Analysis of energy characteristics of acoustic emission signals during uniaxial compression of geomaterial samples

VN Sychev[1], LM Bogomolov[2], DS Kulkov[1]

[1] Science Research Station of the Russian Academy of Sciences in Bishkek city, Kyrgyzstan
[2]Institute of Marine Geology and Geophysics, Far Eastern Branch of the Russian Academy of Sciences

Task

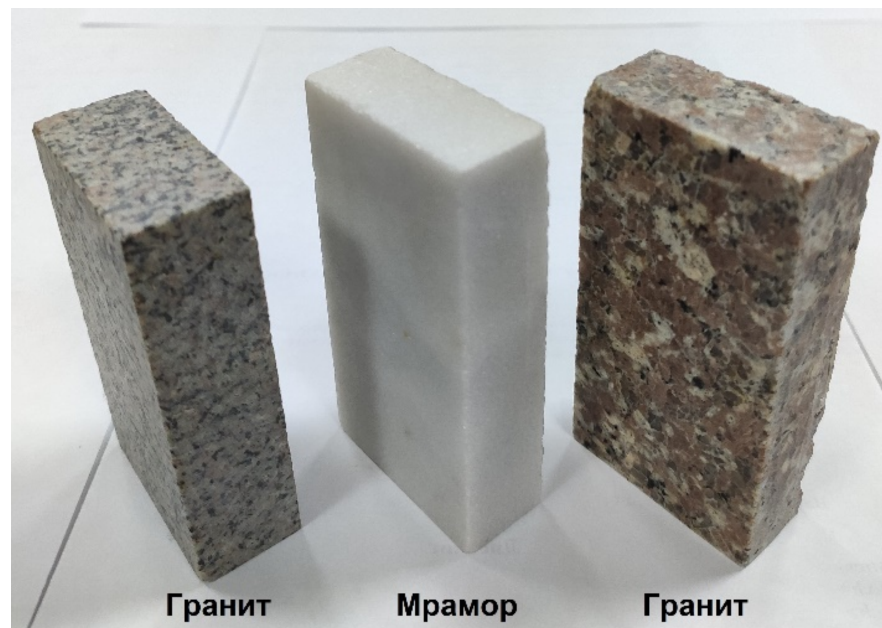
The flow of AE events is considered from the viewpoint of nonequilibrium thermodynamics using the Tsallis statistics. To describe the energy distribution function of the AE signals, we used a modified model of a stick-slip earthquake source - “discontinuous sliding” of two plates over each other along a fault in the presence of friction and the principle of maximum entropy.

Equipment and technique

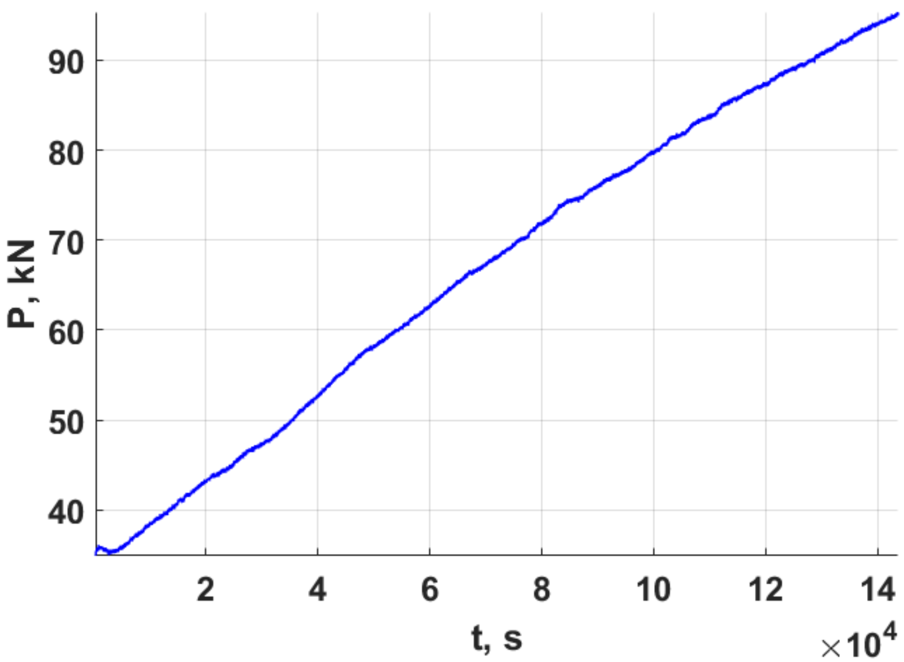
Acoustic emission (AE) signals were obtained during deformation by uniaxial compression of samples of various geomaterials. The uniaxial compression experiments were carried out on a low-noise lever setup with water leakage, where the maximum load on the sample does not exceed 250 kN.

Examples of geomaterial samples

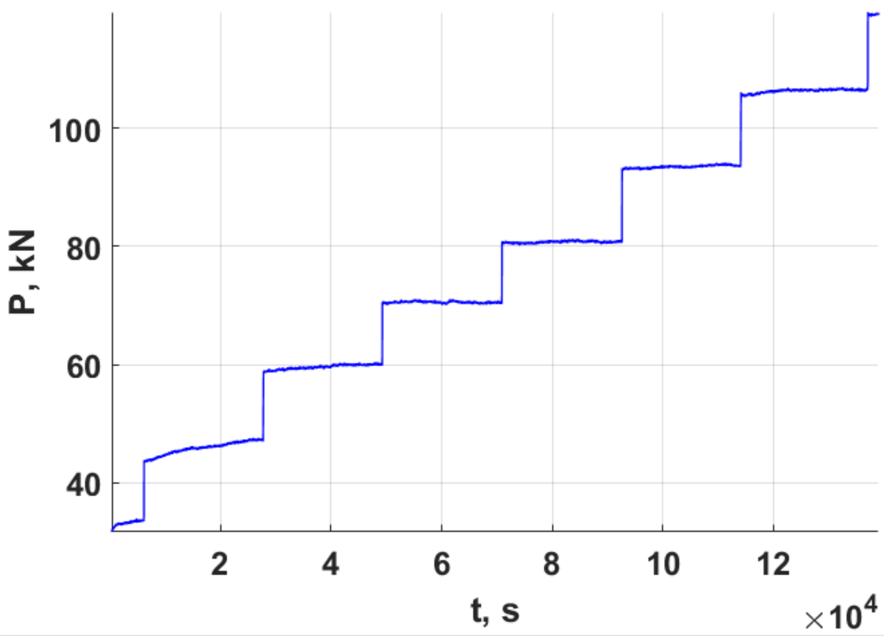
All test specimens were made in the form of a rectangular parallelepiped, sandstone with a square cross section, dimensions 25 x 25 x 60 mm (L x W x H), and granite and marble with a rectangular cross section, dimensions L x W x H (40 x 20 x 80 mm).



Linear load change

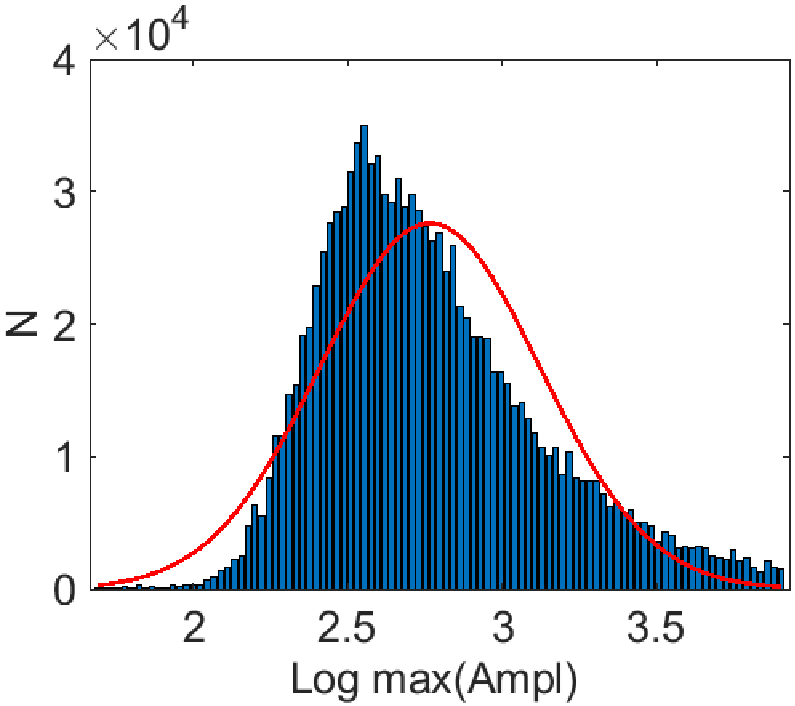


Step load change

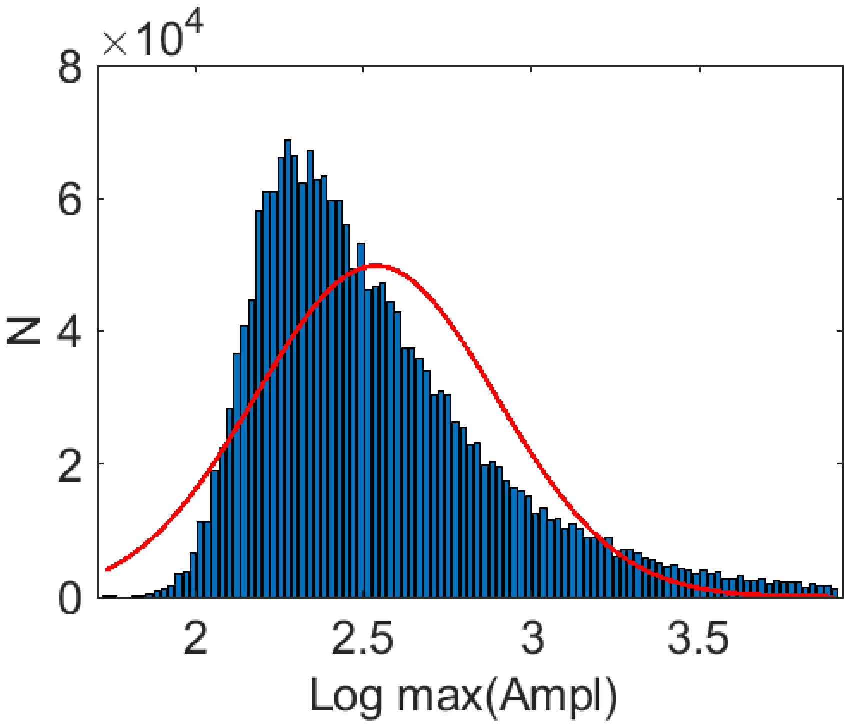


Energy distribution functions of AE signals

Linear load change



Step load change



The maximum amplitude of the AE signal was chosen as an analogue of the magnitude

The most famous relationship is the Gutenberg – Richter energy distribution law for earthquakes :

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

$N(M > m)$ - the number of events with a magnitude M exceeding the value m
b - a constant (b-value)

The expression is empirical and cannot be derived from the provisions of equilibrium thermodynamics.

Nonextensive analysis

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

Boltzmann statistics corresponds to the limit $q \to 1$. And 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.

Using the stick-slip model and the principle of maximum entropy in [Sotolongo-Costa O, Posadas A 2004 Physical Review Letters February vol 92 N 4], an analytical expression was obtained for the earthquake energy distribution function, which generalizes the empirical Gutenberg-Richter function.

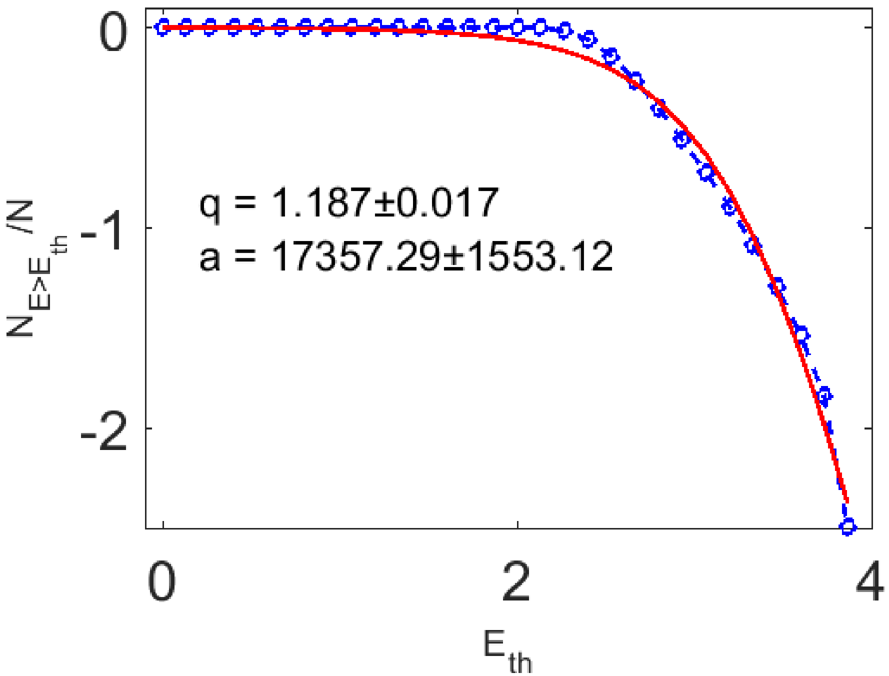
$$\log\left(\frac{N(M>M_{th})}{N}\right)=\left(\frac{2-q}{1-q}\right)\log\left[1-\left(\frac{1-q}{2-q}\right)\left(\frac{10^{M_{th}}}{a^{2/3}}\right)\right]$$

where N ($M>M_{th}$) is the number of earthquakes with energies greater than the threshold value M_{th}, and M ~ 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 r^3 between faults and has the dimension of volumetric energy density.

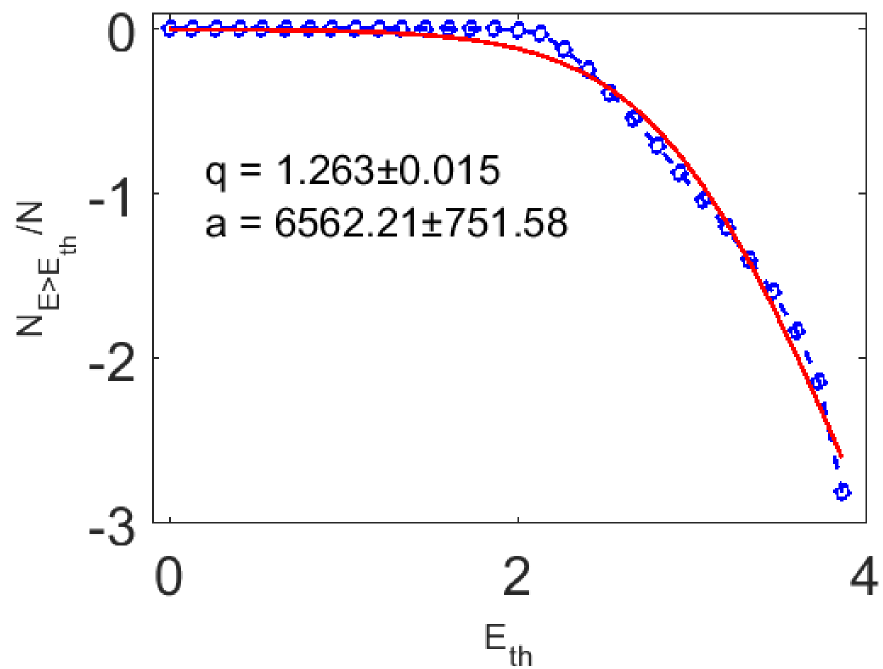
The value of the parameter q can be used as a measure of the stability of the active tectonic zone. A sharp increase in the parameter q indicates an increase in the interaction between fault blocks and their fragments and implies a deviation from the equilibrium state.

Energy distribution functions

Linear load change



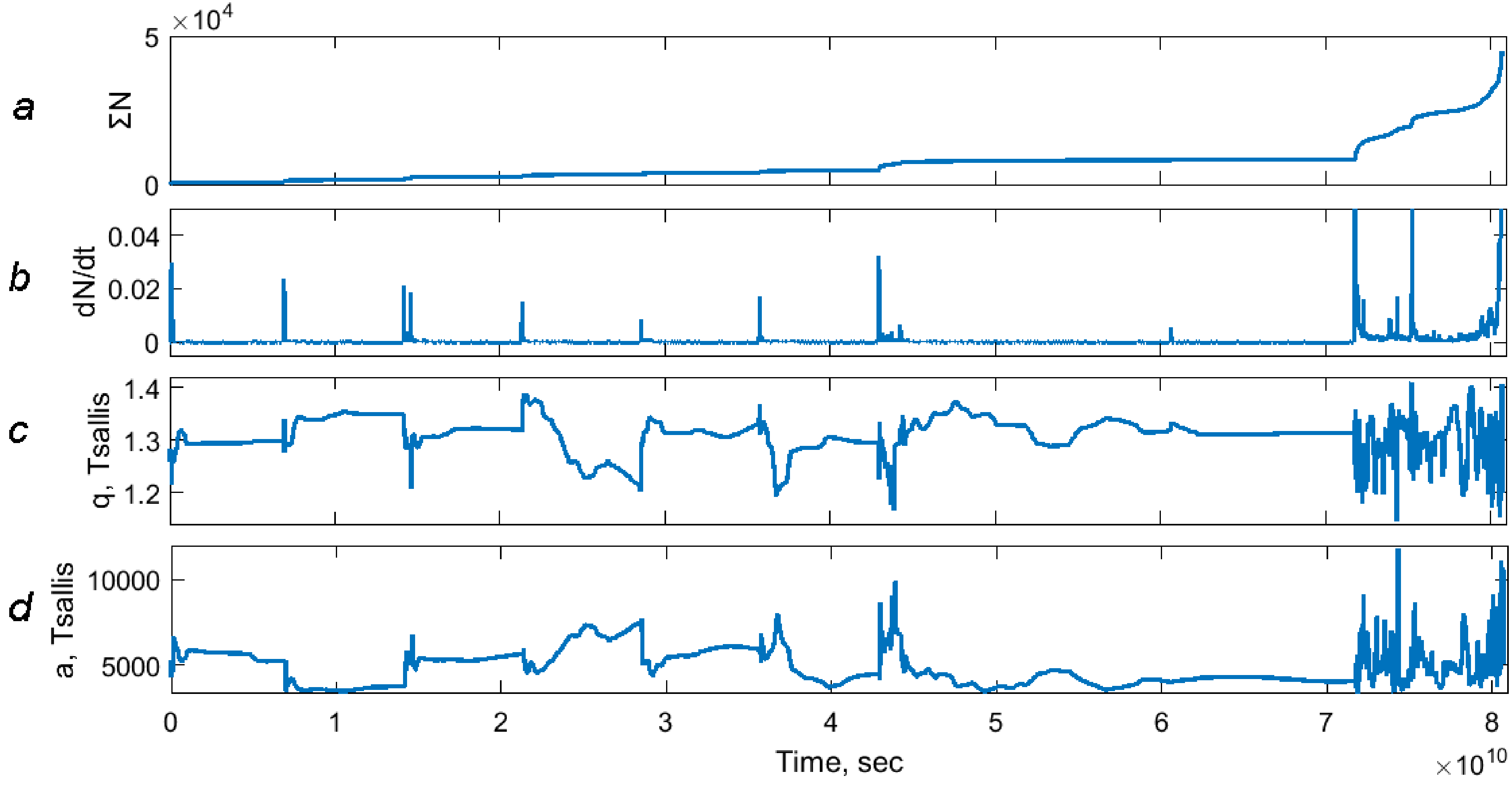
Step load change



Tsallis parameters *q* and *a* for different samples

Rock	N	q	err_q	a	err_a	*load change*
Granite #1	16365	1.208	0.018	4519.27	589.09	*Linear*
Granite #2	162782	1.157	0.017	20917.75	1784.60	*Step*
Granite #3	66789	1.144	0.018	20334.35	1867.91	*Linear*
Marble #1	700	1.25	0.022	1545.20	257.55	*Linear*
Marble #2	76891	1.233	0.012	4229.12	433.01	*Linear*
Sandstone #1	18298	1.188	0.015	18327.72	1475.48	*Linear*
Sandstone #2	24965	1.187	0.017	17357.29	1553.12	*Linear*
Sandstone #3	24707	1.188	0.016	18501.11	1547.93	*Linear*
Sandstone #4	9193	1.164	0.017	22533.06	1848.061	*Linear*
Sandstone #5	61711	1.180	0.017	20202.86	1715.53	*Linear*
Sandstone #6	102098	1.255	0.014	7409.52	727.11	*Step*
Sandstone #7	120697	1.248	0.016	8903.89	974.92	*Step*
Sandstone #8	45087	1.263	0.015	6562.21	751.58	*Step*

Sample - sandstone, loading - linear. a - accumulation of AE events, b - activity of AE events, c - Tsallis parameter *q*, d - Tsallis parameter *a*.



The accumulation of AE events occurs monotonically throughout the entire experiment, except for the stage immediately before destruction. The value of the Tsallis parameter *q*, as already described above, displays the measure of instability of the seismically active zone. a change in the parameters *q* and a is observed with a sharp increases in the AE activity. Moreover, an increase in the AE activity is almost always accompanied by an increase in the value of the parameter q (Fig. 4c). This may mean an increase in long-range spatial correlations between individual recorded acts of microfracture of the sample.At the same time, the behavior of the parameter *a* is of interest, which has the dimension of the volumetric energy density and is determined by the earthquake energy *E* and the size of the fragment of blocks r^3 between the faults [38].With an increase in the AE activity, this parameter (Fig. 4d) tends to increase. By analogy with earthquake aftershocks, an increase in the parameter *a* can mean an avalanche-like formation of defects in a certain local region of the sample. When approaching the point of destruction, an increase in the number of AE events, an increase in AE activity, is also accompanied by significant changes in the Tsallis parameters *q* and *a*.

Conclusion

The work considers AE signals recorded under uniaxial compression of specimens of various geomaterials: sandstone, marble, granite. The logarithm of the maximum amplitude of the waveform of the recorded AE signal is conventionally taken as the energy of the AE signal.To describe the energy distribution function of AE signals, we used the provisions of nonequilibrium thermodynamics with the use of Tsallis statistics, which generalizes classical thermodynamics to the case of nonextensive systems. It is shown that the AE pulses flow is a system with memory and long-range spatial correlations. The change in the activity of the AE and the Tsallis parameters q and a in the sliding window throughout the experiment are considered. An increase in the AE activity is almost always accompanied by an increase in the value of the parameter q.