Analysis of the seismic process of the Bishkek geodynamic test site (Northern Tien Shan)

VN Sychev[1], NA Sycheva[1], LM Bogomolov[2]

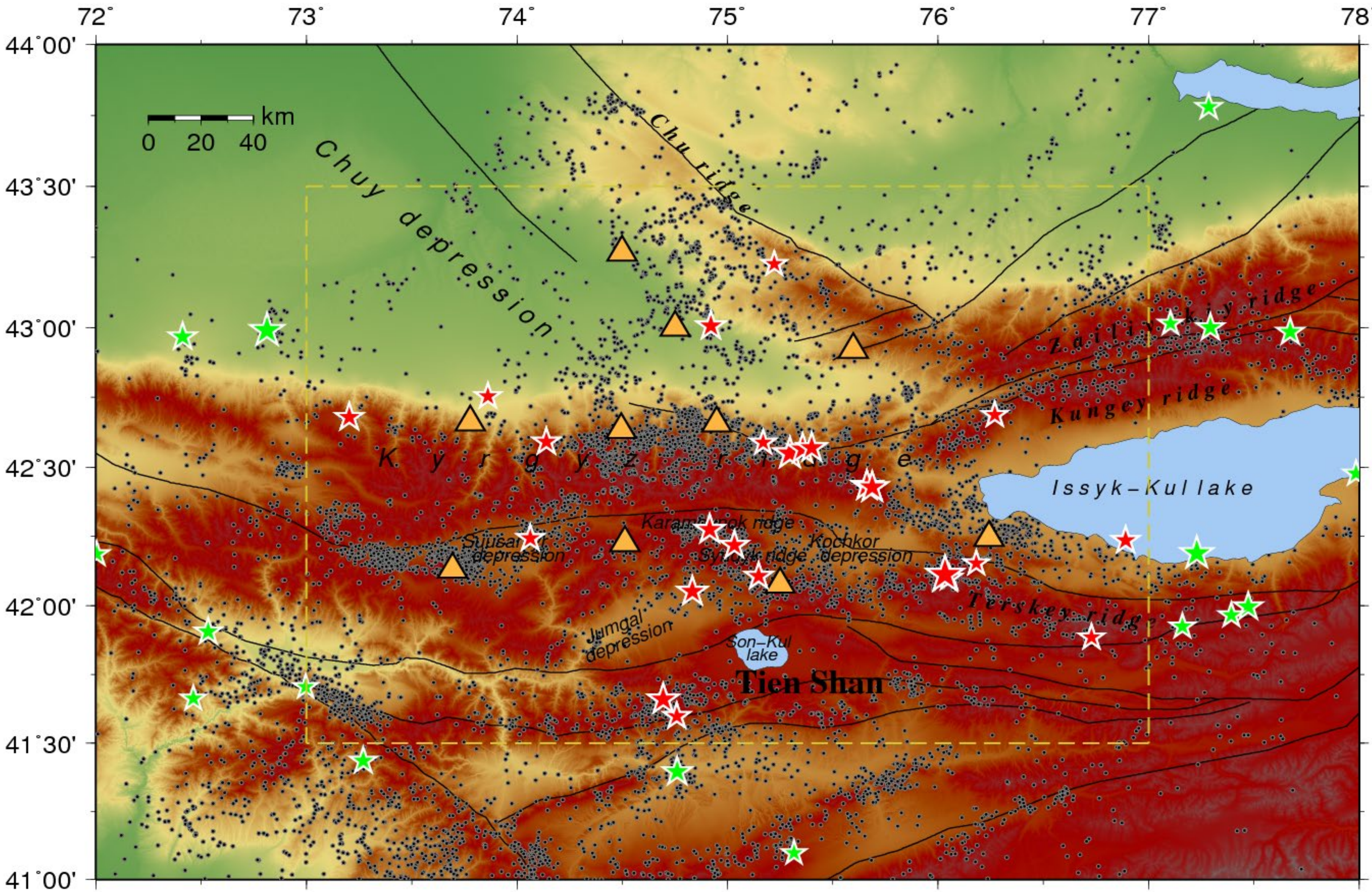
[1]Science Research Station of the Russian Academy of Sciences in Bishkek city, Kyrgyzstan

[2]Institute of marine Geology and Geophysics of the far Eastern branch of the Russian Academy of Sciences

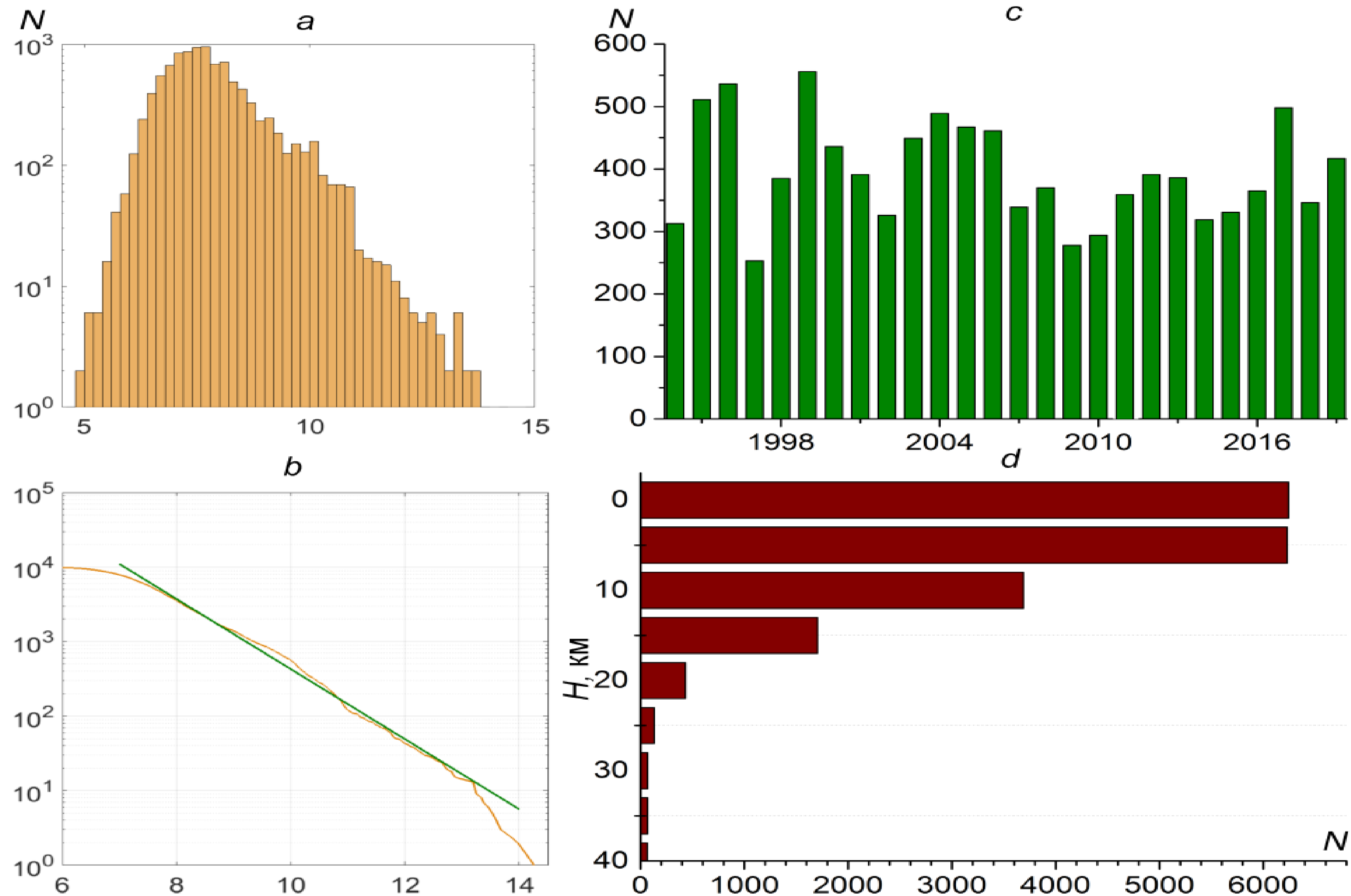
Problem

The objective of this work is to analyze the seismic process of the territory of the Bishkek geodynamic test site based on the calculation of traditional parameters - seismic activity, STD intensity, seismogenic rupture parameter, b-value parameter of the Gutenberg - Richter distribution, as well as the application of the method of unconventional statistical analysis of the seismic process - non-extensive Tsallis statistics.

Epicentral location of events in 1994–2019. (10 202 events). Triangles are KNET stations. The dotted line conventionally marks the territory of the BGP (see Fig. 1). The asterisks show the earthquakes position with $M \geq 4.4$ ($K \geq 12$).



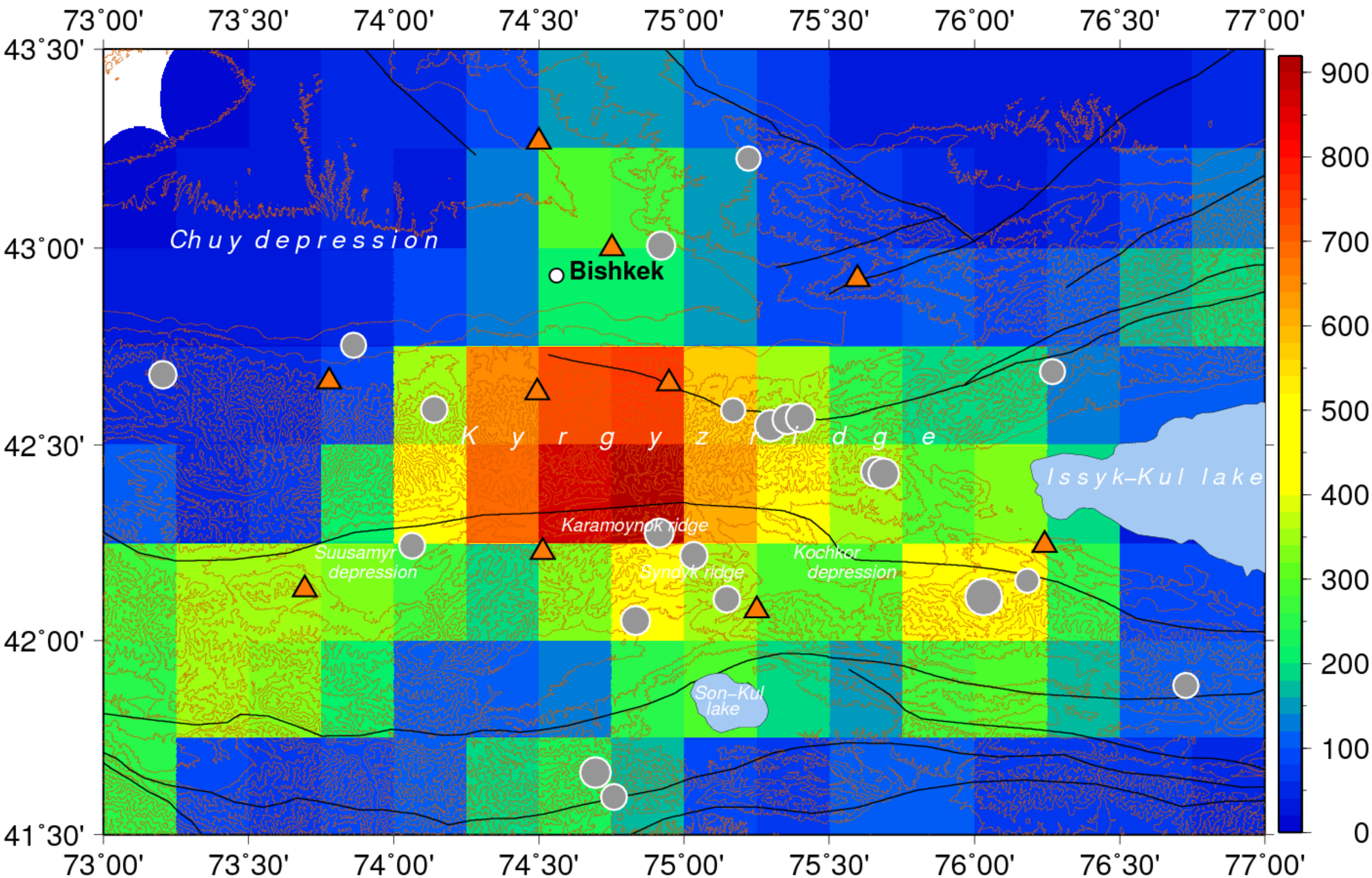
Statistical characteristics of the catalog according to the KNET network (more than 10,000 events): a - repeatability graph; b is the Gutenberg-Richter distribution; c - time distribution of events; d - distribution of events by depth.



Methodology

To calculate the distribution of the studied parameters (seismic activity, STD intensity, seismogenic rupture parameter, Tsallis parameter *q* and *b - value*) over the territory of the BGP, the geostructural region was subdivided into unit cells with a size of 0.5° and the shift was 0.25°. The lower limit of the depth of the investigated layer is 30 km.

Distribution of the number of earthquakes on the territory of BGP according to the data of the KNET network (1994-2019).



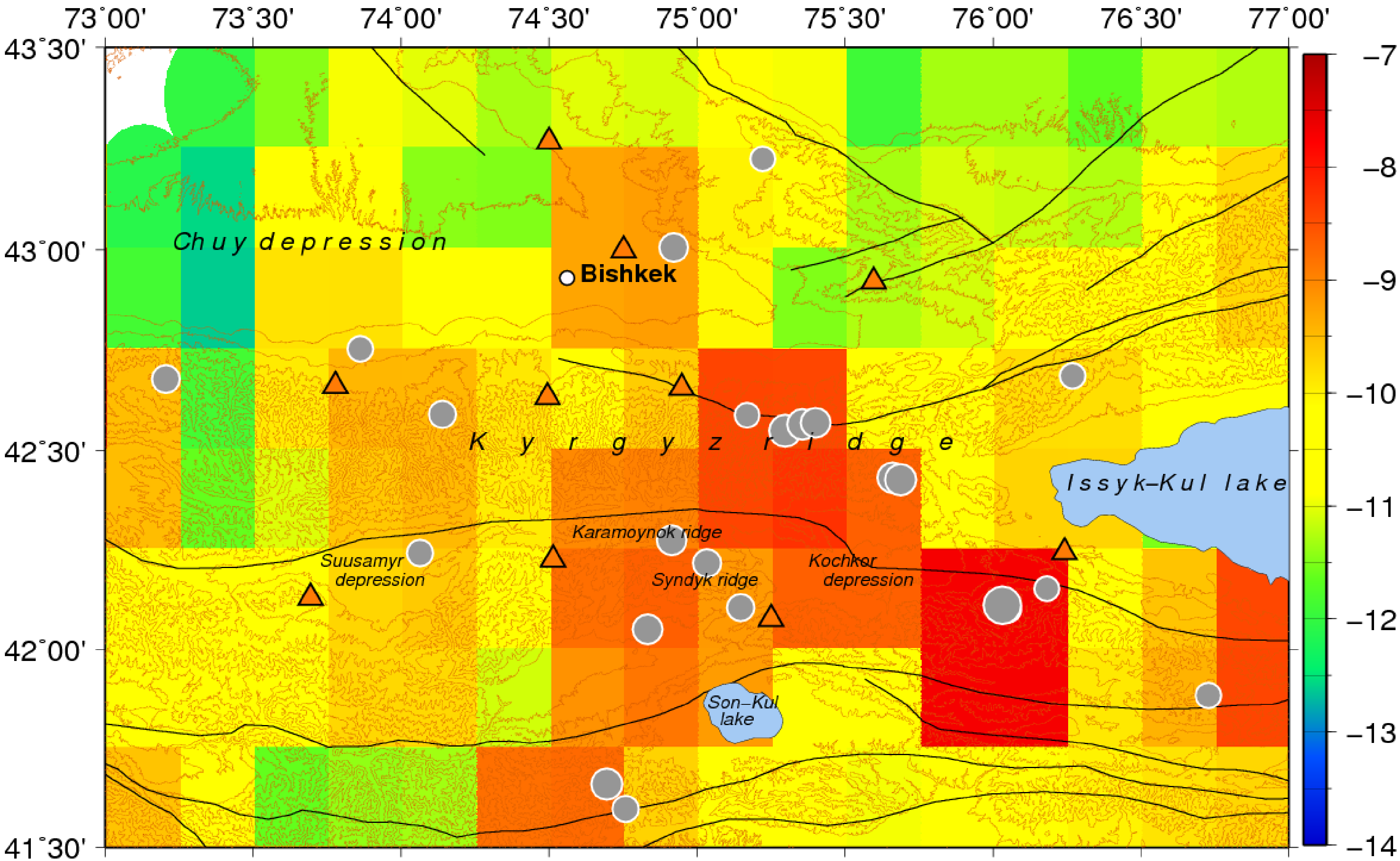
Showing earthquakes with M > 4.4,

STD intensity

The calculation method STD intensity is outlined in

Лукк А.А., Юнга С. Л. Сейсмотектоническая деформация Гармского района // Изв. АН СССР. Физика Земли. 1979. № 10. С. 24–43.
Ризниченко Ю В 1985 *Проблемы сейсмологии* Избр.тр. М: Наука 408 с.
Юнга С.Л. Методы и результаты изучения сейсмотектонических деформаций. М.: Наука, 1990. 191 с.

STD intensity



Distribution of the logarithm of the STD intensity on the territory of the BGP according to the KNET network data (1994-2019).

Crack concentration parameter K_{SR}

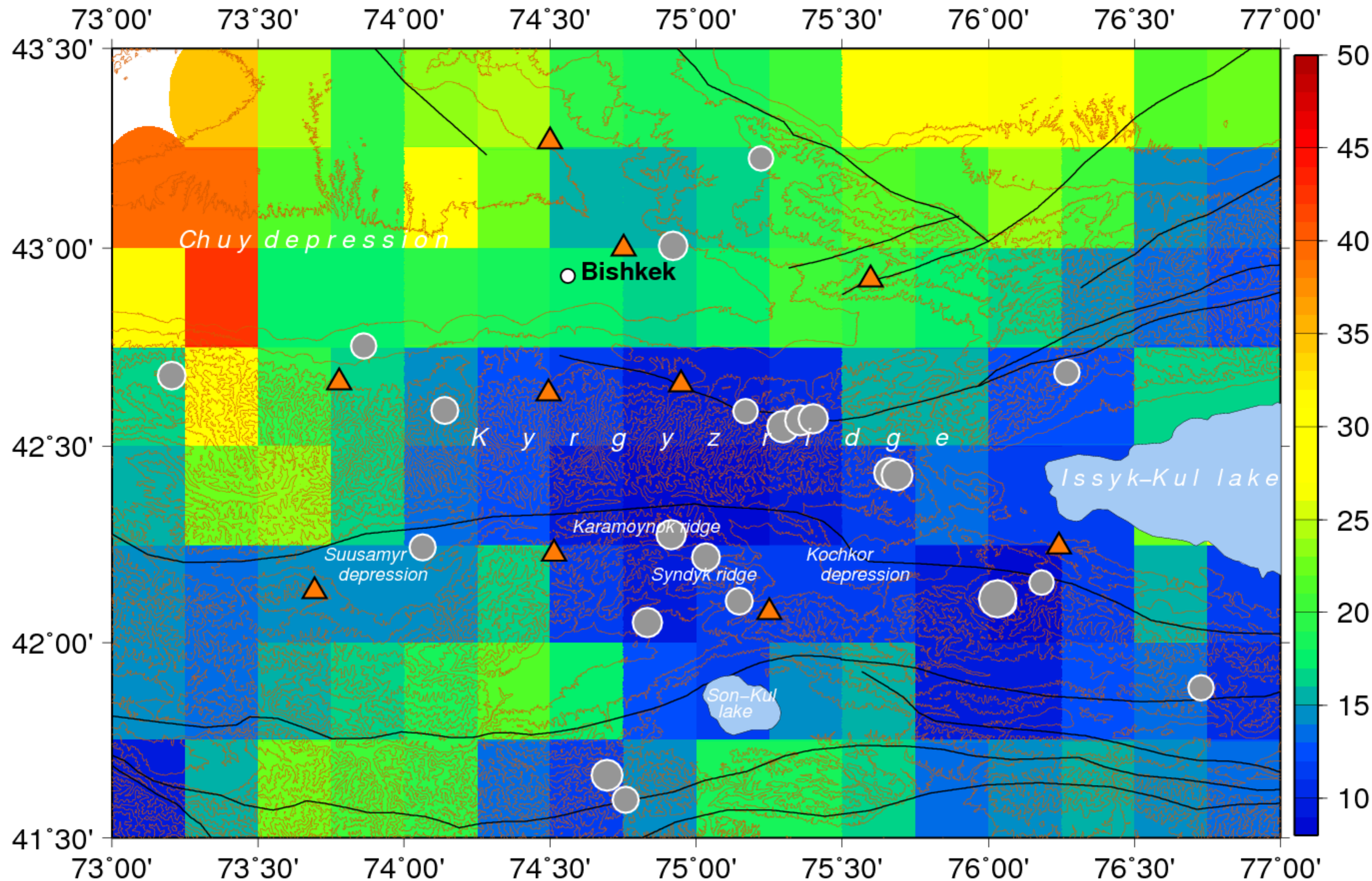
The calculation method $\boldsymbol{K_{SR}}$ *is outlined in*

Завьялов А.Д. 2006 *Среднесрочный прогноз землетрясений: основы, методика, реализация* М: Наука 254 с

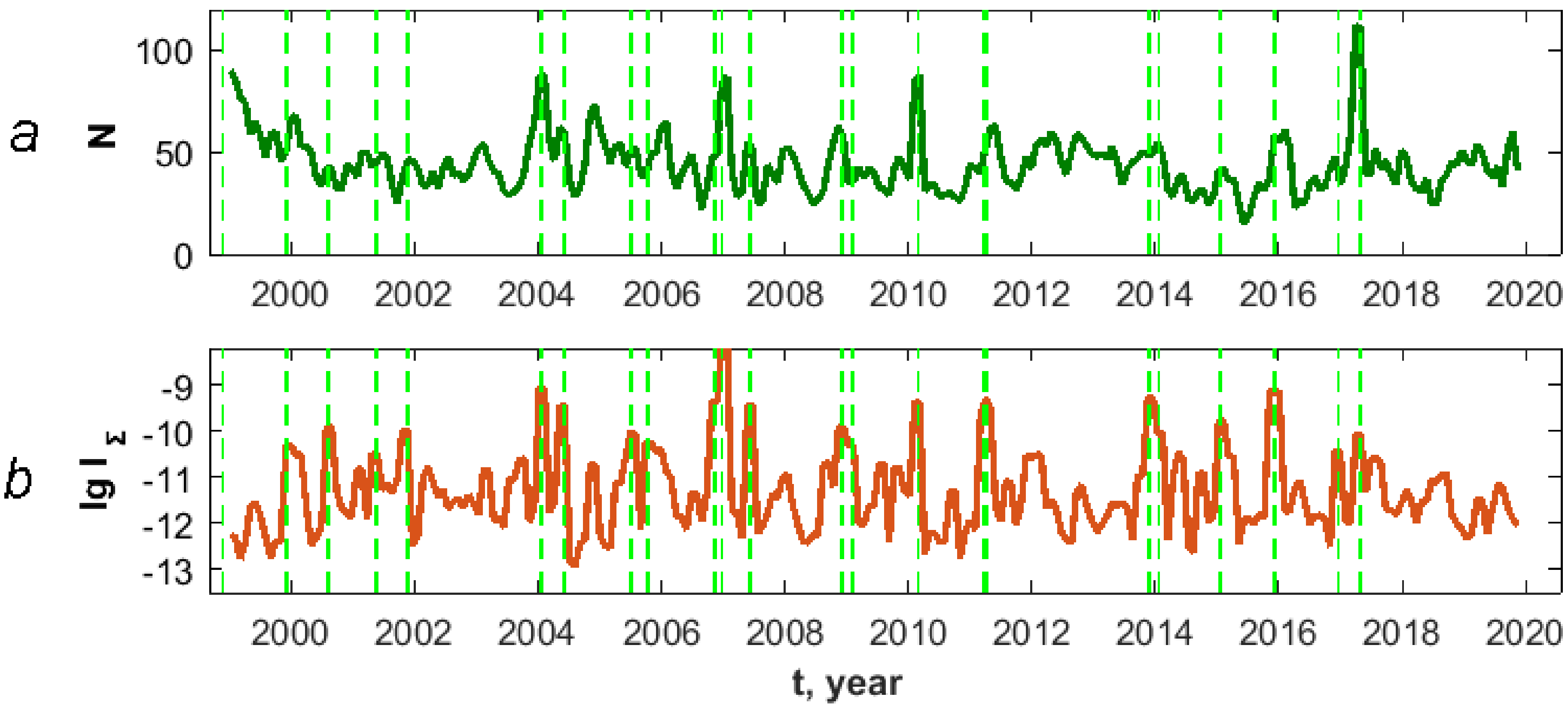
Ризниченко Ю.В. Размеры очага корового землетрясения и сейсмический момент // Исследование по физике землетрясений. М.: Наука, 1976. С. 9–27

Соболев Г.А., Завьялов А.Д. О концентрационном критерии сейсмогенных разрывов // Докл. АН СССР. 1980. Т.252. № 1. С. 69–71

Distribution of the coefficient of seismogenic ruptures in the BGP territory according to the KNET network data (1994-2019)



Time distribution of the number of earthquakes (a), the decimal logarithm of the STD intensity (b) for the territory of BGP (according to the KNET network, 1994-2019)



Параметр b-value.

The most famous relation is the Gutenberg - Richter energy distribution law for earthquakes:

$$P(E) \sim E^{-\gamma},$$

where $\gamma \approx 5/3$, E is the earthquake energy [5]. In terms of the number of events with a magnitude M exceeding m, the distribution law takes the form:

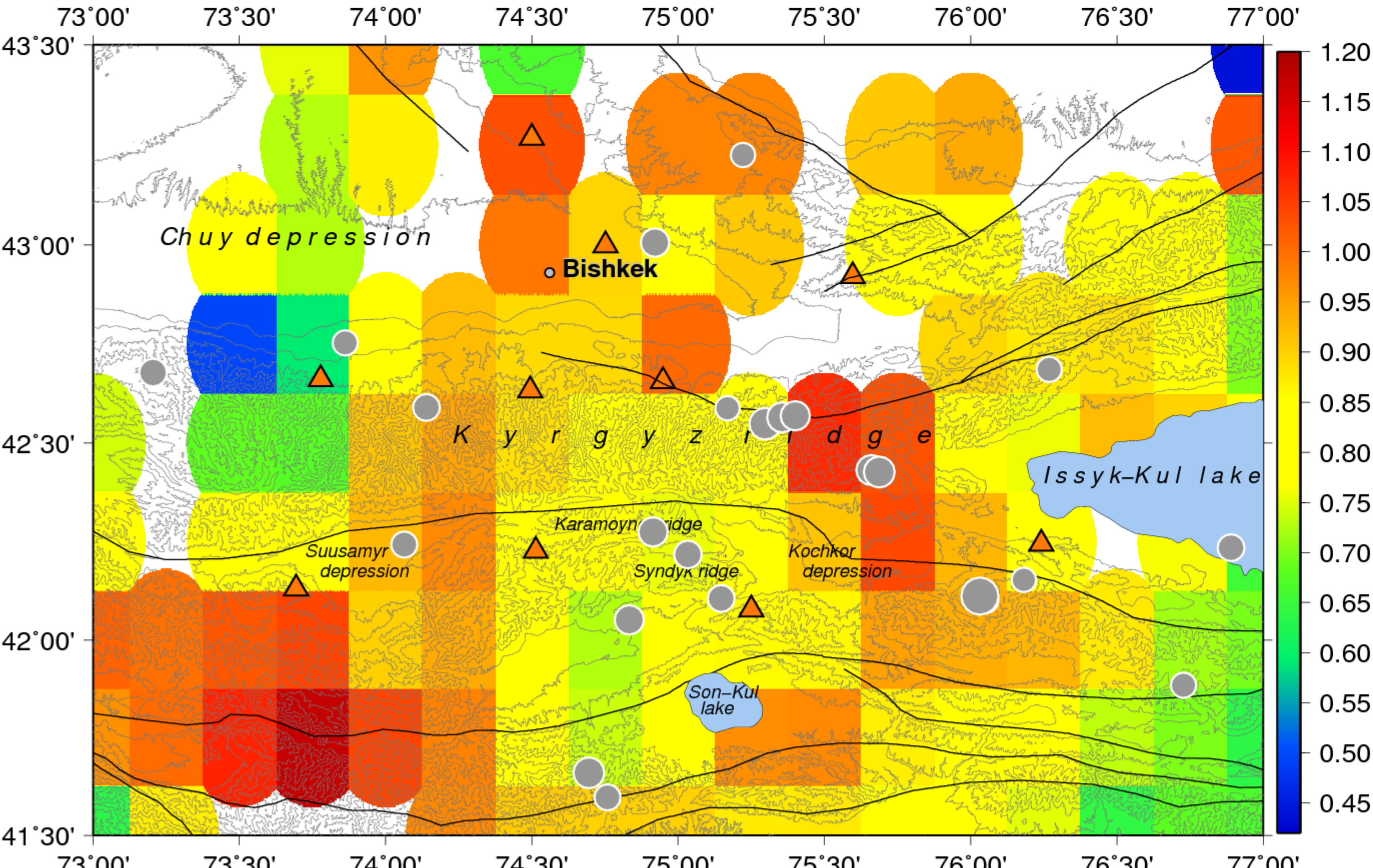
$$N(M > m) \sim 10^{-bm},$$

where N - denotes the number of events for a specified fixed period of time and in a given geographic region, b - a constant (b-value), in most cases takes a value of about 0.9

Gutenberg B., Richter C.F. Frequency of earthquakes in California // Bull. of the Seismological Society of America. 1944. V. 34. P. 185–188.

Касахара К. Механика землетрясений. М.: Мир, 1985. 264 с.

Distribution of b-value on the territory of BGP according to the data of the KNET network (1994-2019)



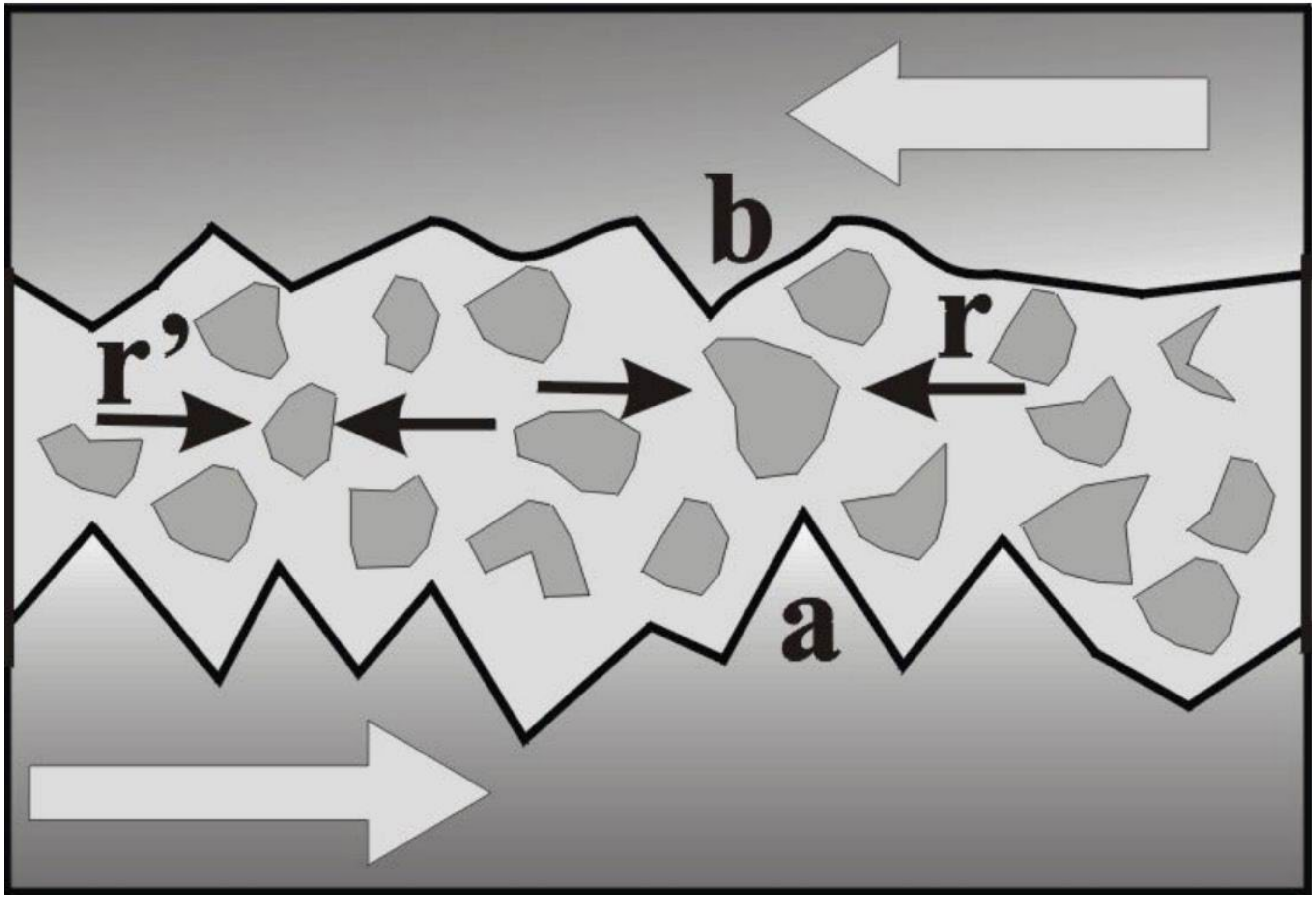
Nonextensive analysis

In 1988, Constantino Tsallis, to describe complex non-additive statistical systems, generalized the classical definition of the Boltzmann-Gibbs entropy by introducing into the expression the parameter *q*, which characterizes the degree of non-additivity, and proposed the so-called nonextensive or non-additive entropy, which is determined on a discrete number of microstates *N* by the following expression:

$$S_q = k\frac{1}{q-1}\left(1-\sum_{i=1}^{N} p_i^q\right); \qquad \sum_{i=1}^{N} p_i = 1,$$

where p_i is the probability that the system is in the *i* - state, *N* is the number of states of the system, *k* is some positive constant that determines the unit of measurement of entropy and in physical formulas serves for a bundle of dimensions, such as the Boltzmann constant. The Boltzmann statistics, corresponding to the limit $q \to 1$, $q > 1$, indicates the presence of long-range correlations and memory in a nonequilibrium system when additivity is violated. Thus, the Tsallis entropy is no longer an extensive function.

Earthquake model



An illustration of the relative motion of two irregular faults in the presence of material filling the space between them. Observe that this material may play the role of bearings or also of particles that hinder the relative motion of the plates as seen in the figure between points a and b.[Sotolongo-Costa and Posadas, 2004].

The analysis of the flow of earthquakes, as an open nonequilibrium system, is based on the energy distribution function of earthquakes proposed in [*Sotolongo-Costa O, Posadas A 2004Physical Review Letters February vol 92 N 4*] based on the well-known model of stick-slip earthquakes - "discontinuous sliding" of two plates over each other along a fault in the presence of friction [*Brown S R, Scholz C H, Rundle J B 1991Geophys. Res. Lett. vol 18 N 2 pp 215–218*] and the principles non-extensive statistical physics.

Using this model and the principle of maximum entropy, an analytical expression was obtained for the energy distribution function of earthquakes, which generalizes the empirical Gutenberg – Richter function

$$\log\left(\frac{N(M > M_{th})}{N}\right) = \left(\frac{2-q}{1-q}\right)\log\left[1-\left(\frac{1-q}{2-q}\right)\left(\frac{10^{M_{th}}}{a^{2/3}}\right)\right]$$

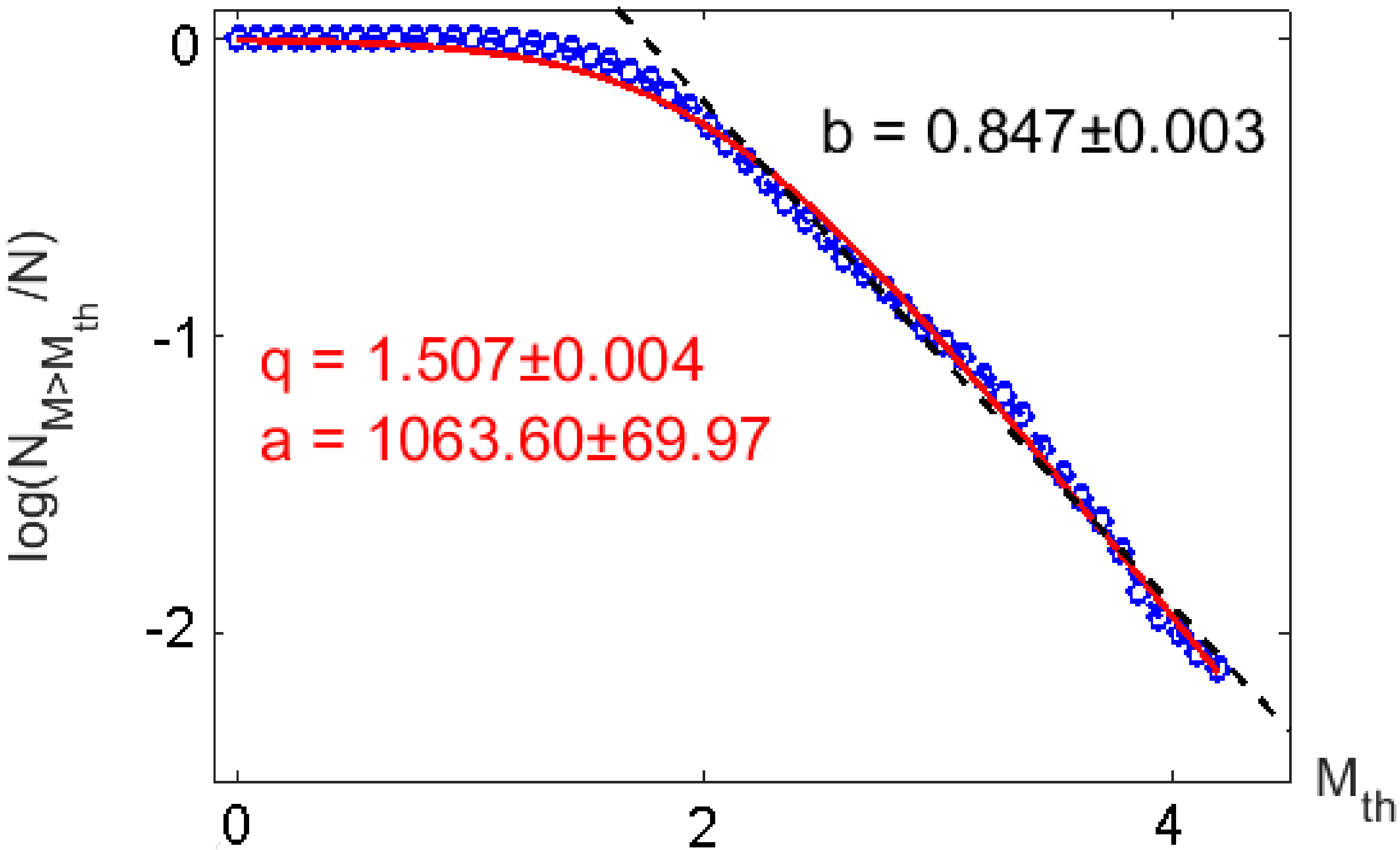
where N ($M> M_{th}$) is the number of earthquakes with energies greater than the threshold value M_{th}, and $M \sim \log(E)$, E is the earthquake energy, N is the total number of earthquakes, a is the proportionality constant between the earthquake energy E and the size of the fragment of blocks between faults and has the dimension of the bulk energy density

Equation makes it possible to estimate the degree of nonextensiveness in the region under consideration. In addition, as noted in [*Vallianatos F., Michas G., Papadakis G*. Non-extensive and natural time analysis of seismicity before the Mw6.4, October 12, 2013 earthquake in the South West segment of the Hellenic Arc // Physica A: Statistical Mechanics and its Applications Vol. 414, 15 November 2014, P. 163-173], this equation can be considered a generalized equation for the distribution of earthquakes by energy, since at magnitudes above a certain threshold value, this distribution reduces to a Gutenberg – Richter expression of the form with the *b-value*

$$b = \frac{2-q}{q-1}$$

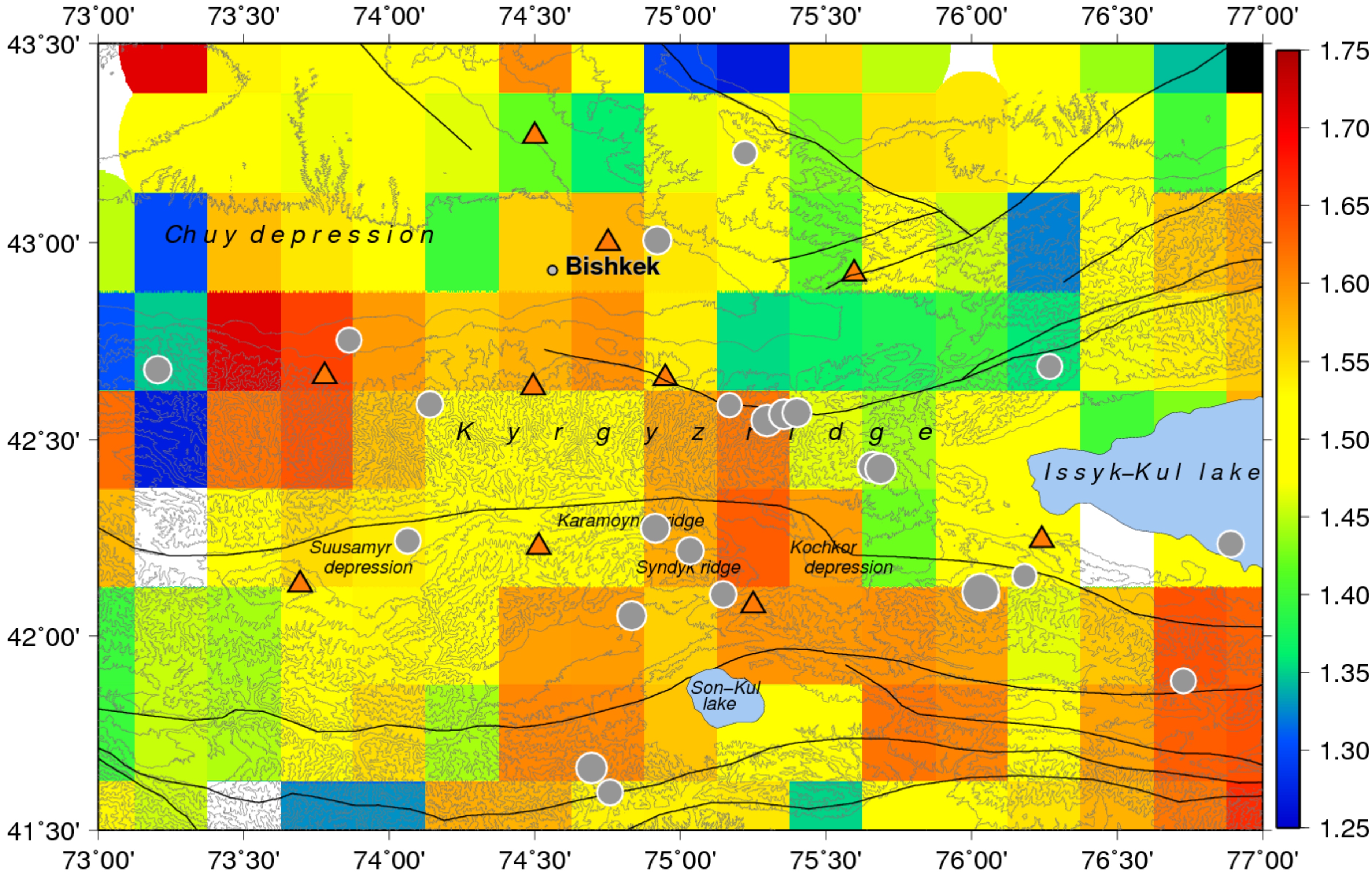
Many publications indicate that the value of the parameter *q* can be used as a measure of the stability of the active tectonic zone [Papadakis G, Vallianatos F, Sammonds P 2016*. Phys.* A 456 pp 135–144; Telesca L 2010a *Tectonophysics* vol 494 pp 155–162; Vallianatos F, Michas G, Papadakis G 2014 *Physica A: Statistical Mechanics and its Applications* vol 414 **15** pp 163–173].

A sharp increase in the parameter *q* indicates an increase in the interaction between fault blocks and their fragments and implies a deviation from the equilibrium state [*Complexity of Seismic Time Series: Measurement and Applica*tion 2018 Edited by Tamaz Chelidze, Filippos Vallianatos, Luciano Telesca. Amsterdam, Netherlands: Elsevier p 548]

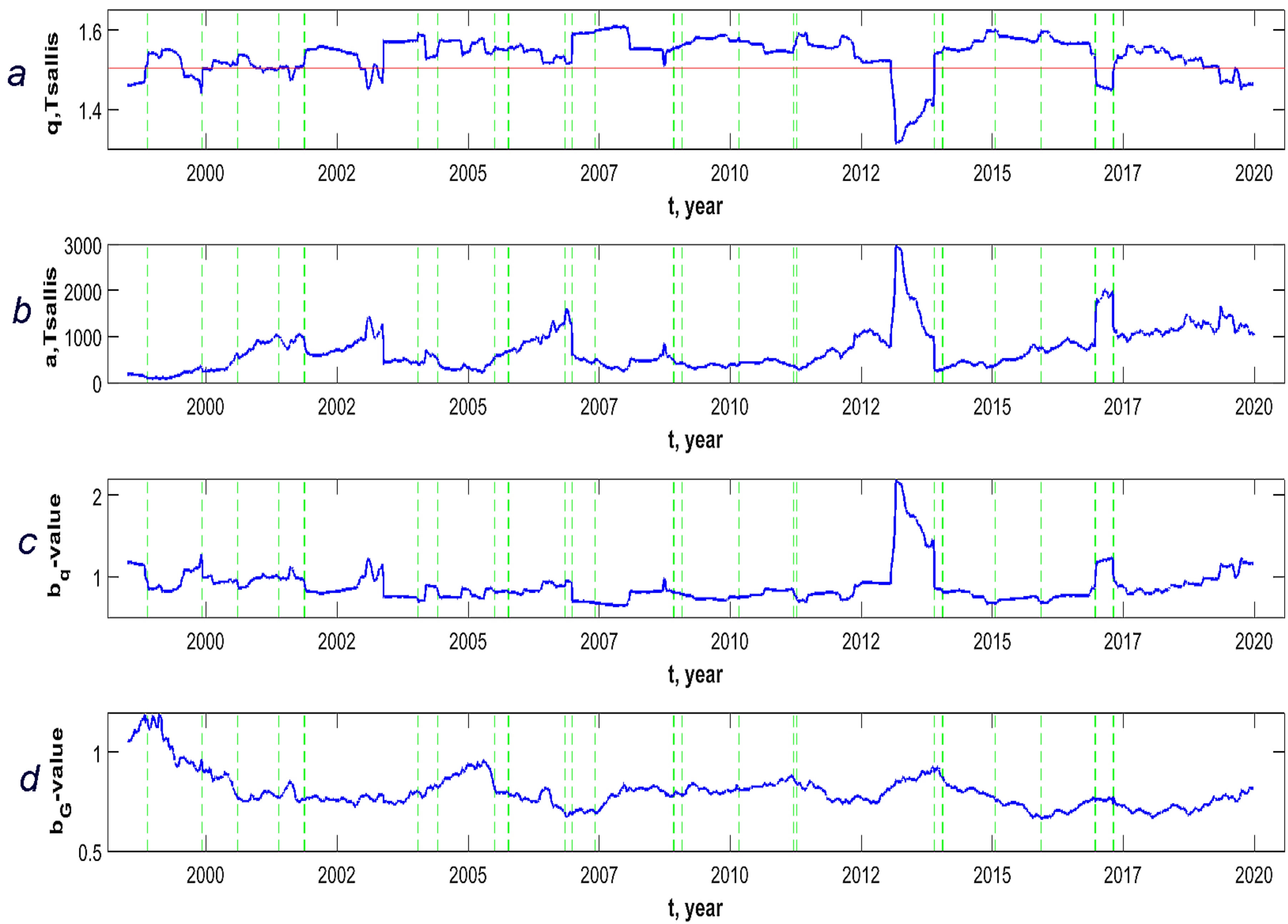


The repeatability graph for earthquakes on the territory of BGP (blue color) and its approximation: red color - calculation based on expression (8), black color - Gutenberg - Richter law (expression (2))

Distribution of the Tsallis parameter *q* on the territory of BGP according to the data of the KNET network (1994-2019).



Change in the Tsallis parameters, b-value



Conclusion

Various parameters characterizing the seismic process of the Bishkek geodynamic test site are considered - seismic activity, STD intensity, seismogenic fracture parameter, Tsallis parameters q and a, as well as the inclination angle (*b-value*) of the Gutenberg - Richter distribution. The combination of these parameters makes it possible to assess the geodynamic process occurring in the area of the junction of the Tien Shan orogen and the Kazakh platform (BGP).