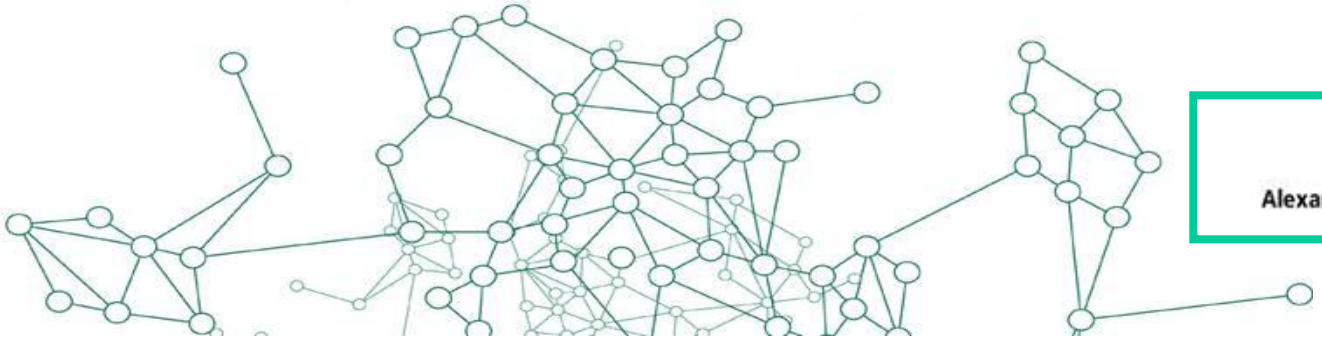
Long-term variations of the gravitational potential and of the geodynamical properties of a deformable Earth due to axial despinning

Péter Varga*
Geodetic and Geophysical Institute Research Centre of Astronomy and Earth Sciences, Hungarian Academy of Science
Kövesligethy Seismological Observatory, Budapest

***the speaker was sponsored by the Alexander von Humboldt Foundtion.**
http://www.humboldt-foundation.de



Alexander von Humboldt
Stiftung/Foundation

Results described in this presentation in a significant extent are based on our common papers with Erik Grafarend written during the last twenty years

- **Varga, P. , Grafarend, E**.,1995: The lunisolar stress tensor. Proceedings of the 12th International Symposium on Earth Tides, ***Science Press Beijing***, 361-378

- **Varga, P. , Grafarend, E.**,1996: Distribution of the lunisolar tidal elastic stress tensor components within the Earth's mantle. ***Physics of the Earth and Planetary Interiors***, 1996. 93. 285-297

- **Grafarend E.**, Engels J, **Varga P**, 1996: The gravitartional potential of a deformable massive body generated by tidal and load potential. ***Acta Geod. Geoph. Hung.***, 31, 283-292.

- **Grafarend, E.**, Engels, J**., Varga, P**., 1997: The deformation potential generated by tidal and load potentials, ***Journal of Geodesy***, l997. 72, ll-30

- **Varga, P., Grafarend, E.W.,** Engels, J.,1999: Earth tide genrated variations of second degree geopotential. ***Marees Terrestres, Bulletin d'Informations***, 131, 10217-10225.

- Engels J., **Grafarend E., Varga P.**,2000: The temporal variation of the spherical and Cartesian multipoles of the gravity field: the generalized MacCullagh representation. ***Journal of Geodesy***. 72, 121-143

- **Varga P.**, Engels J., **Grafarend E**.,2004: Temporal variations of the polar moment of inertia and the second degree geopotential. ***Journal of Geodesy***, 78, 187-191

- **Varga P.** , Krumm F.W. DoglioniC., **Grafarend E. W.**, Panza G., Riguzzi F., Schreider A. A., Sneeuw N., 2012: Did a change in tectonic regime occur between the Phanerozoic and earlier Epochs?, ***Rendiconti Lincei***, 23, 2, 139-148

- **Varga P., Grafarend E.**, Engels J., 2012: From Gravitostatics to Gravitodynamics:The space-time dependent gravity field by Eulerian versus Lagrangean force fields: Examples, ***Geophysical Research Abstracts***, Vol.14, EGU2012-14247 (invited)

- **Varga P.**, Krumm F. W., **Grafarend E.W.**, Sneeuw N. , HorváthF., Schreider A.A., 2013: Axial rotation and paleogeodynamics during Phaneorozoic**. *IAG Scientfc Assembly on the occasion of the 150th anniversary of the IAG*** in co-operaton with the Helm-holtz-Zentrum Potsdam – Deutsches GeoForschungsZentrum GFZ, Theme 4, p. 434

- **Varga P.**, Krumm F.W**., Grafarend E.W.**, Sneeuw N., Schreider A.A., Horváth F., 2014: Evolution of the oceanic and continental crust during Neo Proterozoic and Phanerozoic, ***Rendiconti Lincei***, 25, 2, 255-263

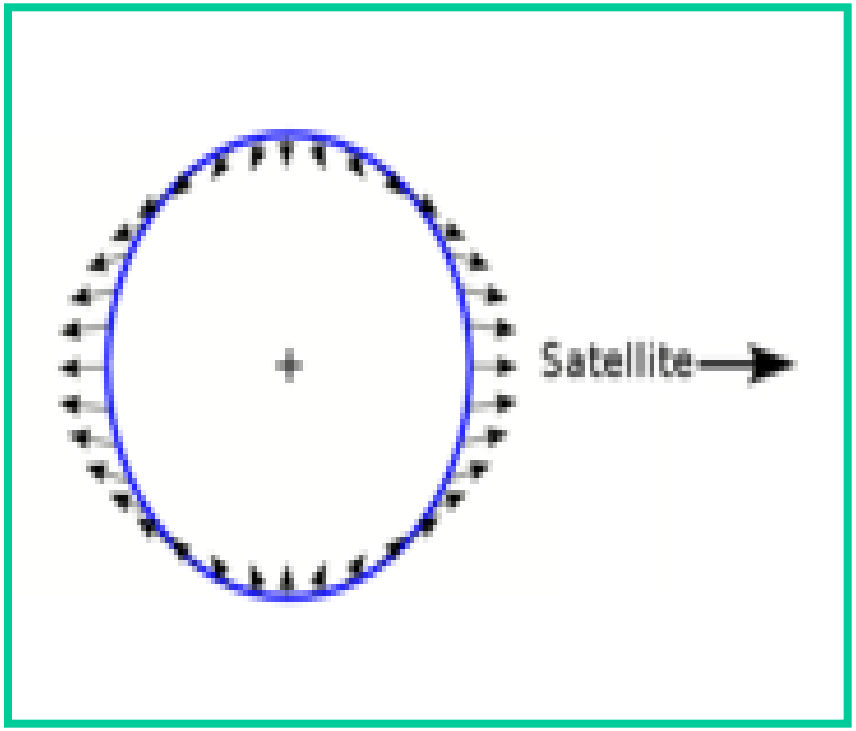
The main source of long-term variations in gravity : the tidal friction

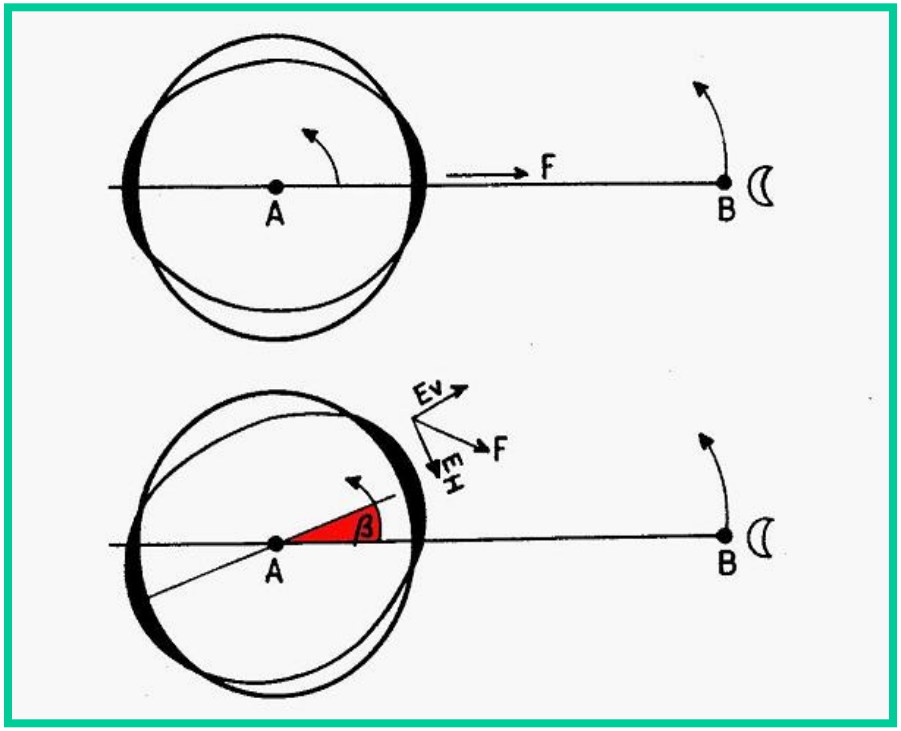
Content of the presentation

- The phenomenon of tidal friction
- The data
- The history of axial despinning due to tidal friction
- The energy
- Variations in flattening
- Long-term gravity variations

The phenomenaon of tides and tidal friction

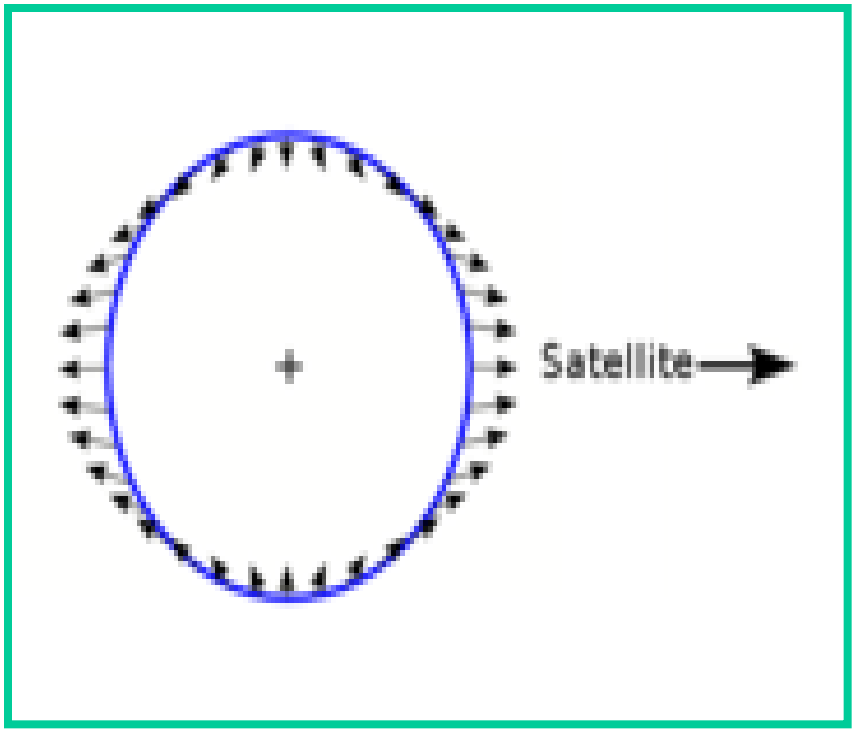
Among the phenomena affecting the long-term evolution and dynamics of the solid Earth only one has an external origin: the long-term despinning of axial rotation due to tidal friction.

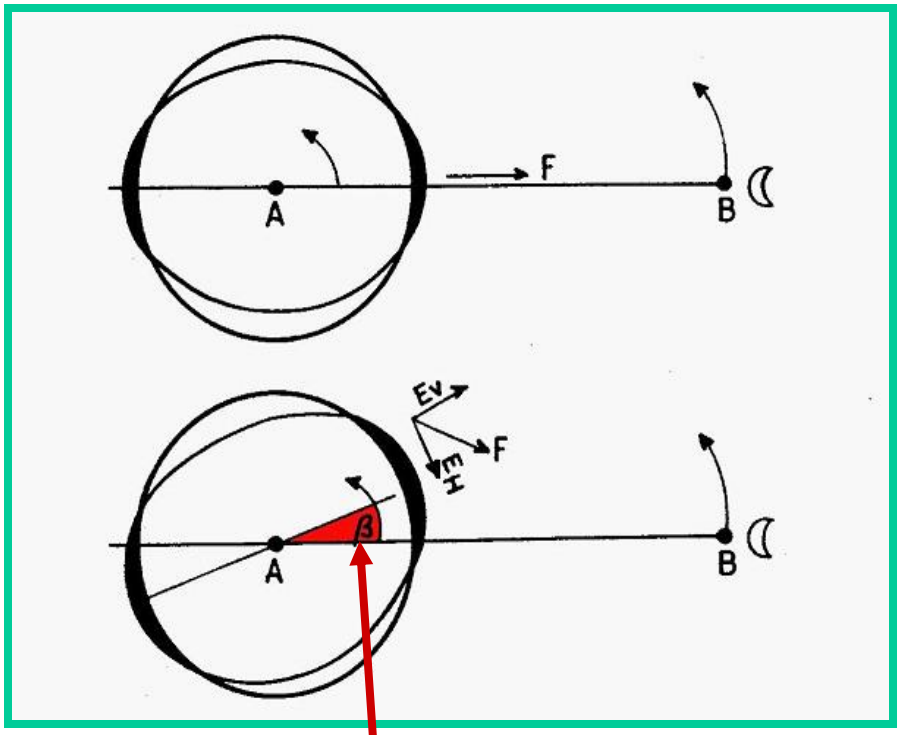




The phenomenon of tides and tidal friction

Among the phenomena affecting the long-term evolution and dynamics of the solid Earth only one has an external origin: the long-term despinning of axial rotation due to tidal friction.





β=6.8˚ for Pz;

β=1.5˚ for Ptz

The data

AXIAL DESPINNING DECREASE DURING THE PHANEROZOIC

Astronomical observations:

$d\omega/dt = -5.6 \cdot 10^{-22} s^{-2}$ *(Pariisky,1959)*

$-5.6 \cdot 10^{-22} s^{-2}$ *(Brosche,1987)*

Space geodetic data:

$-6.07 \cdot 10^{-22} s^{-2}$ *(Christodoulis et al.,1988)*

$-5.98 \cdot 10^{-22} s^{-2}$ *(Newhall et al.,1986)*

Solar eclipses

$-5.6 \cdot 10^{-22} s^{-2}$ *(Stephenson,1978)*

$-4.5 \cdot 10^{-22} s^{-2}$ *(Stephenson&Morrison,1995)*

Paleantological and paleosedimentological data from the Pz

$-5.4 \cdot 10^{-22} s^{-2}$ *(Lambeck,1977)*

$-5.5 \cdot 10^{-22} s^{-2}$ *(Varga et al.,2006)**

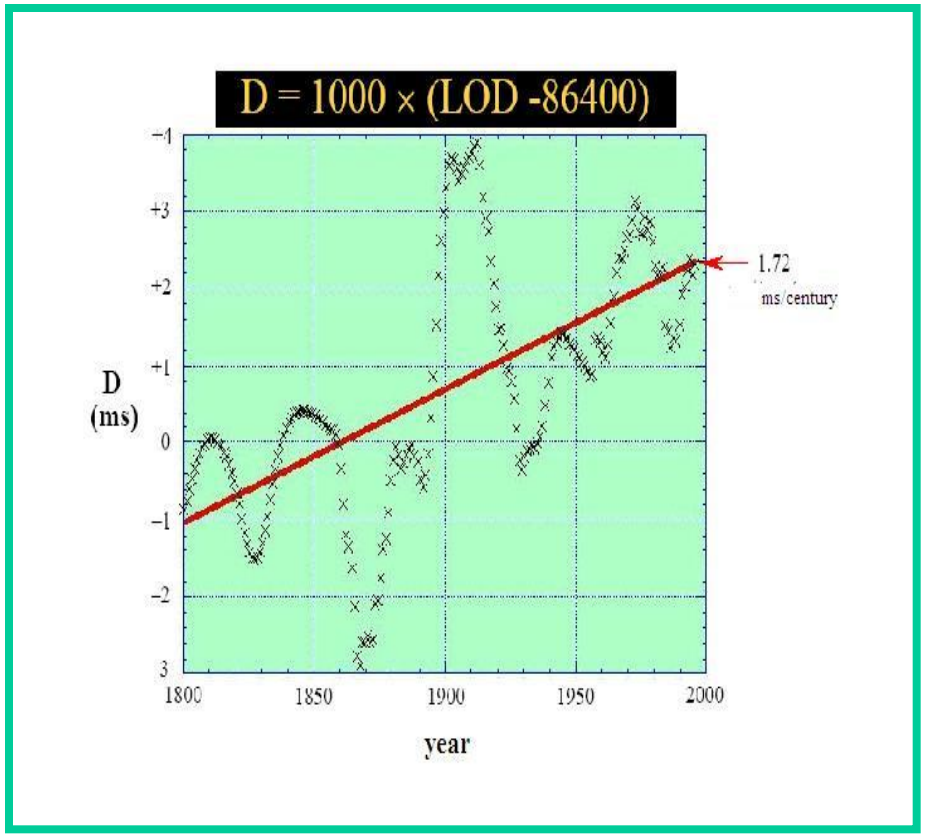
*on the basis of data published in 20 different contributions

DESPINNING RATE USED IN MY STUDIES

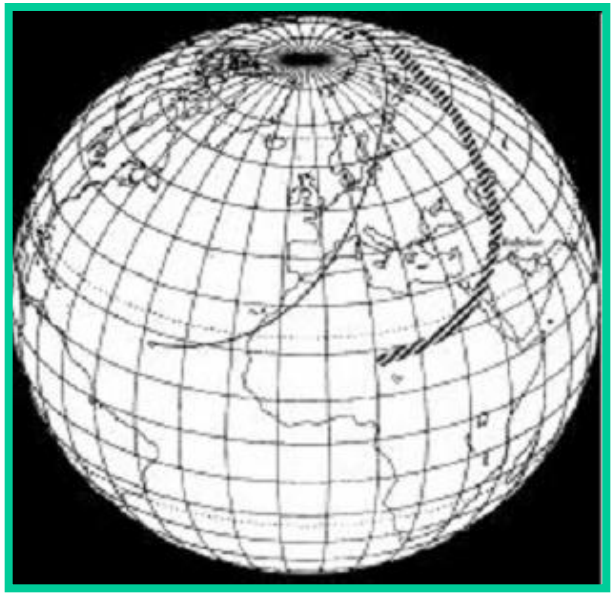
$-5.5 \cdot 10^{-22} s^{-2}$

The data demonstrate: the axial despinning was constant over the last 600 Ma

Historical data

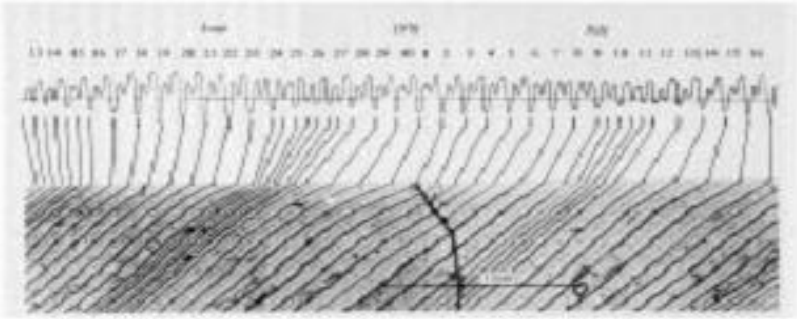


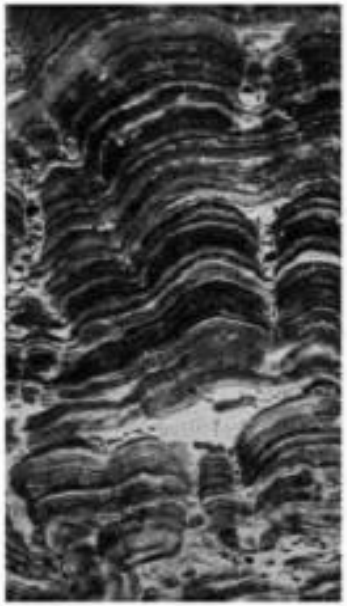
Variation of LOD
(astronomical data)

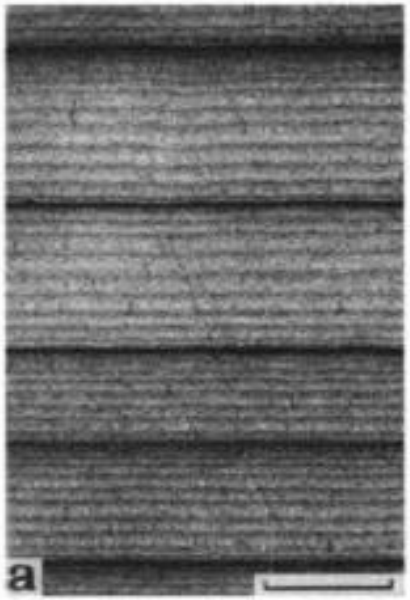


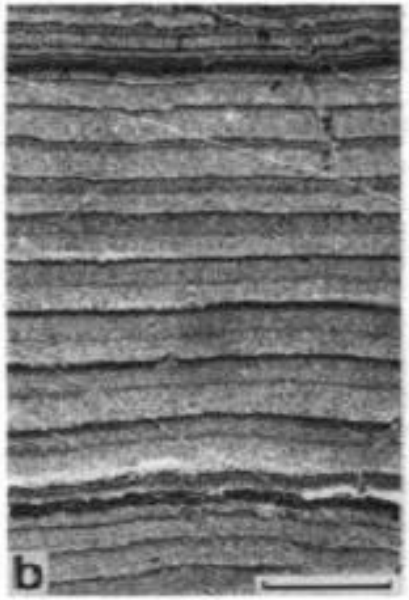
Late Babylonian tablet on the eclipse of
15. 04. 138 BC

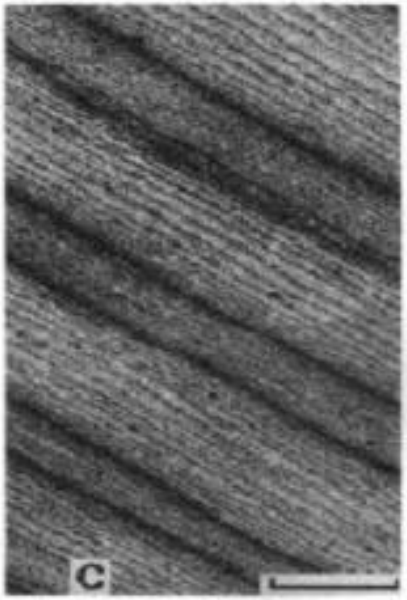
Paleontological and paleo- sedimentological data



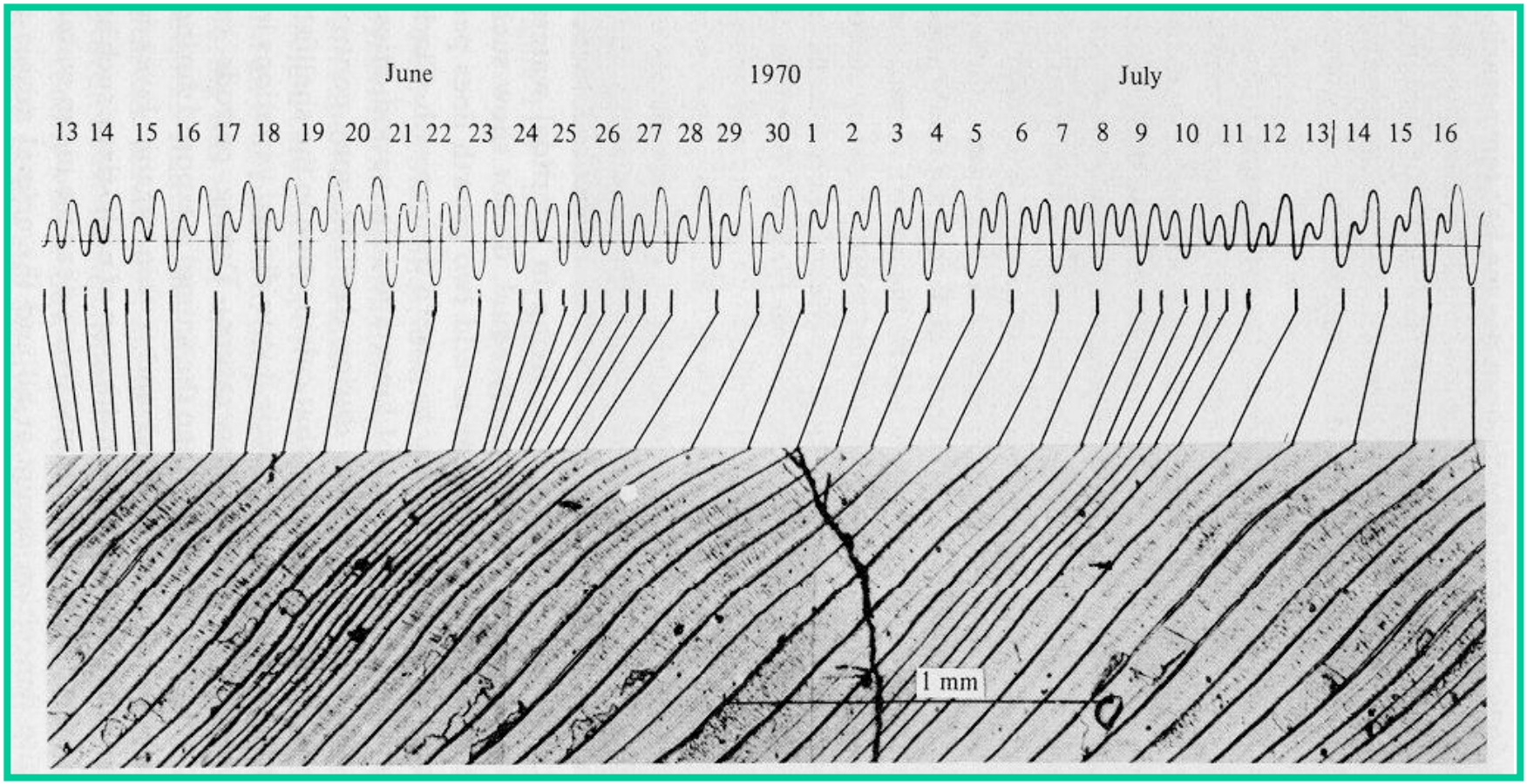






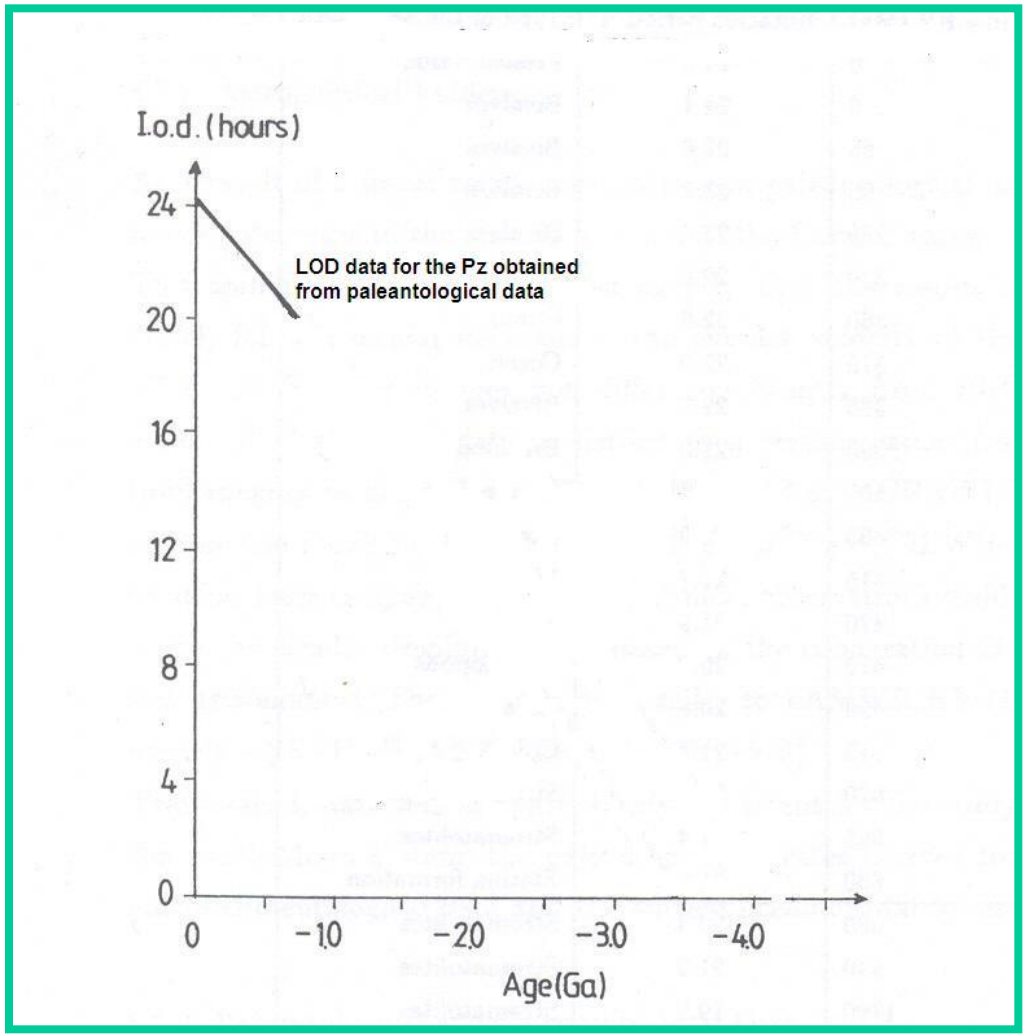


Paleontological and paleo- sedimentological data



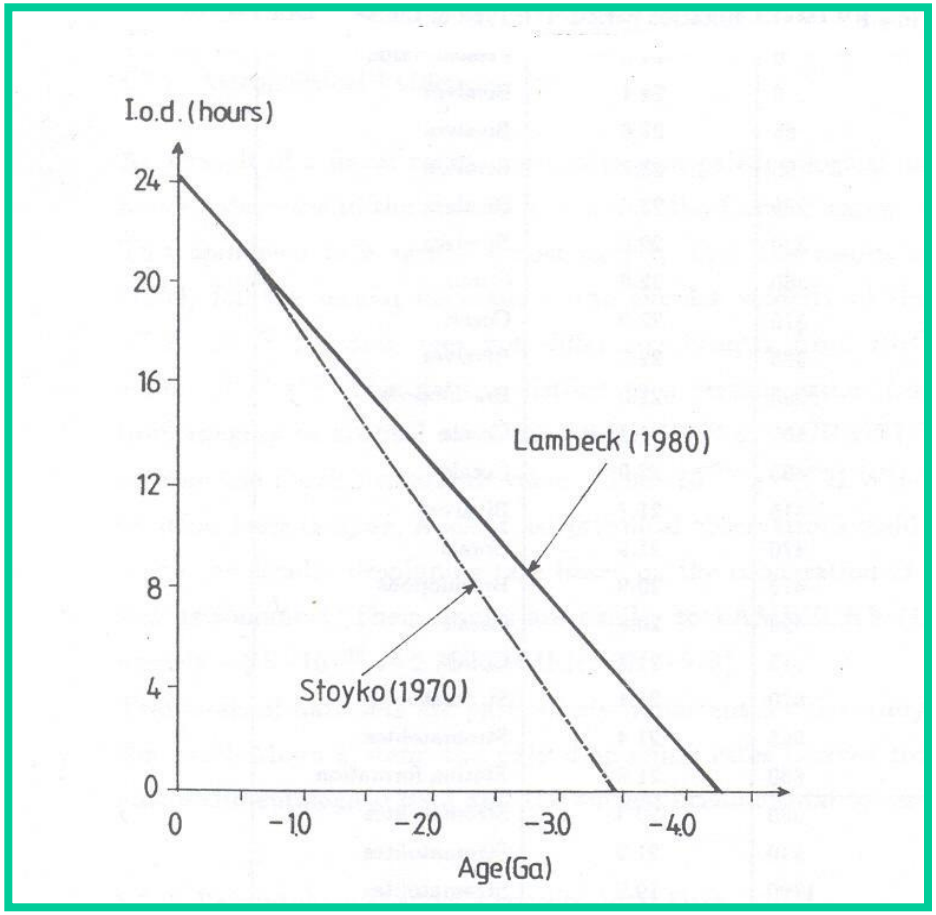
Internal growth lines in Clinocardium nuttalli compared to tidal predictions for the same epoch. (J.W.Evans, 1972).

Paleontological and paleo- sedimentological data



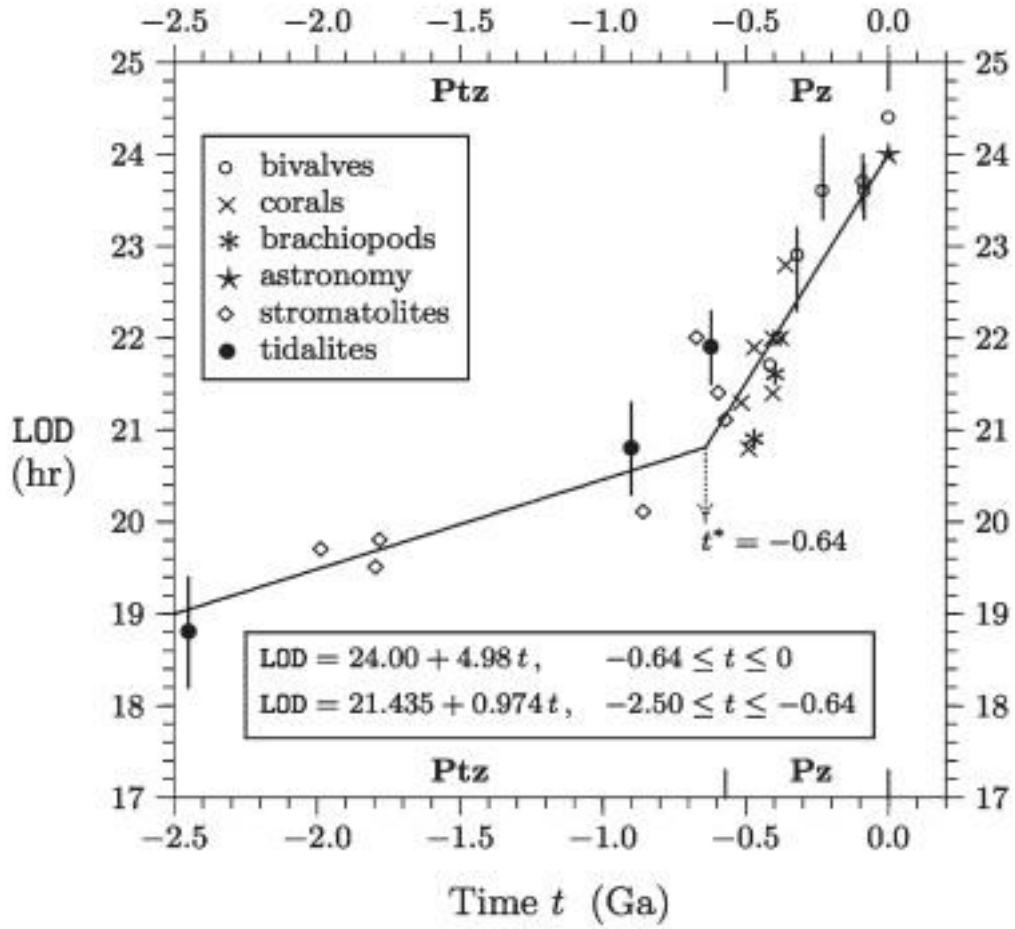
The paleantological LOD data of Stoyko (1970) and Lambeck (1980) for the Pz

Paleontological and paleo- sedimentological data



The data of Stoyko (1970) and Lambeck (1980) provide in average good agreement with geological data for the Pz. The regresion line cannot be extrapolated into the more remote past, because it would lead for times around 3 Ga BP, to LOD < 1.15 hr (Poincaré limit) and to the Earth-Moon distance <18 500km (Roche limit)

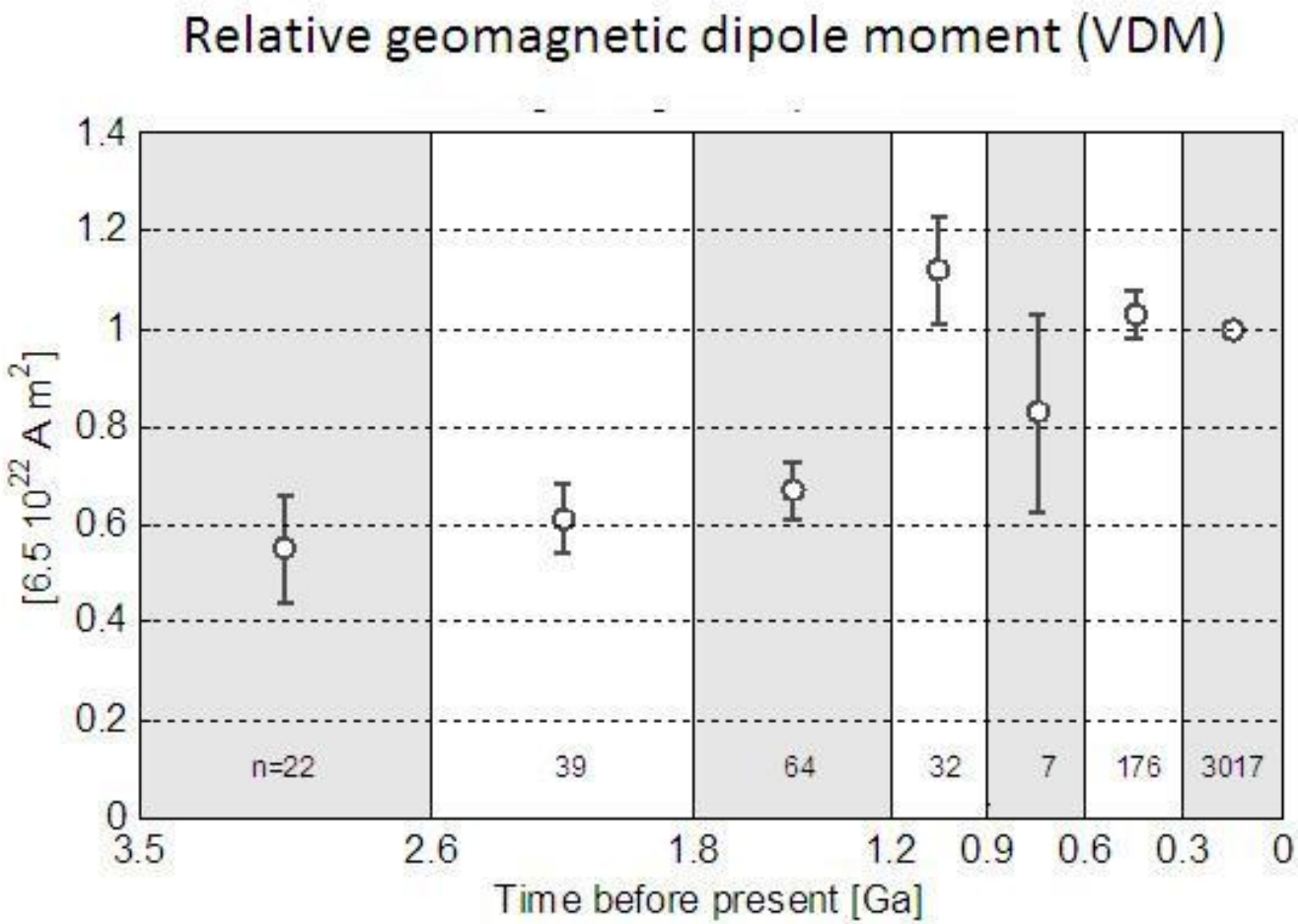
Paleontological and paleo- sedimentological data



The unit of time (t) is Ga

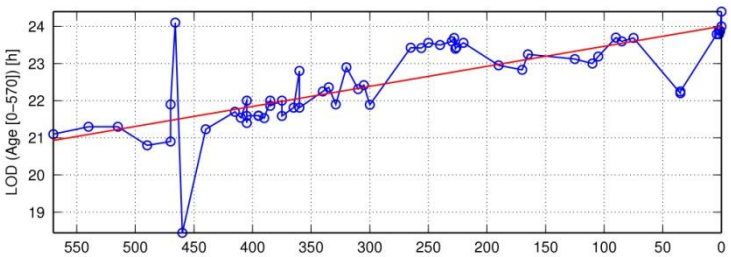
Variationof l.o.d. during the Phanerozoic and Proterozoic (i.e. during the interval of time extending from the present to 2.5 eons in the past).

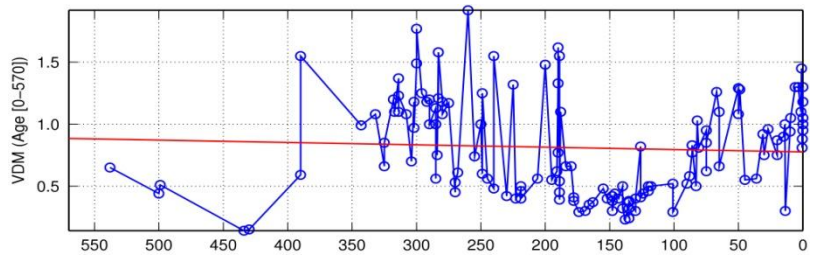
As a comparison: geomagnetic data for the last 3.5 Ga



Statistics of LOD and VDM databases

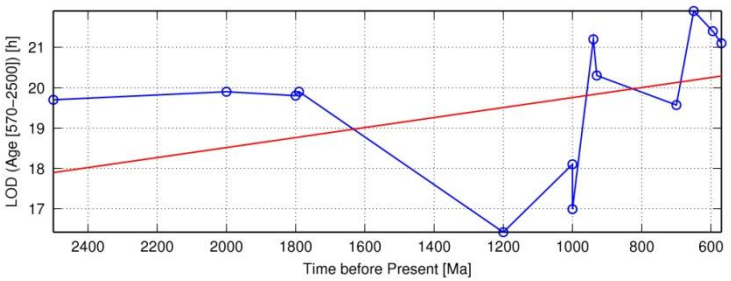
Pz

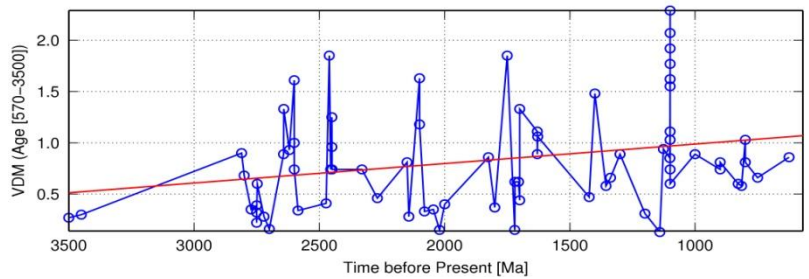




Pz

Arch+Ptz





Arch+Ptz

LOD

LOD data for the time intervals
-from 0.570 Ga to present (above)
-from 2.500 Ga to 0,570 Ga (below).
The straight lines show the regression

$$LOD = a \cdot t + b$$

with numerical values

a=(0.0054±0.0006) h/Ma (Pz)

a=(0.00124±0.00072) h/Ma (Arch+Ptz).

Dipolic geomagnetic moment values
-from 0.570 Ga to present (above)
-from 3.500 Ga to 0,570 Ga (below).
The straight lines show the regression

$$VDM = a \cdot t + b$$

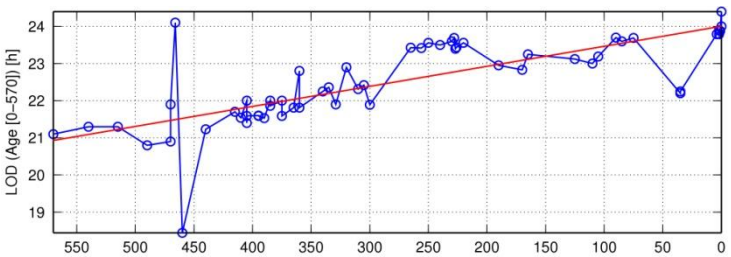
with numerical values

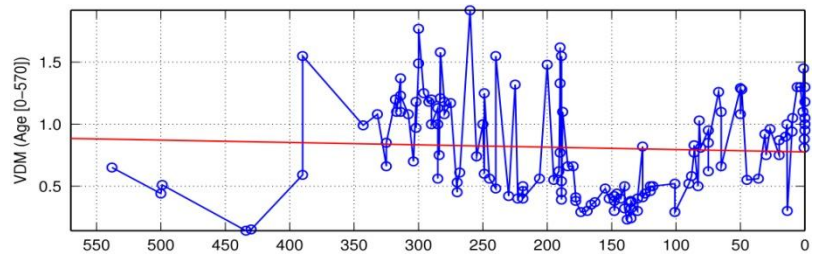
a=(-0.00019±0.000284) A·m²/Ma (Pz)
a=(0.00019±7.89·10-5) A·m²/Ma (Arch+Ptz)

VDM

Statistics of LOD and VDM databases

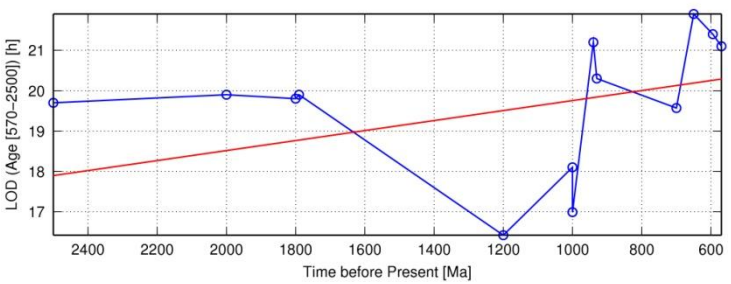
Pz

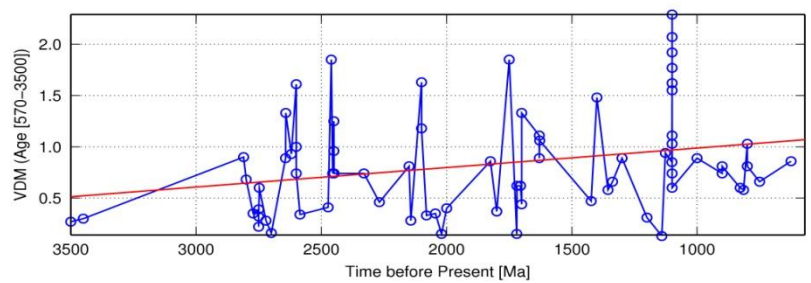




Pz

Arch+Ptz





Arch+Ptz

The significance of slope estimate *a* is verified using the *F* statistical hypothesis test.
Assuming identically normally distributed data the test statistics $T=a^2/(\sigma_a)^2$ (σ_a – standard error) follows F-distribution with n degrees of freedom.
Using a confidence level of α=5% the null hypothesis H_0: $a=0$ the test supports that the slope is statistically significant if $F_{0.05}(1,n)<T$.

Phenomenon		T	n	$F_{0.05}$	Significance
LOD	Ptz+Arc	6.80	13-2	3.36	yes
	Pz	46.25	57-2	2.80	yes
VDM	Ptz+Arc	6.26	74-2	4.00	yes
	Pz	0.40	138-2	3.91	no

ENERGY. The total rotational energy

$$E_T = \frac{1}{2} C\omega^2 + \frac{1}{2} a_m^2 n_m^2 \cdot \left(\frac{M \cdot M_m}{M + M_m} \right) - G \frac{M \cdot M_m}{a_m}$$

The time derivatives should be repleaced by the derivative of the Kepler's law

$$\frac{da_m}{dt} = -\frac{2}{3} \cdot \frac{a_m}{n_m} \frac{dn_m}{dt}$$

The principle of conversation of momentum in the Earth-Moon system is

$$C \cdot \omega + \frac{M \cdot M_m}{M + M_m} \cdot a_m^2 = \quad Const.$$

A simple combination of the two last equations one gets:

$$\frac{d\omega}{dt} = \frac{1}{3} \frac{M_m}{M + M_m} \cdot \frac{Ma_m^2}{C} \cdot \frac{dn_m}{dt}$$

Using da_m/dt and $d\omega/dt$ together with the Kepler's law leads to

$$\dot{E} = C(\omega - n_m) \frac{d\omega}{dt}$$

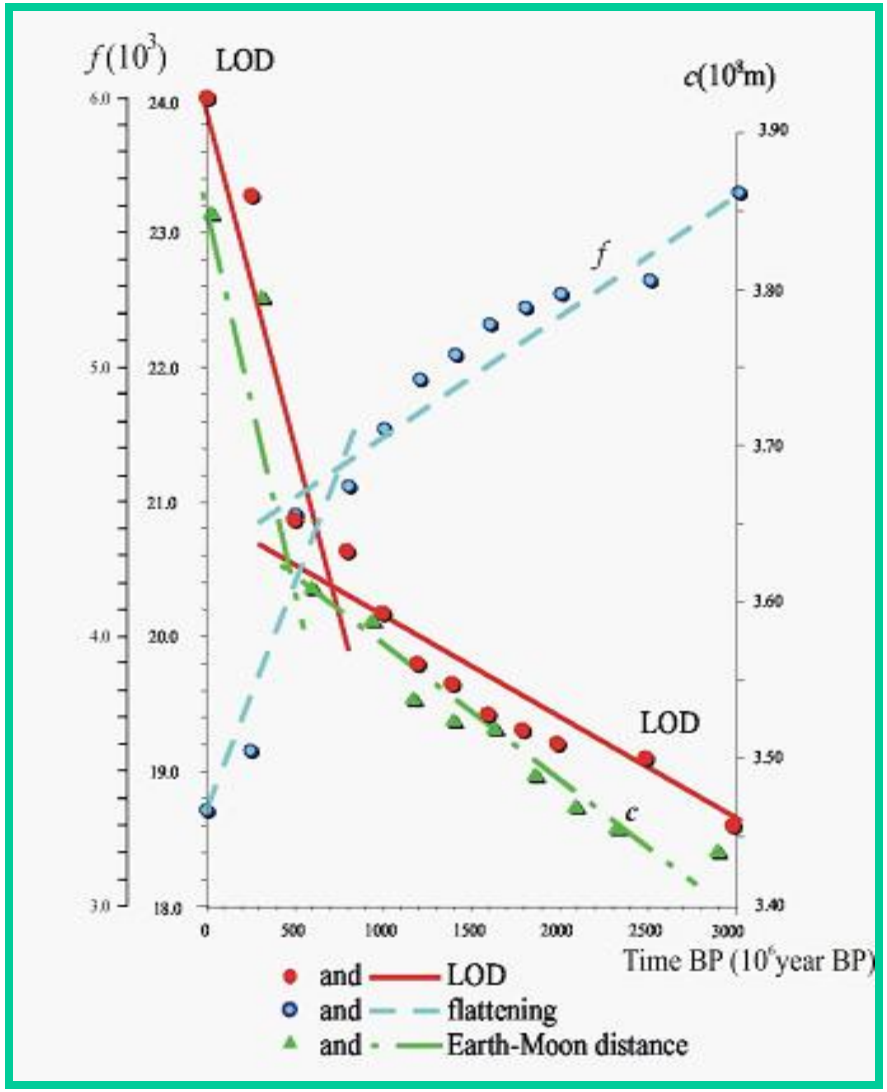
ENERGY. The total rotational energy

$$\dot{E} = C(\omega - n_m)\frac{d\omega}{dt}$$

It should be mentioned that $C \cdot d\omega/dt \sim L$ (where L the tidal torque). From the cotidal map of Schwiderski (*Schwiderski, 1980*) for the tidal torque L=-5·10^{16} J was obtained (*Varga, 1998*) on the basis of numerical integration. Since $(\omega - n_m)$ = 7.026·10^{-5} s^{-1} the last equation gives dE/dt=1.2·10^{20} J/year. Similar value was obtained by Zschau (*Zschau, 1986*) dE/dt =9.2·10^{19}. J/year. On the basis of paleontological and paleosedimentological data dE/dt =1.1·10^{20} J/year.

LOD, flattening and Earth-Moon distance during the last 2.5-3.0 Ga

Geometrical flattening (*f*) and the Earth-Moon distance (c_m) during the last 2.5-3Ga



$$\frac{df}{dt} = \left(1 + k_s\right)\frac{R^3}{GM}\omega\frac{d\omega}{dt}$$

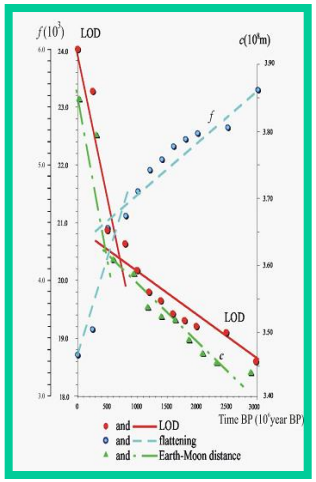
$$\frac{dc_m}{dt} = \frac{2\left(M + M_m\right)}{MM_m}C\left(c_m n\right)^{1}\frac{d\omega}{dt}$$

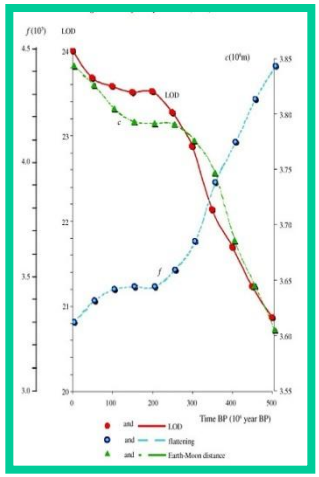
ks - secular Love number (≈0.96)
R - mean Earth radius (=6.371·10⁶*m*)
G - gravitational constant (=6.673·Nm^2kg^{-2})
M and Mm – are masses of the Earth and the Moon

LOD, flattening and Earth-Moon distance during the last 2.5-3.0 Ga (cont.)

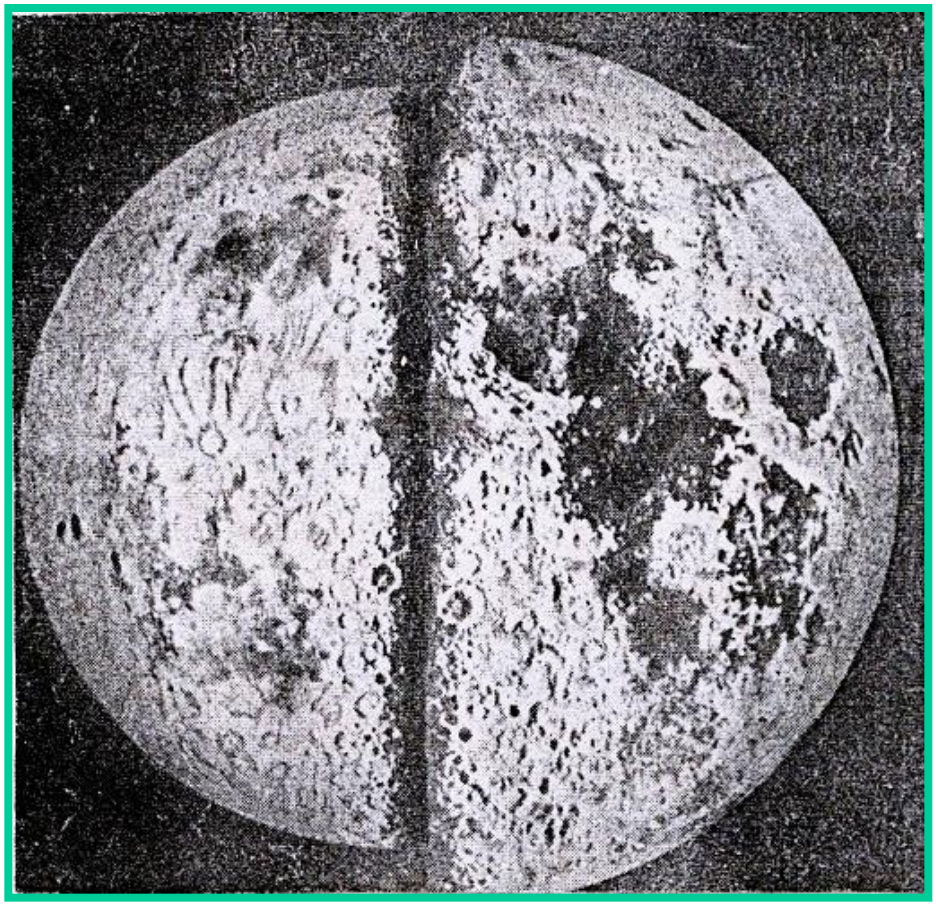
Concerning of LOD curves two question must be answered:

- **What is the accuracy of paleontological and paleosedimentological data?**
- **Are the changes reflected by this curve significant in statistical sense?**





LOD, flattening and Earth-Moon distance during the last 2.5-3.0 Ga (cont.)



The diameter of the full Moon in our days and 2Ga BP

LOD, flattening and Earth-Moon distance during the last 2.5-3.0 Ga (cont.)

- Moons orbital radius remaining within about 90% of the present value 3 Ga BP
- This means: the development of the Earth-Moon system was probably slow
- A statistically significant low was found during the Mesozoic (0.35-0.15 Ga BP), which coincides with the time of Pangea, when probably the shelf areas of the continents were reduced.

Long-term gravity variations

Geometric flattening of the Earth over the the last 2.5 billion years became smaller by 70%.

Accordingly

- **absolute value of the gravitational field at the poles was reduced by 690 mgal**
- **the absolute value of the gravitational field at the equator increased by 2940 mgal**
- **at mid-latitudes (±50°) the the annual variation is 2 ngal/year**

Dear Erik,

a great happiness and experience of my life is that I could work with you together for more than twenty years on research problems of joint interest. I learned a lot from you.

Thank you,

Péter