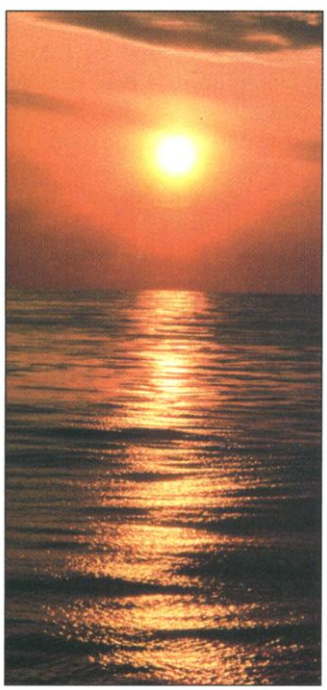
Is Ocean Fertilization Credible and Creditable?

IT IS POSSIBLE THAT THE INCREASE IN atmospheric carbon dioxide, which drives global warming, could be partially mitigated by adding iron to ocean waters. In their Policy Forum "Dis-crediting ocean fertilization" (12 Oct., p. 309), S. W. Chisholm *et al.* argue that "the known consequences and uncertainties of ocean fertilization already far outweigh hypothetical benefits." We believe that they have greatly overstated the current knowledge of ocean processes in reaching their opinion that iron fertilization is not a viable option for CO_2 management.

Presently, there are no easy means to offset the atmospheric increase in CO_2 that results from the burning of fossil fuels. The most optimistic plans, including large reductions in fossil fuel consumption, still allow for a substantial increase in atmospheric CO_2 (*1*). Only one fact seems certain: The ocean will change in response to an altered climate. Indeed, there is substantial evidence that this is already occurring (*2*–*4*). It is not known whether the changes driven by warming in the absence of iron fertilization will be more or less significant than changes that might result from deliberate iron fertilization.



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Chisholm *et al.* assert that ocean fertilization "is not easily controlled." The residence time of iron in surface waters must be substantially less than 1 year (*5*). Following large-scale iron fertilization, concentrations would be reduced to biolimiting values within 1 year, after winter deep mixing and other export processes, and in the absence of other inputs. The particulate carbon standing stock of the ocean, including phytoplankton, is known to turn over on average every 7 days (*6*). Upon cessation of fertilization, the phytoplankton stock would rapidly return to prefertilization conditions as iron concentrations decreased to ambient levels.

They write that ocean fertilization "does not mimic nature." Yet, large, natural episodic iron addition events of similar magnitude to the IronEx II addition (*7*) regularly occur in the ocean. We recently observed an aerosol deposition event in the North Pacific that raised dissolved iron concentrations to 0.7 nM over hundreds of kilometers (*8*). Such events may periodically stimulate nitrogen fixation, alter ecosystem structure, and result in the export of carbon (*9*). Elevated iron concentrations have also been observed in surface waters of the equatorial Pacific after rain (*10*) and along the ice edge in the Antarctic (*11*). In the coastal ocean, large iron injections that fertilize the spring bloom occur during the onset of deep-water upwelling (*12*).

Ocean fertilization "is not easily verified" according to Chisholm *et al.* Neither is global warming, although abundant indirect evidence supports the almost inescapable conclusion that it is occurring. The critical issue regarding ocean fertilization is not verification to claim carbon credits, but whether it is a feasible strategy to mitigate increasing CO_2 in the atmosphere.

Chisholm *et al.* state that ocean fertilization "would likely result in deep ocean hypoxia or anoxia." These conclusions are based on calculations using a model with zero-order kinetics for carbon consumption (*13*). Increasing the carbon flux to the deep sea must increase oxygen consumption there. However, paleoceanographic data do not indicate widespread anoxia (*14*). Oxygen utilization rates appear to decrease in low oxygen areas, which shifts carbon and oxygen consumption to deeper, more oxygenated zones of the ocean (*15*).

Considerable uncertainty remains about these issues. Decisions to initiate or abandon ocean fertilization must be weighed carefully after we have learned substantially more about carbon cycling through the ocean. It is simply not credible, or creditable, to suggest that we know enough to understand the impacts of ocean fertilization at the present time.

KENNETH S. JOHNSON[1]* AND DAVID M. KARL[2]
[1]Monterey Bay Aquarium Research Institute, 7700 Sandholdt Road, Moss Landing, CA 95039, USA. [2]Department of Oceanography, School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, HI 96822, USA.
*To whom correspondence should be addressed. E-mail: johnson@mbari.org

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Response

IN THE LAST DECADE, SCIENTISTS HAVE enriched small patches of the oceans with iron to study the regulation of phytoplankton growth and the role of the oceans in the global carbon cycle. These short-term (1 month), small-scale (10 km^2) experiments have been a valuable tool for understanding the regulation of marine ecosystems. It has been argued that scaled-up ocean fertilization could be used to draw significant quantities of CO_2 out of the atmosphere. This has led to patented procedures for ocean fertilization in anticipation of a global market for carbon credits. In our Policy Forum, we recommend against this approach to greenhouse gas mitigation for two reasons. First

and foremost, models show that if it worked and was scaled up to the global oceans and implemented for 100 years, it could at best postpone the trajectory of climate change by a few years. Second, manipulations of the oceans at this scale will (and indeed must) alter marine ecosystems dramatically.

Our Policy Forum challenges specific claims outlined in the patent applications for ocean fertilization—i.e., that it is an easily controlled, verifiable process that mimics nature and that it is an environmentally benign, long-term solution to atmospheric CO_2 accumulation. Johnson and Karl disagree. We stand by our statements as they apply to ocean fertilization for commercial purposes. If carbon sequestered via ocean fertilization could be traded, the economic incentives would almost certainly lead to multiple manipulations by more than one company or group, with large-scale, long-term cumulative effects that could not be attributed to any one application. We agree with Johnson and Karl that episodic nutrient enrichment events are part of the natural biogeochemical cycles of the oceans and that any single small-scale application of iron would have no lasting effect on the ocean ecosystem. But this is not true of scaled-up, long-term efforts guided by the free market in a global commons. Moreover, a requirement of any carbon sequestration option in the carbon credit market is that it must be verifiable. This is not "easily" done for ocean fertilization, especially in the context of multiple manipulations. In fact, it is currently beyond our capabilities.

We explicitly do not call for restriction of basic research on how iron affects ocean ecosystems or biogeochemical cycles. Indeed, much research is needed to improve our understanding of the carbon cycle and its connection to climate, including possible consequences of altered fluxes of nutrients to the ocean. But the prospect of ocean fertilization for carbon credits should not be driving this research.

S. W. CHISHOLM, P. G. FALKOWSKI, J. J. CULLEN
[1]Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA 02138, USA. [2]Department of Geology, Rutgers University, New Brunswick, NJ 08901, USA. [3]Department of Oceanography, Dalhousie University, Halifax, Nova Scotia B3H 4J1, Canada.

Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 6 months or issues of general interest. They can be submitted by e-mail (science_letters@aaas.org), the Web (www.letter2science.org), or regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space.

Rock Art Revisited

TWO PIECES OF ENGRAVED RED OCHRE FROM Blombos Cave, South Africa, dating to 77,000 years ago and displaying "motifs" evidencing the existence of "arbitrary conventions unrelated to reality-based cognition" are reported by Henshilwood *et al.* ("Emergence of modern human behavior: Middle Stone Age engravings from South Africa," Reports, 15 Feb., p. 1278).

We propose the following hypothesis as an alternative to that presented by Henshilwood *et al.*: that the Blombos Cave engraved ochres represent small, portable objects upon which reality-based tallies were recorded. Three lines of evidence support this hypothesis: (i) the worn condition of the ochre objects, (ii) duplications of lines consistent with erasure and reuse, and (iii) the sequence in which lines were engraved.

First, both the SAM-AA 8937 and 8938 pieces exhibit irregular surfaces blemished by pits and scrapes. Although it may be that preparing surfaces and engraving resulted in objects that look worn, it is also plausible to suggest that a utilitarian function produced a worn appearance. Second, the occurrence of duplicate parallel lines is consistent with active use and reuse. We suggest that such lines were caused by reuse after incomplete erasure by grinding rather than simultaneous scoring occasioned by a change in position of the engraving tool. Finally, the sequence of engraving, wherein a series of lines was first engraved in one direction and then sequentially cross-hatched, suggests that the lines may have served a utilitarian recording or counting function.

We consider the evidence equivocal as to the nature of the symbolic content of the engraved ochre pieces. Perhaps they reflect cognitive shifts facilitating both art and science. Whether motifs, tallies, or yet some other alternative, the patterns on the engraved ochre provide a fleeting glimpse into the minds of those inhabiting Africa some 35,000 years before the beginning of the Upper Paleolithic. Modern minds should remain open to the range of cognitive possibilities represented by these enigmatic data.

JILL BULLINGTON AND STEVEN R. LEIGH
Department of Anthropology, University of Illinois, 607 S. Matthews Street, Urbana, IL 61801, USA. E-mail: bullngtn@uiuc.edu, s-leigh@uiuc.edu

Beauty, Biological Weapons, and Botox

AS DONALD KENNEDY ELEGANTLY STATES IN his editorial "Beauty and the beast" (1 March, p. 1601), "Who would have imagined a world in which terror weapons are employed as beauty aids?" He is right; who would have ever imagined a world in which the poison botulinum toxin would effectively address problems such as back pain, tension headaches, migraine headaches, anal fissures, hyperhidrosis, fibromyalgia, and the neuralgia that lingers after shingles? Could anyone have envisioned that this agent would offer relief to individuals with cerebral palsy or help with the symptomatic treatment of multiple sclerosis?

I had never anticipated a time when my "in office" trainees would include neurologists and when consultations with pain specialists would occur regularly. Suddenly I find myself, a dermatologist, conducting clinical studies with neurologists to develop uses of this terrible toxin.

I enjoy making people look better. Is there value in what I do? You might read *Survival of the Prettiest: The Science of Beauty* (*1*) or even *The Adonis Complex: The Secret Crisis of Male Body Obsession* (*2*). Or I could introduce you to patients of mine with HIV who are on highly active antiretroviral therapy and have lost all their facial fat and, therefore, refuse to leave the house, or maybe the Parkinson's patients, women in particular, who have such severe hair loss from their medication that they stop taking it. Yet, many of the uses I have found for botulinum toxin came from my initial experience with it in cosmesis.

In the field of aesthetic medicine, I am not convinced that the Food and Drug Administration (FDA) has the best record in dealing with these agents. I remember all too well when the FDA took aim at breast implants and created a level of medical hysteria that, to this day, remains unsurpassed.

Although Saddam Hussein may have barrels of botulinum toxin, it would be a poor choice for a biological weapon. The toxin-liberating bacteria are very unlikely to work through inhalation, because they are anaerobes and will not germinate in the air. Furthermore, although their mode of