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GEOPHYSICS

Tidal Wave Period and Seismicity

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Studies on the tidal effect on seismicity began with the work of Perrey [1], who called attention to the relationship between earthquake frequency and lunar phases. Investigations of this sort were activated in the 1930s, when more reliable seismic data appeared for some regions. However, subsequent studies and additional more accurate data failed to clarify the problem. Some authors believed the relationship between tides and earthquakes to be statistically significant [2–4], whereas others [5, 6] arrived at contrary inferences. With such uncertainty surrounding the results, either supplementary data or new approaches and ideas have become essential.

We have attempted to analyze the relationship between tide and seismicity with due regard for the development of creep in the Earth's crust, which depends on the strain duration and, hence, on the harmonic period. We studied the distribution of earthquake moments by tidal phases in 130 000 events for the years 1970–2003 [7]. To obtain statistically significant results, we used catalogs of earthquakes in the nine most active seismic regions of the Earth (Fig. 1).

The analysis of the total impact of a full set of tidal harmonics inevitably provokes some degree of uncertainty in the interpretation of results, since the very notion of "phases" lacks a rigorous definition in this case. Therefore, we restricted ourselves to separate consideration of the eleven strongest harmonics in different tidal ranges. The studies were focused on a comparative analysis of the influence of long- and short-period tidal harmonics. We proceeded from the assumption that, even though long-term harmonics are weaker by an order of magnitude, their impact on the Earth's crust is prolonged.

We believe that, unlike the elastic model of the Earth's crust, the tidal impact depends both on the intensity of the harmonic in question and the duration of its impact. Such an approach is based on the concept of a creep mechanism, which develops under the long-term impact of forces on the Earth's crust and, in particular, at the last stage of earthquake preparation [10–12].

We calculated phases of selected harmonics for the epicenter and time moment of each earthquake [7]. The vertical displacement of a tide was calculated based on the ETERNA, Version 3.30 software [8]. The number of earthquakes was compared to the phase of a tidal gravity change, which coincides with the phase of vertical deformation of upper layers of the crust. The effect could show up at another phase for the other component of the tidal influence; i.e., the observed frequencies would shift to other phases, but they would not change. Therefore, the results do not depend on the tidal component, and the basic inference of this work—long-period tidal waves have a stronger influence on seismicity—does not depend on a specific tidal component.

The statistical reliability of the values was assessed by the Pearson criterion χ^2. The null hypothesis envisages that a seismic event does not depend on the phase of the given harmonic; i.e., an earthquake might fall on any phase with equal probability. In this case, one might expect an equal distribution of the number of earthquakes in phases. The period of each harmonic was subdivided into eight equal classes (intervals) with a length of $\frac{2\pi T}{8}$ (concurrent calculation with a subdivision of the period into 16 classes with a length of $\frac{2\pi T}{16}$ yielded similar statistical inferences). It should be noted that the adopted scheme of investigations underestimates the effect of each selected wave, because the phase effect of the other waves over 24 years is evenly spread throughout the phases of the analyzed wave.

The results obtained (table) indicate that the phase effect would differ greatly for different harmonics. Contrary to our expectations, the null hypothesis is rarely discarded for short-period harmonics, although their amplitude is greater. Thus, these harmonics have rather weak effects, if any, on seismicity. Moreover, the validity of the null hypothesis decreases with the har-

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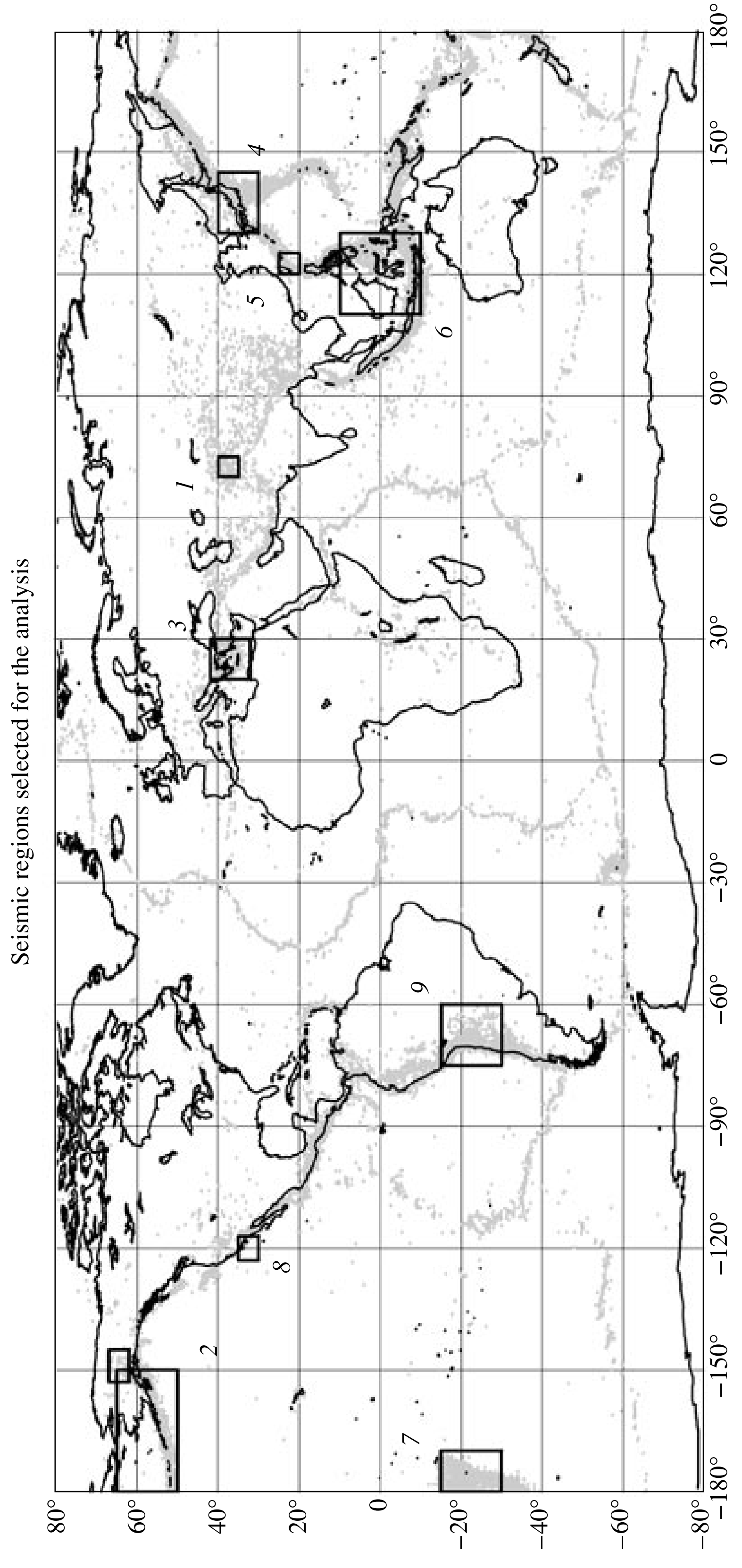

Fig. 1. Seismic regions selected for the analysis: (*1*) Pamir–Hindu Kush; (*2*) Alaska, Aleutian Islands; (*3*) Greece; (*4*) Japan; (*5*) Taiwan; (*6*) Indonesia; (*7*) Oceania; (*8*) San Andreas; (*9*) Chile.

Probability (%) of the null hypothesis, according to which the number of earthquakes does not depend on the tidal harmonic

Region	Number of events	Tidal harmonics and their periods										
		Long-period, day				Diurnal, h			Semidiurnal, h			
		182.62^d SSa	27.55^d MM	14.77^d MSF	13.66^d MF	25.82^h O1	24.07^h P1	23.93^h Kl	12.66^h N2	12.42^h M2	12.00^h S2	11.97^h K2
Pamir–Hindu Kush	5382	10^{-4}	0.17	6.5	28.4	53.3	31.5	29.1	60.2	14.9	39.7	39.3
Alaska + Aleutian Islands	7509	10^{-13}	0.09	6.0	0.12	21.7	28.3	36.8	4.72	17.5	1.4	22.0
Greece	12072	10^{-5}	0.04	23.7	61.8	16.8	0.38	38.7	11.1	16.0	71.1	91.4
Japan	7420	10^{-29}	6.2	0.02	10^{-5}	6.8	7.3	36.5	39.1	77.6	57.1	13.7
Taiwan	3108	10^{-11}	10^{-12}	10^{-8}	13.6	29.1	0.70	68.6	47.3	77.7	47.4	89.6
Indonesia	16236	0.01	0.08	14.2	0.04	33.2	0.73	86.8	47.5	3.8	26.6	56.0
Oceania	16765	10^{-5}	40.0	0.07	36.5	31.4	43.9	32.6	77.8	69.8	16.1	65.6
San Andreas	53488	10^{-99}	10^{-16}	10^{-21}	10^{-15}	10.3	1.4	58.2	51.2	16.3	10^{-14}	68.2
Chile	7687	10^{-26}	10^{-5}	10^{-7}	10^{-4}	11.3	3.3	83.0	88.2	50.4	14.9	84.2

monic period. The null hypothesis for MSF and MF waves should in fact be discarded in most of the regions; for MM and SSA waves, it should be rejected nearly everywhere, although they are two orders of magnitude weaker than M2 wave. This fact emphasized the key role of inelastic strains developed in rocks under prolonged impacts.

Oceania is the only exception for M2 wave, probably because of a different type of crust, distinctions in rock properties, and a supplemental effect of oceanic tide.

The period of MSF wave is equal to the interval between syzygies, when the tidal power of the Moon and Sun are combined due to harmonic beating. How-

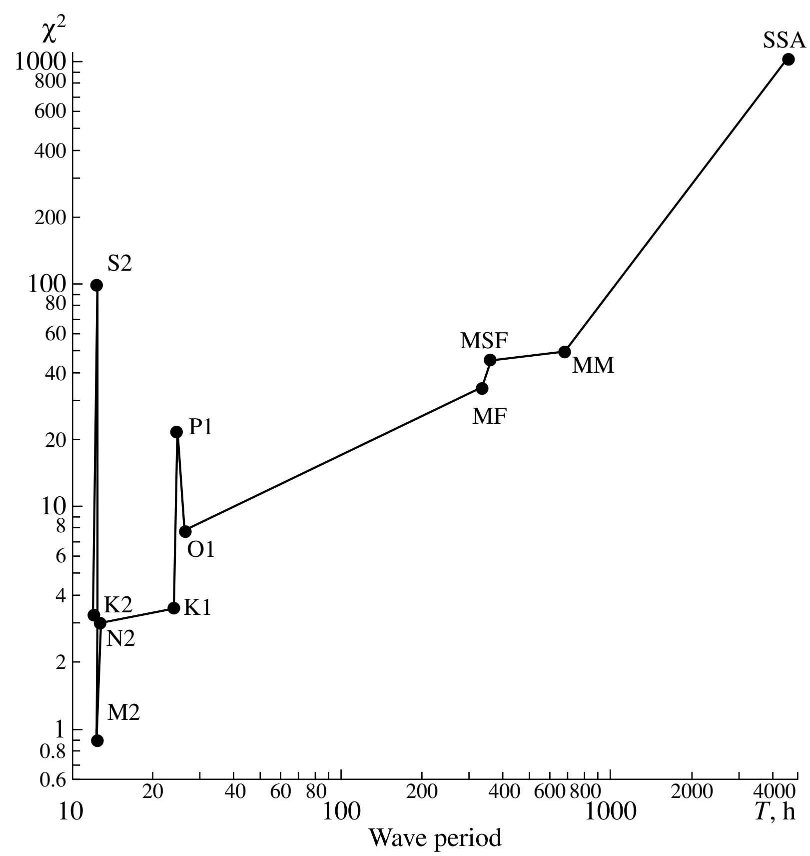

Fig. 2. Pearson criterion χ^2 for harmonics of tidal variations. The high χ^2 value for S2 wave, the period of which is equal to 12 h, might be caused by a nonlinear diurnal effect.

ever, the results for MSF and MF waves with nearly equal periods indicate that their impact is comparable (similar). Thus, not even a three-fold increase in the tidal power during a syzygy yields the expected effect. At the same time, the results for SSA wave convincingly support the role of the harmonic period.

MSF and MF waves mediate between O1–K2 short-period waves, which have a weak influence on seismicity, and between MM and SSA waves, which have a strong influence. This fact is likely to be responsible for the instability in our results (table) for different regions and for the above-mentioned conflicting inferences of different researchers concerning the tidal impact on seismicity as applied to regions with different geological structures and tectonic patterns and, hence, different degrees of sensitivity to tidal forces.

Based on the study of nine regions, the general trend can be formulated as follows: the trigger effect of tidal waves on an earthquake has a positive correlation with the wave period (Fig. 2). The high χ^2 value for S2 wave (the period is equal to 12 h) is likely to be a superposition of the tidal effect and diurnal–semidiurnal variations of other geophysical parameters. However, the discrimination of these factors represents a separate problem. Therefore, we did not analyze SA wave with a 1-yr period, because it was impossible to discriminate tidal and seasonal factors for this wave.

Investigations of the trigger effect of tides in relation to the epicenter depth and the earthquake magnitude are described in [9].

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