with different climate and biome models agree on the broad features of the change, notably a major poleward shift of temperate forest types and an expansion of boreal forests into the tundra. The studies vary in how far this forest expansion is offset by the conversion of temperate forests in more continental climates to grassland or shrubland. All show an increase in the potential area of tropical forest, though this is slight in recent, process-based analyses[11]. Carbon storage at equilibrium tends to increase[8,11,12], but the first attempts to simulate the kinetics involved suggest that for decades climate-driven vegetation changes would produce a source, not a sink, for carbon[13,14]. This is simply because forest decline and oxidation of soil carbon in some regions would occur faster than new forest growth and accumulation of soil carbon elsewhere. We do not yet have realistic estimates of how large this source would be, or how it would interact with the carbon sink due to increasing net primary production.

Considering all the relevant processes, it becomes clear that the biosphere can produce both negative and positive feedbacks to CO_2-induced global warming, and that the direction of these feedbacks can change with time. To understand the interactions among these processes, in a quantitative and predictive sense, is the difficult (but essential) task for global ecology. □

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Organic trouble

THE difficulty of accurately measuring the traces of organic material residing in sea water was highlighted in a recent issue of *Marine Chemistry*, built on a meeting on dissolved organic carbon (DOC) and nitrogen (DON) held in Seattle in 1991. In one article[10], Y. Suzuki retracted results that had stimulated a lot of excitement when they first appeared in 1985[11] and 1988[12] (see my previous News and Views article[13]). In the earlier papers, Suzuki and colleagues unveiled a new technique, high-temperature catalytic oxidation (HTCO), which apparently showed DOC and DON levels to be as much as 2–4 times higher than previously believed. The measurements seemed to highlight an unknown, large, long-lived component of dissolved organic matter that is resistant to microbial oxidation. Also, a strong correlation of the new DOC levels with dissolved oxygen levels in the thermocline suggested that DOC and DON must have a large and unexpected role in the cycling of carbon and nutrients in the ocean.

But now it seems that the actual DOC levels are lower than originally reported by Suzuki and colleagues. Much of the discrepancy seems to come from instrumental carbon contamination, or 'blanks', perhaps associated with the HTCO catalyst[14]. (Typical HTCO samples consist of only 100 μl of sea water; undetected blanks at a level of 5×10^{-9} moles can skew results by as much as 100 per cent.) When a large blank is subtracted from HTCO measurements the mysterious refractory DOC pool largely disappears.

The situation is far from bleak, however. Even with the blank correction, HTCO may still extract DOC that older methods do not extract[15]. It also seems to offer an inherent precision not seen before. Let's hope the bugs can be worked out. J.R.T.

OCEANOGRAPHY

Carbon overconsumption

J. R. Toggweiler

A FUNDAMENTAL observation in biological and chemical oceanography is the ocean-wide consistency in the elemental composition of marine organic matter (plankton biomass and undecomposed detrital particles). Bulk organic matter sieved from sea water combines carbon, nitrogen and phosphorus, on average, in the molar proportions C:N:P = 106:16:1 (ref. 1). Dissolved nitrate, phosphate, inorganic carbon and oxygen in the thermocline and deep sea follow the same ratios, suggesting that detrital organic matter oxidized in the interior of the ocean is identical in composition to the organic matter produced at the surface[2,3]. These constant proportions — known in the trade as Redfield ratios — are often used to link the production of new organic matter to the uptake or supply of nitrate and phosphate.

But measurements by Sambrotto and colleagues on page 248 of this issue[4] show matters to be more complicated. The authors have tracked the concurrent drawdown of dissolved inorganic carbon (DIC), nitrate and phosphate during spring phytoplankton blooms. They find that the amount of carbon removed from the water significantly exceeds the amount expected based on nitrate/phosphate removal and the C:N or C:P ratio in bulk organic matter. Some 30–40 per cent of the carbon removed from the water cycles through the upper ocean in an unknown way.

Monitoring the simultaneous changes in DIC and nitrate during a phytoplankton bloom may sound like a simple thing to do, but it could not have been done in any meaningful way until recently. The day-to-day changes in DIC reviewed by Sambrotto *et al.* amount to only a few micromoles per litre of sea water. Measurements accurate enough to monitor these changes have been possible only since the mid-1980s. Furthermore, the conversion of DIC into organic matter is only one of a number of processes affecting DIC. CO_2 enters the ocean from the atmosphere during spring blooms, raising DIC levels. DIC is also taken up into nonorganic biogenic material, such as $CaCO_3$ skeletons. Isolating the effect of organic carbon production from these competing processes requires simultaneous high-precision measurements of dissolved CO_2(g) and alkalinity.

Sambrotto *et al.* compile time-series data from the southeast Bering Sea continental shelf, the Bransfield Strait area adjacent to the Antarctic Peninsula, the Grand Banks, and the site of the JGOFS (Joint Global Ocean Flux Study) North Atlantic bloom experiment. In each of these areas, late-winter nitrate and phosphate levels are relatively high, providing a nutrient feedstock for rapid phytoplankton growth. Within a month or so of the beginning of the spring bloom, nitrate levels have typically declined by 3–10 μmoles per litre over the upper 30–40 m, while DIC levels have decreased by 30–130 μmoles per litre. Sambrotto *et al.* conclude that the amount of carbon removed from the water during phytoplankton blooms appears to be 10–14 times the amount of nitrate removed. This is 40–80 per cent greater than the carbon uptake explained by the production of biomass. There must be a large pool of organic material that cycles through the system with an anomalous C:N ratio.

Sambrotto *et al.* attempt to explain these results as a consequence of preferential recycling of nitrogen and phosphorus during the decomposition of detrital material. Nitrogen- and phosphorus-rich organic compounds (proteins, amino acids, nucleic acids, ATP) are thought to be consumed by microbial organisms in preference to carbon-rich compounds (such as carbohydrates and lipids). In one model, detrital material is assumed to sink slowly as it is being decomposed. Preferential recycling allows nitrogen and phosphorus to be stripped from the sinking particles in the euphotic (sunlit) zone while a carbon-rich residue settles into the aphotic layers below. The extra nitrogen and phosphorus retained in the euphotic zone fuel still more production and amplify the production of more carbon-rich particles.

There are two problems with this ex-

planation. Simultaneous measurements of organic carbon and nitrogen in marine particulate matter generally do not show a systematic bias towards high C:N ratios either in or below the euphotic zone[5,6]. (Some evidence exists for high C:P ratios in large fast-sinking particles, but there are methodological problems associated with these observations[6].) The idea of a continuously modified sinking particle pool runs into severe problems in the deep ocean. The longer and deeper these modified particles sink, the more carbon-rich they would become. This should lead to strongly skewed ratios in the variations in O_2:N, C:N, O_2:P and C:P when these particles are ultimately decomposed in deep water. A study of water below 400 m in the South Atlantic, Indian and Pacific Oceans shows no such modification[3].

A second example of preferential recycling calls for the build up of a carbon-rich detrital pool that does not sink. For this scheme to work, a large standing stock of organic carbon must accumulate in the euphotic zone over the course of a bloom, around 15–50 μmoles C per litre. This amount greatly exceeds the standing stock of phytoplankton, zooplankton and filterable detrital particles (which is less than 5 μmoles C per litre) but it is not particularly large in relation to upper-ocean pools of dissolved organic material which contain of the order of 100 μmoles C per litre. Thus, one can construct a model in which dissolved organic carbon (DOC) accumulates through the bloom and decomposes later, perhaps during the summer, or perhaps after mixing into the thermocline the following winter. One should expect to see DOC concentrations rise and fall by around 15–50 μmoles per litre with little concurrent variation in levels of dissolved organic nitrogen (DON). Given all the methodological problems associated with DOC and DON measurements (see box), it is too early to tell whether this model works or not.

Recent observations from the Bermuda Station S and the JGOFS Bermuda Atlantic Time Series Station (BATS) widen the scope of the mystery. The upper ocean around Bermuda is characteristically very low in nutrients. Nonzero nitrate levels, 0.5–1.0 μmoles per litre, are seen only briefly during mid-winter[7]. Nevertheless, time-series data of surface DIC levels near Bermuda show a regular seasonal cycle with an amplitude of 30 μmoles per litre (refs 8, 9). The drawdown phase begins at the winter–spring transition and extends into the summer. Virtually all the DIC drawdown in the spring and summer is driven by the production of organic matter[8]. During this time, there is no nitrate or phosphate in the surface water, and there are very low levels of plankton biomass and very small fluxes of sinking particles[7]. Thus, the mysterious carbon drawdown noted by Sambrotto *et al.* may exist even in nutrient-poor regions of the ocean where the spring bloom is quite muted.

The anomalous DIC drawdown at Bermuda and at the more productive sites described by Sambrotto *et al.* amounts to 1–3 moles C m^{-2}. This is a substantial fraction of the annual production of exportable organic matter (new production) at these sites. A large component of the ocean's organic-matter production defies a simple link to nutrient supply. We don't know the form that the anomalous production takes, or where or when it is ultimately oxidized. □

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SOLAR SYSTEM

Vestal voyagers unveiled

William B. McKinnon

VESTA, brightest and third-largest of the asteroids, and named after the virgin Roman goddess of the hearth, turns out to have spawned a small family of minor asteroids and, apparently, other offspring in the form of meteorites found on Earth. R. P. Binzel and S. Xu argue this[1] on the basis of family resemblances discovered spectroscopically.

Spectra of Vesta taken since 1970 indicate that it has a basaltic surface[2]. Basalt is the most common volcanic rock on the Earth and other terrestrial planets, and so it is exciting to contemplate familiar igneous activity on a small world beyond the orbit of Mars. Furthermore, basalts are not uncommon among the meteorites. Some of these extraterrestrial basalts are so young, geologically speaking, that they have been interpreted as coming from Mars. Some are from the Moon. Others form a chemically related group, the eucrites (from the Greek for 'easily distinguished'; see figure), that are geologically ancient. Their crystallization ages are coincident with the beginning of Solar System history[3], 4.5 billion years ago, and a genetic link between the eucrites and the surface of asteroid Vesta has long been suspected. This hypothesis has endured, despite difficulties in seeing how material from Vesta's orbit could reach the Earth, because no other main-belt asteroid provided a spectral match to the eucrites. Until now.

In a spectroscopic *tour-de-force*, Binzel and Xu have found data that seem finally to establish Vesta as the parent body of the eucrites and of two other related classes of meteorites, indicating in the process how these meteorites may get to the Earth. They took spectra of more than 100 small, main-belt asteroids (each less than 10 km in diameter) at or near Vesta's orbital distance; 15 of these had previously been dynamically defined to be Vesta-family objects; that is, they share very similar orbital semimajor axes, eccentricities and inclinations.

Despite the violence done to mythology in ascribing offspring to Vesta, from the standpoint of planetary geology a family of smaller asteroids near Vesta's orbit makes sense. The main-belt asteroids exist on intersecting orbits, and are a collisionally evolving population. Their average encounter speed is around 5 km s^{-1}, too fast for the colliding objects to stick and build into a single super-asteroid. This disruptive situation is attributable to gravitational perturbation of the orbits by Jupiter, and it is rather remarkable that even an asteroid as large as Vesta (520-km average diameter) has retained a basaltic crust at all. There is widespread spectroscopic and meteoritic evidence for igneous differentiation and the formation of planet-like iron cores among asteroids of the inner asteroid belt, but this evidence is coupled with inferences that these asteroids have repeatedly been catastrophically ruptured and reassembled, with only remaining lower mantles and cores surviving[4] (see my previous News and Views item[5]). So at the very least, Vesta should be accompanied by fragments or chips off its surface layers.

Of the 15 members of the Vesta family surveyed by Binzel and Xu, 12 were found to have visual and near-infrared spectra very similar to that of Vesta and the eucrites. Actually, the spectral details are quite revealing. Ten objects (including asteroid Lennon) are essentially spectrally identical to Vesta and the eucrites. Two