On the relationship of lunar events to seismic activity and its seasonality.

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A simple online search for the relationship of lunar syzygies and/or perigee to seismic activity on Earth yields literally an enormous number of research papers; some prove the existence of correlation between syzygies and/or perigee and seismic activity on Earth while the others disprove it. Here we consider two relatively small but significant groups of earthquakes: 1) $M \geqslant 8.1$ earthquakes, 2) the strongest earthquakes of the year as well as VEI $\geqslant 5$ volcanic eruptions. We will show that the correlation does exist but it is *seasonal* in the sense that it can be easily observed only during *correlation seasons* which may last from decades to centuries; outside of the correlation seasons, it is obscured by other factors affecting seismic activity. The correlation seasons are different for different types of earthquakes. The seasonality of correlation is at the root of disagreement between the researchers who prove the existence of correlation and those who disprove it; the former, e. g. [1], use data from a time interval significantly overlapping with a correlation season, while the latter, e. g. [2], use data from a time interval only slightly overlapping with a correlation season.

A *full lunar cycle* is a period of 410 - 416 consecutive days which begins and ends with the same lunar phase and contains 14 New Moons, 14 Full Moons, and 15 perigees[1]. The *closest perigee* of a lunar cycle typically comes within hours of New/Full Moon, the *2nd closest perigee* of the same lunar cycle typically comes within hours of Full/New Moon, the closest and 2nd closest perigees of the same full lunar cycle are typically separated by approximately half of the lunar cycle; e.g. in 2015, the closest perigee and Full Moon were less than 2 hours apart on September 28, the 2nd closest perigee and New Moon were less than 8 hours apart on February 19. Occasionally, the 2nd closest perigee may be merely a month away from the closest perigee, e. g. in 1963 the closest perigee and Full Moon were on November 30, the 2nd closest perigee also coincided with Full Moon on November 2, the 3rd closest perigee and New Moon were on April 23; the distance between the Moon and Earth was almost the same at the time of the three perigees.

The percentage of days within n days of New/Full Moon or within $30 + n$ days of the

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closest/2nd closest perigee is given by[2]

$$\approx \frac{140+40\text{n}}{413} \approx \begin{cases} 63\%, \text{ if } n=3 \\ 53.3\%, \text{ if } n=2 \\ 43.6\%, \text{ if } n=1 \\ 33.9\%, \text{ if } n=0 \end{cases} = 63\%/53.3\%/43.6\%/33.9\% \quad (1)$$

A sufficiently large group of earthquakes randomly distributed over a sufficiently large number of lunar cycles should have more or less the same distribution as (1), a distribution considerably higher than (1) indicates correlation between earthquakes and lunar events.

The most powerful earthquakes of 1900 - 2016. Table 1 shows all $M \geqslant 8.2$ earthquakes in 1938 - 2016, 33 in total. The number of $M \geqslant 8.2$ earthquakes within 33/32/31/30 days of the closest/2nd closest perigee or within 3/2/1/0 days of New/Full Moon is 32/28/24/19 or 97%/84.8%/72.7%/57.6% of the total of 33 earthquakes, much higher than (1) pointing towards a strong correlation in 1938 - 2016. As Table 2 shows, the situation cannot be more different in 1900 - 1937; of the twelve $M \geqslant 8.2$ earthquakes listed, the number of earthquakes within 3/2/1/0 days of New/Full Moon or 33/32/31/30 days of closest/2nd closest perigee was 5/3/3/3 or 42%/25%/25%/25% of the total of 12; significantly lower than (1) as if the earthquakes were "repelled" by New/Full Moon and closest/2nd closest perigees rather than "attracted". The correlation season for $M \geqslant 8.2$ earthquakes started in 1938 and still continues.

As the magnitude of earthquakes decreases, the correlation with New/Full Moon and closest/2nd closest perigees gets less pronounced and the correlation season becomes smaller. Table 3 shows M=8.1 earthquakes in 1900 - 2016. In 1948 - 2016 the number of earthquakes within 3/2/1/0 days of New/Full Moon or 33/32/31/20 days of closest/2nd closest perigee was 8/7/7/7 or 80%/70%/70%/70% of the total of 10. pointing towards weak correlation for the earthquakes within 3/2 days of New/Full Moon or within 33/32 days of the closest/2nd closest perigee and very strong correlation for the earthquakes within 1/0 days of New/Full Moon or within 31/30 days of closest/2nd closest perigee. In 1900 - 1947 the number of earthquakes within 3/2/1/0 days of New/Full Moon or 33/32/31/20 days of the closest/2nd closest perigee was 8/8/5/3 or 61.5%/61.5%/38.5%/23%, more or less similar to (1). The correlation season for M=8.1 earthquakes started in 1948 and still continues.

The most powerful earthquakes of the year in 2010 - 2016. The years 2010 - 2014 may be called the years of $M \geqslant 8.2$ earthquakes, there were five of them, averaging one per year; for

Earthquake date and magnitude	Nearby New/Full Moon, perigee, perihelion	Proximity to the closest or 2nd closest perigee	n
2015/9/16 M=8.3	2015/9/13 New Moon	12 days before 2015/9/28 Full Moon-2nd closest perigee	0
2014/4/1 M=8.2	2014/3/30 New Moon		2
2013/5/24 M=8.3	2013/5/25 Full Moon 2013/5/26 perigee	30 days before 2013/6/23 Full Moon-closest perigee	0
2012/4/11 M=8.6	25 days before 20012/5/6 Full Moon-closest perigee		0
2011/3/11 M=9.1	7 days before 2011/3/18-19 Full Moon-closest perigee		0
2010/2/27 M=8.8	2010/2/27-28 Full Moon-perigee	28 days after 2010/1/30 Full Moon-closest perigee	0
2007/9/12 M=8.4	2007/9/11 New Moon		1
2006/11/15 M=8.3			
2005/3/28 M=8.6	2005/3/25 Full Moon		3
2004/12/26 M=9.1	2004/12/26 Full Moon 2005/1/2 perihelion	15 days before 2005/1/10 New Moon-closest perigee	0
2003/9/25 M=8.3	2003/9/26 New Moon, 2003/9/28 perigee		1
2001/6/23 M=8.4	2001/6/21 New Moon, 2001/6/23 perigee		2
1996/2/17 M=8.2	1996/2/17-18 New Moon-perigee		1
1994/10/4 M=8.3	1994/10/5 New Moon	30 days before 1994/11/3 New Moon-2nd closest perigee	0
1994/6/9 M=8.2	1994/6/9 New Moon		0
1989/5/23 M=8.2	1989/5/20 Full Moon		3
1968/5/16 M=8.2	4 days after 1968/5/12 Full Moon-2nd closest perigee		0
1965/2/4 M=8.7	1965/2/1 New Moon	18 days after 1965/1/17 Full Moon-closest perigee	0
1965/1/24 M=8.2	7 days after 1965/1/17 Full Moon-closest perigee		0
1964/3/28 M=9.2	1964/3/28 Full Moon		0
1963/10/13 M=8.5	20 days before 1963/11/2 Full Moon-2nd closest perigee		0
1960/5/22 M=9.5	1960/5/25 New Moon	16 days before 1960/6/9-10 Full Moon-2nd closest perigee	0
1958/11/6 M=8.3	24 days after 1958/10/13 New Moon-2nd closest perigee		0
1957/3/9 M=8.6	23 days after 1957/2/14 Full Moon-closest perigee		0
1952/11/4 M=9.0	1952/11/1 Full Moon		3
1950/12/9 M=8.2	1950/12/9 New Moon-closest perigee		0
1950/8/15 M=8.6	1950/8/13 New Moon		2
1949/8/22 M=8.2	1949/8/24 New Moon, 1949/8/25 perigee		0
1946/12/20 M=8.3	1946/12/23 New Moon	11 days after 1946/12/9 Full Moon-closest perigee	0
1946/4/1 M=8.6	1946/4/2 New Moon, 1946/4/3 perigee		1
1940/5/24 M=8.2	1940/5/21 Full Moon		3
1938/11/20 M=8.3	1938/11/22 New Moon		2
1938/2/1 M=8.5	1938/1/31 New Moon		2

Table 1: $M \geqslant 8.2$ earthquakes in 1938 - 2016, 33 in total, [3]. Aftershocks, regardless how powerful they were, are not listed.

Earthquake date and magnitude	Nearby New/Full Moon, perigee, perihelion	Proximity to the closest or 2nd closest perigee	n
1933/3/2 M=8.4	Followed 1933/1/8 VEI=5 eruption of Kharimkotan nearby		
1923/2/3 M=8.4	1923/2/3 Full Moon		0
1922/11/11 M=8.5			
1920/12/16 M=8.3	10 days before 1920/12/26 Full Moon-closest perigee		0
1920/6/5 M=8.2	11 days before 1920/6/16 New Moon-2nd closest perigee		0
1918/8/15 M=8.3			
1917/5/1 M=8.2			
1906/8/17 M=8.2 in Chile	1906/8/20 New Moon		3
1906/8/17 M=8.3 in Alaska	1906/8/20 New Moon		3
1906/1/31 M=8.8			
1905/7/23 M=8.3			
1905/7/9 M=8.3			

Table 2: Magnitude $\geqslant 8.2$ earthquakes in 1900 - 1937, 12 in total, [3]. Aftershocks are not listed.

comparison, in 1900 - 2009 there were only 39 earthquakes of $M \geqslant 8.2$ averaging merely 0.3578 per year. Even more importantly, in 2010 - 2016 the most powerful earthquakes of the year showed remarkable correlation with Full Moon-closest perigee; the particulars are shown in Tables 4, 5. If the pattern continues, the next most powerful earthquake of the year should strike within 33 days of the next Full Moon-closest perigee on January 1, 2018; Full Moon and perigee will be only four hours apart and only three days away from the January 3, 2018 perihelion. In 2010 - 2016, the number of the strongest earthquakes of the year within 33/32/31/30 days of the closest/2nd closest perigee or within 3/2/1/0 days of a New/Full Moon was 7/6/6/4 or 100%/85.7%/85.7%/57% of the total of 7, pointing towards a strong correlation.

The pattern does not extend to previous years, Table 6 shows that the most powerful earthquakes of 1990 - 2009 did not correlate with New/Full Moon and closest/2nd closest perigee in the same manner; yet of the 20 years, the strongest earthquake of the year struck within 33/32/31/30 days of closest/2nd closest perigee or within 3/2/1/0 days of New/Full Moon in 17/14/12/9 years or 85%/70%/60%/45% of the total of 20, indicating correlation of the earthquakes with New/Full Moon and closest/2nd closest perigees, yet not as good as that in 2010 - 2016.

One contributing factor to a better correlation in 2010 - 2016 of the strongest earthquakes of the year with Full Moon-closest perigee might be the extremely low level of solar activity; with

Earthquake date and magnitude	Nearby New/Full Moon, perigee or perihelion	Proximity to the closest or 2nd closest perigee	n
2009/9/29 M=8.1			
2007/4/1 M=8.1	16 days before 2007/4/17 New Moon-2nd closest perigee		0
2007/1/13 M=8.1	10 days after 2007/1/3 New Moon-perihelion		0
2004/12/23 M=8.1	2004/12/26 Full Moon	18 days before 2005/1/10 New Moon-closest perigee	0
1998/3/25 M=8.1	3 days before 1998/3/28 New Moon-2nd closest perigee		0
1971/7/26 M=8.1	1971/7/22 New Moon		
1966/10/17 M=8.1	28 days after 1966/9/14 New Moon-2nd closest perigee		0
1963/11/4 M=8.1	26 days before 1963/11/30 Full Moon-closest perigee 2 days after 1963/11/2 Full Moon-2nd closest perigee		0
1957/12/4 M=8.1	1957/12/7 Full Moon		3
1952/03/4 M=8.1	18 days after 1952/2/14 New Moon/2nd closest perigee		0
1945/11/27 M=8.1	37 days after 1945/10/21 Full Moon-closest perigee		
1944/12/7 M=8.1			
1943/4/6 M=8.1	1943/4/4 New Moon		2
1942/8/24 M=8.1	1942/8/26 Full Moon		2
1939/12/21 M=8.1			
1932/6/3 M=8.1	1932/6/4 New Moon		1
1929/6/27 M=8.1	20 days before 1929/7/6 New Moon-closest perigee		0
1923/9/1 M=8.1			
1920/9/20 M=8.1			
1919/4/30 M=8.1	1919/4/30 New Moon-2nd closest perigee		0
1918/9/7 M=8.1	1918/9/5 New Moon		2
1914/5/26 M=8.1	1914/5/25 New Moon		1
1910/4/12 M=8.1	2 days after 1910/4/10 New Moon-2nd closest perigee		0

Table 3: Magnitude 8.1 earthquakes in 1900 - 2016; 23 in total, [3]. The 1960/5/21 foreshock to the 1960/5/22 magnitude 9.5 earthquake is not shown. The 2007/1/13 earthquake struck 10 days after 2007/1/3 New Moon-perihelion, when the effect of New Moon was amplified by perihelion, making it similar to closest/2nd closest perigee when the effect of New/Full Moon is amplified by perigee.

the solar activity at its lowest, the effect of the Moon on earthquakes becomes more pronounced. But that may not be the only factor. The correlation of the most powerful earthquakes to Full Moon-closest perigees may be also related to a rare event of Full Moon coming within less than 66 minutes of the closest perigee of the year for five years in a row: on 2011/3/11, 2012/5/6, 2013/6/23, 2014/8/10, 2015/9/28 Full Moon and the closest perigee were correspondingly 59, 2, 23, 27, and 65 minutes apart.

Every 54 years, lunar phases, perigees, perihelions and 11-year solar cycles "almost' repeat themselves[3]; we may expect a period starting with 1956 to be somewhat similar to 2010 - 2016.

Earthquake date and magnitude	Nearby lunar/solar events	Proximity to Full Moon-closest perigee of the year	n
2010/2/27 M=8.8	2010/2/27-28 Full Moon-perigee	21 days after 2010/1/30 Full Moon-closest perigee	0
2011/3/11 M=9.1	2011/3/9 X1.5 solar flare	8 days before 2011/3/19 Full Moon-closest perigee	0
2012/4/11 M=8.6	2012/4/6-7 Full Moon-perigee	25 days before 2012/5/6 Full Moon-closest perigee	0
2013/5/24 M=8.3	2013/5/25-26 Full Moon-perigee 2013/4/27-5/13 γ-ray blast 2013/5/13-14 X2.8-3.2 solar flares	31 days before 2013/6/23 Full Moon-closest perigee	1
2014/4/1 M=8.2	2014/3/30 New Moon, 2014/3/29 X.1 solar flare		1
2015/9/16 M=8.3	2015/9/13 New Moon	12 days before 2015/9/28 Full Moon-closest perigee	0
2016/12/17 M=7.9	2016/12/14 Full Moon	33 days after 2016/11/14 Full Moon-closest perigee	3

Table 4: Most powerful earthquakes of the year in 2010-2016; aftershocks are not shown, [3].

2010/1/30	2011/3/19	2012/5/6	2013/6/23	2014/8/10	2015/9/28	2016/11/14
2010/2/27			2013/2/6			
	2011/3/11					2016/3/2
2010/4/6		2012/4/11		2014/4/1	2015/4/25	2016/4/18
			2013/5/24		2015/5/30	
				2014/6/23		
	2011/7/6					
					2015/9/16	
2010/10/25		2012/10/28				
						2016/11/13
						2016/12/17
8.8,7.8,7.8	9.1, 7.6	8.6, 7.8	8.0, 8.3	8.2, 7.9	7.8,7.8,8.3	7.8,7.8,7.8,7.9

Table 5: Most powerful earthquakes in 2010-2016, [3]. Above the horizontal line are the dates of the closest perigees of the year, all coincided with Full Moon. Below the horizontal line are the dates of the earthquakes of the two highest magnitudes; fore/aftershocks are not shown. Underlined are the strongest earthquakes of the year. The strongest earthquake of the year struck within 33 days of the Full Moon-closest perigee every year but 2014. An earthquake of the highest/2nd highest magnitude struck in March - May every year. The only strongest earthquakes of the year that was more more than 33 days away from Full Moon-closest-perigee was on 2014/4/1, right after 2014/3/30 New Moon and 2014/3/29 X.1 solar flare, it was part of the March - May pattern.

Indeed, as shown in Table 7, in 1956 - 1968, the number of strongest earthquakes of the year within 33/32/31/30 days of the closest/2nd closest perigee or within 3/2/1/0 days of New/Full Moon was 13/11/10/9 or 100%/84.6%/76.9%/69.2% of the total of 13, pointing towards strong correlation of the earthquakes to New/Full Moon and closest/2nd closest perigees. The periods of 1956 -

Earthquake date and magnitude	Nearby lunar/solar events	Full/New Moon-closest/2nd closest perigee of the year	n
2009/9/29 M=8.1			
2008/5/12 M=7.9		22 days before 2008/6/3 New Moon-2nd closest perigee	0
2007/9/12 M=8.4	2007/9/11 New Moon		1
2006/11/15 M=8.3			
2005/3/28 M=8.6	2005/3/25 Full Moon		3
2004/12/26 M=9.1	2004/12/26 Full Moon 2005/1/4 perihelion	14 days before 2005/1/10 New Moon-closest perigee	0
2003/9/25 M=8.3	2003/9/26 New Moon, 2003/9/28 perigee		1
2002/11/3 M=7.9	1 day before 2002/11/4 New Moon-2nd closest perigee		0
2001/6/23 M=8.4	2001/6/21 New Moon, 2001/6/23 perigee		2
2000/11/16 M=8.0			
1999/9/20 M=7.7	1999/9/17 solar flare		
1998/3/25 M=8.1	1998/2/26-27 New Moon-perigees	3 days before 1998/3/28 New Moon-2nd closest perigee	0
1997/10/14 M=7.8	1997/10/15-16 Full Moon-perigee	29 days after 1997/9/16 Full Moon-2nd closest perigee	0
1997/12/5 M=7.8	1997/11/6-27 X9.4, X2.6 solar flares		
1996/2/17 M=8.2	1996/2/17-18 New Moon-perigee	30 days after 1996/1/19 New Moon-2nd closest perigee	0
1995/7/30 M=8.0	1995/7/27 New Moon		
1995/10/9 M=8.0	1995/10/8 Full Moon		1
1994/10/4 M=8.3	1994/10/5-6 New Moon-perigee	28 days before 1994/11/3 New Moon-2nd closest perigee	0
1993/8/8 M=7.8			
1992/12/12 M=7.8	1992/12/9 Full Moon		3
1991/4/22 M=7.6			
1991/12/22 M=7.6	1991/12/22 Full Moon-perigee	28 days before 1992/1/19 Full Moon-closest perigee	0
1990/4/18 M=7.8	29 days before 1990/5/24 New Moon-2nd closest perigee		0

Table 6: Most powerful earthquakes of the year for 1990-2009, [3]. Aftershocks, regardless of how powerful they were, are not shown.

1968 and 2010 - 2016 exhibit stronger correlation for the strongest earthquakes of the year then the period of 1969 - 2009. The 2010 - 2016 correlation season may, and most likely will, continue beyond 2016; however, as the paper is written in 2017, no data are available beyond 2016.

Volcanic eruptions with VEI $\geqslant 5$ in 1600 - 2016. Unlike earthquakes which strike at a certain moment of time, volcanic eruptions may take weeks, months or even years to develop, often inside the volcanoes, invisible to human eye; so it is somewhat difficult to correlate them to lunar events. However, Table 8, with all VEI $\geqslant 5$ eruptions in 1600 -2016, reveals an interesting

Earthquake date and magnitude	Nearby lunar/solar events	Full/New Moon-closest/2nd closest perigee of the year	n
1956/7/9 M=7.7	1 day after 1956/7/8 New Moon-closest perigee		0
1957/3/9 M=8.6	23 days after 1957/2/14 Full Moon-closest perigee		0
1958/11/6 M=8.6	23 days after 1958/10/23 New Moon-2nd closest perigee		0
1959/5/4 M=7.9	1959/5/7 New Moon	18 days before 9/5/22 Full Moon-closest perigee	0
1960/5/22 M=9.5	1960/5/25 New Moon		3
1961/8/19 M=7.7	6 days before 1961/8/25 Full Moon-2nd closest perigee		0
1962/5/21 M=7.5	1962/5/19 Full Moon		2
1963/10/3 M=8.5	30 days before 1963/11/2 Full Moon-2nd closest perigee		0
1964/3/28 M=9.2	1964/3/28 Full Moon		0
1965/2/4 M=8.7	1965/2/1 New Moon	within 14 days of 1965/1/17 Full Moon-closest perigee	0
1966/10/17 M=8.1	1966/10/14 New Moon 1966/10/13 perigee	33 days after 1966/9/14 New Moon-2nd closest perigee	3
1967/7/22 M=7.4	1967/7/21 Full Moon		1
1968/5/16 M=8.2	4 days after 1968/5/12 Full Moon-2nd closest perigee		0

Table 7: Most powerful earthquakes of the year for 1956 - 1968, 13 in total, [3].

pattern: the columns are separated by 81 ± 5 years, with only a few exceptions that do not fit in Table 8. That VEI $\geqslant 5$ eruptions recur after 81 ± 5 years, might be due to the 81-year periodicity in lunar behavior[4]. The number of years between the 1st and 2nd rows, the 3rd and 4th rows and the 5th and 6th rows is ≈ 20, while the number of years between the 2nd and 3rd rows, and the 4th and 5th rows is ≈ 10; the reason for that is not clear. Even deviations from the pattern seem to compensate each other; e.g. the number of years between the 1963 eruption and the 1956 eruption is 7, the number of years between the 1956 eruption and the 1932-1933 eruptions is 23 - 24, the 1956 eruption seems to be 3 years overdue; if it had struck in 1953, it would have fit the pattern much better.

The pattern of Table 8 is sharper near the upper left corner but gets fuzzier as we move towards the lower right corner and most likely will disappear if we add pre-1600 earthquakes. That suggests that the pattern has a finite life span, somewhat like a correlation season; with time it will too disappear.

Discussion. Tables 1, 2, 3 show strong correlation between lunar events and seismic activity during correlation seasons. The earthquakes of 1905/7/23, 1905/7/9, 1906/1/31, 1917/5/1, 1918/8/15, 1920/9/20, 1922/11/11, 1923/9/1, 1933/3/2, 1944/12/7, which do not show correlation with lunar

	1st column		2nd column		3rd column		4th column		5th column
	Date, volcano, VEI, location		Date, volcano, VEI, location		Date, volcano, VEI, location		Date, volcano, VEI, location		Date, volcano, VEI, location
1st row	**2011/6/3** Puyehue, 5 $41^{\circ}S, 72^{\circ}W$	78-80 years	**1933/1/8** Kharimkotan,5, $49^{\circ}N, 154^{\circ}E$ **1932/4/10** Cerro Azul, 6, $36^{\circ}S, 71^{\circ}W$	78-80 years	**1854/2/18** Shiveluch, 5, $57^{\circ}N, 161^{\circ}E$				
	19-20 years		20 - 21 years		19-20 years				
2nd row	**1991/8/8-12** Hudson, 5, $46^{\circ}S, 73^{\circ}W$ **1991/6/15** Pinatubo, 6, $15^{\circ}N, 120^{\circ}E$	78-80 years	**1913/1/20** Colima, 5, $19^{\circ}N, 104^{\circ}W$ **1912/6/6** Novarupta, 6, $58^{\circ}N, 155^{\circ}W$	77-78 years	**1835/1/20** Cosiguina, 5, $13^{\circ}N, 88^{\circ}W$	79-80 years	**1755/10/17** Katla, 5, $64^{\circ}N, 19^{\circ}W$	82-83 years	**1673/5/20** Gamkonora, 5, $1^{\circ}N, 128^{\circ}E$
	9 - 11 years		10 - 11 years		13 years		15-16 years		9-10 years
3rd row	**1982/5/28** El Chichon, 5, $17^{\circ}N, 93^{\circ}W$ **1980/5/18** St. Helens, 5, $46^{\circ}N, 122^{\circ}W$	78-80 years	**1902/4/24** Santa Maria, 5-6, $15^{\circ}N, 92^{\circ}W$	79-80 years	**1822/10/8** Galunggung,5, $7^{\circ}S, 108^{\circ}E$	82-83 years	**1739/8/** Tarumai, 5, $43^{\circ}N, 141^{\circ}E$	76 years	**1663/8/16** Usu, 5, $43^{\circ}N, 141^{\circ}E$
	17 - 19 years		16 - 19 years		22 - 23 years		18-19 years		20-23 years
4th row	**1963/3/17** Agung, 5, $8^{\circ}S, 116^{\circ}E$	77-80 years	**1886/6/10** Tarawera, 5, $38^{\circ}S, 177^{\circ}E$ **1883/8/27** Krakatoa, 6, $6^{\circ}S, 105^{\circ}E$	82-86 years	**1800** St. Helens, 5, $46^{\circ}N, 122^{\circ}W$	78-79 years	**1721/5/11** Katla, 5, $64^{\circ}N, 19^{\circ}W$	80-81 years	**1640/7/31** Komaga-take,5, $42^{\circ}N, 141^{\circ}E$
	7 years		8-11 years		7-8 years		14 years		14-15 years
5th row	**1956/3/30** Bezymianny 5, $56^{\circ}N, 161^{\circ}E$	81 years	**1875/3/29** Askja, 5, $65^{\circ}N, 17^{\circ}W$	81-82 years	**1793** Alaid, 4-5, $51^{\circ}N, 156^{\circ}W$	85-86 years	**1707/12/16** Fuji, 5, $35^{\circ}N, 139^{\circ}E$	82-83 years	**1625/9/2** Katla, 5, $64^{\circ}N, 19^{\circ}W$
	23-24 years		21 years						25-26 years
6th row	**1933/1/8** Kharimkotan,5, $49^{\circ}N, 154.5^{\circ}E$ **1932/4/10** Cerro Azul, 6, $36^{\circ}S, 71^{\circ}W$	78-80	**1854/2/18** Shiveluch, 5, $57^{\circ}N, 161^{\circ}E$						**1600/2/19** Huaynaputina,6, $17^{\circ}S, 71^{\circ}W$
The 1907/3/28 VEI=5 eruption of Ksudach at $52^{\circ}N, 158^{\circ}E$ and the 1815/4/10 VEI=7 eruption of Tambora at $8^{\circ}S, 118^{\circ}E$ do not fit in the Table. VEI$\geqslant$ 5 eruptions seem to be missing around 1775 and 1695. There may have been a VEI$\geqslant$ 5 eruption of an unknown volcano in South Pacific in 1808 - 1809 and a VEI=6 eruption of Long Island at $5^{\circ}S, 147^{\circ}E$ in 1640-1700.										

Table 8: Volcanic eruptions with VEI $\geqslant$5 in 1600 - 2011; earthquakes were selected if they were listed as VEI $\geqslant$5 in at least one of the references [4], [5], [6]; only the data after 1800 may be considered reliable, data for 1600 - 1800 should be treated with care. The cells with the word "year" indicate years between the eruptions in the adjacent cells. Coordinates are rounded off to the nearest degree.

events, and the 1907 eruption of Ksudach, which does not fit the pattern of Table 8, occurred in 1905 - 1944. It was the time of many wars, civil unrest, the 1917 - 1921 Russian civil war, two

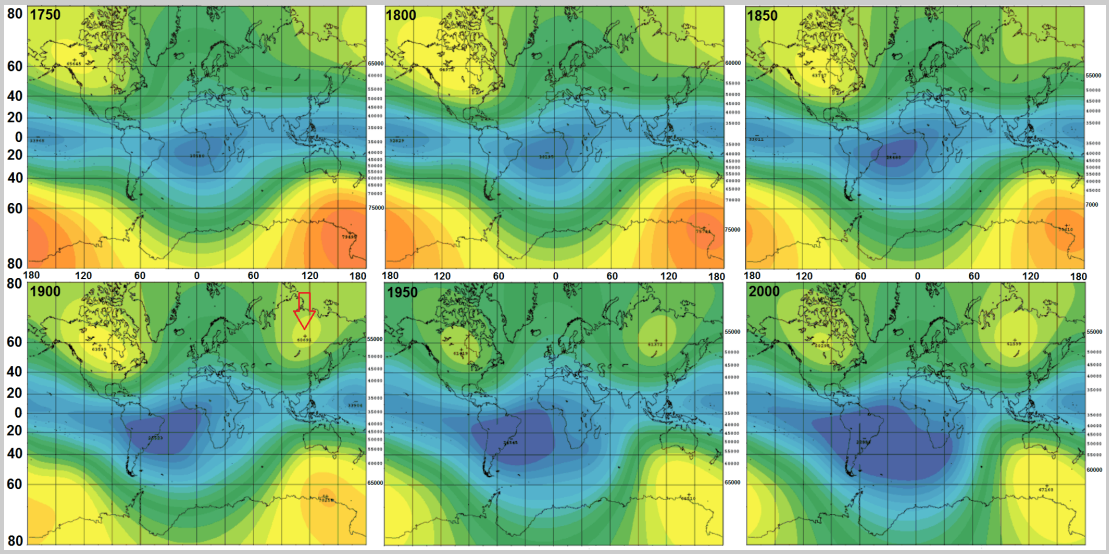

Figure 1: Total intensity of the Earth's magnetic field in nT for 1750 - 2000, [7]. In 1600 - 1850 there were two maxima of total intensity of the Earth's magnetic field: one near Antarctica and one in North America. A third maximum in Asia just north of lake Baikal, pointed to by an arrow in frame '1900', appeared some time in 1850 - 1900 and by 2015 superseded the maximum in North America.

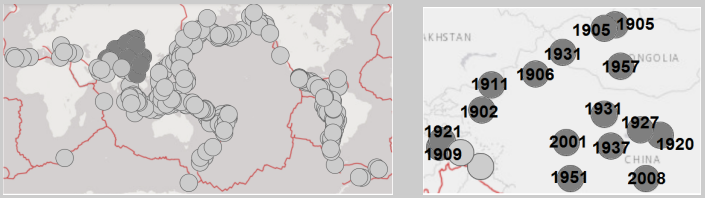

Figure 2: The left frame shows earthquakes of $M \geqslant 7.6$ in 1900 - 2016; almost all, shown in light gray, struck in/close to water. A few, shown in dark gray, struck far from water and off tectonic lines.The right frame zooms in on the latter showing the year of each of them. Of the 16 $M \geqslant 7.6$ earthquakes that struck far from water, 6 struck in 1902 - 1911, 6 in 1920 - 1937, and only 4 in 1932 - 2016.

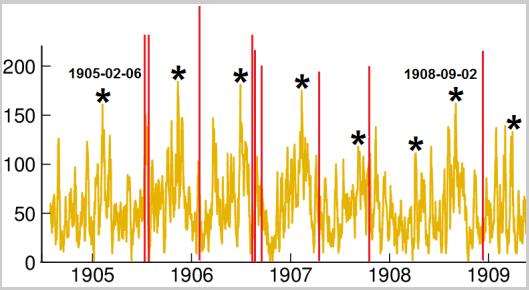

Figure 3: Sunspot numbers in 1905 -1908, [8]. The peaks, marked by asterisks, recurred on average every 212 days. The earthquakes of $M \geqslant 7.9$, shown by vertical lines, are clustered into groups: 1) 1905/7/9, 1905/7/23; 2) 1906/1/31, 3) 1906/8/17, 1906/4) 8/17, 1906/9/15, 1907/4/15; 5) 1907/10/21; 6) 1908/12/12; [3]; the average time between groups 1-5 is 208 days. The time between groups 5 and 6 is 419; there was no $M \geqslant 6.0$ earthquake between 1907/10/21 and 1908/12/12.

world wars; it is possible that these seismic events do not fit the patterns simply because they were not measured properly; the recent changes to USGS data base of earthquakes confirm the uncertainty in the pre-1950 earthquake data.

However, there might have been natural factors which skewed the correlation of earthquakes with New/Full Moon and closest/2nd closest perigees. As shown in [9], the geomagnetic field in 1938 - 1947 changed at a rate much higher than usual, possibly due to an unusually large number of solar storms, [10]; and, as shown in Figure 1, a new maximum of the Earth's magnetic field formed north of lake Baikal some time in 1880 - 1930. These changes in the geomagnetic field, most likely, were responsible for skewing the correlation between earthquakes and lunar events in 1905 - 1947. Figure 2 shows $M \geqslant 7.6$ earthquakes in 1900 - 2016, only sixteen of them struck inland far from water and close to the new location of the geomagnetic maximum near lake Baikal. Of the 16 earthquakes, 12 struck in 1905 - 1937, averaging 0.375 earthquakes per year; while only 4 struck in 1938 - 2016, averaging 0.051 earthquakes per year. The 1905/7/23, 1905/7/9, 1906/1/31 earthquakes and the 1907 eruption of Ksudach preceded the 1908 Tunguska explosion just north of the inland earthquakes of Figure 2.

The periodic recurrence of the maxima in solar activity shown in Figure 3 may have also contributed to triggering powerful earthquakes and Ksudach's eruption in 1905 -1907; the frequency of the peaks in solar activity in Figure 3 averaged 212 days, and may have resonated with the frequency of the closest/2nd closest perigees which recur approximately every 200 - 215 days. Of the six *extreme perigees*, i .e. perigees closer than 356,425 km, in 1548 - 2016, three occurred in 1893 - 1930, namely on 1893/12/23, 1912/1/4, 1930/1/15. The 1917/5/1 earthquake struck at $\approx 31^{o}S, 176^{o}W$, almost antipodally to a strange and unexplained phenomenon known among Catholics as apparition of Virgin Mary or the Miracle of Sun, at $\approx 40^{o}N, 9^{o}W$ in May - October of 1917; whatever the phenomenon really was, it might have also been related to the changes in the Earth's magnetic field and seismic activity.

As to the true nature of whatever affected the seismic activity in 1905 - 1947 we may only speculate, as there are precious little data to make any definitive conclusions. But even the little data currently available suggest that the seismic activity on Earth is affected by solar activity and cosmic rays. The 1960/5/22 M=9.5 earthquake struck amidst 1959/3/29, 1960/4/1, 1960/10/7, 1960/11/13 solar storms and was preceded by the 1960/5/4 solar flare which accelerated particles to cosmic ray energies briefly increasing cosmic ray intensity; the 1991/6/15 eruption of Pinatubo was preceded by six X10.0 - 12.0 solar flares in June 1-15, 1991, and seven X9.3 - 20 solar flares in 1989/2/6 - 1991/3/22; that is 37% of all known solar flares $\geqslant X9.0$ recorded in 1978 - 2016,

[11]. The 1965/2/4 M=8.7 and 2004/12/26 M=9.1 earthquakes struck correspondingly before the 1965/2/5 solar flare and 2004/12/27 $\gamma-$ ray burst; suggesting that either the 1965/2/5 solar flare and 2004/12/27 $\gamma-$ ray burst were preceded by undetected leading fronts which contributed to the two earthquakes, or both the earthquakes and the cosmic events were caused by a third agent, possibly cosmic rays, which caused the earthquakes first and then the cosmic flare and γ -ray burst.

Not much is known about 1815, the year of VEI = 7 eruption of Tambora which does not fit in Table 8; yet the 1811 - 1812 New Madrid earthquakes, powerful eruption of Bocas de Fogo in 1808, and a hypothesized VEI = 6 - 7 eruption in 1808 - 1809 suggest that something must have amplified the intensity of seismic activity at the time.

In Table 1, only the 2006/11/15 earthquake did not correlate with New/Full Moon or closest/2nd closest perigee. It struck at the Kuril Islands in the wake of hurricane Ioke and typhoon Yagi which passed through the same regions in late August - September of 2006; hurricanes and typhoons rarely reach that far north. The earthquake struck merely 20 days before X9.0 solar, the last flare of such magnitude in 1978 - 2016. Both the 2006/11/15 earthquake of Table 1 and the 2009/9/29 earthquake of Table 3 struck within months of the 2006 and 2009 geomagnetic pulses, [12].

The seismic activity on Earth seems to be affected by extraterrestrial factors, including but not limited to, the movement of the Moon around the Earth, the movement of the Earth around the Sun, solar activity exhibited by sun spots, cosmic rays, and, most likely, many more. With the effects of so many factors tangled up, it is often hard to figure out how each one of them affects seismic activity; simple statistics only leads to confusion. Sometimes, one factor becomes dominant providing us with a window of opportunity to study how that particular factor correlates with and affects earthquakes and volcanic eruptions; e.g. Table 1 illustrates how $M \geqslant 8.2$ earthquakes correlated with New/Full Moon and closest/2nd closest perigees in 1938 - 2016, yet Table 2 reminds us that the correlation may be easily obscured by other factors as was the case in 1900 - 1937; Tables 4, 5, 7 illustrate how strongest earthquakes of the year correlated with New/Full Moon and closest/2nd closest perigees in 2010 - 2016 and in 1956 - 1968, yet Table 6 shows that the correlation was weakened by other factors in 1990 - 2009. The time patterns in powerful volcanic eruptions, illustrated in Table 8, indicate that the relationship of seismic activity and lunar events

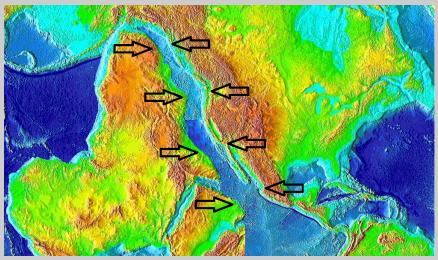

Figure 4: The east cost of Africa is almost antipodal to the west coast of North America. Shown in the picture are the antipode of Africa moved closer to North America. As may be easily seen, the antipode of the east coast of Africa, indicated by the right-pointing arrows, is almost the same as the west coast of North America, indicated by the left-pointing arrows.

goes much further than simple correlation with New/Full Moon and closest/2nd closest perigees.

That Earth's seismic activity is affected by the Moon and Sun as well as solar flares and cosmic rays, it also seems to be related to the changes in the geomagnetic field. That leads us to the conclusion that the most powerful seismic events draw their power not from the liquid core. Indeed, since the liquid core is fluid, the Moon and Sun produce tides inside the liquid core; these tides put additional pressure on the mantle, which in turn relays the pressure to the crust leading to powerful earthquakes and eruptions. Since the liquid core contains electric currents, it is also affected by solar CME/flares and cosmic rays carrying fast-moving electric charges; the interaction of the fast-moving electric charges with the currents in the liquid core also leads to powerful earthquakes and eruptions. The changes in the Earth's magnetic field in 1900 - 1945 are also due to the motion of the changed liquid metal inside the liquid core.

The tidal force is almost antipodally symmetric; so if the tidal force plays a significant role in seismic activity, then the remnants of the antipodal symmetry should be seen on the Earth's surface. Indeed, as Figure 4 shows, the antipode of the east coast of Africa and west coast of North America, located close to each other, are of almost identical shape. The antipodal symmetry on Earth's surface is discussed in more detail in [13].

The presence of patterns in seismic activity paves a way to seismic forecasts; yet as of now we simply do not have sufficient data to determine all patterns required for successful forecasts. All we have is a good record of seismic activity for ≈ 70 years 1947- 2017; a not very reliable record of seismic activity for another 50 years 1900 - 1950; and even less reliable data for 1600 - 1900. As more data become available, more patterns will be identified eventually allowing successful seismic forecasts.

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Notes

[1] While the exact lengths of synodic and anomalistic months vary, the *average synodic month* is ≈ 29.530587981 days and the *average anomalistic month*is ≈ 27.554551. The concept of a full lunar cycle is due to the fact that 15 average anomalistic months of ≈ 413.318 days are almost the same as 14 average synodic months of ≈ 413.428 days. The exact length of a full lunar cycle varies around its average length.

[2] Determination of the total number of days in a full lunar cycle that are either within $30 + n$ days of the closest/2nd closest perigee or within n days of New/Full Moon for $n = 0, 1, 2, 3$. Here 30 is the rounded up length of a synodic month; for simplicity's sake we round off the length of a full lunar cycle to 413. The number of days within $30 + n$ days of the closest perigee is (the day of the closest perigee) + ($30 + n$ days before the closest perigee) + ($30 + n$ days after the closest perigee)= $61 + 2n$; similarly the number of days within $30 + n$ days of the 2nd closest perigee is also $61 + 2n$. Together the number of days within $30 + n$ days of the closest/2nd closest perigee is $122 + 4n$; these $122 + 4n$ days include 5 New Moons and 5 Full Moons. The number of New Moons and Full Moons outside of these $122 + 4n$ days is 18, the total number of days within n days of New or Full Moon but more than $30 + n$ days away from the closest or 2nd closest perigee is $18 \times$ (the day of New or Full Moon + n days before New or Full Moon + n days after New or Full Moon = $18 \times (2n + 1) = 36n + 18$. Thus the total number of days that fall within $30 + n$ days of the closest/2nd closest perigee or within n days of a New/Full Moon is $122 + 4n + 36n + 18 = 140 + 40n$. The portion of a full lunar cycle that falls within $30 + n$ days of the closest/2nd closest perigee or within n days of a New/Full Moon is $\approx \frac{140 + 40\text{n}}{413}$.

For simplicity's sake, we just count days between two events and disregard hours. With such count an event at 01:00 am on June 2, 2000 is a day away from an event at 23:00 June 3, 2000 and a day away from an event at 23:00 on June 1, 2000; even though the event at 01:00 am on June 2, 2000 is separated from the event at 23:00 June 3, 2000 by 46 hours while it is separated from the event at 23:00 June 3, 2000 by merely 2 hours. As most compared events in this paper are more or less 12 - 36 hours apart, such simplification does not significantly affect our conclusions.

[3] It is because 669 average synodic months of ≈ 19755.96336 days $\approx$ 54 years 32.5 days are almost equal to 717 average anomalistic months of ≈ 19756.61307 days $\approx$ 54 years 33.1 days.

[4] Since the difference between 1004 average synodic months $\approx 1004 \times 29.530587981 \approx$ 81 years 63.46033 days and 1076 average anomalistic months $\approx 1076 \times 27.554551 \approx$ 81 years 63.44688 days is less than 20 minutes, we may think of the lunar motion as periodic with the period of 81 years 63.5 days on the time scale of several centuries.