specify how much iron will be needed to affect climate. In the laboratory, the ratio can be 100,000 or more[4]. By contrast, the ratios reported in previous OIF experiments[3] have been much lower, in part because iron uptake by plankton in the ocean is inefficient compared with that under laboratory conditions, but also because of differences in the amounts of iron and carbon that are recycled at the surface, or which sink to depth. Smetacek *et al*. report that the carbon/iron molar ratio in their long experiment was 13,000 — higher than in the previous OIF studies — and argue that this number would have increased further had they followed the bloom for longer.

Furthermore, the authors' results defied expectations[5] that the availability of light would limit phytoplankton growth in their experiment. Phytoplankton grow in the 'mixed layer' of the ocean, the region in which the uppermost layers of the ocean are homogenized by wind and other physical effects; the mixed layer in Smetacek and colleagues' experiment was deep, extending down to 100 metres, where little light would penetrate. Comparison of Smetacek and colleagues' study with naturally occurring blooms[6,7] in iron-rich waters near islands in the Southern Ocean also suggests that their experiment was similar to natural OIF events, and that higher sequestration was potentially possible.

Although the authors conclude that OIF does indeed sequester carbon in the deep ocean, questions remain about the possible unintended consequences of geoengineering. For example, OIF might cause undesirable effects, such as the production of nitrous oxide (a more potent greenhouse gas than carbon dioxide); oxygen depletion in mid-waters as algae decompose; or stimulation of a toxic algal bloom. And, as with all carbon-removal methods, OIF is no silver bullet for mitigating climate change. The ocean's capacity for carbon sequestration in low-iron regions is just a fraction of anthropogenic CO_2 emissions, and such sequestration is not permanent — it lasts only for decades to centuries. However, humans have already embarked on an ocean geoengineering experiment through our energy practices (which are affecting climate and acidifying the seas), by fishing, and through our other uses of ocean resources.

Most scientists would agree that we are nowhere near the point of recommending OIF as a geoengineering tool. But many think[8,9] that larger and longer OIF experiments should be performed to help us to decide which, if any, of the many geoengineering options at hand should be deployed. EIFEX certainly does not answer all of the questions about geoengineering, but by showing how the addition of iron to the ocean not only enhances ocean productivity, but also sequesters carbon, it is one of the best OIF studies so far. ■

Ken O. Buesseler *is in the Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA.*
e-mail: kbuesseler@whoi.edu

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CARDIOLOGY

Bad matters made worse

Heart attacks occur when lipoprotein-driven inflammation called atherosclerosis triggers blood clotting in the arteries. It seems that the attacks can, in turn, accelerate atherosclerosis by fanning the inflammation. SEE LETTER P.325

IRA TABAS

Heart attack, or myocardial infarction, is a leading cause of morbidity and mortality worldwide, and people who have had one infarction are at increased risk of another in the first year or so after the attack[1]. Myocardial infarction results from acute, occlusive thrombosis (blood clots) within the coronary arteries. These clots form at sites of atherosclerosis, a chronic disease process in which fat and cholesterol build up along the artery walls[2]. Atherosclerosis starts when circulating fat-carrying particles called lipoproteins, most notably low-density lipoprotein (LDL), are retained in the subendothelium, a tissue layer in the artery wall[3]. This induces an inflammatory response that involves the influx of immune cells called monocytes, which differentiate into other inflammatory-cell types, including phagocytic cells called macrophages and dendritic cells[3,4]. On page