Evolution of Aerobic Respiration. J. Hemp[1] and L. A. Pace[2], [1] Center for Biophysics and Computational Biology and Department of Biochemistry, University of Illinois at Urbana-Champaign, Illinois, USA (jim.hemp@gmail.com), [2] Medical Scholars Program, University of Illinois at Urbana-Champaign, Illinois, USA.

Introduction: The evolution of oxygenic photosynthesis in the ancestors of modern Cyanobacteria during the Archean eon was one of the most important events in the history of life on Earth [1]. Recent geochemical studies provide strong evidence that by 2.5 Ga oxygen was present in the surface waters of the ocean [2-5], and by 2.4 Ga oxygen had begun to accumulate in the atmosphere in what is known as the great oxidation event (GOE). The production of molecular oxygen by oxygenic Cyanobacteria had major ramifications for the geochemistry of Earth's surface, leading to redox state changes which modified the bioavailability of redox sensitive metals such as iron, molybdenum, and copper [6]. Biologically the availability of O_2 provided life with the ultimate oxidant, paving the way for the evolution of aerobic respiration, the most exergonic metabolism known. Coupling the oxidation of substrate molecules to the reduction of molecular oxygen ($E^{o'}$ = +0.82V), aerobic organisms are able to extract larger amounts of energy from a given substrate than anaerobic organisms. The ability to utilize O_2 as an oxidant also allowed organisms to thermodynamically access many previously unavailable sources of reductants, greatly increasing the metabolic diversity of life.

In the modern biosphere aerobic respiration is performed by many Bacteria and Archaea. All known Eukaryotes either have mitochondria, or evolved from ancestors which had mitochondria, suggesting that the origin and evolution of aerobic respiration may be central to the origin of modern Eukaryotes. The energy demands of multi-cellular life are very high, therefore aerobic respiration is very likely an absolute requirement for the evolution of complex macroscopic life.

Genomic approaches to the evolution of aerobic respiration: Aerobic respiration is performed by oxygen reductase members of the heme-copper oxidoreductase superfamily. These enzymes not only utilize O_2 but also require copper and heme to function. We used genomics to access the biological record of copper utilization, heme availability, and the adaptation to the presence of O_2. We analyzed all of the currently available microbial genomes for genes associated with oxygen detoxification, copper utilization, heme biosynthesis and aerobic respiration. Analysis of oxygen detoxification and copper utilization genes show no evidence for biologically relevant oxygen levels on early earth. Analysis of the quinol:electron acceptor oxidoreductases (Complex III) and oxygen reductase members of the heme-copper oxidoreductase superfamily (Complex IV) demonstrate that aerobic respiration originated within early Cyanobacteria after the evolution of oxygenic photosynthesis. All other phyla of Bacteria and Archaea received the ability to perform aerobic respiration via lateral gene transfer. In most currently known phyla early branching groups are always anaerobic, implying that at the time of the major diversification of microbial life aerobic respiration had not yet evolved. Further analysis of Complex III genes also demonstrated that the electron transfer chains in extant anoxygenic photosynthetic clades (Chlorobi, Chloroflexi, Firmicutes and Proteobacteria) were assembled after the origin of aerobic respiration.

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