Stochastic effects of ionizing cosmogenic radiation and its impact on the evolution of life and mass extinctions

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Word count: ~1,458
Word count (with references and captions): 1,943

1.0 Introduction

Radioactivity is one of the principal drives for mutagenesis, its ionizing nature causes extensive damage to the DNA and RNA. The effects of ionization can be deterministic (direct) or stochastic (random). This report will focus on the stochastic effects. Ionization shuffles or destroys individual nucleotides, creating point mutations. A point mutation can lead to animal developing new beneficial attributes, which can aid the process of speciation, *or* cause a tumour/genetic defect contributing to fall in population numbers. For the mutation to be inheritable, the ionization has to affect gametes; contrary to cancer that can form in any cell. It is highly debatable how much background radiation is required to be fatal or how much is required to be useful and manifest in a beneficial mutation.

The cosmogenic radiation makes up a fraction of the background radiation, albeit it is arguable if this input has globally directed the evolutionary path of species. The amount of cosmogenic isotopes entering the biosphere varied with time, as an example, the values had to be much higher before the Great Oxygenation Event, due to ionizing muons and UVB having higher chances of entering the biosphere without the ozone layer.

The fossil record is filled with unexplained events of speciation and sudden extinctions without a direct correlation to rapid environmental changes. May these anomalies be associated with radical fluctuations in cosmogenic radiation, or just an element of preservation bias? This report will highlight three major studies regarding large-scale interaction of life with cosmogenic radiation: effect of background neutron radiation, the Gamma Burst theory and geomagnetic pole reversals.

1.1 History and origins of cosmogenic radiation

Currently, an average natural radiation dose is 2.4mSv/yr (UN, 2000); the number might vary with local bedrock materials and concentration of radon gas. This value was probably higher earlier in the geological history, due to lack of ozone (Sagan, 1957), undeveloped Van Allen Radiation Belt and higher concentrations of radiogenic minerals in the primordial soil which had less time to decay. The elevated levels of background radiation might have acted as a barrier for development of life (Uffen, 1963), or a mutagenic catalyst allowing for the rapid evolution of life in Proterozoic.

The cosmic source makes a fraction of the annual radiation dose (0.39mSv/yr) (UN, 2000), almost 90% coming from muons not halted by the O_3 (Thorne, 2003). These levels vary with latitude and altitude, state of the ozone layer, and solar/cosmogenic activity. Cosmic rays in close proximity to the planet may increase the muon dose and radiation levels up to ~100mSv/yr. (Todd, 1994); such events are predicted to occur once every billion years, it is predicted at least one has occurred in the Earth's history (see 2.1).

The most common way of cellular damage by ionisation comes from cosmic-sourced UVB (short wave ultraviolet B radiation) which enters biosphere via exploiting damages in the ozone layer and is capable of affecting the ecosystem at the bottom level of the trophic chain (Bothwell, 1994). UVB originates from the sun and other energetic events like supernova and gamma bursts. Amount of UVB is controlled by the thickness of ozone layer, which fluctuates due to numerous natural causes (Ellis, 1995) (see 2.2).

Different animals have adapted numerous DNA repair mechanisms that withstand the effects of low-level radiation, adding to complications when coming to modelling response to immediate low-dose radioactivity.

2.0 Background Neutron Radiation: a catalyst for mutation

Background neutron radiation (BNR) is predominantly cosmogenic in its origin. It is recognized as a major electrical disruptor in high-altitude computers (Gonzalez, 2014). The cosmogenic radiation interacts with the electrons in the water leading to ionization, which can adversely affect organic matter. The study by González (2014) suggests these particles may cause spontaneous mutations and have a cascading effect on the organism population. A population of *E. coli* was exposed to the natural neutron flux, damaging its DNA and DNA repair mechanism, which failure leads to permanent mutation. The changes in the population size were recorded after 20000 generations. The bacteria in the close proximity to the ion shower were more likely to be affected by the radiation, some bacteria populations experienced 100 x increases in the mutation rates, allowing for higher chances of evolving a beneficial protection mechanism shielding from the effects of radiation. The number of point mutations in the bacteria was 3×10^{8}. Due to nature of the protein coding, point mutations rarely have an observable impact.

This study has shown that while BNR does increase mutation potential in the population, it does not affect the population size, nor has a significant amount of observable, beneficial or notorious mutations. The study can be repeated in future by cultivating *E. coli* populations and exposing them to various levels of ionizing radiation, similar to that of modern and ancient background radiation levels, allowing for comparison of the two for a number of mutations and changes in the population size.

2.1 A link between Gamma-ray burst and mass extinction

Extinction events are caused by either decreased rates of speciation (dependant on numbers of favourable mutations) or increased rates of extinction (numerous causes, most common being rapid climate change) or both. The Ordovician mass extinction from 455-430 Ma has heavily hit index fossil populations, such as trilobites, conodonts, and graptolites (Hallam, 1997).

Causes and effects of the Ordovician extinction remain speculative. Most common theory includes the climate change, which had led to sudden cooling and glaciation, lowering the sea level and destroying continental shelf habitats (Hallam, 1997). A NASA computer model (Melott, 2004) suggests that sudden spike in UV radiation was responsible for the Ordovician Great Dying. The UV surplus could originate from a ten-second-long gamma burst, which could possibility damage 50% of the ozone layer, for a considerable amount of time, such as four weeks.

The UV could have severely damaged the roots of the food chain by killing the microbial near-surface life (Ellis, 1995) (Fig. 1). Removal of ozone and the predicted increase in NO_y, could attribute to the widespread cooling (Thomas, 2005), possibly triggering the devastating glaciations.

There is no direct fossil evidence to support this hypothesis, as it does not affect $^{87}Sr/^{86}Sr$ trends (Hallam, 1997); the gamma outbursts are relatively rare, with one event being evidenced by radioactive Fe^{60} on the lunar surface (Fimiani, 2016). There is no fossil evidence for nitrogen oxide or UVB increased flux. There is a lack of radioisotopes generated from such events with a lifetime of above one million years, save for ice core record, which does not encompass the geological timescale.

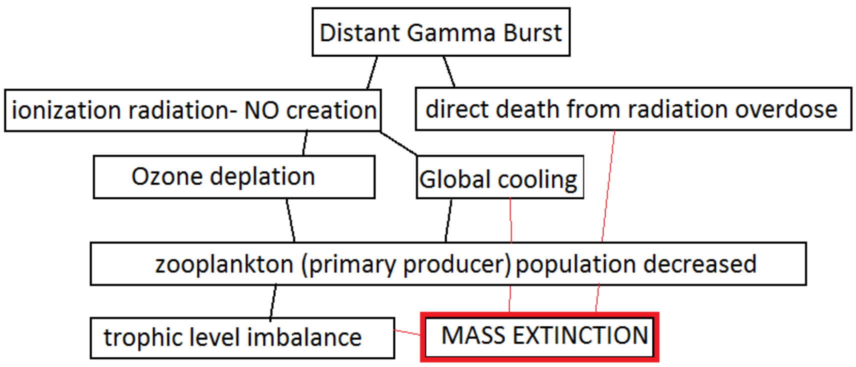

Figure 1: How Gamma Burst may cause Mass Extinction (based on points made by Ellis, 1994)

2.2 Ozone depletion and Van Allen radiation belt

It is now widely accepted that the global polarity flips at irregular time scales. A pole reversal would weaken the magnetic field by 5-10%, and theoretically allow entrance of charged particles liberated from the Van Allen radiation belt. The Iceland ice cores do show increase in Beryllium-10 related to the secular magnetic field variations (Knudsen, 2008), but other associated radioisotopes have half-lives shorter than 1 million years, leaving no trace of evidence regarding the increase of radioisotopes in biosphere associated with the switch. However, the fossil record does not provide significant information regarding widespread extinctions linked to the pole reversals, save for correlated disappearance of some Radiolarians (Hays, 1971). Therefore the pole reversal influence, if any, is too small to cause a significant dent in the record (Raup, 1985) (Plotnick,1980) and be responsible for global extinction patterns.

3.0 Conclusion and discussion

It is highly probable that the life during the primordial stages of the planet was heavily restricted by the lethally high levels of cosmogenic radiation, while its subsequent fall allowed for later diversification and colonisation of land.

The Earth is naturally becoming less radioactive with time as the elements decay with the natural half-lives. The primordial earth was more prone to cosmogenic irradiation, without the ozone layer, not developed magnetic field (and therefore Van Allen radiation belt) and more radioactive elements in the soil. The radioactivity decreasing in Ediacaran and Cambrian allowed oxygen to be a safer and more valuable resource and aided colonisation of land; albeit more studies have to be done to understand the correlation between the background radiation and macroscopic evolution.

It is certain that background radiation is mutagenic, albeit there is no solid proof that cosmic perturbations, such as gamma bursts, have directly and profoundly affected the course of life. It cannot be disapproved that if burst event was to occur, it may be capable of accelerating the extinction rates. To see how catastrophic such event could be and test if the cosmogenic flux can have a positive effect on the population; more studies on *E. coli*, in style of Gonzales, 2014, have to be undertaken; with changed variables reflecting different levels of ionizing radiations and observed for development of beneficial mutations.

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