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Causes of earthquakes and lithospheric plates movement

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Causes of earthquakes and lithospheric plates movement

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Abstract

The goal of the paper was to verify triggering of earthquakes by the length of day variations, i.e. the sidereal 13.66 days Earth's rotation variations, in contrast with tidal biweekly 14.76 days variations (full and new Moon), which for hundred years of investigation give negative results. Earthquake triggering governed by sidereal variations caused by variable Moon's declination accelerates and decelerates the Earth's rotation. Profound Schuster's test proved that earthquakes are triggered both in Earth's deceleration and acceleration. For this investigation the most prominent earthquakes from 2010–2011 were used from Mid-Atlantic Ridge, Southeast Indian Ridge, Sumatra and Andaman Sea, Chile trench, Haiti and Honshu region including important older earthquakes of Sumatra 26 December 2004 and Denali Fault 3 November 2002. Dominant number of earthquake occurring in extremes of length of day variations initiated the calculation of forces acting in these time intervals. Calculated forces of tidal force acting on Earth's flattening and the westward drift are strong enough to trigger earthquakes and the movement of plates follows from GPS performed immediately after earthquakes on continents and from increased number of earthquakes of the side of the mid-ocean ridge belonging to the moving plate. Generally the Northern Hemisphere moves quicker westward than the Southern one. Earthquakes are repeated in 19 yr Metonic cycle. Repetitions caused by tidal force acting on Earth's fattening are exact in date. Repetitions caused by westward drift are delayed for several months.

1 Introduction

Consideration of the Earth's rotation as a factor influencing the Earth's surface is based on very old data. Already Darwin (1881) recognized that owing to the Earth's rotation, the equatorial regions are subjected to greater forces than the polar regions. Böhm von Böhmersheim (1910) presented an opinion that the Earth's rotation and its changes is an energy source of orogenetic processes. Next I mention authors Veronnet (1927),

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Schmidt (1948) and Stovas (1957). The development of Earth's rotation theories begins after the confirmation of Earth's rotation variations by comparison with the atomic clock and later by exact measurements using very long baseline interferometry (Munk and Mac-Donald, 1960). The detailed conception presented Chebanenko (1963), considering inertial forces acting on continents, requiring however the slip of the Earth's crust. Mac-Donald (1963) considers also the relation of the deep fault tectonics to rotation changes. After confirmation of the continental drift by interpretation of linear magnetic anomalies and dating of oceanic basalts by Morley and Vine and Mathews (1963) and introduction of the plate tectonics principles, hypotheses occurred considering tidal forces as driving agents of the plate movements (Bostrom, 1971; Knopoff and Leeds, 1972; Moore, 1973). These hypotheses were rejected by estimation of the mantle viscosity by Cathles (1975), and Jordan (1975) presented a simple calculation that the mantle viscosity should be 10 orders of magnitude lower to make possible the movement, and most of geophysicists preferred the mantle convection as the plate driving agent originated in Holmes (1939) and later in McKenzie and Weiss (1975) and others. Later, Ranalli (2000) supported such hypotheses refusing the rotational drag as driving agent. Then 20 yr ago at XX. General Assembly of the International Union of Geodesy and Geophysics in Vienna 1991, the author (Ostřihanský, 1991) presented a hypothesis that Earth's rotation variations trigger earthquakes and introduce lithospheric plates into movement. In the monograph "The causes of lithospheric plates movements" (Ostřihanský, 1997), the hypothesis was elaborated in detail. The two largest earthquakes of the beginning of this century, the large M7.9 Denali Fault Alaska earthquake in 2002 and the M9.1 Great Sumatra earthquake in 2004, confirmed this hypothesis (Ostřihanský, 2004). In the meantime, extensive investigations in global tectonic earthquakes have shown evidence of a correlation with diurnal tides (Tanaka et al., 2002; Cochran et al., 2004). The Sumatra 26 December 2004 earthquake was triggered not only on exact winter Earth's rotation maximum speed but also on the full Moon. This inspired Crocket et al. (2006) to present a hypothesis of earthquake correlation with biweekly tides. This hypothesis was strictly refused by Cochran and Vidale

(2007), presenting histograms of global data rejecting coincidence of earthquakes with biweekly tides. Supporters of the Earth's rotation effect are also Doglioni et al. (2007), showing that geological and geophysical asymmetries of rifts and subduction zones are a function of their polarity and may be interpreted as controlled by some astronomical mechanical shear (Scoppola et al., 2006). Crespi et al. (2007) have shown that plates follow a westward mainstream but inclined to equator ±7°. Riguzzi et al. (2009) presented paper summarizing previous results of Doglioni et al., Scoppola et al. and Crespi et al. Already for almost three decades ago two serious objections has been also raised against the triggering of earthquakes and the plate movement by Earth's rotation variations. The first one the Forsyth and Uyeda,s (1975) recognition that in oceans undoubtedly the ridge push and the slab pull act, disqualified the tidal forces acting in range 4×10^3 Pa for semidiurnal tides and 8×10^3 Pa for biweekly tides (Bodri and Iizuka, 1989). Ostřihanský (1997) however has shown that the slab-pull force represents the dropping down by gravity of the oceanic lithosphere opening the space for moving plates driven by week forces. The hydrostatic pressure (ridge-push) acts on the both sides, lower and upper, of the oceanic lithosphere, however this force acts directly in the oceanic ridge only in case when the drag following from the Earth's rotation opens the ridge and the ascending magma reaching the crest of the ridge acts by its pressure. This pressure accompanying pressures following from the Earth's rotation can be especially effective in case that the ridge is close to subduction zone. The second one the Wahr (1985) and Gipson and Ma (1998) calculations that LOD excites stress only 0.1 Pa seemingly excluded LOD. It was the same error as to consider the ITRF 2005 GPS measurement as the real lithospheric plates movements. These movements are related to the stable lithosphere to GPS satellite framework and this says nothing about the plate movements above mantle. In China the westward moving Eurasian plate collides with Indian plate moving in N-W direction. In that site Wang et al. (2000) measured the decadal (for 20 yr) LOD correlated stress change in order of 10^4–10^5 Pa. Wang et al. (2000) found this stress on tilt meters in western China where the moving westward Eurasian plate collides with the Indian plate. The purpose of this paper is to prove that just large continental plates with some oceanic parts are driven by LOD variations and from this reason the Wang's et al. (2000) measurement can be explained. The nature of the decadal LOD variations exhibiting irregular 60 yr variations derived from stars occultations by Moon, available from the end of 18th century (Aoki et al., 1982), follows from distant (6 times weaker tidal forces than from the Moon) of large planets Jupiter, Saturn Uranus and Neptune (P. Kalenda, private communication, 2012), which by their long time contribution to every Moon's and Sun's LOD variation, crate this irregular decadal variations. This phenomenon only underlines the importance of astronomical parameters for the Earth surface; however the decadal variations in spite that ranging 3–4 ms, owing to 60 yr time span, have no significant effect in earthquake triggering and the plate movement. Nevertheless some indications show that in decadal LOD variations extremes, earthquakes are more numerous. This concerns for example the almost continuous number of earthquakes < 4 M in LOD minimum 2002–2006 (Ostřihanský, 2010b) in Norcia-Marche-Abruzzi region of Apennines and the number of earthquakes in the wide LOD maximum 1964–1983 in Alaska described in Sect. 3.3.

2 Earth's rotation variations, syzygy and coincidences with earthquakes

The Earth's rotation velocity is measured daily by IERS (International Earth's Rotation Service) (Fig. 1a and b), expressed as the length of a day (LOD) in seconds. The LOD is therefore dependent on Moon and Sun configuration, on position of these bodies to the equator, which part of the Earth's surface these bodies pass over oceans and continents during their apparent daily movement, in less extent on atmospheric effects, however more distinctly on El Nino or La Nina effects (Rosen et al., 1984; Ostřihanský, 2004). The time span from the Moon's crossing the equator to another equatorial crossing during its apparent movement takes 13.66 days. However, the corresponding Earth's decelerations can be different. LOD peaks do not have the same size owing to changing the Moon-Earth distance by Moon's perigee rotation in 8.85 yr.

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Practically LOD peaks close to the perigee are enlarged, LOD peaks close to apogee are lowered, LOD minimums close to perigee are uplifted, and those close to apogee are deepened. The Sun causes semiannual variations: On the LOD graph there are winter and summer accelerations. More distinct is the summer acceleration (shifted to the late summer in July), influenced by the heating of the Northern (mostly continental) Hemisphere and corresponding volume expansion in summer (Kalenda et al., 2010). Le Mouel et al. (2010) found correlation between the amplitude of the semiannual oscillation in LOD with 11-yr solar sunspot activity. Meteorological effect and atmospheric super rotation (e.g. Hide, 1984) can be also considered.

As introduction to this paragraph, I strictly mention the Denali Fault and Sumatra earthquakes, which initiated my investigation. The Denali Fault Alaska earthquake is an arc shaped rupture and its central part is roughly sub parallel to latitudes. It reflects the boundary between the slow westward movement of the American plate in higher latitudes and quicker NW movement of the Pacific plate. Therefore, it is sensitive to deceleration of the Earth's rotation and accordingly the M7.9 earthquake of 3 November 2002 was triggered during the Earth's rotation deceleration (Fig. 1a) (Ostřihanský, 2010a) in LOD maximum. Because the earthquake was triggered on the third LOD maximum peak, the resonance effect is considered as an earthquake increasing factor (Fig. 1a). For the next investigation I chose the group of earthquakes on faults subparallel with longitudes. The investigated rectangle (14° N–5° S, 105–90° E) (Fig. 2.2) of earthquakes taken from USGS NEIC and ANSS Catalog was chosen on the west side of continental lithosphere on the Eurasian plate to avoid westward pressures. These earthquakes cover the subduction zone of the Sumatra and Andaman Sea. Northward pressures triggered earthquakes at the time of Earth's rotation acceleration on Sumatra 26 December 2004, M9.1 (Fig. 1b). Repeating Earth's rotation accelerations (LOD minimums) triggered this huge earthquake followed by tsunamis. According to coincidence with LOD minimum, the Sumatra earthquake 26 December 2004 was triggered exactly at the time of the full Moon (Fig. 2.4), which evoked hypotheses about biweekly tides triggering (Crockett et al., 2006).

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This study should be distinguished from studies dealing with semidiurnal or biweekly tidal triggering of earthquakes, which for more than 150 yr (first attempts are described in Varga and Denis (2010) and over the Schuster's test (Schuster, 1897) present mostly negative results. These attempts are based on comparison of tidal semidiurnal phase between high and low tide to earthquakes. Studies of Cochran et al. (2004) and Tanaka et al. (2002) are considered as positive. Quite negative are studies of biweekly tides ranging from syzygy in rhythm 14.7 days of lunar synodic time-scale (Weems and Perry, 1989). Decisive for the earthquakes triggering are 13.66 days frequencies of sidereal lunar scale, which reflect the Earth's deformation in rhythm of Moon's declination variation. Variations of Earth's rotation caused by Moon are ≈ 1.5 ms and by Sun ≈ 3 ms in late summer, but in longer 182.6 days period. Rotation variations sufficiently shake the Earth and this knocking effect moves lithospheric plates in hard medium of viscous mantle 10^{19} Pa s only two orders of magnitude less viscous than lithosphere 10^{21} Pa s.

Let us perform a simple calculation to compare biweekly tides with Earth's rotation variations. Substituting the exact sidereal semiperiod of Moon's orbit t_1 = 13.66008305 days and synodial syzygy of the Moon's full or new semiperiod t_2 = 14.765294 days, the coincidence $s = t_1 \times t_2/(t_2 - t_1)$ = 182.63 days. Therefore, the coincidence occurs twice in the year and always at the time of winter or summer solstices. The stable coincidence of LOD minimum with the full or new Moon in solstices is an interesting phenomenon. The explanation is the following: The LOD minimum means that the Moon has the highest declination. The full or new Moon means that Moon, Earth and Sun are on the same line and this means that at that moment the Moon exerts the largest torque on the Earth's axis. For this reason the coincidence of full or new Moon with LOD minimum occur always in winter or summer solstices. However, from this logically follows that also the full or new Moon has to coincide with LOD maximums in equinoxes. Solstices and equinoxes are therefore the time of the largest earthquake activity. In addition, the close frequencies of sidereal and synodial periods create beats.

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3 Calculation of forces and their possible repetitions

3.1 Calculation of forces acting on plates and the plate movement

Variations of the Earth's rotation are caused by the effects of Moon and Sun deforming the Earth's shape and by this way the Earth's angular polar moment of inertia leading to the change of its rotation velocity according the law of angular momentum conservation (Wahr, 1988). In winter solstices 1985 and 2004 owing to high ecliptic's declination and even higher the Moon's declination being for 4° above ecliptic in nutation 18.6 yr period, this high Moon's declination and the Earth deformation in direction of the Earth's axis, the Earth's rotation was extremely high. On the other hand this high Moon's declination caused (Fig. 2.1) that the Moon pulled the Indian plate northward and caused the earthquake. In this case the pull of the Moon is not caused directly by the Earth's tides but the tidal force rectifying the Earth's flattening to the plane of ecliptic and Moon's orbit. Brož et al. (2011) present simple calculation of torque acting at that moment on the flattened lithosphere, i.e. on the Indian plate.

Earth's angular velocity $\varpi = 7.29 \times 10^{-5}\,\mathrm{rad\,s^{-1}}$, Earth's moment of inertia $I = 8.07 \times 10^{37}\,\mathrm{kg\,m^2}$ (Stacey, 1977). Earth's angular momentum $L = I \times \varpi = 5.89 \times 10^{33}\,\mathrm{kg\,m^2\,s^{-1}}$. Mass of the lithospheric bulge is

$$m_{\mathrm{bulge}} = \frac{1}{2}\left(\frac{4}{3}\pi abc - \frac{4}{3}\pi c^3\right)\rho_{\mathrm{crust}}, \quad (1)$$

where we insert $a = b = R \approx 6378\,\mathrm{km}$, $c = R - 21\,\mathrm{km}$, $\rho_{\mathrm{crust}} \approx 2700\,\mathrm{kg\,m^{-3}}$ and we get $m_{\mathrm{bulge}} \approx 9.6 \times 10^{21}\,\mathrm{kg} \approx 1/624 m_{\mathrm{e}}$. (Earth's mass $m_{\mathrm{e}} = 5.9 \times 10^{24}\,\mathrm{kg}$). The torque of force couple acting on the Earth is then: in case of the Sun

$$M_{\mathrm{s}} = 2 \times \frac{2G m_{\mathrm{bulge}} m_{\mathrm{s}}}{r_{\mathrm{e}}^3} R_{\mathrm{e}} \cos\varepsilon . R_{\mathrm{e}} \sin\varepsilon, \quad (2)$$

where $\varepsilon = 23.45°$ is the obliquity of ecliptic to equator. This is valid only in case if the mass of bulge were concentrated in one point on equator and the Sun were just in

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highest point above equator. In reality we should integrate over the bulge because some its parts are closer to the axis of rotation and to center over the Earth's rotation because the instant angle of the Sun above equator varies. We would get:

$$\overline{M}_{\mathrm{s}} = \frac{1}{4} M_{\mathrm{s}} \approx 5.7 \times 10^{21}\,\mathrm{N\,m} \tag{3}$$

The same calculation is for the Moon:

$$M_{\mathrm{m}} = 2 \times \frac{2G\, m_{\mathrm{bulge}} m_{\mathrm{m}}}{r_{\mathrm{m}}^{3}} R_{\mathrm{e}} \cos \iota \,.\, R_{\mathrm{e}} \sin \iota, \tag{4}$$

where ι is the Moon's declination. The result is $\overline{M}_{\mathrm{m}} = \frac{1}{4} M_{\mathrm{m}} \approx 1.2 \times 10^{22}\,\mathrm{N\,m}$. The torques simply summarize $\overline{M} = \overline{M}_{\mathrm{s}} + \overline{M}_{\mathrm{m}} = 1.8 \times 10^{22}\,\mathrm{N\,m}$.

This important result calculates that the torque $1.8 \times 10^{22}\,\mathrm{N\,m}$ is able to move the plate. The seismic moment of the Sumatra earthquake is $3.5 \times 10^{22}\,\mathrm{N\,m}$ (Varga and Denis, 2010; Lay et al., 2005; Stein and Okal, 2005). Because the torque exerted by tidal force acting on Earth's flattening represents the kinetic energy and also the seismic moment represents energy according to definition $M_0 = \mathrm{mu}\, A\, D$, where μ is the shear modulus $\mathrm{N\,m^{-2}}$, D is displacement on area A, this quantity of N m dimension represents also energy, both quantities can be compared.

Because astronomical parameters of both earthquakes 1985 and 2004 were almost the same in both cases, the repetition of these earthquakes after the 19 yr Metonic cycle is evident. The GPS measurement (Fig. 2.2) shows that the plate moves almost exactly in N–S direction. Table 1 presents comparison of parameters of 1985 and 2004 earthquakes:

Figures 2.3 and 2.4 show the LOD records for earthquakes Sumatra 1985 and 2004. Coincidence of full Moons and LOD minimums is evident (extreme Earth's rotation is unimportant in this case) but it shows the extreme high Moon's and Sun's declinations. Further there are coincidences with the 235 full Moons and 19 Earth's rotations round the Sun and 254 sidereal Moon's rotations round the Earth fulfilled in the Metonic cycle.

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Except of the northward movement, all plates move westward. The simple calculation of this force can be performed from equivalence of mechanical work and kinetic energy.

$$P \times s = \frac{1}{2} m v^2, \quad (5)$$

where P is the force acting on drive s, m is the mass of the plate and v is the plate velocity. The plate velocity v during the Earth's rotation can be calculated from relation 1 ms = 0.015″ = 46.5 cm on equator. The LOD increment for 1 ms means the increment of Earth's surface velocity 0.465 m/0.001 s = 465 m s^{-1}. The Eurasian continent has area 54×10^6 km^2 and thickness 300 km and density 3100 kg m^{-3}, then the mass of this continent is $54 \times 3 \times 3.1 \times 10^{17}$ kg = 5×10^{19} kg. From it the kinetic energy is $2.2 \times 10^5 \times 5 \times 10^{19}/2 = 5.5 \times 10^{25}$ J. Corresponding force on the drive s is 11.8×10^{25} N and considering the Earth's radius 6378 km, the torque of Eurasian continent situated on equator is 7.5×10^{29} N m. However variations of the Earth's rotation do not act 1 ms but 1/4 of sidereal Moon's rotation time, i.e. 6.830 days. For this reason considering the maximum variation amplitude 1.5 ms and therefore the drive 698 cm, the variation velocity is 11.83×10^{-7} m s^{-1} and the kinetic energy is 3.514×10^7 J. Corresponding force is $3.514 \times 10^7/0.698 = 5.034 \times 10^7$ N and the torque is $4.152 \times 10^7 \times 6378 \times 10^3 = 3.21 \times 10^{14}$ N m. Continents stroke the mantle with torque 3.21×10^{14} N m 53.4 times in the year, and if every stroke shifts the Eurasian plate for 1 mm then during the year the westward drift is 5 cm, as it corresponds to reality. Westward drift is very important Earth's phenomenon; it is caused by both Earth's acceleration and deceleration. When the Earth accelerates owing to enlarged shape in rotation axis, lithosphere remains behind, i.e. moves westward. When the Earth moves more slowly owing to enlarged equatorial diameter, internal part moves eastward and lithosphere remains behind, i.e. moves again westward. Figure 2.7 shows the long term LOD record over 38 yr. The nature of the decadal LOD variations exhibiting irregular 60 yr variations (Aoki et al., 1982) follows from distant (6times weaker tidal forces than from the Moon) of large planets Jupiter, Saturn Uranus and Neptune (P. Kalenda,

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private communication, 2012), which by their long time contribution to every Moon's and Sun's LOD variation, crate this irregular decadal variations. Let us mention that considering the tidal friction the long term LOD record should be the line inclined for 0.0023 s / 100 yr reflecting the Earth's deceleration by tidal friction. The torque caused by tidal friction is only 5.1×10^{16} N m (Burša, 1987). It is possible also to count the torque M acting on the mantle itself. Motion equation for the rotation of the solid body is

$$M = J\varepsilon \quad (6)$$

where J is the moment of inertia and ε is acceleration. The mantle moment of inertia is

$$J = \frac{2}{5}m_1 r_1^2 - \frac{2}{5}m_2 r_2^2 \quad (7)$$

where m_1 and m_2 are masses of the mantle and core, $r_1$and r_2 are corresponding radiuses of mantle 6078 km and core 3478 km. Considering the Earth's mass 5.98×10^{24} kg and the mass of the mantle 67.5 % and the core 32.5 % of the Earth's mass, then $m_1 = 4.036 \times 10^{24}$ kg and $m_2 = 1.941 \times 10^{24}$ kg. After calculation $J = 5.01 \times 10^{37}$ kg m^2. If 1 ms = 0.015″, and the maximum amplitude of Earth's rotation is 1.5 ms then the corresponding arc is 0.0225″. It takes to shaking Earth for 6.83 days, i.e. 5.901×10^5 s. The acceleration $\varepsilon = 0.0225'' / 5.901 \times 10^5\,\mathrm{s}^2 = 3.806 \times 10^{-11}{}'' / \mathrm{s}^2 = 1.845 \times 10^{-16}\,\mathrm{rad/s}^2$ and $M = J\varepsilon = 5.01 \times 10^{37} \times 1.845 \times 10^{-16} = 9.24 \times 10^{21}$ N m.

This alternating torque acting on plastic mantle can influence the movement of plates, to open the mid-ocean ridges, considering ratcheting mechanism of ascending magma solidification and to break the subducting oceanic lithosphere.

Figure 2.5a shows the movement of plates over equator and their growth during the movement. The growths of plates exceeding the length of the Earth's one half of its circumference have the stable position on the pole. Considering the Eötvös force

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(Eötvös, 1913), all plates were moved to equator. Considering the tidal force acting on the Earth's flattening the Antarctica and the Eurasian plate remain fixed in higher latitudes. The tidal force acting on the Earth's flattening, in contrast to the Eötvös force, pulls out the plates from equator. Figure 2.5a 570 M.Y. shows the separation of Gondwana from Laurasia. Because Gondwana exceeded to equator, it was pulled to the south. During the movement it had grown by accretion of oceanic lithosphere behind into large plate, which was shifted as far as on the South Pole. There it decayed into small plates, which moved back to the north. The movement of the Indian Peninsula Fig. 2.5a 120 M.Y. is quite typical. The Indian Peninsula formed the rear side of the long oceanic plate subducting in front of Laurasian today's Eurasian continent. The whole oceanic lithosphere subducted, pushing the deep oceanic sediments to the highest levels of Himalayas. Because this plate has grown by accreted oceanic lithosphere behind the Indian Peninsula, it is still pulled against Eaurasian continent and subduces in Indonesia. The westward movement of plates is well observable in Antarctica (Fig. 2.5c). That all plates move westward is evident from Fig. 2.5b. This map, from (Ostřihanský, 1997), was constructed under assumption that the plates Cocos and Nazca are stable on the mantle. These plates are small and therefore exert the smallest torque westward. Because evidently the American continent overrides the East Pacific Rise, the Cocos and Nazca plates should stay on the mantle firmly. The double hotspot tracks from the Galapagos hotspot (Carnegie and Cocos) were created during the consequent tearing of Cocos and Nazca plates apart (Fig. 4e), (Ostřihanský, 1997). The fossil mid-ocean ridge on the east from the East Pacific Rise presents another proof of the stability of the Nazca plate over mantle as a part lost behind during the quick westward movement of the Pacific plate.

Figure 2.5b shows the present westward and northward components of all plates (Ostřihanský, 1997).

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3.2 Metonic cycle in Sumatra and Andaman Sea

Table 1 presents results of 17 earthquakes with magnitudes over M5.8, which occurred at solstices time from 49 earthquakes triggered in the LOD minimums in chosen rectangle (Fig. 2.2) covering the Sumatra and Andaman Sea from 1963 to 2011 with a total 264 earthquakes. The strongest of them, the M9.1 Sumatra earthquake of 26 December 2004 (Fig. 2.4), and the next strongest the Sumatra earthquake of 27 December 1985 (M6.6) were triggered exactly 19 yr apart. Figure 2.3 shows this important repetition. Comparison of Figs. 2.3 and 2.4 shows striking similarity of both earthquakes in maximums and aftershocks. LOD minimums and the full Moons differ only one day: 26 December 2004 and 27 December 1985, respectively. It is not due to chance the similarity of these two dates during the 19 yr time span because the Metonic cycle governs the earthquake triggering. The Metonic cycle is a period of very close to 19 yr, which is remarkable for being very nearly a common multiple of solar year and the synodic month. The Greek astronomer Meton of Athens observed that a period of 19 yr is almost exactly equal to 235 synodic months, 254 sideric months and rounded to full days counts 6940 days. No wonder that the earthquakes of 26 December 2004 and 27 December 1985 coincide not only in the LOD minimum but also on the full Moon. This configuration represents the greatest torque acting on the Earth trying to rectify the Earth's bulging caused by flattening to the plane of ecliptic and the Moon's orbit (Fig. 2.1). Similar repetition occurred between 21 December 2010 M5.9 and 22 December 1991 M5.8 in winter solstice, exact coincidence on LOD minimum and full Moon 21 December. in both cases. There are many other 19 yr repetitions but their identification with astronomical parameters will be performed in future.

3.3 Metonic cycle and Alaskan earthquakes

Figure 2.6a shows the investigated area of Alaska covering the Great Alaska earthquake 1964 M8.5 and the earthquake on the Denali Fault 2002 M7.9. The block model Fig. 2.6b shows the westward directing velocities. Let us try to answer the question

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why worldwide the lithospheric plates move to the west. Let us start with Ward's (2008) imagination that variations of the Earth's rotation are caused by the Moon's and Sun's deforming the Earth, changing therefore the inertia moment leading, considering the angular momentum conservation, to the change of the Earth's rotation. The Earth, deformed in direction of rotation axis by the high Moon's or Sun's declination, moves quicker. The Earth moving quicker from the west to the east leaves the lithospheric plates by inertia behind and plates therefore move towards west. On the other hand the Earth, deformed by Moon and Sun situated on equator with 0° declination, moves more slowly. However the belt corresponding to the increased flattening has higher moment of inertia and therefore it moves more slowly than the interior part of the Earth. The result: Lithospheric plates move again towards west. Lithospheric plates by regular 6.83 days strokes move westward through mantle like pneumatic pike. This concerns namely of the continental plates which regardless their deep bottom (over 300 km) overrides the oceanic plates. Westward moving plates creating earthquakes by 6.83 days strokes during both LOD minimums and maximums do not give so unequivocal results as plates moving in S–N direction (Indian plate, African plate, Pacific plate).

Figure 2.7 shows earthquakes of Alaska 1962–2011 and two 19 yr Metonic cycles bounded by three earthquakes 1964, 1983 and 2002. The first Metonic cycle has in average higher LOD corresponding to the slow Earth's rotation. Most of the Earth's abrupt rotation increments result in earthquakes. This resembles to 19 yr aftershock occurrence. The first earthquake of the Metonic cycle the Great Alaska earthquake M8.5 in Prince William Sound was triggered on 28 March 1964 (Fig. 2.8). The reason for this earthquake triggering is following: From very slow Earth's rotation in point (A) of Fig. 2.8 the Earth's rotation abruptly increased for 1.5 ms to point (B) triggering small earthquake of 5th magnitude, but the Great Alaska earthquake was triggered only when the Earth's rotation decreased in the next LOD maximum in point (C) and also in the full Moon, which probably helped to deceleration, but this will not have the decisive effect as we shall see in next. It is necessary to realize the difference between S–N moving plates (Sumatra) where the LOD minimum, i.e. maximum Moon's declination, the full

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Moon for greater torque and solstice for Sun's maximum declination are decisive for earthquake triggering. In E–W moving plates earthquakes are triggered in acceleration and deceleration, plates move in both cases westward and previous extreme Earth's rotation acceleration had supporting triggering effect in following deceleration. Before interpreting the next earthquake of the Meton's cycle we shall realize the shaping of the LOD graph. As it was explained before the LOD maximum corresponds to the slow Earth's rotation and the LOD minimum to the Earth's maximum rotation. LOD peaks do not have the same size owing to changing Moon's Earth distance by Moon's perigee rotation in 8.85 yr. Practically, LOD peaks close to the perigee are enlarged, LOD peaks close to apogee are lowered, LOD minimums close to perigee are uplifted, and those close to apogee are deepened.

Figure 2.9 explains causes of the earthquake M6.4 of 12 July 1983 starting the second Metonic cycle. The fixed Metonic period shows that the full Moon is exactly on LOD maximum 28 March 1983 (point C) as it had been with previous earthquake on 28 March 1964. But this LOD maximum is higher then the previous LOD maximum (point A) owing to the different Moon's perigee position, which now is close to the second LOD maximum in point (C). Because between points (A) and (B) the take-off run for the earthquake was very short, none earthquake was triggered in point (C). Convenient for triggering is the previous couple of LOD maximums 1 March 1983 and 17 March 1983 where really there are two small earthquakes M4.3 in LOD minimum and M4.0 in LOD maximum. However the largest take-off run is between points (D) and (E), what caused that not at the next LOD maximum but after that in LOD minimum (point F) the earthquake 12 July 1983 M6.4 was triggered. The whole area had been disturbed and series of earthquakes on LOD minimums were created.

In Fig. 2.10 in the third earthquake of the Metonic cycle on 28 March 2002 the situation is repeated. Between points (A) and (B) the take-off run is very short for the earthquake triggering and therefore in point (C) (28 March 2002) none earthquake was created. Best conditions for the take-off run is between points (D) and (E) and really in point (F) small earthquake M4.7 is triggered. Such situation is three times repeated and

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owing to the take-off run between points (G) and (H) the strong Mt. Nenana earthquake in point (I) was triggered. The whole area was strongly disturbed, what resulted in the great Denali Fault earthquake 3 November 2002 by resonance of previous 4 repetitions of LOD maximum peak (see also Fig. 1a).

3.4 Characteristic of earthquakes repeating in Metonic cycle

The earthquakes Sumatra 27 December 1985 and Sumatra 26 December 2004 were triggered by almost identical astronomical parameters given by the firm bound in repetitions of these parameters given by the Metonic cycle, i.e. by 254 Moon's rotations round the Earth and 19 rotations of the Earth round the Sun. Identical Moon's declinations and the full Moon coincidence creating the maximum torque triggered these earthquakes of calculated value 1.8×10^{22} N m equivalent in order of magnitude to the seismic moment 3.5×10^{22} N m sufficient to move the Indian plate.

The earthquakes in Alaska are characteristic, in the first Meton's period 1964–1983, by very slow Earth's rotation (Fig. 2.7). Many abrupt accelerations react on it by earthquakes so as the aftershocks from the Great Alaska earthquake 1964 were triggered for 19 yr. The Alaska earthquake itself, triggered in the Prince William Sound on 28 March 1964, was triggered by a large acceleration for 1.5 ms / 6.83 days from 16 March 1964 to 22 March 1964 and following deceleration on 28 March 1964. In the next Metonic coincidence of parameters on 28 March 1983 there is none earthquake. The reason is owing to distant coincidence of Moon's perigee with LOD maximum on 17 March 1983, the Earth's rotation increment between 17 March 1983 and 23 March 1983 is very small. The large Earth's rotation increment is on 27 June 1983; the earthquake was triggered on 12 July 1983, M6.4, i.e. for over 3 months delay. Similar situation is with coincidence on 28 March 2002 and only after three months on 23 October 2002 the Mt. Nenana earthquake M6.7 was triggered. By the following resonance the Great earthquake on the Denali Fault M7.9 on 3 November 2002 was triggered.

The earthquakes in Sumatra were triggered by tidal forces acting on the Earth's flattening varying in 24 h period. The repetitions in dates are almost exact. The

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earthquakes in Alaska were triggered by westward drift evoked by 53.4 repetitions per year of Earth's rotation variations by changing Moon's declination. In this case the repetitions are not exact, they are for several months delayed, triggered in moment of better conditions for earthquake occurrence. However even the Sumatran earthquakes are not sufficiently exact. As follows from Fig. 2.1, the maximum torque occurs at midnight of local time. The earthquake 26 December 2004 occurred for 6 h sooner and the earthquake 27 December 1985, even eleven hours sooner.

In California the 19 yr repetitions are evident in many strongest earthquakes in last 200 yr documented by amateurs. Table 3 presents the review.

Statistical evaluations of earthquakes repetitions in 19 yr Metonic cycle need not always lead to the goal. At present time in Sumatra there are known two repetitions 26 December 2004 – 27 December 1985 and 21 December 2010 – 22 December 1991. These two repetitions differ for only 6 yr. The coincidence of maximum Moon's declination in 18.61 yr cycle of the inclined Moon's rotation plane and the Metonic 19 yr cycle of the Earth's rotation round the Sun and Moon's 254 rotations round the Earth with 235 Moon's synodic rotations are decisive for the earthquake triggering as Figs. 2.1, 2.3 and 2.4 show. Using formula for coincidence of two rotation frequencies from 2nd paragraph $s = t_2 \times t_1/(t_2 - t_1) = 18.61 \times 19/(19 - 18.61) = 900.6$ yr. Therefore the situation of the Strong Sumatra earthquake Dec. 2004 can be repeated only after 900.6 yr.

The 6 yr difference of two 19 yr couples of earthquakes is remarkable considering that also the spiral movement of the pole repeats also in 6 yr. This spiral movement of the pole is resultant of two components; one is the rotation of the true pole round the principal of inertia axis with the period about 1.20 yr (Chandler wobble) and 1 yr LOD variation. Using again the formula for coincidence $s = t_2 \times t_1/(t_2 - t_1) = 1.2 \times 1/0.2 = 6$ yr. In (Ostřihanský, 2010b) it has been found that in the time of 26 December Sumatra 2004 earthquake the true pole was at distant and reverse side of Sumatra from the principal axis of inertia. The earthquake 21 December 2010 corresponds also the same distance of the true pole from principal axis of inertia. Earth's wobbling is also the factor of earthquake triggering. Figure 2.11 shows three types of LOD variations: 13.66 days

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variation, one year variation and decadal variation. Attached records of the tilt meter and the fault deformation (Wang et al., 2000) show how the Earth's crust reacts on one year and decadal variations.

4 Characteristics of 2010–2011 earthquakes

Variations of the Earth's rotation coincide with earthquakes, offering strong evidence that just Earth's rotation variations can facilitate the lithospheric plates movement over the mantle.

4.1 M7.0 Haiti region 12 January 2010

Identifying the time of magnitude 7.0 Haiti region earthquake on 12 January 2010 with LOD record, it can be seen that this earthquake corresponds to the quickest Earth's rotation, owing to the maximum Moon's declination, deforming the Earth in direction to poles, and resulting in a decrease of the polar mass moment of inertia and the increment of rotation speed in LOD winter minimum (Fig. 4a). The Haiti earthquake occurred (Fig. 4e) on the east-west directing transform fault with left-lateral strike slip faulting on the northern side of the Caribbean plate (Enriquillo-Plantain Garden fault system) (USGS Poster, 2010). This transform fault therefore expresses the quicker westward movement of the North American plate than the Caribbean plate and probably also than the whole South American plate. No wonder that just during the increment of Earth's rotation velocity (minimum of LOD curve) the earthquake occurred. The quicker movement of the Northern Hemisphere is also evident from the westward shift of the Mid-Atlantic ridge in the North Atlantic Ocean, whereas in the South Atlantic Ocean the Mid-Atlantic ridge keeps its original meridional direction. A smaller opening of the Atlantic Ocean in the Northern Hemisphere shows that also the Eurasian plate moves westward (Fig. 4b). A more detailed explanation of the Haiti earthquake origin a comparison provides of earthquakes in Enriquillo-Plantain Garden transform

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fault with earthquakes on Mid-Atlantic Ridge, which are in close relation (Fig. 4c and d). Variations of the Earth's rotation by their accelerations and decelerations open the Mid-Atlantic Ridge and trigger shallow earthquakes in rhythm of inflection points of LOD record. It is not chance that, consequently from equator to higher latitudes, earthquakes were triggered from the end of December 2009, to as far as an earthquake had occurred at the most western site of the Mid-Atlantic Ridge on 8 January 2010 (Fig. 4b and d), where the pressure reached maximum. Cooperation of the ridge-push force is also possible.

The westward drift of the American plate, enlarged by the resonance effect of four LOD minimums (Fig. 4c left), caused distinctive westward shift of the Northern Hemisphere and triggered the Haiti earthquake on the transform fault at the northern side of the Caribbean plate.

4.2 M8.8 Offshore Maule Chile 27 February 2010

Increasing LOD amplitudes at the end of January 2010 are displayed by an increased occurrence of earthquakes in the Mid-Atlantic Ridge. After 28 days, the largest LOD peak (i.e. the Earth's deceleration) is in coincidence with triggering earthquake M8.8 Offshore Maule Chile 27 February 2010 (Fig. 4f). This was the 56th earthquake that occurred in 3 days interval before maximum from 349 earthquakes $>$M6 during the 1973–2011 period. The earthquake occurred three days before the maximum length of a day, i.e. with the slowest Earth rotation of the first half of that year. The Moon at that time was situated over the equator during its apparent movement. The Earth had been deformed, which enlarged its equatorial size and evoked an increment of the polar mass moment of inertia and the Earth's rotation deceleration. The enlarged bulging of oceans caused an increment of the westward drag of the lithosphere. Let us also mention the extremely high tides off the Argentina coast: Rio Gallegos 29 m. The fundamental important confirmation of the plate movement was the GPS measurement performed before and after the earthquake, showing an exceptional westward displacement near the epicenter, entering the city of Concepcion 3.04 m. The most

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exciting news was that the whole continent of South Central Chile and Argentina had displaced itself westward in Buenos Aires 2–4 cm as far north as the Chilean border with Peru (Fig. 6). This important discovery was performed by international US, Chilean and Argentinean research groups led by the head of CAP (Central and Southern Andes GPS Project) Mike Bevis (SOEST News 2010). This GPS measurement confirmed the quick westward movement of the continental and oceanic part of the South American plate shown before (Ostřihanský 1997) by the movement and opening of the Scotia Sea back-arc basin (Fig. 2.5c). This is final proof that the South American plate overrides the oceanic lithosphere of the Nazca plate, which is static or moves very slowly over the asthenosphere. GPS measurements performed later over a larger part of the southern region of the South American continent (Madariaga et al., 2010) showed that the GPS movements follow exactly the westward direction. Let us mention that the idea that the American plate overrides the Pacific plate was first claimed by Tuzo Wilson (1965). In Fig. 4a the record of earthquakes shows that earthquakes (mostly aftershocks of the Maule Chile) remained at rest after May 2010 till the end of year. Only two earthquakes occurred over 6th magnitude: The earthquake M7.1 Ecuador 12 August 2010 (depth 106 km) and the earthquake M6.2 in vicinity of Maule Chile (50 km south) at depth 16 km on 9 September 2010. Both of these earthquakes coincide exactly with maximums of LOD record corresponding to the Earth's rotation deceleration and the westward movement of the whole South American plate in the same way as the Maule Chile earthquake confirmed.

Most of the earthquakes in the Chile Trench, as shown by the earthquake M8.8 Maule Chile, are preceded by an earthquake on Mid Atlantic Ridge (black bars – Fig. 4f). However, at the beginning of 2011 a change occurred: The earthquake M7.1 Araucania 2 January 2011 occurred at LOD minimum followed by earthquakes in the Mid-Atlantic Ridge. Similarly, the earthquakes M6.8 Biobio Chile 11 January 2011 and M6.6 Offshore Maule Chile 14 February 2011 preceded the earthquake in the Mid-Atlantic Ridge (Fig. 4g). This is a very important change of earthquake occurrence and their relation to LOD polarity, which needs an explanation. Mid-ocean ridge reacts first on

Earth's variations; however, after the continent overthrust the subduction zone is released by melted magma and the reverse process occurs. The subduction zone reacts first on Earth's variation at that moment of LOD minimum. Earthquakes in subduction zone occur first and then in the mid-ocean ridge. Therefore, the initial positive LOD earthquake is changed in reciprocal cycles after 7 days, triggering earthquakes in the subducton zone in LOD minimum (Fig. 4g). The last mentioned earthquakes occurred in the second LOD minimum. The next LOD second minimum occurred exactly after 27.32 days on 11 March 2011, exerting a crucial effect on the Honshu earthquake (described in detail in Sect. 4.4).

4.3 Earthquakes in the Indian plate

Several strong earthquakes also occurred in 2010 on the Indian plate (Fig. 4h). Similarly as in the Sumatra earthquake of 26 December 2004, most of earthquakes were triggered on the LOD minimum. The most striking case is the Moro Gulf Philippines earthquake 27 July 2010, exactly corresponding to the summer LOD minimum. Other earthquakes also correspond to the LOD minimums: M6.6 Northern Sumatra 5 May 2010, M6.1 N. Guinea 26 November 2010, M7.7 Kapulauan Mentawai 25 October 2010, most of the earthquakes from Papua (M7.7 on 4 August 2010, M6.0 on 28 September 2010), and M7.0 New Zealand 3 September 2010. Out from minimum or maximum LOD are earthquakes from Vanuatu (N. Hebrides). This is a collision of two oceanic lithospheres: the oceanic Pacific plate and the oceanic part of the Indian plate, which act against each other and from which the earthquake triggering is indefinite. Exact coincidence with LOD minimum is M6.7 Salomon Island 26 June 2010, whereas other earthquakes from this area from the beginning of the year are out of coincidence. The earthquake M7.2 Northern Sumatra 9 May 2010 was 7 days delayed and situated on smaller LOD maximum. The same was true for the earthquake of 28 March 2005, which was 10 days delayed (Fig. 3a). Similarly, the earthquake of 9 May 2010 preceded the strong 1.38 ms velocity increment (Fig. 3b). Conclusion: There is a possibility that both earthquakes were triggered by the ridge-push force in opening of closely situated

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mid-ocean ridge by previous strong Earth's rotation increments 1.5 ms (Fig. 3a) and 1.38 ms (Fig. 3b).

The earthquake M7.1 Christchurch 3 September 2010 occurred on the second LOD minimum, as did most of the earthquakes in the Indian plate in autumn 2010 (Fig. 4h and i). However, the disastrous earthquake M6.3 Christchurch 21 February 2011 occurred in reciprocal cycles in LOD maximum (Fig. 4i). To distinguish the movement of the Indian plate according to earthquakes triggered by the Earth's rotation variation to the north and to the west, a special graphic method was performed (Fig. 4j). The Southeast Indian Ocean Ridge presents a very important proof of force acting on the plate. According to number of earthquakes in ascending and descending branches of LOD record for 2010 (Fig. 4k), we find that number of earthquakes on the descending branch of LOD record is 33 (blue bars), whereas on the ascending branch there are only 22 (orange bars). This result shows that there is a force acting during the Earth's acceleration, pushing the plate northward. It can be seen that this force acts on the descending branch of the LOD graph from May to July and also from October to December. Less frequent earthquakes are on the ascending branch from January to March and from September to November. Similar results for 2008 show 29 earthquakes on the descending branch and only 19 on the ascending one. However, in the years 2009 and 2007–2004, differences between earthquakes on the ascending and descending branches are less than ±5 earthquakes.

4.4 M9.0 Near the coast of Honshu Japan 11 March 2011

Studying the last strongest M9.0 earthquake near the coast of Honshu Japan on 11 March 2011, it was also found that this earthquake was triggered by the Earth's rotation variation. Surprising was its exact position on the second LOD minimum (Fig. 5a). The second LOD minimum earthquakes are typical for many earthquakes in the second half of year in the Indian plate and also in the Chile Trench. The earthquake M6.8 Biobio Chile 11 February 2011 occurred in the second LOD minimum, confirming the reverse mode of Earth's variation triggering when originally the LOD maximum triggering for

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the whole year 2010 was changed in the beginning of 2011 into the LOD minimum triggering. The cause of M9.0 near the coast of Honshu Japan 11 March 2011 earthquake is the following: The accelerating Earth left behind on the west by inertia the Eurasian plate. For a better understanding, in accordance with GPS measurements, which considers the continental lithosphere as fixed with GPS satellite system, let us imagine that the rolling mantle beneath the continental lithosphere shifted the oceanic lithosphere of the Pacific plate eastward, separated it from the Japan Trench and shifted the Japan continent in Honshu 8 feet (≈ 2.44 m) eastward (NASA, 2011) (Fig. 5b) and caused the subsidence of oceanic lithosphere (in cooperation with the slab-pull), which resulted in the huge tsunami. Supposing the continental lithosphere of the South American and Eurasian plates fixed in GPS satellite system, then the mantle beneath rotates during the Earth's rotation increment eastward. Rotating mantle drags the Nazca plate down the Chile Trench forming the M6.8 Biobio Chile 11 February 2011 earthquake and exactly 27.32 days later (Moon's rotation period) the earthquake of M9.0 near the coast of Honshu Japan 11 March 2011 (Fig. 5a).

5 Statistics and histograms evaluating acquired results

It is possible to perform the Schuster's test (Schuster, 1897; Tanaka et al., 2002; Wilcock, 2009) for the histogram. The vector sum D of phasors is defined

$$D^2 = \left(\sum_{i=1}^{N} \cos\phi_i\right)^2 + \left(\sum_{i=1}^{N} \sin\phi_i\right)^2 \quad (8)$$

where φ is the phase angle of the i-th earthquake and N is the total number of earthquakes included in the data set. When φi (i = 1...N) distribute randomly, the probability p that the length of a vectorial sum is equal or larger than D is given by

$$p = \exp\left(-\frac{D^2}{N}\right) \quad (9)$$

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Thus, the p-value represents the significance level to reject the null hypothesis that earthquakes occur randomly irrespective of the phase angle. The p-value ranges between 0 and 1, and the smaller the p-value is, the higher the confidence in rejecting the null hypothesis is. Similarly, as do Tanaka et al. (2002), I tentatively adopt a threshold of $p < 5\,\%$ to judge a significant correlation between the Earth's variations and earthquake occurrence.

In the Schuster's test, the number of histogram intervals should be the number divisible by 4, otherwise the phasor with cosφ does not give the same number of intervals above and below the φ axis. For this reason the number of suitable intervals of 14, which approximately reflects the 13.66 days sidereal period of the Earth's rotation variations, is necessary to reduce for 12 intervals by the linear interpolation. Because this is tedious work, I performed this for syzygy with a 14.77 days period and for the sidereal 13.66 period, investigating in both cases the earthquakes of Sumatra and Andaman Sea 1963–2011 (Table 3). Using 14 days distribution, intervals $\varphi = \pm 90^{\circ}$ are omitted in cosφ phasor, however in phasor with sinφ they are multiplied by ±1, so that the differences for 14 and 12 intervals are mostly insignificant (Table 3). The transfer from the phase angle φ to coordinate x of histogram interval is given in corresponding figure of histogram. The origin of counting days in the sidereal LOD cycle can be performed from inflexion point on the ascending LOD branch or back from inflexion point on the descending branch (e.g. Fig. 7c). This procedure brings certain uncertainties because the LOD curve is not a theoretical curve with a constant number of days; the ascending or descending branches contain 6, 7 and 9 points with the most probable being 7 day points. This results in decrease of count in the LOD maximums or minimums and the increase of count before these points (Fig. 7c). A better way is therefore to contribute to minimum and maximum the fixed number, e.g. 7 and 14, and to count earthquakes back and forward from these points. To perform linear interpolation and to divide every branch for constant 7 points would mean that intervals in maximums and minimums of histogram were extended, which would result in false increment of earthquakes in these intervals. Exact Schuster's tests were performed for 8 histogram intervals covering the

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LOD descending or ascending branch with one day excess. In some cases, 8-interval Schuster's test were performed for LOD maximum or minimum. In the Chile Trench the 28-histogram interval test was performed, characterizing the LOD graph typical for given time of earthquake occurrence. Declustering (Reasenberg, 1985) was not performed because aftershocks of earthquakes over $M > 5.8$ are not numerous. The purpose of this study is not exact determination of the earthquake starts, but to investigate the influence of the Earth's rotation on earthquakes, which just for aftershocks is often important and well observable. Histograms were performed for earthquake coincidence with sidereal amplitudes (LOD maximums and minimums) and for synodial amplitudes (full and new Moon). These histograms were statistically evaluated, calculating the standard deviation from average of earthquake occurrence and calculating the Schuster's test. The areas of investigation chosen were in the Sumatra and Andaman Sea, Southeast Indian Ocean Ridge, Chilean Subduction zone, Mid-Atlantic Ridge, Haiti region, New Zealand region Japan Trench Honshu region and East Pacific Rise. Earthquakes for period 1973–2011 were taken from NEIC USGS catalog and for period 1963–1973 from ANSS catalogue. LOD variations were taken from IERS, which started its measurement in 1962, performing measurements in ms.

6 Results

In 2007, Cochran and Vidale presented 12 interval histogram to determine the correlation of earthquakes with biweekly tides using 1428 earthquakes of global occurrence, and for the shear tidal stress histogram they received $0.584 \pm 0.94\,\%$ more earthquakes than average. This resulted in non-existence of statistically significant correlation of earthquake timing with the biweekly tides. I performed a similar calculation for 266 earthquakes of Sumatra and Andaman Sea using 15 interval histogram covering 14.77 days syzygy period and earthquakes in time span 1963–April 2011. The result gives $1.11 \pm 0.97\,\%$ more earthquakes than average 17.73 earthquakes. This negative result can be confirmed by the Schuster's test (Table 3), which for 14-interval histogram

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gives parameter $p = 19.88\,\%$ and for 12-interval histogram $p = 14.88\,\%$ (Fig. 7a). Great surprise: the histograms for correlation of earthquakes with 13.66 days Earth's rotation variations show (Fig. 7b) that the calculations for the 14 days histogram and for the more accurate 12 days histogram give the parameter $p = 50.75\,\%$ and $p = 50.42\,\%$, respectively – far more negative results than for biweekly tides. The solution is simple. The Earth's rotation variations expressed on LOD graph trigger earthquakes in both Earth's rotation acceleration and deceleration, and in the Sumatra Andaman Sea region in almost the same amount in both LOD graph extremes (Fig. 7b) and branches (Table 3). Performing the more accurate 8-interval histogram for LOD branches with one day excess, the result gives very low values of parameter $p = 0.000059\,\%$ and similar values for extremes of LOD graph in LOD maximum and minimum (Fig. 7b1–4). Figures from 7b1–4 to 7n1–2 are in the Supplement. Figure 4l from the South Indian Ocean Ridge shows the difference in number of earthquakes in descending and ascending branches of LOD graph. The verification by histogram confirms the excess of earthquakes in the Earth's rotation acceleration (Fig. 7d, d1 and d2). Parameter $p = 5.89\,\%$ shows relatively probable correlation of earthquakes with Earth's rotation acceleration, whereas in the Earth's rotation deceleration, the parameter $p = 87.9\,\%$ shows quite irregular and improbable coincidence. The histogram for Chilean subduction zone (Fig. 7e) shows surprisingly good correlation: $p = 1.30\,\%$ for the whole 28-interval histogram. This confirms that together the LOD second minimum and 2–3 days before the first LOD maximum are the most probable earthquakes occurrences. Separating the 28 days histogram into four 8 days histograms shows that the first LOD maximum $p = 1.39\,\%$ is the most probable LOD area of earthquake triggering (Table 3, Fig. 7e and e1–4).

Maximum attention was paid to earthquakes of the Mid-Atlantic Ridge, to confirm assumption that the Haiti earthquake was triggered by quicker movement of the Northern Hemisphere at the moment of the Earth's maximum rotation (Fig. 4c). Next question was whether earthquakes in descending and ascending branches of LOD from Mid-Atlantic Ridge on 8 January 2010, 4 January 2010, 27 December 2009 (Fig. 4b–d) are

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real precursors of the Haiti earthquake. Figure 7f shows that earthquakes from the Mid-Atlantic Ridge are triggered both in LOD maximums and minimums, giving very high value of parameter $p = 52.84\,\%$. Detailed Schuster's tests for 8-interval histograms for branches and extremes confirm the clear correlation of earthquakes with LOD record (Table 3, Fig. 7f1–4).

Section 10–5° N in Northern Mid Atlantic Ridge shows for time span 2 May 1991–15 February 2001 regular changes of earthquakes triggering in the middle of descending and ascending LOD branches (Fig. 8). Later, no significant coincidence with LOD record occurred. Since 4 January 2010, an absolute absence of earthquakes occurred till 22 October 2010, probably owing to the Haiti earthquake of 12 January 2010. After 27 October 2010, an exclusive coincidence of earthquakes with LOD minimums occurred. Histograms (Fig. 7g, g1 and g2) confirm this. In Fig. 7g during period 1999–July 2006, yellow bars show regular changing of earthquakes on both branches, later with increased number of earthquakes in LOD maximum. Summarizing all earthquakes from period 1973–2011, typical LOD minimum occurs, so the result is (Fig. 7g blue bars) three earthquake maximums and absolute no correlation $p = 88.70\,\%$.

Next section of northern part of the Mid-Atlantic Ridge was chosen 23.5–15° N and in narrow section 44–48° W where the Mid Atlantic Ridge is parallel with longitude (Fig. 7h and h1–4) to avoid maximally the effect of transform faults intersecting perpendicularly with the Mid-Atlantic Ridge. Earthquakes on ascending LOD branch are more numerous (Table 3) and do not correlate with LOD maximum (Fig. 7h2). There are earthquakes in the Mid-Atlantic Ridge preceding earthquakes in transform faults, including the Haiti earthquake of 12 January 2010 see Fig. 4c.

Another narrow section of the Mid-Atlantic Ridge covers section 2–2.5° N, almost parallel with latitude in the middle close to equator 0°. Histogram (Fig. 7i) shows a large number of earthquakes outside LOD maximum or minimum but the number of earthquakes in descending branch is larger than it is with sections in the Northern Mid-Atlantic Ridge where the ratio desc./asce. LOD branch was reciprocal.

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The section of the southern part of the Mid-Atlantic Ridge (Fig. 7j and j1–2) shows an even larger number of earthquakes in descending LOD branch. Logically, in the mid-ocean ridge the branch containing more earthquakes shows that the plate forward (in the Mid-Atlantic Ridge the plate on the west from the ridge) moves quicker than the plate behind. There is no doubt that the South American plate with the oceanic part behind moves quickly to the west considering the large amount of oceanic lithosphere created between South America and Africa. How to explain the previous claim that the Northern Hemisphere moves quicker towards the west than the Southern Hemisphere? It contradicts the number of earthquakes in the Northern Mid-Atlantic Ridge, which are less numerous on the descending branch than on the ascending one. The reason is not only that the North American plate moves westward, but also the whole Eurasian plate, which as one of the largest continental plates, reacts more effectively on LOD variations and triggers more earthquakes on LOD ascending branch.

The Haiti region (Fig. 7k, k1 and k2) shows the same amount of earthquakes on both LOD branches. However, the earthquake occurrence in the descending branch including the LOD minimum is the most probable $p = 0.13\,\%$.

Both earthquakes M7.1 Christchurch 3 September 2010 and M6.3 Christchurch 21 February 2011 in New Zealand (Fig. 4i) were created as shallow earthquakes (5–10 km) in eastern continuation of the Southeast Indian Ocean Ridge. The histograms for Southeast Indian Ocean Ridge (Fig. 7d, d1 and d2) and the southern part of N. Zealand (Fig. 7l, l1 and l2) are therefore very similar. Both regions, by the excess of earthquakes in descendant LOD branch, manifest the northward movement of the Indian plate during the Earth's rotation increment. The occurrence of earthquake 3 September 2010 in LOD minimum is very probable $p = 2.11\,\%$; nevertheless, histogram Fig. 7l also shows large number of earthquakes in LOD maximum peak.

Histogram for the Japan Trench in Honshu region (Fig. 7m, m1 and m2) and the Schuster's test show very low probabilities of earthquakes occurrences in LOD extremes. Nevertheless, the LOD minimum shows an increase number of earthquakes.

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The large parameter $p = 23.36\,\%$ is incorrect (Fig. 7m1), owing to evidently non-random distribution.

Histograms for the northern part of the Mid-Atlantic Ridge show larger number of earthquakes in LOD ascending branch (Fig. 7f, f1 and f2). Then it is possible that also in the eastern side of the Eurasian plate the ascending LOD branch will have more earthquakes. This is the case of the Japan Trench and the earthquake of 11 March 2011 near the east coast of Honshu M9.0 (Fig. 5a). In the histograms (Fig. 7m, m1 and m2), the counting of earthquakes was stopped on 11 March 2011 to avoid aftershocks. The subduction zone of very old oceanic lithosphere of the Pacific plate is less sensitive or delayed on LOD variations and the Eurasian plate during its westward movement looses the continental lithosphere of Japan behind, which can also hide reaction on Earth's rotation variations.

Histogram for the East Pacific Rise shows that one side of the Rise moves quicker. Comparing the ratio for the southern part of the Mid-Atlantic Ridge $177/140 > 197/173$ (Table 3) to the ratio for the East Pacific Rise, it is possible to conclude that the South American continent overrides the Nazca plate including the East Pacific Rise in future.

7 Conclusions

Triggering of earthquakes by the Earth's rotation variations is proven by histograms showing an increment number of earthquakes during Earth's rotation maximums and minimums. Earthquakes are therefore triggered by both the Earth's rotation deceleration and acceleration. Asymmetric distribution of earthquakes occurrence in histograms of LOD graph branches from mid-ocean ridges also give information about unilateral movement of plates in agreement with author's (Ostřihanský, 1997) conception of lithospheric plates movements and movement of mid-ocean ridges with the average speed of adjacent plates. The increased number of earthquakes of LOD branch record during the Earth's acceleration in the Southeast Indian Ocean Ridge shows that the Indian plate moves northward, driven an attraction of Moon and Sun rectifying the Earth's

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flattening to ecliptic and Moon's orbit. The Mid-Atlantic Ridge and the East Pacific Rise show the quicker westward movement of westerly sided plate by inertia of plates during the Earth's rotation acceleration and deceleration causing the westward drift. However, the possibility of the plate movement is given by the gravity subsidence (slab pull) of all oceanic lithosphere older than 180 mil. years, i.e. by its subduction releasing place among plates. On the western side, the oceanic lithosphere of the Pacific plate drops down due to gravity, its old age and thickness on eastern side of Eurasian and Indian plates. From eastern side, the oceanic lithosphere of the Pacific plate is overridden by the American continent. Because earthquakes are triggered during the Earth's rotation acceleration or deceleration and earthquakes occur during distinctive lithospheric movements confirmed by shifts along faults, slips determined by seismology and most perfectly by GPS measurement (Figs. 5b and 6), any objections of Jordan (1974) and Ranalli (2000) about impossibility of the plate movement owing the high mantle viscosity are out of discussion.

Remarkable repetition of Sumatran earthquakes 19 yr ago exactly on one day in the full Moon on LOD minimum and close to solstice, in connection with Meton's cycle, only underline the effect of the Earth's rotation. Precursor of the Sumatra earthquake 2004 in the Macquarie Is. three days before can be completed by precursors of earthquake in Northern Mid-Atlantic Ridge 8 January 2010 before the Haiti earthquake 12 January 2010 (Fig. 4d) and by several LOD maximums and minimums before the Chilean earthquake of 27 February 2010 (Fig. 4f). The earthquakes in Alaska were triggered by westward drift evoked by 53.4 repetitions per year of Earth's rotation variations by changing Moon's declination. In this case the repetitions in the 19 yr Metonic cycle are not exact, they are for several months delayed, triggered in moment of optimum variations amplitudes for earthquake occurrence. Similar situation is indicated in California. This area will be subjected to the detailed investigation in future.

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Supplementary material related to this article is available online at: http://www.solid-earth-discuss.net/4/1411/2012/sed-4-1411-2012-supplement.zip.

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Table 1. Astronomical parameters of Sumatra 27 December 1985 and 26 December 2004 earthquakes.

	Sumatra 1985	Sumatra 2004
Date of earthquake	27 December 1985	26 December 2004
Earthquake magnitude	6.6	9.1
Date of LOD minimum	28 December1985	26 December 2004
Moon's declination	$27°32'$	$27°41'$
Sun's declination	$23°20'$	$23°21'$
Date of full Moon	27 December 1985	26 December 2004
Length of ascending node	35.8235°	28.3244°
Date of Moon's apogee	23 December 1985	27 December 2004
Date of 0° ascending. node	9 November 1987	20 June 2006
Maximum Moon's declination	$28°42'$	$28°43'$
Date of maximum Moon's declination	13 October 1987	15 September 2006

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Table 2. List of 17 earthquakes magnitudes over M5.8 that occurred in the solstices time, taken from 49 earthquakes triggered in LOD minimums in chosen rectangle 14° N–7° S, 106–90° E covering the Sumatra and Andaman Sea from 1963 to 2011, totaling 264 earthquakes.

Date of earthquake	Syzygy	Magnitude	Date of syzygy	Date of LOD minimum
21.12.2010	☺	5.9	21.12.2010	21.12.2010
12.6.2010	●	7.5	12.6.2010	12.6.2010
22.12.2007	☺	6.1	23.12.2007	24.12.2007
22.12.2006	●	6.2	20.12.2006	21.12.2006
27.6.2006	●	6.3	26.12.2006	25.12.2006
5.7.2005	●	6.7	6.7.2005	5.7.2005
26.12.2004	☺	**9.1**	**26.12.2004**	**26.12.2004**
15.1.2002	●	6.1	13.1.2002	14.1.2002
17.7.1997	☺	5.9	20.7.1997	17.7.1997
20.1.1993	●	6.2	22.1.1993	20.1.1993
22.12.1991	☺	5.8	21.12.1991	21.12.1991
29.12.1990	☺	6.0	31.12.1990	31.12.1990
27.12.1985	☺	**6.6**	**27.12.1985**	**27.12.1985**
11.1.1979	☺	6.2	13.1.1979	13.1.1979
17.12.1975	☺	6.2	18.12.1975	18.12.1975
2.7.1970	●	5.8	3.7.1970	2.7.1970
16.12.1963	●	6.0	16.12.1963	17.12.1963

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Table 3. Results of Schuster's test and ratio of earthquakes on descending and ascending branches of LOD record in investigated areas: Sumatra and Andaman Sea, Southeast Indian Ocean Ridge, Chilean subduction zone, Mid-Atlantic Ridge Haiti region, New Zealand region, Japan Trench and East Pacific Rise.

Locality	Area	Date range	Type of correlation	Number of histogr. intervals	Schuster's test	Number of earth-quakes	Minimum earthquake magnitude	Earthquakes desc./asc. LOD branch	Figure
Sumatra and Andaman Sea	14° N–7° S 106–90° E	1963–IV.2011	Syzygy	14	19.88 %	254	5.8		7a
			Syzygy	12	14.87 %	244	5.8		7a
			LOD 13.66 days record	12	50.42 %	219.7	5.8		7b
			LOD 13.66 days record	14	50.75 %	264	5.8	131/133	7b
			LOD desc. branch	8	0.000059%	151	5.8		7b1
			LOD asce. branch	8	0.0016 %	146	5,8		7b2
			Negative LOD peak	8	0.000073 %	151	5.8		7b3
			Positive LOD peak	8	0.010 %	138	5.8		7b4
			Inflexion 13.66 days	14	47.86 %	283	5.8		7c
			Inflexion desc. bra.	8	4.11 %	164	5.8		7c
			Inflexion asc. bran.	8	1.89 %	148	5,8		7c
Southeast Indian Ocean Ridge	45–60° S 165–90° E	2008–VII2011	LOD 13.66 days recors	14	9.54 %	167	3.0	92/75	7d
			LOD desc. branch	8	5.89 %	101	3.0		7d1
			LOD asce. branch	8	87.90 %	80	3.0		7d2

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Table 3. Continued.

Locality	Area	Date range	Type of correlation	Number of histogr. intervals	Schuster's test	Number of earth-quakes	Minimum earthquake magnitude	Earthquakes desc./asc. LOD branch	Figure
Chilean subduction zone	5° N–50° S 60–80° W	1973–IV.2011	LOD 27.32 days record Inflex. point	28	1.30 %	349	6.0	186/203 (93/123)*	7e
			LOD first maximum	8	1.39 %	214	6.0		7e1
			LOD first minimum	8	10.66 %	88	6.0		7e2
			LOD sec. maximum	8	18.35 %	80	6.0		7e3
			LOD sec. minimum	8	50.66 %	111	6.0		7e4
Mid-Atlantic Ridge	28–5° N 35–55° W	2000–VII2011	LOD 13.66 days record	14	52.84 %	348	3.0	162/186	7f
	Northern part		LOD desc. branch	8	0.012 %	186	3.0		7f1
			LOD asce. branch	8	0.042 %	201	3.0		7f2
			Negative. LOD peak	8	0.052 %	186	3.0		7f3
			Positive LOD peak	8	0.00022 %	185	3.0		7f4
	10–5° N 35–55° W	1973–VI.2011	LOD 13.66 days record	14	88.70 %	219	3.0	111/108	7g
			LOD desc. branch	8	78.76 %	110	3.0		7g1
			LOD asce. branch	8	1.44 %	120	3.0		7g2
		1999–VII2006	LOD13.66 days ecord	14	0.81 %	57	3.0	22/35	7g

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Table 3. Continued.

Locality	Area	Date range	Type of correlation	Number of histogr. intervals	Schuster's test	Number of earth-quakes	Minimum earthquake magnitude	Earthquakes desc./asc. LOD branch	Figure
Mid-Atlantc Ridge Parallel with meridian	23.5–15° N 44–48° W	1976–V.2011	LOD 13.66 days record	14	4.88 %	110	3.0	107/119	7h
			LOD desc. branch	8	0.0039 %	129	3.0		7h1
			LOD asce. branch	8	25.43 %	126	3.0		7h2
			Negative LOD peak	8	0.013 %	139	3.0		7h3
			Positive LOD peak	8	0.36 %	107	3.0		7h4
Mid-Atlantic Ridge 0° Parallel with equator	2–2.5° N 10–35° W Central part	2000–II.2011	LOD 13.66 days record	14	0.34 %	266	3.0	143/123	7i
			LOD desc. branch	8	1.00 %	162	3.0		7i1
			LOD asce. branch	8	35.76 %	133	3.0		7i2
Mid-Atlantic Ridge	10–45° S 10–20° W Southern part	2000–VII2011	LOD 13.66 days record	14	0.024 %	317	3.0	177/140	7j
			LOD 13.66 days record	12	0.18 %	272.9	3.0		
			LOD desc. branch	8	0.00008 %	203	3.0		7j1
			LOD asce. branch	8	0.062 %	154	3.0		7j2
Haiti region	20–16° N 65–85° W	1976–I.2010	LOD 13.66 days record	14	4.95 %	324	4.5	162/162	7k
			LOD desc. branch	8	0.13 %	182	4.5		7k1
			LOD asce. branch	8	84.16 %	176	4.5		7k2
			Negative LOD peak	8	26.00 %	210	4,5		7k3
			Positive LOD peak	8	22.45 %	164	4,5		7k4

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Table 3. Continued.

Locality	Area	Date range	Type of correlation	Number of histogr. intervals	Schuster's test	Number of earth-quakes	Minimum earthquake magnitude	Earthquakes desc./asc. LOD branch	Figure
New Zealand region	41–52° S 160° E-175° S	1973–III.2011	LOD 13.66 days record	14	4.85 %	175	5.0	98/77	7l
			LOD desc. branch	8	2.11 %	109	5.0		7l1
			LOD asce. branch	8	22.03 %	88	5.0		7l2
		2000 VII2011	LOD 13.66 days record	14	58.23 %	85	5.0		7l
Japan Trench Honshu region	36–42° N 138–145° E	1963–III.2011	LOD 13.66 days record	14	18.47 %	173	5.8	83/90	7m
			LOD desc. branch	8	23.36 %	91	5.8		7m1
			LOD asce. branch	8	26.17 %	99	5.8		7m2
East Pacific Rise	0–30° S	2000–VI2011	LOD 13.66 days record	14	50.11 %	370	3.0	197/173	7n
			LOD desc. branch	8	2.14 %	218	3.0		7n1
			LOD asce. branch	8	11.94 %	195	3.0		7n2

* ↘ first minimum/ ↗ first maximum

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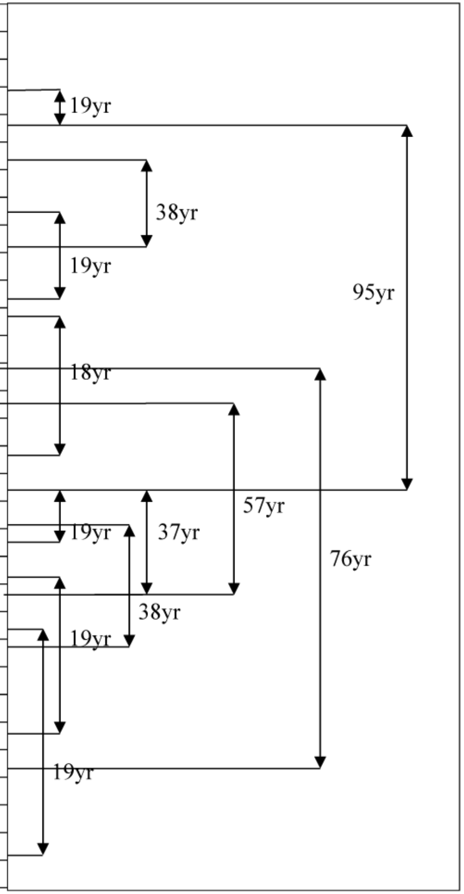
Table 4. 19 yr repetition of major Californian earthquakes and their multiples.

Location	Mag.	Dy	Mth	Year
Wrightwood	7.0	08	12	1812
Santa Barbara Channel	7.0	12	12	1812
San Francisco Peninsula	7.0	00	06	1838
Great Tejon earthquake	8.25	09	01	1857
Hayward Fault	7.0	21	10	1868
Owens Valley	7.6	26	03	1872
West of Eureka	7.0	16	04	1899
Great San Francisco quake	8.25	18	04	1906
Pleasant Valley, NV	7.3	03	10	1915
San Jacinto	6.9	21	04	1918
West of Eureka	7.3	31	01	1922
Cape Mendocino	7.2	22	01	1923
South West of Lompoc	7.3	04	11	1927
Cedar Mountain, Nevada	7.2	21	12	1932
Colorado River	7.0	31	12	1934
Imperial Valley	7.1	19	05	1940
Kern County	7.7	26	07	1952
Fairview Peak, NV	7.1	16	12	1954
San Fernando	6.6	09	02	1971
West of Eureka	7.2	08	11	1980
Loma Prieta	7.1	18	10	1989
West of Crescent City	7.1	17	08	1991
Cape Mendocino	7.2	15	04	1992
Landers	7.3	28	06	1992
Mendocino Fracture Zone	6.9	01	09	1994
Hector Mine	7.2	16	10	1999
San Simeon	6.5	22	12	2003
Offshore Northern CA	7.2	15	06	2005
Baja California	6.9	03	08	2009
Necicali, Baja California	7.2	04	04	2010
Baja California	6.9	22	10	2010



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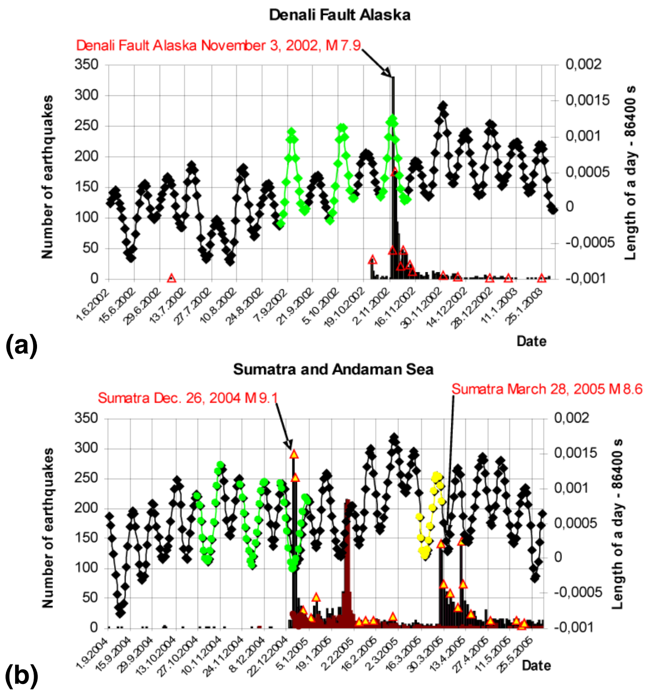

Fig. 1. (a) The coincidence of LOD record and the 3 November 2002 Denali Fault Alaska earthquake (M = 7.9) evoked by the resonance effect of 27.6 days repeating LOD amplitudes (marked in green color). Earthquakes of magnitude M > 4.8 are marked by triangle. **(b)** The coincidence of LOD record and the 26 December 2004 Sumatra earthquake (M = 9.1) evoked by the negative repeating amplitudes of LOD record (marked in green color). The earthquake of 28 March 2005 Sumatra (M = 8.6) had been created by the extreme (1.5 ms) previously long lasting Earth's velocity increment (marked in yellow color), but owing to vicinity of vernal point it was triggered 2 days after the LOD maximum. Earthquakes of magnitude M > 5.8 are marked by triangle. Earthquakes from Andaman Sea are marked in violet.

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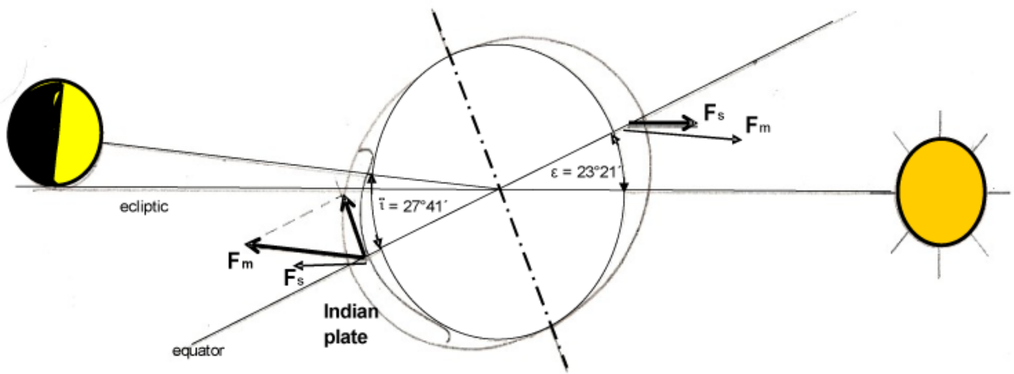

Fig. 2.1. Positron of Moon, Earth and Sun during the earthquakes M6.6, of 27 December 1985 and the Great Sumatra Earthquake of M9.1, 26 December 2004. Values of obliquity $\varepsilon = 23^{\circ}21'$ and the Moon's tilt to equator $í = 27^{\circ}41'$ concern of 2004 earthquake but they differ from 1985 earthquake negligibly, see Table 1. Evidently the largest northward torque on the Indian plate was at midnight. The triggering times of the latter is 00:58:53 UTC and the former 05:38:53 UTC, they differ for 5 h. The time shift for Sumatra is 7 h. F_m and F_s are tidal forces of Moon and Sun respectively.

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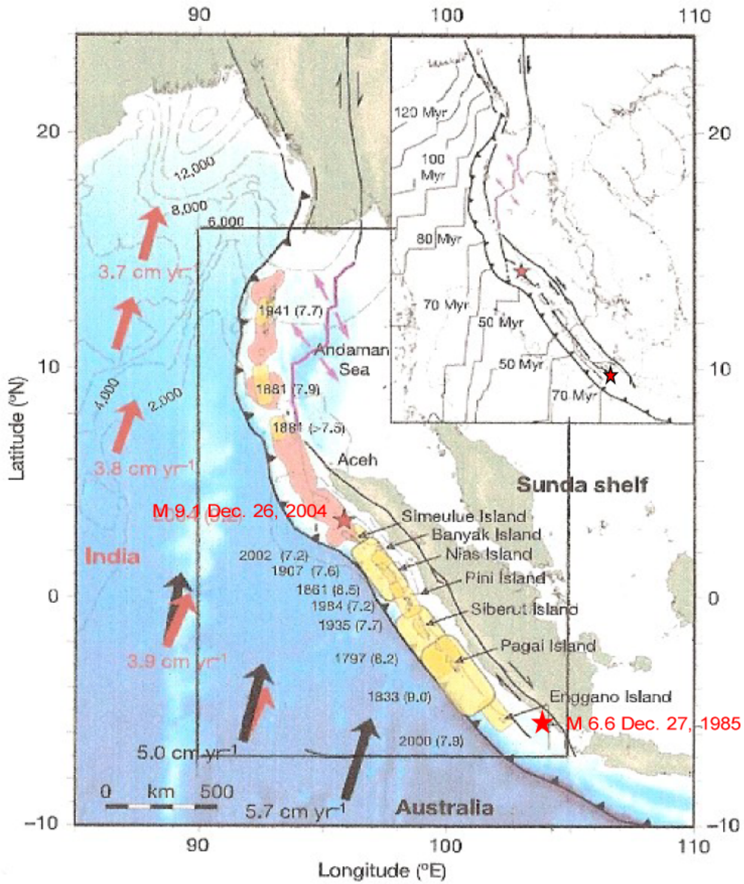

Fig. 2.2. Positions of 1985 and 2004 earthquakes. Northward movement of the Indian plate confirmed by GPS from Subarya et al. (2006). Black arrows are related to Australia, the red one to India.

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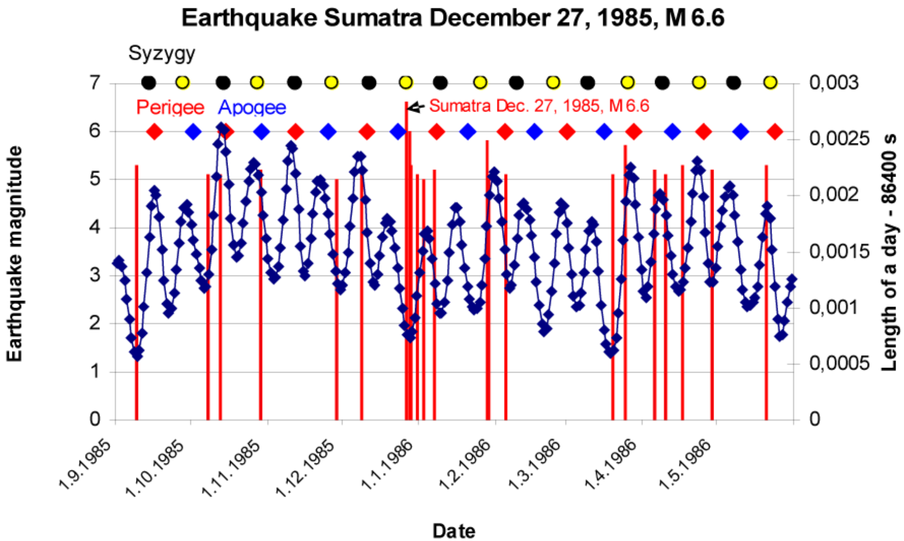

Fig. 2.3. Earthquake Sumatra 27 December 1985, M6.6. Coincidence of the full Moon, LOD minimum and small difference between apogee (23 December 1985) and winter solstice is evident.

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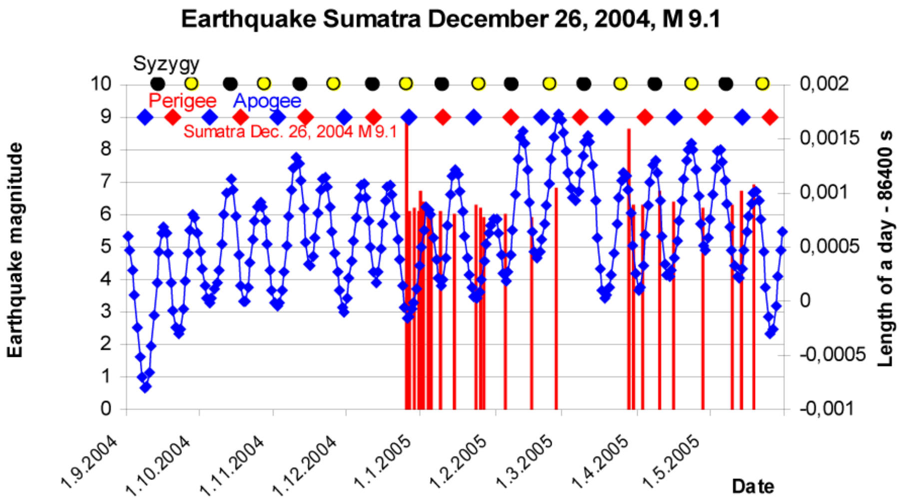

Fig. 2.4. Earthquake Sumatra 26 December 2004, M9.1 as repetition of the Sumatra 1985 earthquake after 19 yr of Metonic cycle. Concidence of full Moon, LOD minimum and apogee is evident. 5 days difference of winter solstice.

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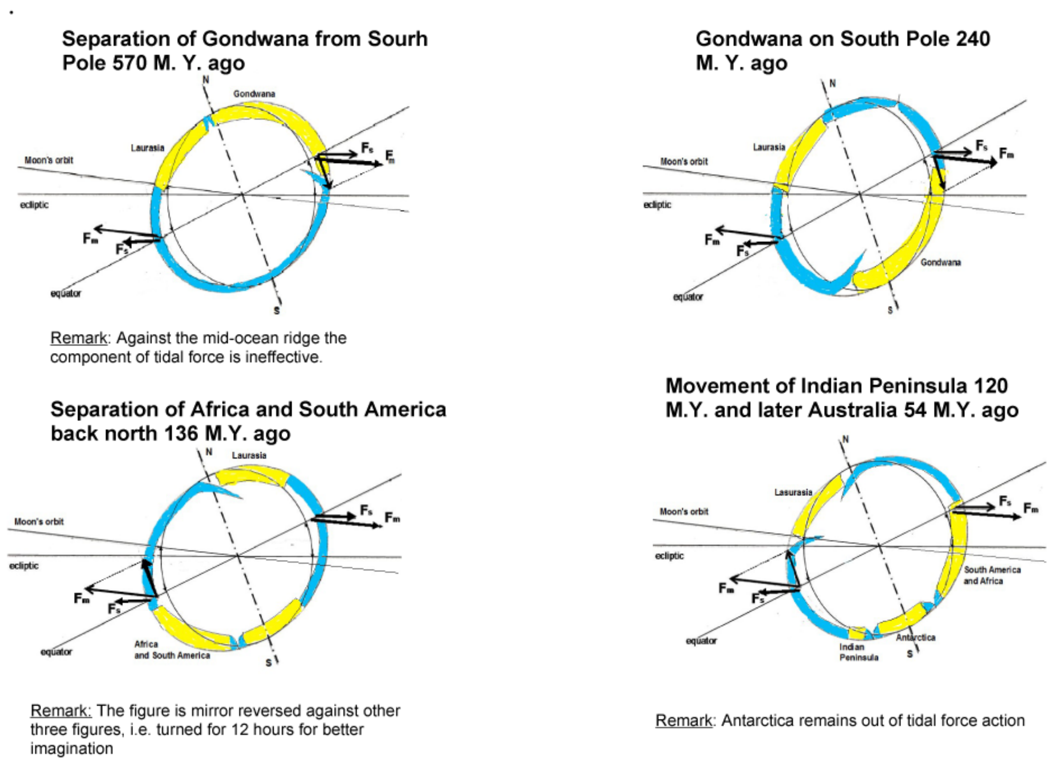

Fig. 2.5a. The movement of lithospheric plates in N–S direction since the decay of Pangaea 570 M.Y. ago. F_m and F_s are tidal forces from Moon and Sun respectively acting on Earth's flattening. Continents are yellow and oceanic lithosphere blue.

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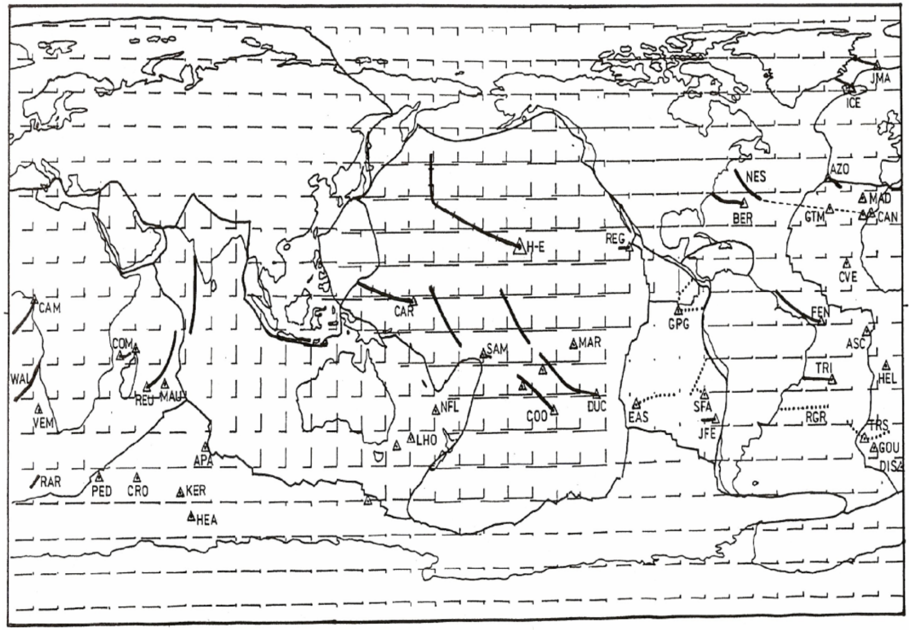

Fig. 2.5b. Components of northward and westward movements of plates. The most reliable hotspot tracks (Ostřihanský, 1997).

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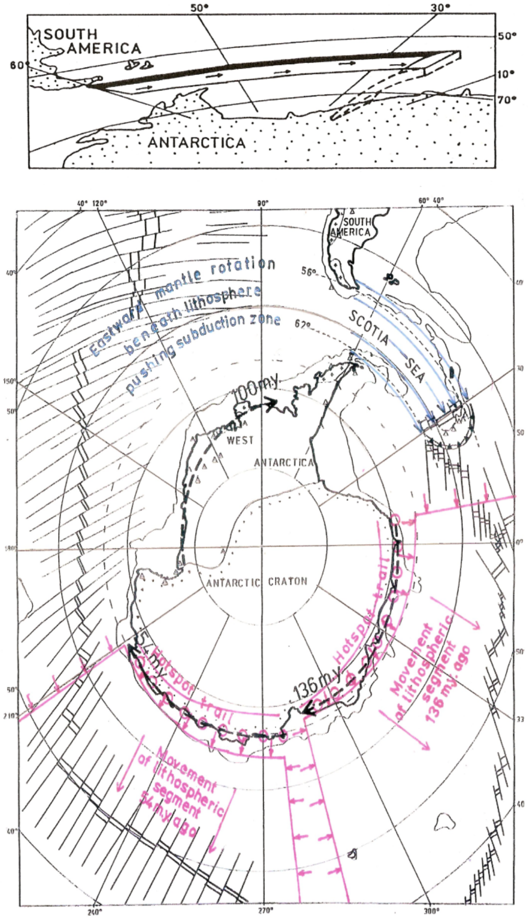

Fig. 2.5c. Westward rotation of lithosphere confirmed by the cut-out in Scotia Sea basin (Ostřihanský, 1997).

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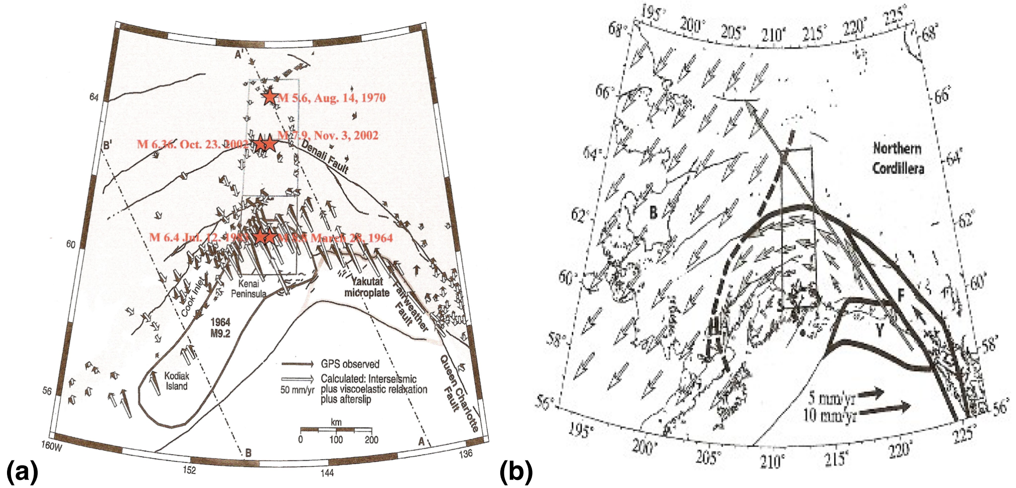

Fig. 2.6. (a) Position of two strongest earthquakes in Alaska and smaller earthquakes repeating in 19 yr of Metonic cycle. Rectangle marks chosen area of investigation perpendicular to the westward movement. Blue contoured rectangle marks area close to the Denali Fault. Earthquakes from this area correspond to blue bars in Fig. 2.7. Directions of movement from Freymueller et al. (2008). **(b)** Block model with block velocities relative to North America. Block boundaries are shown with thick lines, and other active faults with thin lines. Block boundaries are dashed where they are indistinct or uncertain. B, Bering; S, Southern Alaska or SOAK; Y, Yakutat; F, Fairweather. From Freymueller et al. (2008). Rectangle marks investigated area.

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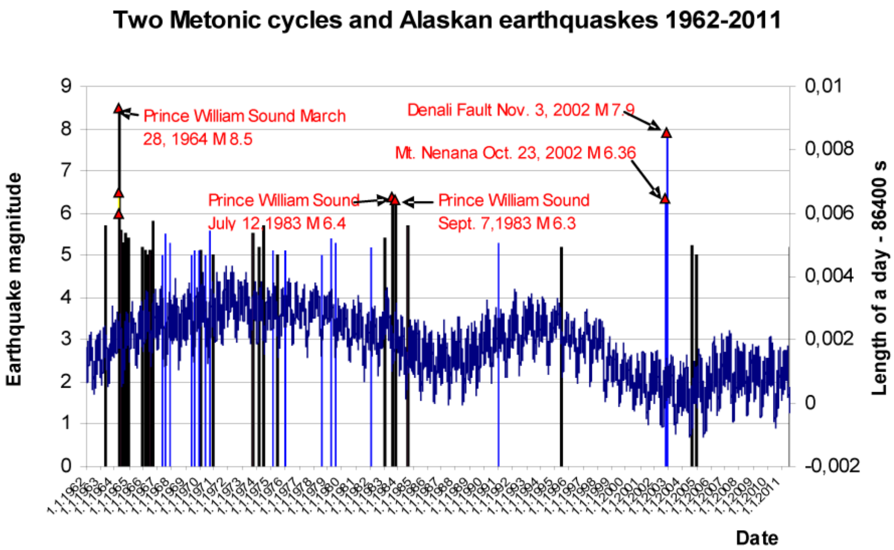

Fig. 2.7. The figure shows two 19 yr Metonic cycles in Alaska 1964–1983 and 1983–2002. Cycles are bordered by earthquakes M8.5 Prince William Sound 28 March 1964, M6.4 Prince William Sound 12 July 1983 and M7.9 Denali Fault 3 November 2002. Blue bars mark earthquakes from area of the Denali fault from blue contoured rectangle of Fig. 2.6a. The first Metonic cycle is characteristic by area of increased LOD and large number of earthquakes resembling aftershocks of M8.5 earthquake but they can be explained as originated in any Earth's velocity increment from the slow movement. The investigated area covers rectangle 60–65° N, 146–149° W with Anchorage and Fairbanks. Triangles mark earthquakes > M6.

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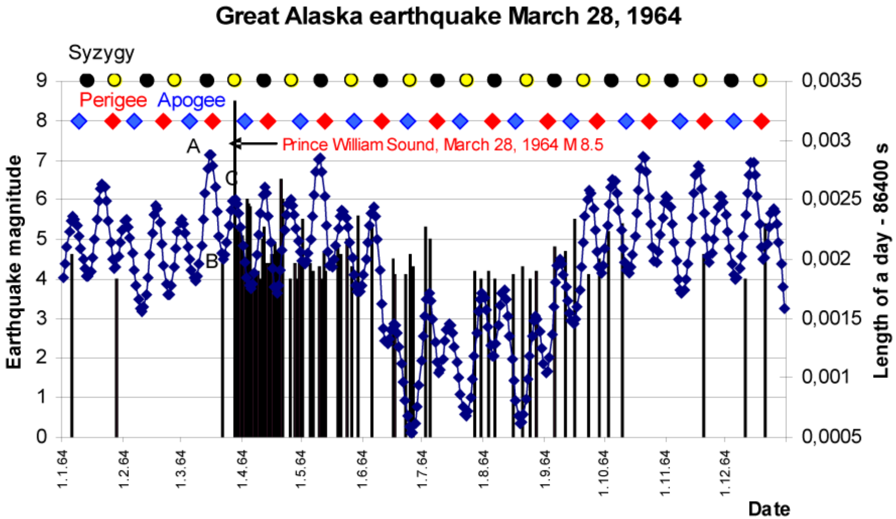

Fig. 2.8. The first earthquake of the Metonic cycle the Great Alaska earthquake M8.5 in Prince William Sound was triggered on 28 March 1964. The reason for this earthquake triggering is following: From very slow Earth's rotation in point (A), the Earth's rotation abruptly increased for 1.5 ms to point (B) triggering small earthquake of 5th magnitude, but the Great Alaska earthquake was triggered only when the Earth's rotation decreased in the next LOD maximum in point (C) and also in the full Moon, which probably helped to deceleration, but this will not have the decisive effect as we shall see in the next earthquakes.

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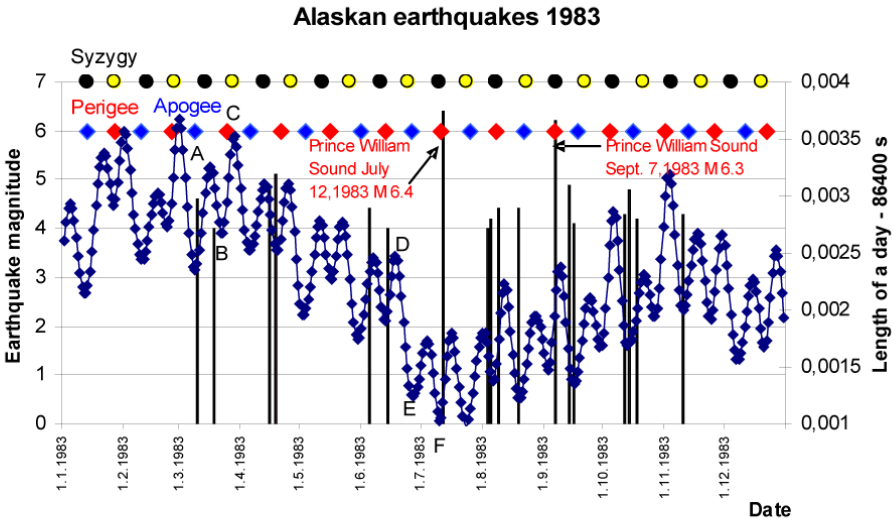

Fig. 2.9. The figure explains causes of the earthquake M6.4 of 12 July 1983 starting the second Metonic cycle. The fixed Metonic period shows that the full Moon is exactly on LOD maximum 28 March 1983 (point C) as it had been with previous earthquake on 28 March 1964. But this LOD maximum is higher then the previous LOD maximum (point A) owing to the different Moon's perigee position, which now is close to the second LOD maximum in point (C). Because between points (A) and (B) the take-off run for the earthquake was very short, none earthquake was triggered in point (C). Convenient for triggering is the previous couple of LOD maximums 1 March 1983 and 17 March 1983 where really there are two small earthquakes M4.3 in LOD minimum and M4.0 in LOD maximum. However the largest take-off run is between points (D) and (E) what caused that not at the next LOD maximum but after that in LOD minimum (point F) the earthquake 12 July 1983 M6.4 was triggered. The whole area had been disturbed and series of earthquakes on LOD minimums were created.

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Causes of earthquakes and lithospheric plates movement

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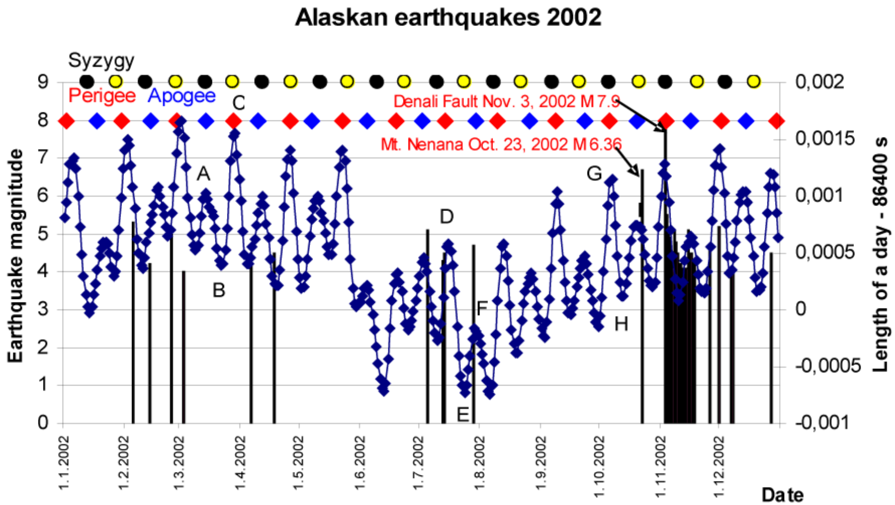

Fig. 2.10. In the third earthquake of the Metonic cycle on March 28, 2002 the situation is repeated. Between points (A) and (B) the take-off run is very short for the earthquake triggering and therefore in point (C) (28 March 2002) none earthquake was created. Best condition for the take-off run is between points (D) and (E) and really in point (F) small earthquake M4.7 is triggered. Such situation is three times repeated and owing to the take-off run between points (G) and (H) the strong Mt. Nenana earthquake in point I was triggered. The whole area was strongly disturbed what resulted in the great Denali Fault earthquake 3 November 2002 by resonance of previous 4 repetitions of LOD maximum peak (see also Fig. 1a).

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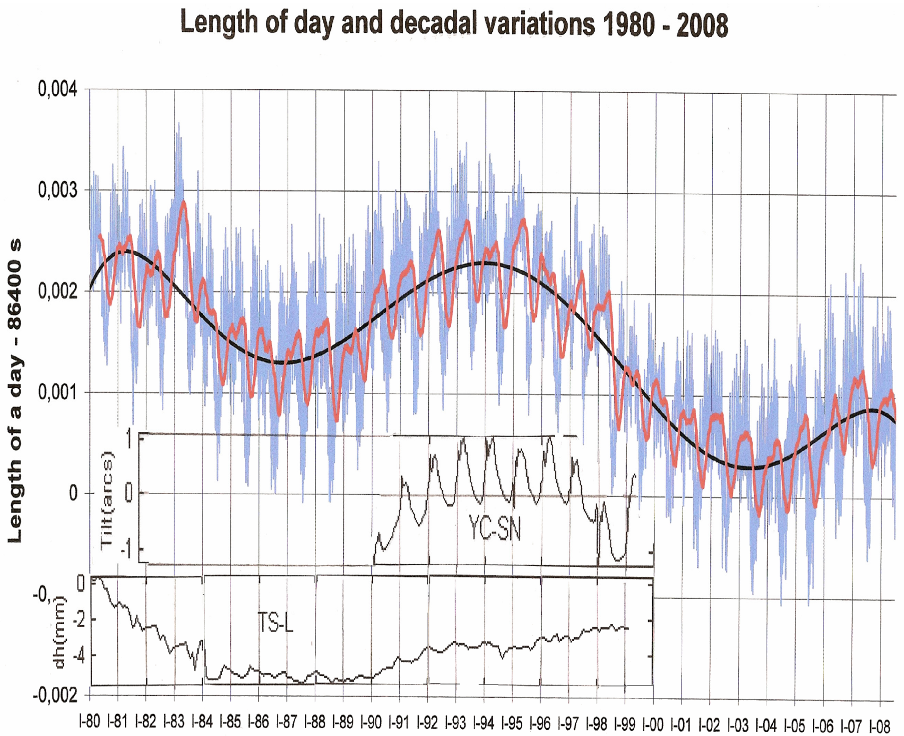

Fig. 2.11. Length of a day and an approximate construction of decadal (black curve) and annual (red curve) variations. The decadal variation has been constructed by fitting the polynomial of 6th degree to the LOD record. The annual variation has been constructed from LOD record by the moving average method. The record of tilt from southern China (Wang et al., 2000) from station YC-SN shows striking similarity with the decadal modulation of annual LOD record in minimums and also in the steep gradient in 1998. The fault deformation from station TS-L shows similarity with the decadal variation trend.

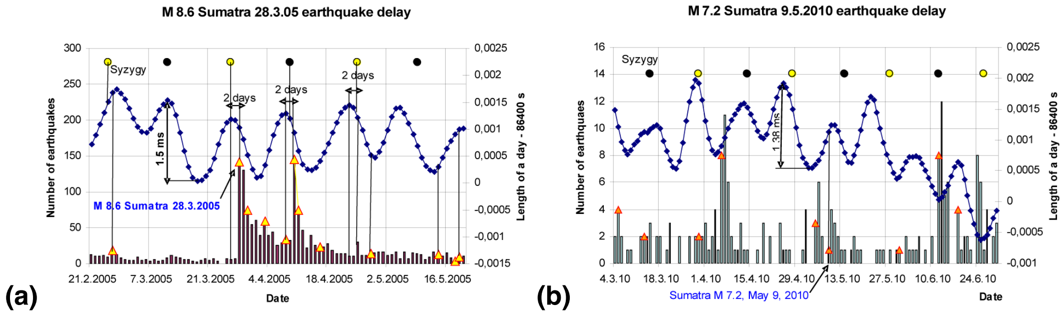

Fig. 3. (a) The 1.5 ms extreme velocity increment and following deceleration owing to vicinity of vernal point the 28 March 2005 earthquake was triggered on LOD maximum however with 2 days delay. Aftershocks repeated this 2 days delay twice with 13.66 (1 / 2 of Moon's sidereal period) LOD variations. Earthquakes M > 5.8 are marked by triangle. **(b)** Shows the similar case of the earthquake delay as Fig. 3.3a of M8.6 Sumatra 28 March 2005 earthquake. The full Moon of 30 March 2010 close to equinox is in LOD maximum and the full Moon of 26 June 2010 close to summer solstice is in LOD minimum. Except of the earthquake delay for 7 days M7.2 9 May 2010 owing to previous exceptional acceleration 1.38 ms / 7 days, earthquakes and aftershocks cover minimums and maximums of LOD graph. The figure represents in fact the 1-day interval histogram. Earthquakes over 5.8 M are marked by triangle. The figure represents the typical earthquake distribution in comparison with LOD graph and syszygy. Earthquakes fill a post in minimums and maximums of LOD graph or can be delayed. The Full Moon coincides with LOD maximum in spring equinox and with LOD minimum in summer solstice. Full or new Moon have no influence on earthquake triggering.

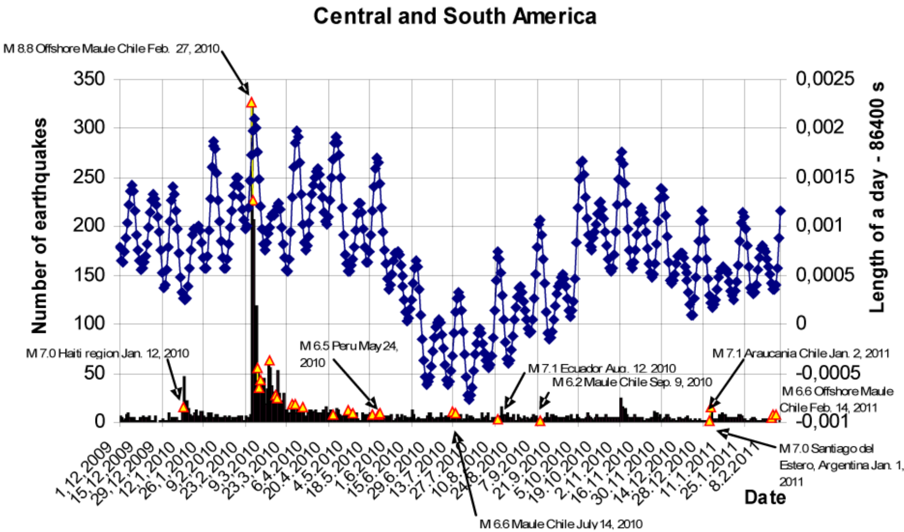

Fig. 4a. The LOD record showing the Earth's rotation acceleration during the Haiti 7.0 magnitude earthquake of 12 January 2010. and the Earth's rotation deceleration during the Maule Chile 8.8 magnitude earthquake of February 27, 2010. Other Earth's decelerations triggered earthquakes M7.1 Ecuador, 12 August 2010 (depth 106 km) and the earthquake M6.2 in vicinity of Maule Chile earthquake (50 km on the south) at depth 16 km on 9 September 2010. Both these earthquakes coincide exactly with maximums of LOD record. Earthquakes are taken from NEIC, rectangle 25° N–50° S, 60–80° W. Magnitude over 6 is marked by triangle. (See four negative LOD amplitudes before the Haiti earthquake triggering).

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Causes of earthquakes and lithospheric plates movement

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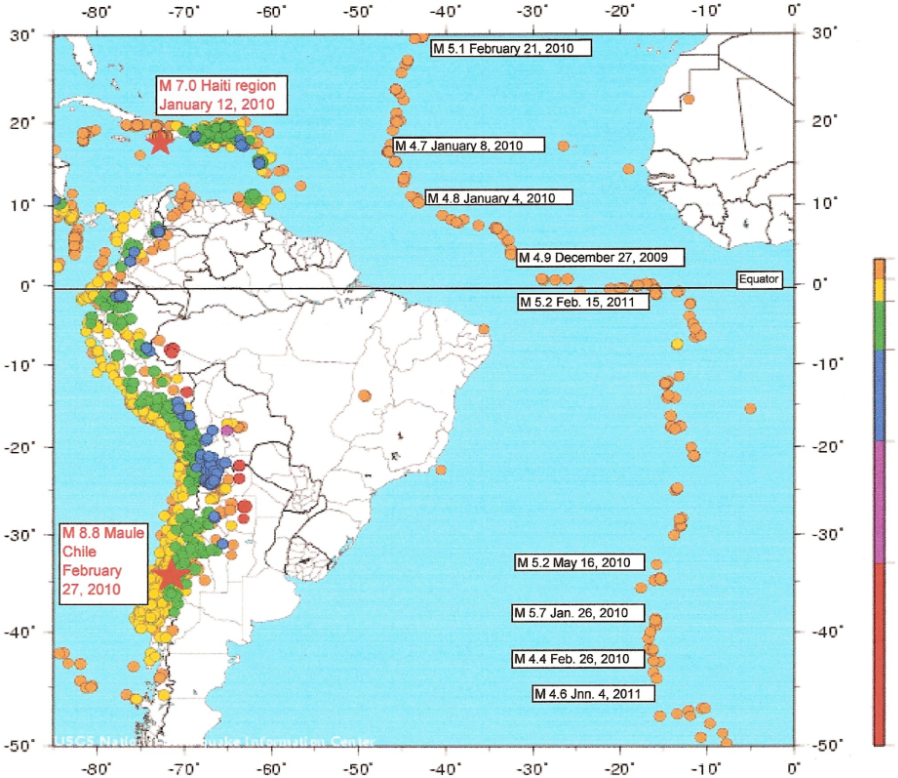

Fig. 4b. The figure shows positions of Haiti and Maule Chile earthquakes in 2010 and situation of the Mid-Atlantic Ridge, originally of N–S direction, but shifted along equator in northern hemisphere by quick movement of the North American plate westward.

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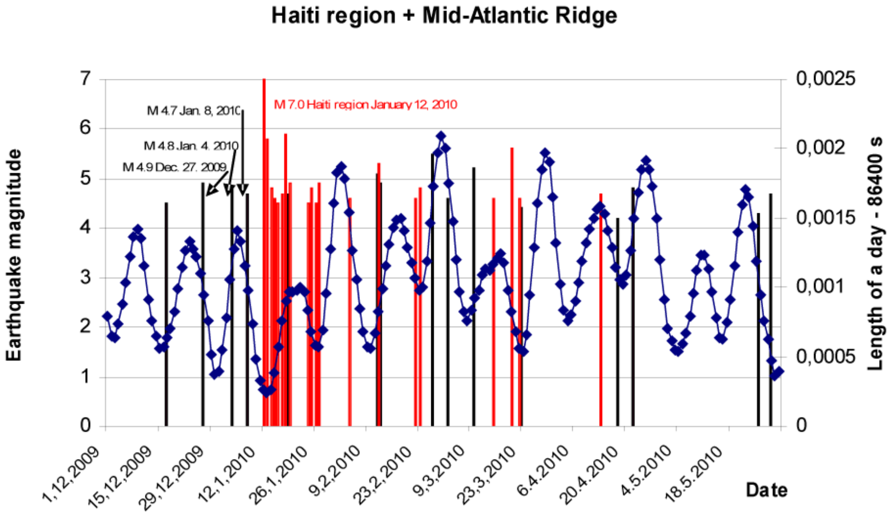

Fig. 4c. Earthquakes in Mid-Atlantic Ridge (black bars) triggered close to inflection points of LOD record consequently on ascending (decelerating) and descending (accelerating) branch, created pressure on the North American plate. Earthquakes in transform fault of Haiti earthquakes (red bars) were triggered at the moment of LOD minimum, i.e. when the extreme pressure of Earth's rotation was released and the Earth's rotation started to decelerate.

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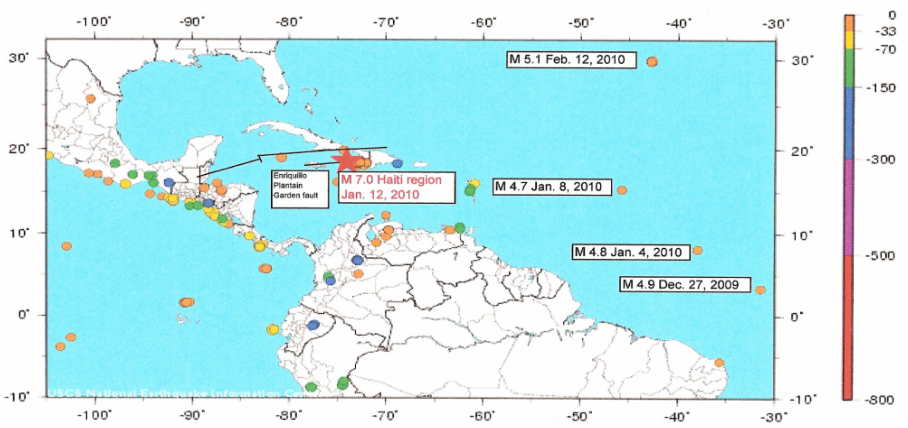

Fig. 4d. The figure shows how earthquakes in Mid-Atlantic ridge have occurred consequently from equator northward. Shortly after the triggering of the earthquake on the most western rim of Mid-Atlantic Ridge on 8 January 2010 M4.7, the Haiti earthquake 12 January 2010 M7.0 was triggered.

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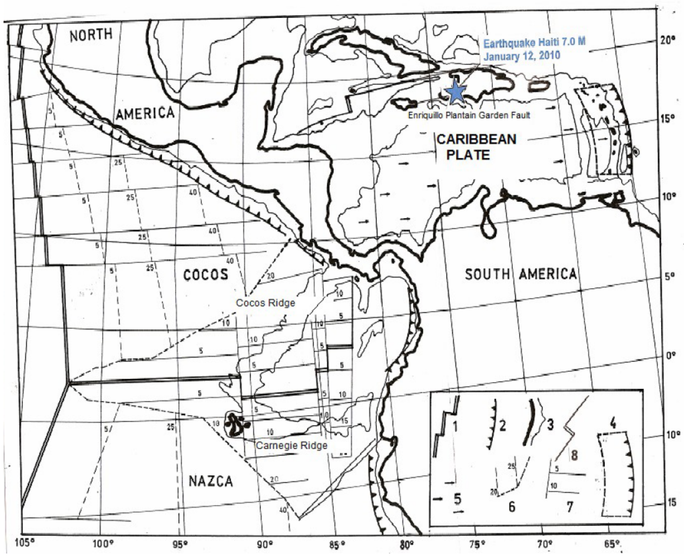

Fig. 4e. Position of the Haiti earthquake M7.0 of 12 January 2010 on the transform fault (left-lateral stroke slip faulting on northern side of the Caribbean plate, Enriquillo-Plantain Garden fault system) (USGS Poster of Haiti earthquake 2010), separating the North and South American plates. The Caribbean plate as a cut-out in oceanic lithosphere and setting of the Galapagos Rift system between the Cocos and Nazca plates as a rupture of a narrow plate caused by the rolling mantle. 1 – spreading center, 2 – subduction zone, 3 – shoreline with 500 m isobath, 4 – subduction zone and the schematic contour of submerged plate. 5 – direction of the rolling mantle, 6 – isochrones in M.Y. on the Nazca and Cocos plates, 7 – isochrones from the Galapagos rift (Hey and Vogt, 1977), 8 – transform faults. For formation of the Cocos and Nazca plates better imagination is, than the westward movement of the American plate, that the Cocos and Nazca plates are firmly connected to mantle and rotating mantle drift them beneath the American plate causing their rupture. Fixed Galapagos hotspot forms two hotspsot tracks on the both sides the rupture forming Cocos and Carnegie Ridges created by consequent opening of the rupture.

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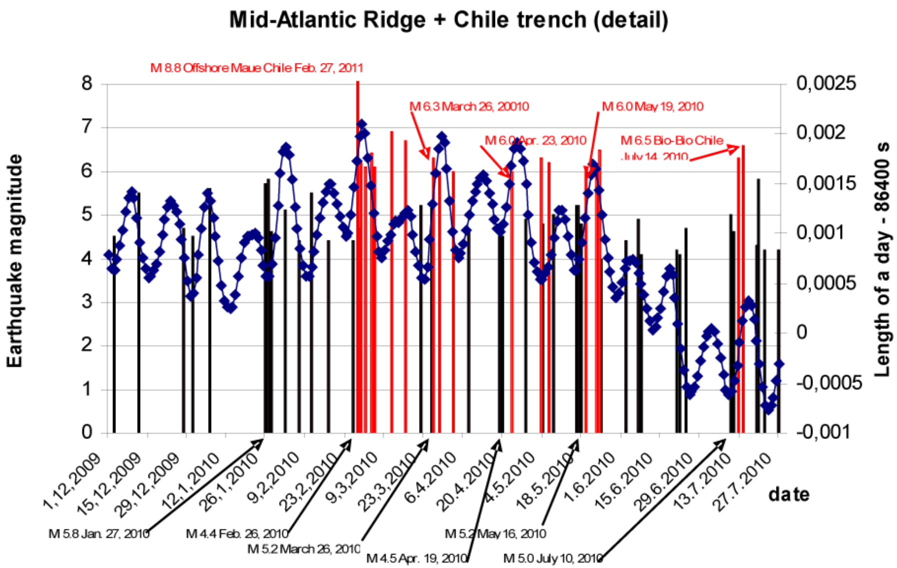

Fig. 4f. Increased LOD variations after the end of January 2010 caused earthquakes in the Mid-Atlantic Ridge (black bars) and earthquakes in Chile Trench subduction zone (red bars). In most cases earthquakes in Mid- Atlantic Ridge precede earthquakes in the Chile Trench.

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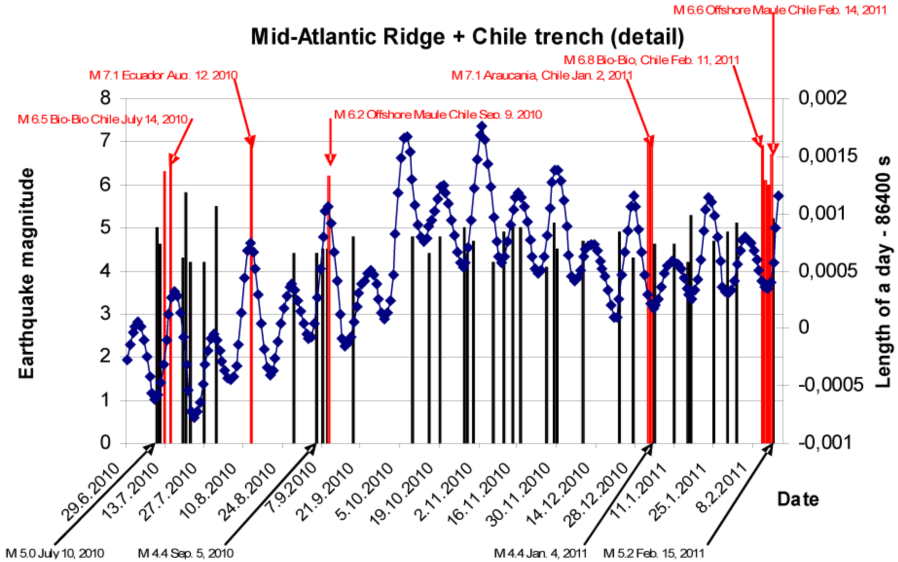

Fig. 4g. Earthquakes in summer 2010 coincide exactly with LOD maximum. After quiet period September–December 2010 at the beginning of the year 2011 earthquakes of the Chile Trench occur in LOD minimum. This convinces about the release of the subduction zone. Earthquakes in subduction zone react first on Earth's variations in reverse mode (in LOD minimum) and then earthquakes in Mid-Atlantic Ridge occur.

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Causes of earthquakes and lithospheric plates movement

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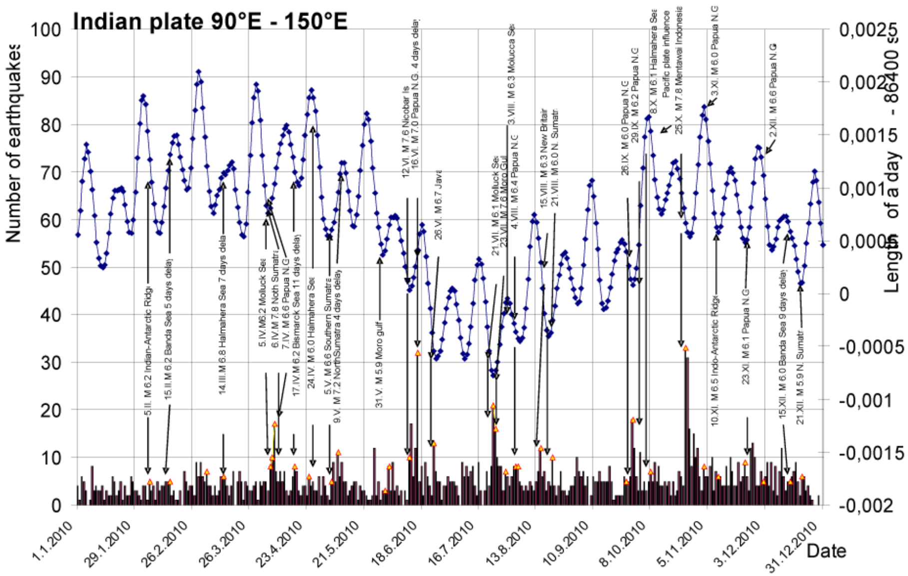

Fig. 4h. Earthquakes of the Indian plate in 2010. To avoid influence of earthquakes triggered by westward movement of the Pacific plate, only band 90–150° E was taken. Triangles mark earthquake > 6 M.

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Causes of earthquakes and lithospheric plates movement

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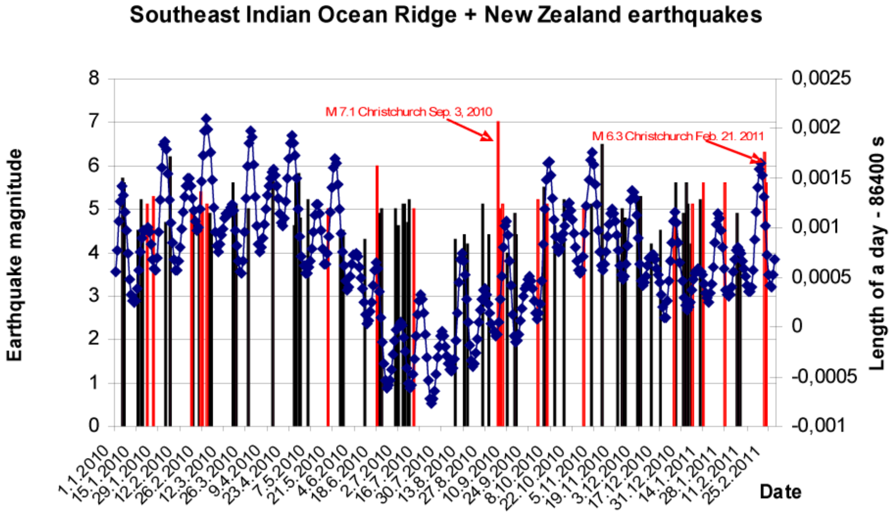

Fig. 4i. Earthquakes in N. Zealand region in 2010 till February 2011. The earthquake of Christchurch 3 September 2010 occurred in the second LOD minimum as most of earthquakes in the Indian plate in autumn 2010. See 3 repetitions of this earthquake after 27.6 days. Disastrous earthquake Christchurch 21 February 2011 occurred in reciprocal cycles in LOD maximum.

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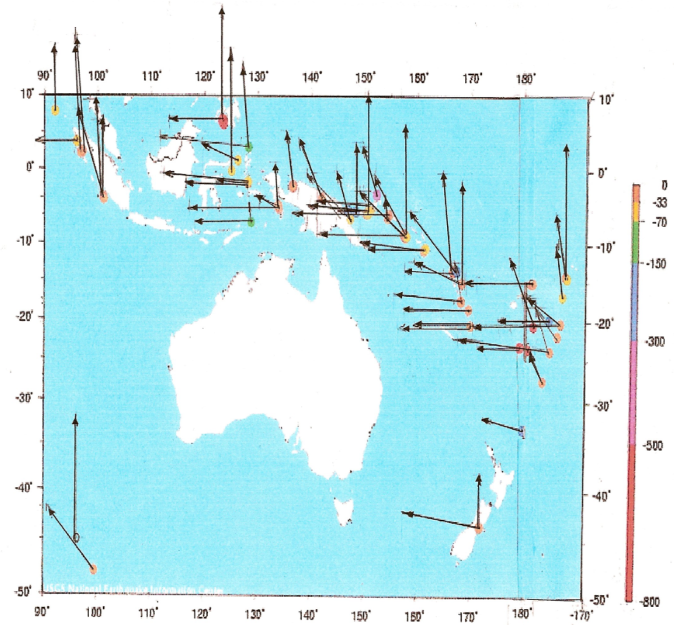

Fig. 4j. Construction of northward and westward movement of the Indian plate. Directions were measured from LOD graph back for 7 days after the earthquake. It means that earthquakes triggered exactly on LOD minimum were caused by northward movement. Those triggered on LOD maximum were caused by westward movement. Earthquakes between LOD extremes determined sections on ascending or descending branch (back in 7 days), which were added vectorially. Figure shows that most of earthquakes on Sumatra were triggered on LOD minimum with only one exception caused probably by delay. Earthquakes from Banda Sea directs westward similarly as subduction zone in that site. Earthquakes in LOD small maximum between 28 days maximums show that those earthquakes were probably delayed. For those the area on the west from N. Guinea is typical. Earthquakes on the north rim are triggered on the LOD minimum. Most of earthquakes from Banda Sea, N. Hebrides, Kermadek and Tonga direct westward.

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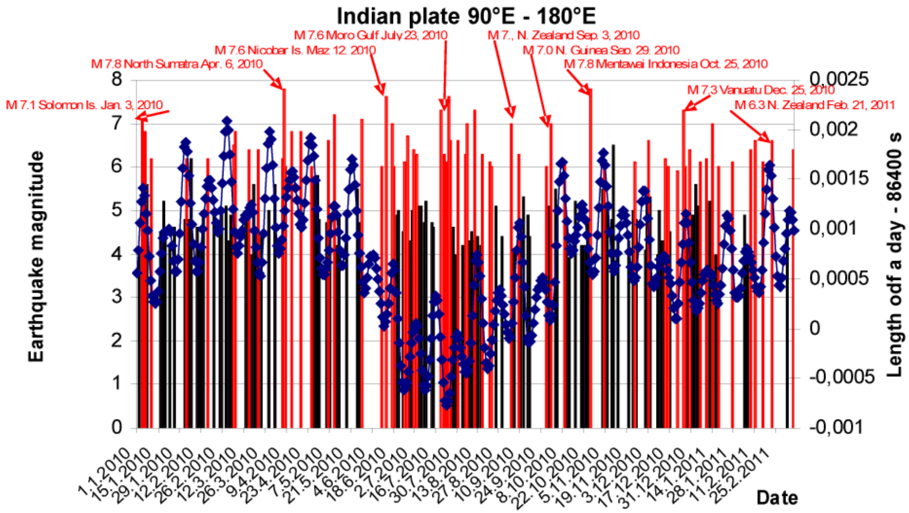

Fig. 4k. The figure shows comparison of Indian plate earthquakes > M 6 (red bars) and earthquakes on the Southeast Indian Ocean Ridge (black bars) separating the Indian plate from Antarctica. The large number of earthquakes in summer LOD minimum is evident.

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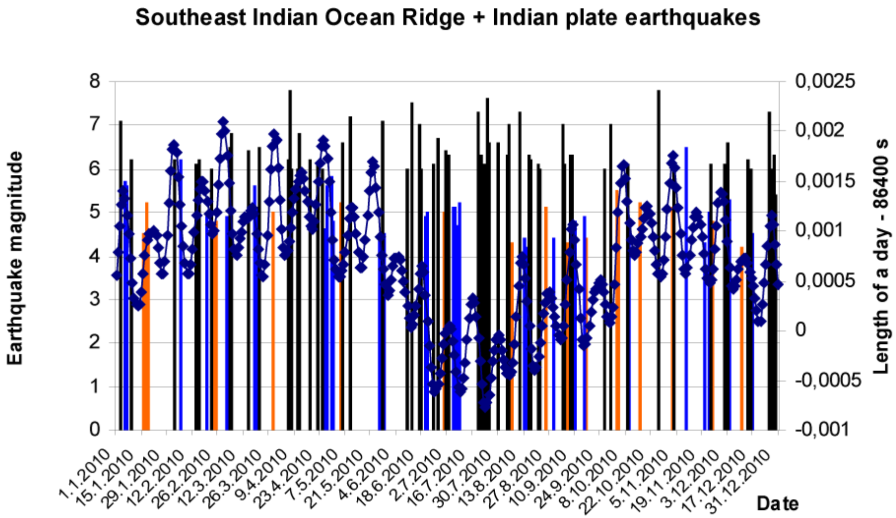

Fig. 4l. Earthquakes in Southeast Indian Ocean Ridge show differences whether they are on descending LOD branch (blue bars – 33 earthquakes) or ascending branch (orange bars – only 22 earthquakes). This shows that there is force acting during the Earth's acceleration pushing the Indian plate northward.

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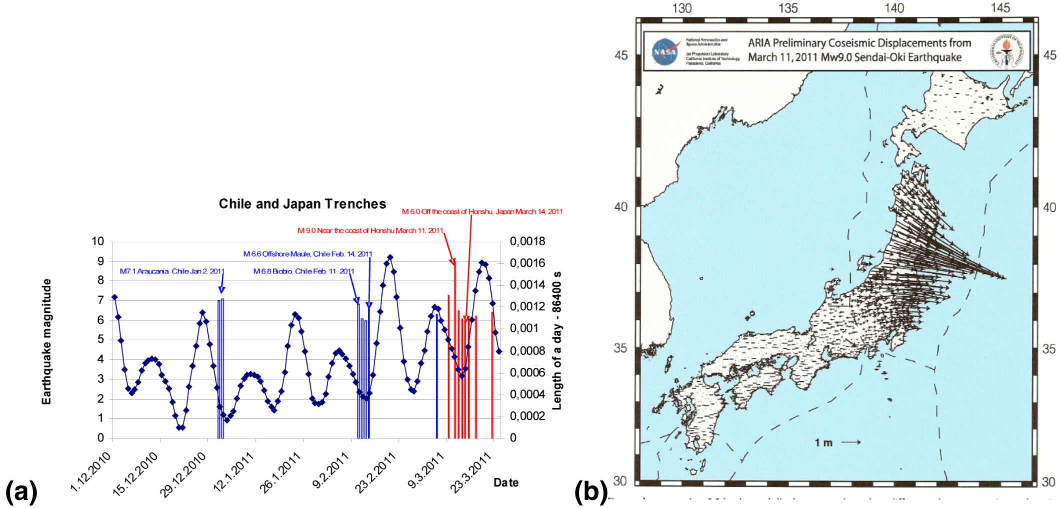

Fig. 5. **(a)** The LOD record and earthquakes in Japan and Chile at the beginning of 2011. Seemingly incoherent earthquakes in Chile Trench (blue bars) and Japan Trench (red bars) over 6 M were triggered by the second LOD minimum (Earth's rotation increment) but in Chile Trench one months (exactly 27.32 days) sooner. Supposing the continental lithosphere of the South American and Eurasian plates fixed in GPS satellite system, then the mantle beneath rotates during the Earth's rotation increment eastward. Rotating mantle drags the Nazca plate down the Chile Trench and the oceanic lithosphere of the Pacific plate moves away from Japan. At the same time it drags the continental lithosphere of northern Honshu 8 feet eastward. **(b)** GPS horizontal movement of northern Honshu (NASA 2011). Honshu was dragged by the rolling mantle out from the continental lithosphere of Eurasian plate.

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Fig. 6c. The movement of South American continent during the magnitude 8.8 – offshore Maule Chile earthquake and the 3.04 m westward jump of the continent in the city of Concepcion after the earthquake. Read more (Report from Wired Science, 2010) http://www.wired.com/wiredscience/2010/03/chile-earthquake-moved-entire-city-10-feet-to-the-west/#ixzz0hr4xF7ZM.

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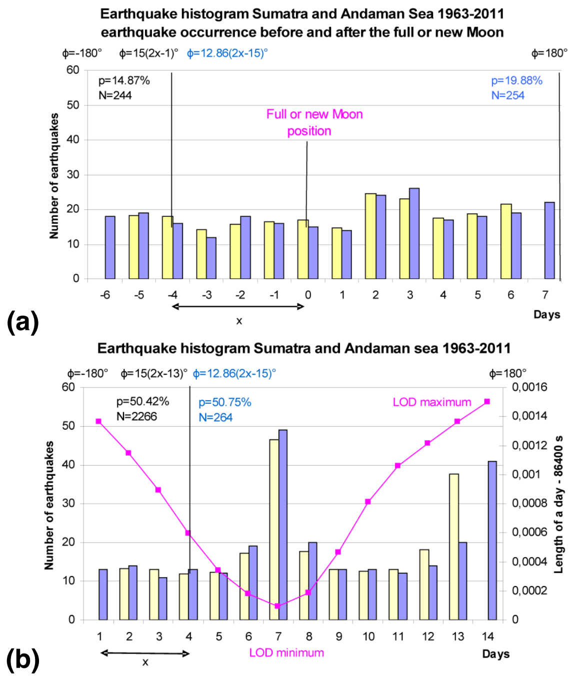

Fig. 7. (a) Histogram of earthquake occurrence in days before and after the full or new Moon for 14 and 12-interval distribution. Transformation formulas from days x to phase angle ϕ for the Schuster's test are given above. **(b)** Histogram for earthquake occurrence during the 13.66 days sidereal Earth's rotation cycle. Owing to distinctive earthquake occurrences in LOD minimum and LOD maximum the Schuster's test gives very high value of the parameter p over 50 %. Separating the 13.66 days histogram into two 8-interval histograms along descending and ascending LOD graph braches, result gives $p = 0.000059$ % for descending branch and $p = 0.0016$ % for ascending branch Fig. 7b1 and 7b2. 8-interval histogram in LOD minimum gives $p = 0.000073$ % and symmetric random distribution of earthquakes Fig. 7b3 and 7b4 for LOD maximum gives partly asymmetric earthquake distribution and $p = 0.010$ %

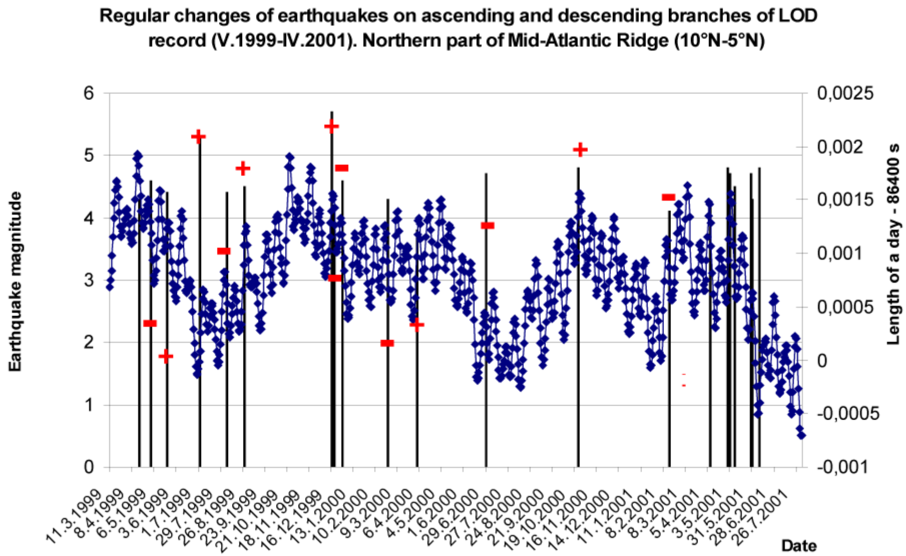

Fig. 8. Regular changes of earthquakes position on ascending (+) and descending (−) branches of LOD record. Compare histogram Fig. 7g.

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