

COSMIC GENES IN THE CRETACEOUS-TERTIARY TRANSITION

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Abstract. It is proposed that genes coding for Aib-polypeptides arose early on in the K/T transition, presumed from the Earth's accretion of interplanetary (comet) dust. Aib-fungi flourished because of the evolutionary advantage of novel antibiotics. The stress on Cretaceous biology led directly and indirectly to mass species extinctions, including many dinosaur species, in the epoch preceding the Chicxulub impact.

If cosmic genes are to be a driver of species evolution, Hoyle and Wickramasinghe (1981) developed the idea of pathogenic carriers to establish them in terrestrial ecosystems. Carriers could be viruses or more complex organisms. That viable bacteria could reach the Earth within meteorites, such as those known to derive from Mars, is now considered fully plausible. But such material has been reaching the Earth throughout evolutionary history, so it would take material from more unusual sources to cause significant episodic evolutionary changes.

We consider the major evolutionary change of the K/T transition. The K/T boundary as measured by the spike in iridium abundance is now well identified with the asteroid or comet impact that caused the Chicxulub crater. However, the K/T transition as measured by the mass extinctions of Cretaceous species lasted of order 100 kyr or more, right across the 65.0 Myr impact event. The immense outpouring of lava that created the Deccan Traps could well have played a part in the extinctions, but just post-impact if the impact set off volcanic lava flows. The global wild-fires and atmospheric changes consequent on the impact also cannot explain the earlier extinction record.

The iridium data do provide an extraterrestrial signal pre-Chicxulub impact. The iridium abundances in samples above and below the impact spike in the boundary sediments at Stevns Klint (Zhou and Bada, 1989) indicate a strong enhancement of extraterrestrial debris reaching the Earth over some 10^5 years. The same boundary clays are also remarkable for high levels of the exotic aminoacid Aib, which was known from the 1980's to be a major aminoacid in extracts from the Murchison meteorite (Engel and Macko, 2001). By 'exotic' I mean a non-protein aminoacid, not in the standard 21 or 22 making up DNA. It was therefore hypothesised that Aib and a second exotic aminoacid, isovaline, are remnants of extraterrestrial organic material (Zhou and Bada, 1989; Zahnle and Grinspoon, 1990).

It is however, quite unclear how this material could be linked to the pre-Chicxulub mass extinction. We previously investigated if a dust veil could cut down the solar radiation (Wickramasinghe and Wallis, 1994). Alternatively, we suggested that the exotic aminoacids could have been highly poisonous (Ramadurai et al., 1994). Dust veiling was considered to be consequent on the fragmentation of a giant comet, which injects vast amounts of debris down to the smallest sizes into the



inner solar system over a 100 000 yr period (Napier and Clube, 1979). Quantitative analysis showed dust veiling to be a plausible mechanism, assuming the comet had similar composition in non-volatiles to that of the Murchison meteorite, but it implied that the Aib-carriers had to largely survive degradation processes before being fixed in the sedimentary rocks. The sediment data shows Aib to be comparable in abundance to the ordinary aminoacids in the same samples. Aib also tracks these aminoacids rather than iridium levels. The absence of some compounds like n-alkanes implies extensive microbial reworking of the organic matter (Brisman et al., 2001). Moreover, natural degradation processes exist at the present epoch and Aib is now known as a component of relatively rare biological peptides, which are associated with select microfungi.

Let's hypothesise that Aib is an indicator of an unusual biology – probably with abundant Aib-fungi – that flourished through the K/T boundary. This fits with the concept that the genes coding for the peptaibol-generating enzymes arrived with microorganisms from space – perhaps as actual Aib-fungi. Alternatively the novel genes were incorporated into existing microfungi. The novel species of peptaibol-based fungi were pathogenic to many cretaceous organisms and were particularly virulent because of the novel biochemical properties. Their stress on faunal and floral species caused not only mass extinction but also accelerated evolution and speciation – species that evolved defence mechanisms tended to survive the fungal attack. The competitive evolution of the ordinary and alien organisms resulted in resistant species (including mammals) winning through and symbiotic relationships developing. While the fall-off in Aib in the upper sediments indicates that the fungal invaders lost out in the end, their novel genetic input may have stimulated the evolutionary upsurge of the early tertiary epoch.

Aib Terrestrial and Extraterrestrial

Figure 1 shows the run of Aib and iridium levels in the Stevns Klint sediments. Other Raton Basin sediment data from Brisman et al. (2001) run up against detection limits, having lower aminoacids generally. However, the presence of Aib in the Colorado (Starkville South) but not the Mexico (Raton Pass) sections implies some variability in the occurrence of Aib-fungi and/or peptaibol degrading organisms. The failure to find Aib in pre-impact samples (two each location) may be just a detection limit problem.

We don't know the composition of the organics in Murchison and K/T clays, but do know that hydrolysis releases Aib. It is strikingly abundant in K/T clays – 10^4 times above detection limit and comparable to standard amino acids (10–20 times less than main aminoacids, but similar abundance to minor ones). Isotope and/or isomer analysis might be used to distinguish terrestrial and extraterrestrial origin, but the Brisman et al. work (2001) did not reach that far. In comparison, the iridium does indicate ET material – early in the boundary clays it was evident at

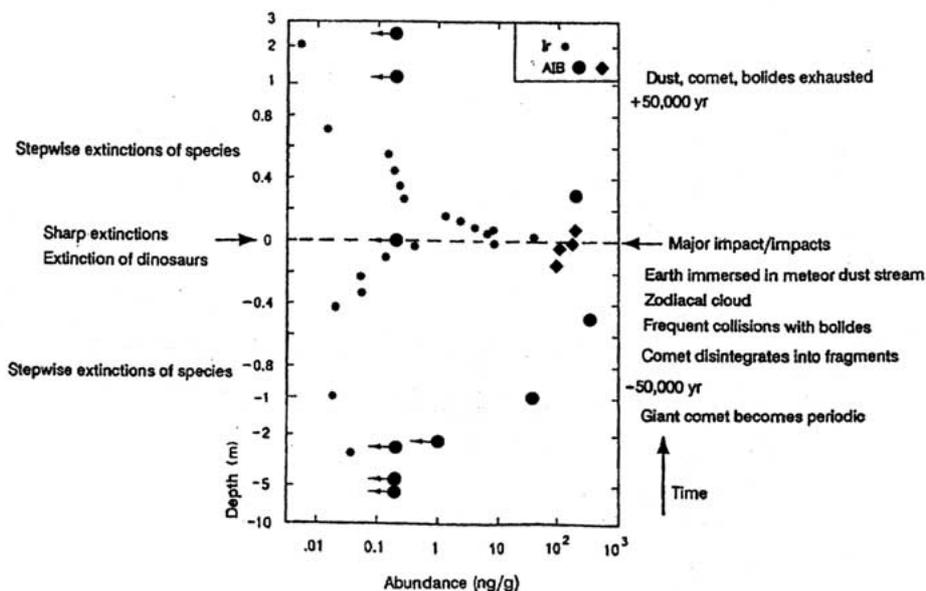


Figure 1. Interpretation of the K/T boundary record after Wallis and Wickramasinghe (1994). Iridium and Aib data in K/T marine boundary clays at Stevns Klint are from Zhou and Bada (1989 – circles: small Ir and large Aib) and Brisman et al. (2001 – diamonds: AIB). Sediments vary around the planet – Brisman et al., 2001 also analysed for aminoacids the non-marine K/T clays of Raton Basin in Colorado and in New Mexico. Aib was found in the Colorado site above the iridium spike, but not below it and not at all in the New Mexico clays. When one takes into account the likely degradation of sedimentary organic matter and the solubility of aminoacids, these new results confirm the significance of Aib found by Zhou and Bada.

10 times the detectable limit compared with 100 times generally and 10⁴ times in the peak.

Aib in Structural Biochemistry

Aib (α -aminoisobutyric acid or α -methylalanine) has quite a simple formula:



Polypeptides that contain Aib are termed *peptaibols*. *Alamethicin* is the best studied natural one (Cosette et al., 1999), but all peptaibols have high percentages of Aib. Examples are *Efrapeptin C* (Jost et al., 2001):



Trichorzin (Duval-Delphine et al., 1998)

Ac-Aib1-Ser-Ala-Aib-Iva-Gln-Aib-Val-Aib-Gly10-
Leu-Aib-Pro-Leu-Aib-Aib-Gln-Pheol18

Note that Trichorzin contains too the non-standard aminoacid isovaline (*Iva*) that was found in hydrolysed residues from the Murchison meteorite. Alamethicin similarly contains the non-standard α -methyl alanine. But Aib is the predominant exotic component, showing up as the major aminoacid including consecutive monomers in the formulas above.

Aib was identified as a curious non-proteinogenic aminoacid in the 1980s (Das et al., 1986). Even short (<4 aminoacids) peptaibols tend to form stable helices, whereas most short peptides do not have well-defined 3-D structures. The peptaibol Efrapeptins have been of particular interest for antibiotic properties (Gupta et al., 1991, 1992). Efrapeptin F affects insect nervous systems while Efrapeptin tolypin is an anti-mosquito agent and found to inhibit ATP-synthase. Peptaibols have a strong propensity to form helical structures, as exemplified by alamethicin and analogues. They adopt helical monomeric and dimeric (helix-bend-helix) structures, which self-assemble into ion-conducting channels. Probably the hydrophilic faces form the channel lining and the outside hydrophobic side chains interact with phospholipid membranes (Duclohier and Wroblewski, 2001). A channel conducts ions diffusively with little ion selection, implying long-range electrostatic interactions dominate. Forming a channel through a cell membrane enables leakage of the contents.

Anti-microbial peptides in general are the prime mechanism whereby plants and animals repel attacks by the range of bacteria, fungi, viruses and protozoa (Zasloff, 2002). Such peptides can be α -helical, like peptaibols. The above studies indicate that peptaibols could be utilised by Aib-fungi to penetrate microbial membranes. Peptaibols may also constitute part of fungal mechanisms for penetrating plants' cellulose walls. But present-day animals and plants presumably have effective defence mechanisms against peptaibols.

Genes are Cosmic

Fred Hoyle's writings on the theme of cosmic genes envisaged RNA or DNA reaching us from space, but left the question open as to whether it arrived as fragments, as viroids or viruses, or as complete cells (Hoyle and Wickramasinghe, 1981). The cosmic genetic material is ready to function. It could, like HIV, take over existing cell-DNA and set to work generating its own armoury of polypeptides. Genetic engineering has now made this concept familiar, but Fred had the idea well ahead of his time.

In regard to evolution on Earth, terrestrial biology takes the novel cosmic genes into existing biosystems and assimilates or rejects them long-term in accord with any survival advantage. Copying-error or spontaneous mutations do assist with

integrating novel genes into the genome, but are seen as contributing only fine-tuning.

The present idea is that cosmic genes drove the K/T species transition. The exotic (peptaibol) biology arose early in the K/T transition, at the start of or early in the extinction period for cretaceous species. It flourished world-wide after 30 000 yr, then dwindled after another 50–70 000 yr (20–40 000 yrs post Chicxulub). The new genetic material not only generated ecological space through extinction of many species, but also caused accelerated evolution and speciation in response to the novel virulence.

One concept is of fungal invaders: Aib-fungi arrived within the extraterrestrial debris alongside the Iridium. Their toxic properties were peptaibol-based and novel to the cretaceous ecosystems. They were immediately pathogenic to bacteria, but may have required some evolutionary adaptation before they were able to effectively attack higher organisms (plants, reptiles etc.) with cellulose walls and polypeptide defences. Maybe the fungi directly attacked the dinosaurs, maybe they indirectly stressed the Cretaceous ecosystems and so provoked faunal mass extinction.

A variant of the concept is of a genetic invasion: irrespective of the carrier organism, the peptaibol-genes gave existing biology the opportunity of adding importantly to the armoury of anti-microbial peptides. Organisms that adopted these genes rapidly, integrating them into their existing genomes, gained a substantial evolutionary advantage. A range of microfungi adopted them for purposes of attack, perhaps other organisms adopted the peptaibol genes for defence against fungi, bacteria and protozoa. For animals and potentially other multi-cellular organisms, the balance between retaining symbiotic bacteria and repelling hostile bacteria might have tipped the scales against peptaibol antibiotics. The anti-microbial peptides of modern biology (Zasloff 2002) can presumably be more sensitively tuned than peptaibols.

Whether fungal or genetic invaders started off the cretaceous extinctions, there followed 100 000 yrs of competitive evolution of alien and ordinary organisms. The invaders were successful for a period, but eventually lost out. Defence mechanisms against peptaibols had to be developed, but evidently resistant species (including mammals) won through. The peptaibol-genes did enrich the kingdom of fungi but in the end proved to be of little overall advantage and retreated to select specialist organisms. They remain, however, in the terrestrial ecosystem, still available for future eventualities.

To test this hypothesis, further data on Aib-peptides in K/T sediments around the world would be useful, with particular emphasis on slightly earlier cretaceous sediments. Identifying the enzyme systems generating peptaibols and the related DNA should also help. If the genes were confined to the specialist microfungi rather than widely distributed but unexpressed, this would support the fungal invader concept.

Where in the evolutionary record might one look for other examples of cosmic genes arriving on Earth? One suggestion (Hoover et al., 1986) was for diatoms, which appeared suddenly at the 112 Myr Cretaceous boundary. These microscopic algae have cell walls of a complex siliceous biopolymer attached to an $\text{Si}(\text{OH})_4$ matrix on a protein template. Similar shells of radiolarians are evident in the earlier fossil record but not the distinct diatoms. As production of the intricate cell organisation via an 'evolutionary jump' is implausible, it's worth considering if diatoms provide a second example of the arrival of new cosmic genes.

References

- Brisman, K., Engel, M.H. and Macko, S.A.: 2001, *Precambrian Res.* **106**, 59–77.
- Cosette, P., Rubuffat, S., Bodo, B. and Molle, G.: 1999, *Biochim. Biophys. Acta* **1461**, 113–122.
- Das, M.K., Raghobama, S. and Balaram, P.: 1986, *Biochemistry* **25**, 7110.
- Duclohier, H. and Wroblévsky, H.: 2001, *J. Membrane Biol.* **184**, 1–12.
- Duval, D., Riddell, F.G., Rebuffat, S., Platzer, N. and Bodo, B.: 1998, *Biochim. Biophys. Acta* **1372**, 370–378.
- Engel, M.H. and Macko, S.A.: 2001, *Precambrian Res.* **106**, 35–45.
- Gupta, S., Krasnoff, S.B., Roberts, D.W., Renwick, J.A., Brinen, L.S. and Clardy, J.: 1992, *J. Org. Chem.* **57**, 2306.
- Hoover, R., Hoyle, F., Wallis, M.K. and Wickramasinghe, N.C., 1986: in: C.-I. Lagerkvist et al. (eds.), *Asteroids Comets Meteors II*, Uppsala University, 359–362.
- Hoyle, F. and Wickramasinghe, N.C.: 1981, *Evolution from Space*, New York.
- Jost, M., Neumann, B., Stammler, H.-G. and Sewald, N.: 2001, <<http://oc3web.chemie.uni-bielefeld.de/5ps/beitrag/mjo01.htm>>
- Napier, W.M. and Clube, S.V.M.: 1979, *Nature* **282**, 455.
- Ramadurai, S., Lloyd, D., Wallis, M.K. and Wickramasinghe, N.C.: 1994, *Adv. Space Res.* **15**(3).
- Wickramasinghe, N.C. and Wallis, M.K.: 1994, *MNRAS* **270**, 420–426.
- Zahnle, K. and Grinspoon, D.: 1990, *Nature* **348**, 157–160.
- Zasloff, M.: 2002, *Nature* **415**, 389–395.
- Zhau, M. and Bada, D.L.: 1989, *Nature* **339**, 463–465.