THE GEOLOGICAL ORRERY: USING EARTH'S SEDIMENTARY RECORD TO MAP THE CHAOTIC EVOLUTION OF THE SOLAR SYSTEM

Paul E. Olsen

Lamont-Doherty Earth Observatory of Columbia University; E-mail: polsen@ldeo.columbia.edu

A classical Orrery is clockwork physical planetary model that illustrates or predicts the relative positions and motions of the bodies of the Solar System, usually according to the heliocentric model in a Newtonian context, named after the 4th Earl of Orrery, Charles Boyle, and dating from the early 18th Century to the present (1). The Digital Orrery (2) was an early parallel computer designed to do the massive computations for numerical gravitational solutions of the Solar System that resulted in early demonstrations of the chaotic behavior of Pluto (3) and the inner planets (4) integration that was presaged by the dynamical theory of Poincaré in the late 19th century, itself a response to the 3-body problem left unsolved by Newton. Despite major advances in the last 40 years, the stability of the Solar System and its actual long-term behavior remains a fundamental problem. However, the Earth System has produced a record of climate change that, because it is paced by linked variations in Earth's axial orientation, orbital shape and motion, themselves dynamically linked to the gravitational interactions of the other bodies of the Solar System (and perhaps beyond), is also a record of the chaotic evolution of the Solar System itself. We can call the investigation of the geological record of Solar System dynamics "The Geological Orrery". The Geological Orrery has the potential to escape the inherent predictive limitations of Physics and Mathematics by taking advantage the record of sedimentary archives of orbital variations to which the chaotic solutions for the gravitational system of the Sun, planets, and smaller bodies must conform.

Using the 405 ky metronome of the highly stable Venus-Jupiter eccentricity cycle (g2 – g5, in terms of secular frequencies) expressed as a beat cycle in climatic precession, the Newark Basin Coring Project (NBCP) of the 1990s, which recovered 6700 m of continuous Triassic-Jurassic (230 to 199 MA) lacustrine core, was the first to demonstrate a strong deviation in the period of the Mars-Earth eccentricity (g3 – g4) cycle from the present (5). That cycle now has a period of 2.4 m.y., but during the

Late Triassic and Early Jurassic it was about 1.8 to 1.6 m.y., a deviation attributable to chaotic diffusion in planetary gravitational interactions. This deviation from the present has been corroborated by independent studies of Panthalasan pelagic marine sequences in Japan (6).

The validity of the large difference between the present and Triassic periods for the Mars-Earth eccentricity cycle is dependent on the veracity of the age models for the sequences, which thus far are largely based on the frequency structure of the sedimentary sequences themselves. Testing these age models with independent U-Pb dates is a major goal of Phase I of the Colorado Plateau Coring Project (CPCP; refs. 7, 8), coring of which was completed in late 2013 (9). If the age models for these sequences pass this independent test, the numerical solutions for the Solar System must conform to these parameters, which they currently do not.

According to Laskar (10), the Mars-Earth cycle has a resonance that is an important contributor to chaos in the Solar System that is expressed as either a 2 : 1 or 1 : 1 ratio of eccentricity to obliquity periods [$(s4 – s3) − 2(g4 – g3) = 0$ or $(s4 – s3) − 2(g4 – g3) = 0$ in frequency, with $s4 – s3$ being the obliquity modulating frequency], which is now in the former relationship, a 2.4 : 1.2 m.y ratio. The tropical Triassic NBCP and Panthalasan sequences have no record of obliquity, but recent analysis of high-latitude, Triassic-Jurassic fluvio-lacustrine strata of the Junggar Basin, western China (11) indicates that obliquity records for that time exist and that there are hints in the presumed obliquity beat cycles that the Mars-Earth cycle was in in its present 2 : 1 (1.6 : 0.8 m.y.) ratio. However, for the interval between the latest Triassic and the late Paleogene, the ratios are unknown and the periods of the Mars-Earth cycles remain very poorly documented.

The planned Phase II of the CPCP, which aims predominantly at the Late Triassic and Early Jurassic age part of the Colorado Plateau sedimentary record (8), should provide a series of datable ashes (e.g., ref. 12) and an exportable paleomagnetic polarity stratigraphy extending the results of CPCP-Phase I though the end-Triassic and Toarcian extinction events. Coupled with the existing NBCP record, paleo-high-latitude coring in Triassic-Jurassic strata of Jamesonland, East Greenland (known to have a recoverable polarity record; ref. 13) or the Junggar basin, China where obliquity is already shown to have a strong record (11), these modest projects would test and extend the preliminary obliquity results and serve as be a proof-of-concept for The Geological Orerry by showing that obtaining reliable fundamental Solar System parameters from deep-time sedimentary records is in fact possible.

Full development of The Geological Orrery will be an ambitious and challenging project, however the potential rewards could be transformational. In parallel with the proof-of-concept outlined above, a series of temporally overlapping coupled low- and high-latitude coring projects (or analysis of extraordinary outcrops) would be needed to span the Paleogene to Jurassic, most likely in lacustrine or restricted marine basin settings to maximally isolate precession- vs. obliquity-related beat cycles (i.e., eccentricity vs. obliquity-modulating). These projects will be expensive and multiple international workshops plausibly involving hundreds, if not thousands of participants, will be needed to identify the very best target sequences. Industry participation would be highly desirable and mutually beneficial. In the end, The Geological Orrery, will provide an entirely new venue for gravitational theory and complimenting present experimental and astronomical observational venues, because it has the power to constrain Solar System dynamical solutions by 104 to 1010 (14). The Geological Orrery can be expected to provide an accurate astronomical clock not only for Earth and also for the paleoclimate of other planets with sedimentary records, constrain the habitability of exoplanets, and most provocatively, identify anomalies constraining the largest scale gravitational theories themselves.

References

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