within the context of longer-term changes in sea level, climate and other factors that have influenced biotic diversity throughout Earth history. Disentangling the effects of the sudden event from those of the larger trend is not simple, particularly when the environmental changes conspire to degrade the quality of the fossil record in the crucial interval. A drop in sea level, for example, will not only reduce habitable area in both shallow marine shelves and swampy coastal plains, and thus potentially drive extinctions; it will also reduce the area of outcrops or the breadth of palaeoenvironments available for sampling, and thus create potential biases that could artificially reduce observed biodiversity.

Much of the K–T debate has shifted to whether the apparent declines in diversity seen in groups as disparate as dinosaurs and ammonites during the last few million years before the K–T boundary are genuine biotic effects of such longer-term perturbations, or artefacts of sampling or preservation. For example, the apparent decline in global ammonite diversity through the last five million years or so of the Cretaceous — that is, from the Early to the Late Maastrichtian Stage — may reflect the drop in the number of known ammonite localities[7]. It could thus be a sampling artefact rather than a true biotic pattern, particularly because the diversity observed in each locality seems to hold steady over that interval.

Even without such biases, the natural patchiness of living populations and the incomplete nature of the fossil record mean that the last observed occurrence of a species rarely coincides with its final, true demise. So even abrupt extinctions will tend to look gradual or stepped, a phenomenon termed 'backwards smearing', or the Signor–Lipps effect[4–8]. The rigour of palaeontological analysis has been greatly improved by the development of protocols, based on the number, placement and size of the gaps within the known temporal range of a species or evolutionary lineage, for putting confidence limits on the last observed occurrence in the rock record[6,8]. This allows quantification of the intuitive perception that the extinction record of enormously abundant and resistant elements such as pollen and calcareous marine microfossils is more robust than that of rarer or poorly fossilized forms such as dinosaurs or sea cucumbers, and allows a new assessment of extinction patterns at critical localities and time intervals.

Turning again to the ammonites, for example, a literal reading of their record in some well-collected areas would be one of rapid but gradual decline leading up to the K–T boundary. But confidence-limit analyses on stratigraphical ranges in the classic sections at the Bay of Biscay[9] and Seymour Island, Antarctica[10], show that most of the observed range terminations are equally consistent with an abrupt extinction at the boundary (see Fig. 1).

As if these pitfalls were not enough, the churning activities of burrowing organisms or physical erosion and redeposition can produce a kind of 'forward smearing' of an abrupt event by artificially spreading the last occurrences of species beyond the true extinction horizon. This potential bias can now be factored out by using sediment-mixing models and time-specific isotopic signatures to recognize temporally displaced fossils[5,11,12]; some species did indeed persist a bit above the K–T boundary, but many specimens have proven to be reworked.

This is not to say that all Late Cretaceous extinctions coincided with the K–T boundary. Confidence limits on the extinction of inoceramid bivalves, using the dissociated microstructural elements of the shell as distinctive microfossils and thus greatly increasing the number and density of records, show that this important group became extinct well before the end of the Cretaceous[9,13], and in a geographically complex pattern[13,14]. It is still puzzling why so few other taxa were lost in whatever perturbation drove the disappearance of this once-pervasive and species-rich group.

The K–T debates are not over in the palaeontological community, but one gets the sense that they have turned a corner. The new methods that have been developed with the emergence of an increasingly rigorous quantitative palaeontology, collecting programmes designed in light of insights derived from palaeontological sampling theory[8,15], improved temporal correlations within the interval concerned[16], greater interplay with other disciplines such as marine biology[17] and geochemistry[11,12] — all are combining to produce a clearer picture of one of the critical times in the history of life. □

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1. Phillips, J. *Life on the Earth: Its Origin and Succession* (Macmillan, Cambridge, 1860).
2. Alvarez, L. W., Alvarez, W., Asaro, F. & Michel, H. *Science* **208,** 1095–1108 (1980).
3. Sharpton, V. L. *et al. Geol. Soc. Am. Spec. Pap.* **307,** 55–74 (1996).
4. Keller, G. *et al. Geol. Soc. Am. Bull.* **109,** 410–428 (1997).
5. MacLeod, N. *et al. J. Geol. Soc. Lond.* **153,** 265–292 (1997).
6. Jablonski, D. *Geol. Soc. Am. Spec. Pap.* **307,** 1–9 (1996).
7. Ward, P. D. in *Ammonoid Biology* (eds Landman, N. H. *et al.*) 815–825 (Plenum, New York, 1996).
8. Sepkoski, J. J. Jr & Koch, C. F. in *Global Events and Event Stratigraphy in the Phanerozoic* (ed. Walliser, O. H.) 21–34 (Springer, Berlin, 1996).
9. Marshall, C. R. & Ward, P. D. *Science* **274,** 1360–1363 (1996).
10. Marshall, C. R. *Geology* **23,** 731–734 (1995).
11. Huber, B. T. *Geol. Soc. Am. Spec. Pap.* **307,** 319–334 (1996).
12. MacLeod, K. G. & Huber, B. T. *Geology* **24,** 463–466 (1996).
13. MacLeod, K. G., Huber, B. T. & Ward, P. D. *Geol. Soc. Am. Spec. Pap.* **307,** 361–373 (1996).
14. Crame, J. A. & Luther, A. *Cret. Res.* **18,** 179–185 (1997).
15. Marshall, C. R. in *The Adequacy of the Fossil Record* (eds Donovan, S. K. & Paul, C. R. C.) (Wiley, Chichester, in the press).
16. Odin, G. S. *et al. Bull. Inst. R. Sci. Nat. Brussels, Sci. Terre* **66** (Suppl.), 111–117 (1996).
17. Levinton, J. S. *Paleobiology* **22,** 104–112 (1996).

Daedalus

Forcible foam

Surface-active compounds, such as detergents and membrane lipids, have molecules in which a hydrophobic grouping is coupled to a hydrophilic one. They can stabilize a fluid interface by crowding along it as a monolayer, with the hydrophilic groups in the aqueous phase and the hydrophobic ones outside it. Certain biolipids have highly compact hydrophilic groups, but rather bulky hydrophobic ones. A monolayer of such wedge-like molecules therefore tends to impose a curvature on the interface, with the compact hydrophilic groups inside.

Daedalus is now extending this idea. His new foaming detergent has unusually bulky hydrophilic groups. Normally, aerated foams are unstable: small bubbles shrink while big ones expand and burst. But the molecules of the new surfactant will bend a surface into a concave curve, with gas inside it. It will stabilize small gas bubbles at a specific radius, defined by the packing geometry of its molecules.

Really stable gas-rich foams will have many uses. Fire-fighters will welcome them, brewers will use them to make even frothier beers, while manufacturers of cake-mixes and slimming breads will create new products of almost airborne lightness. Farmers may be able to grow their crops under a mulch of stable foam that lets light and air diffuse in, but keeps insects out. You might even be able to breathe such a foam, which would form an appealing environment for relaxation and play. But Daedalus's main goal is a foam to stabilize very small bubbles, maybe less than 50 nm across. Such tiny bubbles can exert up to a hundred atmospheres on the gas inside them. Daedalus's 'nanofoam' could hold as much gas, weight for weight, as a standard steel gas cylinder.

The obvious application is in rocketry. Existing rockets increase the density of their hydrogen and oxygen fuel by cooling them to liquids, with vastly expensive cryogenic consequences. Nanofoams of these gases could pack the fuels almost as densely, but could be stored and pumped at ambient temperature and pressure. A nanofoam would slowly lose gas by diffusion, but probably no faster than the evaporation of a cryogenic propellant.

A nanofoam could also be a high explosive. Butane nanofoamed in hydrogen peroxide, or oxygen nanofoamed in fuel oil, would be splendid blasting agents. And if the detonator failed, you need only wait a few hours or days for the gas to diffuse out, when the charge would be quite safe.

David Jones