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Decoding Earth's supercycles: A 600 Myr supercontinent cycle modulated by a longer superocean cycle

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The Earth's history for the past 2000 Myr has been dominated by repeated assembly and break-up of supercontinents with a cyclicity of ca. 600 ± 100 Myr: Nuna (lifespan ca. 1600?–1400 Ma), Rodinia (lifespan ca. 900–700 Ma), and Pangaea (lifespan ca. 320–170 Ma). A similar cyclicity, with a 50–100 Myr time lag, is found in global mantle plume intensity, leading to the geodynamic model of a coupled supercontinent-superplume cycle in Earth history. However, global zircon Hf isotopic signatures, seawater Sr isotope ratios, and the abundance of numerous mineral deposit type, suggest the existence of a cycle twice the duration of the supercontinent cycle. Here we demonstrate that since 2 Ga the superocean surrounding a supercontinent, as well as the circum-supercontinent subduction girdle, survive every second supercontinent cycle. This interpretation is supported by global palaeogeography and by variations in passive margin and orogenic records that both exhibit two periodic signals at 500–700 and 1000–1500 million years. We propose that supercontinents assemble alternatingly through dominantly extroversion (the previous supercontinent turned inside-out through the destruction of the Panthalassa-type superocean) after a more complete breakup, and dominantly introversion (survival of the superocean) after an incomplete breakup of the previous supercontinent, giving rise to the two harmonic cycles (or supercycles). Co-existence of the two cycles may reflect an oscillatory feedback system between supercontinent assembly tectonics and mantle thermal state and structure. A supercontinent assembled dominantly through introversion (e.g., Rodinia) features a partially inherited degree-2 mantle structure, leading to a more complete supercontinent breakup. As a consequence, longer passive margins are generated, and more orogens are involved in the next, predominantly extroversion supercontinent assembly (e.g., early Paleozoic assembly of Pangea). Enhanced continental collision and consequent erosion of the orogens during such a predominantly extroversion supercontinent assembly could explain the elevated continental input indicated by both global zircon Hf record and in seawater Sr isotope ratios. Conversely, a supercontinent assembled dominantly through extroversion (e.g., Pangea) involves a more complete reorganization of the mantle structure, and an incomplete subsequent breakup. Our model provides a conceptual geodynamic framework that is testable with increasing resolution of global palaeogeography in deep time and more realistic 4D geodynamic modelling.