# ELASTIC ENERGY OF SUPERPOSITION OF THE EARTH TIDES: NEW COMPONENT AND ITS ROLE IN GEODYNAMICAL PROCESSES

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**Abstract.** We have obtained formula for elastic energy of lunisolar tides superposition. It was shown that the full energy is not additive sum of elastic energies of separated tides and contains additional terms of mutual character, which play significant role in geodynamical life of the Earth. Correlation of the extreme variations of the elastic tidal energy of the Earth with earthquakes and moonquakes events (in period 1971-1976 years) was established. This regularity of seismic process have used for prediction of the dates of some large earthquakes in 2003 year. In particular the date of phenomenal Hokkaido quake of 25 September (M=8.3) was predicted with high accuracy.

**Introduction.** The Earth oceanic and elastic shells are deformed due to lunar-solar attraction, due to non-inertial rotational effects in pole motion and others. Different types of tides are observed on the Earth. We have introduced in consideration also a new class of tides of the inner nature. They are caused by gravitational attraction of moving core (rigid and liquid). In classical approximation all these tides are described by linear theory of elasticity. And full effect of Earth deformations is presented as linear superposition of all pointed tides. Tensional state of the Earth is characterized by the elastic energy stored in superposition of tides.

We have obtained formula for elastic energy of tide superposition. Full energy is not additive sum of elastic energies of separated tides and contains additional terms of mutual character. For example mutual action of the Moon and Sun on the Earth mantle generates additional energy with maximal value about 91.6% of elastic energy which is generated by the Moon ( $E_M$ ). Full elastic energy of the lunar-solar tides is changed in diapason 212.6%W- 75.2% $E_M$ . This big change is observed in every orbital period of the Moon.

These additional terms of energy are very important. They are sufficiently big and lead to remarkable conditionally-periodic variations of elastic energy. So pointed variation in  $137.4\% E_M$  sufficiently more then variation of energy caused by eccentricity of the Moon orbit  $67.8\% E_M$ . Full variation of the elastic energy achieves 209.4%W. Also superposition of rotational tide with lunar-solar tides leads to additional elastic energy terms.

Part of elastic energy dissipates and goes to warm energy and to an energization of different geodynamical processes in definite rhythms. In the paper we discuss correlation of the extreme variations of the elastic tidal energy of the Earth with earthquakes and moonquakes events (in period 1971-1976 years). Established regularities of seismic process have let us to predict the dates of some large earthquakes including phenomenal Hokkaido quake of 25 September 2003 with magnitude M=8.3.

### 1 Elastic energies of lunisolar tides in the Earth mantle

We discuss here expression and numerical value of the full energy of mantle deformations caused by lunar and solar attractions. Let us introduce the following geometrical and dynamical notations. 1.  $x_M$ ,  $y_M$ ,  $z_M$  and  $x_S$ ,  $y_S$ ,  $z_S$  are Cartesian coordinates of the Moon and Sun. 2.  $r_M = \sqrt{x_M^2 + y_M^2 + z_M^2}$  and  $r_S = \sqrt{x_S^2 + y_S^2 + z_S^2}$  are corresponding distances between Earth center of mass and the Moon and the Sun consequently. 3.  $\cos S_{MS} = (x_M x_S + y_M y_S + z_M z_S)/r_M r_S$  is a cosine of the angle  $S_{MS}$  between geocentric directions to the Sun and to the Moon. 4.  $a_M$  and  $a_S$  are unperturbed values of major semi-axes of the lunar and solar orbits. 5.  $e_M$  and  $e_S$  are unperturbed values of eccentricities of lunar and solar orbit. 6.  $e_2$  is a elastic coefficient, which can be calculated for example on the base classical solution of problem elasticity theory about lunar–solar tide deformations for some models of the Earth (Getino, Ferrandiz, 1991).

In papers (; Getino, Ferrandiz, 1991; Getino, 1992) it was shown that elastic energies reserved in Earth tides caused by solar attraction are determined by formulae:

$$E_M = e_2 \frac{m_M^2}{r_M^2}, \quad E_S = e_2 \frac{m_S^2}{r_S^2}$$
 (1)

We have shown that full elastic energy of lunar-solar tides E does not equal to sum of mentioned energies (Barkin, Ferrandiz, 2003;  $E \neq E_M + E_S$ ). This effect is caused by quadratic structure of elastic energy and by geometry of Earth mantle deformations. Calculations to proof this statement are not trivial and we do not give their here in short paper but we bring here final expression of elastic tidal energy of the Earth taking into account only second harmonic:

$$E = e_2 \left[ \frac{m_M^2}{r_M^6} + \frac{m_S^2}{r_S^6} + 2 \frac{m_M m_S}{r_M^3} P_2(\cos S_{MS}) \right].$$
(2)

Formula (2) for elastic energy contains new additional term:

$$E_{MS} = e_{MS} P_2(\cos S_{MS}) \text{ where } e_{MS} = 2e_2 \frac{m_M m_S}{r_M^3 r_S^3}.$$
 (3)

It is easy to see that  $e_{MS} = E_{MS}$  by  $S_{MS} = \pi/2$ ;  $3\pi/2$ . In these cases geocentric directions to the Moon and to the Sun are orthogonal.  $e_{MS}$  is a maximal value of energy  $E_{MS}$ . Real values  $E_{MS}$  changes in domain ( $(e_{MS}, -e_{MS}/2)$ . It is worth to remark that energy (2) presents only main term (of second order) of the full development for elastic energy. General expression also was obtained but we omit it in this paper. We confirm and will show below that this additional term of energy is significant and plays important role for geodynamical and geophysical processes.

#### 2 Evaluations of energy values

Let us accept following values of parameters of Earth - Moon - Sun system:

1 a.e. = 149 597 870 km, 
$$a_s = 1.00000101778$$
 a.e.,  $a_M = 384000$  km,  
 $\frac{m_M}{m_E} = 0.012300038$ ,  $\frac{m_E}{m_S} = 3.0034896 \cdot 10^{-6}$ ,  $e_2 = 3.252 \cdot 10^{35} c.g.s.$  (4)

Let's note some simple relations between energies of the Sun and the Moon:

$$E_{S} = E_{M} \frac{m_{S}^{2} r_{M}^{6}}{m_{M}^{2} r_{S}^{6}}, \ e_{MS} = 2\sqrt{E_{M} E_{S}} = 2e_{2} \frac{m_{S} m_{M}}{r_{S}^{3} r_{M}^{3}}, \ e_{MS} = 2E_{M} \frac{m_{S} r_{M}^{3}}{m_{M} r_{S}^{3}}.$$
 (5)

Here  $e_{MS}$  is a coefficient by  $P_2(\cos S_{MS})$  in additional term of full energy (3).

Unperturbed values of energies are obtained on the base values (4) and relations (5) by  $r_M = a_M$ ,  $r_S = a_S$ . Using 1 unit =10<sup>23</sup> c.g.s. we determine:

$$E_M^{(0)} = 5.473$$
 c.g.s.,  $E_S^{(0)} = 1.148$  c.g.s. and  $e_{MS}^{(0)} = 2\sqrt{E_M^{(0)}E_S^{(0)}} = 5.0132$  c.g.s.

## **3** Variations of elastic tidal energy

Maximal value of the full elastic energy of the Earth (the full Moon) is

$$E_{SM}^{\text{max}} = E_S^{(0)} + E_M^{(0)} + 2\sqrt{E_S^{(0)}}E_M^{(0)} = 11.6342 \text{ c.g.s.}$$

Minimal value of this energy (the Moon in quadratures) is

$$E_{SM}^{\min} = E_S^{(0)} + E_M^{(0)} - \sqrt{E_S^{(0)} E_M^{(0)}} = 4.1144 \text{ c.g.s.}$$

and variations of full energy consist  $\Delta E_{SM} = 3\sqrt{E_S^{(0)}E_M^{(0)}} = 7.5198 \cdot 10^{23} \text{ c.g.s.}$  (every sinodic month).

Lunar and solar eccentricity variations of the Earth tidal energy (pericenter-apocenter positions) are determined by formulae:

$$\Delta E_{M} = E_{M}^{(0)} \left[ \frac{1}{(1 - e_{M})^{6}} - \frac{1}{(1 + e_{M})^{6}} \right] = 0.6776 \cdot E_{M}^{(0)} = 3.7084 \cdot 10^{23} \text{ c.g.s.}$$
$$\Delta E_{S} = E_{S}^{(0)} \left[ \frac{1}{(1 - e_{S})^{6}} - \frac{1}{(1 + e_{S})^{6}} \right] = 0.2015 \cdot E_{S}^{(0)} = 0.2314 \cdot 10^{23} \text{ c.g.s.}$$

It means that full variation of the tidal energy can be evaluated as  $11.4596 \times 10^{23}$  c.g.s.



Fig.1 illustrates graphics of variations of elastic energy of the Earth due to Moon and Sun influence and graphic of variation of the full elastic energy of the Earth with taking into account the mutual additional term (3). For illustration we have restricted by interval of time since 1 Jan 2004 till 1 Jan 2005. Behavior of curves on Fig. 1 is in accordance with simple evaluations of average values and of amplitude of variations of elastic energy given above.

# 4 Correlation of earthquakes and moonquakes with variations of elastic energy

Here we study correlation of moments of the earthquakes and moonquakes with moments of the extreme values of Earth elastic energy and Moon elastic energy. We have studied theoretical curves of change of elastic energy of lunar-solar deformations of the Earth mantle and terrestrial-solar deformations on the Moon in period 1971-1976 years. It was shown that the moments of quake events as usually sufficiently close to moments of extreme values of elastic energy. Moments of big earthquakes (with magnitude 7 and 8 and more) and moonquakes in pointed period of time are correlated with moments of elastic energy extremes.

On this base we can suggest that variations of elastic energy are connected with seismic activity. Of course it means that correlation between Moon and Sun orbital motions and planetary seismic process has place in reality. The mutual term of elastic energy is sufficiently big and significantly controls and dictates a seismic process. It seems naturally. Part of elastic energy with every orbital cycle of the Moon (and Sun) dissipates to inner geodynamical processes.

Although it is possible that another or third mechanism exists which controls seismic processes. In present time we study the rule of mechanical interaction between core and mantle (and between lithosphere plates) of the Earth induced by gravitational action of the Moon and Sun on non-spherical Earth's shells (Barkin, 2002).



Fig. 2 Earthquakes and moonquakes events in 1975 year and variations of Earth elastic energy  $(1 \text{ unit } = 10^{23} \text{ c.g.s.}).$ 

For illustration we used date about 26 great shallow earthquakes (with M>7) and about 28 shallow moonquakes from paper (Shirley, 1985/1986) in which was fulfilled analysis of their mutual temporal correlation in 1971-1976 years. Here for simplicity we point temporal positions

of earthquakes (points) and moonquakes (stars) indirectly on the curve of elastic energy variations (Fig.2) only for 1975 year. Sufficiently clearly we observe here simple tendency: 12 from 14 quakes are situated closely to extremes of elastic energy curve. Positions of 3 points correspond to value of elastic energy about 7.7 units.

Analysis of all period of 1971-1975 shows that 45 from 54 quakes points (signs) are situated closely to extreme peaks of elastic energy. 14 points are occupied positions with average character

value 6.0-7.7. Probably mentioned particularities are general for longer period of time (for hundred, thousand and millions years) and are regularities of the seismic process.

Predicted dates of possible big earthquakes in 2004 year and corresponding values of elastic energy of the Earth E (1 unit =10<sup>23</sup> c.g.s.) are presented in the Table 1. The shaded lines correspond to dates for which large earthquakes are improbable.

N	E	Dates	Months	N	Ε	Dates	Months
1	10.3	7.3	Jan.	25	15.6	1.8	Jul.
2	4.7	13.9	Jan.	26	3.5	9.8	Jul.
3	14.9	21.1	Jan.	27	9.3	17.1	Jul.
4	3.2	29.2	Jan.	28	4.5	23.7	Jul.
5	11.2	6.0	Feb.	29	14.7	31.1	Jul.
6	5.1	12.6	Feb.	30	3.2	8.2	Aug.
7	13.2	19.5	Feb.	31	10.1	15.9	Aug.
8	3.1	27.6	Feb.	32	5.0	22.3	Aug.
9	12.5	6.6	Mar.	33	13.5	29.4	Aug.
10	5.2	13.4	Mar.	34	3.1	6.6	Sep.
11	11.5	20.0	Mar.	35	11.5	14.6	Sep.
12	3.1	28.0	Mar.	36	5.3	21.2	Sep.
13	13.8	5.1	Apr.	37	12.1	27.9	Sep.
14	5.0	12.2	Apr.	38	3.1	6.0	Oct.
15	10.2	18.7	Apr.	39	13.1	14.1	Oct.
16	3.2	26.3	Apr.	40	5.1	21.0	Oct.
17	15.0	4.5	May	41	10.9	27.6	Oct.
18	4.4	11.9	May	42	3.2	4.3	Nov.
19	9.4	18.5	May	43	14.9	12.5	Nov.
20	3.5	25.7	May	44	4.6	19.7	Nov.
21	15.7	2.7	Jun.	45	10.2	26.3	Nov.
22	3.9	10.4	Jun.	46	3.4	3.8	Dec.
23	9.1	17.3	Jun.	47	16.2	11.8	Dec.
24	4.0	24.2	Jun.	48	4.1	19.3	Dec.
				49	9.8	26.1	Dec.

Table 1. Dates of potential big earthquakes in 2004 year.

### 5 Prediction of large Earthquakes

Of course earthquakes and moonquakes are observed not for all pointed extreme tidal variations. Probably it is caused by process of accumulation of seismic energy. But in any case we can predict in definite statistical sense the dates of future big earthquakes and moonquakes. In result of analysis of theoretical curve of elastic energy of lunar-solar tides we have determine dates of possible big earthquakes in 2003 years. These dates are: 2.3; 10.4; 18.4; 25.2; 31.9 (January); 8.8; 16.9; 24.0 (February); 2.5; 10.2; 18.3; 25.7 (March); 1.3; 8.6; 16.5; 24.2 (April); 1.1; 8.0; 15.7; 23.7; 30.9 (May); 6.5; 13.9; 22.1; 29.7 (June); 6.2; 13.3; 21.4; 29.4 (July), 5.0; 11.7; 19.8; 28.0 (August); 3.9; 10.4; 18.2; **26.3** (September); 3.6; 10.1; 17.6; 25.6 (October); 2.1; 8.9; 16.0; 23.8 (November); 1.6; 8.7; 15.5; 23.1; 31.0 (December). The first figure of date specifies day of month, and the figure after a point specifies time of earthquake in decimal shares of this day.

In same dates moonquakes can be expected on the Moon. Given approach does not let us to determine region of earthquakes but let us to analyze dates of extreme perturbed states of the Earth caused by gravitational influence of external celestial bodies.

### 6 Prediction date of Japonquakes in September 2003

**Great earthquake with M=8.3.** In our studies and electronic publication (Barkin, Ferrandiz, Navarro, 2003) we have pointed that one from great earthquake must take place on 26.1 September 2003. This date with high accuracy coincides with date of real Japonquake from 25.8 September (19:50:06 UTC) with big magnitude M= 8.3. This phenomenal earthquake has taken place on Hokkaido Island with epicenter location:  $41^{0}78$  N,  $143^{0}86$  E and with depth 27 km. This earthquake was accompanied tsunami with an estimated wave height of 4.0 meters along the southeastern cost of Hokkaido. At least 589 people injured, extensive damage, landslides and power outages occurred and many roads damaged in southeastern Hokkaido. Felt strongly in much of Hokkaido (http://seismosurfing).

More close to predicted date of great earthquake has second Japonquake on 25 September 2003 with M=7.0. It has taken place 25.9 September (21:08 UTC) with big magnitude M= 7.0 at Hokkaido Island. Epicenter has coordinates:  $41^{0}81$  N,  $143^{0}51$  E and with depth 33 km.

Previous deadly earthquakes in this region has taken place in 4 March 1952 (M=8.1), 16 May 1968 (M=7.9) and 15 January 1993 (M=7.6).

The last great earthquake (magnitude 8 or greater) in the world was a magnitude 8.4 that occurred on June 23, 2001, near the coast of Peru.

About mechanism of earthquake. In accordance with interpretation (http://seismosurfing) this earthquake imply that it occurred as the result of thrust-faulting on the plate interface between the overriding North American plate (which extends into the northeast corner of the Eurasian landmass) and the subducting Pacific plate. The Pacific plate is moving west-northwest at a rate of about 8.2 cm per year relative to the North American plate. In addition to experiencing great thrust earthquakes that originate on the interface between the plates, eastern Hokkaido experiences great earthquakes that originate from the interior of subducted Pacific plate. The earthquakes of March 4, 1952, and May 16, 1968 were interface-thrust earthquakes, whereas the earthquake of January 15, 1993 occurred within the interior of the subducted Pacific plate. The recent earthquake appears to have involved rupture of the same section of the plate interface that ruptured in 1952.

Magnitude 8 and greater earthquakes are capable of devastating large areas. The shallow September 25 Hokkaido earthquake occurred about 60 km offshore. If the earthquake had occurred directly beneath a populated region, damage would have more severe.

But from our research it follows, that the Moon renders dynamic influence on seismic process and, in particular on earthquake discussed here to Hokkaido. In what image the Moon participates in the process described above? Apparently, tidal deformations of the Earth, besides at extreme joint influence of the Moon and the Sun, result in additional influences lithosphere plates the friend on an arch. Thus they on miscellaneous prove along borders of plates depending on tidal displacement on a surface of the Earth. And in some areas, as it happened to Hokkaido, they reach (achieve) the maximal values. In result conditions for "gearing" plates in the certain areas of the interface of the cooperating hung and immersed plates in region of island of Hokkaido were created. And further more powerful relative movement of the specified plates results in a failure - push in the specified point which represents an epicenter of earthquake. It is actually the description of work of the trigger mechanism of earthquakes, dictated by an attraction of the Moon.

It is not the unique explanation. The Moon (Sun) renders differential influence on cooperating plates, forcing them cyclically that to nestle to make a start from each other. This phenomenon is caused by a various dynamic structure of lithosphere plates. Thus and this mechanism allows to explain a dynamic role of influence of the Moon on earthquakes. Certainly, we discuss only assumptions which require empirical generalization and in dynamic interpretation here are stated.

Earthquake in Russia-Xinjiang border region with M=7.3. This earthquake has taken place on September 27.5 (11:33:24 UTC), 2003. This date also is close to predicted date 26.1 September, 2003 of possible great earthquake.

This earthquake resulted from stresses originating with the collision of the Indian plate against the Eurasian plate. The collision of the two major plates has generated the Himalayan mountains, far to south of the epicenter of this earthquake, and produces deformation of the Earth's crust over a broad region of central and eastern Asia. In the epicenter region of southern Russia, north-western China, eastern Kazakhstan, and western Mongolia, earthquakes of past decades have been caused by strike-slip faulting (as with this earthquake) and reverse faulting.

This earthquake is the largest in this region since an earthquake on December 20, 1761 that is thought to have a magnitude of about 7.7.

In accordance with our approach the gravitational influence of the Moon and Sun on elastic Earth in days 25-26-27 September, 2003 was very significant comparatively with another dates. As result were realized Hokkaidoquakes. Later gravitational attraction of the Moon and Sun (in condition of extreme value of elastic deformation energy) has led to the realization of trigger mechanism. "To take off from a hook" gearing of Indian and Eurasian plates the Moon and Sun could only 252 years after previous similar state.

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