Assessing the relationship between hypoxia and life on Earth, and implications for the search for habitable exoplanets

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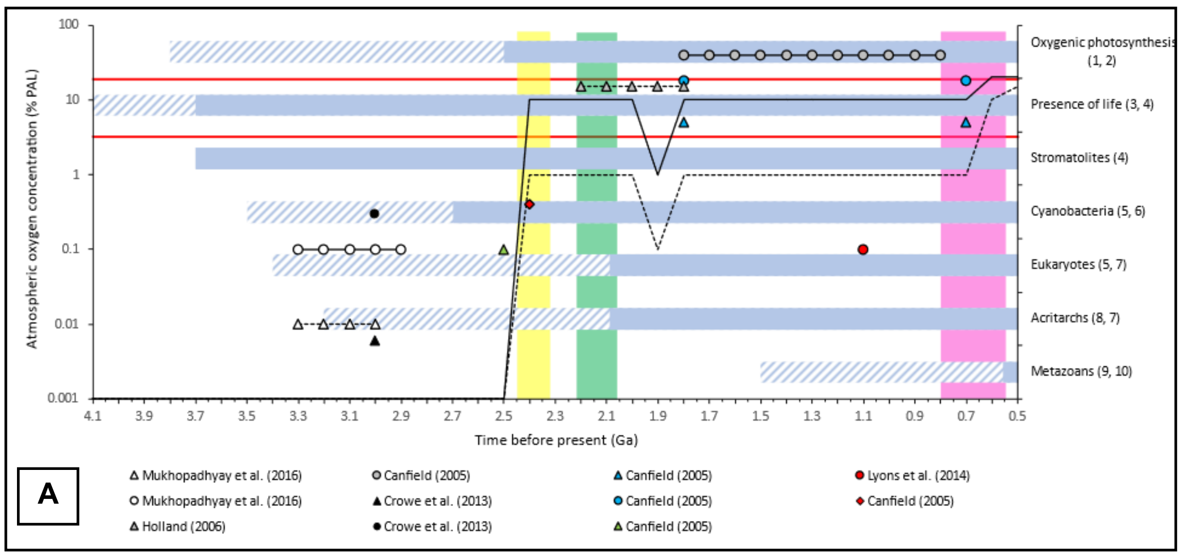
Atmospheric oxygen around the levels we experience on Earth today (21%) are commonly considered as a requirement for large, multicellular life to develop. This idea has been applied to the search for life beyond Earth, thus limiting the search to planets with 'sufficient' levels of oxygen.

However, this may not have to be the case – low oxygen levels (1–5%, commonly called **hypoxia**) are common on Earth (e.g. at high altitudes, in parts of the ocean), as well as *within* multicellular organisms. The bone marrow of many vertebrate groups is an hypoxic environment, and hypoxia is heavily involved in mammalian embryogenesis. Therefore, higher levels of oxygen may not be necessary, or indeed optimal, for the development of large multicellular life. Perhaps the search for habitable planets beyond our own should be reconsidered to accommodate this hypothesis?

It was found that hypoxia is essential for many aspects of multicellular life. One of the most important roles of hypoxia is the maintenance of the undifferentiated state of stem cells—these cells have the capacity to change into multiple types of cells with different functions, and their maintenance in an undifferentiated state under hypoxia allows the organism to rapidly renew a large variety of cell types, and efficiently maintain tissue function during times of stress.

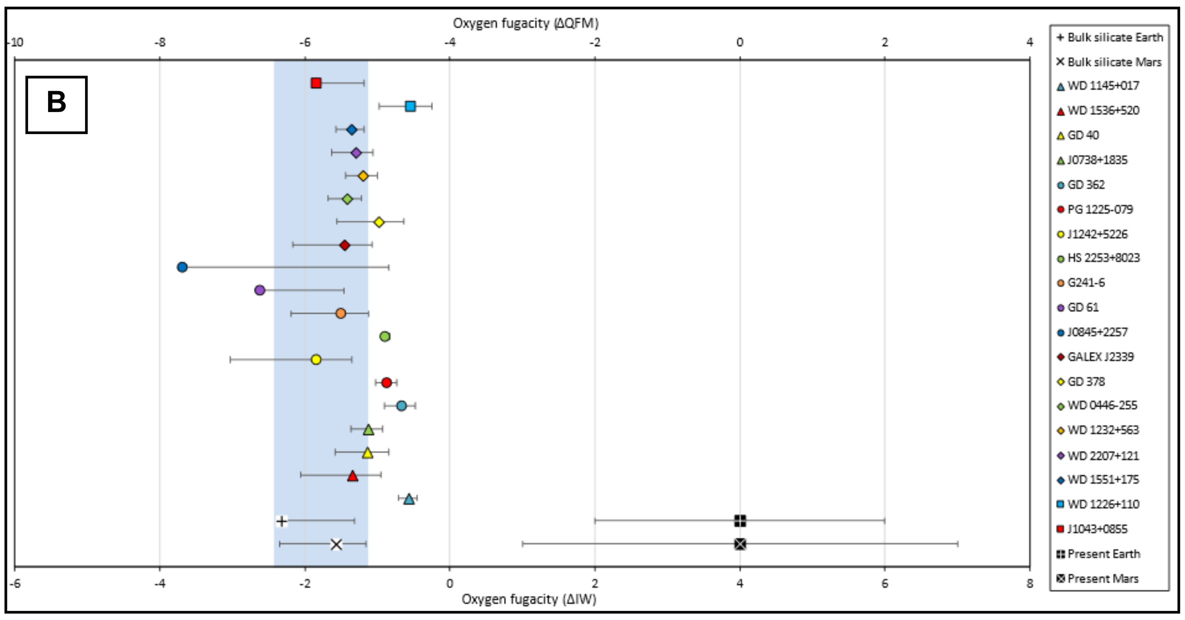
Hypoxia-inducible factors (HIFs) are transcription factors that control biological function and gene expression in animals under hypoxia. HIFs are 'silenced' during periods of increased oxygen, which likely developed as an adaptation to rising oxygen levels. This mean their control of animal genes and processes during hypoxia developed first, suggesting that animals were initially adapted to survive in low-oxygen conditions.

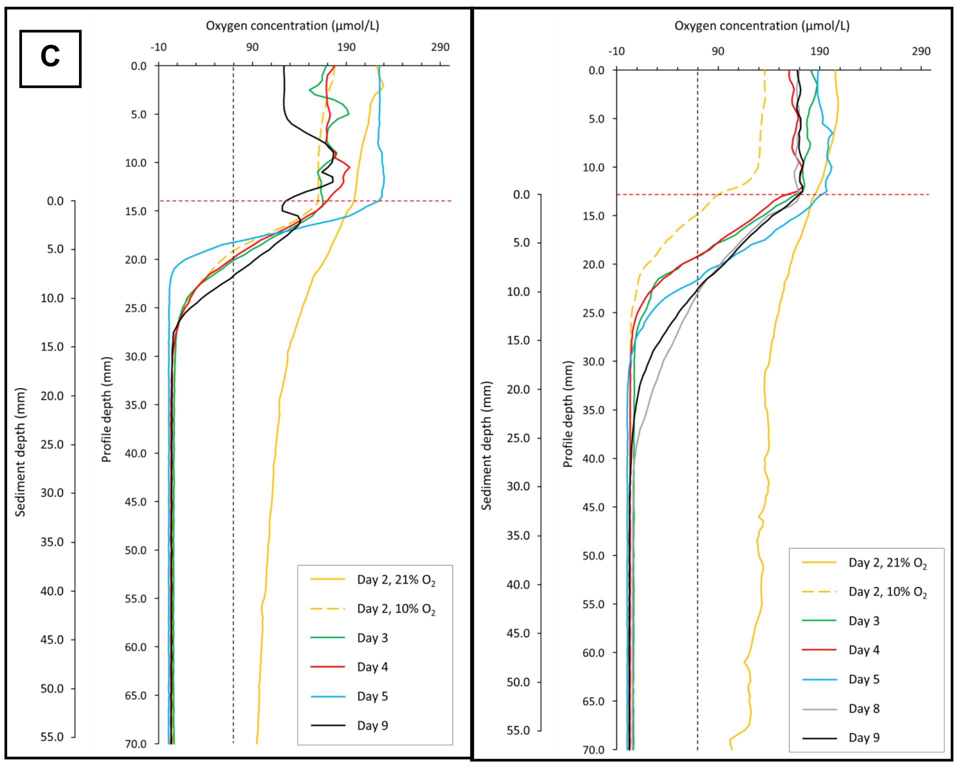
Vertebrates have a version of HIF, HIF-2, which appears to 'trick' the organisms into believing they are in hypoxic conditions, even if they are not. This suggests again that animals need hypoxia to survive, and utilise it in many aspects of their lives.



This study attempts to defend the hypothesis that hypoxia, rather than higher levels of oxygen, is required for the development of large multicellular life forms. This idea was then applied to the search for habitable exoplanets, to include those with lower levels of oxygen.

An extensive literature review was undertaken, encompassing research on the history of Earth's atmospheric oxygenation correlated with the history of life, as well as the roles played by hypoxia in the development of life. An experiment was conducted to assess the expansion of hypoxia within different types of sediment under an atmosphere containing ~10% oxygen (roughly 50% of the atmospheric concentration of the present Earth). Finally, the elemental abundances of white dwarfs are used to estimate the oxygen levels of exoplanets orbiting these stars.





The theory of hypoxia being required for multicellular life can be applied to the search for habitable exoplanets. Using data from white dwarfs polluted by external material, it is possible to calculate the oxygen fugacities (fO_2) of the planets which orbited these stars. This can be used to estimate the atmospheric oxygen levels of these planets.

Of the white dwarfs studied, only one had a lower initial fO_2 than the early Earth (above). This may indicate that this planet could have developed an hypoxic atmosphere during its lifetime, and hence that it was habitable. However, this assumes that it had a similar evolution to that of Earth, which may not be the case.

The results of my experiment (left) suggest that hypoxia may extend deeper within coarser sediment than finer sediment, assuming an atmosphere of ~10% oxygen and the absence of microbial life. Therefore, it may be beneficial to search for exoplanets with atmospheres of ~10% oxygen, and the possibility of coarser sediments on the surface.

*Figure descriptions: **A**: history of atmospheric oxygen and life on Earth; **B**: the oxygen fugacities of polluted white dwarfs; **C**: oxygen concentrations within fine and coarse sediment, respectively.*

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