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MULTIPLE PATHS TO ENCEPHALIZATION AND TECHNICAL CIVILIZATIONS: CONSTRAINTS INFERRED FROM THE BIOSPHERE'S EVOLUTION. D. W. Schwartzman¹ and G. Middendorf¹, ¹Department of Biology, Howard University, Washington, DC 20059, dschwartzman@gmail.com, gmiddendorf@gmail.com

Introduction: We propose that at least two possible evolutionary paths should be considered for the emergence of intelligent life with the potential for technical civilization. The first is the path to encephalization in warm blooded animals, the second is to swarm intelligence in so-called superorganisms such as termite colonies.

Discussion: The first path is constrained by climatic temperature. The long-term cooling history of the Earth's biosphere correlates with the timing of major events in biotic evolution, e.g., the emergence of phototrophs, eucaryotes and Metazoa apparently occurred when temperatures reached their maximum tolerable values for these organisms, i.e., 70°C (3.5 Ga), 60°C (2.8 Ga) and 50°C (1-1.5 Ga) respectively [1]. This temperature scenario with a very warm early climate was recently reinforced by the measurement of melting temperatures of proteins resurrected from sequences inferred from robust molecular phylogenies [2] and is consistent with the paleotemperatures derived from the oxygen isotopic record of ancient cherts [3].

We proposed that the emergence of vertebrates and their encephalization likewise was similarly constrained by temperature [4-5]. Given an upper temperature limit for vertebrate growth, indeed warm-blooded animals is about 10 °C below the limit for Metazoa, the surface temperature history of the biosphere suggests an even narrower window exists for maximum encephalization, roughly 500 million years ago through the present when climatic cooling became sufficient to allow additional and efficient heat loss from the large energy-intensive brain necessary for the burst in encephalization. During this period, encephalization is observed in hominid evolution, as well as for other groups of warm-blooded animals including birds and toothed whales in the Cenozoic, and perhaps even for the mammal-like "reptiles" in the Permo-Carboniferous.

We derived a first approximation estimate of the cooling required for hominin brain size increase from a simple model of heat loss [5]. The result was rather modest cooling corresponding to 1 to 2°C, quite compatible with regional cooling during glacial episodes in the Pleistocene. We suggest that fire and cooking combined with climate to release brain size constraints. If climatic cooling was indeed a releaser for bigger brains, then a synergy is suggest, i.e., colder nights would have favored more fire use and greater opportunities for cooking, providing a more easily digestible food, freeing up energy for the brain as Wrangham has

recently argued [6]. To this we might also suggest that cooking allowed for reduction in jaw and concomitant increase in other areas of the skull. The critical overheating challenge for bigger brains came during periods of activity, especially during the heat of the day if our ancestors were so compelled to obtain food then. So with onset of a glacial epoch or migration to higher elevations colder nights should have required fires to keep warm, while temperatures during activity were low enough for bigger brains to emerge, even with some pre-adaptations for cooling such as sweating and the cranial radiator, both plausibly present in the proximate ancestor to Homo.

The second path suggests a different constraint, sufficient oxygen levels in the atmosphere. Insect gigantism has been noted at times of elevated atmospheric oxygen levels, especially during the Carboniferous, the time of huge burial of organic carbon that was transformed into coal [7-9]. Insect physiology entails the diffusion of oxygen through their tracheal system, thus gigantism, especially for flying insects, imposes an oxygen demand satisfied by higher ambient levels. While bigger insect brains are likely correlated with bigger bodies in general, it is recognized that mushroom bodies in the insect brain (there are two in each brain) function as the higher processing centers, particularly for those insects with generalist feeding habits [10]. Remarkable structural, functional and developmental convergence between insect mushroom bodies and the higher brain centers of vertebrates is noted [11].

Thus, an outstanding question is whether there is an atmospheric oxygen level for insect encephalization that is analogous to the climatic temperature constraint for warm-blooded animals? Did the insect giants of the Carboniferous show a burst of encephalization analogous to that of warm-blooded animals? And on a note of wild speculation, is the emergence of the collective superorganism intelligence of social insects [12-13] the product of millions of individually communicating brains, in some colonies, linked to climatic changes?

Should we humbly view the marvelous attine ant and termite fungal agriculture and the functional architecture of the termite mound [14] the technology of this superorganism, as the analog of the human technosphere? Thus, can the collective intelligence observed in social insects be the second path to technical civilizations? Can we expect to eventually find insectoid civilizations on some Earth-like planets around sun-like stars?

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