

Gene rearrangement triggered the global salinity divergence of heterotrophic archaea in the aftermath of the Cryogenian Snowball Earth

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Brackish environments such as estuaries and enclosed seas are critical ecosystems where land-ocean interactions greatly impact the evolution of coastal life on Earth. However, genetic mechanism and ancient geological driving force for the evolution of the brackish populations are still in mist. Here, we infer the evolutionary trajectory of the ubiquitous heterotrophic archaea Poseidoniales (Marine Group II archaea) between brackish and marine habitats in the aftermath of the Cryogenian Snowball Earth. Phylogenomic analysis reveals that the Poseidoniales genomes from global estuaries and enclosed seas formed six distinct clades within the Poseidoniales. These clades were enriched at salinities between 6.6 and 23‰ but are depleted or absent at salinities beyond this range. The divergence of Poseidoniales between brackish and marine waters was triggered by the insertion, inversion, and possibly regulatory coupling of a key gene *corA* in a highly conservative osmotic-stress tolerance gene cluster, which was followed by metabolic acclimation and diversification that were characterized by proteome acidity change. Molecular clock analysis revealed that genus-level subgroups divergence of Poseidoniales was from 0.834 to 0.28 Ga, while the divergence of the brackish and the marine subgroups was from 0.299 to 0.094 Ga. According to the geological events, we speculated that rapid environmental salinity change caused by drastic landform changes on the continental margins during the Pangea period (0.335-0.175 Ga) was the key selective force. Our results highlight the close interplay of genetic change and major geological events in the emergence of novel life groups in Earth's early history.