be characteristic of the Laurasiatheria, the superorder of mammals that includes bats (order Chiroptera), as well as several other orders. Chiroptera is further divided into two suborders, and Gracheva *et al.*[1] show that *Trpv1* occurs in both. The authors call these suborders microbats (Microchiroptera) and megabats (Megachiroptera). However, the two bat suborders are now called Yinpterochiroptera and Yangochiroptera[9], and the split of species between the two is not the same as for microbats and megabats. Gracheva and co-workers' analysis of the *Trpv1* gene in bats does not alter the current view[9] of bat phylogeny.

Gracheva *et al.*[1,3] have placed infrared detection high on the list of astonishing discoveries about the perceptual abilities of animals: it seems to have evolved in parallel within two snake lineages, and converged with the appearance in vampire bats. Their data, together with other recent findings, also enrich our knowledge of the sensory world of bats. Previous work suggested, for instance, that bats' wing membranes are as sensitive to touch as our fingertips[10]. And tactile receptors associated with sensory hairs on the bat wings are known to monitor flight speed and air flow[11]. The perceptual world of bats undoubtedly has many more intriguing secrets yet to be discovered. ■

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OCEANOGRAPHY

Forecasting the rain ratio

Marine algae known as coccolithophores produce much of the ocean's calcium carbonate. A large survey reveals how these organisms' calcification processes and species distribution change in response to carbon dioxide levels. SEE LETTER P.80

DAVID A. HUTCHINS

Coccolithophores are humble marine phytoplankton that are the subject of a simmering controversy in marine science concerning their response to ocean acidification. On page 80 of this issue, Beaufort *et al.*[1] report a finding that should help settle the matter: coccolithophores produce thinner calcium carbonate shells as oceans become more acidic. But the mechanisms involved, and an unexpected exception to the general rule, may surprise those studying global change.

Over the past 220 million years or so, coccolithophores have performed a unique dual function in the ocean's carbon cycle. Like all phytoplankton, coccolithophores make their living by converting dissolved inorganic carbon in sea water into organic carbon through photosynthesis. But they also have a singular ability to use dissolved inorganic carbon to produce a mineral shell consisting of coccoliths, overlapping plates of calcium carbonate ($CaCO_3$). Although the alga's long evolutionary history spans several major fluctuations in atmospheric carbon dioxide content, predicting the responses of coccolithophore calcification to ocean acidification — the anthropogenic enrichment of the modern ocean with CO_2 — has been anything but straightforward.

The question of how coccolithophore calcification will respond to future high CO_2 conditions has big implications for the ocean's carbon cycle, and perhaps also for global climate. The ratio of $CaCO_3$ to organic carbon in the continuous 'rain' of biogenic particles that sink down from the ocean's surface (the 'rain ratio'[2]) is a key factor in carbon biogeochemical models, for several reasons[3]. One of the most important is that, in contrast to the photosynthetic production of organic carbon, which consumes CO_2, the calcification reaction produces CO_2 by converting two bicarbonate ions (HCO_3^-) into one $CaCO_3$

NATURE

50 Years Ago

It should not be deduced from this that, his scientific training and proclivities apart, the good scientist of to-day is ignorant about or, even worse, unaware of, other branches of man's culture. In fact, the contrary is true; indeed, so far as the community of scientists is concerned, the so-called 'two cultures' (fashionably ascribed to C. P. Snow) scarcely exist. Many scientists are well read outside their own discipline, sometimes still within the ambit of science, but more often well beyond it — in philosophy, history, art, music, the theatre, literature, in fact, in the humanities generally. (Good scientists seldom make good politicians, which is probably understandable.) … In short, it is high time that the general opinion, still very extant, that the man of science is so wrapped up in his scientific literature and so confined to his laboratory that, apart from his calling, he is culturally unbalanced, be challenged. Indeed, the shoe is on the other foot; it is the student of, and savant among, the humanities, art, music and non-scientific literature (especially fiction) who are — and are often proud to admit they are — quite ignorant of science and its now 'jet-propelled' progress.
From *Nature* 5 August 1961

100 Years Ago

'The Birmingham meeting of the British Medical Association' — According to Dr. Provan Cathcart, the quality, and not the quantity, of the protein is the important matter physiologically, for the nearer the composition as regards the constituent amino-acids approaches that of the tissue-protein of the animal being fed, the less will there be of nitrogenous waste from that animal. Thus dogs wasted less nitrogen when fed on dog-flesh than on any other kind of protein.
From *Nature* 3 August 1911

and one CO_2 molecule (Fig. 1). Thus, the concentration of CO_2 in sea water is sensitive to changes in the rain ratio, which is a proxy for the amount of calcification versus photosynthesis occurring in the ocean.

The link between calcification and fluxes of climate-altering CO_2 prompted experiments that found that the production of $CaCO_3$ was reduced in coccolithophores growing at elevated CO_2 levels[4–6]. Given that future ocean CO_2 concentrations are expected to be high, concomitant reductions in calcification would lower the rain ratio, potentially helping to counter the rise in atmospheric CO_2 concentrations. But just as marine scientists were becoming comfortable with this emerging ocean-acidification model, other papers[7,8] stirred the pot by reporting that high CO_2 levels increase the amount of $CaCO_3$ produced by coccolithophore cells.

Beaufort *et al.*[1] have now boldly charged into the resulting confusion and dissension. Unlike the previous studies, their work did not manipulate CO_2 levels in cultures[4,6] or in natural communities[9,10] of coccolithophores. Instead, they used image-analysis techniques to determine the masses of more than half a million individual coccoliths from hundreds of modern surface seawater samples and from ancient marine sediment cores, collected from all over the world. They also measured the corresponding concentrations of dissolved inorganic carbon in the modern seawater samples, or calculated these concentrations for the sediment cores using accepted palaeoceanographic proxies.

Their findings are unequivocal: as CO_2 concentration increases, coccolith mass declines in a more or less linear fashion. This relationship holds up regardless of the large local variations in seawater CO_2 concentrations found in today's oceans, and it also holds up over long-term temporal fluctuations in atmospheric CO_2, such as those that have occurred over glacial–interglacial cycles. The results seem to offer solid support for the hypothesis that coccolithophore cells will be less calcified in the future acidified ocean. But there is another twist to the story.

Beaufort *et al.* point out[1] that the variations in coccolith mass measured in their study are much larger than the decreases in cellular $CaCO_3$ typically observed when single species of coccolithophores are grown in culture at high CO_2 concentrations. In fact, much of the coccolith-mass variability they recorded was apparently the result of taxonomic shifts in the coccolithophore community, rather than the result of reduced calcification within individual species. As levels of CO_2 in sea water increase, assemblages of the algae progressively shift away from larger, heavily calcified species and towards smaller, lightly calcified ones.

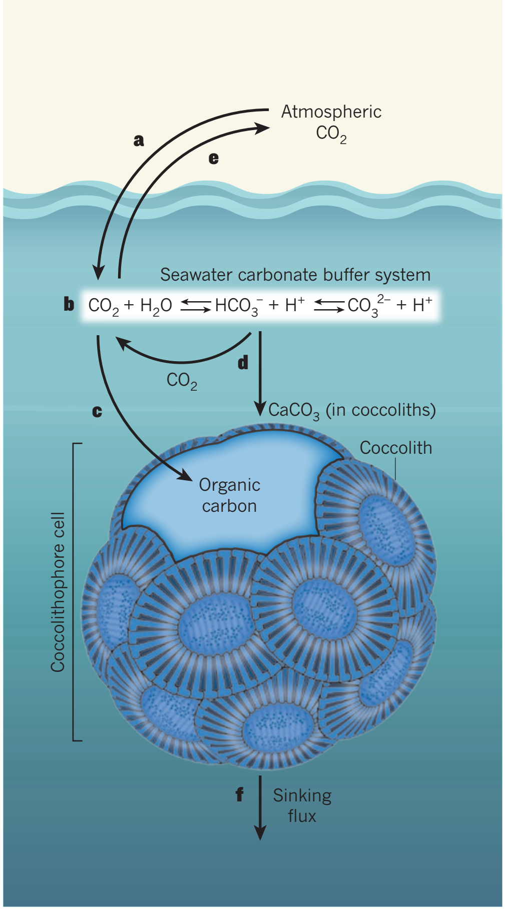

Figure 1 | Coccolithophore carbon chemistry. **a**, **b**, When atmospheric CO_2 enters the sea surface (**a**), it undergoes a series of reversible chemical reactions known as the seawater carbonate buffer system (**b**), which releases protons (H^+) that acidify the sea water. **c**, Coccolithophores and other algae assimilate CO_2 to produce organic carbon through photosynthesis. **d**, Coccolithophores also perform calcification reactions, in which two bicarbonate ions (HCO_3^-) are converted into one calcium carbonate ($CaCO_3$) and one CO_2 molecule. The $CaCO_3$ is incorporated into coccoliths in the algal shell. The CO_2 from calcification is released, and can either contribute to ocean acidification or degas back to the atmosphere (**e**), contributing to global warming. **f**, Biogenic particles from coccolithophores and other phytoplankton sink from the ocean surface. The ratio of $CaCO_3$ to organic carbon in this 'rain' of biogenic particles is a critical parameter in the marine carbon cycle. Beaufort *et al.*[1] show that coccolithophores produce less calcium carbonate at higher seawater concentrations of CO_2.

This trend occurs even within species, so that robustly calcified strains or morphotypes are replaced by more delicately calcified ones as CO_2 levels rise. The authors' results therefore seem to imply that seawater carbonate chemistry is a strong selective force determining the taxonomic composition of coccolithophore communities.

So does this mean that the previously reported observations of increased cellular calcification in cultured coccolithophores at elevated CO_2 concentrations were simply wrong? Not necessarily. Provocatively, Beaufort *et al.*[1] also discovered one particular coccolithophore morphotype in their modern data set that goes decidedly against the general trend. This strain became much more heavily calcified as CO_2 levels increased and as pH decreased along a sampling transect that ranged from the open ocean to coastal upwelling waters. The strain seems to be genetically similar to the widely distributed coccolithophore morphotype used in the controversial culture studies[7,8].

This surprising exception to the rule raises new questions. For instance, if there are common strains of coccolithophores that thrive and calcify more at high CO_2 concentrations, why don't they always dominate where seawater CO_2 is elevated? (They obviously don't do this, because if they did, they would have obscured the strong negative correlation between CO_2 and calcification observed by Beaufort *et al.*[1].) The most likely reason is that many unknown factors also influence the abundance and calcification of coccolithophores. In fact, despite decades of intensive research effort, the environmental controls on coccolithophore growth are probably less well understood than for almost any other major phytoplankton group. What is clear, however, is that the environmental controls involved include many of the same factors that will also change concurrently with CO_2 levels and pH under future global-change scenarios, such as temperature, visible and ultraviolet light intensity, and the availability of nutrients and trace elements[11].

The next challenge for marine scientists is to try to understand how coccolithophore calcification and ecology will respond to evolutionary selection induced by this complex web of simultaneously changing environmental variables. Only then will we be able to predict what the net outcome will be for the future rain ratio of the ocean, and for the enigmatic phytoplankton group that drives it. ■

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