THE TEKELI EARTHQUAKE OF 2009 IN KAZAKHSTAN: SOURCE AND EFFECTS

N.N. Mikhailova, N.N. Poleshko
Institute of Geophysical Researches of the National Nuclear Center of the Republic of Kazakhstan, Almaty, Kazakhstan

The article investigates parametrization issues of the main shock from the earthquake of June 13, 2009, m_b=6.3 felt in Tekeli town with intensity 7. Spatial characteristics of the source, mechanism and CMT, aftershock activity regularities were studied. Rupture plane in the source was defined with high probability. Information and pictures about destructions and damages of buildings on the territory of Tekeli town as well as isoseismal map are shown. In 1993 almost at the same place the earthquake with the same focal parameters and processes occurred. Very close parameters of seismic effects on the territory of Almaty having two almost the same sources were noted.

Key words: focal parameters, Tekeli earthquake, mechanism, isoseismal map, accelerograms, response spectrum.

Introduction

On June 13, 2009 at 23 h 17 min by local time (17 h 17 min by UTC) a large earthquake occurred in the south-east of Kazakhstan. Tekeli town located in the earthquake epicentral zone was the most damaged. The intensity in this town reached 7. Note that this earthquake is the second earthquake of this force in Tekeli town for the last 16 years. The previous earthquake occurred on December 30, 1993 [Kalmykova et al. 1999]. Table 1 shows the hypocenter coordinates and magnitudes of both Tekeli earthquakes. It is obvious that main characteristics of both earthquakes – hypocenters location and magnitudes are very similar.

Figure 1 shows the photographs of Tekeli town made immediately after the earthquake and put on the website http://www.today.kz/ru/news/kazakhstan/2009-06-16/tekeli13. Two earthquakes with force 7 occurring at the same place for relatively short period is an unusual phenomena for Kazakhstan seismicity. This causes to analyze in details the situation in this seismic active region.

Table 1. Instrumental characteristics of Tekeli earthquakes focals.

Date dd, mm, yy	Focal time τ_0, h, m, s (UTC)	Latitude, N	Longitude, E	Depth, km	*mb*	*Ms*
13.06.2009	17:17:40.0	44.77	78.82	25	6.3	5.4
30.12.1993	14:24:06.4	44.82	78.77	20	6.4	5.4

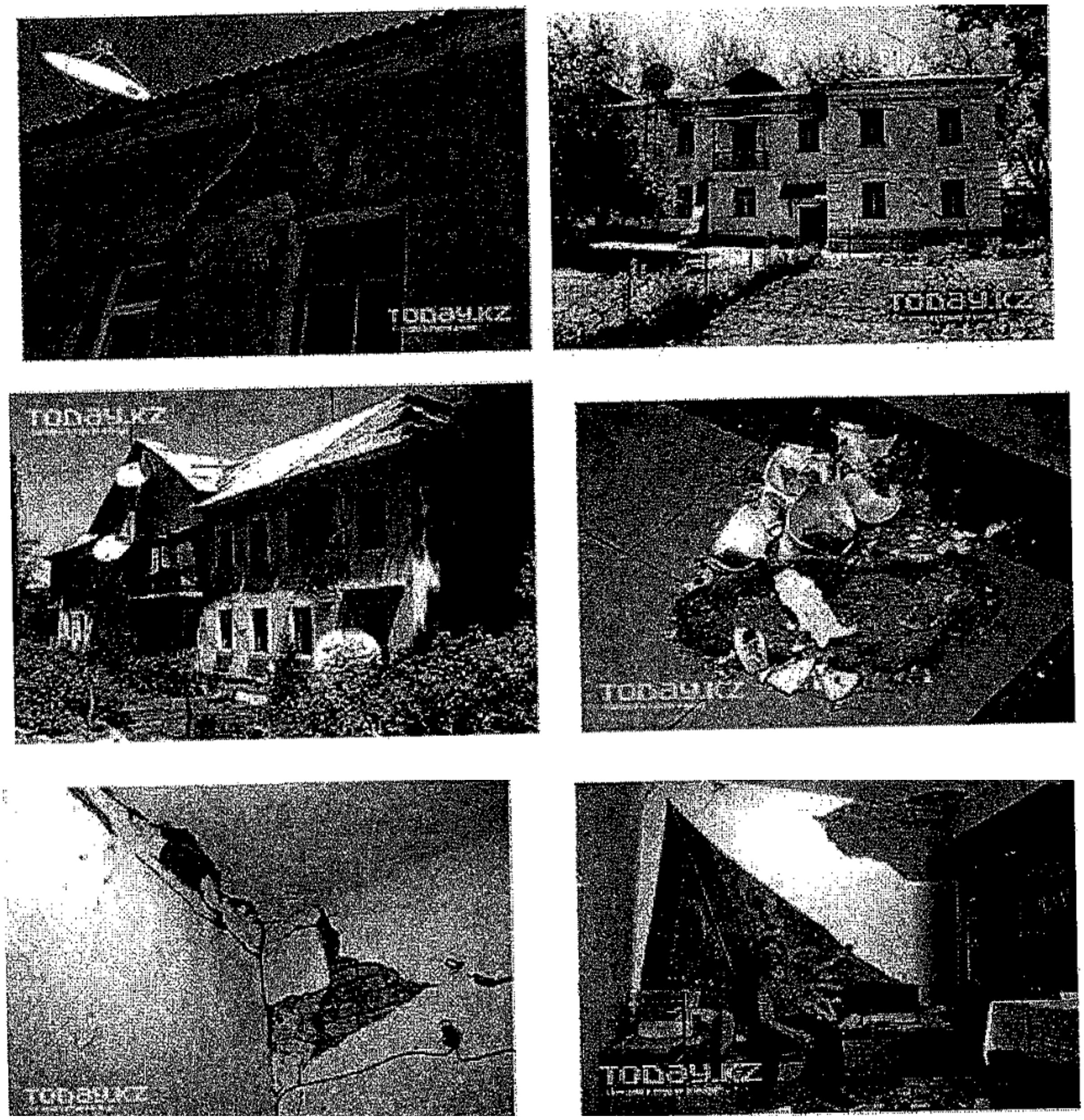

Figure 1. Buildings damages in Tekeli town after the earthquake of 13.06.2009 (from www.today.kz site)

CHARACTERISTICS OF TECTONIC CONDITIONS AT TEKELI EARTHQUAKES REGION

Dzhungar region along with Northern Tien Shan region is the most investigated in seismic active belt of Kazakhstan. The work [Seismic…, 2000] shows a map of seismogenerating zones in Dzhungariya (Figure 2) with epicenters location of the Tekeli earthquakes of 1993 and 2009.

According to this map, earthquakes with magnitude up to 8.0 might occur at Dzhungar Alatayu. The most dangerous are Borotalinskaya (#22) and South-Dzhungar (#23) zones located close to the Tekeli earthquakes focuses. The epicenters of both investigated earthquakes are in the zone of complex intersection of oppositely directed faults in the southern part of West-Dzhungar (#18) seismogenerating zone. Here, the maximum earthquake magnitude is 7.0.

West-Dzhungar seismogenerating zone is connected with eponymous fault referred to deep faults. West-Dzhungar fault along with Aktasskiy fault located on the north part of Balkhash form a united zone extended on 500 km. The crust thick in this region is 44-46 km. In the historical past this zone was noted with earthquakes having magnitude up to 5.5. There is indication on seismogravitational nature of rock burst which break caused catastrophic flow of mud at Tekeli town region.

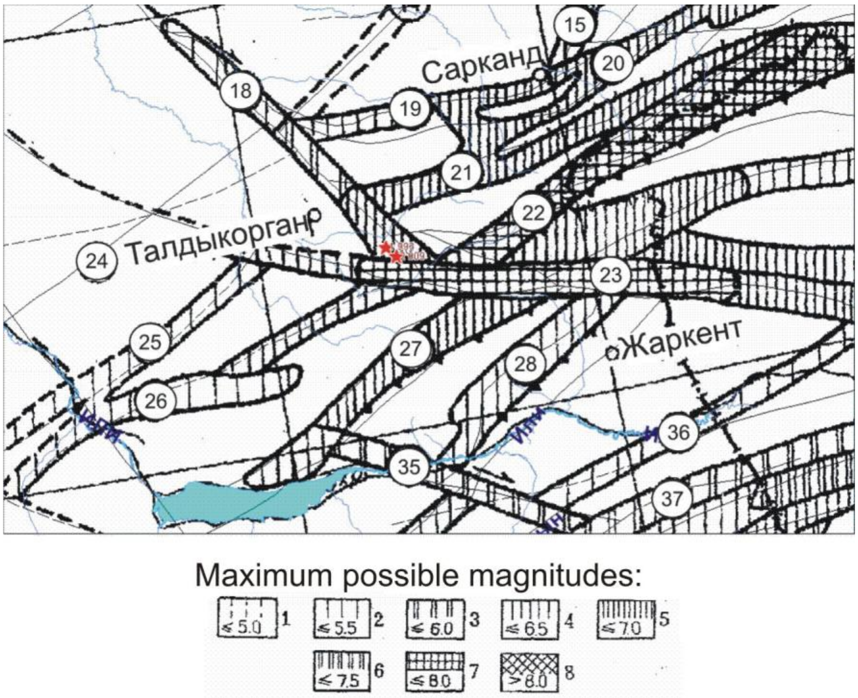

Figure 2. Seismogenerating zones of Dzhungar region. The stars indicate the epicenters of Tekeli earthquakes of 1993 and 2009.

South-Dzhungar seismogenerating zone adjoining to the investigated area from the south part is related to the deep fault separating South and Central Dzhungar blocks. The zone extends from China to the north-west and further under Cenozoic stratum of South-Balkhash depression breaking up by transverse faults. Crustal thickness in the same direction decreases from 50 to 44 km.

According to instrumental observation data the earthquakes with magnitude 5.9-6.5 occurred along South-Dzhungar fault zone since 1951. However, potential of this zone is much higher. This fact is confirmed by intensive movements during the newest stage appeared as thrust movements along the fault and formation of near-fault folds in neogene stratum, deformations and rupture of the Holocene terraces. According to the whole set of available data, maximum magnitude at the east front of South-Dzhungaria zone is assumed within 7.0 – 8.0, decreasing to 6.5 in north-west direction, and reaching 6.0 at near Balkhash region.

Figure 3 shows a system of active faults and historical seismicity of Dzhungariya. The faults were revealed following the results of work under ISTC CASRI Project (2006 – 2009) [Final…, 2009] and confirmed by space images made by A.Ye. Velikanov. The map in Figure 3 shows that the focuses of Tekeli earthquakes are “constrained” between two deep faults – South-Dzhungar and West-Dzhungar. The sizes of focus area are restricted by the borders of cuneiform block located in the zone of oppositely directed compressive forces from the north-east and south-west.

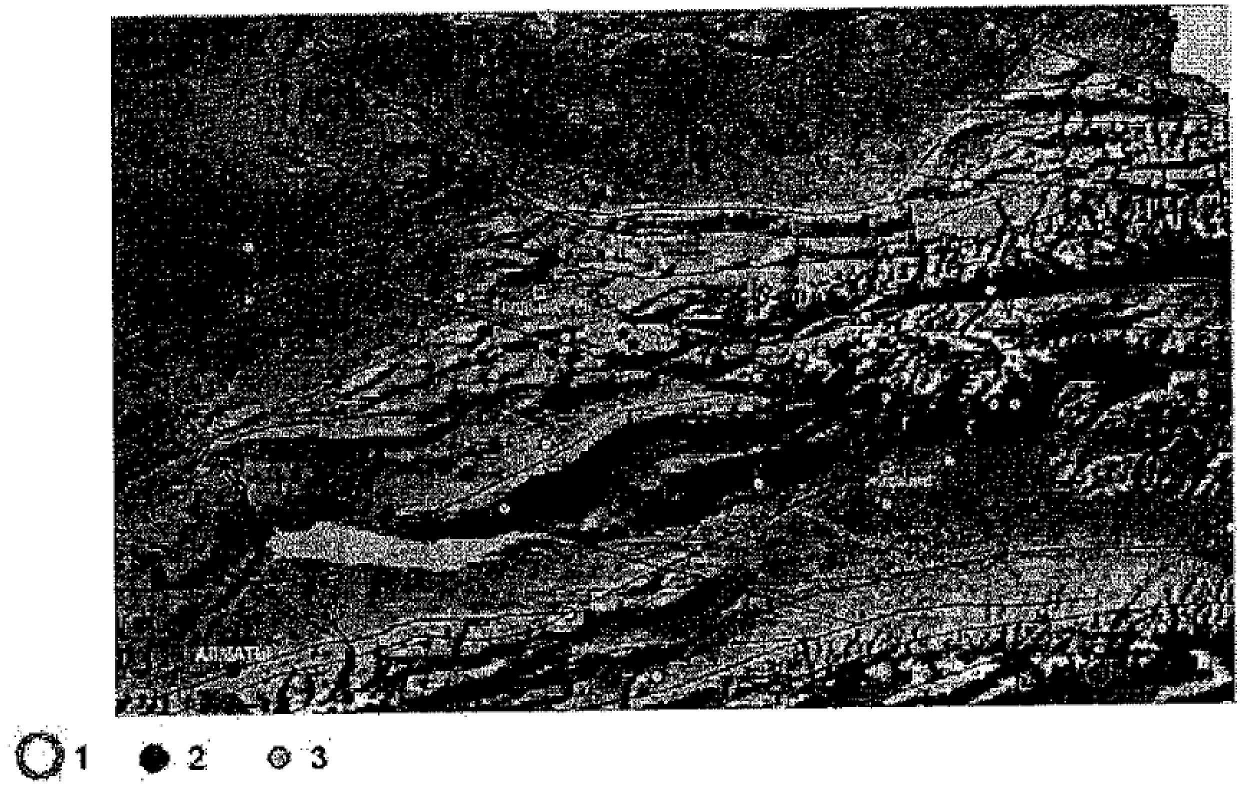

Figure 3. The map of Dzhungar region relief. The stars indicate the epicenters of Tekeli earthquakes of 1993 and 2009, black lines – active tectonic faults; 1-3 – earthquakes with $Ms \geq 7.1$ (1), $7.0 \geq Ms \geq 6$ (2), $5.9 \geq Ms \geq 5.0$ (3)

The analysis of seismotectonic conditions in this region following the results of focal mechanism study for the last 30 years showed the following [Nyusipov at al. 2007]. The stress system in Dzhungaria is characterized by near-horizontal submeridional compression and near-horizontal extension in the East-West direction. Dominant type of deformation in this conditions is horizontal shear on which background the local zones deformed by uniaxial compression and uniaxial extension were revealed. In particular, one of these zones of uniaxial extension is located in the block between South- and West-Dzhungar faults.

FOCAL MECHANISM OF THE TEKELI EARTHQUAKES

Focal mechanism of the Tekeli earthquake happened on June 13, 2009 was calculated by standard technique on the base of first arrivals of body waves (MO) and using technique of surface waves inversion (the catalogue of Centroid Seismic Moment Tensor (CMT) of Harvard University) [www.seismology.harvard.edu]. Figure 4 shows mechanism stereograms. For comparison, MO and CMT for the earthquake of 1993 are also shown (Figure 4, Table 2).

The solution of the earthquake focal mechanism of 2009 on the base of standard technique MO (line 4) used 27 signs of first arrivals of P- and S-waves recorded by seismic stations network of Seismological Experience-Methodical expedition (SEME) network and Institute of Geophysical Researches of the National Nuclear Center of the Republic of Kazakhstan (IGR NNC RK).

The signs distribution allowed to obtain MO solution with signs consistency of 100%, scattering of defined parameters did not exceed 15^0. The first nodal plane oriented in north-east direction decreases drastically to the south-east. The second plane is near-vertical, it has north-west extension coinciding with South-Dzhungar fault extension. The motion on the first plane is left-lateral strike-slip; on the second – oblique reverse with domineering right lateral strike-slip component. Orientation of strain in focal shows that the rupture occurred under influence of near-horizontal submeridional compression strain.

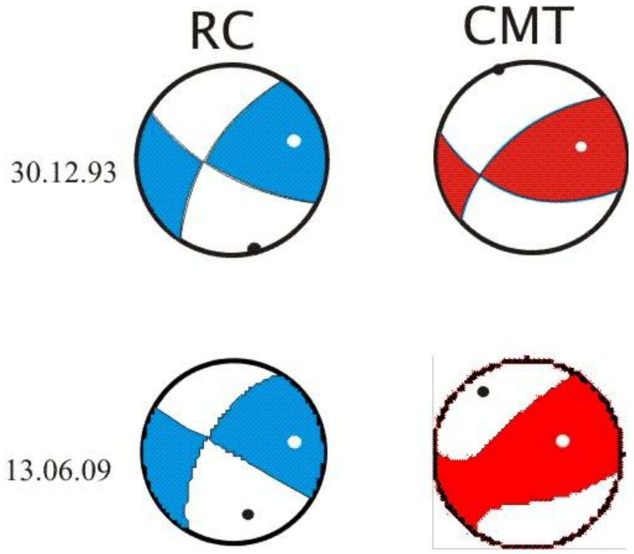

Figure 4. Stereograms of focal mechanisms of earthquakes occurred in 1993 and 2009 by data from regional MO catalogue and CMT catalogue.

CMT-solution (line 6, Table 2) was obtained by data from 24 stations of the Global monitoring network and in general coincides with a solution obtained by standard technique (line 5, Table 2). The difference between centroid and start time is 2.7 s by regional catalogue, it can characterize the time of process development in focus [Smith et al., 1997]. Location of the centroid epicenters and focus coincide in the first movement, only depth values differ significantly. Comparison of the mechanisms solutions obtained by two techniques shows that orientation of the first plane is almost the same, discrepancy of its parameters does not exceed 9^0, i.e. is within the solution error. Larger discrepancy of parameters was noted for the second plane: its dip in the main phase is more gradual, and extension is sublatitudinal. Orientation of compressing strain at rupture development remains, but parameters of tension stress and intermediate change significantly. This stipulates the change in motion type: strike-slip component decreases along both nodal planes, and reverse component increases. In result, the motion type changes to reverse faulting, this type of movement on rupture plane conforms with lesser hypocenter depth by CMT catalogue relating to the regional.

Table 2. Parameters of Tekeli earthquakes of 1993 and 2009 by data of regional and CMT catalogues.

№	каталог	дата	время	n	λ	H	Mb	AzP	eP	AzT	eT	AzN	eN	STR	DIP	SLIP	STR	DIP	SLIP	N
1	MO	30.12.93	142406.4	4449	7846	20		164	2	73	30	258	60	32	68	21	115	70	157	85
2	Δ(CMT-MO)		3.8	8	0	1		0	-2	-5	-17	8	17	-9	-6	-19	5	-15	12	61
3	CMT		142410.2	4457	7846	21	5,8	344	4	78	47	250	43	41	62	40	110	55	145	24
4	MO	13.06.09	171737.9	4446	7849	25		168	18	71	20	296	63	30	63	2	300	89	154	27
5	Δ(CMT-MO)		2.7	0	1	-13		169	-17	-3	37	-49	-30	9	-8	46	-24	-36	-21	-3
6	CMT		171740.6	4446	7850	12	5,8	337	1	68	57	247	33	39	55	48	276	53	133	24
7	ΔMO	1993-2009		3	-3	-5		-4	-16	2	10	-38	-3	2	5	19	-185	-19	3	58
8	Δ CMT	1993-2009		11	-4	9	0	7	3	10	-10	3	10	2	7	-8	-166	2	12	0

Focal mechanism solution within applied model assumes two equiprobable position of rupture plane. To identify true direction of rupture of extended focal I.V. Gorbyunova [1992] technique based on construction and analysis of azimuthal travel-time curve was applied. The travel-time curve was constructed on materials from SEME stations, vertical axis indicates values $\delta(tp_{max}-tp_1)$, where tp_{max} – peak time in *P*-wave train, and tp_1- time of P-wave first arrival. Figure 5 shows that the travel-time curve has one clear maximum assigned to azimuth of 40^0, the travel-time minimum inclines to values of 180 – 220^0. These values, shown in the Figure as vertical lines, are close to direct and back azimuths of extension of the first nodal plane, respectively. This view of azimuthal travel-time curve assumes that orientation of the rupture plane is close to 40^0, the rupture was unidirectional and propagated from azimuth 40^0 to azimuth of 220^0. Azimuthal travel-time curve data coincides well with focal mechanism parameters and allow to suppose that the rupture propagated along the first nodal plane (Az =30-39^0) from the north-east to the south-west.

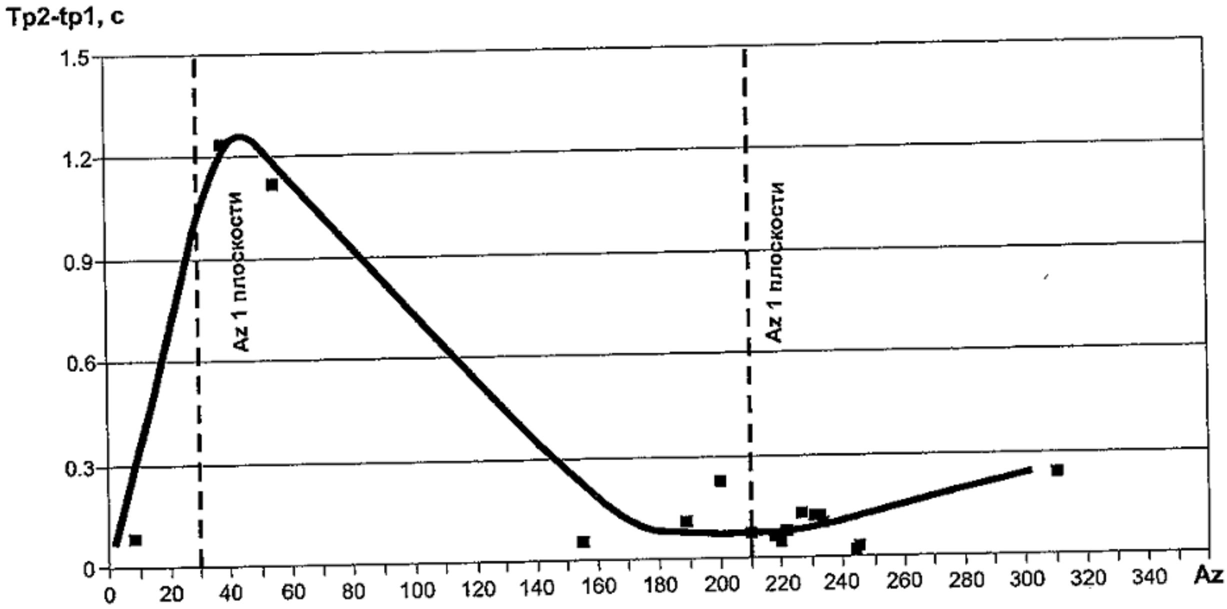

Figure 5. Azimuthal travel-time curve for the earthquake of 2009.

Comparison of focal mechanisms solutions of two Tekeli earthquakes of 1993 and 2009 by MO and by CMT shows their similarity (see Figure 4), difference in parameters values does not exceed the solution error limits (lines 7,8 Table 2). In both cases the mechanism solution represents combination of steep dipping planes of north- and south-east extension with motions realized in conditions of near-horizontal submeridional compression. In the first movement, horizontal component of motions along steep dipping planes prevails, and in the main phase – reverse fault and planes dipping at the rupture development becomes gentler.

The main characteristics of aftershock mechanisms of these two large earthquakes also appeared the same. In 71% of aftershocks in 1993 there was plane of north-east extension, note that in 32% both planes had north-east direction, and in the rest cases the second plane had north-west extension. Reverse faults (55%) and normal faults (45%) have almost the same values. Secondary stresses were relieved in almost all aftershocks (reverse and normal fault types).

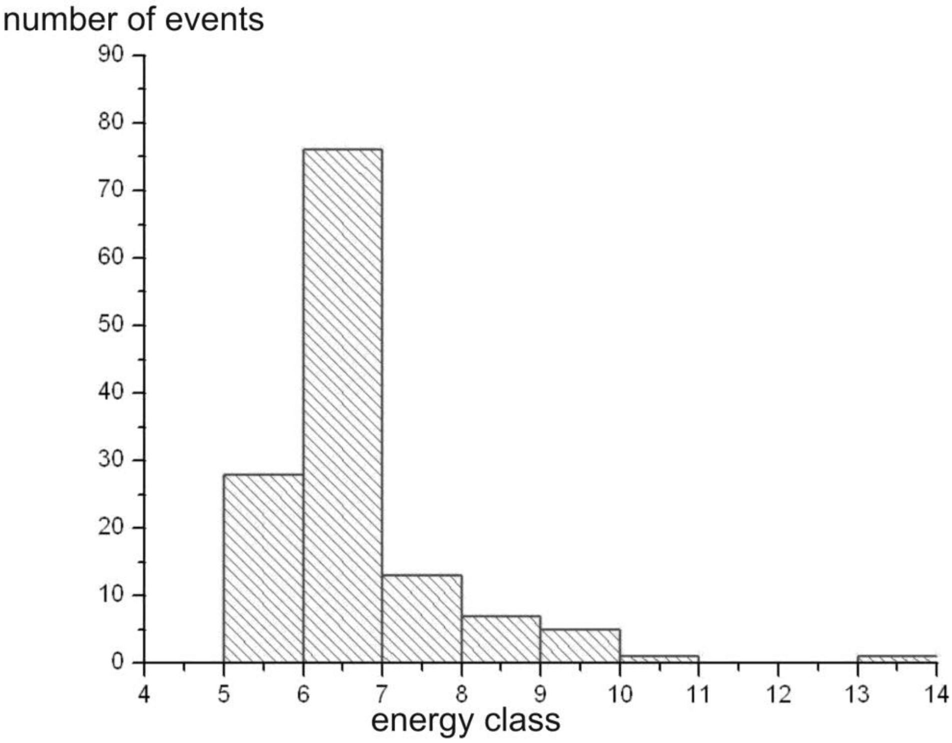

Figure 6. A histogram of aftershock distribution by energy class

SPATIAL-TEMPORAL AFTERSHOCKS DISTRIBUTION OF TEKELI EARTHQUAKE OF 13.06.2009. The Catalogue and seismological bulletins of 2009 contain more than 150 aftershocks of the main shock in the energy class range K=5-11 (Figure 6). The largest aftershock having K=10.7 occurred 7 minutes later after the main shock and was felt in Tekeli town with intensity 5. In the plan the aftershock cloud is concentrated in a block between the West- and South-Dzhungaria faults (Figure 7) and extends in south-east direction. The aftershocks area size in the plan is assessed by the following values: length L = 21 km, width W = 10 km. The same pattern is observed for the earthquake of 1993, but the main shock and consequent aftershock field is shifted to the north-west.

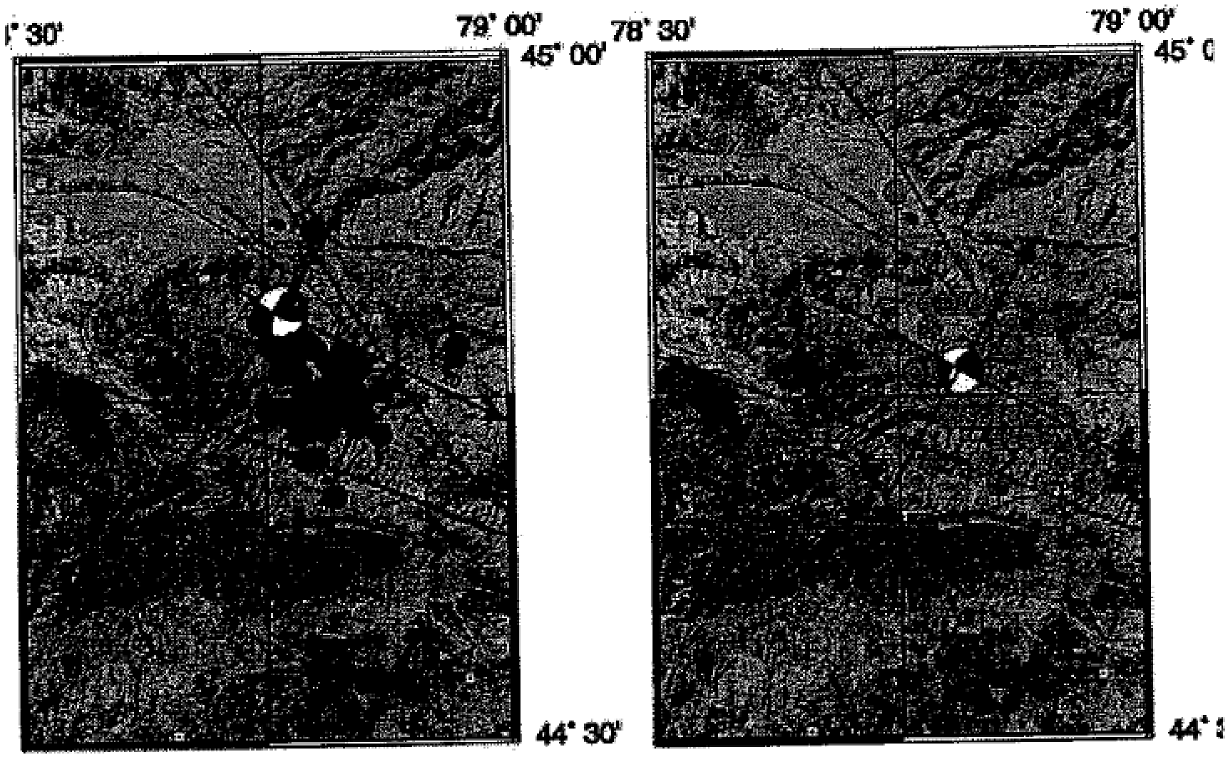

Figure 7. The map of epicenters of main shocks and aftershocks of the earthquake in 1993 (left) and in 2009 (right)

Note that position of the aftershock field in the plan only does not allow to define direction and size of a rupture at the main shock. It is necessary to analyze three-dimensional model of a focus in the crust. We have considered distribution of the aftershocks hypocenters projection on to orthogonal vertical planes oriented in the strike of the first and second nodal planes of the main shock (Figure 8). The analysis of depth distribution of aftershocks shows that all hypocenters in the earth crust are from 5 to 25 km depth. With distance increase from the main shock hypocenter southward the depths of aftershock focals decrease. However, it is clearly seen that all aftershock focals are located only at one side of the rupture plane, on the southern part. This fact allows to assume the rupture plane dip in southward direction. Orientation of the first nodal plane corresponds best to this aftershock distribution. It is clearly seen in Figure 8b: all aftershocks are concentrated in southern hanging wall of the rupture. Thus, although according to the aftershock distribution in the plan it seems that the rupture in the main shock extends in the south-east direction, the analysis of the aftershock distribution along vertical sections allows to suppose that the rupture in the focus occurred along south-eastward steep dipping plane of north-east extension (*Str* = 30-39^0). Geometric size of the focus assessed by vertical sections of aftershock distribution (see Figure 8) is: *L* = 15 km, *W* = 15 km, *H* = 25 km. According to available focus size and magnitude dependencies [Sadykov, 2004], such focus size corresponds to M = 6 and geologically fixed block size.

Investigation of aftershock attenuation with time showed sharp decrease of aftershock number during first 15 days (Figure 9). The Figure 10 shows that value of released seismic energy also quickly decreased. Aftershock activity of two Tekeli earthquakes was compared. Aftershocks hypocenters depths in 1993 were defined for several aftershocks only and are 12 – 18 km. The similarity is observed in aftershock attenuation with time – sharp decrease of activity during first day.

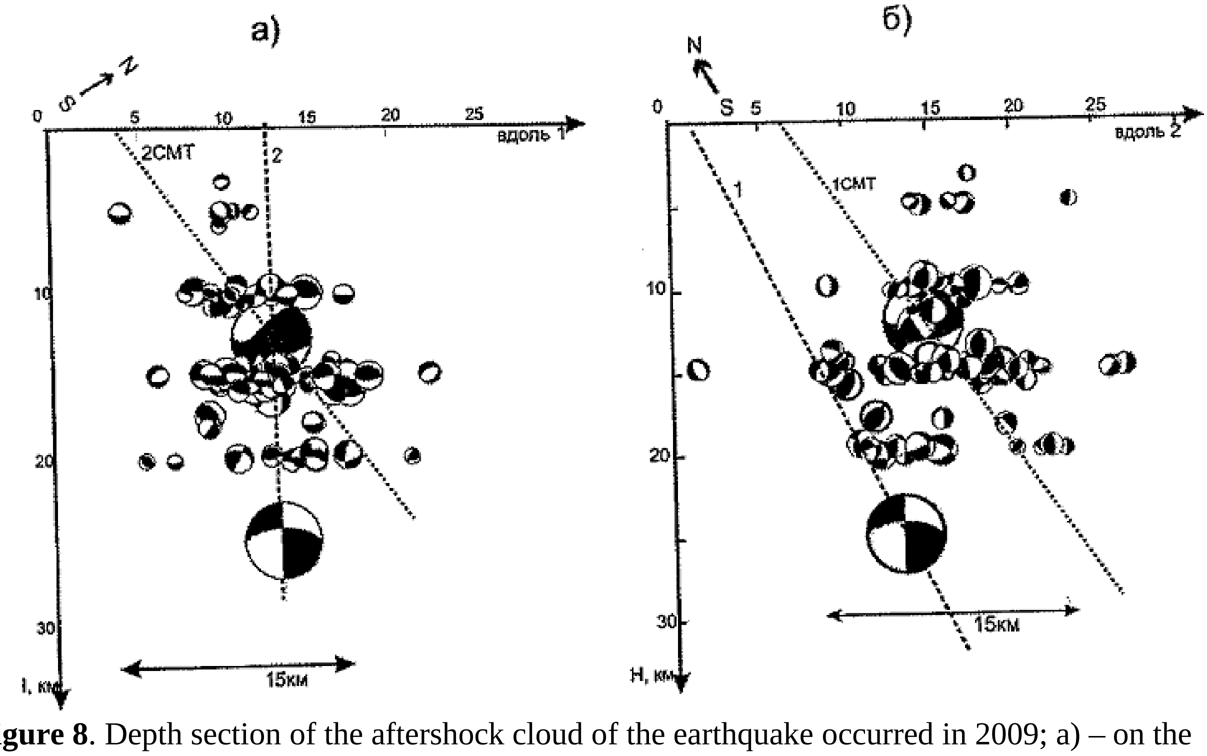

Figure 8. Depth section of the aftershock cloud of the earthquake occurred in 2009; a) – on the first nodal plane, b) – on the second nodal plane

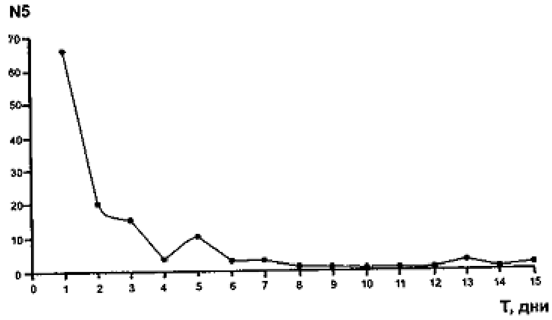

Figure 9. Attenuation of aftershock activity of Tekeli earthquake. X-axis shows five-day numbers beginning from the main shock.

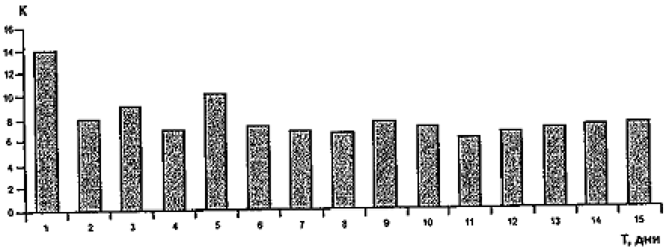

Figure 10. Maximal energy classes of aftershocks of Tekeli earthquakes for five days

MICROSEISMIC INVESTIGATION RESULTS

Microseismic investigation had been implemented from June 14 to June 20, 2009 by a team consisted of scientists and engineers from the Institute of Seismology of the Republic of Kazakhstan, Seismological experience-Methodical Expedition MES RK, “Prognoz” RAPC MEmS RK [Earthquake…, 2009]. Figure 11 shows an isoseismal map of Tekeli earthquake made by T.D. Abakanov, A.N. Lee, T.Ye. Nysanbayev, V.I. Panin, N.A. Taradayev and N.B. Uzbekov.

With highest intensity of 7 the earthquake occurred in Tekeli and Ryudniy towns. Tekeli town is located 8 km away from the instrumental epicenter. According to the map of seismic zoning for Tekeli town, its eastern part is located on unfavorable territory in seismic sense, this region is distinguished by frequent appearance of subsidence loess type loam soil of 20-30 m thick. Some buildings were constructed on the slopes. Possibly, these factors affected the seismic effect of Tekeli earthquake.

In consequence of the earthquake in Tekeli town adobe dwelling houses were damaged heavily by deep large through cracks and partial collapse. The brick chimneys collapsed everywhere, some stoves were destructed.

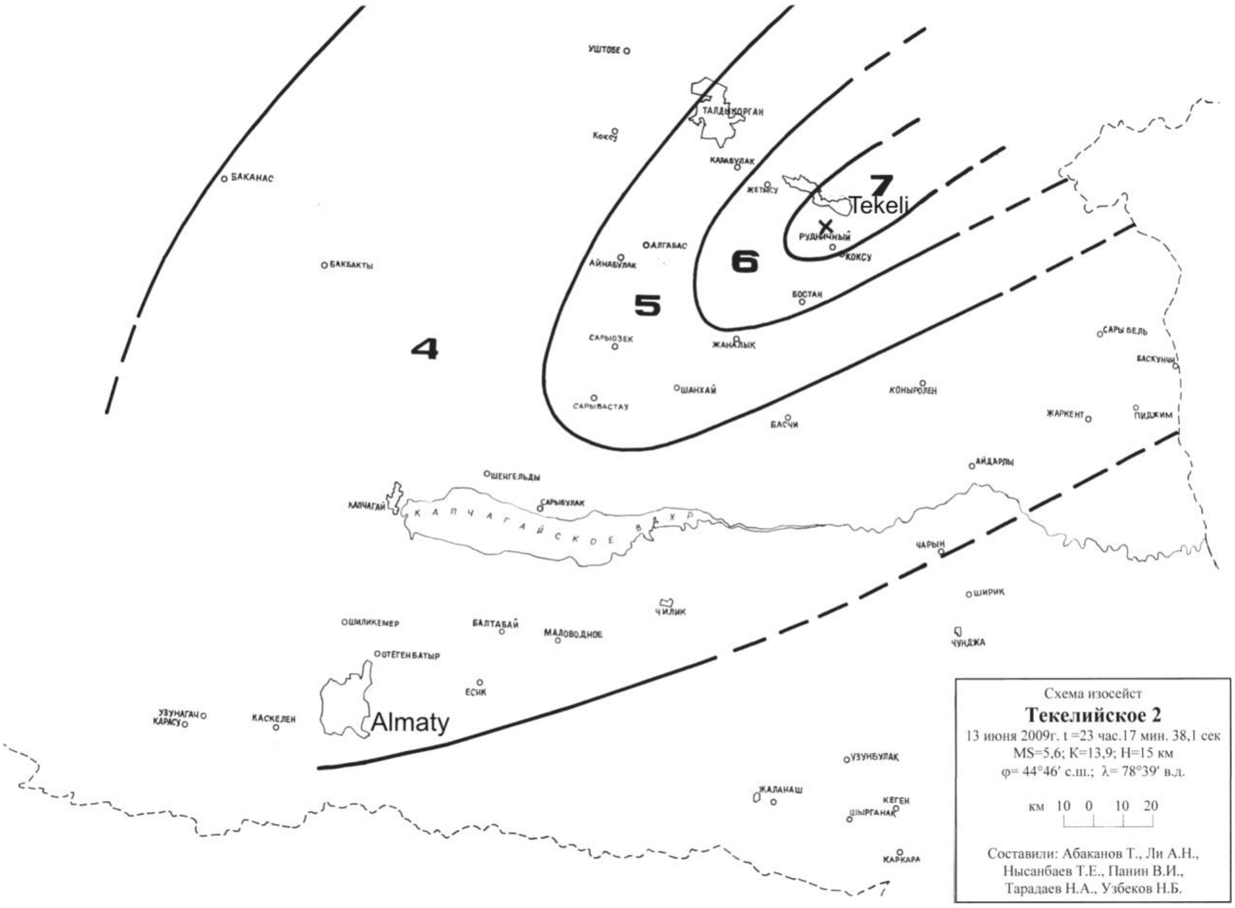

Figure 11. The isoseismal map of Tekeli earthquake of 13.06.2009

Major part of buildings of “A” type had damages of 3 level, and separate dwelling houses had 4 level damage characterized by through cracks and breaches in walls, connection loss between separate parts of buildings, collapse of internal walls.

There were no earthquake victims or injured. According to the estimate of especially assembled commission, the earthquake damage was 400 millions tenge (about 2.7 million dollars).

INTERPRETATION OF RUPTURES FOCAL POSITION OF TEKELI EARTHQUAKES

Thus, the analysis of different materials allows to conclude that the earthquake of 13.06.2009 occurred under influence of regional near-horizontal compression stress in submeridional direction. The focus of the main shock and a cloud of its aftershocks were located between South- and west-Dzhungaria faults.

The rupture process in focal was, most probably, from the north-east to the south-west direction. Aftershock activity concentrated in the south-east wall of the rupture. During aftershock activity the secondary stress caused by the main shock was relieved. Stress relief was caused by reverse and normal motions along the planes either in north-east extension or north-west matching with extension of the main faults primarily at H>10 km depth.

Proposed interpretation of processes in Tekeli earthquakes focals recorded in the block between South- and West Dzhungaria faults is shown in Figure 12. These are south-eastward steep dipping subparallel ruptures of the north-east extension. In the first movement the motions represent strike-slips on steep planes; as the rupture develops the dislocation type changes to reverse fault, dip plane becomes gentler. Geometric size of the focuses is restricted by the block size: L≈15 km, W≈15 km, H= 20-25 km, this coincides well with the earthquake magnitude.

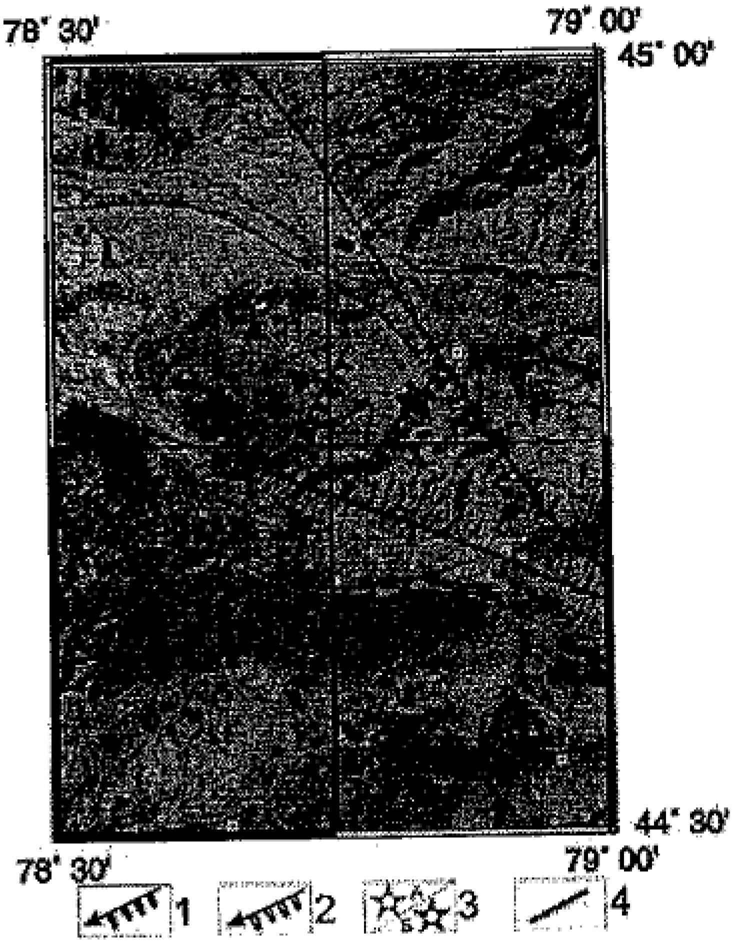

Figure 12. Interpretation of the Tekeli earthquakes (1993 and 2009) focuses position.

Two Tekeli earthquakes are so similar by all parameters that can be considered as two "acts of one drama" implemented by one scenario. The second earthquake continued the earth crust block breaks initiated by the first earthquake developing relief processes in the south-east direction in the similar stress volume due to consequent shocks.

STRONG MOTIONS PARAMETERS

Unfortunately, the authors do not have records of strong motions in near-epicenter zone. There are records of strong motions on the territory of Almaty city, 230 km away from the epicenter obtained by KNDC station. The station is located in the southern part of the city on thick mass of rubble-gravel on the territory of the Data Center of IGR NNC RK where a digital accelerometer (APT+Quanterra) is installed and using which the records from the earthquake of 13.06.2009 were obtained. At the recording point the earthquake felt with intensity 3-4. Figure 13 shows acceleration records, their peak values are 2.6 cm/s^2.

After accelerations integration the records of particle velocity were received. Peak values of particle velocity amplitudes are 0.17 cm/s.

Intensity values in points at the place of strong motion record can be assessed by acceleration amplitudes and by velocity amplitudes according to the obtained earlier instrumental scale of intensity [Scale…, 2004]. The intensity value in points is 3-4.

Calculated response spectrum at 5% attenuation is shown in Figure 14. It is clearly seen that periods of peak acceleration range from 0.11-0.4 s. According to particle velocity the peak of response spectrum is observed at periods of 1-2 s.

Close parameters of strong motions were obtained on the territory of Almaty for the earthquake of 1993 [Kalmykova et al. 1999]: on accelerations the dominant periods in different parts of the city were 0.15 s, and on velocity – 1.0 s. Relative duration of fluctuations is also characterized by close values of two earthquakes. Note that in 1993 the fluctuations were recorded in analogue form only. Table 3 shows comparison of the records parameters of the earthquakes occurred in 1993 and 2009 from close to each other stations located in Almaty.

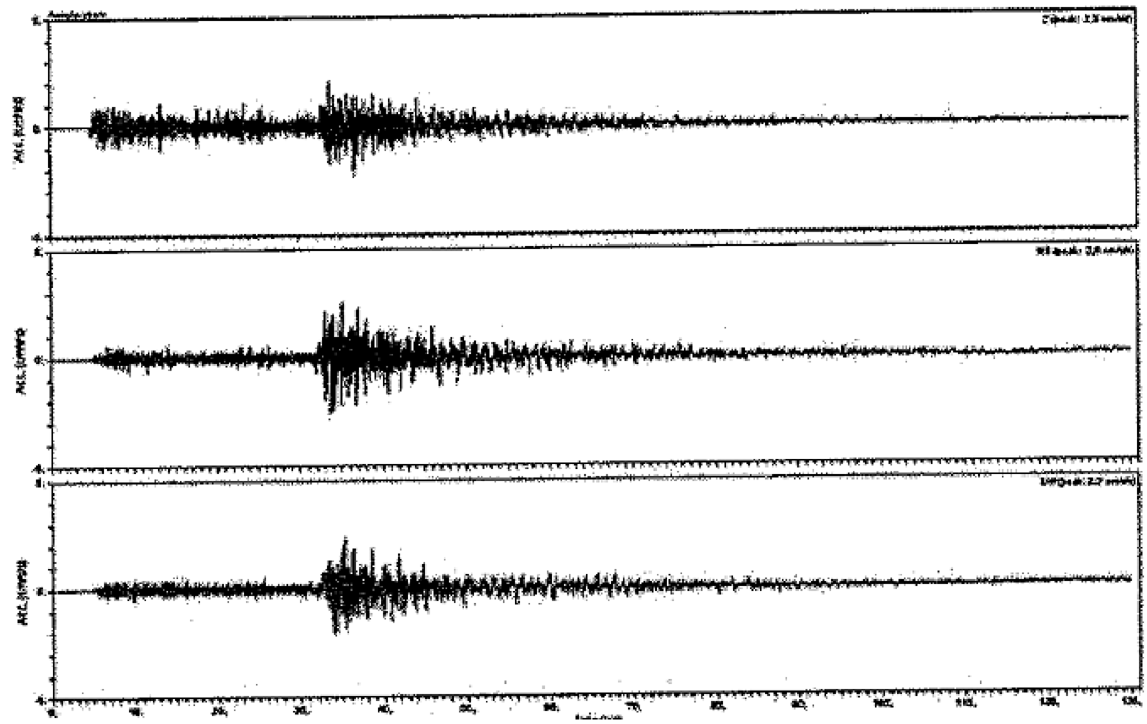

Figure 13. Accelerograms of Tekeli earthquake of 13.06.2009 by KNDC station (Almaty)

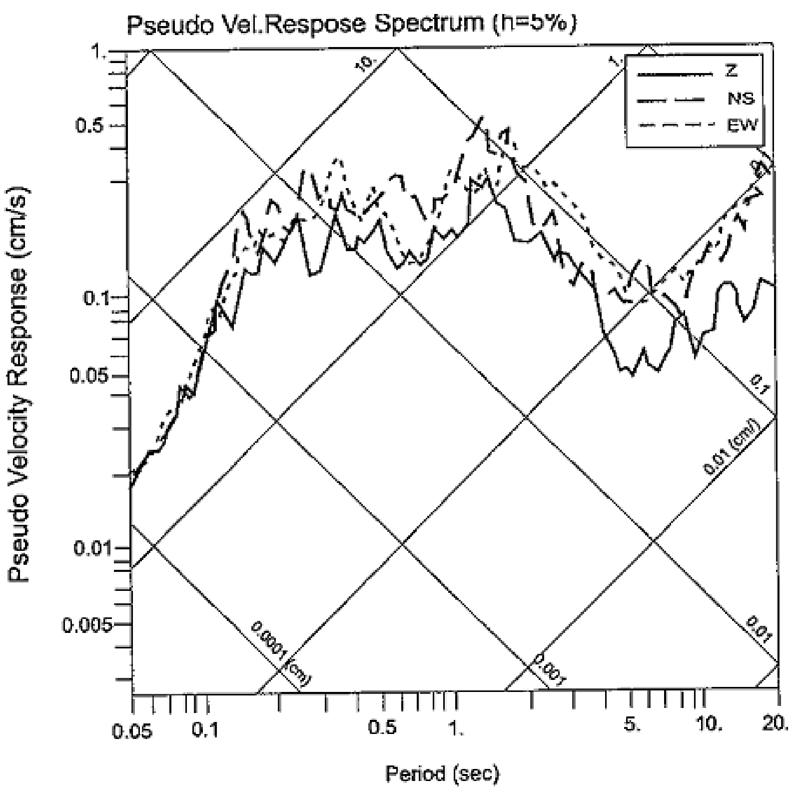

Figure 14. Response spectra by three components of the records from KNDC station

Table 3. Parameters of strong motions of Tekeli earthquakes on the territory of Almaty

Date	Station	Recorded kinematic parameter	Fluctuations parameters			
			component	A, cm/s^2 and cm/s	*T*, c	*d*, c
30.12.1993	Almaty, Al-Farabi	acceleration	Z E	1.4 1.7	0.15 0.15	11 11
13.06.2009	Almaty, KNDC	acceleration	Z E N	2.3 2.3 2.6	0.18 0.13 0.12	10 8 8
30.12.1993	Almaty, Markova	velocity	N	0.30	1.0	30.0
13.06.2009	Almaty, KNDC	velocity	Z E N	0.13 0.34 0.19	1.8 1.3 1.2	28.0 26.0 27.0

CONCLUSION

1. Two earthquakes similar by force and location caused 7-point shakes in Tekeli town in 1993 and 2009 represent a unique possibility to investigate conditions stimulating their appearance.
2. Similarity of mechanisms of two focuses was established, and it showed that the earthquakes occurred under influence of regional compression stress in submeridional direction. Comparison of MO and CMT solutions allows to conclude the following: initially the ruptures represented strike-slips along south-eastward steep dipping planes of the north-east extension. As the rupture developed the motion type had been changing to reverse fault on gentler planes. Geometric size of the ruptures are restricted by the block size and correspond to average size of earthquake focuses with magnitude *M*=6.
3. The whole aftershock activity after both earthquakes developed only in southern hanging wall of the ruptures mainly at H>10 km depth. Aftershock activity attenuated quickly in time with alternation of dilatational strengthening and softening processes.
4. Parameters of strong motions on the territory of Almaty show close similarity for both events indicating that there is regular connection of effects with focal parameters at similar propagation path of seismic waves. The same focal mechanisms at the same sources size stipulate reoccurrence of effect parameters at the same observation point.
5. Ruptures orientation in focals of main shocks and their aftershocks indicates that most probably in the block between South- and West Dzhungaria faults of north-west extension there is a system of seismic active faults of higher order dipping steeply south-eastward along mountain ridge of north-east extension penetrating into the earth crust up to 20-25 km at least.

REFERENCES

Gorbyunova I.V., Kalmetyeva Z.A., Mikhailova N.N. et al. Interpretation of focal waves in earthquake records. Bishkek – Moscow: Science, 1992.

An earthquake at Almaty region (Tekeli town, June 13, 2009) // Collected scientific works of the scientific-technical conference. Emergency Situations Department for Almaty. Ministry for Emergency Situations of RK. Almaty, 2009. P.79-80.

Kalmykova N.A., Mikhailova N.N., Neverova N.P. Earthquakes of Northern Tien Shan // Earthquakes of North Eurasia. Moscow: NIA-Priroda, 1999. P.55-59.

Nyusipov Ye., Sadykov A., Poleshko N.N. Seismotectonic deformation of medium by data of earthquake focal mechanisms // Geodynamics and seismicity of lithosphere. Almaty: IS MES RK, 2007. P.243-244.

Sadykov A. Seismic setting of Kazakhstan territory // Almaty: Gylym, 2004. Pp. 268.

Seismic zoning of Kazakhstan Republic. Almaty:Evero, 2000. Pp.219.

Final Technical Report under ISTC Project KR-1176 "Assessment of seismic risk in Central Asia". 2009.

A seismic scale MSK-64 (K) to estimate the earthquake intensity. Almaty: Committee on construction and housing and utilities infrastructure of the Ministry for Industry and Trade of the Republic of Kazakhstan Press. 2004. Pp.16.

Smith G.P., Ekstrom G. Interpretation of earthquake epicenter and CMT centroid locations, in terms of rupture length and direction // Phys. Earth Planet. Int. 1997.V.102, No. 1-2. P. 123-132.

www.seismology.harvard.edu