VARIATIONS IN THE EARTH’S ROTATION PERIOD AND VIRTUAL DIPOLE MOMENT IN GEOLOGICAL HISTORY

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Abstract. According to satellite data, the Moon’s orbit radius increases by about 3.8 cm/year. A small decrease in angular velocity (dΩ/dt) and a small increase in Earth’s rotation period (T) correspond to the Moon’s moving away from the Earth. These global processes probably also took place in the geological past, as shown by studying the number of annual growth rings of different-aged fossils. 550 Ma ago, T was 3±1 hour shorter, i.e. the angular rotation velocity of the Earth’s mantle was about 14% higher, exceeding the modern angular rotation velocity of the inner core. The mantle retardation energy estimated is commensurable with the output of a modern dynamo, and could be one of the sources of generation of the main geomagnetic field. The increase of T in Phanerozoic time generally shows a near-linear pattern, but there is a distinct anomaly in the 350-200 Ma interval: the Earth’s rotation was retarded much faster at that time. The Earth’s virtual dipole moment (VDM) decreased in the same interval. Another similar T- and VDM- anomaly is observed in Precambrian time over the interval 1.0–0.6 Ga. Known VDM-values at the end of this interval were probably also much smaller than at the present level and at the preceding time. However, it seems more essential that both T-anomalies observed began at the time of generation of magmatic activity cycles that mark these events in the crust of all continents. There were at least four such cycles in the Earth’s Proterozoic history. For the time being, variations in VDM and T in Precambrian time cannot be traced in detail because reliable data are scarce.

Introduction. The behavioral study of the amplitude, inversion frequency and other parameters of the main geomagnetic field in the remote past could have marked global cosmic and inner terrestrial processes. However, geoscientists are not unanimous as to whether endogenous and cosmic processes are interrelated. I do believe, however, that after the 7-th International Conference on “Problems of Geocosmos” we worked hard and our results show that we will come to agreement. In the past few years new extensive data for the values of the virtual dipole moment (VDM) of the Earth, obtained in Russia chiefly by V.V. Shcherbakov’s team, were reported. The global IAGA Paleointensity Database (IPD) was formed and is now available at the website ftp://ftp.ngdc.noaa.gov/Solid_Earth/Paleomag/access/ver3.5/access2000/PINT00.MDB. There are about 3900 values for the VDM in IPD. Unfortunately, most known VDM-values are concentrated within the last 100 Ma. An interesting hypothesis, formulated by Yu.N. Avsyuk in 1991, was put forward (Avsyuk, 1993). He assumed that the Moon’s orbit had a great variable and periodical radius in the Phanerozoic. Therefore, the lunar tidal forces on the Earth were variable, too, and the Earth began to rotate slowly, then rapidly, then slowly again. In [Kurazhkovskii et al., 2007], the IPD values on paleointensity and the inversion frequency were compared with phases of variations in the Moon’s orbit radius according to Yu.N. Avsyuk and with folding phases (Bertran’s cycles), but no correlation was established. However, it was shown in the same paper that the Earth’s geomagnetic paleointensity is well correlated with its volcanic activity. Furthermore, evidence for the historical deceleration of the Earth’s rotation, related to the entirely different evolution of the Moon’s orbit, is available. Satellite data show that its radius now increases by 3.82±0.07 cm/yr. It is important that the dΩ/dt value was estimated by space observation. The value numerically corroborates a general increase in T during the Phanerozoic, which exhibited a roughly linear pattern (Varga, 1996; Zharkov, 2003). Last time I told you about the reasons for a decrease in the Earth’s angular rotation velocity (Ω) through the Phanerozoic (Zemtsov, 2009). The Earth’s rotation period (T) or the length of the modern day (LOD) in seconds is equal to approximately 86164 s or 23 h 56 min 04 s. Then, Ω=2π/T=7.291x10^-5 1/s. Astronomically, T is now measured very accurately. Over the past century LOD has increased by about 2 ms, and minor fluctuations of LOD show a connection between variations in the Earth’s rotational energy and its global seismic activity (Fig.1). The authors show that the rotation energy is by far the biggest component of energetic household of our planet and its yearly variation is somewhat bigger than annually released seismic energy (Table). They concluded that “a seismic event (even the biggest one) is not able to influence the rotation speed of the Earth. Variation in rotation speed through stress, caused by the corresponding flattening variations, is related to the longitudinal distribution of seismicity and seismic energy. It is likely that the seismicity does not generate LOD anomalies”. On the contrary, the LOD...
variations influenced the planet’s seismic activity. Anomalies in LOD deceleration (or T) can be used to estimate the time intervals of Earth’s highest paleoseismicity in geological history.

Fig. 1. Variations in day length (LOD) and annual number of seismic events M>7 during the 20th century. (After P. Varga et al., 2004).

<table>
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<tr>
<th>Annual variations in energies</th>
<th>Energies</th>
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<tr>
<td>Solar energy received - 2.1 × 10^24 J/a</td>
<td>Rotation energy -2 × 10^29 J</td>
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<td>Atmospheric circulations - 6.3 × 10^22 J/a</td>
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<td>Loss by heat flow - 1.0 × 10^23 J/a</td>
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<td>Rotational energy - 1.6 × 10^19 J/a</td>
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<td>Energy of earthquakes - 9.5 × 10^18 J/a</td>
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<td>Volcanic energy - 2.0 × 10^18 J/a</td>
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<tr>
<td>Geomagnetic storms - 3.2 × 10^13 J/a</td>
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Table. The Earth’s energy budget (After P. Varga et al., 2004).

**Results.** The increase of T in Phanerozoic time generally shows a near-linear pattern (Fig.2) and corresponds to the cosmic value dΩ/dt. 550 Ma ago, T was 3±1 hour shorter, i.e. the angular rotation velocity of the Earth’s mantle was about 14% higher, Ω≈8.34·10^-5 s^-1, exceeding the modern angular rotation velocity of the inner core (Zemtsov, 2009). In this case, a geomagnetic field could not have been generated. Assuming that the Earth’s core radius remained unchanged over that period of time, we can roughly estimate old linear velocity V at the core-mantle boundary (CMB), which is one of major “constants” in the geomagnetic field generation theory (Starchenko, 2000), and average mantle retardation energy with the mass (m≈4·10^{24} kg) over the entire Phanerozoic (∆E), using a known formula for the inertia momentum (J) of the hollow sphere with the radii of the Earth (R_E) and the core (R_c):

\[
\Delta E = -\frac{\Delta \Omega}{2} \cdot J = -\frac{\Delta \Omega}{2} \cdot \frac{2}{5} m \frac{R_c^5 - R_E^5}{R_E^3 - R_c^3} \approx -0.5 \cdot 10^{28} J,
\]

\(\Delta \Omega\) is the decrease in the angular rotation velocity of the mantle.

Part of this tremendous energy could be one of the sources of generation of the geomagnetic field in Phanerozoic time. Transforming 550 Ma in seconds, we obtain that the average energy dissipation power at the CMB boundary could be ≈0.3x10^{12} W, i.e. it is commensurable with the output of a modern dynamo (10^9 - 10^{12} W).
Fig. 2. Estimation of the Phanerozoic Earth’s rotation period (T) after Varga, 1996; Zharkov, 2003; Zemtsov, 2009 and the Paleozoic anomaly T and the VDM values in the Carboniferous-Triassic interval. Solid circles are the T values; red triangles and stars are the VDM values after Shekerbokova et al., 2006; the vertical segments are estimation errors T, which were received for the number of days in an ancient year and were estimated from the growth rings of fossil corals and mollusks of various ages (Varga, 1996); red dotted line is the modern VDM value (approximately 8x10^{22} Am^{3}).

A more detailed examination of T-curve (see Fig. 2) has led us to conclude that it has a nonlinear and quasi-periodic pattern. In particular, the Earth’s rotation slowed down much faster over the interval 350 to 200 Ma (the early Jurassic) than at the beginning, especially in the Late Paleozoic. The decrease in VDM during the same interval is directly proportional to the increase in T (LOD), but is slightly belated (100 Ma) relative to the decrease in Ω of the mantle. Furthermore, the beginning of the decelerated mantle at ca. 400 Ma (the end of the Lower Devonian), accompanied by a “transitory” rise in ΔΩ between the mantle and the inner core, is quite understood, and is expected to be characterized theoretically by abnormally high VDM values. At first, the process was presumably accompanied by a temporary increase in ΔΩ between the mantle and the inner core. However, what part of deceleration energy could have been absorbed by the core is not clear. The smallest tidal energy values and decreased Moon’s orbit radius growth are modeled over the same interval (350-150 Ma) (Zharkov, 2003). Furthermore, the maximum value of the LOD deceleration anomaly can be calculated. During 100 Ma LOD deceleration was approximately 1.5 h (see Fig. 2). Hence, the average LOD deceleration was ca. 5.5 ms for 100 years. The Earth’s seismicity in the middle of that ancient interval might be 10 times the seismicity estimated for last century (2 ms).

A second similar but less reliable T- and VDM- anomaly is assumed for Precambrian time in the interval 1.0–0.6 Ga, when the accretion of the continental lithosphere continued. Sparse known VDM-values at the end of this interval were probably also much smaller than at the present level and at the preceding time (Fig. 3).

Fig. 3. Precambrian anomaly T and VDM, x10^{22} Am^{3}.

Solid circles are T values after Varga, 1996; Zharkov, 2003; Zemtsov, 2009; red squares are VDM values according to IPD; red dotted line is a modern VDM value (approximately 8x10^{22} Am^{3}); blue segments are magmatic activation cycles.

Discussion. According to V.N. Zharkov (2003) the movement of the Moon away from the Earth had begun to accelerate by the end of the Mesoproterozoic, the era of the putative supercontinent Rodinia (900±100 Ma). The main reason for the deceleration of the Earth’s rotation is probably tidal friction and the
periodical pattern of the tidal forces of the meridian wave $M_2$. Tidal energy dissipation values were shown by many authors to vary within \((0.34\div4.5)\times10^{12} \text{ W}\) (Zharkov, 2003). If, however, Precambrian anomaly $T$ is attributed to the disintegration of Rodinia, then the Pangaea supercontinent was completely formed in the middle of the Paleozoic anomaly interval. It seems, therefore, that the most important factor is where and how large continents were situated relative to equatorial latitudes, at which wave $M_2$ is most powerful. Pangaea, in particular, could have influenced the above anomaly, but it is not related directly to a rise in $T$, which began earlier (350 Ma). It is also essential that according to paleomagnetic data at the turn of the Phanerozoic Gondwana was situated in the polar domain of the Southern Hemisphere, where ocean tide energy is smallest, but as the Moon’s orbit was about 12000 km closer to the Earth (Zharkov, 2003), ocean tides must have been much higher. There might have been other factors that somehow retarded the Earth’s rotation: global glaciations that temporarily reduced the world ocean’s mass, the movement of lithospheric plates etc. The effect of the Earth’s own rotation on continental drift was discussed earlier by the author in Zemtsov, 2007. Using the continental model from the publication, the rotation energy ($E$) of an individual continent, e.g. Eurasia, can be estimated, assuming that it is similar to a cylinder, which has thickness $l$ and radius $r$ and rotates on the mantle surface at average angular velocity ($\omega$) relative to the vertical axis ($z$), which extends across its middle. If $\omega=4\times10^{-16} \text{ s}^{-1}$, then $E\approx2.5\times10^6 \text{ W}$. Thus, continental motion energy power is ca. million times smaller than tidal retardation energy. Such small values can be neglected.

The retardation of the Earth’s mantle could also be due to the extinction of the putative slow nuclear reactors located on the surface of the inner core. Their power is estimated at $30\cdot10^{12} \text{ W}$ (Rusov et al., 2007). Interestingly, “in the depth interval 4983.64–5000.0 km (BC), the $P$ wave velocity drops sharply from 10.86 to 9.7 km/s” (Burmin, 2004), and the author assumed that a ca. 215 km thick, less viscous layer (BCDE) could be located here (Fig. 4).

Fig. 4. Distribution of the $P$ wave velocity in the Earth: (1) IASPEI91 model; (2) model after V.Yu. Burmin (2004).

It seems more essential that both $T$- anomalies observed began at the time of generation of magmatic activity cycles (see Fig.3) that mark these events in the crust of all continents and are assumed to have resulted from global geoid restructuring and the Earth’s highest seismicity. According to V.M. Moralev (Zemtsov, 2007), there were at least four such cycles in the Earth’s Proterozoic history. For the time being, variations in VDM and $T$ in Precambrian time cannot be traced in detail because reliable data are scarce. We are about to begin solving this problem.
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