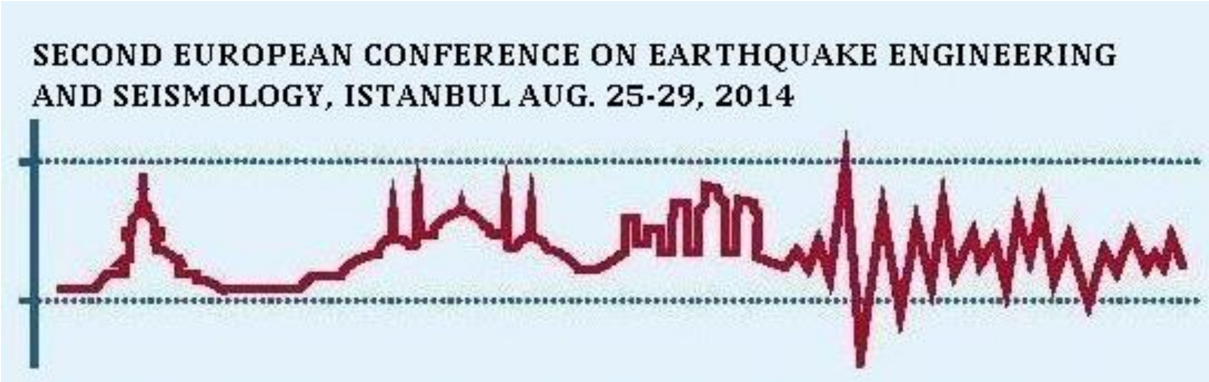

SEISMIC WAVES ATTENUATION AROUND EPICENTERS OF TUVA EARTHQUAKES WITH MS=6.6, 6.7 (RUSSIA)

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ABSTRACT

In the present study we investigated the decay of seismic intensity with distance and seismic waves attenuation in the focal area of two strong Tuva earthquakes (27.12.2011, *MS*=6.6 and 26.02.2012, *MS*=6.7).

INTRODUCTION

Two pairs of strong earthquakes occurred in 2011-2012 in Obruchev ridge (Tuva Republic, Russia). They have a small distance from each other and close values of magnitudes. They had been called Tuva earthquakes. The first of them Tuva-I earthquake with magnitude *MS*=6.6 occurred 27.12.2011 at 15:21:55 UT at a distance of 95 km northeast of Kyzyl city. Two months later, 26.02.2012 at 06:17:16 UT, 20 km north-east of it was registered Tuva-II earthquake with *MS*=6.7.

High magnitude of Tuva earthquakes as well as intensive aftershock process (about 50 aftershocks had a magnitude of 4.0 and higher) allowed us to study the decay of seismic intensity with increasing of distance to earthquakes hypocenters and code waves attenuation with determination of its parameters Q (quality factor) and n (frequency parameter).

MACROSEISMIC EFFECTS OF TUVA EARTHQUAKES

Tuva earthquakes were felt in several Siberian regions. In different localities was conducted to collect data on the intensity of tremors. Information was received from the Russian Emergencies Ministry regional offices based on filling in the questionnaires. Some of the information was obtained from the regional press, as well as forums information sites. As a result, information was collected on the intensity of the shock in more than 45 villages in each earthquake. Summarized results are presented in Table 1.

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Table 1. Macroseismic data Tuva earthquakes

	Tuva-I earthquake	Tuva-II earthquake
№	site	site
	6-7 balls	6-7 balls
1	Saryg-Sep	Saryg-Sep
	5-6 balls	5-6 balls
2	Kyzyl	Kyzyl
	4-5 balls	4-5 balls
3	Abakan; Ermakovskoe; Minusinsk; Syanogorsk; Shushenskoe	Abakan; Ermakovskoe; Minusinsk; Syanogorsk; Shushenskoe
	4 balls	4 balls
4	Askiz; Nazarovo; Sorsk; Ust Abakan; Yurty	Zheleznogorsk; Kansk; Krasnoyarsk; Minusinsk
	3-4 balls	3-4 balls
5	Achinsk; Gurevsk; Zheleznogorsk; Zelenogorsk; Kansk; Kedrovi; Kemerovo; Krasnoturansk; Krasnoyarsk; Leninsk-Kuznetsk; Mejdurechensk; Orlik; Prokopevsk; Sosnovoborsk; Tulun; Sharypovo; Shelekhov	Achinsk; Belovo; Berezovka; Zelenogorsk; Kemerovo; Kiselevsk; Nazarovo; Novokuznetsk; Novosibirsk; Polysaevo; Sayansk; Sosnovoborsk; Sharypovo
	3 balls	3 balls
6	Belovo; Berdsk; Byisk; Bratsk; Zarinsk; Irkutsk; Nizhneudinsk; Novokuznetsk; Novosibirsk; Osinniki; Seversk; Tayshet; Ust-Kamenogorsk; Yugra	Angarsk; Belokuriha; Berdsk; Byisk; Bratsk; Zima; Irkutsk; Koltsovo; Leninsk-Kuznetsk; Mejdurechensk; Prokopevsk; Slyudyanka; Tashtagol; Tomsk; Tulun; Tyuhtet city; Usolie Siberian; Yugra
	2-3 balls	2-3 balls
7	Angarsk; Barnaul; Tomsk; Sheregesh	Barnaul; Gorno-Altaisk; § Linevo; Seversk; Ust-Kamenogorsk; Chita; Shelekhov

Based on the data collected on macroseismic manifestations Tuva earthquakes were built graphics decay intensity *I* with increasing distance from the earthquake hypocenters *r* (Fig. 1).

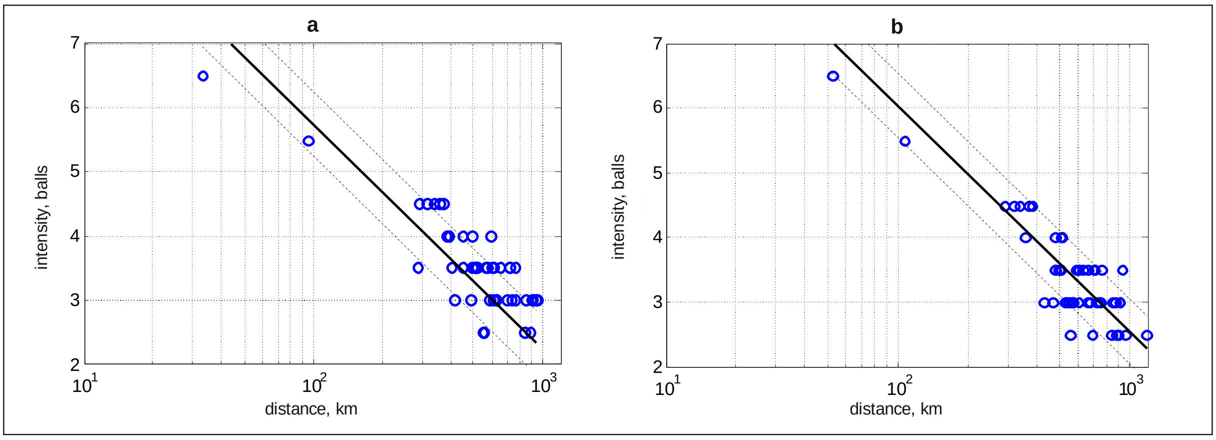

Figure 1. Decay of intensity with distance from the epicentre a) Tuva-I earthquake and b) Tuva-II earthquake; thick line shows the decay of the intensity according to Shebalin's formula, dashed lines indicate the boundaries of the interval with intensities that differ by no more than 0.5 balls from the calculated values

Analysis of collected data about macroseismic effects of Tuva earthquakes showed that they can be well described by N.V. Shebalin's formula with average coefficients for North Eurasia.

$$I = 1.5\ MS - 3.5 \lg r + 3.0, \qquad (1)$$

where *I* – intensity and *r* – distance from hypocenter.

For Tuva-I earthquake about 2/3 of the observed intensities vary from the calculated values no more than 0.5 balls (Fig. 1). In the case of the Tuva-II earthquake corresponding part of the data is about 85%.

SEISMIC WAVES ATTENUATION

For the first time the possibility of the determination of the attenuation parameters using the coda waves (as the nature of the coda waves) was considered by K.Aki (Aki and Chouet, 1975). For explaining of the coda waves existing K.Aki suggested a single backscattering model which explains the coda waves as a superposition of a secondary waves reflected from heterogeneities randomly distributed in the lithosphere (Aki and Chouet, 1975). The decrease of the seismic energy in the coda wave is sequent of energy attenuation, scattering and geometrical spreading; it's independent on source pattern, path effect and site amplification and gives a chance to numerically calculate of the seismic quality-factor.

Generally, the Q factor increases with the frequency following the next relation (Mitchell, 1981):

$$Q_C(f) = Q_0 \cdot (f / f_0)^n, \qquad (2)$$

where Q_C – the quality-factor for the coda waves, Q_0 – the Q_C value at the reference frequency f_0 (usually f_0=1Hz), n is the frequency parameter, which is close to 1 and varies from region to region depending on heterogeneity of medium.

A preliminary evaluation of the attenuation parameters of seismic waves in the area of the Sayan-Tuva mountain range was carried out by means of code waves analysis of 28 earthquakes with magnitude 4.0 or higher of the Tuva aftershock sequence. We used records obtained by seismic stations Tiberkul (TBRR), Arshan (ARS), Orlik (ORL), Mondy (MOY), Zakamensk (ZAK), Talaya (TLY) (Fig. 2). The average distance between these stations and the earthquake epicentres was about 390 km.

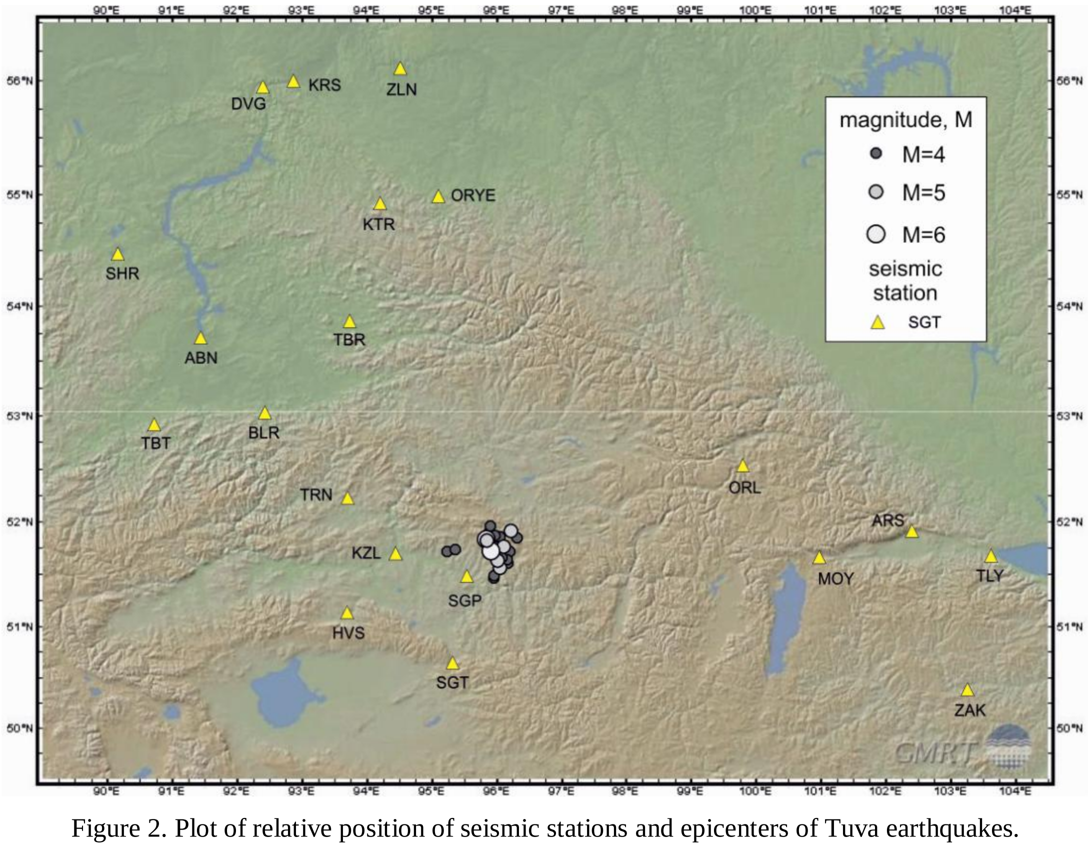

Figure 2. Plot of relative position of seismic stations and epicenters of Tuva earthquakes.

The results of this study have showed that for the area of Tuva earthquakes values of frequency parameter *n* are in the range 0.63-1.21 (Table 2). In general, the region is characterized by the value of *n*=0.72. This range frequency parameter values for the Sayan-Tuva mountain is typical for areas with high level of tectonic activity. Calculated *n*-values are in good agreement with previously established values for the south-western side of the Baikal rift system, where *n* ranges from 0.84 to 0.97.

Additionally, the empirical dependence of quality factor on frequencies for different depths of coda's formation was determined (Table 2). Increasing of *Q* value with depth is caused by decreasing of heterogeneity of medium with growth of the distance from the surface.

Table 2. Attenuation parameters around Tuva earthquakes

W, sec	*N*	Q_0	δ*Q*	*n*	δ*n*	*t*, sec	*c*, km	*W*, sec	*N*	Q_0	δ*Q*	*n*	δ*n*	*t*, sec	*c*, km
1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
10	210	60	5	0.6	0.12	165	367	60	301	226	20	0.86	0.06	190	405
15	169	69	2	0.92	0.04	167.5	371	65	296	243	19	0.83	0.06	192.5	408
20	188	102	12	0.72	0.12	170	374	70	317	254	23	0.82	0.07	195	412
25	186	122	4	0.86	0.03	172.5	378	75	326	263	25	0.82	0.08	197.5	416
30	200	146	7	0.84	0.03	175	382	80	336	282	26	0.8	0.08	200	420
35	221	151	3	0.9	0.01	177.5	386	85	335	302	28	0.76	0.08	202.5	424
40	254	163	8	0.92	0.03	180	389	90	341	312	33	0.75	0.09	205	428
45	267	185	9	0.89	0.04	182.5	393	95	350	324	34	0.75	0.09	207.5	432
50	279	202	11	0.86	0.04	185	397	100	332	338	38	0.71	0.1	210	436
55	285	214	13	0.85	0.04	187.5	401	105	40	383	0	0.96	0	212.5	440

Note: in the column 1 shows the time window size, 2 – the number of measurements, 3, 4 – *Q*-value at a frequency of 1 Hz and its standard deviation, 5, 6 – the frequency parameter and its standard deviation, 7 – average length of the time window for processing codes (measured from the earthquake), 8 – depth of coda-wave forming according to (Pulli, 1984).

Comparison of the characteristics of attenuation of seismic waves in different regions showed that the values of the frequency parameter ranges from *n* <0.5 (for stable regions) to *n* = 0.3-0.8 for areas with moderate tectonic activity and *n*> 0.8 for active regions (Mak et al., 2004).

Table 3 shows the values of the frequency parameter, defined in this paper for the Tuva region of earthquakes, as well as the south-western flank of the Baikal rift system (BRS) at (Dobrynina et al, 2011) and for the stable regions of the world such as the Canadian Shield (Hasegawa, 1985) and the North American Plate (Pulli, 1984). Obtained for the Sayan-Tuva mountain frequency parameter values (Table 3) are typical for high-level and tectonically fractured areas. Estimating the parameter n, made separately for each seismic station, located on the territory of the Baikal rift system (Table 3) are in good agreement with similar definitions from earlier work (Dobrynina et al, 2011).

Table 3. Frequency parameter values for the Tuva region of earthquakes, the south-western flank of the Baikal rift system and tectonically stable regions

area	n	source	area	n	source
Tuva earthquakes area			South-western flank of the Baikal rift system		
Whole area	0.72	the present study	Eastern Sayan	0.89	Dobrynina et al., 2011
ARS	0.71	the present study	Khamar-Daban block	0.84	Dobrynina et al., 2011
MOY	0.77	the present study	rift basins	0.92-0.97	Dobrynina et al., 2011
ORL	0.63	the present study	Siberian craton	0.48	Dobrynina et al., 2011
TLY	1.21	the present study	tectonically stable regions		
ZAK	0.9	the present study	North American Plate	0.4	Pulli, 1984
TBR	0.82	the present study	Canadian Shield	0.35	Hasegawa, 1985

CONCLUSIONS

Magnitudes of Tuva earthquakes, as well as accompanying them powerful aftershock process allowed the study decay of the intensity with distance from the earthquakes hypocenters and attenuation code waves.

Analysis of data collected from macroseismic effects Tuva earthquakes showed that they are well can be described based on the use of the formula N.V. Shebalin. For Tuva-I earthquake about 2/3 of the observed intensities differ from the calculated values by no more than 0.5 balls. In the case of the Tuva-II earthquake corresponding share is about 85%.

Based on the analysis code waves 28 earthquakes with magnitude 4.0 or higher of the Tuva aftershock sequence was performed preliminary evaluation attenuation parameters of seismic waves in the area of the Sayan-Tuva mountain areas: seismic quality factor (Q_C) and its frequency dependence (frequency parameter, n); Q obtained functional dependence of frequency for different depths of formation codes. Changes Q and its frequency dependence (frequency parameter) with depth explained the existing vertical heterogeneity of the medium and its decrease with depth.

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