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**Advanced Conference on Seismic Risk Mitigation and Sustainable Development**

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# Global and temporal distribution of seismic activity and its importance for seismic risk assessment

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# Global and temporal distribution of seismic activity and its importance for seismic risk assessment

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**Conference on**
***„Seismic risk mitigation and sustainable development"***

**Abdus Salam International Centre for Theoretical Physics**
**Trieste, 10-14 May 2010**

**Content**

## 1. Some incomplex introductive remarks on seismic risk assessment

•An additional problem is that both PSHA and DSHA are developed for seismically active areas. Therefore their use in areas of medium or low activity is not demonstrated.

•Modern instrumental seismology emerged at the end of the XIXth century, i.e. a little more than a century ago. At the same time the return period of characteristic seismic events, **particularly** in the case of the most active seismic sources, is well above centuries. This circumstance makes the prediction of future seismic events extremely complicated.

We suppose that the source area approximately coincides with the aftershock area ***A***, which can be obtained with the use of the equation $Lg\ A = 6.0 + 1.02 \cdot M$ ( ***A*** is expressed in square cm)

| | |
|---|---|
| M= 6.0 we have | $A=1.3 \cdot 10^2$ km$^2$ |
| M= 7.0 | $A=1.4 \cdot 10^3$ km$^2$ |
| M= 8.0 | $A=1.4 \cdot 10^4$ km$^2$ |
| M= 9.0 | $A= 1.5 \cdot 10^5$ km$^2$ |
| M= 9.5 | $A= 4.9 \cdot 10^5$ km$^2$ |
| M=10.0 | $A= 1.6 \cdot 10^6$ km$^2$ |
| M=10.5 | $A= 5.1 \cdot 10^6$ km$^2$ |

# SEISMICITY OF THE WORLD

## Seismicity in time

**Average annual number, frequency of seismic events and their energy contribution (in %)**

**$8.0 \leq Mw \rightarrow n = 1$ (49%)**
**$7.0 \leq Mw \leq 7.9 \rightarrow n \approx 10$ (43%)**
**$6.0 \leq Mw \leq 6.9 \rightarrow n \approx 10^2$ ( 4%)**
**$5.0 \leq Mw \leq 5.9 \rightarrow n \approx 10^3$ ( 3%)**
**$4.0 \leq Mw \leq 4.9 \rightarrow n \approx 10^4$ ( 1%)**

## Seismicity in space

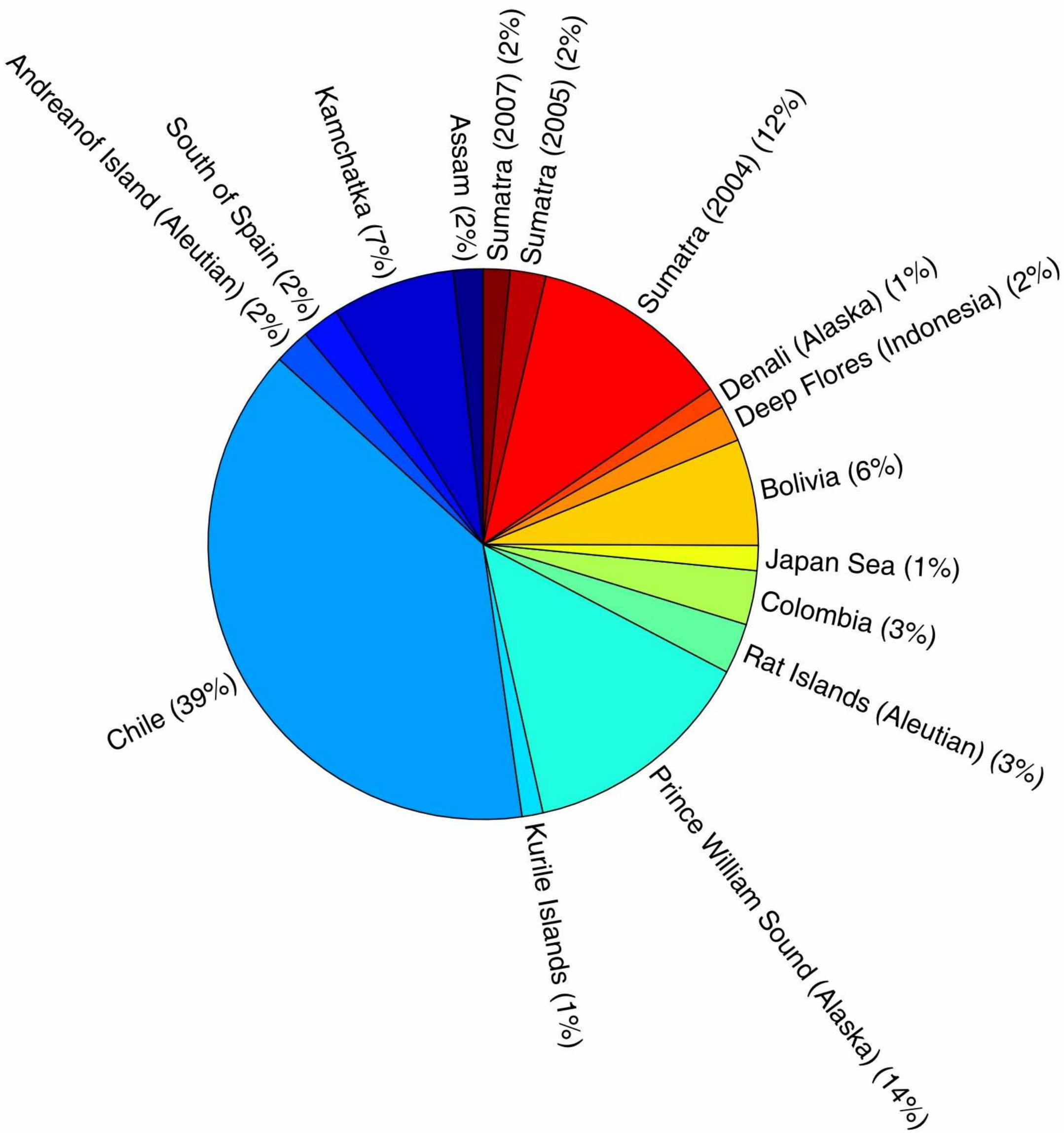
| Seismic belts | Shallow | Medium | Deep |
|---|---|---|---|
| *Pacific* | 75.4% | 89% | 100% |
| *Transasiatic-Mediterranean* | 22.9% | 11% | 0% |
| *Further zones* | 1.8% | 0% | 0% |
| *Sum-total* | 100% | 100% | 100% |

**INFORMATION ON COMPLETED EARTHQUAKE CATALOGUE USED IN OUR INVESTIGATIONS**

- As a basis the Centennial Catalogue (Engdahl and Villaseñor, 2002) was used.
- It extends from 1900 to April 2002. The earthquakes magnitudes; $Mw \geq 7.0$ were used.
- To expand the time span up to 2008, we have added all the events with $Mw \geq 7.0$ from the USGS/NEIC global catalogue.
- The updated dataset consists of 1719 events with $Mw \geq 7.0$, from 1900 to September 2007
- The elastic energy released by earthquakes listed in the catalogue were calculated with $\log E = 1.5\, Mw + 4.8$

# SEISMICITY OF THE WORLD

**Data Time Interval: [1950-2007]: Energy Distribution of Earthquakes M ≥ 8.5**




The energy of the Chilean earthquake energy was $1.1 \cdot 10^{19}$, while the global annual seismic energy release is on average $(1\text{-}3) \cdot 10^{18}$ Joule.

For a comparison

Tunguska meteorit (1908) E=~$1 \cdot 10^{17}$ J
Berringer Crater (Arizona) E=~$5 \cdot 10^{17}$ J
Yucatan (K/T) event E=~$1 \cdot 10^{23}$ J

Sumatra cunami (2004) E=~$2 \cdot 10^{16}$ J

# 1. Some incomplex introductive remarks on seismic risk assessment (continuation)

**An examble to illustrate the shortness of our seismological memory:** ***earthquakes in Tangshan and Komárom before 1976 (The destructive Tangshan event occured 28 July 1976)***

| TANGSHAN | | | | KOMÁROM | | | |
|---|---|---|---|---|---|---|---|
| year | Epicentral intensity | M | Energy (joule) | Year | Epicentral intensity | M | Energy (joule) |
| 1527 | VII | 5.5 | $1.10.10^{13}$ | 1599 | VIII | 5.6 | $1.58.10^{13}$ |
| 1567 | VI | 4.75 | $8.41.10^{11}$ | 1754 | V | 3.8 | $3.16.10^{10}$ |
| 1624 | VII | 6.25 | $1.50.10^{14}$ | 1759 | V | 3.8 | $3.16.10^{10}$ |
| 1795 | VI-VII | 5.25 | $4.73.10^{12}$ | 1763 | IX | 6.2 | $1.26.10^{14}$ |
| 1805 | VII | 5.50 | $1.12.10^{13}$ | 1783 | VIII | 5.3 | $5.62.10^{12}$ |
| 1880 | VI | 5.00 | $2.00.10^{12}$ | 1806 | VII | 5.0 | $2.00.10^{12}$ |
| 1934 | VI | 5.00 | $2.00.10^{12}$ | 1822 | VI-VII | 4.7 | $7.08.10^{11}$ |
| 1935 | VI | 5.00 | $2.00.10^{12}$ | 1822 | VI | 4.4 | $2.51.10^{11}$ |
| 1945 | VIII | 6.25 | $1.50.10^{14}$ | 1851 | VII | 5.0 | $2.00.10^{12}$ |
| 1974 | V-VI | 4.8 | $1.00.10^{12}$ | 1857 | V | 3.8 | $3.16.10^{10}$ |
| 1974 | V-VI | 4.8 | $1.00.10^{12}$ | 1923 | V | 3.8 | $3.16.10^{10}$ |
| | | | $\Sigma\ 3.35.10^{14}$ | | | | $\Sigma\ 1.52.10^{14}$ |

**Some aditional information on seismicity of two regions**

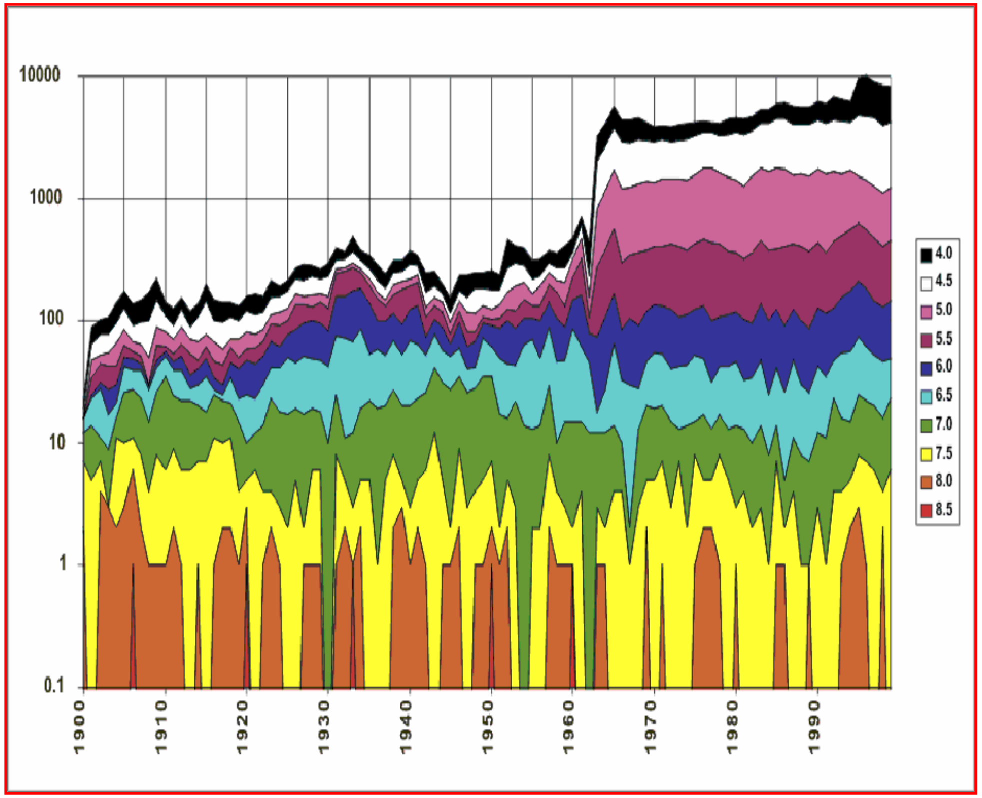
Number of seismic events with epicentral intensity $I_0 \geq V$ since 1600

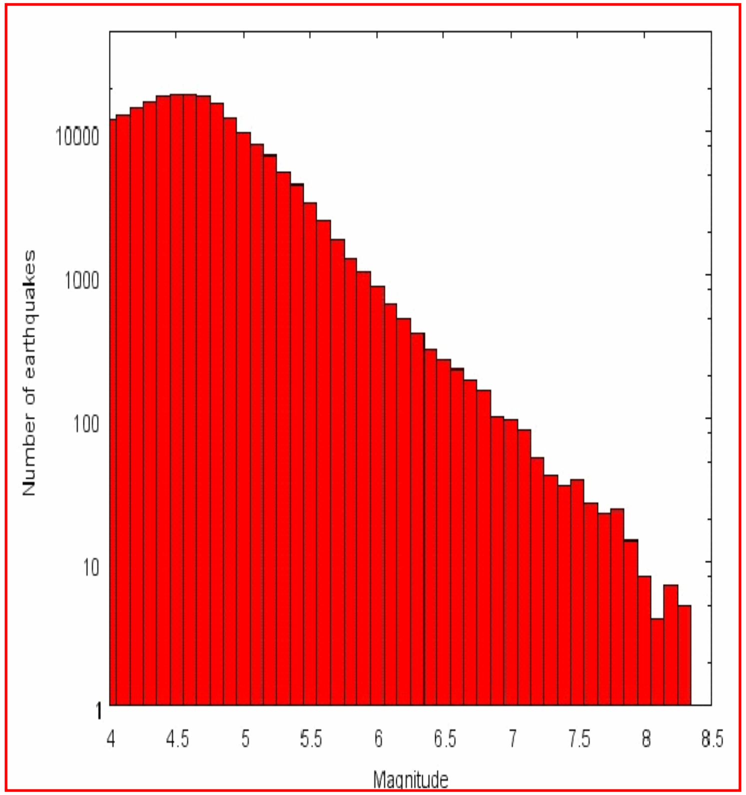
Tangshan: 9 Komárom: 10

Length of longest seismic quietness:

Tangshan: 171 year Komárom: 155 year

**The earthquake catalogue formally satisfying the requirement of completeness seismic events in case of magnitudes M≥7.0 for the whole time span**



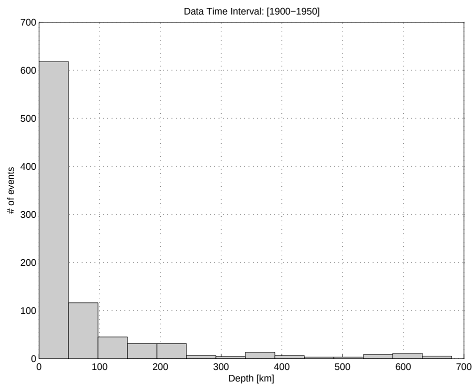

**Annual number of earthquakes 4.0 ≤ M ≤8.5 during the XXth century (Kosobokov V.G., Acta Geod. Geoph. Hung., 2004)**

**Histogram of earthquakes during second half of XXth century (Varga & Mentes, Marees Terrestres Bull. d'Inf., 2006)**

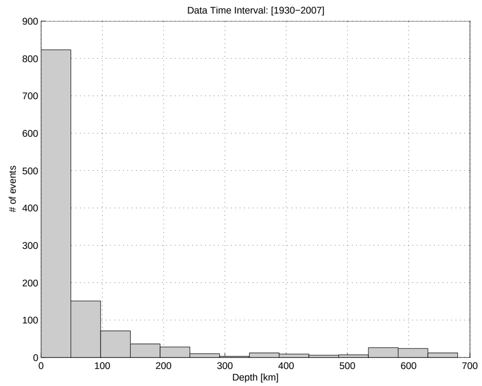
## 1. Some incomplex introductive remarks on seismic risk assessment (continuation)

**Adequacy of the catalogue for the seismicity studies from different point of view: we shall study distribution of the earthquake number and energy for $M_w \geq 7$**

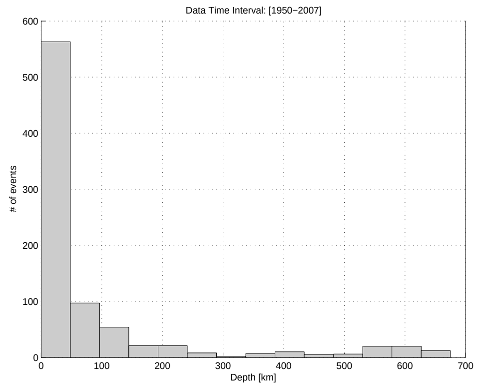
- **along radius of the Earth from the surface to 700 km depth**
- **along latitude**
- **along longitude**




1900-1930

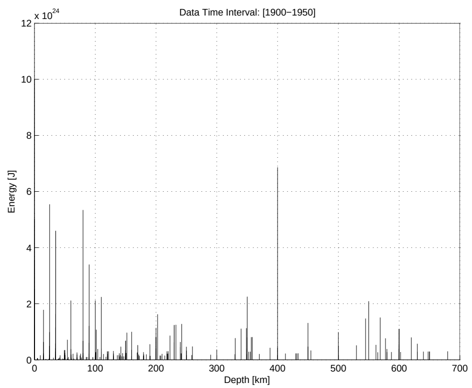



1930-2007

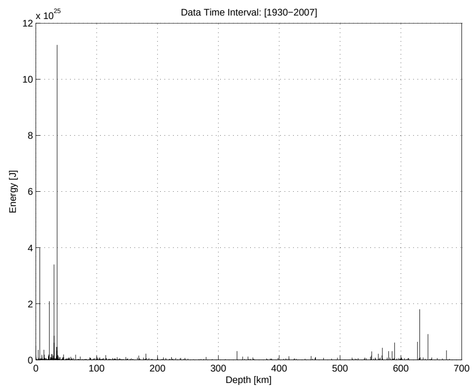



1950-2007

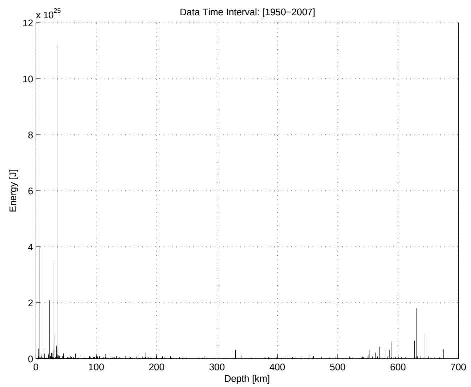
**Distribution of the earthquake number for M≥7 along radius from the surface up to the depth 700km**




1900-1930

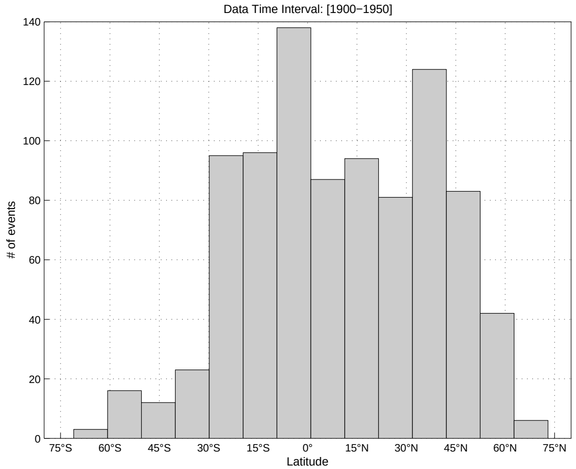



1930-2007

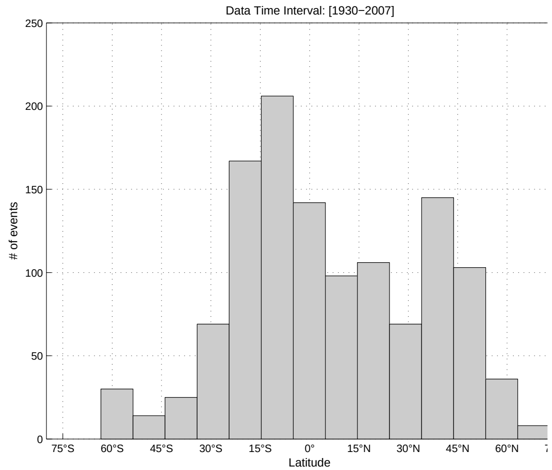



1950-2007

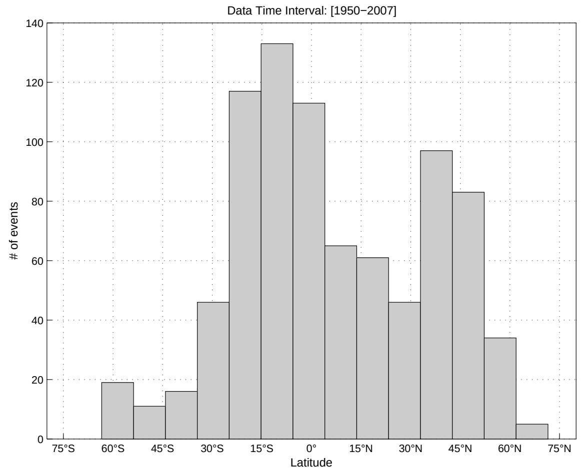
**Distribution of the earthquake energy along radius from the surface up to the depth 700km**




**1900-1930**

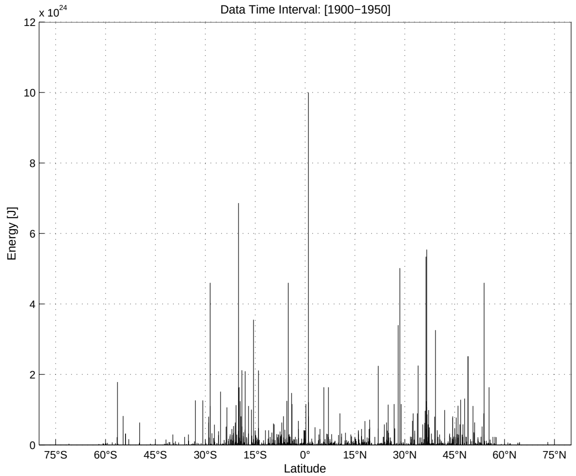



**1930-2007**

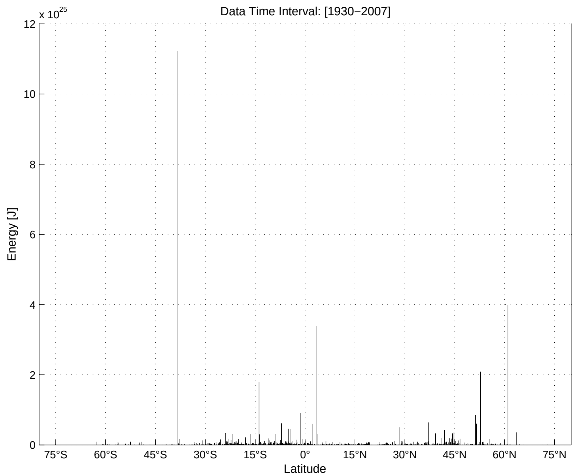



**1950-2007**

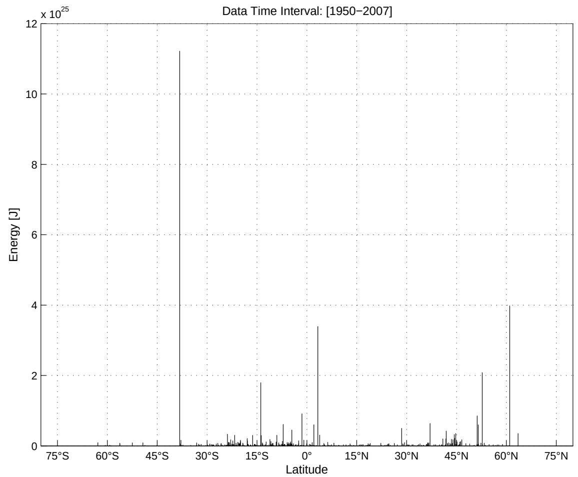
**Distribution of the earthquake number for M≥7 along latitude from the north pole to the south pole**




**1900-1930**

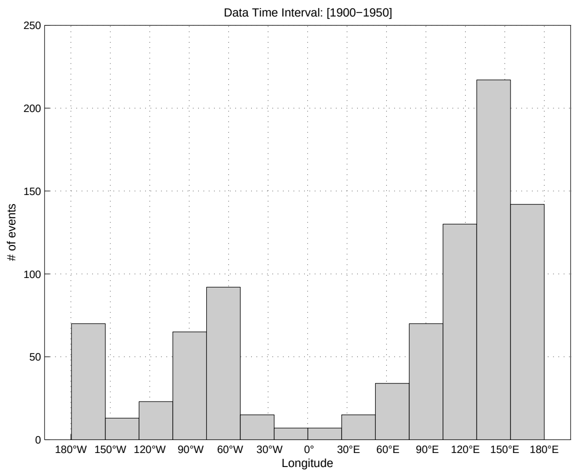



**1930-2007**

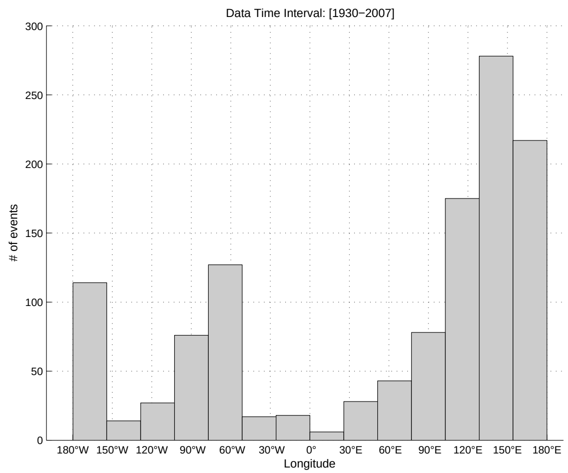



**1950-2007**

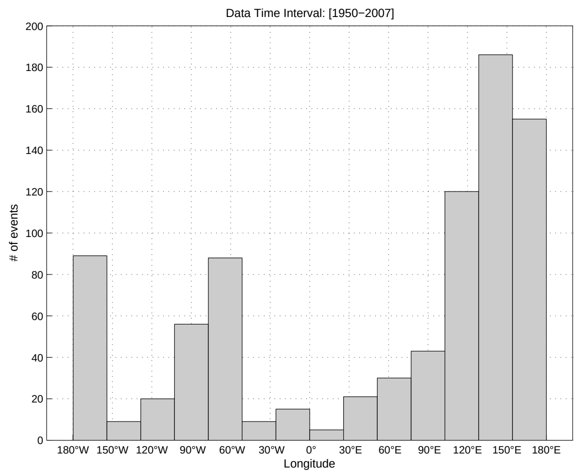
**Distribution of the earthquake energy along latitude from the north pole to the south pole**




**1900-1930**

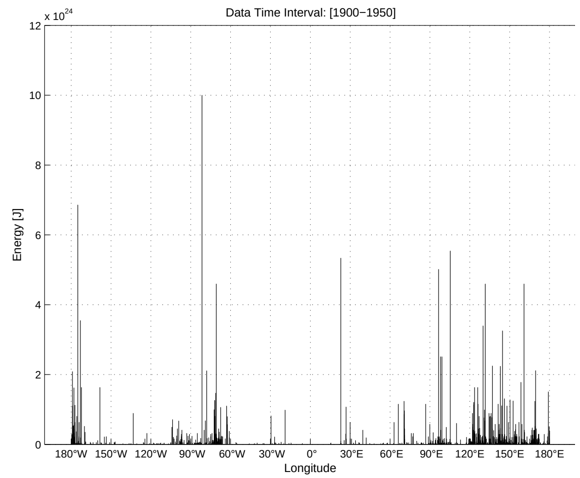



**1930-2007**

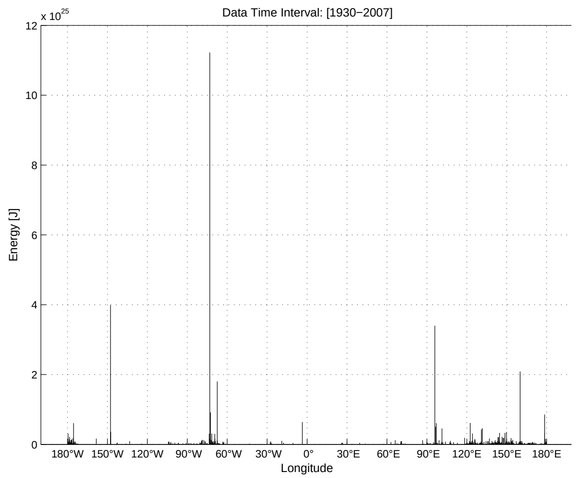



**1950-2007**

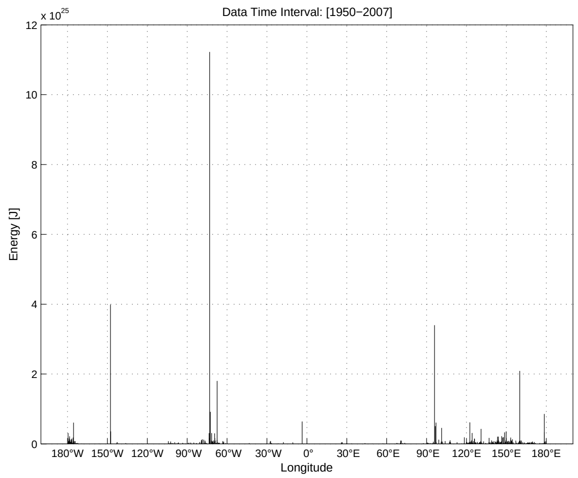
**Distribution of the earthquake number for M≥7 along longitude (the 0°meridian) is in the middle of the figures**




**1900-1930**




**1930-2007**




**1950-2007**

**Distribution of the earthquake energy along longitude (the 0°meridian) is in the middle of the figures**

## 2. Latitudinal distribution of earthquake energy release and lengths of subduction zones

**We search answers for the following questions:**

- **latitudinal distribution of strong ($Mw \geq 7$) seismicity**

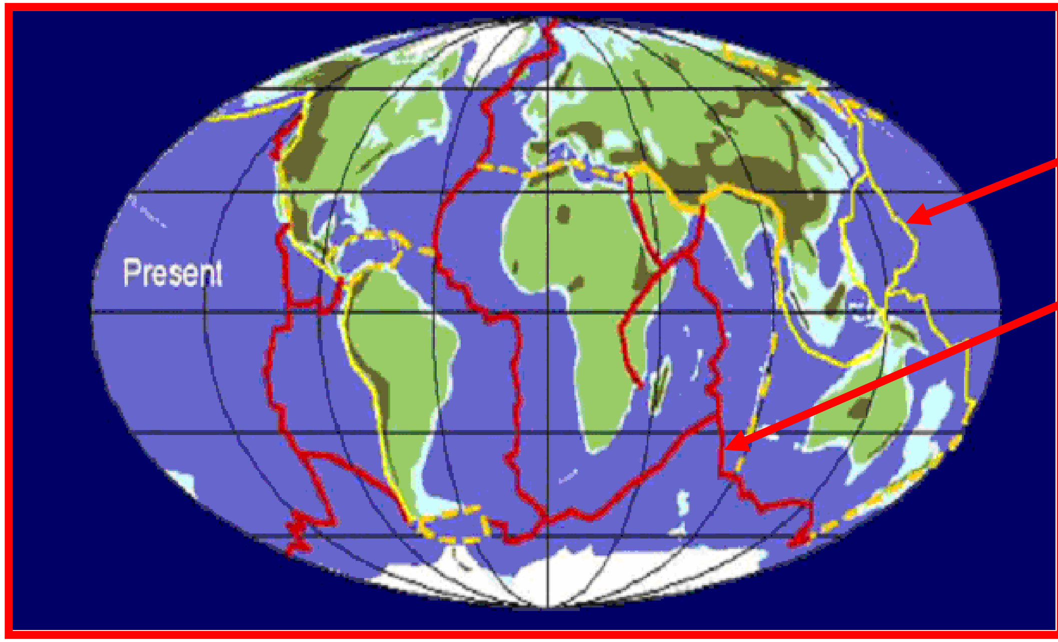
- **correspondence of latitudinal distribution of seismicity (deep and shallow earthquakes) and subduction zones**

- **differences of latitudinal distribution of deep and shallow focus seismicity**

- **possible effect of despinning of axial rotation (length of day - $\Delta$LOD- variations) on seismic event distribution**

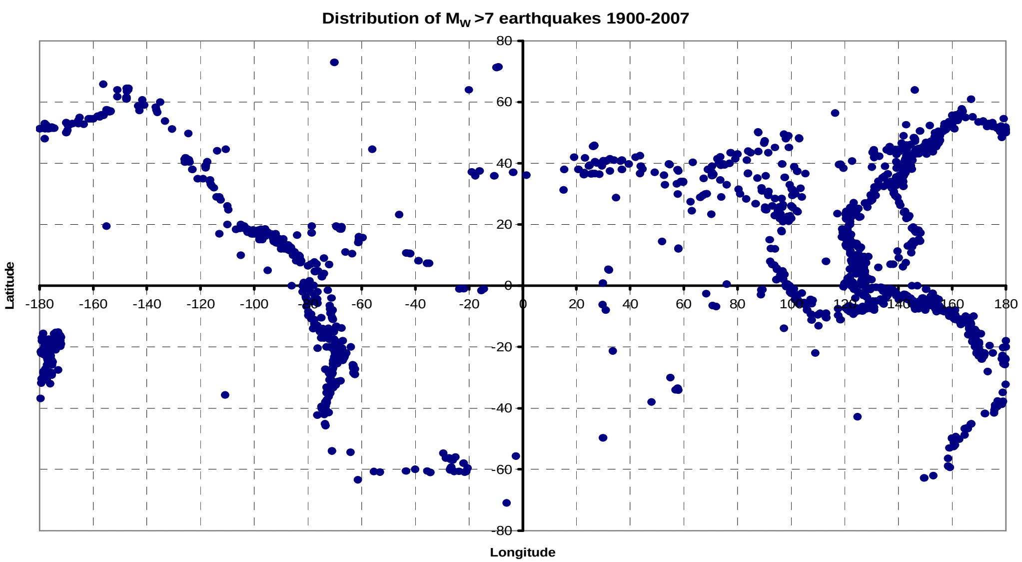
# Latitudinal distribution of earthquake energy releaseand lengths of subduction zones

GLOBAL TECTONICAL MAP by Malcom Ross and Chris Scotese




Subduction zones

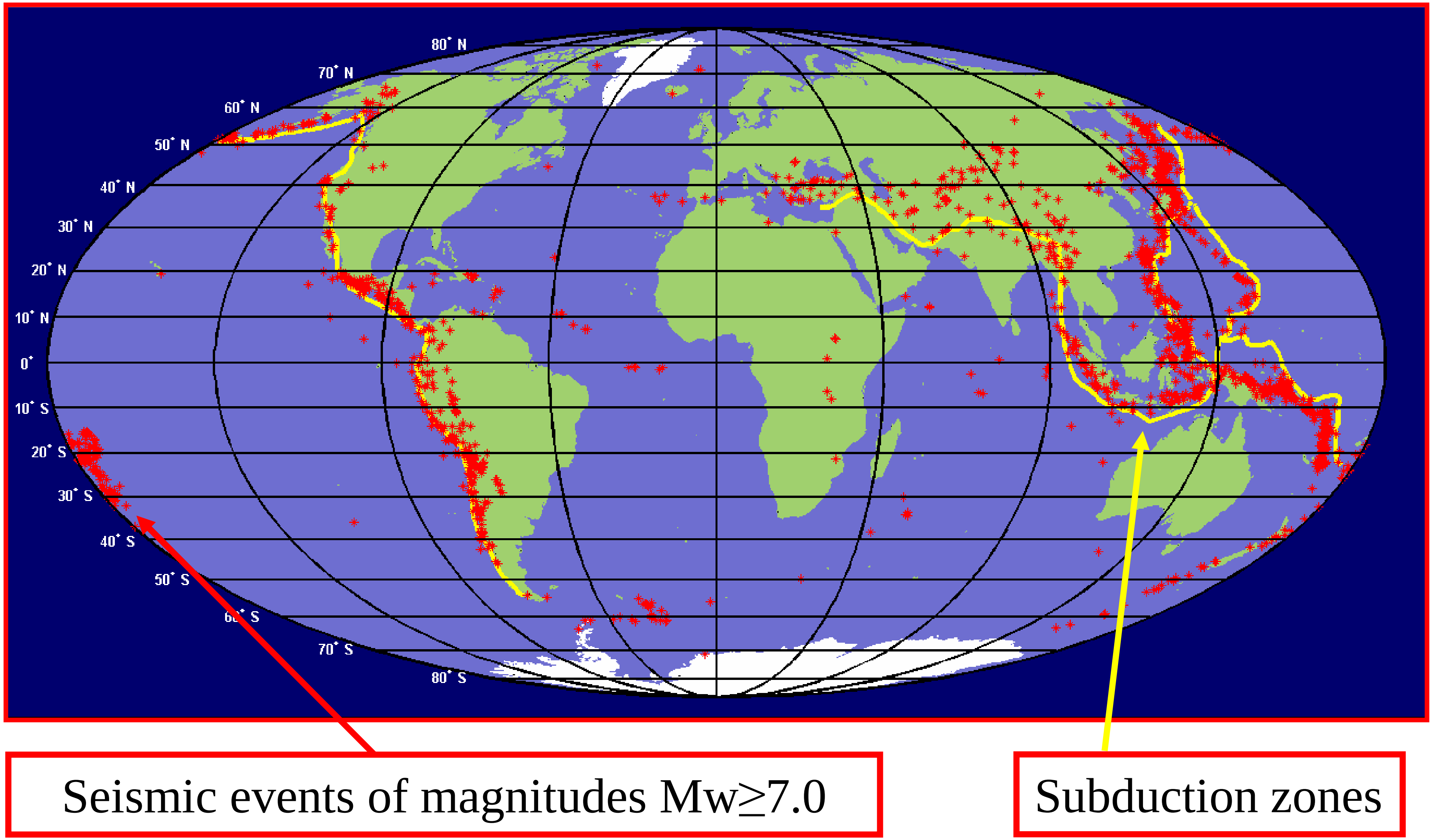
Middle oceanic ridges



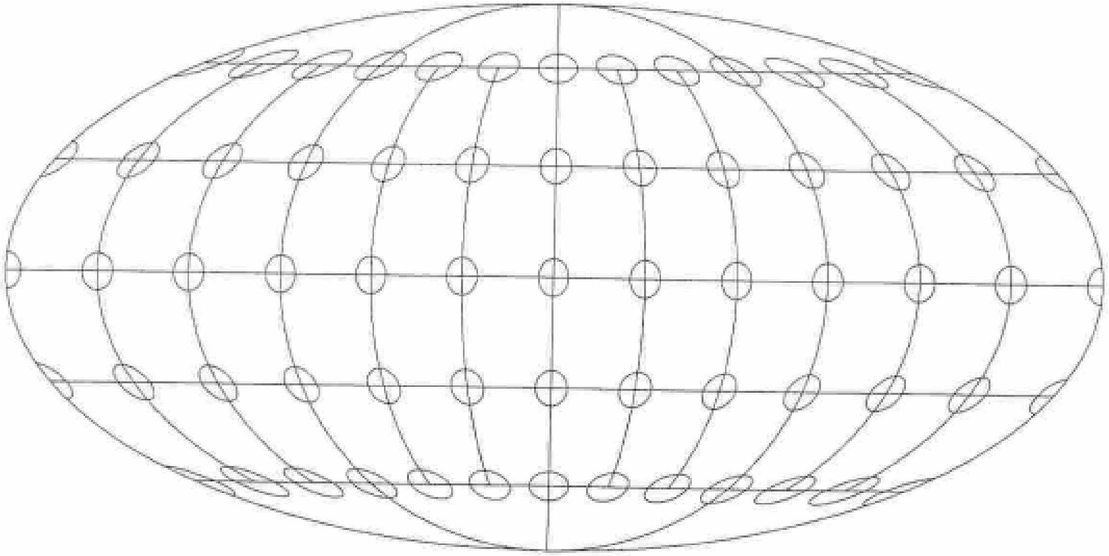

Subduction zones determined on the basis of our earthquake catalogue for great seismic events

# Map for determination of the length of subduction zones and the number of earthquakes Mw ≥7 in equal area latitude zones

**Equal area Mollweide projection of a spherical Earth (radius 6371km, centred on Greenwich Meridian)**



# Mollweide Projection



*Source: Erik W. Grafarend, Friedrich W. Krumm, 2006. Map Projections: Cartographic Information Systems, Springer*

**<u>Classification: pseudocylindrical equal area projection</u>**

***Graticule:***

- ***Meridians*: central meridian is a straight line (1/2 of the equatort's length), ±90° form a circle, others are equally spaced ellipses**
- ***Parallels*: equally spaced straight parallel lines**
- ***Poles*: points**
- ***Scale*: true along latitudes ±45°15'**

***Software to calculate true length and area ont he basis of data plotted ont he mapwas developed inInstitute of Geodesy, Stuttgart University***

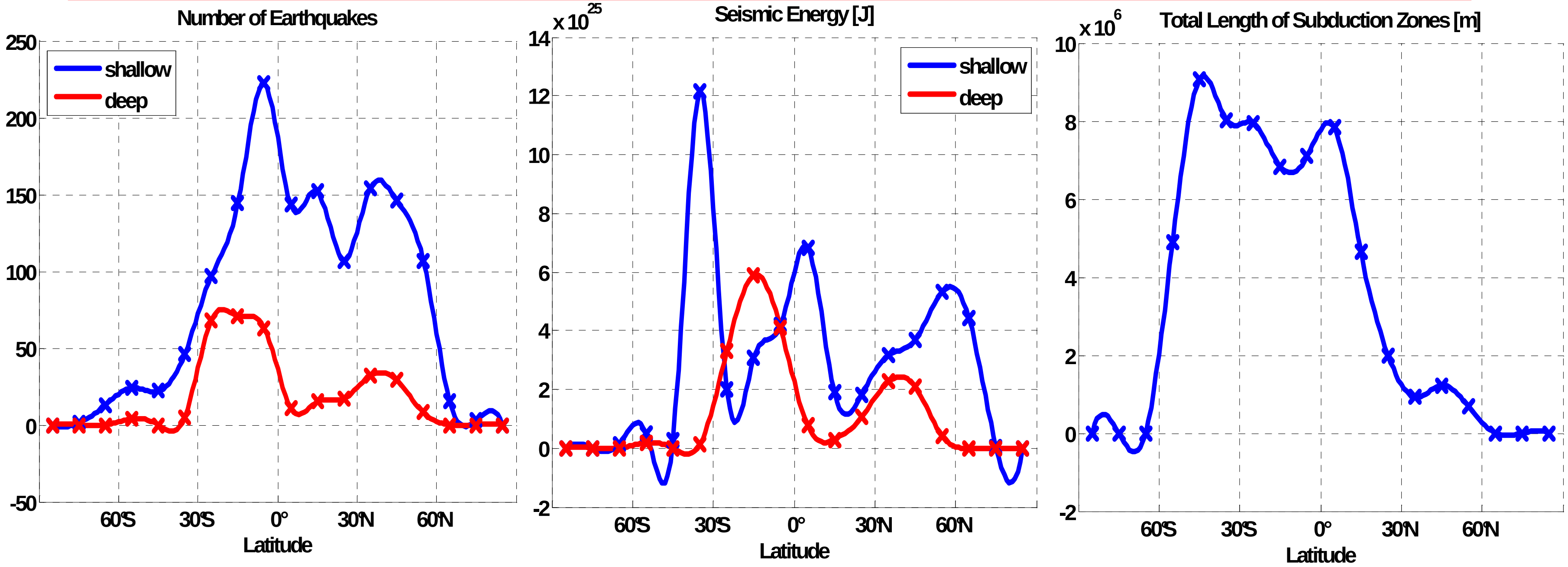
**Problems which can be solved with the common use of**

- **earthquake catalogue for Mw ≥7 seismic events**
- **tectonical data base of subduction zone length**
- **map projection techniques**

- **Latitudinal distribution of strong (Mw ≥7 ) seismicity**
- **Correspondence of latitudinal distribution of subduction zones and seismicity (deep and shallow earthquakes)**
- **Differences of meridian distribution of deep and shallow focus seismicity**
- **Possible effect of despinning (Δ LOD) on seismic event distribution**

# Longitudinal distribution of seismic and tectonic activity

10°-samples: 90°S-80°S, ..., 80°N-90°N



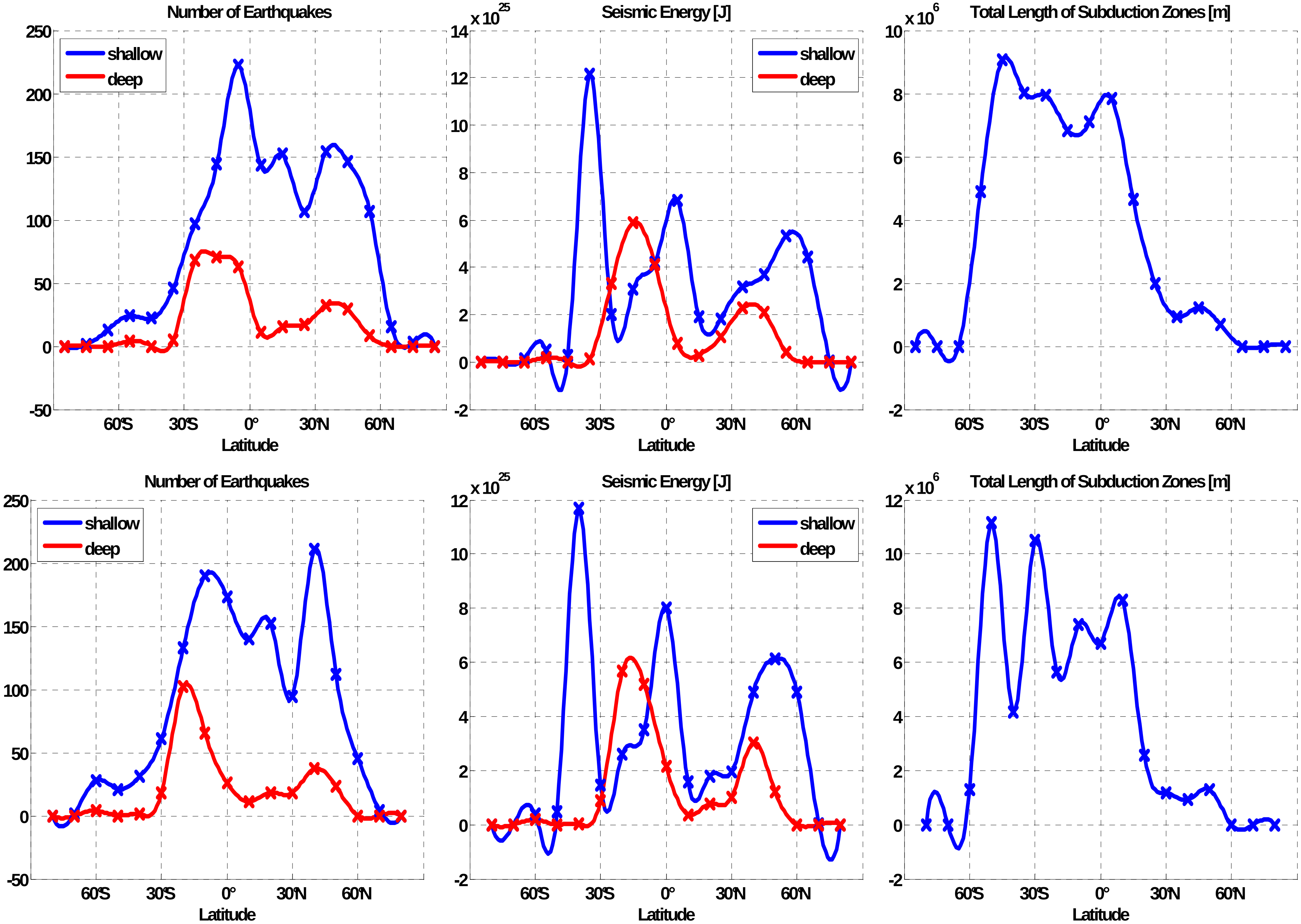

**It can be concluded that:**

1. **The seismic energy first of all connected with shallow focus events and it has no correlation with energy released with deep focus seismic events.**
2. **Practically no events Mw≥7.0 if $\beta \geq \pm 65°$.**
3. **There is no correlation along latitude between distribution of <u>*n, length of subduction lines*</u> and <u>*E*</u>.**
4. **The distribution of *E* has maxima around $\beta = \pm 45°$.**
5. **The number of events has different distributions in case of shallow and deep focus earthquakes.**

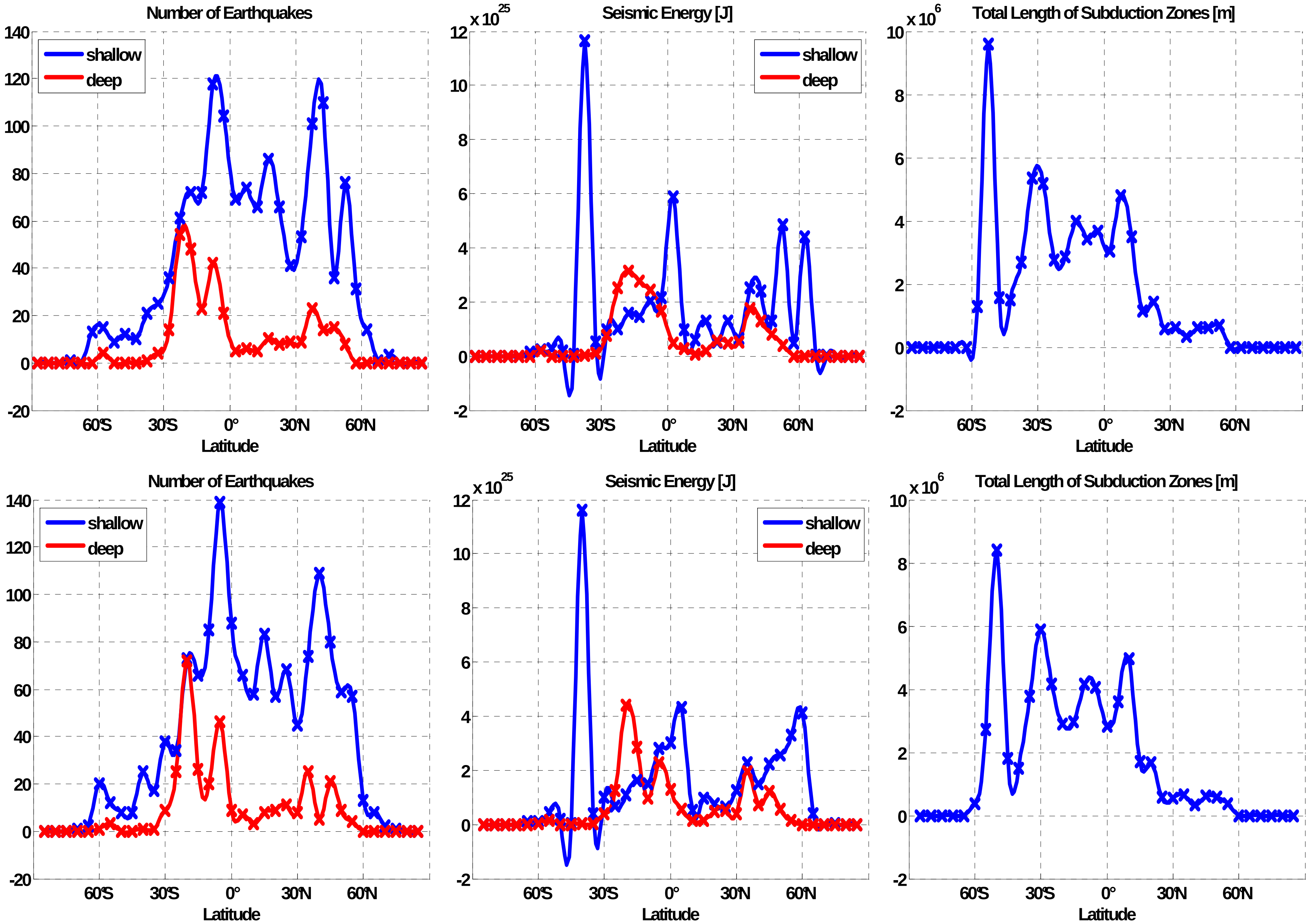
## Discussion of objectivity of the graphical representation of seismicity and tectonic activity along latitudes

- **Sampling rate 10°, shifting of the coordinates by 5°**
- **Sampling rate 5°, shifting of the coordinates by 2.5°**
- **Sampling rate 20, shifting of the coordinates by 10°**

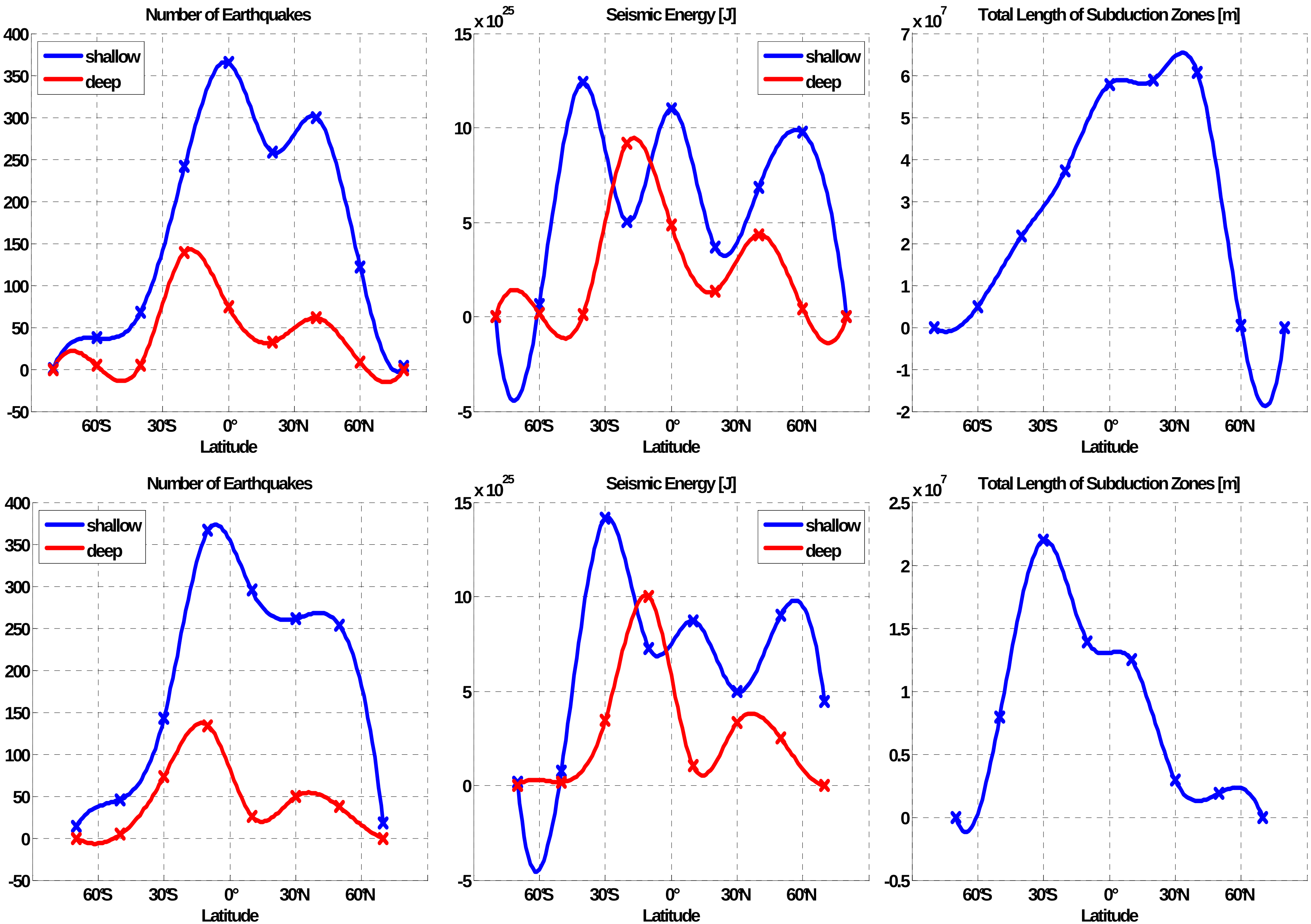
10°-samples: 90°S-80°S, ..., 80°N-90°N (Top) / 85°S-75°S,...,75°N-85°N (Bottom)



5°-samples: 90°S-85°S, ..., 85°N-90°N (Top) / 87.5°S-82.5°S,...,82.5°N-87.5°N (Bottom)



20°-samples: 90°S-70°S, ..., 70°N-90°N (Top) / 80°S-60 °S,...,60°N-80°N (Bottom)



# Some conclusions concerning the graphical representation of seismicity and tectonic activity along latitudes

•There is no correlation between seismic energy release and length of subduction zones et all.

•The tectonic activity represented by subduction zones and seismicity are minimal in polar regions.

• In case of comparison of different samplings it can be concluded that the maxima of the numbers and energies remains the same while the figure of the total length of subduction zones altering significantly.

•The distribution of deep and shallow seismicities along the latitude (both in case of numbers and energies) are not related to one another.

# 3.Physical background of connection between despinning of axial rotation and distribution of seismic energy release

The despinning of the acceleration of the angular rotation of the Earth generates attenuation the flattening ($\Delta f$) of the Earth as

$$\Delta f = (1+k_s)\frac{R}{GM}\omega\frac{d\omega}{dt}$$

Here $k_s$ is the secular Love number (~0.96); $G$, $M$ and $R$ are the gravitational constant, the Earth's mass and radius, while $\omega$ serves for the angular speed.

$$\sigma_{\varphi\varphi} = -\frac{\mu\Delta f}{11}\left[5 - 3\cos 2\varphi - 4\varepsilon(3 + 7\cos 2\varphi)\right]$$

$$\sigma_{\lambda\lambda} = +\frac{\mu\Delta f}{11}\left[1 + 9\cos 2\varphi - 4\varepsilon(5 + \cos 2\varphi)\right]$$

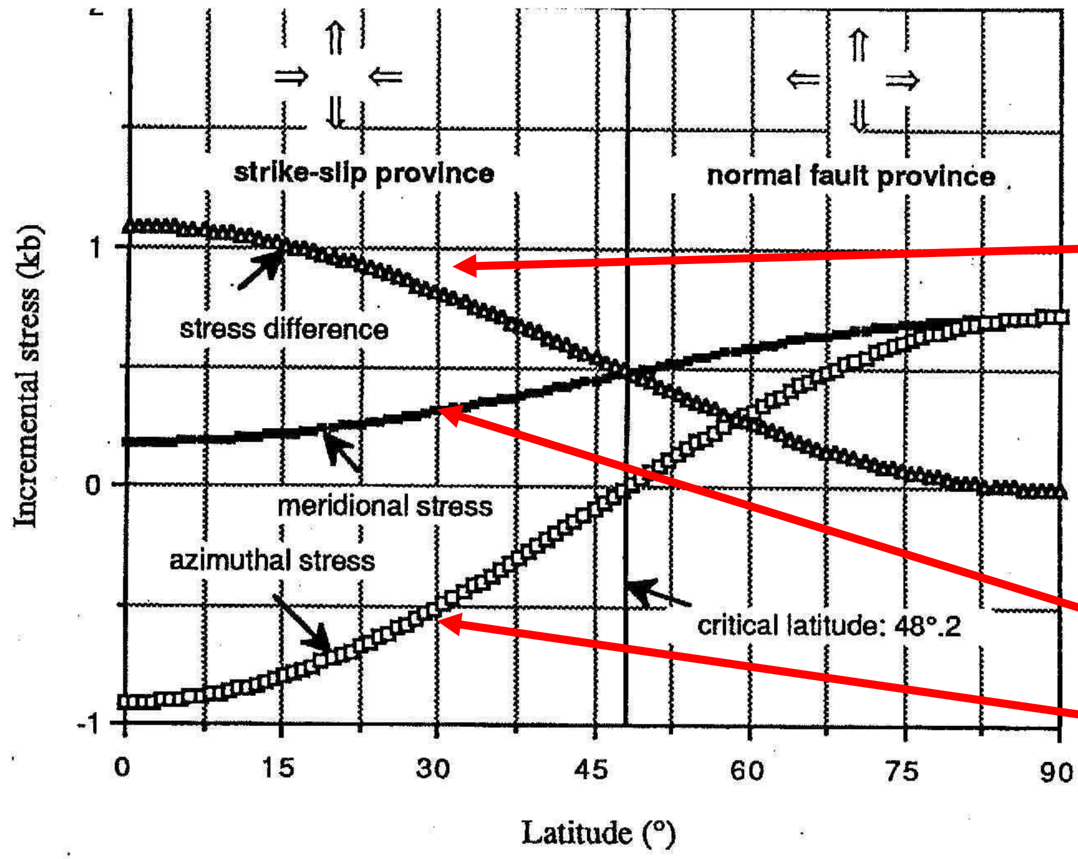
($\mu$ -effective shear modulus, $\varphi$ and $\lambda$ are the latitude and longitude, $\varepsilon$-normalized thickness of a brittle lithosphere which encompasses a soft anelastic mantle). Consequently the resulting incremental stress difference is

$$\Delta\sigma = \sigma_{\varphi\varphi} - \sigma_{\lambda\lambda} = +\frac{\mu\Delta f}{11}(6 - 32\varepsilon)\cdot(1 + \cos 2\varphi)$$

The calculated meridional, azimuthal and resulting incremental stresses have their inflection at the critical latitude $\varphi = \pm 45°$, what means: the maxima of the force components are at this-so-called- critical latitudes. The meaning of the critical latitude can be explained on the following way. Let us consider a circle $AC=4\pi R\cdot R$ and an ellipse $AE=\pi ab$ of the same area and with coinciding centres they will intersect at the latitudes .

The bimodal latitudinal earthquake energy distribution is recognizable on the figures of energies along latitudes properly.

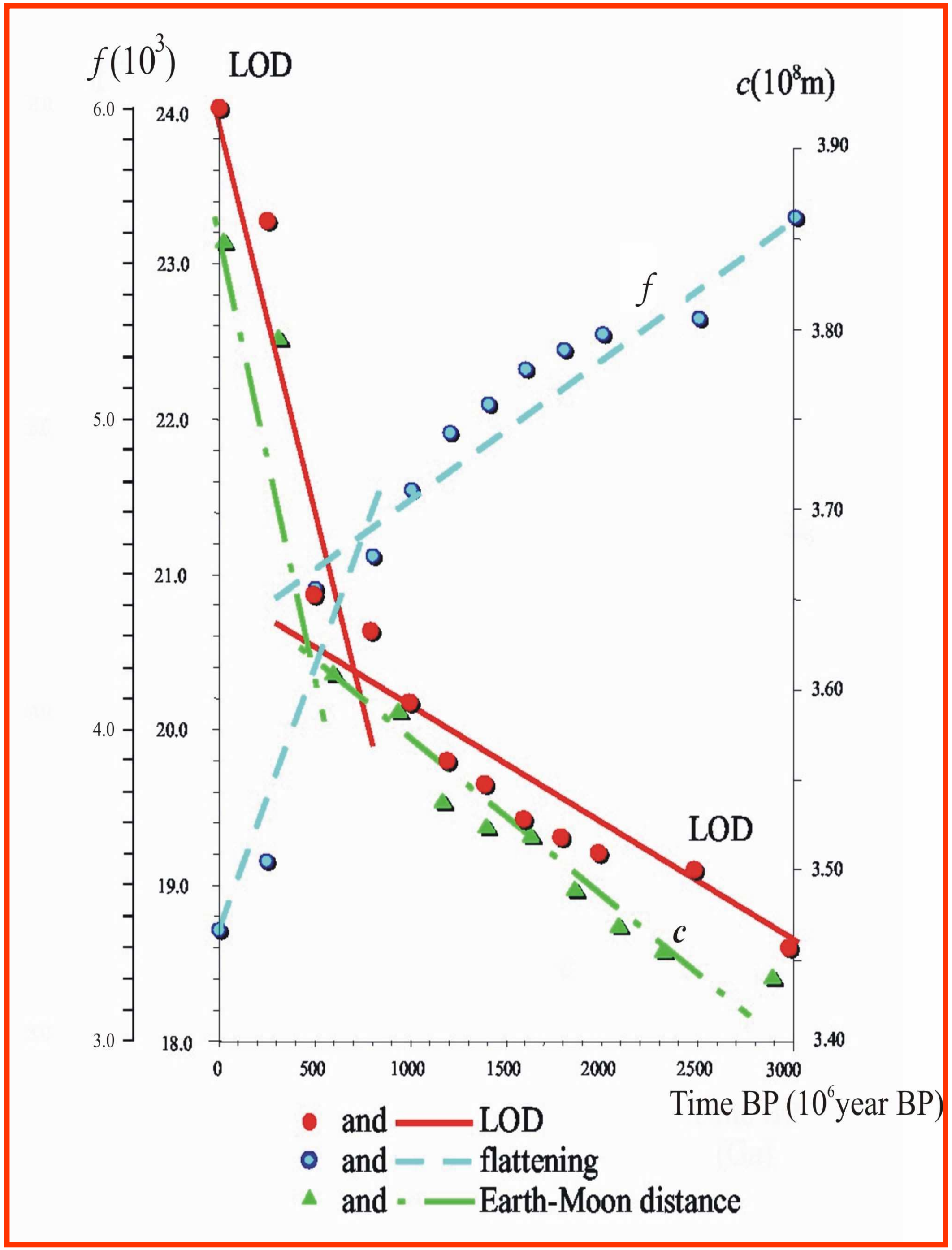
# Physical background of connection between despinning of axial rotation and distribution of seismic energy release (2)



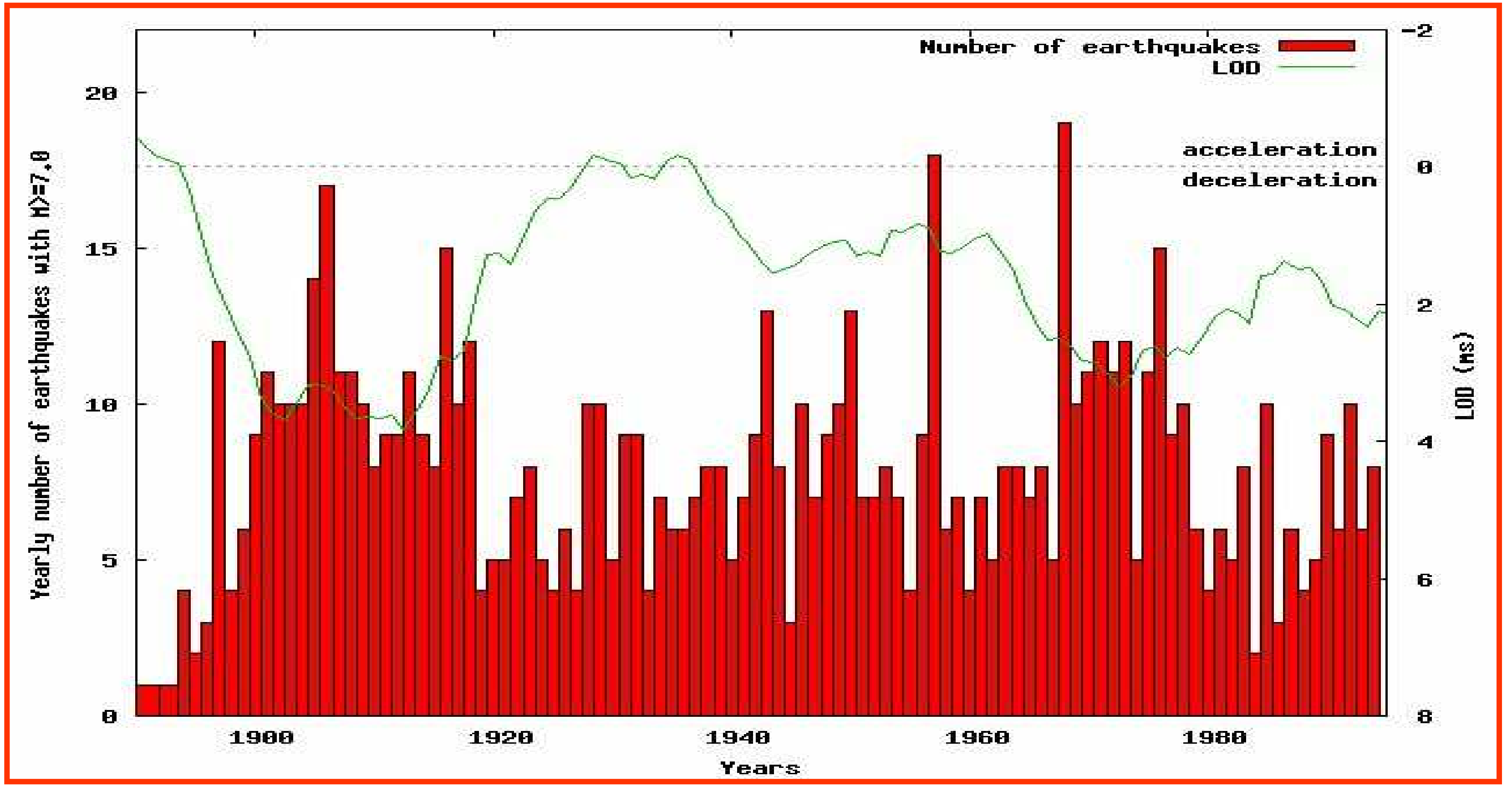

$$\Delta\sigma = \Delta_{\beta\beta} - \Delta_{\lambda\lambda} = +\frac{\mu\Delta f}{11}(6-32\varepsilon)\cdot(1+\cos 2\beta)$$

$$\sigma_{\beta\beta} = -\frac{\mu\Delta f}{11}\left[5-3\cos 2\beta-4\varepsilon(3+7\cos 2\beta)\right]$$

$$\sigma_{\lambda\lambda} = +\frac{\mu\Delta f}{11}\left[1+9\cos 2\beta-4\varepsilon(5+\cos 2\beta)\right]$$




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

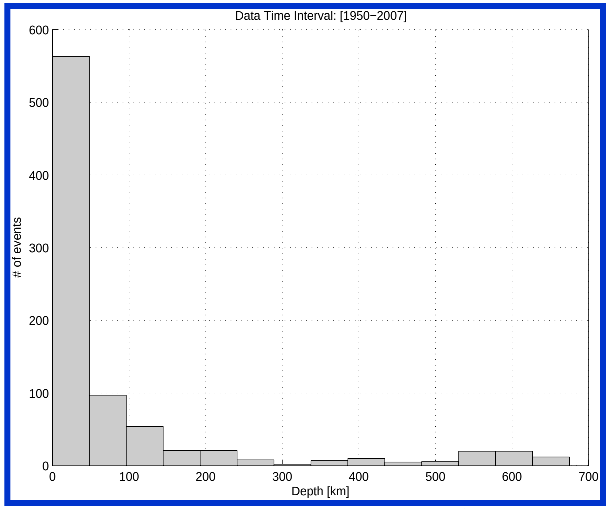


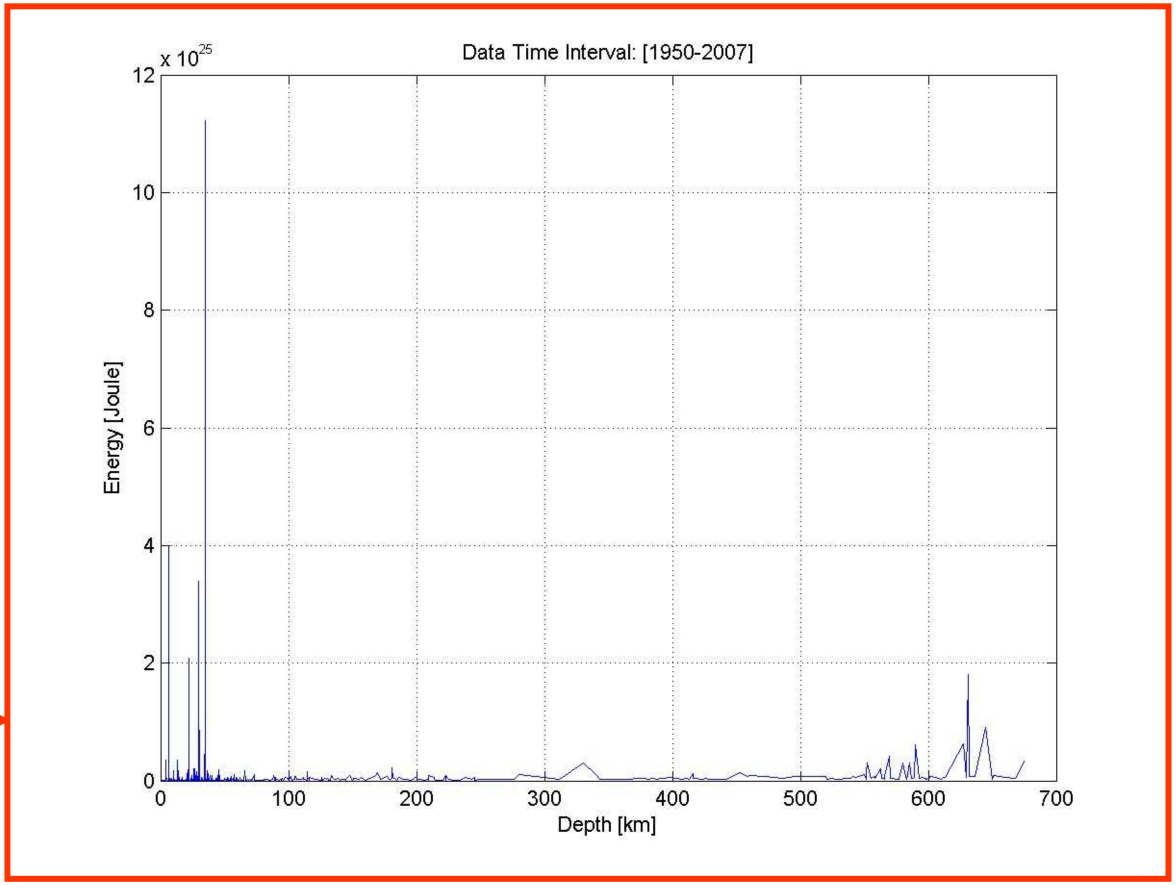

Question: is there any relationship between LOD and seismicity?

**YES!!**

But not the seismicity influences the rotation vector, on the contrary the variations of LOD have some influence on temporal distribution of seismic activity

# 4.Depth distribution of earthquake energy release



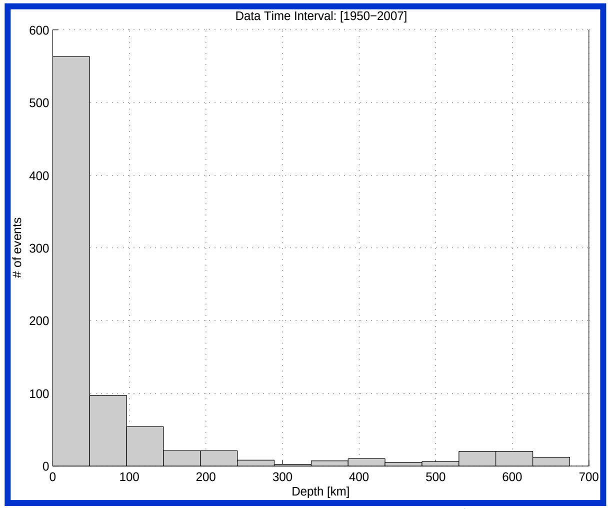



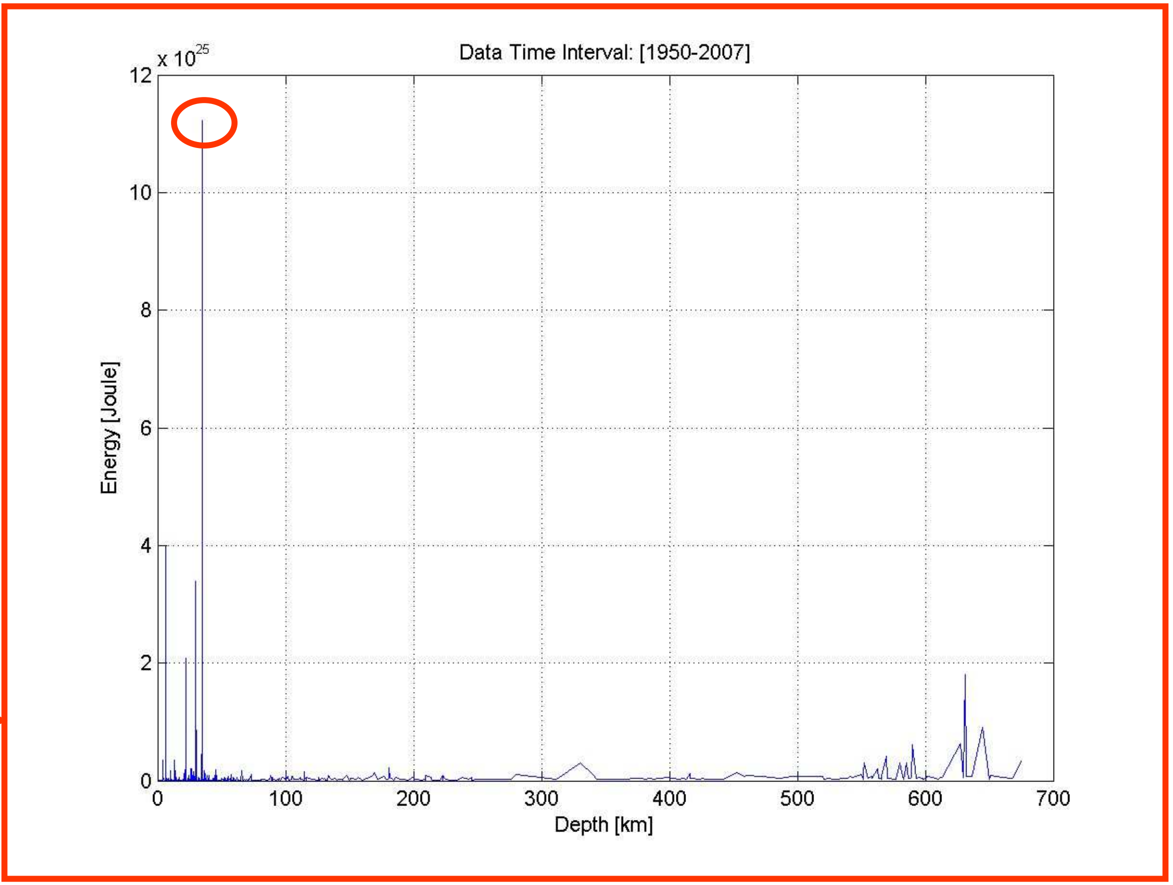

*Distribution of the number*

*and energy*

*of earthquakes $M_W \geq 7.0$ along radius for time interval 1950-2007*

# Depth distribution of earthquake energy




*Distribution of the number*

*and energy*

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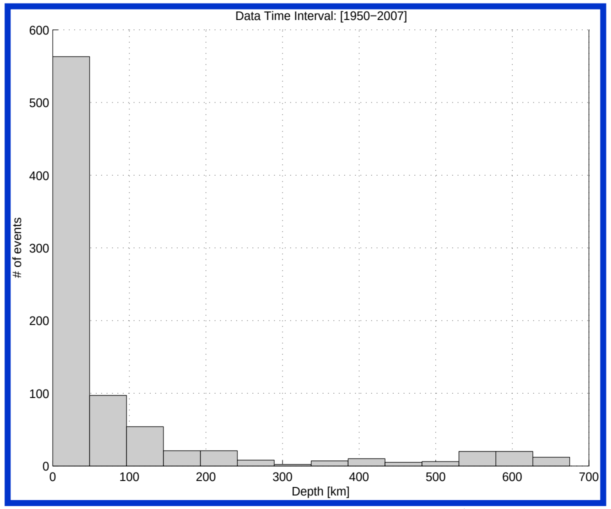
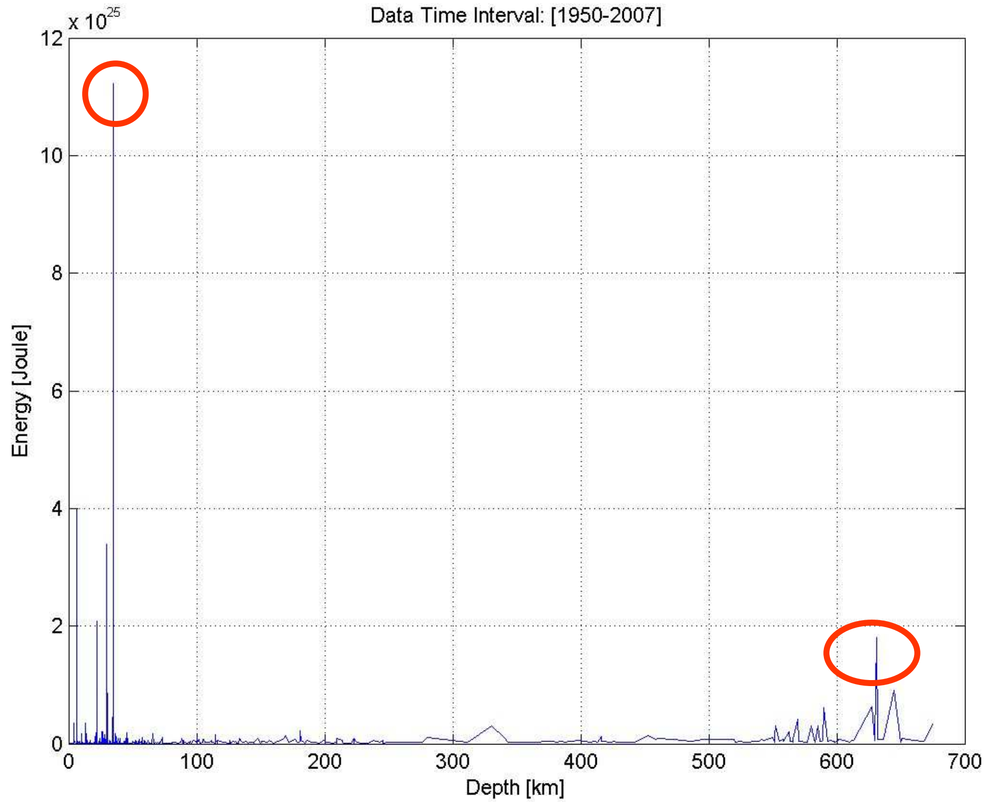
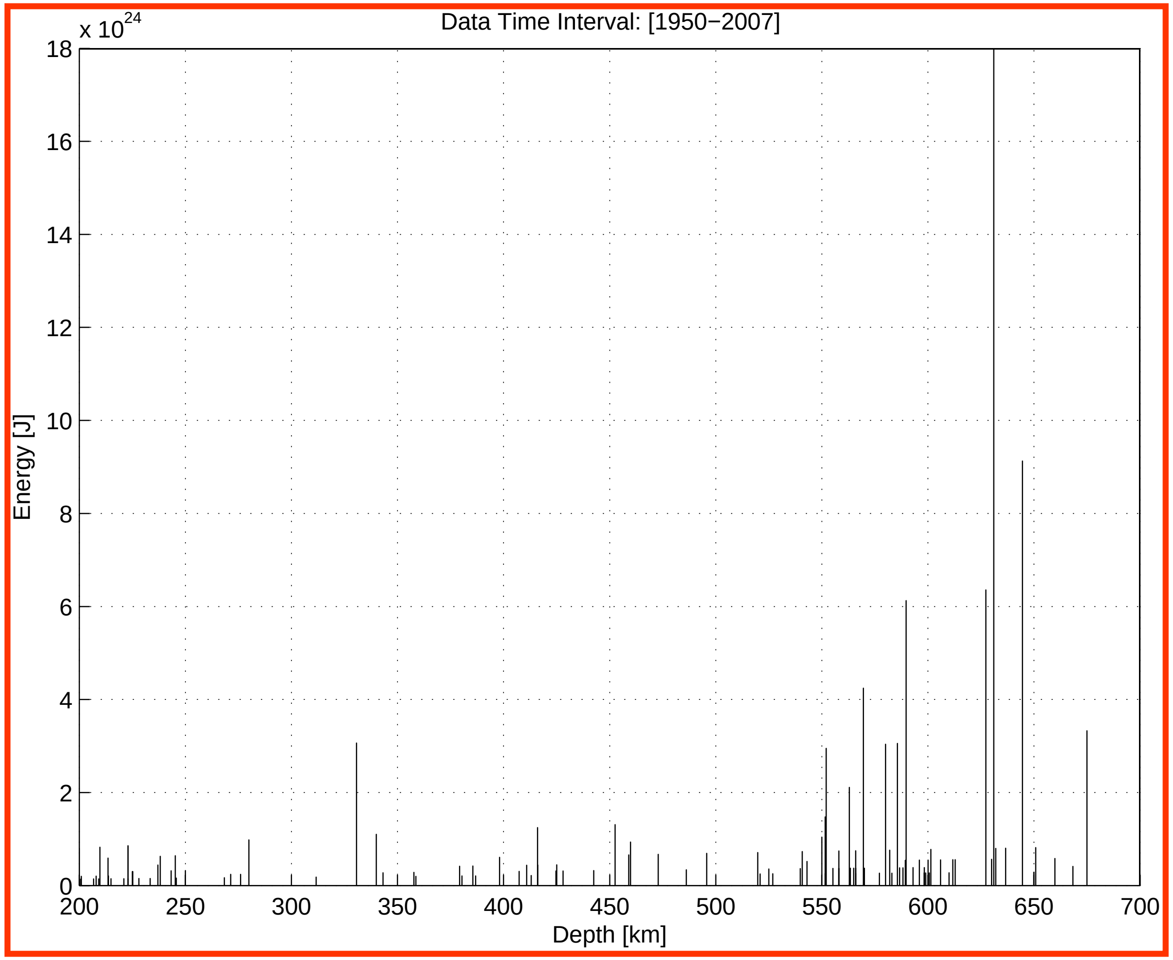
# Depth distribution of earthquake energy

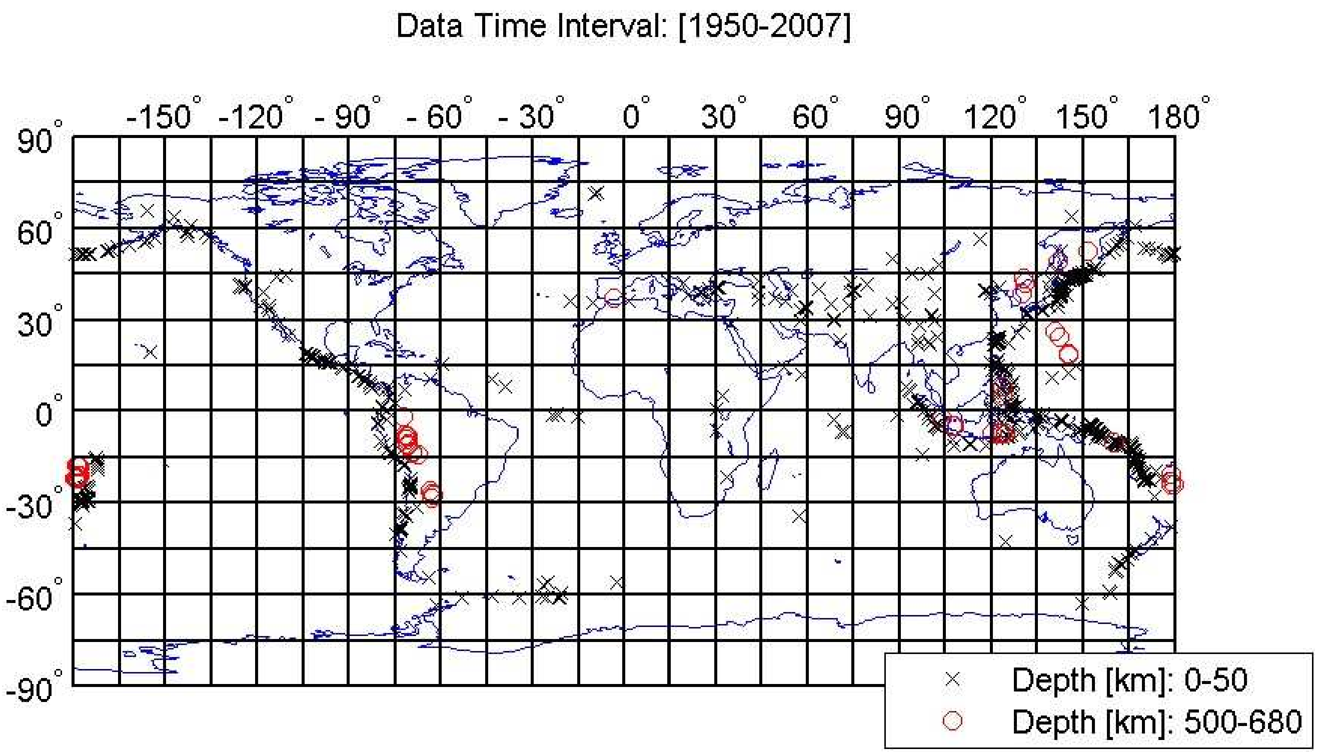


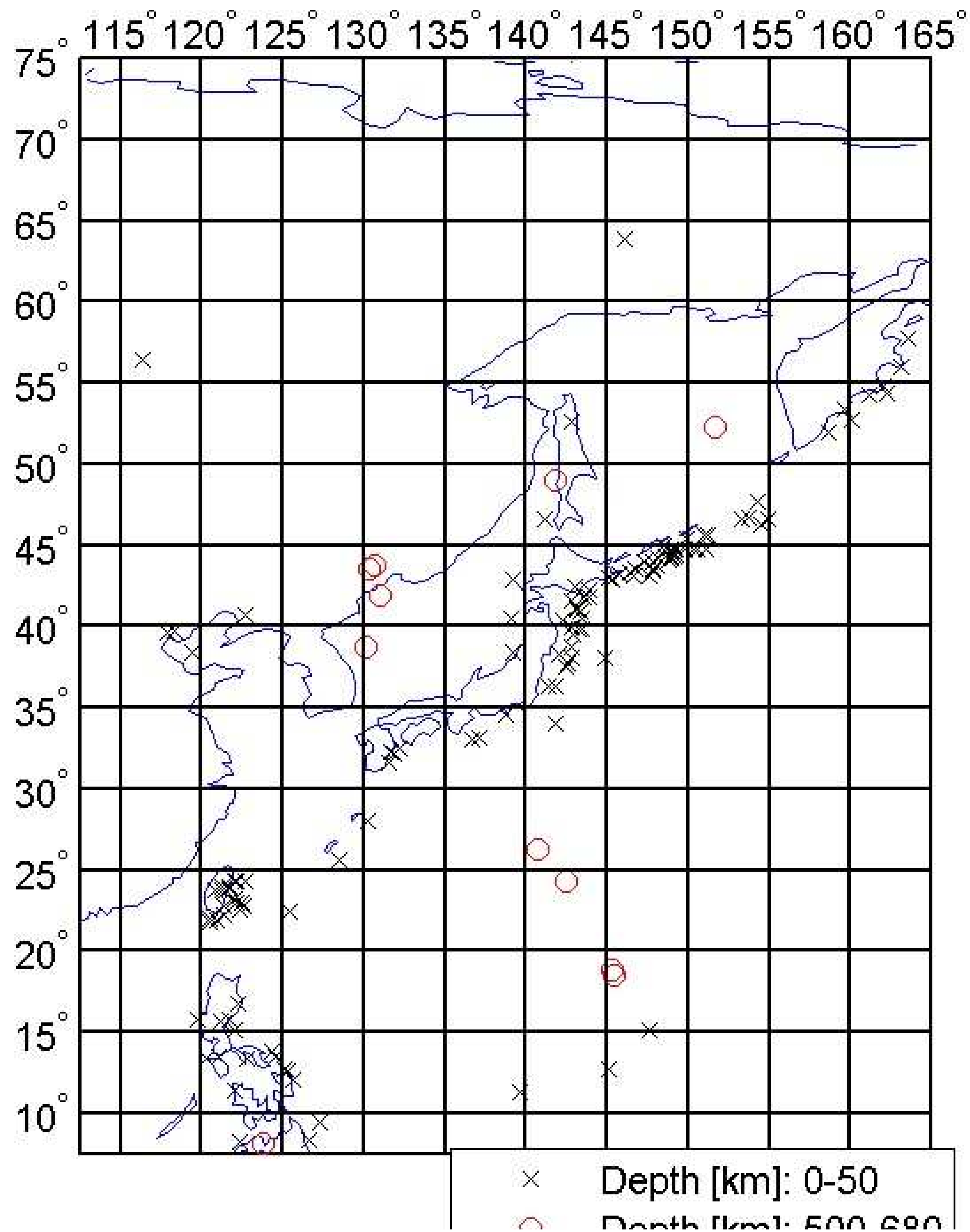

*Distribution of the number and energy of earthquakes $M_W \geq 7.0$ along radius for time interval 1950-2007*



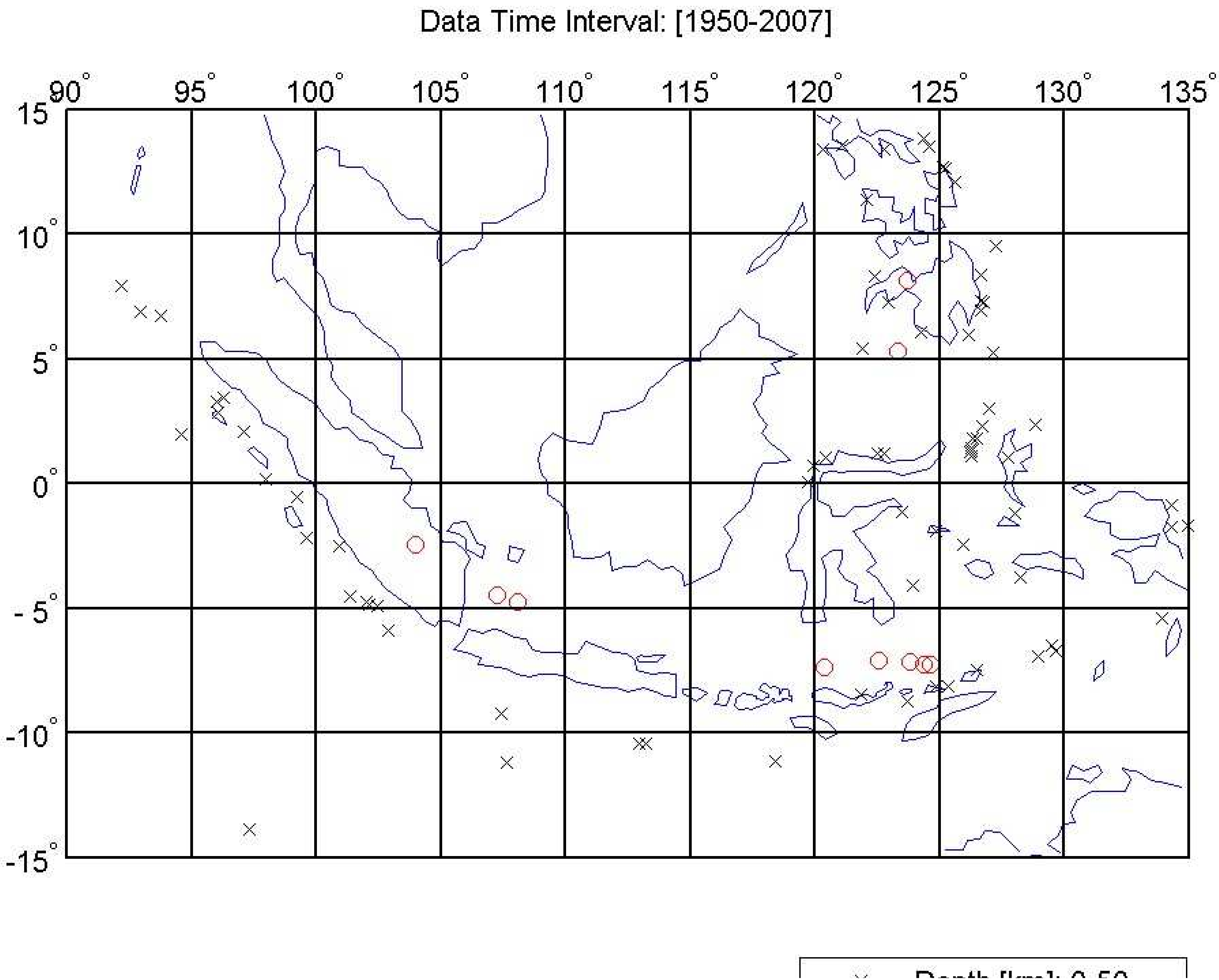


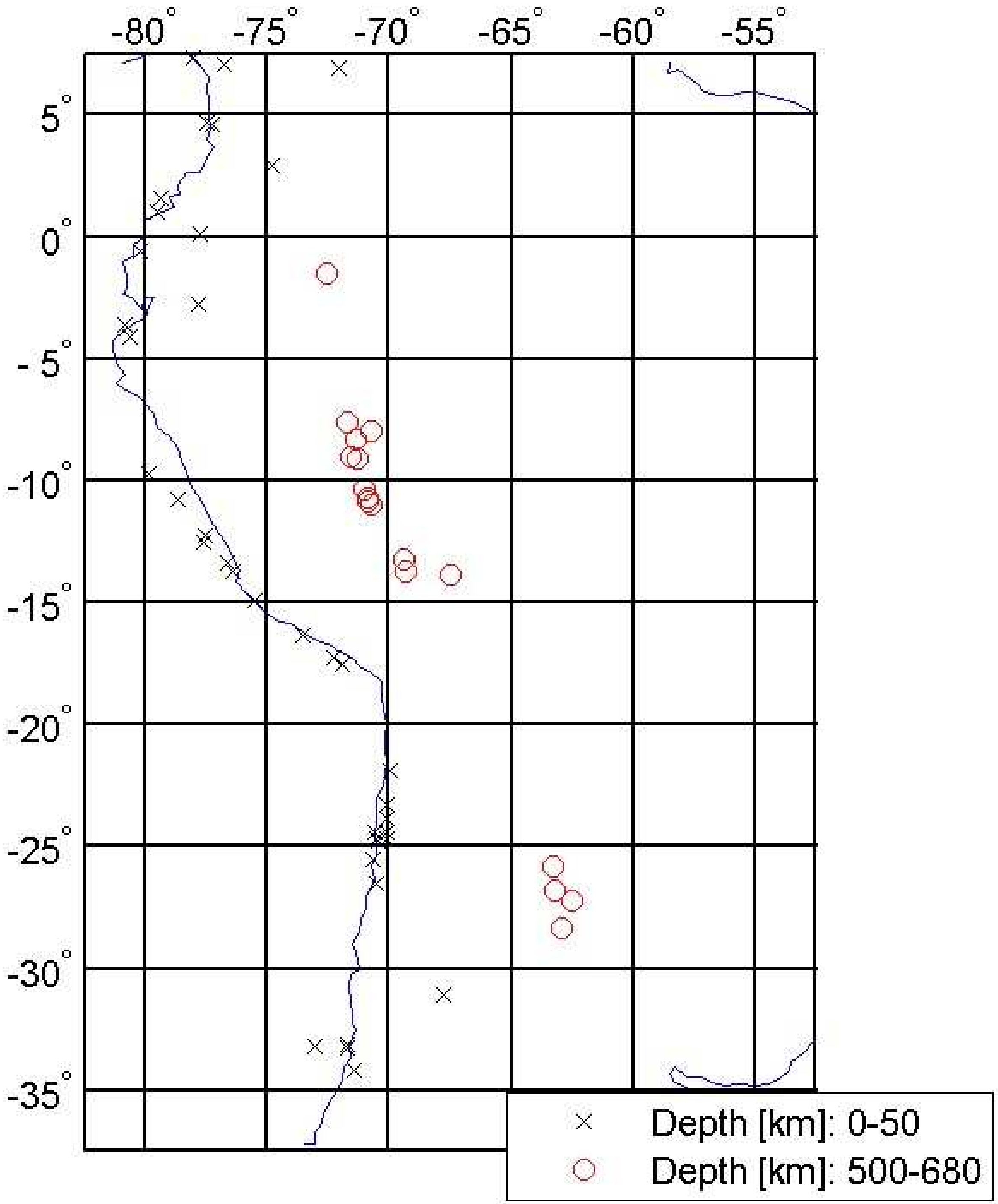

*Earthquake energy released at of depth interval 200-680 km*


Data Time Interval: [1950-2007]
-150°
-120°
- 90°
- 60°
- 30°
0°
30°
60°
90°
120°
150°
180°
90°
60°
30°
0°
-30°
-60°
-90°
Depth [km]: 0-50
Depth [km]: 500-680



115° 120° 125° 130° 135° 140° 145° 150° 155° 160° 165°
75° 70° 65° 60° 55° 50° 45° 40° 35° 30° 25° 20° 15° 10°
Depth [km]: 0-50
Depth [km]: 500-680

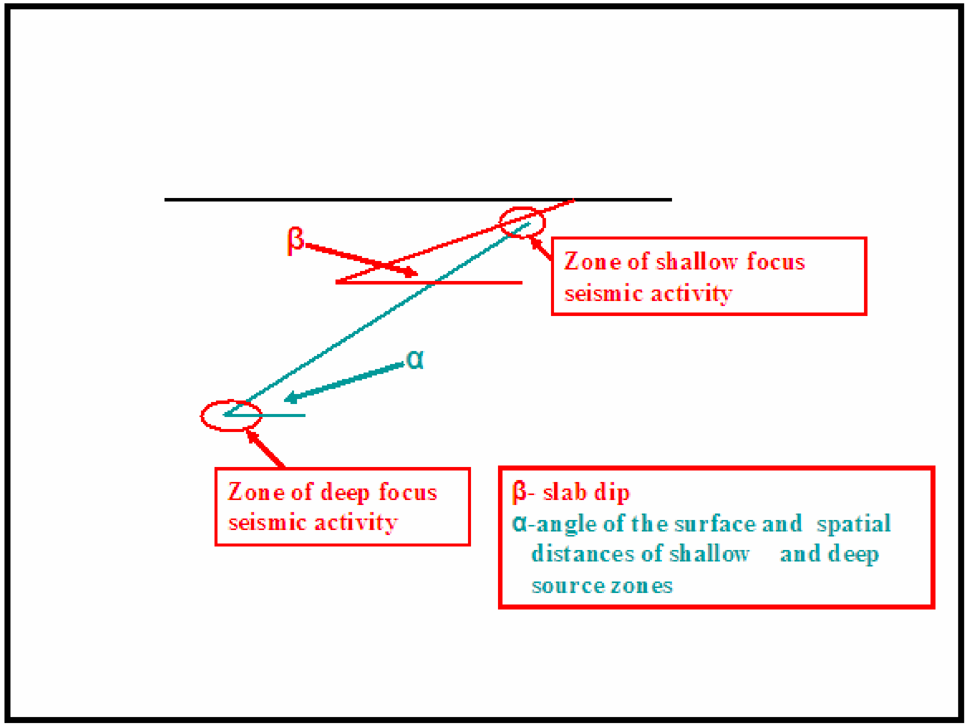

Data Time Interval: [1950-2007]
90°
95°
100°
105°
110°
115°
120°
125°
130°
135°
15°
10°
5°
0°
- 5°
-10°
-15°



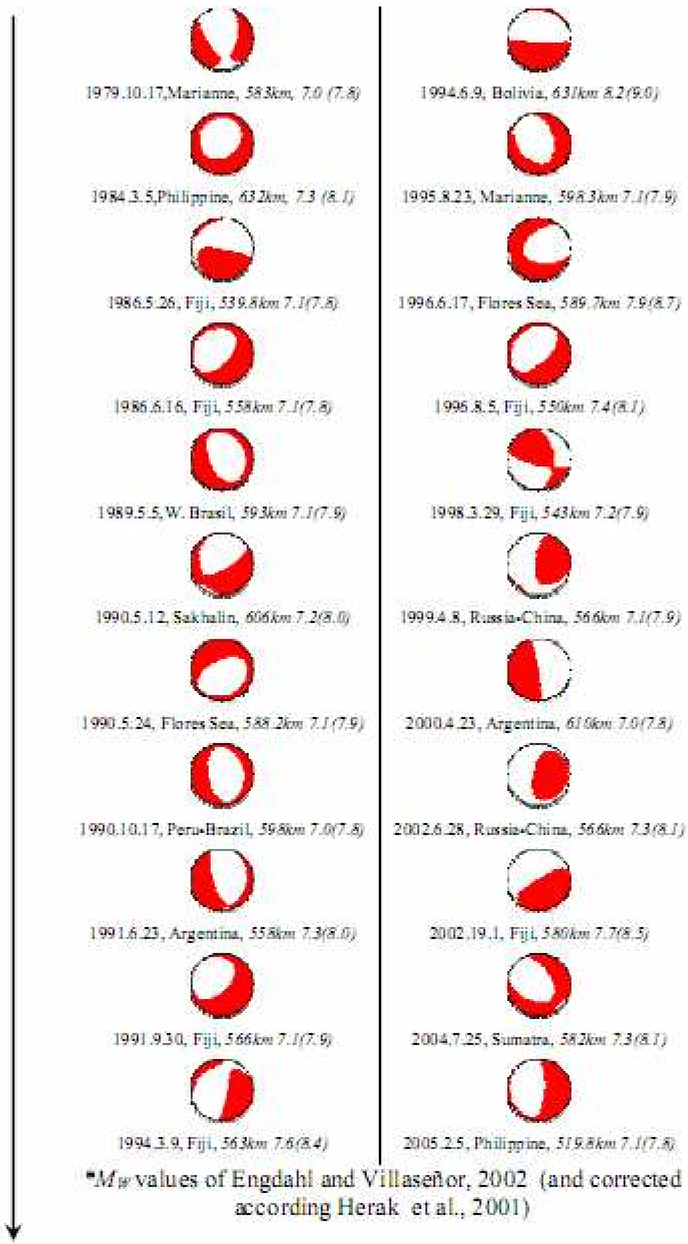
-80°
-75°
-70°
-65°
-60°
-55°
5°
0°
-5°
-10°
-15°
-20°
-25°
-30°
-35°
Depth [km]: 0-50
Depth [km]: 500-680

| Subduction zones with deep earthquake activity | *α*° | *β*° |
|---|---|---|
| Peru | 49 | 15 |
| Chile | 54 | 23 |
| Sumatra | 60 | 32 |
| Banda Sea (Timor) | 74 | 55 |
| Philippine (East Luzon) | 66 | 63 |
| Japan | 42 | 35 |
| Kuriles - Kamchatka | 45 | 45 |
| Kermadec Islands | 55 | 58 |

*Angles of the surface and spatial distances of shallow and deep source zones (α) and slab dips (β)*



Focal mechanisms for earthquakes $M_W \geq 7$* for time-interval 1979-2005 in the vicinity of the bottom of the transition zone ( depth interval 500-680 km)




*$M_W$ values of Engdahl and Villaseñor, 2002 (and corrected according Herak et al., 2001)

# Conclusions

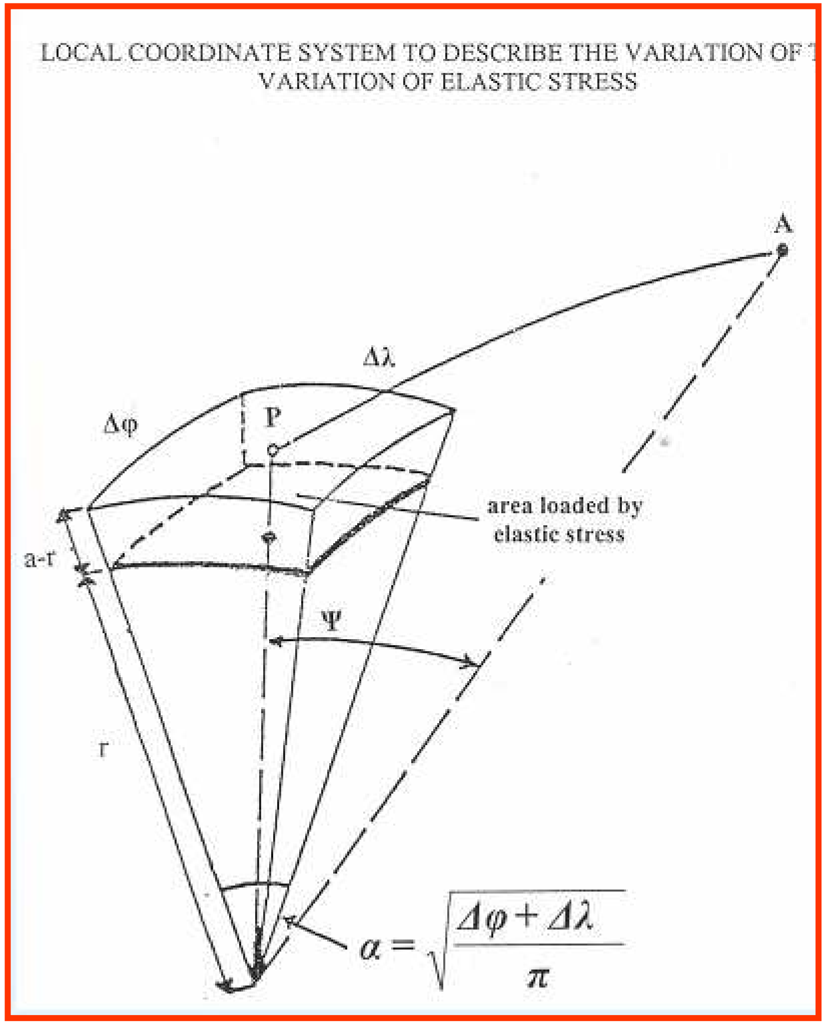
- As it was shown in the first part of the presentation the surface distribution of the radiated earthquake energy has axial symmetry, indicating the presence of an external stress generating force. Due to the fact that the stress accumulating force should be a monotonous not altering force we arrive to the conclusion that it should be the tidal friction. The annual dissipation due to tidal friction is $1.6\times10^{19}$ J/year, while the radiated earthquake energy is $9.5\times10^{18}$ J/year . The energy generated by despinning of the Earth is converted into elastic energy due to deformation of the brittle outermost part of the Earth in the vicinity of the critical latitude first of all due to attenuation of geometrical flattening (during the Phanerozoic the value of flattening has changed by 36%).
- The depth dependent seismic energy release has a discrete distribution along the depth and it is radiated practically only from two different types of sources. The most important earthquake energy source is connected to the seismicity of the brittle crust (~30 km). The deep source of seismic energy is situated at the lower boundary of the transition zone and it is related to the stresses generated during the collision of this surface and lithospheric slabs. It is remarkable that the upper boundary of the transition zone does not show any elastic energy radiation caused by passage of the slabs. Benioff-Wadati zones of E directed slabs consisting of both shallow and deep source zones are bent while the west oriented ones not.

**Until now we investigated spatial distribution of global seismicity and relationship of the earthquake activity and earth rotation.**

**Now we shall raise an another question: can an earthquake influence in mensurable degree the components of the earth rotation vectors, the length of day (LOD) and polar motion (PM)?**

**5. Variation of EOP and the time dependent seismicity**

**5a. Discussion of connection between temporal distribution of earthquake occurrences and LOD variations**




Model for study of surface displacements and gravity variations due to elastic stress accumulation

## Surface displacements and gravity variations

$p_N$ and $p_M$ are the normal (radial) and tangential (horizontal) stresses acting at the depth $a - r$ (where $a$ is the earth's radius) on a spherical surface

$$\Delta\alpha = \sqrt{\frac{\Delta\phi + \Delta\lambda}{\pi}}$$

At the $\psi$ angular distance from the centre of the influenced area the corresponding potentials are

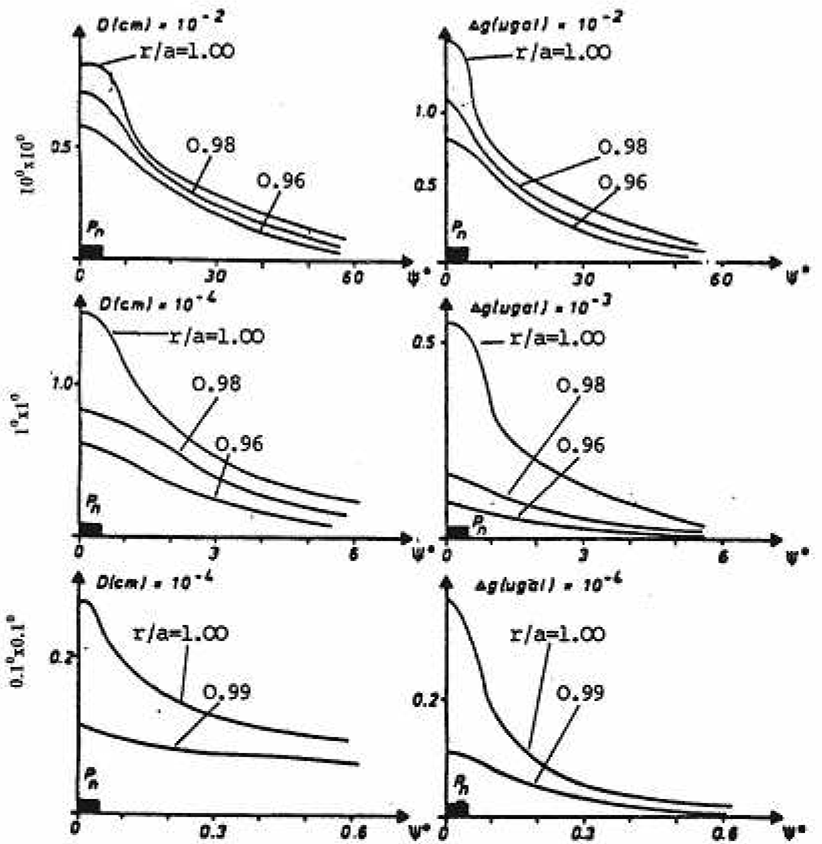
$$V_N = \frac{4\pi G r}{g(r)} \sum_{n=0}^{\infty} p_N(\psi) \left(\frac{r}{a}\right)^{n+1} \frac{1}{2n+1}$$

$$V_M = \frac{4\pi G r}{g(r)} \sum_{n=0}^{\infty} p_N(\psi) \left(\frac{r}{a}\right)^{n+1} \frac{n(n+1)}{2n+1}$$

Both stress components $p_N(\psi)$ and $p_T(\psi)$ can be expanded into Legendre series and the vertical displacements $D_N(\psi)$ and $D_T(\psi)$ on the surface of the Earth can be described with the use of the potential free Love numbers $h_n^N$ and $h_n^T$:

$$D_N = \frac{4\pi G r}{g^2} \sum_{n=0}^{\infty} \frac{h_n^N}{2n+1} p_N(\psi) \left(\frac{r}{a}\right)^{n+1}$$

$$D_M = \frac{4\pi G r}{g^2} \sum_{n=0}^{\infty} \frac{h_n^T n(n+1)}{2n+1} p_N(\psi) \left(\frac{r}{a}\right)^{n+1}$$




- The acting normal elastic stres
  $p_N$ is $10^2$ N/m$^2$ (1 mbar)
- D - surface level displacement
- $\Delta g$ - gravity variation ($\mu$gal)
- r/a - relative depth
- the dark area below $p_N$ shows
  the half of the loaded area

If $\rho(r)$ is the density function the variation of the polar momentum of inertia due to the layer occupying a spherical layer of thickness $D$ is

$$\Delta C = \int_{r}^{r+D}\int_{\phi_1}^{\phi_2}\int_{\lambda_1}^{\lambda_2} \rho(r) r^4 \cos^3\phi \, dr\, d\phi\, d\lambda =$$

$$\frac{(r+D)^5 - r^5}{5}\rho(r)\Delta\lambda\left[\left(\sin\phi_2 - \sin\phi_1\right) - \frac{1}{3}\left(\sin^3\phi_2 - \sin^3\phi_1\right)\right]$$

Since $(r+D)^5 - r^5 \approx r^5\left[\left(1+\frac{D}{r}\right)^5 - 1\right] \approx 5r^4 D$

the $\Delta C$ can be written in the following form $\Delta C \approx r^4 D\rho(r)\Delta\lambda\left[\left(\sin\phi_2 - \sin\phi_1\right) - \frac{1}{3}\left(\sin^3\phi_2 - \sin^3\phi_1\right)\right]$

If an extreme load is considered (the loaded area is 10° ·10° (~10 000 km$^2$) and the vertical displacement is $D$ = 1.0 cm over an area 60° ·60° ~ 3.6 · 10 ^ 5 km $^2$) the anomaly $\Delta C$=7.80·10^27 kgm $^2$ Eq. (33) gives with $C$ = 8.04 · 10 ^ 37 kgm $^2$, and therefore $\Delta LOD = LOD \cdot \Delta C / C$~ 8 microseconds. Due to the fact that the accuracy of the $\Delta LOD$ observations at present is ~10 microseconds it can be concluded that the seismic events are not able to produce any observable for the moment change in LOD.

**5. Variation of EOP and the time dependent seismicity**

**5b. Interaction of polar motion (PM) variations due to earthquakes.**

The magnitude of stresses can be up to (1-10)·10^7 N/m2. These values are typical for stress drops in earthquake foci. For the model used by Love we obtain the normal ($\sigma_\lambda, \sigma_\psi$) and shear ($\tau$) stresses as

$$\sigma_\lambda = \frac{1}{5+\nu} \cdot E \cdot \sin\theta \cdot (\sin^2\lambda + 2) \cdot \sin(2\psi - \theta)$$

$$\sigma_\psi = \frac{1}{5+\nu} \cdot E \cdot \sin\theta \cdot (3\sin^2\lambda - 2) \cdot \sin(2\psi - \theta)$$

$$\tau = -\frac{2}{5+\nu} \cdot E \cdot \sin\theta \cdot \cos \cdot \cos(2\psi - \theta)$$

$\theta$ is the polar shift, $E$ and $\nu$ are the Young modulus and the Poisson ratio while $\psi$ and $\lambda$ are polar coordinates in a system origin of which lies in the equator ($\psi$ is the azimuth angle defined from the great circle and is the spherical distance measured along the azimuth)

The necessary deformation energy which generates the required stresses generated by PM is

$$E_{def} = \frac{\nu + 1}{2E}\left(\sigma_\lambda^2 + \sigma_\psi^2\right) + \frac{\nu + 1}{E}\tau^2 - \frac{\nu}{2E}\left(\sigma_\lambda^2 + \sigma_\psi^2\right)^2$$

With the use of equations for normal and shear stresses

$$E_{def} = \left(\frac{32\pi}{15}\right) \cdot \frac{1}{\nu + 5} \cdot Edr^2 \sin^2\theta$$

$M_0$ (the moment) can be obtained with differentiation respect to the polar shift θ and therefore

$$\theta = \frac{1}{2} \arcsin\left(\frac{15(\nu + 5)M_0}{32\pi Ehr^2}\right)$$

The seismic moment of greatest earthquakes varies between 2.0·10 ^23 Nm (Chile, 1960, Mw=9.5) and 3.5·10^22 Nm (Sumatra, 2004, Mw=9.0). The corresponding PM values are 130 cm and 17 cm. In case of Mw≤8.5 the ΔPM is ≤2 cm. The level of present day accuracy of pole position determination is around 10 cm. This means the pole shift caused by events Mw≤8.5 are on the border of perceptibility and the great Chilean earthquake will be observable in our days.