HUNGARIAN CONTRIBUTION TO THE RESEARCH OF EARTH ORIENTATION, EARTH ROTATION, POLAR MOTION, NUTATION AND PRECESSION – IAG COMMISSION 3

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The absence of long series of complete earthquake data is a serious difficulty in seismic hazard research as well as in preparation of the worst-case models for the location, size, and peak ground acceleration (PGA) of potential future earthquakes. That is why predictions based on probabilistic and to a lesser extent on deterministic principia do not fit in aptly with observed reality and do not help to determine reliable design parameters even in the comparatively well-known past occurrences, despite their evidently serious mathematical foundations (Varga 2011a). By means of combined use of geodetic strain rate data and the seismic moment data set, the probable recurrence time was determined for past seismic events. This combination represents a new and independent approach to estimate the order of magnitude of future seismic activity. Using a modified version of Kostrov's equation and the catalogue of seismic moments, the recurrence of the strongest earthquakes of a source area was estimated. It was found in Varga (2011b) that the recurrences in a given source zone in case of earthquakes $M_W \geq 9.0$ are of the order of some hundred years. For the large and medium earthquakes the expected Δt is well above some 10^3 years.

The geographical locations of great ($M \geq 7$) earthquakes, first of all the shallow ones, delineate the lithospheric plates, among them primarily the lithospheric slabs penetrating into the mantle. Only a part of subduction zones are marked beside shallow by deep earthquake zones too. The estimated global length of subduction zones is $6.7 \cdot 10^4$ km, while length of those which are related to deep events – according to our calculations carried out with a methodology based on inverse mapping equations and applied to a given map projection – is only $1.9 \cdot 10^4$ km (28%). For the aims of the present study maps completed with Mollweide projection were in use. Examination of the seven source zones circumscribed in Varga and Süle (2014), aside from one (Honsu-Kamchatka), in which both shallow and deep $M \geq 7.0$ earthquakes occur, shows that linear distribution of deep earthquakes is considerably shorter than that found for the shallow earthquakes, which determine the length of the zone (Figure 1). The distribution of earthquake energy release along latitudes has no correlation with the number of earthquakes and with the distribution of topographic structures usually interpreted as subduction zones. At the same time a clear axial co-ordination of radiated seismic energy is demonstrated with maxima at latitudes close to critical values (±45°).The radiated energy has the highest peak close to 0°±5°, with respect to the tectonic equator, which is inclined about 30° with respect to the geographic equator.

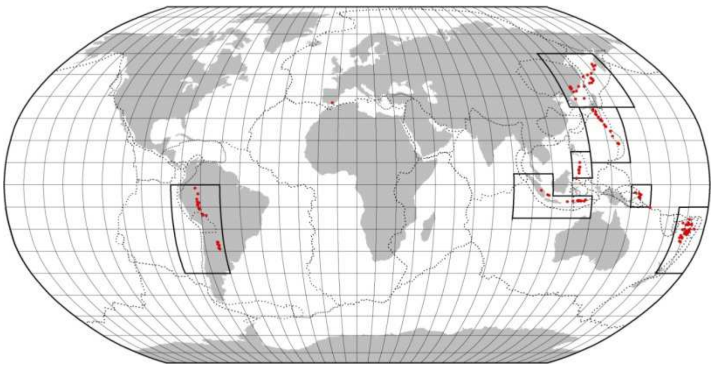

Figure 1. The geographical locations of deep $M \geq 7$ earthquakes. The epicentres are marked with dotes, the boundaries of investigated source zones are shown with thick straight lines

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This fact indicates the presence of external forces that influence seismicity and it is consistent with the fact that Gutenberg-Richter law is linear, for events with $M > 5$, only when the whole Earth's seismicity is considered, and it points at an astronomical control on plate tectonics. This external factor is most probably the despinning (reduction of the Earth's angular rotation) of the Earth axial rotation caused primarily by tidal friction due to the Moon (Varga et al. 2012b, Varga and Süle 2014).

Examining variations in the Earth's rotation during the geological history the relationship between the axial despinning and changes in the structure of the planetary interior was investigated. It was found that for the present epoch a growth rate of the core comprised between 1 and 10 mm/cy seems to be plausible guess, leading to a relative decrease of LOD comprised roughly between 10 and 100 μs/cy. Such values do not affect significantly the observed secular increase of LOD caused by tidal braking, which amounts to about 1.79 ms/cy. However, in the remote geological past, before Phanerozoic, the effect of the core growth may have been much more important, because the total change of LOD associated with core formation has been estimated to be 2.4 hours for an initially undifferentiated old Earth, and 3.1 hours for an initially undifferentiated hot Earth. Paleo-LOD measurements see to far slow core formation during the Proterozoic contrarily to the now largely prevailing hypothesis that the iron core formed very early in the Earth's history and during a geologically short time interval. From recent estimates of the age of the inner core based on the theory of thermal evolution of the core, it was estimated that nowadays the growth of the inner core generates a relative decrease of 2 to 7 μs/cy, what may contribute to the observed overall secular increase of LOD caused mainly by tidal friction (i.e., 1.72 ms/cy) by a relative decrease of 2 to 7 μs/cy, what does not produce any detectable change of length of day (Denis et al. 2011).

From the study of palaeogeographical maps for the last 600 Ma it was concluded that during this time-interval of Earth's history the tectonic activity had a significant change: increase occurred in the lengths of mid-ocean ridges (spreading centres) and subduction zones. In the same time there has been a large change of the length of the shelf zones. This change can explain contemporary change of the despinning rate from about 0.35 ms/cy to about 1.79 ms/cy (Varga et al. 2012c). The mechanisms that move plates are not entirely understood. In order to clarify the issue the compilation of palaeogeographical maps in the time span 0.6 Ga BP to Present in terms of (a) the ratio between continental to oceanic crust areas in order to estimate the speed of continental growth, and (b) the surface motion of continental plates under the influence of global forces of tidal friction and Eötvös force ("pole-fleeing") was investigated. It was concluded that the area of the continents during the Phanerozoic was continuously growing and it exhibited a rate ~0.5 km^3/yr. On the other hand, it was found that beside the westward oriented tidal frictional forces the Eötvös force can possibly play also a role in the plate tectonic processes. In Figure 2 it is shown that the continental plates on average tend to find a position close to the equator during the whole investigated 600 Ma time-interval (Varga et al. 2014a).

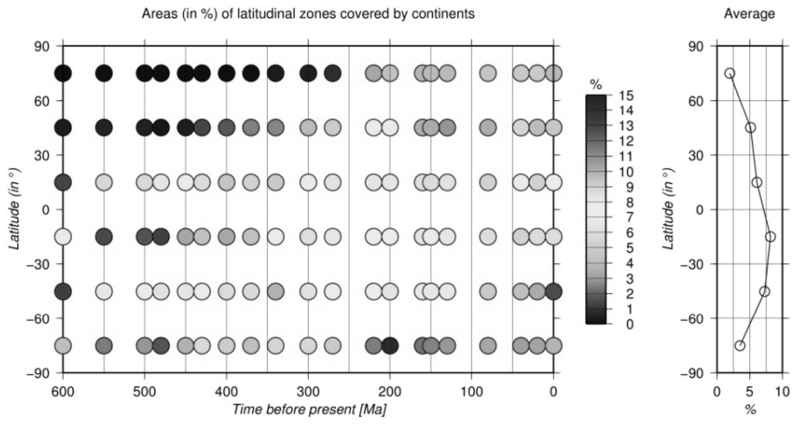

Figure 2. Areas (in %) of latitudinal zones covered by continental crust in different epochs of Late Proterozoic and Phanerozoic and the average distribution

Based on mathematical considerations an extension of the MacCullagh formulae was derived. In particular, for excitation functions with a vanishing harmonic coefficient of degree zero, the diagonal incremental moments of inertia can be expressed by excitation coefficients. Four types of excitation functions are considered: (i) tidal excitation, (ii) loading potential, (iii) centrifugal potential, and (iv) transverse surface stress. One application of the results could be a model computation of the length-of-day variations and polar motion, which depend on the moments of inertia (Varga et al. 2012a).

In order to study theoretically the geodynamic behaviour of the Earth on a short (elastic Earth) and on a long scale of geological periodic variations (for an almost perfectly liquid Earth), the changes of the moment of inertia are decomposed into two parts: the first, described by a volume integral, explains the effect of the density variations, while the second gives the impact of the surface variations using a surface integral. Based on mathematical considerations it was concluded that only minor changes occurred during time interval from 2.5 to 0.5 Ga BP in the main features of the inner structure of our planet which was practically finished at the very beginning of the history of the Earth. This conclusion coincides with recent results of geochemists who concluded that the formation of the core and of the main features of the mantle was completed 3.5-4.0 billion years ago (Varga et al. 2014b).

References

Denis C, Rybicki KR, Schreider AA, Tomecka-Suchon S, Varga P (2011): Length of the day and evolution of the Earth's core in the geological past. Astronomisches Nachrichten, 332(1), 24-35.

Varga P (2011a): Earthquake prediction (in Hungarian). Hungarian Science, 7, 826-843.

Varga P (2011b): Geodetic strain observations and return period of strongest earthquakes of a given seismic source zone. Pure and Applied Geophysics, 168(1-2), 289-296, DOI: 10.1007/s00024-010-0112-2

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

Varga P, Krumm F, Riguzzi F, Doglioni C, Süle B, Wang K, Panza GF (2012b): Global pattern of earthquakes and seismic energy distributions: insights for the mechanisms of plate tectonics. Tectonophysics, 530-531, 80-86, DOI:10.1016/j.tecto.2011.10.014

Varga P, Krumm FW, Doglioni C, Grafarend EW, Panza G, Riguzzi F, Schreider A, Sneeuw N (2012c): Did a change in tectonic regime occur between the Phanerozoic and earlier Epochs? Rendiconti Lincei, 23(2), 139-148, DOI 10.1007/s12210-012-0172-6

Varga P, Süle B (2014): Great deep earthquakes (in Hungarian). World of Science, 145(5), 202-206.

Varga P, Krumm FW, Grafarend EW, Sneeuw N, Schreider AA, Horváth F (2014a): Evolution of the oceanic and continental crust during Neo Proterozoic and Phanerozoic. Rendiconti Lincei, 25(2), 255-263, DOI: 10.1007/s12210-014-0298-9

Varga P, Grafarend E, Engels J (2014b): Temporal variations of the polar moment of inertia and the second-degree geopotential. Geophysical Research Abstracts Vol.16, EGU2014-1745, 2014 EGU General Assembly 2014.