PS Microseismic Event Spectrum Control and Strain Energy Release in Stressed Rocks*

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Abstract

Studying of passive seismicity concerns the physical processes of sound generation by cracks, propagation and recording of elastic waves. One of the main questions remains open - how do radiated elastic waves carry information about physical parameters of their sources (cracks) through a complex geomedium?

To develop this problem lab experiments have been carried out, in GFZ Potsdam, Germany, on different kinds of rock put under different load conditions. Acoustic emission (AE) method has been used to study fracture processes in rocks. Two types of deformation processes in rocks have been investigated: brittle deformation of granites and strain hardening in highly porous sandstone. To analyze AE signals the author has developed a computer program based on spectral density calculations and correlation analysis over continuous AE data.

To analyze AE spectral data the author suggests a normal mode and median frequency approach. It is based on the following assumptions:
1. An output AE spectrum is strongly influenced by the normal mode spectra of discrete geomedium and transducer.
2. Any AE spectrum can be quantified by the mode, the median, and the mean.
3. The mode indicates most intensive normal mode of a medium, the median and the mean characterize the source time function of AE event, square root of spectral density integral is a measure of AE event energy.

Using this technique we observed a good correlation between AE median/mean frequency trend and the time change of load in brittle fracture experiments. To interpret this observation the author makes a following assumption: the median/mean frequency of AE signal is proportional to the critical stress for a certain material contained in rock mass and for an initial crack length contained in this material. As rock mass yields, a smaller amount of elastic energy flux from intact area is possible to initiate a crack. Only those areas characterized by small critical stresses are involved in further fracture process. This process of rock weakening is indicated by the clear median/mean frequency decrease.

AE frequency trends for strain hardening in sandstone are less obvious because the fracturing is going on at micro-scales within the bands of localized deformation. Nevertheless, the above considerations for granites can also be useful for sandstones.

This method needs to be developed and could be used as a remote seismic control of stress in situ.

Selected Reference

Stanchits, S., J. Fortin, Y. Gueguen, and G. Dresen, 2009, Initiation and propagation of compaction bands in dry and wet Bentheim Sandstone: Pure and Applied Geophysics, v. 166, p. 843-868.

Microseismic Event Spectrum Control and Strain Energy Release in Stressed Rocks

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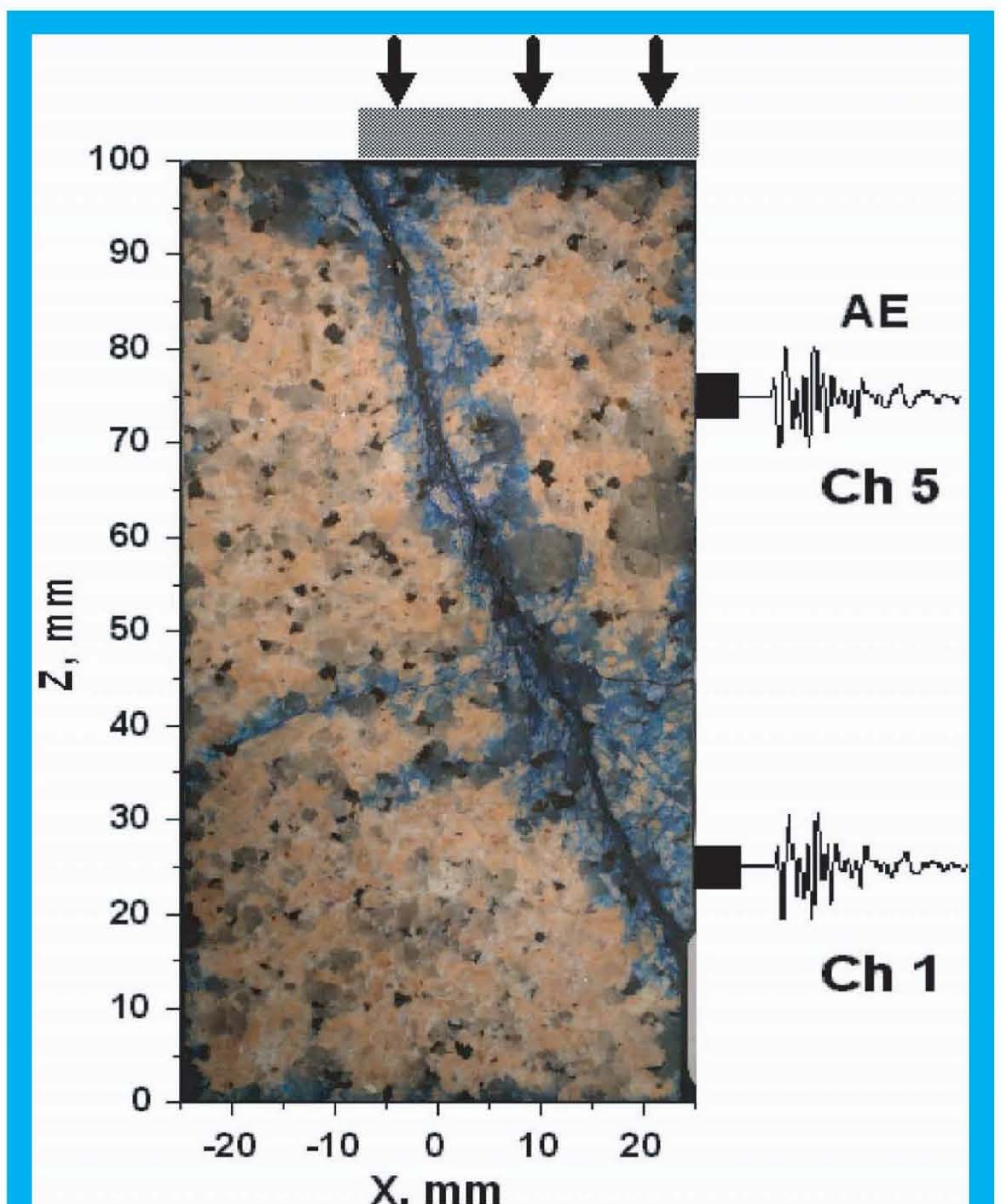
Constituting a challenge: Production of hydrocarbon reservoirs is associated with microseismicity. Changes of in situ stress conditions can result in sudden movements along pre-existing faults or can generate new fractures which in turn induce the emission of seismic energy. Monitoring and analyses of microseismic events can clarify the physics of geodynamical processes in rock mass. Microseismic study concerns the physical processes of sound generation by cracks, propagation and recording of elastic waves. One of the main questions remains open - how do radiated elastic waves carry information about their sources (cracks) through a complex geomedium?

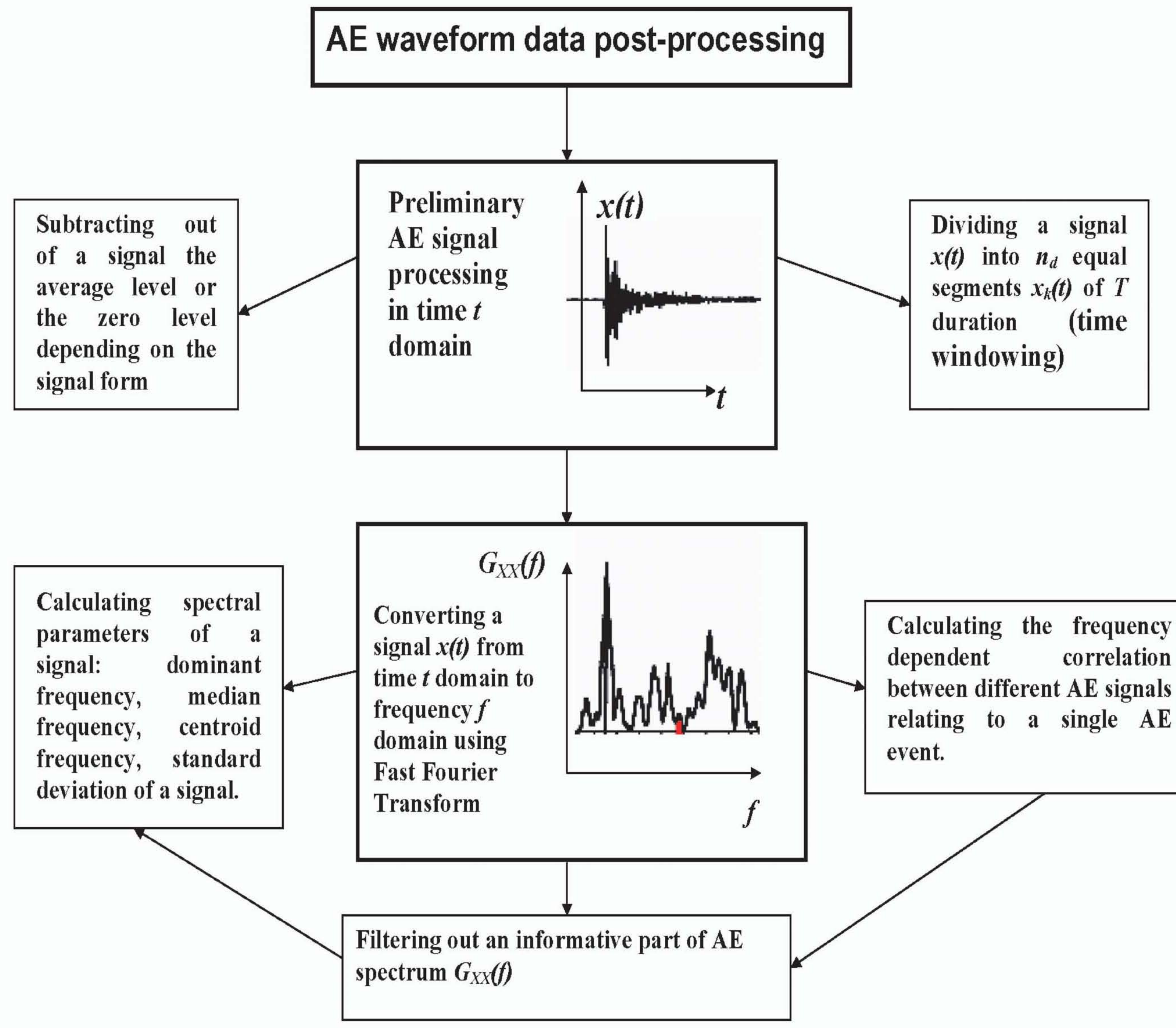
Study: To answer this question lab rock deformation experiments have been carried out in GFZ Potsdam, Germany: brittle deformation of granites, and strain hardening in high porous sandstone. Acoustic emission (AE) method has been used to detect microseismic energy. To analyze AE signals the author has developed a computer program based on spectral density calculations and correlation analysis over continuous AE data.

AE spectral analysis: The analysis of AE spectral data is based on normal mode and median frequency approach.

Illustration of lab experiment



Granite Ag65r asym.
Pc = 40 MPa

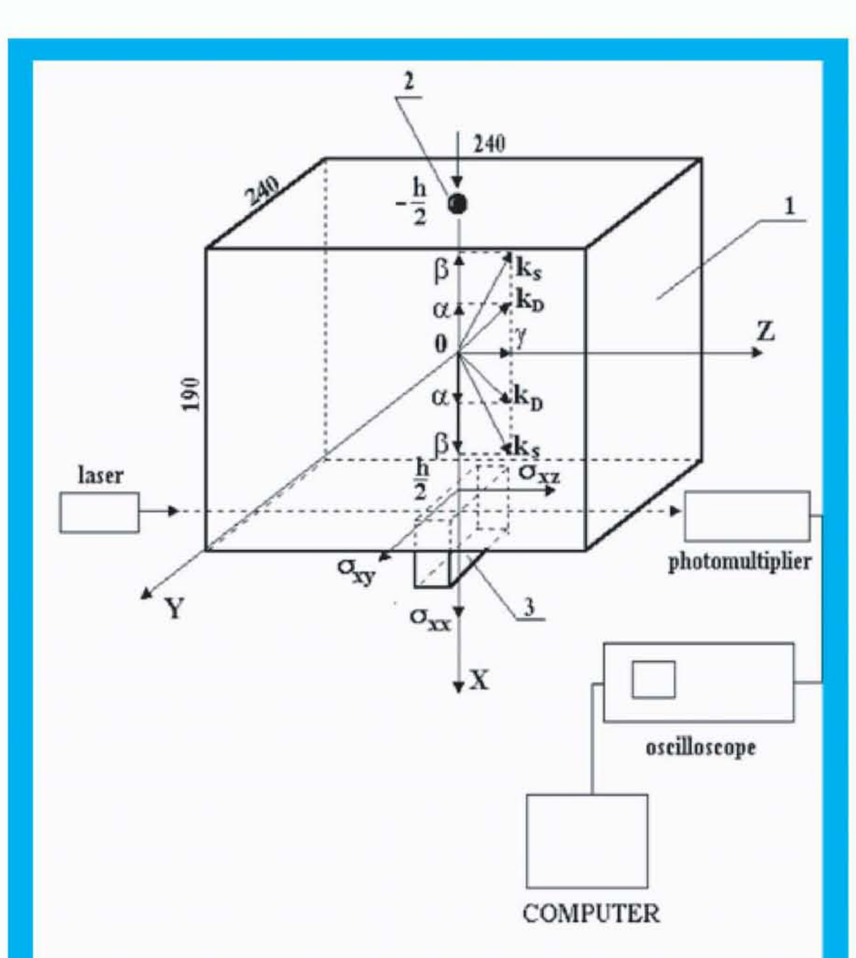


Observations of normal modes:

Normal mode of a linear system is a specific space distribution of displacements which can not be decomposed into elementary distributions. Each normal mode is energy isolated from another. Thus a total energy of a system can be represented as a sum of energies of each normal mode. Response of a discrete linear system to wide-band spectrum (short pulse) is a superposition of normal modes:

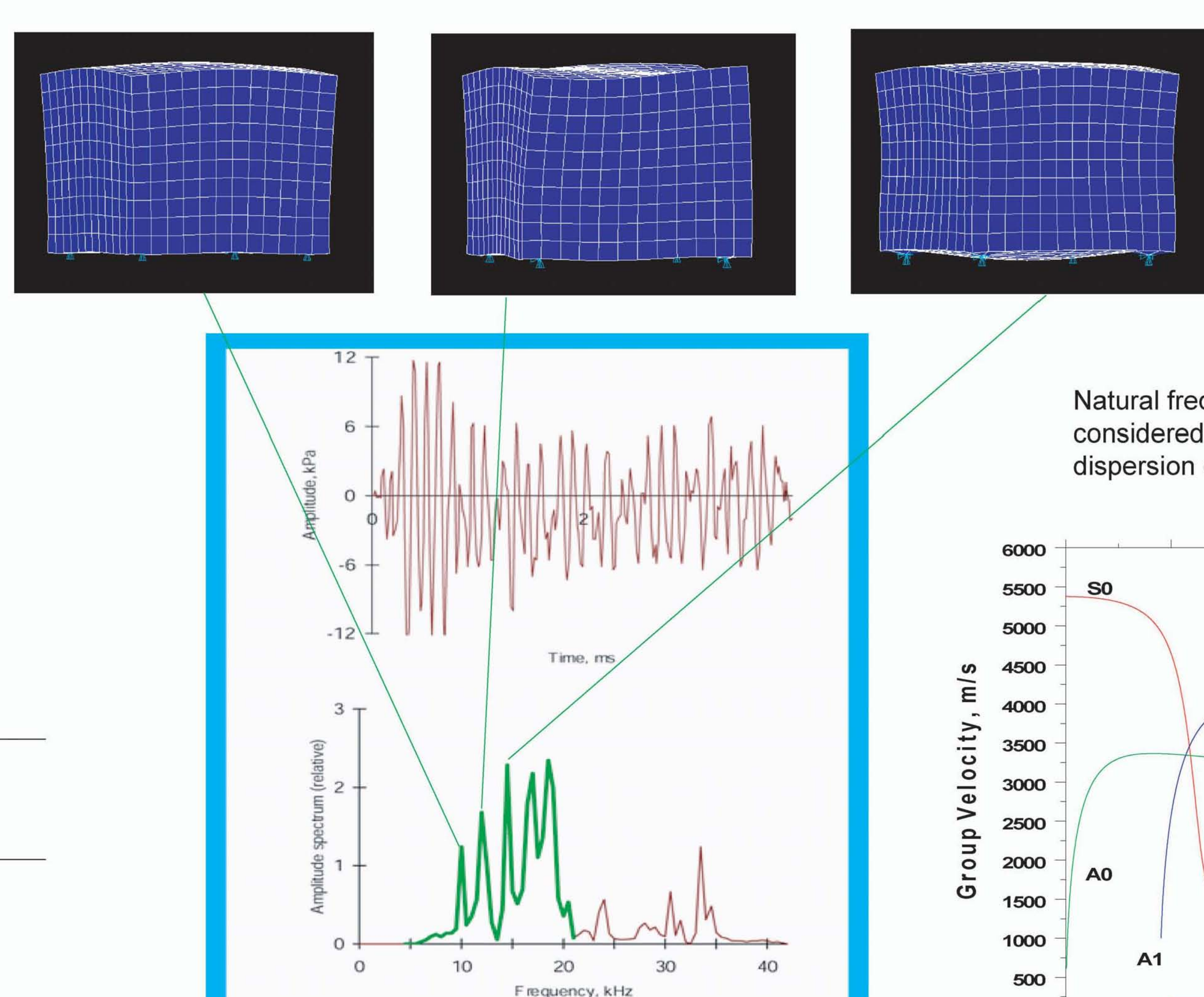
$$\{x(t)\} = \sum_{i=1}^{n} \{\phi_i\} A_i e^{-\alpha_i t} \sin(\omega_{Di} t + \varphi_i)$$

where $\{x(t)\}$ – vector of system displacements; $\{\phi_i\}$ - the i-th mode; α_i - damping factor of i-th mode; ω_{Di} - natural frequency of damped oscillations of a system.



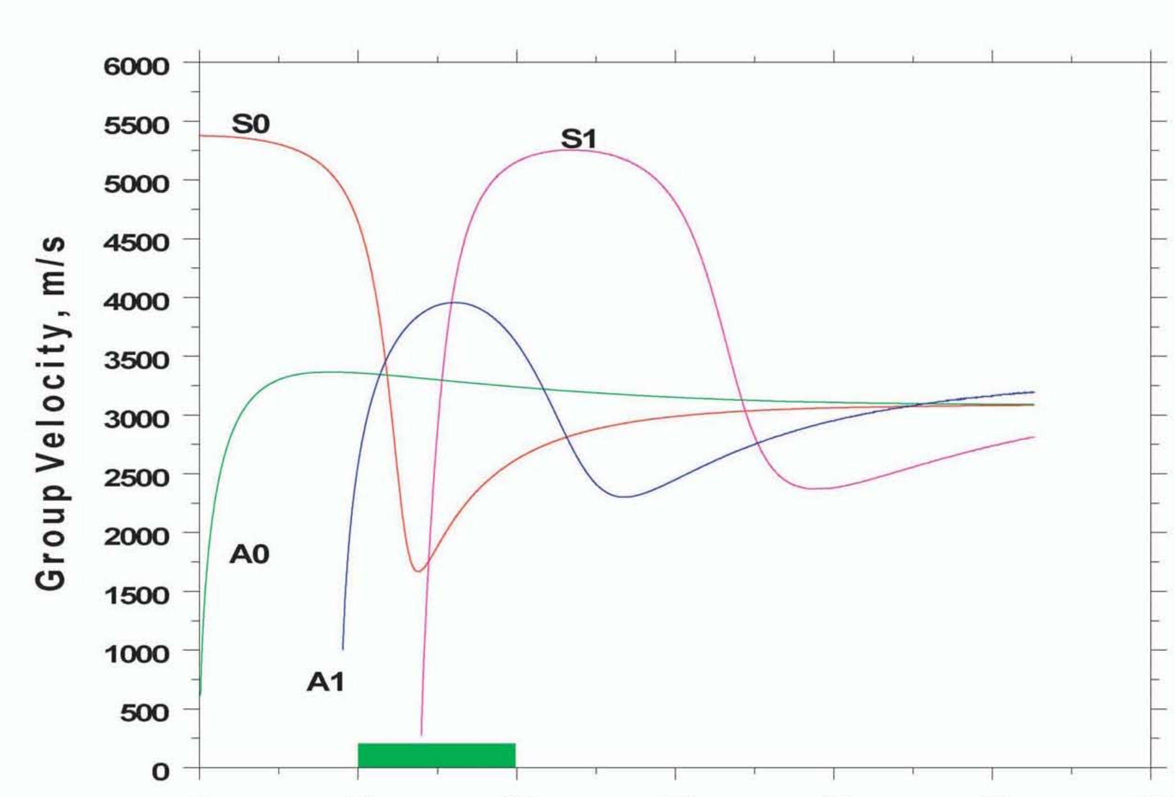
The scheme of experiment carried out for normal mode investigation (A.F. Ioffe Physical-Technical Institute of the Russian Academy of Sciences).

N	Mode	Frequency f_n(calc.*), kHz	Frequency f_n(exper.), kHz.
1	Shear	8.9	10.0
1	Lame	12.6	12.2
1	Dilatation	14.7	14.7



Prism natural oscillations, and prism natural frequencies (green).

Natural frequency of a certain normal mode can be considered as a cut-off frequency on the Rayleigh-Lamb dispersion curve calculated for an equivalent layer.



Laboratory experiments on granites and high porous sandstone using AE control

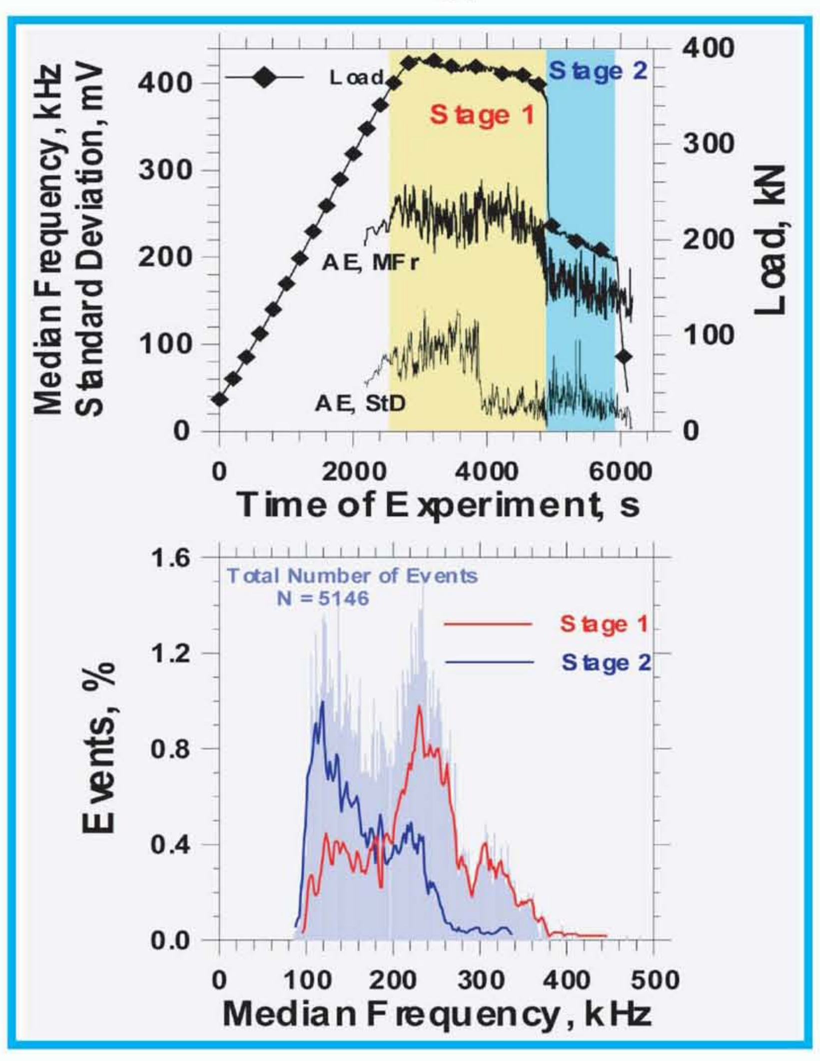
Triaxial compression tests on rock cores (diameter 50 mm, height 100 mm) have been carried out at different confining pressures. The experimental set-up consisted of MTS 4600 kN servo-controlled loading frame (MTS Systems Corporation 1996), a set of piezoceramic sensors, and AE transient recording system.

Data acquisition: In the brittle deformation experiments on granites the KRENZ PSO9070 transient recorder (12 channels, 10-bit resolution, 20 MHz sampling frequency) has been used to acquire acoustic emission and sonic data. In the plastic deformation of high porous sandstone an acquisition system with sampling rate of 10MHz and 16-bit resolution has been used (DaxBox, Prokel GmbH, Germany). To register acoustic waves transducers made of piezoceramic disks of 5mm diameter and 1mm or 2mm thickness (Marco GmbH, Hermsdorf) have been used.

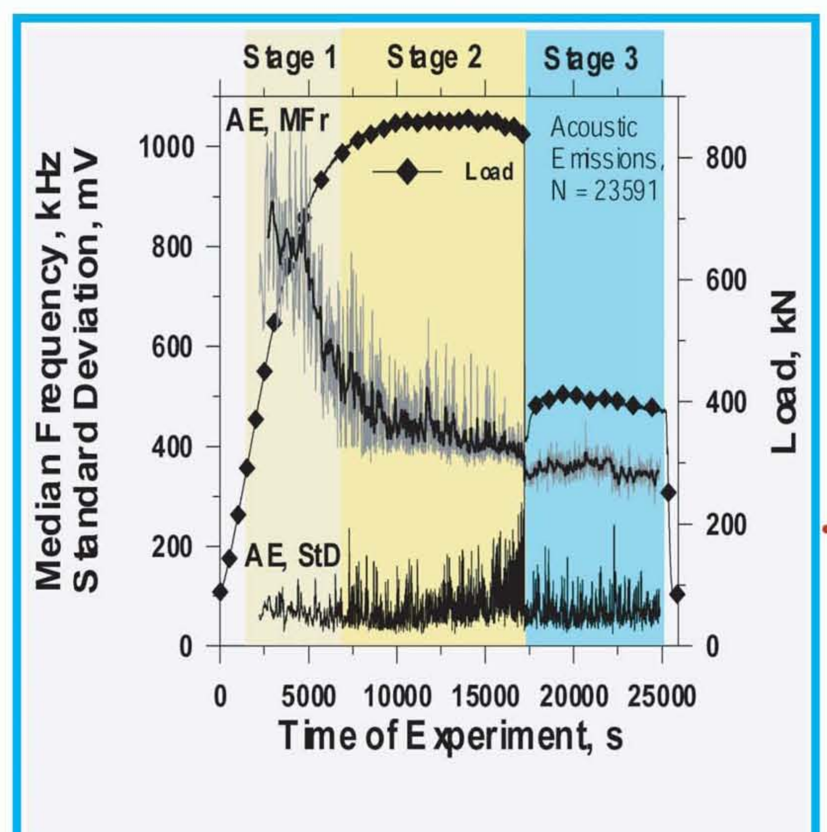
Rock cores: The rock cores of red granite from Blauenthal, Germany, have been used in brittle deformation experiments. The grain size of granite varies from 0.9 to 1.8 mm with an average of 1.3 mm. Porosity is 1.3%.
Porous Bleurswiller sandstone has been used to study the hardening process. This type of sandstone has a porosity of 25%, grain size ranges from 0.08 to 0.15 mm with a mean value of 0.11 mm. Results have been obtained for saturated samples deformed at 60, 80 and 100 MPa of confining pressure, a pore pressure of 10 MPa. Hardening process in porous sandstone is associated with deformation being localized within thin areas perpendicular to the axial stress. That, in turn, results in the formation of so-called compaction bands. These bands have a thickness of the order of a few particle diameters in size.

AE spectral data of the experiments on granite
Brittle fracturing (from microfracturing to macrofault)

10 MPa confining pressure

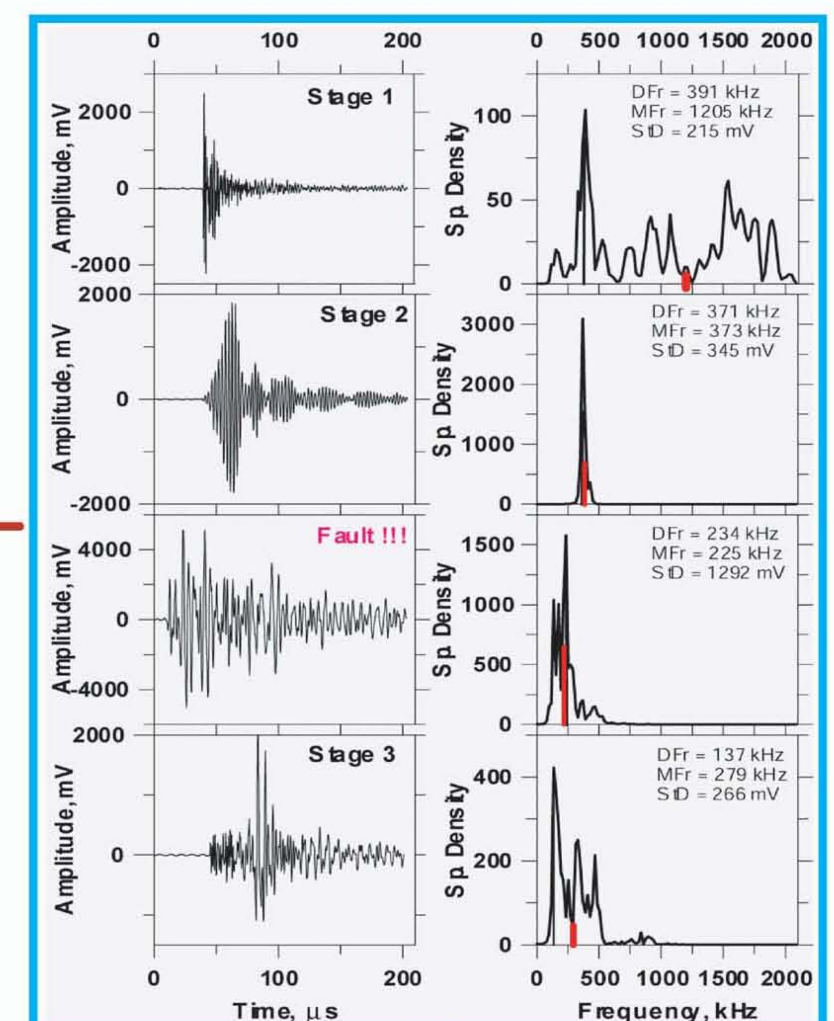


40 MPa confining pressure



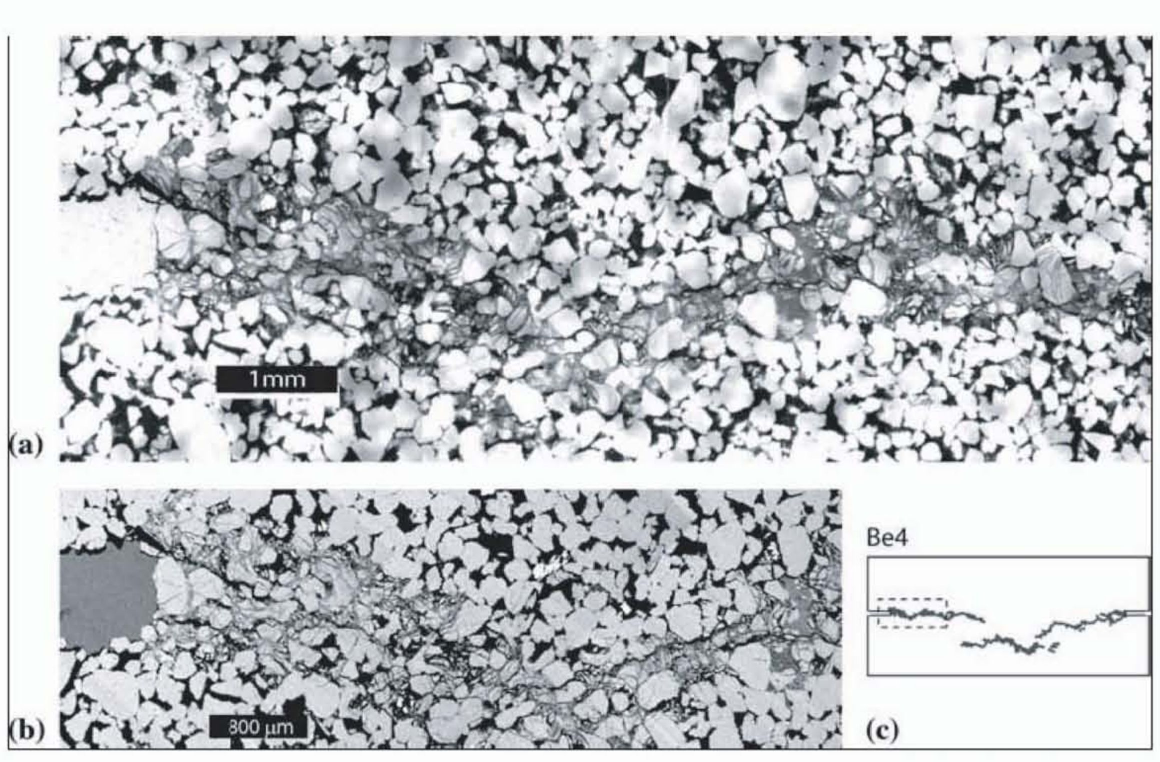
AE median frequency and standard deviation change in time, granite experiment of 40 MPa confining pressure. The loading curve is plotted versus time of experiment for reference.

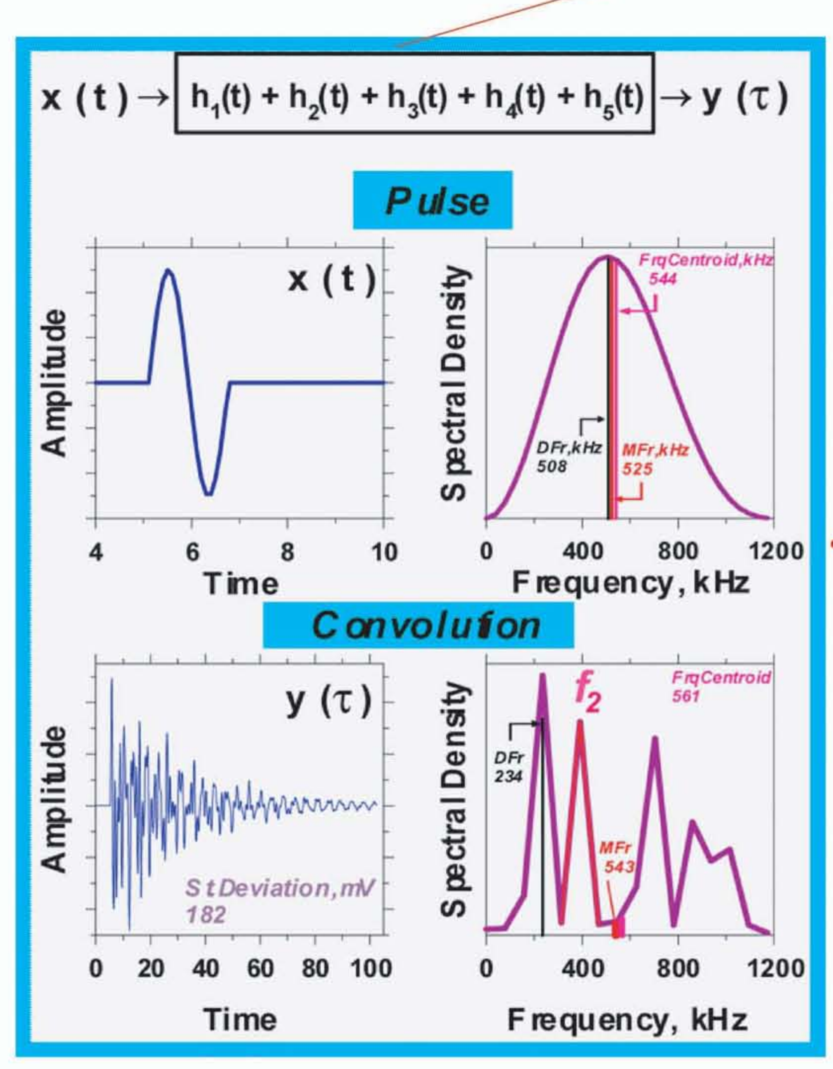
Typical waveforms at different stages of granite fracturing

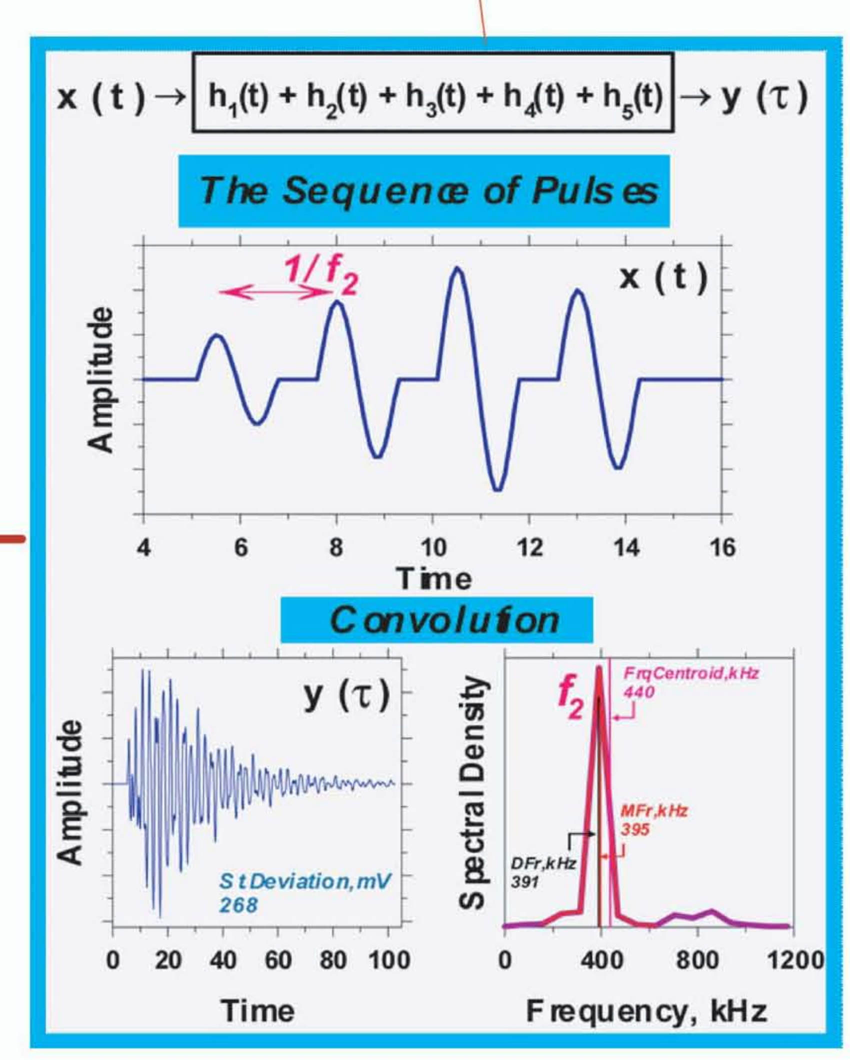


Interpretation of AE waveforms at different stages of fracturing

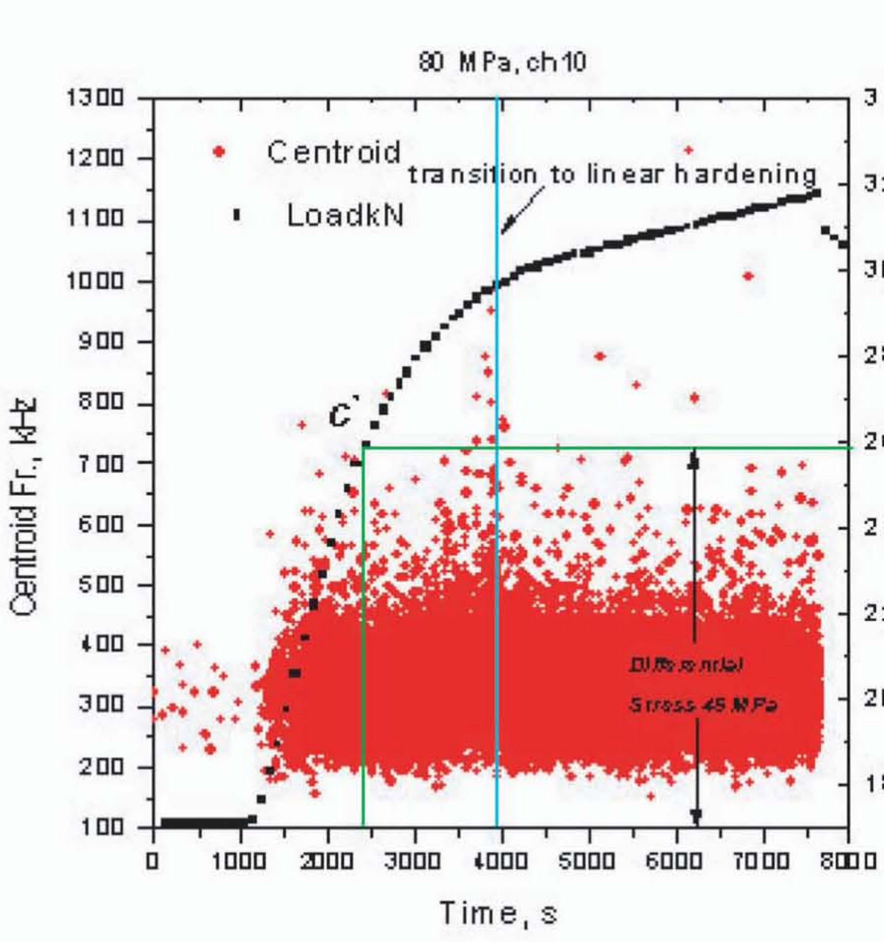
(a) Optical and (b) SEM microphotos of compaction bands (*S. Stanchits, J. Fortin, Y. Gueguen, and G. Dresen. Initiation and Propagation of Compaction Bands in Dry and Wet Bentheim Sandstone. Pure and Applied Geophysics 166 (2009) 843-868*). Inside the bands, grains are crushed and fragments fill up the collapsed pore space. Reduced porosity inside the bands is in the range of 10-15%.

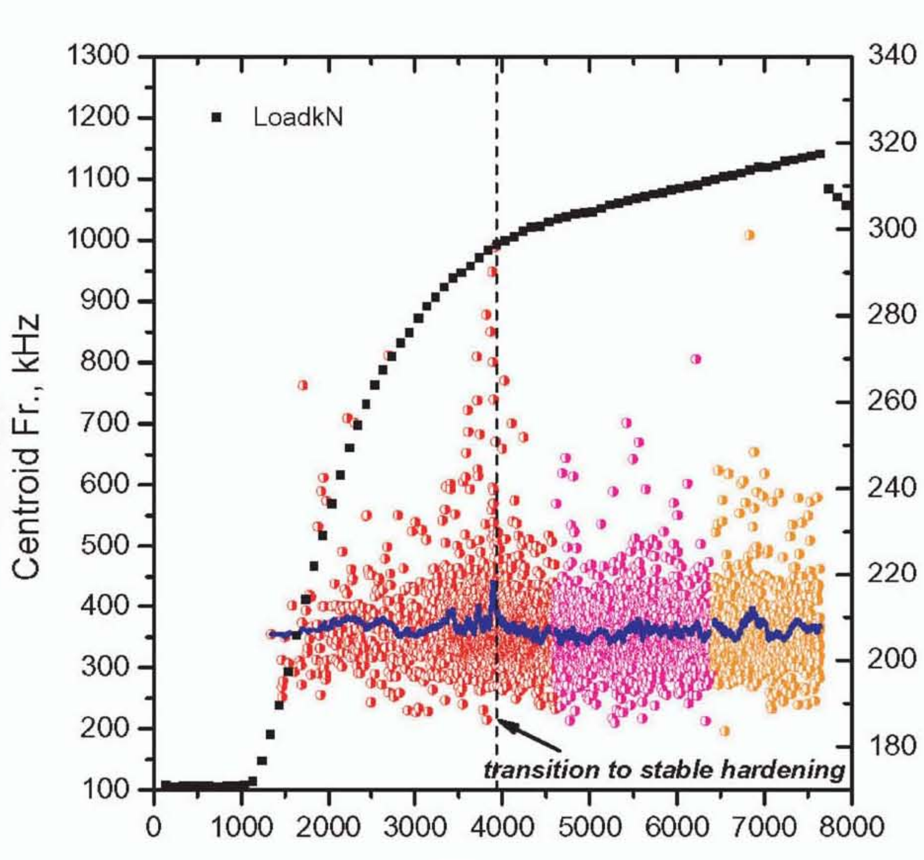




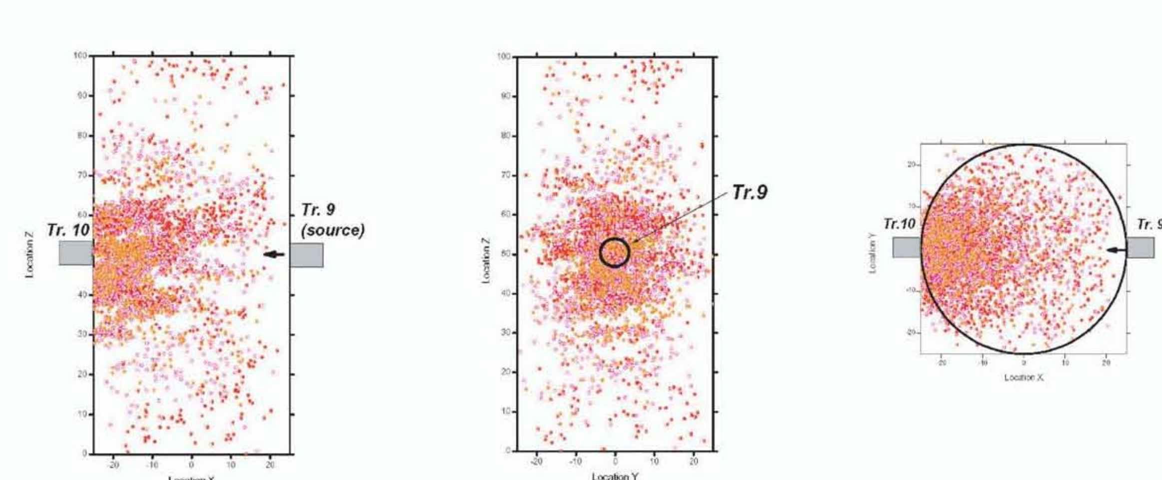


AE spectral data for 80 MPa confining pressure experiment on porous sandstone.





Centroid frequency (red) is plotted versus time of experiment. For reference the loading curve (black) is plotted versus time of experiment. C^{*} is a critical stress state at which inelastic compaction starts (the yielding).



Locations of the sorted AE events ranging within 190-450 mV of standard deviation

This selection has been made in order to make centroid frequency pick more clear.

Centroid frequency pick indicates the transition to linear (stable) phase of hardening.

Transition to inelastic phase (granites) and to stable hardening phase (high porous sandstone) is characterized by a pick of strain energy emission ??? - a problem to develop and prove.