

stimulates insight consist of? Explicit memory tasks are generally thought to be more sensitive to deprivation of slow-wave sleep⁴. On the other hand, most of the famous cases of scientific insight and artistic creativity (Fig. 1) are reported as emerging from a dream, which is a mental activity that occurs more frequently during the sleep pattern known as rapid-eye-movement (REM) sleep. Another possibility is that both non-REM and REM sleep are sequentially needed to optimize the memory^{5,6}. Wagner *et al.* give us the tools to explore these questions experimentally. Their paper constitutes steps forward in investigating the unpredictable and elusive phenomenon of insight, and in broadening the scope of the research on sleep, cognition and brain plasticity (the brain's ability to persistently change its structure and/or function).

The role that sleep plays in human creativity will be a mystery for some time yet. But at the very least, Wagner *et al.* give us good reason to fully respect our periods of sleep — especially given the current trend to recklessly curtail them.

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Biogeochemistry

Carbon budget in the black

Michael W. I. Schmidt

A significant fraction of a common organic component of marine sediments has an unexpected source, providing a fresh context for studies of the global carbon cycle in oceanic and terrestrial settings.

The global carbon cycle is both a consequence and a determinant of the state of the planet. Not surprisingly, then, a small army of scientists is at work studying the exchange of various guises of the element between land, atmosphere and ocean. One of those guises is 'black carbon', a relatively inert form that is produced by incomplete combustion during wildfires or the industrial burning of fossil fuels. It initially accumulates in soils, and is then distributed to lake and river sediments, and eventually to marine sediments.

On page 336 of this issue, Dickens *et al.*¹ describe the results of their investigations into how much black carbon is stored in marine sediments. They have analysed sediment laid down in pre-industrial times, and conclude that the fire-derived carbon content has been overestimated. As much as half of the organic carbon previously identified as black carbon instead appears to be fossil 'graphitic' black carbon — that is, carbon derived from the weathering of rocks.

This conclusion is based on two pillars of evidence. One is that although it was previously not possible to distinguish chemically between fire- and rock-derived carbon, Dickens *et al.* have done so using a novel chemical approach. They have therefore been able to isolate graphitic black carbon. The other arises from application of the isotope ¹⁴C as an analytical tool. Organic carbon that originates in terrestrial wildfires has a ¹⁴C signature. Carbon derived from fossil-fuel burning in the industrial era, or

from geologically much older sources (such as metamorphic rocks), has no such signature — that is, it is 'radiocarbon dead'. The literature on this topic is rather scant. But by combining their own data from

pre-industrial samples with previous results, Dickens *et al.* make the case that the proportion of fire-derived black carbon in global marine sediments has been overestimated.

Here, however, a comment by Alexandre Dumas in the nineteenth century comes to mind: "All generalizations are dangerous, even this one." The results of Dickens *et al.* stem from a limited number of samples, originating mostly from the continental shelf off the American Pacific northwest. They may therefore be representative of such regions — tectonically active continental margins, with high erosion rates on land and high sedimentation rates in the adjacent marine environment. But there are not enough data from other places to be sure that the results apply more widely to the same extent. For example, sediments from open ocean areas are represented by only one sample from the central Pacific.

As always, more data would be helpful, and would increase confidence in Dickens and colleagues' conclusions. But to be fair, Dumas' point applies to much research in this field, and the authors do present a plausible case. If their results are indeed typical for many regions of the world, they will have considerable influence on both oceanographic and terrestrial studies of the carbon cycle.

The authors themselves describe some of the implications. For instance, they consider that radiocarbon dating of sedimentary organic carbon may need a rethink. And they calculate that 7×10^{11} g of graphitic black



Figure 1 Carbonized conundrum. Black carbon is formed during wildfires in ecosystems such as savannah grasslands and high-latitude coniferous forests. a, Immediately after a fire, the local area is covered by large pieces and dust-sized particles of black carbon. b, After 60 years, a few charred tree stumps remain among a new generation of trees, and only small quantities of black carbon can be detected in the soil. c, Its fate could be export by rivers into the oceans (the Yenesei River, which runs into the Arctic Ocean, is shown here). But given the finding¹ that marine sediments contain less fire-derived black carbon than previously thought, some of the carbon must be degraded at an earlier stage or stored elsewhere.

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carbon is deposited annually in the world's oceans. This is only some 0.5% of the total amount of organic carbon estimated to be buried in marine sediments each year. But because graphitic black carbon is thought to be created and destroyed very slowly, Dickens *et al.* think that this loop may act as a significant 'holding pool' of organic carbon distinct from the main parts of the carbon cycle.

As far as terrestrial studies are concerned, a host of questions arise. Black carbon is produced in enormous quantities by wildfires and by burning fossil fuels², and it is virtually ubiquitous in the terrestrial environment³. But if much less black carbon is ending up in marine sediments than we had thought, where is the excess? Possibilities include retention in the marine water column, or in rivers, soils or the atmosphere. If it is not stored in these 'sinks', it might be degraded before it reaches them, possibly both mechanically and chemically.

There has, however, been little unambiguous evidence that either process is occurring^{3–5}. As an example, take high-latitude coniferous forests, which are large, fire-prone ecosystems (Fig. 1). These forests burn quite often, but the amounts of black carbon on the forest floor and underlying soil can be surprisingly small⁶. Is the black carbon re-burnt during subsequent fires? Do freezing and thawing break it up into smaller particles, thus making it more susceptible to chemical degradation? There is evidence that atmospheric black carbon can be oxidized and become water-soluble⁷, a fate to which terrestrial black carbon might also succumb. Further, water-soluble carbon, discharged in groundwater and rivers, may not be accounted for in carbon budgets at the regional scale⁸.

The work by Dickens *et al.*¹ gives us a lot to think about. If the quantity of black carbon in marine sediments has indeed been overestimated, then the rates at which it is degraded have been underestimated and its contribution to the global carbon cycle^{2,9} must be redefined. The terrestrial aspect of that cycle is especially poorly understood; black carbon is just one of the many pieces still missing from the jigsaw¹⁰.

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Virology

A class act

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Membrane fusion occurs in many situations in living organisms — when certain viruses enter host cells, for instance. Three crystal structures shed light on the protein rearrangements that bring about such fusion.

Many viruses, such as the dengue fever, influenza and human immunodeficiency viruses, are encased in a lipid membrane. To reproduce, such 'enveloped' viruses must enter a host cell by fusing their own membrane coat with that of the cell. Fusion is caused by specific proteins in the viral membrane, and at least two classes of these proteins have been identified. In both classes, tightly regulated conformational changes are involved in membrane fusion. But class I and class II fusion proteins have distinct structural features — raising the expectation that the details of the two fusion mechanisms would also be unique. Yet the crystal structures of the post-fusion forms of three class II proteins, described elsewhere in this issue^{1,2} and in *EMBO Journal*³, suggest an unanticipated mechanistic parallel between class I and class II fusion proteins. The new structures also provide the first view of a key region of the proteins (the fusion loop) in the conformation that is predicted to insert into the target membrane.

The haemagglutinin protein from influenza virus has provided the model for class I fusion machines, because the atomic structures of three different forms of this protein have been determined⁴. The class I model, in

its essential features, applies to many unrelated virus families and their fusion proteins, including the HIV gp120 protein, the F proteins from paramyxoviruses, the retroviral SU/TM proteins and the Ebola virus Gp2 protein. For influenza haemagglutinin, a drastic refolding of the protein is observed between its pre-fusion and post-fusion forms (Fig. 1). Related refolding events have been inferred for the other class I proteins⁵.

The second class of viral fusion protein was postulated⁶ from the striking structural conservation of the pre-fusion forms of three particular proteins. Two of these, the E proteins of tick-borne encephalitis virus (TBE)⁷ and dengue virus⁸, are likely to be representative of a large and diverse family of RNA viruses, the Flaviridae, which also includes yellow fever virus, West Nile virus and hepatitis C virus. The third protein — the E1 protein of Semliki Forest virus⁶ — represents a family of RNA viruses called Togaviridae, of which the best known is the rubella virus, which causes German measles. The post-fusion structures of dengue virus E protein¹, Semliki Forest virus E1 protein² and TBE E protein³ have now been determined; they reveal a marked and surprising convergence of the class I and II fusion mechanisms.

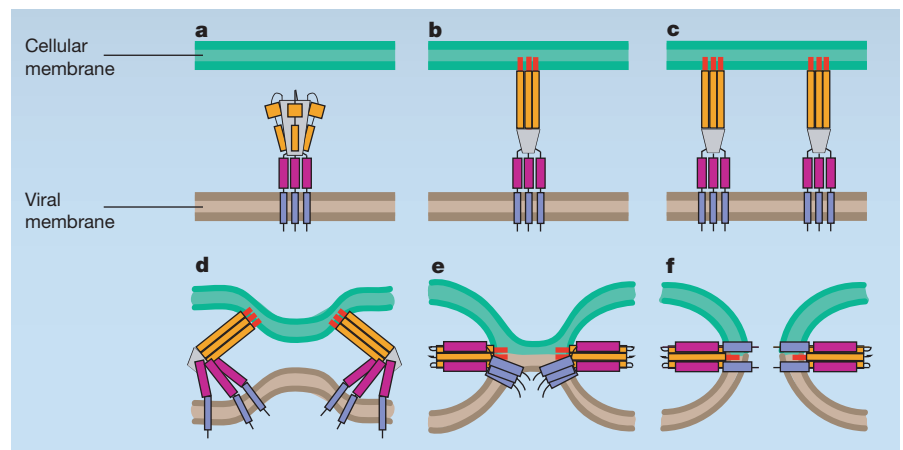


Figure 1 Proposed mechanism for membrane fusion by class I fusion proteins. a, The metastable conformation of a trimeric generalized fusion protein, with helical domain A in orange, helical domain B in pink, and the transmembrane domain in purple. b, After binding to a receptor on the cellular membrane, or on exposure to the low pH found in intracellular compartments (endosomes), the protein forms an extended conformation and the hydrophobic fusion peptide (red) inserts into the target membrane. c, Several trimers are thought to be involved. d, Protein refolding begins. The free energy thereby released causes the membranes to bend towards each other. e, Formation of a restricted hemifusion stalk allows the lipids in the outer leaflets of the membranes to mix. f, Protein refolding completes, forming the final, most stable form of the fusion protein, with the fusion peptide and transmembrane domain anti-parallel to each other but in the same membrane. Only a and f have been observed by crystallography, but biochemical data support many of the proposed steps.