SIMULATION OF THE TIDES OF ANCIENT OCEANS AND THE EVOLUTION OF THE EARTH-MOON SYSTEM

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ABSTRACT. We will simulate the spatial and temporal characteristics of the ocean tides for the present time as well as for a time slice of the Neoproterozoic Era (∼620 Ma b.p.). A focus will be on the transfer of angular momentum between the Earth and the Moon in order to physically simulate the observed increase of day length and the Moon's distance. The numerical results will be validated against geological proxy data of the tidal spectrum of the Australian continental plate.

Subsequently, the evolution of the ocean tides under the influence of the continental drift from present time until the Neoproterozoic will be simulated. Again, a focus will be on the transfer of angular momentum between the Earth and Moon in order to physically explain the dynamical evolution of the Earth-Moon system and, therewith, the increase of day length of about 2 hours as well as the decrease of month length of about 1 day.

Present geodetic and astronomical observations confirm a secular increase of day length of about 2 ms/cy and a lunar recession rate of about 4 cm/year (Williams et al., 2008), which equals a decrease of Earth's rotational energy of about 4×10^{12} W and a mean torque around the Earth's rotational axis of about 5×10^{16} Nm.

The transfer is mainly determined by the ocean tides and is closely interlinked with their resonance characteristics. First model simulations of the M_2 tide for the Permian ocean 250 − 230 Ma b.p. depicted that the angular momentum transfer in the Earth-Moon system was smaller by a factor 2 than at recent time − with comparable tidal amplitudes (Sündermann and Brosche, 1978). Brosche and Hövel (1982) have investigated the angular momentum transfer under the continental drift of the American plates over the last 20 Ma until 10 Ma in the future. Already on this time scale the transfer varies by a factor 2. Comparatively, the deceleration of the Earth's rotation is currently quite high. A variation of the mean tidal torque of about 10% already during the last ten thousand years was evinced by simulations of the M_2 and O_1 tide (Thomas and Sündermann, 1999). Backward simulations of the M_2 tide for 10 topographies of the Precambrian indicate that the angular momentum transfer was almost smaller during the Earth's history than today (Nerge, 1998). If we go backward in time, the Moon approaches the Earth, but it does not reach the Roche limit.

However, there are still considerable deficits in the understanding of Earth's history on the geological time scale. The limited availability of geological proxy data has so far prevented a detailed quantification of the transfer of angular momentum in the Earth-Sun-Moon system far back in the Earth's history. Considering recent paleontological data, and advances in numerical modelling and high performance computing, we will strive to reduce these deficits. First self-consistent geological data on ocean tides, Earth's rotational parameters and orbital elements of the Moon have been provided by the research of Williams (2000) on the sediment layers of South Australia for the Neoproterozoic (∼620 Ma b.p.).

Further, Li, et al. (2008) presented a synthesis of formation (1300 Ma b.p.– 900 Ma b.p.) and breaking up (< 600 Ma b.p.) of the supercontinent Rodinia and devised detailed new paleographical maps for the Neoproterozoic containing the time slice around ∼620 Ma b.p.

Special efforts must be given to the modelling of ephemerides through the Earth-Moon history. A new solution for the computation of the insolation quantities on Earth spanning from -250 Ma to 250 Ma was given by Laskar, et al. (2004), with the evolution of the Earth-Moon semimajor axis of approximately

58.5 Earth radii for 250 Ma b.p., which seems to be in conflict with 58.16 ± 0.30 Earth radii for $\sim$620 Ma b.p. deduced by Williams (2000); one main source of uncertainty is the evolution of the tidal dynamics and other related factors. However, the most regular components of the orbital solution could still be used over a longer time span.

The simulation of the ocean tides shall be carried out with the three-dimensional Max-Planck-Institute ocean circulation model (Marsland, et al., 2003) forced by the complete lunisolar tidal potential (Thomas, 2001). A curvilinear grid with freely selectable grid poles is utilized by the model. Hence, the resolution can be efficiently increased around Australia for evaluation of our results.

At least 100 years will be the simulation period to also resolve the lunar nodal period of 18.6 years at present. For the time interval back to $\sim$620 Ma b.p. we plan at least 62 simulations with an interval of 10 Ma. Continuous simulation of the whole interval would require too much computational effort. For the paleogeographical maps, also considering the paleobathymetries, we will base ourselves e.g. on Li, et al. (2008), Müller et al. (2008), Williams et al. (2008) and the Paleomap Project of C.R. Scotese.

The whole work will result in *one* considerably denser reconstruction of tidal dynamics from the Neoproterozoic until the present. Appropriate to the uncertainties in the knowledge of the Earth's history, it will be a first contribution to a statistical treatment of preferably a great many configurations as recommended by Brosche and Sündermann (2011). Astronomers and geodesists could access the energy and angular momentum budgets for the analysis of the evolution of the Earth-Moon system; geologists as well for the analysis of periodic growth features or sedimentary rhythmites.

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