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CHANCE AND NECESSITY IN THE MINERAL EVOLUTION OF TERRESTRIAL PLANETS

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Four factors contribute to roles played by necessity and chance in determining mineral distribution and diversity of terrestrial planets: (1) planetary stoichiometry; (2) crystal chemical characteristics; (3) mineral stability ranges; and (4) the probability of occurrence for rare minerals. Measurements of stellar stoichiometry reveal that stars can differ significantly from the Sun in relative abundances of rock-forming elements, which implies that bulk compositions of some extrasolar Earth-like planets likely differ significantly from those of Earth.

Comparison of Earth's upper continental crust and the Moon shows that differences in element ratios are reflected in ratios of mineral species containing these elements. The most abundant elements generally have the largest numbers of mineral species, though several elements that mimic other more abundant elements are less likely to form their own species. Total mineral diversity for different elements is not appreciably influenced by the relative stabilities of individual phases, e.g., the broad pressure-temperature-composition stability range of zircon ($ZrSiO_4$) does not significantly diminish the numbers of observed Zr minerals. Moreover, the significant expansion of near-surface redox conditions on Earth through the evolution of microbial oxygenic photosynthesis tripled the available composition space of Earth's near-surface environment, and resulted in a corresponding tripling of mineral diversity subsequent to atmospheric oxidation.

Statistical analysis of mineral frequency distributions suggests that thousands of plausible rare mineral species await discovery or could have occurred at some point in Earth's history, only to be subsequently lost by burial, erosion, or subduction—i.e., much of Earth's mineral diversity associated with rare species results from stochastic processes. Thus, while deterministic factors control the distribution of rock-forming minerals, stochastic processes play a significant role in the diversity of less common minerals. Were Earth's history to be replayed, and thousands of mineral species discovered and characterized anew, it is probable that at least 25% of those minerals—more than 1000 species—would differ from species known today.