must fold post-translationally. CCT chaperonins apparently interact with very few substrates, including actin and tubulin⁹. Netzer and Hartl point out that, although actin is a multidomain protein, its domains are composed of discontinuous amino-acid sequences, and therefore it would not be expected to fold co-translationally. So CCT chaperonins may have been retained in eukaryotes for the specific but limited task of coping with polypeptides that cannot fold in a stepwise fashion, domain by domain, as translation proceeds.

The molecular mechanisms underlying the different treatment of nascent polypeptides, following synthesis by prokaryotic and eukaryotic ribosomes, remain to be defined. Netzer and Hartl rule out the higher speed of translation in bacteria as a significant factor, but raise the possibilities that the prevention of folding of ribosome-bound polypeptides in *E. coli* might be effected either by ribosomal components or by molecular chaperones. One *E. coli* chaperone that can be exonerated is GroEL itself, because it does not recognize ribosome-bound chains⁵. By con-

trast, Hsp70 chaperones^{5,10} do interact with ribosome-associated nascent polypeptide chains, both in *E. coli* and in mammalian cells. Whether a previously unsuspected difference in the way in which prokaryotic and eukaryotic Hsp70 proteins interact with newly synthesized polypeptides underlies the failure of prokaryotes to support co-translational folding, or whether other translational co-factors are involved, is sure to be the subject of intensive studies in the coming months. □

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Extraterrestrial impacts

Earth rocked by combination punch

Dieter Stöffler and Philippe Claeys

The 100-km-diameter Popigai structure in Siberia is probably the fifth largest impact crater on Earth. Its age has been disputed — it could be anything from 5 to 65 million years (Myr) old. But this controversy appears to be finally settled: on page 365 of this issue¹, Bottomley *et al.* report ages of 35.7 ± 0.2 Myr for rocks from the Popigai crater that were melted by the impact. That means that 35.5 million years ago, in the space of only a few hundred thousand years — or perhaps much less — two large asteroids or comets struck the Earth, one in Siberia and another just off the west coast of North America.

The Late Eocene age for Popigai opens up intriguing questions about how two large impacts in quick succession might have affected the Earth. The period from the Late Eocene to the Eocene/Oligocene boundary (which is dated at 33.7 ± 0.5 Myr ago) is marked by the most severe mass extinction since the dinosaurs disappeared 65 Myr ago. The climate also worsened considerably in the Late Eocene, with cooling oceans and the first appearance of ice sheets in Antarctica.

Could these changes be the result of two almost coeval large impact events? We now know¹ that the Popigai crater is the same age as impact indicators (iridium and shocked quartz) found below the Eocene/Oligocene boundary in the Massignano section, Italy^{2–4}, which are dated radiometrically using volcanic ash layers at 35.7 ± 0.4 Myr

old^{2,3}. However, compositional evidence linking the Popigai crater and the Massignano ejecta is lacking; more work on this topic is urgently required. But the age coincidence is remarkable.

Excitement about the Popigai date grows in the light of the discovery a few years ago of a contemporaneous impact event on the other side of the world: the 85-km-diameter Chesapeake Bay impact structure, off the Virginia shore^{5,6}. The Chesapeake Bay crater had already been dated at 35.5 to 35.2 Myr old⁶. It is probably the source of the huge field of tektites (characteristic glassy nodules produced by melting of the target rock in an impact event) strewn mainly over Georgia, as indicated by the chemical similarities between the glass and the Chesapeake Bay target rocks^{7,8}. Similarly, the crater appears to be the source of microtektites and layers of excess iridium found on Barbados and in several ocean-floor drilling cores (such as DSDP 612), and dated at 35.4 ± 0.6 and 35.5 ± 0.3 Myr old^{9,10}, respectively.

So, within the error bars, the Popigai and Chesapeake Bay craters are the same age; at most, they occurred a few hundred thousand years apart. The tremendous energy released by these two successive huge impacts may have induced the long-lasting perturbation of the global environment which led to the terminal Eocene cataclysm and global changes.

We finally have a second solidly based case study, after the Cretaceous/Tertiary

100 YEARS AGO

We endeavoured before to ascertain what density of atmosphere might be conceded to the moon. This density being very feeble, it follows that the surface of our satellite must now be at a low temperature — at least, near the poles. There is even cause to ask if it is not totally or partially covered with ice. The most complete representation of the southern region ... inclines us to the opposite view — that is to say, that the presence of a great accumulation of ice must be considered improbable, as well for the polar caps as for the equatorial region. One is, therefore, led to imagine that the total moisture on the surface must have disappeared, undoubtedly by penetration into the interior of the globe, before the polar regions sank permanently beneath freezing-point. ... The cooling of our satellite, more rapidly than that of the earth, has shortened the period of condensation of the vapours. The water was filtered as fast as it was formed in innumerable volcanic orifices, which seemed prepared to receive it. Pl. vi. gives us an idea of the abundance of these openings in the neighbourhood of the pole, and one is led to think that the same constitution must have existed on the whole of the moon previously to the formation of seas.

From *Nature* 22 July 1897.

50 YEARS AGO

[Dr. Fossdick] does not deny that knowledge is dangerous, but he insists that the answer does not lie in trying to curb science or to fix boundaries beyond which intellectual adventure should not be allowed to go. The search for truth, he maintains, is, as it always has been, the noblest expression of the human spirit. Man's hunger for knowledge about himself, his environment and the forces by which he is surrounded, gives human life its meaning and purpose, and clothes it with final dignity. Civilisation is not being betrayed by science: the danger lies in the failure to use science wisely. ... The fundamental issue of our time is whether we can develop understanding and wisdom reliable enough to serve as a chart in working out the problems of human relations, or whether our lopsided progress will be allowed to develop to a point that capsizes our civilization in a catastrophe of immeasurable proportions. From *Nature* 26 July 1947.

Figure 1 Popigai topography. The 100-km Popigai impact crater in Siberia shows up clearly on this topographic map. It has now been dated to around 35 million years ago, close to the time of another huge impact, and to a mass extinction in the Late Eocene.

(K/T) boundary, of the Earth's response to large impacts. In both cases, the location, size and age of the impact craters are known, there is a reasonable though not yet complete record of global or regional ejecta layers, and a detailed fossil succession is present in coeval, often continuous sediments from which a climatic and oceanographic record can be extracted.

In the case of the K/T boundary, 65 Myr ago, the coincidence and possible cause-effect relationship between the large impact which formed the 180–310-km-diameter Chicxulub crater in Yucatán, and the mass extinction of organisms, is striking. In the light of the K/T event, a rigorous assessment is needed of the fossil and climate record at small timescale across the Late Eocene. A concerted and open-minded effort¹¹ from palaeontologists, sedimentologists, geochemists and impact researchers should determine the role played by the Popigai and Chesapeake Bay impacts on the biological and climatic evolution of the Earth in the Late Eocene.

These two almost coeval impacts shed new light on the random behaviour of the terrestrial impact flux and the size-frequency distribution of impactors as a function of time. According to Bottomley *et al.*¹, "the expected repeat rate of impact structures of this size is of the order of ten million years". So the question arises: how important are the statistics of small numbers for the effectiveness of impact-induced disturbances in the evolution of the Earth, and the related mass extinction events and climate changes in the past 600 million years? □

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Homogeneous catalysis

On the trail of dioxygen activation

Craig L. Hill and Ira A. Weinstock

An 'ideal' homogeneous catalyst for dioxygen (O_2) oxidations would be selective, useful for tackling a variety of substrates and chemical structures, reasonably fast, and stable. Critically, and particular to the use of O_2 , the process should not require the wasteful addition of reducing agents. Such a system has remained a dream, but the work described by Neumann and Dahan on page 353 of this issue¹ constitutes notable progress towards realizing it.

All living matter and synthetic organic materials within the biosphere share a common condition and fate: they are thermodynamically unstable with respect to CO_2 and H_2O , products of reaction with O_2 . Fortunately for us, however, O_2 is a diradical, possessing a triplet ground-state electronic configuration (two unpaired electrons), whereas almost everything else possesses singlet ground states (paired electrons only). Because of this difference in ground electronic states, strong electronic interactions, which go hand-in-hand with low activation barriers to chemical reactivity, are spin-forbidden. This kinetic barrier is what makes the existence of life (as well as most synthetic organic materials) possible.

On the other hand, once dioxygen is 'activated' (that is, greater reactivity is induced), its reactions with organic substrates are difficult to control. This is because the diradical nature of dioxygen facilitates the formation of highly reactive and nonselective radical intermediates and radical-chain processes. Furthermore, because of the thermodynamic instability, such oxidations, once begun, are often highly exothermic and the resulting temperature increases further decrease selectivity. In consequence, the great majority of spontaneous O_2 reactions, such as those that lead to rancid butter, or the more rapid ones that occur during the combustion of fossil fuels, are nonselective and difficult to control.

Between the extremes of chemical inertia and uncontrollable radical-chain autoxidation processes lie opportunity and challenge. The opportunity: to make use of O_2 , the most abundant, inexpensive, energy-efficient and

Figure 1 The Neumann–Dahan¹ catalyst, $\{[WZnRu_2(OH)(H_2O)](ZnW_9O_{34})_2\}^{11-}$, contains two sterically protected ruthenium atoms sandwiched between $[ZnW_9O_{34}]^{12-}$ halves (represented here as semicircles) of the oxidatively resistant polyoxometalate. The catalyst facilitates direct O_2 activation (right side of the figure) and substrate oxidation (left side) without generating nonselective radicals. Oxygen is incorporated directly into the substrate, the sole source of the electrons needed for the reductive activation of O_2 .

environmentally compatible oxidant available. The challenge: to control the reactivity of activated O_2 so that high chemical selectivities, and thus useful products, might be obtained. At the same time, the catalytic chemistry of oxygen and its inorganic and organic derivatives, while remarkably rich, is painfully complex and experimentally difficult. The design of homogeneous catalysts for both activation and selective use of O_2 is an extraordinarily tough task.

A third issue pertains to material and energetic efficiency. Dioxygen has four oxidizing electron equivalents. A common activation strategy, however, is to 'waste' some of them by partially reducing O_2 to peroxides or other reduced oxygen species that are more active and selective than O_2 (refs 2, 3). Many extremely useful homogeneous systems catalyse the selective reactions of reduced oxygen compounds⁴. Reductive activation of O_2 can also be accomplished by *in situ* introduction of an external supply of electrons (as with the effective reduction of O_2 by the coenzyme NADH in oxidative phosphorylation); this is a strategy exemplified by many