ANOXIC GEOTHERMAL FIELDS OF THE PRIMEVAL EARTH AND THE EMERGENCE OF THE FIRST CELLS

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The cell cytoplasm of archaea, bacteria and eukaryotes is characterized by the prevalence of potassium over sodium, which is crucial for the integrity of the translation system [1]. This distinct ionic composition has been attributed to the emergence of the first cells in K^+-rich habitats [2]. Different, albeit complementary scenarios have been suggested for the K^+-rich environments on the primordial Earth on the basis of experimental data [3,4] and theoretical considerations [5,6]. Specifically, building on the observation that $[K^+]/[Na^+]$ is much greater than unity at vapor-dominated zones of inland geothermal systems (geothermal fields), we have argued that the first cells could have emerged in the pools and puddles at the periphery of such fields [3,4]. Under anoxic, CO_2-dominated atmosphere, the elementary composition of the condensed vapor would resemble the internal milieu of modern cells. Even at modern, oxidized geothermal fields, the exhalations contain high amounts of ammonia, phosphate, and hydrocarbons [3], suggesting that anoxic geothermal fields were conducive to the formation of sugars and nitrogen-containing organic molecules which could serve as "building blocks" as well as nutrients for the primordial cells.

Marine and freshwater environments, generally, show $[K^+]/[Na^+] < 1.0$. Therefore, the spread of the primordial cells into such environments must have been limited by their ability to keep the cytoplasmic $[K^+]/[Na^+]$ ratio at > 1.0, which would require ion-tight membranes and membrane ion pumps to extrude sodium ions out of the cells [7]. Comparative structural and genomic analyses reveal how an interplay between several, initially independently acting sodium pumps might have gradually led to the modern-type membrane bioenergetics.

References

1. Spirin, A. S., and Gavrilova, L. P. (1969) *The Ribosome*, Springer, New York.
2. Macallum, A. B. (1926) The paleochemistry of the body fluids and tissues. *Physiol Rev* **6**, 316-357.
3. Mulkidjanian, A. Y., Bychkov, A. Y., Dibrova, D. V., Galperin, M. Y., and Koonin, E. V. (2012) Origin of first cells at terrestrial, anoxic geothermal fields. *Proc Natl Acad Sci U S A* **109**, E821-830.
4. Mulkidjanian, A. Y., Bychkov, A. Y., Dibrova, D. V., Galperin, M. Y., and Koonin, E. V. (2012) Open questions on the origin of life at anoxic geothermal fields. Orig Life Evol Biosph ***42***, 507-516.
5. Galimov, E. M., Y.V., N., Ryzhenko, B. N., and Cherkasova, E. V. (2012) Chemical composition of the primary aqueous phase of the Earth and origin of life. *Geochem. Intern.* **50**
6. Maruyama, S., Ikoma, M., Genda, H., Hirose, K., Yokoyama, T., and Santosh, M. (2013) The naked planet Earth: Most essential pre-requisite for the origin and evolution of life. *Geoscience Frontiers* **4**, 141-165.
7. Mulkidjanian, A. Y., Galperin, M. Y., and Koonin, E. V. (2009) Co-evolution of primordial membranes and membrane proteins. *Trends Biochem Sci* **34**, 206-215.