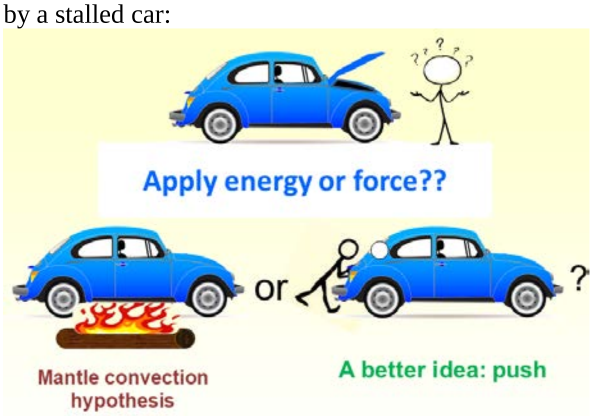
A New Mechanism for Plate Tectonics Based on Gravitational Torques that Explains Differences Among Rocky Planets. A. M. Hofmeister[1], R. E. Criss, [1] and E. M. Criss[2,3], [1]Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130, USA, [2]Panasonic Avionics Corporation, Lake Forest, CA 92630, USA, [3]E. M. Criss contributed to preparing this article independent of his employment and without use of information, resources, or other support from Panasonic Avionics Corporation.

Introduction: The rocky planets have similar sizes and bulk compositions, yet Earth is set apart by its unique geologic character, history, and the lateral motions of its tectonic plates [1]. This abstract summarizes our detailed discussion [2] on the internal and external processes underlying these differences, and our proposed mechanism for plate tectonics.

Recognized Model Flaws: Earth's internal workings are popularly modeled as dissipation of radiogenic and primordial heat via mantle convection. Yet, convection proponents recognize that the available heat-energy is inadequate to drive mantle convection, and that insufficient evidence exists for the predicted thin, thermal plumes from the lower mantle [3]. Seismic counter-evidence for whole mantle convection is abundant [4]. That the Raleigh number (Ra) is large does not bear on motions of solid rock because this criterion applies only to fluids (e.g., water, gas) in a rectangular box [5]. In contrast, solids require imbalanced (deviatoric) stress to deform or fracture, but conditions are hydrostatic in the lower mantle.

Moreover, convection models do not address the complexity of plate motions, nor do they elucidate their driving mechanism.

Forces, not heat, move big objects: Throughout the universe, motions of large bodies are caused by the force of gravity. Examples are numerous, e.g., orbits. The different effects of heat and force are exemplified by a stalled car:



Energy and force differ fundamentally. Note that:

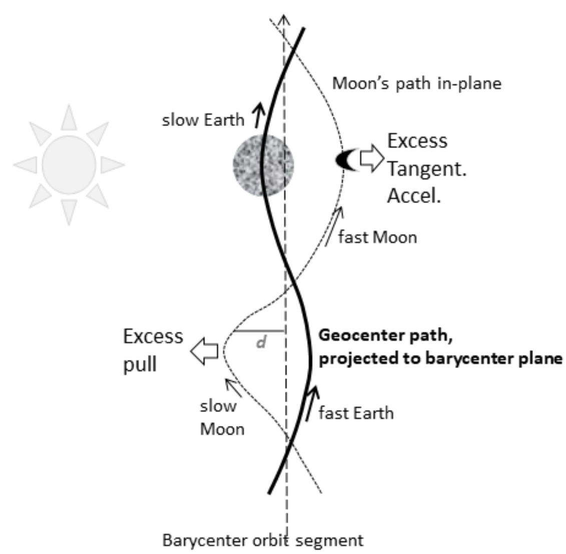
- Kinetic energy of ~20 cars on freeway = 10^6 J.
- K. E. of whole lithosphere at 6 cm/yr = 10^6 J.

Thus, kinetic energies of moving cars and huge continents are similar, yet the forces required to move these masses differ tremendously!

Heat is tied to the temperature of a solid, not to its largescale motion. Earth's orbit and spin are not tied to its temperature. The same applies to its plates.

The New Plate Tectonics Mechanism: Because lateral accelerations require lateral forces, we propose that force imbalances and torques in the unique Earth-Moon-Sun 3-body system cause large-scale, co-operative tectonic motions. The gravitational phenomenon of spin is also important because it involves enormous energies and forces, is dissipated internally, and has been linked to plate motions (e.g., [6,7]). Tidal forces are not discussed here because existing models are 2-dimensional, and their influence was previously invoked [8].

The 3-body system. Depicting the Moon as orbiting the Earth ignores that the Sun is the dominant, central body [9]. The barycenter, not the geocenter, orbits the Sun nearly circularly in a plane. The Earth and Moon chase each other around the Sun in whirligig paths, where neither path lies in the fixed plane of the barycenter. Here is a schematic, with Earth and Moon projected to the barycenter plane, and not to scale:



Importantly, Solar gravitational pull on the Moon is 2.2 times that of Earth. This causes lunar drift - the Sun is stealing our Moon! Drift has led to a highly elongated apparent elliptical path of the Moon around Earth.

Because the various force vectors are imbalanced and not parallel, torque exists, and angular momentum in the Moon's apparent path around the Earth is not conserved. Changes in the Earth-Moon distance produce a monthly, 600 km radial excursion of the barycenter position inside Earth's mantle. Earth's spin superimposes a ~longitudinal 24 h circuit of mantle rocks through the barycenter.

Because the barycenter lies ~4600 km from the geocenter, Earth's tangential orbital acceleration and Solar pull are also imbalanced (see sketch above). Furthermore because these forces are not parallel, torque exists. This torque alters the spin angular momentum of the Earth. Cohesion of a completely frozen Earth would offer great resistance to force imbalances, but Earth has a weak, liquid-bearing layer below the lithosphere.

Hence, near-surface motions are enabled by the cold, brittle lithosphere being underlain by a weak low velocity zone (LVZ): The thermal states of both layers result from leakage of Earth's internal heat to space, primarily that generated in the upper mantle [10,11].

Here we note that the Nusselt number of the Earth is low, which is consistent with the plate motions being very slow, and with mantle rock heat generation of ~100 W per km^3 being very weak. Hence, conductive profiles represent the Earth [10,11].

Uniaxial, east-west motions dominate due to spin. The inertial response of a high-spin planet with an LVZ is ~6 cm yr^{-1} westward drift of the entire lithosphere, which dominates plate motions. This aspect of plate tectonics is the same phenomenon as differential rotation in stars.

Spin plays another important role. Concomitantly, uniaxial stress induced by spin cracks the brittle lithosphere in a classic X-pattern, creating mid-ocean ridges and plate segments [6].

Asymmetry stems from 3-body imbalances. The barycenter is a point in space, but is not a point set in the Earth. As Earth spins, its mantle rocks move through the barycenter, so the imbalances and torques on any given rock vary through the day. Cyclical stresses are effective agents of failure: this is known as fatigue in engineering [12]. The daily and monthly cycling of the forces add asymmetry to plate motions, besides promoting failure.

Plate tectonics occurs above 660 km. As plates descend, they warm and thin [11]. Earthquakes cease and the two Benioff ones merge by depths of ~200-660 km, corroborating slab thinning during re-equilibration. The earthquake cessation depth depends on angle and speed, consistent with conductive heat transfer and measured thermal conductivity values of the plates [11].

Implications for Other Rocky Planets: Comparing rocky planets shows that the presence and longevity of volcanism and tectonism depend on the particular combination of moon size, moon orbital orientation, proximity to the Sun, and rates of body spin and cooling [2]. Earth is the only rocky planet with all the factors needed for plate tectonics.

Volcanism differs from tectonism. Volcanism is related to heat-energy, is predominantly vertical, and is concentrated where inhomogeneous heating produces buoyant melts which passively rise. Hence, the age of volcanism on rocky planet surfaces expresses their evolutionary state, where mass and size control cooling rate, and spin provides uniaxial stress and adds frictional heat, up until freezing.

Venus and Mercury lost their spin and their moons to the immense proximal Sun, quelling their geologic activity early on. Venus could be warm inside due to its size, but without spin related stress, deep fractures do not exist that would facilitate the ascent of interior melt. While Venus resembles Earth in size, its interior workings are vey different.

References:

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