Harmonic hierarchy of mantle convective cycles: Time series analysis of hafnium isotopes of zircon

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Hafnium isotopes of zircon represents a well-dated proxy for the evolution of magmatic arc systems through Earth history. Time series analysis on the hafnium isotopes of zircon reveals a hierarchy of statistically significant periodic signals that can be attributed to the organizing mechanisms of mantle convection at various time and length scales. The 500-600 Myr supercontinent cycle is the strongest periodic signal present in the hafnium data. Subtracting the supercontinent signal in order to interrogate other periodic signals present in the hafnium data reveals a 60-80 Myr mantle transit cycle, i.e., the time it takes a slab to reach the core-mantle boundary as parameterized by extrapolation of a reasonable tectonic drift velocity at the surface. Both the mantle transit cycle and the Wilson cycle (200-350 Myr), which is also evident in the data and related to the opening of interior, Atlantic-type oceans, exhibit systematic amplitude modulations due to the presence of longer and related cycles. The Wilson cycle signal reveals a ~1.2 Gyr cycle at twice the wavelength of the supercontinent cycle. We interpret this harmonic coupling as the consumption of a long-lived, exterior, Pacific-type ocean system (a "superocean") every other supercontinent cycle. Due to the geometry of degree-2 mantle structure during supercontinent breakup, the 90° "orthoversion" longitude shift every supercontinent cycle implies that a ~180° "extraversion" longitude shift is accomplished over the course of two orthoversion cycles, where one superocean survives two supercontinents. The mantle transit cycle, the smallest possible positive divisor associated with whole mantle convective harmonics, is modulated by longer cycles at all wavelengths: ~1.6 Gyr, ~800 Myr, and ~500 Myr, ~400 Myr, and ~330 Myr. Analysis of high-resolution hafnium records of individual magmatic systems suggests also the presence of an even higher frequency signal (20-30 Myr) attributable to an upper mantle transit cycle due to layered mantle convection occurring above the transition zone.