NATURE

### 100 YEARS AGO

**"Average Number of Kinsfolk in Each Degree." May I ask you to insert yet another brief communication on the above subject, because private correspondence shows that paradoxical opinions are not yet wholly dispelled? The clearest way of expressing statistical problems is the familiar method of black and white balls, which I will now adopt. Plunge both hands into a dark bag partly filled with black and white balls, equal in number, and well mixed. Grasp a handful in the right hand, to represent a family of boys and girls. Out of this unseen handful extract one ball, still unseen, with the left hand. There will be *on the average* of many similar experiments, as many white as black balls, *both* in the original and in the residual handful, because the extracted ball will be as often white as black. Using my previous notation, let the number of balls in the original handful be $2d$. Consequently, the number in the residual handful will be $2d-1$, and the average number in it either of white or of black balls will be half as many, or $d-\frac{1}{2}$. It makes no difference to the average result whether the hitherto unseen ball in the left hand proves to be white or black. In other words, it makes no difference in the estimate of the average number of sisters or of brothers whether the individual from whom they are reckoned be a boy or a girl; it is in both cases $d-\frac{1}{2}$. The reckoning may proceed from one member of each family taken at random, or from all its members taken in turn.** **Francis Galton**

From *Nature* 12 January 1905.

### 50 YEARS AGO

**The "Proceedings" for 1954 of the Croydon Natural History and Scientific Society contains interesting articles on deneholes… Deneholes are excavations in underlying chalk reached by vertical shafts through the overload… The age of the deneholes seems to be pre-Roman, and they are probably of the Iron Age. Many explanations have been given as to why they were made; but none is satisfactory. Underground granaries or stores have been suggested, or pits for obtaining chalk for agriculture; but, if the latter explanation be the correct one, why have they been so carefully made?… It would seem clear… that some connexion must exist between these artificial caves and the earth-houses of northern Scotland. But unfortunately we do not really know why these latter were made, either.**

From *Nature* 15 January 1955.

Mammalian palaeobiology

# Living large in the Cretaceous

Anne Weil

Discoveries of large, carnivorous mammals from the Cretaceous challenge the long-held view that primitive mammals were small and uninteresting. Have palaeontologists been asking the wrong questions?

Although more than two-thirds of mammalian evolution occurred between about 180 million and 65.5 million years ago, many people think that these early mammals were not very exciting. Mesozoic mammals are usually portrayed as rat-sized, nocturnal prey animals, ecologically marginalized and constrained from evolving diverse body types and sizes until the extinction event at the end of the Cretaceous removed non-avian dinosaurs from the scene. Two fascinating discoveries of near-complete fossil skeletons, described by Hu *et al.* on page 149 of this issue[1], overturn this outdated view. Neither is of a small mammal. One is more than a metre long. The other appears to have a dismembered juvenile dinosaur in its stomach.

Both skeletons were found in the Lujiatun fossil beds at the base of the Yixian Formation in northeastern China. They are at least 128 million years old, dating from the Early Cretaceous period. The diversity and astounding preservation of fossils from the Yixian is well established; from feathered dinosaurs to insects, it continues to produce scientific riches[2]. These latest finds should trigger another avalanche of questions and speculation among palaeontologists.

The dinosaur-eater belongs to a species of large mammal, *Repenomamus robustus*, which was described first from a skull[3]. The new specimen is more complete — and on its left side, under its ribs where a mammal's stomach might well have been, lies a fragmentary and disarticulated skeleton of a young *Psittacosaurus*, estimated to have been about 14 cm long. The devourer of this little dinosaur was more than half a metre long, and is estimated[1] to have weighed 4–6 kg.

*Repenomamus robustus* is a runt, however, next to its newly discovered relative, *Repenomamus giganticus*. Hu *et al.*[1] provide the first description of this Mesozoic mammal. Curled on one side, the skeleton looks like nothing so much as that of a sleeping dog. Uncurled, *R. giganticus* would have been about 105 cm long, and the authors estimate that it would have weighed about 12–14 kg. Both *Repenomamus* species had proportionately shorter legs than living mammals, but their posture may have been similar to that of living quadrupeds of the same size. They were squat, toothy, heavily built animals, in some respects reminiscent of the Tasmanian devil (*Sarcophilus*) or of the ratel (*Mellivora*). They belong to an early mammalian lineage that has no living descendants. *Repenomamus* is closely related to *Gobiconodon*, another mammal discovered in the Lujiatun beds[4], and perhaps more distantly to the much smaller *Jeholodens* that was discovered higher in the Yixian Formation[1,5].

If *R. robustus* supped on young dinosaurs, did *R. giganticus* go after the adults? None of the dinosaurs described so far from the Lujiatun beds[2] is very big; most published specimens have skull lengths near or less than 10 cm. *Repenomamus giganticus* was longer and heavier than adults of *Sinovenator changii*, a dinosaur species found in the same deposits[6], for instance. However, modern-day mammalian carnivores that weigh less than 21.5 kg prey mostly on animals of less than half their weight[7]. If *R. giganticus* behaved like living mammals, it might have preyed on dinosaurs weighing less than 7 kg. Indeed, although the new *R. robustus* specimen provides evidence that it ate young dinosaurs, how much of its diet was composed of dinosaurs — or even of meat — is open to speculation. Many living mammalian carnivores, particularly those under the 21.5-kg threshold, also eat invertebrates and plants[7], and their diets can vary considerably with season. Small mammals related to *Repenomamus*, such as *Jeholodens*, have been reconstructed as insectivores[5].

Despite the frequently made generalization that Mesozoic mammals were rat-sized, palaeontologists have known for some time that this was not the case. Larger mammals include *Kollikodon* from the Early Cretaceous of Australia[8], and *Schowalteria*[9] and *Bubodens*[10] from the Late Cretaceous of North America. But exactly how large those animals were is a mystery, because *Schowalteria* is known only from the front end of a fragmentary skull, *Kollikodon* from a partial lower jaw with three teeth, and *Bubodens* from a single tooth. These mammals were at least as large as *R. robustus*, and may have been as large as *R. giganticus*, but because their remains are so incomplete it is hard to tell. The fossil of *R. giganticus*, however, is nearly complete, and its height and length are indisputable.

Hypotheses developed to explain the evolution of mammalian size often focus on dinosaurs. The most frequently repeated speculation is that Mesozoic mammals were forced to remain small by a combination of heavy predation pressure from dinosaurs and the saturation of ecological niches by large reptiles. Are the mammals from the Lujiatun beds large because the dinosaurs are small? This question may be premature, as the fossil deposits are under active excavation and description of the fauna is not complete. Yet the two new specimens of *Repenomamus* prompt a reversal of the question, if only in speculation: how might mammals have influenced dinosaur evolution? It seems likely that small dinosaurs experienced predation pressure from mammals. Indeed, in describing the diminutive *S. changii*, which lies evolutionarily at the base of a lineage closely related to that of birds, Xu *et al.*[6] express surprise that, although the avian lineage continued an evolutionary trend towards small size, closely related dinosaurian lineages became larger again. Maybe these small dinosaurs got larger — or got off the ground — to avoid the rapacious mammals. ■

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Astrophysics

# The process of carbon creation

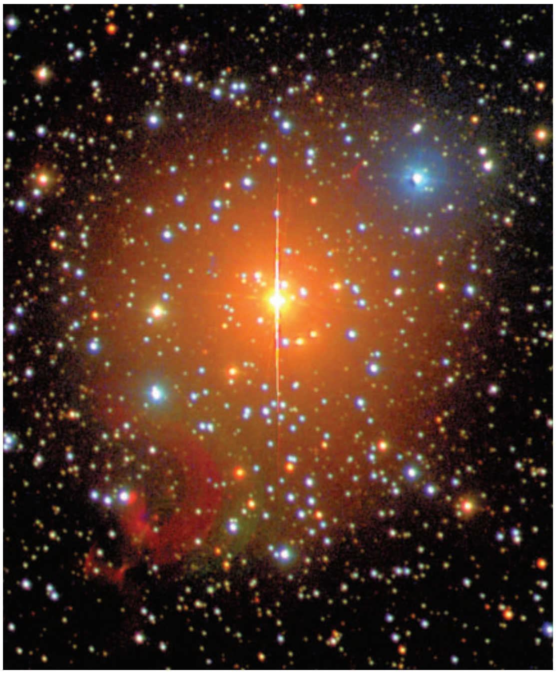
Mounib El Eid

**In the Universe, the element carbon is created only in stars, in a remarkable reaction called the triple-α process. Fresh insights into the reaction now come from the latest experiments carried out on Earth.**

In the first few moments of the Universe's existence — the famous 'three minutes' — no elements heavier than helium were made, with the exception of a tiny amount of lithium. So how were the other elements, including the carbon that is so important to life on Earth, created? On page 136 of this issue, Fynbo *et al.*[1] present new and exciting measurements of the rate of the nuclear fusion reactions that produce $^{12}$C. The element is mainly synthesized inside stars when they evolve to the red-giant and later stages (Fig. 1).

The starting point for the relevant reactions is helium, $^4$He, the nucleus of which is known as the α-particle. In 1952, Edwin Salpeter[2,3] suggested that the nuclear fusion process leading to the synthesis of $^{12}$C is a two-step process, with two α-particles combining to form a minuscule amount of an unstable form of the element beryllium ($^8$Be). Although the lifetime of $^8$Be is only about $10^{-16}$ seconds, the close proximity of atomic nuclei inside the dense matter of a star in principle allows the capture of a third α-particle to form $^{12}$C. Hence the term 'triple-α' for the presumed process of carbon formation. But the probability of this occurring seemed too low to explain the abundance of carbon in the Universe.

Fred Hoyle[4] and Dunbar *et al.*[5] then recognized a crucial point, in predicting that the third α-particle could be captured through what is called a 'resonant reaction'. This occurs when the energy of the captured particle matches the difference between the energy of the nuclear state and the threshold energy — the minimum energy required to initiate the reaction. This prediction meant that the probability of a $^8$Be nucleus capturing another α-particle was dramatically increased. It was based on purely theoretical grounds, but was soon verified experimentally[6] and represents one of the triumphs of astrophysics.



T. CREDNER & S. KOHLE/OBS. BONN

Figure 1 **Carbon factories. This three-colour composite image[9] of the constellation Auriga includes several red-giant stars, a primary site of carbon synthesis.**

Once carbon is formed, the other elements — especially those, such as oxygen and neon, that can be created simply by adding yet more α-particles — are readily made without effective destruction of $^{12}$C. Moreover, understanding the rate at which the triple-α process proceeds is fundamental to understanding many mechanisms in astrophysics beyond the production of elements. It is important for the generation of energy inside stars more massive than the Sun, and for their appearance in the later stages of stellar evolution[7]. It also influences the properties of giant stars, and is relevant to the formation of the very first stars in the Universe.

Curiously, however, the rate of the triple-α process has not been accurately determined over the entire range of temperatures at which it is astrophysically important. Recent calculations of stellar structure and nucleosynthesis use rates produced by the NACRE (Nuclear Astrophysics Compilation of Reaction Rates) collaboration[8]. These data include a mixture of measurements, theoretical predictions and extrapolations, but are subject to continual reassessment.

Working with data from particle-accelerator facilities, Fynbo and colleagues[1] analysed the inverse process, where $^{12}$C decays into two or three α-particles through the creation of the unstable isotopes $^{12}$N and $^{12}$B. They used the decay properties of these nuclei to search for or confirm resonant states in the $^{12}$C system, which are expected to have energies in the range of $10^6$ electronvolts (MeV). They found a broad resonance at one energy level, 11.23 MeV. But they could not confirm the resonance at 9.1 MeV assumed in NACRE's figures. The main difference in the rate occurs in the temperature ranges below $5 \times 10^7$ K, where the reaction proceeds much more quickly, and above $10^9$ K, where it is slower.

The consequences of this new rate will need to be investigated in detail. But the higher rate at low temperatures will affect our understanding of the evolution of the first generation of stars. In such stars, the lack of heavy elements implies that the CNO (carbon–nitrogen–oxygen) cycle can't operate to deliver the energy and to transform hydrogen into helium, until some small amount of carbon is created. This is only possible through the triple-α reaction, and at higher temperatures (near $10^8$ K) that are in a range where the reaction rate has the higher value obtained by the new evaluation. The net effect is that, with the new rate, this phase of evolution of first-generation stars is expected to be shorter. At the high-temperature end,