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EDITORIAL

Biology and Chemistry: Life and Death

A few days ago a report in the newspaper asked a provocative question in its title: 'Did algae kill off the mighty dinosaurs?'. The subheading suggested a possible cause: 'Toxins released by tiny organisms may've played major role in 5 mass extinctions' (*Times of India*, 31 October 2009). Mass extinctions also featured in *The Economist* (24 October 2009) under an even more intriguing heading: 'I am become Death, destroyer of worlds'. Both reports seemed to focus on the causes of the sudden disappearance of dinosaurs about 65 million years ago. The generally accepted (or so I thought) view is that the cataclysmic events following the impact of an asteroid on Earth exterminated the dinosaurs. Nearly three decades ago, Luis Alvarez and his colleagues advanced an 'extraterrestrial cause for the Cretaceous–Tertiary extinction' (Alvarez, L. W. *et al.*, *Science*, 1980, **208**, 1095). Using the higher iridium abundance in deep sea limestones, as a diagnostic for an extraterrestrial origin, these authors argued that an 'earth-crossing asteroid would, upon impact, inject about 60 times the object's mass into the atmosphere as pulverized rock. The resulting darkness would suppress photosynthesis and the expected biological consequences match quite closely the extinctions observed in the paleontological record'. They estimated the diameter of the asteroid as 10 ± 4 kilometers. The possible site of impact was later suggested to lie in the Yucatan peninsula, in what is now Mexico. The Chicxulub crater appears to have a diameter (180 km) that may account for the proposed asteroid impact. *The Economist* article raises an interesting possibility 'that everyone was wrong'. The report describes a presentation made by Sankar Chatterjee of Texas Tech University which suggests that a much bigger crater, 500 km across located off the coast of Mumbai, may be a better candidate. 'Bombay High', an underwater mountain, is evidence for a squeezing upwards of magma, following the dramatic impact. Chatterjee has christened the crater as Shiva, a tribute to the awesome power of the impact. There are anomalies in extinction theories following asteroid impact which suggest that this will remain an area that will continue to be a fertile ground for new hypotheses. While there is compelling drama in asteroid impact scenarios, I found the suggestion that algal toxins are likely suspects in mass extinction, intriguing. Here, death would come slowly, creeping up unseen upon the victims.

The algal toxin hypothesis has been advanced in a recent paper by J. W. Castle and J. H. Rodgers Jr (*Environmental Geosciences*, 2009, **16**, 1), 'based on evidence from the geologic record and modern environments'. In this scenario the responsibility for mass extinctions of life that have taken place over hundreds of millions of years rests on microorganisms, whose ability to produce poisonous molecules seems unmatched. Castle and Rodgers base their hypothesis on the fact that 'mass mortalities of invertebrates, fish, birds and mammals caused by algal-produced toxins are occurring in modern environments'. They note that 'in addition to direct effect of these toxins, the large mass of organic material produced by algal blooms can lead to oxygen depletion during decay, which indirectly causes death of some biota'. The authors base their hypothesis on geologic evidence that is obtained from the fossil record, which 'demonstrates a pronounced increase in abundance and environmental range of algae, including stromatolitic cyanobacterial mats, coincident with Phanerozoic mass extinctions'. The evidence for the alleged involvement of cyanobacteria in the mass murder of other forms of life seems circumstantial; their entombment in rocks that date back to the geological period of the mass extinctions and their ability to cause death in modern environments seem to come together in allowing Castle and Rodgers to point an accusing finger. Unschooled, as I am, in the subjects of geology, microbiology, paleobiology and ecology, this report would not have attracted my attention if the *Times of India* subeditor had not chosen a dramatic headline 'Did algae kill off the mighty dinosaurs?'. Curiously, the authors of the original paper are circumspect. They provide evidence for 'increased microbial activity associated with mass extinction' for the first four of the five major extinctions that are now established. The most recent that occurred about 65 million years ago (End Cretaceous) does not seem to have a clear correlation with any rise in cyanobacterial populations. It is the end of the Cretaceous period, which follows the Jurassic (a name brought into the public consciousness by Michael Crichton and Steven Spielberg), which marked the end of the dinosaurs. The possible role of algal blooms in mass extinctions assumes importance in view of the various projections for global warming, climate change and the attendant consequences. Castle and Rodgers provide a warning note: 'Environmental changes such as climatic warming, sea level fluctuations, and increased nutrient supply may have promoted algal blooms over vast expanses of marine to freshwater environments. From the increasing frequency of modern, toxin-producing algal blooms, which may be related to global warming, another massive biotic crisis could be forthcoming'.

In thinking about the unseen agents of large scale extinctions, I was reminded of an essay entitled 'Planet of the Bacteria' written by Stephen Jay Gould over a dozen years ago (*Washington Post Horizon*, 1996, **119**, 344). Gould begins, in characteristically engaging style, noting that his 'interest in paleontology began in a childhood fascination with dinosaurs'. He recalls the old method of dividing the fossil record 'into a series of "ages" representing the progress that supposedly marked the march of evolution: the "Age of Invertebrates" followed by the Age of Fishes, Reptiles, Mammals and finally, with all the parochiality of the engendered language then current, the "Age of Man" '. In his critique of this system of developing a 'history of life', Gould argues that 'we certainly should honor life's constant mode. We live now in the "Age of Bacteria". Our planet has always been in the "Age of Bacteria" ever since the first fossils – bacteria, of course – were entombed in rocks more than 3 billion years ago'. Gould's essay must be required reading for every student of biology and all those interested in the history of living organisms. The antiquity of bacteria, their resilience over geological time scales, their chemical virtuosity and their central role in the ecological cycles which recycle organic matter justifies Gould's assertion: 'On any possible, reasonable or fair criterion, bacteria are – and always have been – the dominant forms of life on Earth'. His eloquence is evident when he concludes: 'Bacteria have been the stayers and keepers of life's history'.

The microbial world also throws up somewhat more complex unicellular organisms, fungi, which are also capable of producing an amazing repertoire of molecules, some of which prove to be extremely potent toxins. Recent interest in the role of microorganisms in causing a precipitous decline in amphibian populations has focused on a group of fungi called chytrids, specifically on the formidably named organism *Batrachochytrium dendrobatidis*, which rapidly kills frogs. 'The pathogen infects over 350 species of amphibians and is found on all continents except Antarctica' (Fisher, M. C. *et al.*, *Annu. Rev. Microbiol.*, 2009, **63**, 291). This ongoing extinction provides an unparalleled opportunity to examine a biological phenomenon that must have repeatedly shaped the planet's biodiversity. An analysis of an outbreak of chytridiomycosis in Panama concludes that 'it is no longer correct to speak of global amphibian declines but, more appropriately, of global amphibian extinctions' (Lips, K. R. *et al.*, *Proc. Natl. Acad. Sci. USA*, 2006, **103**, 3165). These authors suggest that a commonly held view that infectious disease may not lead to extinction may need to be reexamined. They note that 'understanding the causes and consequences of diminishing biodiversity and understanding the ecology and evolution of infectious diseases are two of the eight grand challenges in environmental sciences'. The mechanisms by which microorganisms commit mass murder are invariably mediated by molecules, most often misleadingly called 'secondary metabolites'. It is clear that microbes invest a considerable genetic effort in synthesizing complex organic molecules, which target other organisms with a frightening degree of efficiency. Chemistry is central to both life and death. While a large number of algal (cyanobacterial) toxins have been identified, the molecular weapons used by the frog killing fungus remain unknown. Can toxicity be avoided? Curiously, frogs may host another bacterium on their skin which in turn produces a metabolite that eliminates the pathogenic fungus (Bruckner, R. M. *et al.*, *J. Chem. Ecol.*, 2008, **34**, 1422). A renaissance of an old discipline, 'natural products chemistry' is undoubtedly being catalysed by the growing realization that novel molecules may be central actors in shaping the biological world.

The morbid side of chemistry is wonderfully highlighted in a delightful book, entitled *Molecules of Murder: Criminal Molecules and Classic Cases*', by John Emsley (Royal Society of Chemistry, 2008). He examines some of the most famous cases of poisoning 'from the point of view of the forensic scientist with a special focus on the toxic agents involved'. In a section titled 'From medicine to murder', Emsley features some of chemistry's most infamous molecules; ricin, a protein for which a lethal dose for an adult is estimated to be as little as 70 micrograms, the alkaloid hyoscine and the more common chemical, adrenaline. A second section establishes that extremely simple molecules can exhibit high toxicity. Emsley's text is compelling as he mixes chemistry and murder; each case proving to be a formidable forensic challenge. But Emsley's catalog of the 'molecules of murder' can be no match for the weapons of mass destruction that have been perfected over hundreds of millions of years by microbes. Biology and chemistry merge seamlessly when we consider life and death.

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