Major Transitions in Planetary Evolution

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Abstract

Earth has undergone a succession of stages driven by physical, chemical, geological, biological, and social processes. Among the most significant transitions in Earth's planetary evolution are the emergence of life and subsequent biochemical innovations, the emergence of social behavior and cognition, and the emergence of technology. After life emerged, planetary processes became much more complex due to increased diversity in what is biogeochemically possible. With the evolutionary emergence of collective behaviors, social systems, and cognition, an increasing number of planetary processes became controlled by life. Since the emergence of technology, intentional steering of the environment became possible. In each stage, new mechanisms of control, mediated by new information processing architectures, are added to existing levels of control on the planetary environment. We can classify these evolutionary stages of planets into matter-dominated, life-dominated, and agency-dominated phases, where each is distinguished by the extent to which information processing systems control planetary processes. We aim to characterize how each phase shapes planetary environments.

Looking back at the history of our planet suggests we are at a critical juncture in Earth's planetary evolution: for the first time in Earth's history, a species has the collective knowledge to understand how life co-evolved with the Earth and is co-committingly witnessing its own enormous impact on the Earth system over a relatively short timescale. It is also the first time a species possess the ability to steer the planetary environment *intentionally*. The emergence of another highly intelligent system, artificial intelligence (AI), may be around the corner. Observing our present transitory phase in the context of Earth's long history raises the question of whether the emergence of humans, our civilizations, and AI (and beyond) are unique transitions or typical when compared to past planetary transitions. Comparing our current phase to past ones requires distinguishing how matter, life, intelligent agency, and technology each shape planetary evolution.

Distinguishing life, intelligence, and technology from each other and from physics is a notoriously difficult subject. In this paper we characterize these in terms of the role of information in controlling matter, and how this shapes the planetary environment, allowing the possibility of placing these phases on the same continuum. This suggest three phases of planetary evolution for comparison: matter-dominated (no life), life-dominated, and intelligence-dominated, where transitions between these correspond to changes in the organization of information in physical systems, and how that organization constructs and controls the planetary environment.

Differences and similarities between matter-dominated, life-dominated, and agency-dominated planets will be most apparent when studying the physical characteristics of the planetary environment. In matter-dominated environments without life, physical, chemical, and geological processes control planetary formation and evolution (Frank et al., 2017). On planets where life takes hold, substances are assembled and reassembled by different ways of information processing (Walker et al., 2017) and heritable memory permits certain biogeochemical processes to be controlled over long timescales. Shifts in the planetary state are driven by increasing accessibility of energy sources for control by life and by increasing diversity in biogeochemistry generated by life (Frank et al., 2017; Judson, 2017). Examples include the harnessing of geochemical energy by the emergence of life, the start of anoxygenic photosynthesis, the Great Oxidation Event, the emergence of animals, and the evolution of animals capable of harnessing fire (Judson, 2017). For the first three examples, new genetic information emerged allowing heritable control of geochemical cycles, for the latter two other informational architectures emerged - collective behavior among different kinds of cells (animals) and cultural exchange of information (fire). In each event, planetary capacity was expanded by access to new energy sources, allowing more diversity and complexity. The addition of new informational architectures by life thus clearly expanded the evolutionary paths of this planet by reassembling matter in different ways.

Just as life expands the evolutionary paths of planets, activities associated with intelligent agency also affect the evolutionary paths of planets in unique ways (Grinspoon, 2016).

The emergence of collective and social groups enabled the use of planetary resources in distinctive ways, by permitting intentional steering and intervening on local ecosystems to meet the needs of collectives (Rockström et al., 2009; Barton et al., 2016; Grinspoon, 2016). This 'intelligent' control differs markedly from earlier life, which simply emitted or consumed substances without engineered outcomes. Steering of ecosystem function has become most apparent with the emergence of cumulative intelligence by human beings. While a high level of individual intelligence and collective intelligence has been observed in social insects and social animals such as bees, ants, mammals, and birds (Holekamp et al., 1999; Benson-Amram et al., 2016; Sasaki et al., 2013), their influence on global-scale environment remained relatively small since their activities mainly stayed in local areas and their social knowledge does not accumulate, because information is not transmitted via language. Humanity has been managing ecosystems extensively on Earth, utilizing and moving resources across the globe and causing global-scale perturbations and fluctuations (Rockström et al., 2009). Humanity's ways of storing, sharing, and using information are transitioning Earth from a life-dominated planet to an agency-dominated planet.

Following the emergence of humans, the emergence of ever more powerful technology, including AI and beyond will likely mark the new phase of agency-dominated planet, where informational architectures become increasingly abstracted from the physical substrates tied to geochemical cycles. AI can continuously evolve by sharing large volumes of information without any boundaries between individual bodies or hardwares, thus they do not require the much longer generational timescales of humans to adapt and evolve. Their physical lifetime is also less dependent on the global biogeochemistry of a planet, allowing partial decoupling of the processes supporting them from the planetary environment as compared to earlier life-forms: this transition has never happened to any life in the history of this planet so far. Once AI flourishes, either hybridized with humans or in a post-biological phase of evolution, intelligently steered ecosystems will change dramatically compared to the current man-managed ecosystems of the Anthropocene, via even more significant decoupling of information processing systems from their planetary context.

Discussion and Future Outlook

Life and intelligent life have invented ways to harness energy from the Earth system, leading to major shifts in energy use and biogeochemical diversity. How this comes about is much less understood. We have suggested the driving forces behind these transitions are associated with how information is organized and controls planetary processes such as flows of energy and material resources. In contrast to the major transitions in evolution of biological entities (Szathmáry and Maynard Smith, 1995), which also have been unified in terms of changes in information storage and management, here we have classified major transitions in planetary evolution by the planetary-scale consequences of informational architectures that mediate global-scale changes. While some major evolutionary transitions do lead to planetary-scale changes in the Earth-system, others do not. A general model for planetary-scale transitions must account for these differences, enabling a framework for dynamic planetary evolution useful for re-conceptualizing the nature of information and intelligence in an astrobiological and planetary context.

References

Barton, C. M., Ullah, I. I. T., Bergin, S. M., Sarjoughian, H. S., Mayer, G. R., Bernabeu-Auban, J. E., Heimsath, A. M., Acevedo, M. F., Riel-Salvatore, J. G., and Arrowsmith, J. R. (2016). Experimental socioegology: Integrative science for anthropocene landscape dynamics. *Anthropocene*, 13:34–45.

Benson-Amram, S., Dantzer, B., Stricker, G., Swanson, E. M., and Holekamp, K. E. (2016). Brain size predicts problem-solving ability in mammalian carnivores. *Proceedings of the National Academy of Sciences of the United States of America*, 113:2532–2537.

Frank, A., Kleidon, A., and Alberti, M. (2017). Earth as a hybrid planet: The anthropocene in an evolutionary astrobiological context. *Anthropocene*, 19:13–21.

Grinspoon, D. (2016). *Earth in Human Hands: Shaping Our Planet's Future*. Grand Central Publishing.

Holekamp, K. E., Boydston, E. E., Szykman, M., Graham, I., Nutt, K. J., Birch, S., Piskiel, A., and Singh, M. (1999). Vocal recognition in the spotted hyaena and its possible implications regarding the evolution of intelligence. *Animal Behavior*, 58:383–395.

Judson, O. P. (2017). The energy expansions of evolution. *Nature Ecology Evolution*, 1:1–9.

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F. S. I., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Synder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., and Foley, J. A. (2009). A safe operating space for humanity. *Nature*, 461:472–475.

Sasaki, T., Granovskiy, B., Mann, R. P., Sumpter, D. J. T., and Pratt, S. C. (2013). Ant colonies outperform individuals when a sensory discrimination task is difficult but not when it is easy. *Proceedings of the National Academy of Sciences of the United States of America*, 110:13769–13773.

Szathmáry, E. and Maynard Smith, J. (1995). The major evolutionary transitions. *Nature*, 374:227–232.

Walker, S. I., Davies, P. C. W., and Ellis, G. F. R. (2017). *From Matter to Life*. Cambridge University Press.