Механизм движения лавового потока, сопровождающегося сейсмическим режимом «drumbeats», на вулкане Кизимен

Mechanism of lava flow movement accompanied by a seismic mode drumbeats on the Kizimen volcano

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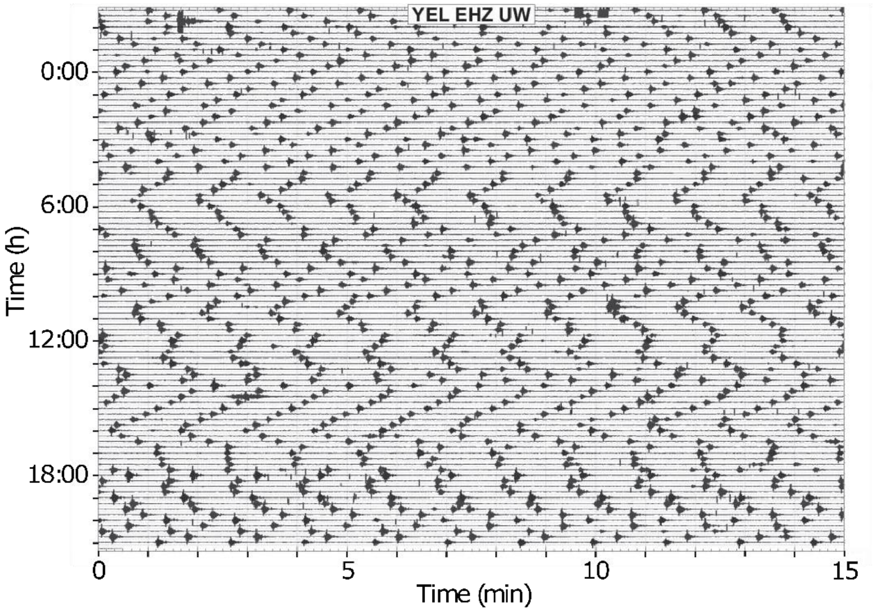
The seismic mode drumbeats is an unusual seismic mode, consisting of quasi-regular volcanic earthquakes with uniform waveforms (multiplets) that are recorded from tens of minutes to months. Drumbeats mode is recorded during the squeezing of extrusive domes.

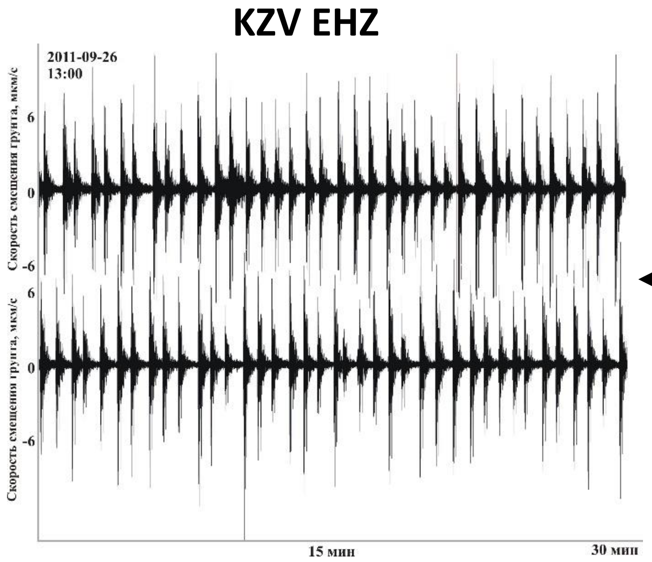
The mechanism of the drumbeats mode at St. Helens (Cascade Mountains, North America) in 2004-2005: the squeezing of extrusive blocks of viscous magma by the "stick-slip" mechanism.

The mechanism on the Tungurahua (Andes, Ecuador) in 2015: movement of fluid/gas flow ahead of the rising magma front. Does not explain the quasi-regularity of earthquakes.

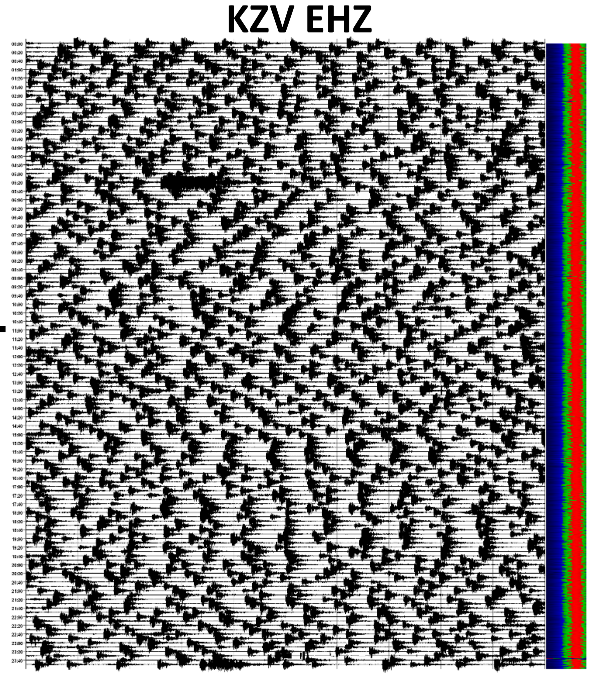
The mode recorded during the eruption of Kizimen volcano, was generated by the movement of a powerful lava flow, what, apparently, was not described in the practice of world research.



Daily seismogram from the YEL seismic station in 1.5 km from the Saint Helens crater, December 1, 2005 (Iverson et al., 2006).

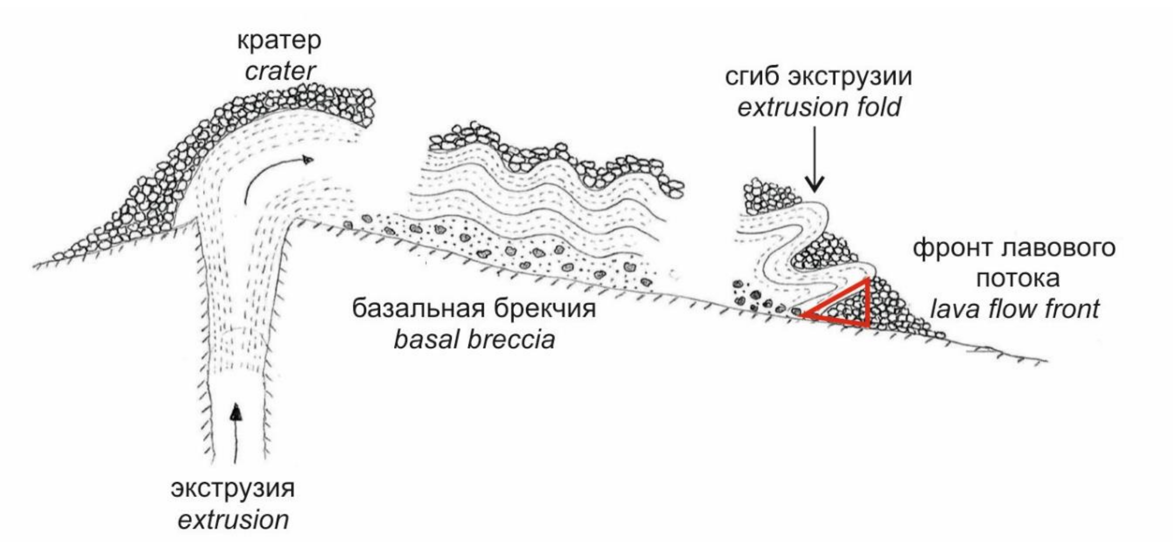


Seismogram hourly fragment



Daily seismogram from the KZV (seismic station of the Kamchatka Branch of Geophysical Survey) in 2.6 km from the Kizimen crater, September 26, 2011.

General view of the block lava flow resulting from the eruption Kizimen volcano in 2011-2012



When studying a block lava flow on the volcanic island of San Pietro (Sardinia, Italy) [Harris, Rowland, 2015] it was found:

❶ Lava flows move by sliding along the basal breccia

❷ In the frontal part, the lava is subject to more brittle deformation due to cooling and degassing

❸ The central part of the lava flow consists of a dense active core. Due to the movement of the nucleus, the block in the frontal part of the flow is shifted

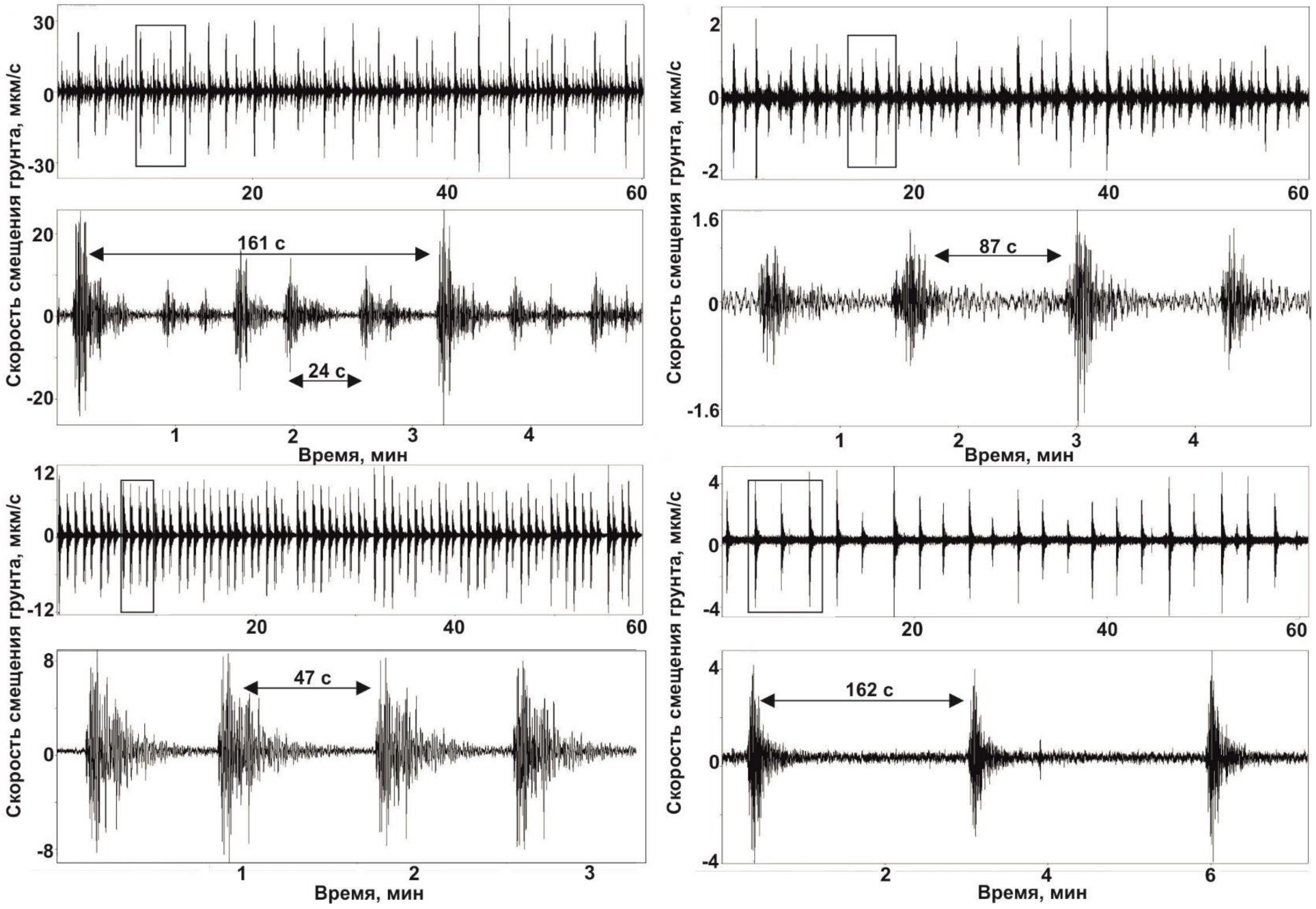
Hourly fragments of the drumbeats multiplets (upper panels)
Detailed structure of multiplets highlighted by a rectangle (bottom panels)

September 6, 2011

November 10, 2011

September 26, 2011

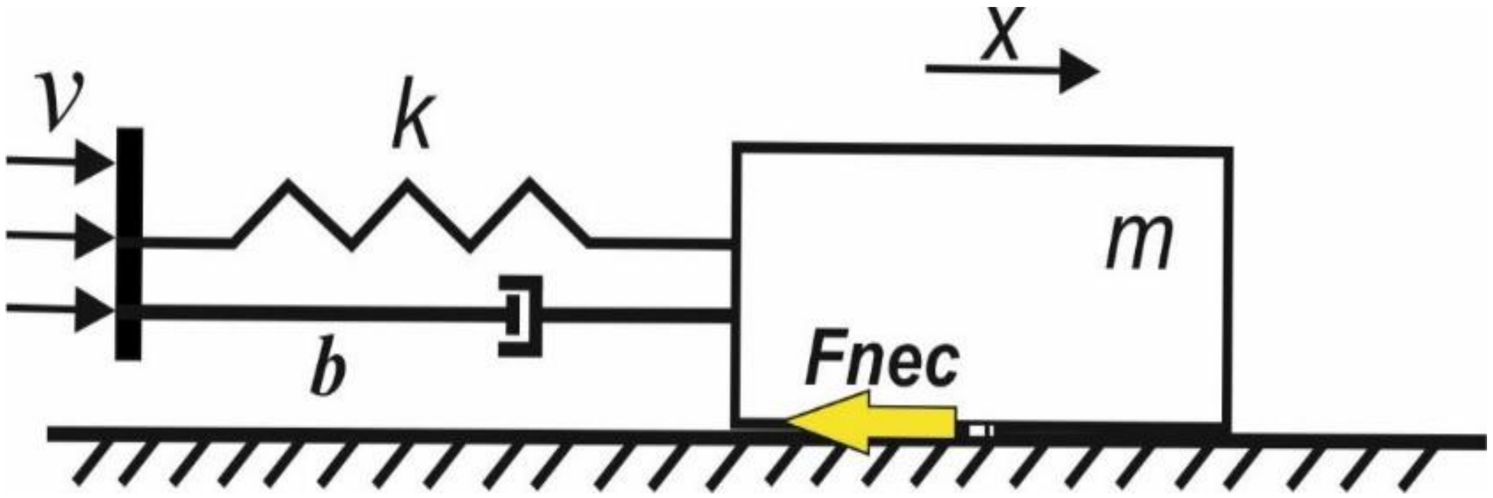
February 25, 2012



The structure of multiplets depends on the thickness of the lava flow front and, apparently, on the speed of its movement associated with the consumption of lava material.

A model of the emergence of quasiperiodic motion of individual blocks of the flow front with the generation of the drumbeats mode

At the flow front, separate lava blocks ***m*** are formed (we will take them in the form of a parallelepiped conditionally), which move under the action of an active core moving with a constant velocity ***v***. In this case, block ***m*** can be considered as the right element of the system, moving due to the forces of non-cumulative friction ***Fnec*** with a falling characteristic depending on the speed. Naturally, elements with a stiffness coefficient ***k*** and a viscous resistance coefficient ***b*** should be included between the active core and individual blocks.

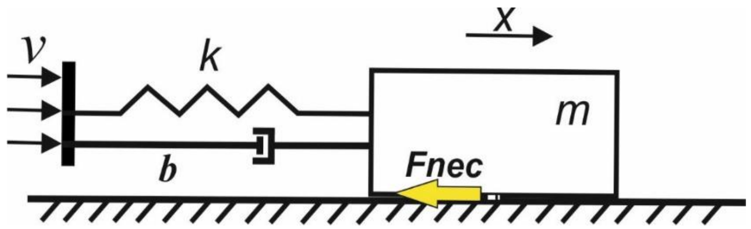


Consider this model from the standpoint of a fractional nonlinear oscillator with a stick-slip mechanism. Using a generalization of Newton's second law, the movement of a load can be written using fractional derivatives [Parovik, 2016]:

Fnec

$$m\partial_{0t}^{\alpha}x(t)+b\partial_{0t}^{\beta}x(t)+kx(t)=f\left(x(t),t\right),x(0)=x_0,\dot{x}(0)=y_0,$$

где $x(t)$ - функция смещения, $t\in[0,T]$ - время, $T>0$ - время моделирования, $f\left(x(t),t\right)=vt+c\sum_{n=1}^{\infty}a_n\sin\left(nx(t)\right)$, c - энергия «примерзания» поверхности; b - коэффициент вязкого трения; k - жесткость упругого элемента, $a_n=2n\int_0^1\frac{\cos(\pi n\tau)d\tau}{\cosh^2(\pi\tau)}$ - коэффициенты разложения ряда Фурье, x_0,y_0 - заданные константы, определяющие начальное условие колебательной системы (2), $\partial_{0t}^{\alpha}x(\tau)=\frac{1}{\Gamma(2-\alpha)}\int_0^t\frac{\ddot{x}(\tau)d\tau}{(t-\tau)^{\alpha-1}},\partial_{0t}^{\beta}x(\tau)=\frac{1}{\Gamma(1-\beta)}\int_0^t\frac{\dot{x}(\tau)d\tau}{(t-\tau)^{\beta}}$ - дробные производные порядков $1<\alpha<2,0<\beta<1$. Γ(x)-Гамма-функция Эйлера; точки над функцией решения $x(t)$ означают классические целочисленные производные.



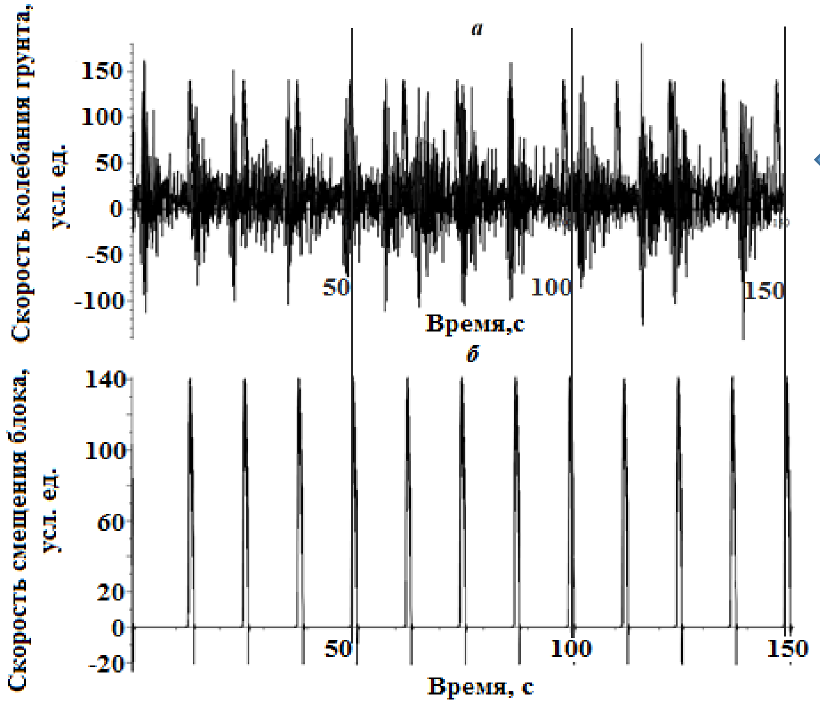
In case α=2, β=1, we obtain a classical nonlinear oscillator with friction and an external force, that is, the classical "stick-slip" effect.

Let's apply this mathematical model to the occurrence of the seismic drumbeats mode.
We selected two fragments of drumbeats mode record with a duration 150 s, but with a different repetition period of individual earthquakes.

The input data for better agreement with the experimental were:

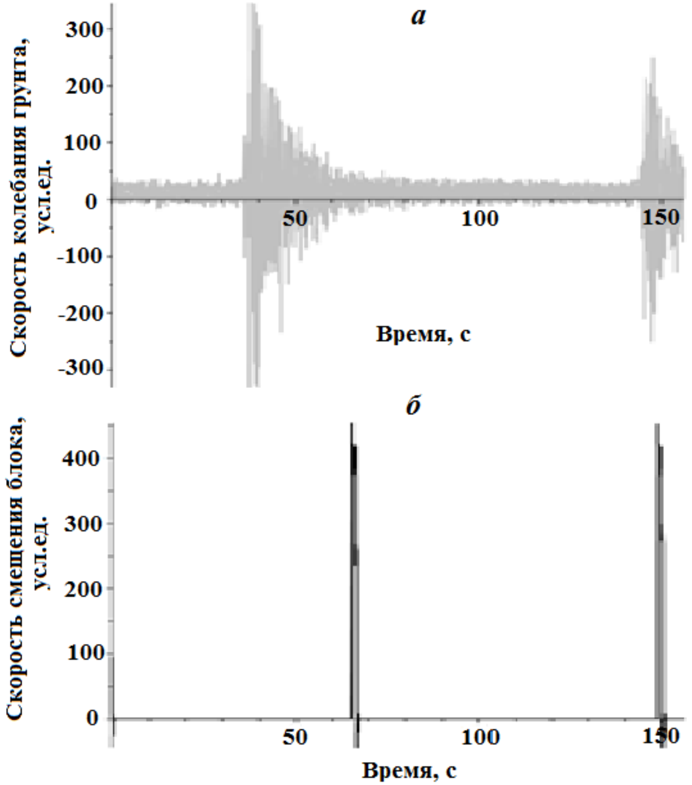
k=2.83, v=26, c=400, α = 1.5, β=0.9, m=1, b=0.6, $t \in [0, 150]$

k=2.00, v=18, c=1300, α =1.6, β=0.8, m=1, b=0.6, $t \in [0, 156]$



experimental data

simulated data



March 20, 2011 with an earthquake frequency 4.5 ± 0.2 cycles per minute.
Seismic record is characteristic for the movement of a thin lava flow at high speed

October 5, 2011 with an earthquake frequency 0.45 ± 0.05 cycles per minute.
Seismic record is characteristic for the movement of the powerful lava flow

Conclusions:

With an increase in the thickness of the front of the Kizimen lava flow, the friction at the contact between the base of the flow and the underlying rock increases. The flow pressure leads to the "breakdown" of individual blocks at the front, their slipping and stopping, thus the model of generation of quasiperiodic earthquakes is consistent with the "stick-slip" model. The qualitative coincidence of the results of mathematical modeling by a fractional nonlinear oscillator with experimental data shows that such a model can provide self-oscillating motion of a block with a frequency close to the observed one.

Thanks for your attention!

Photo Auer et al., 2018