Neutron Production from Crushing Piezoelectric Rocks

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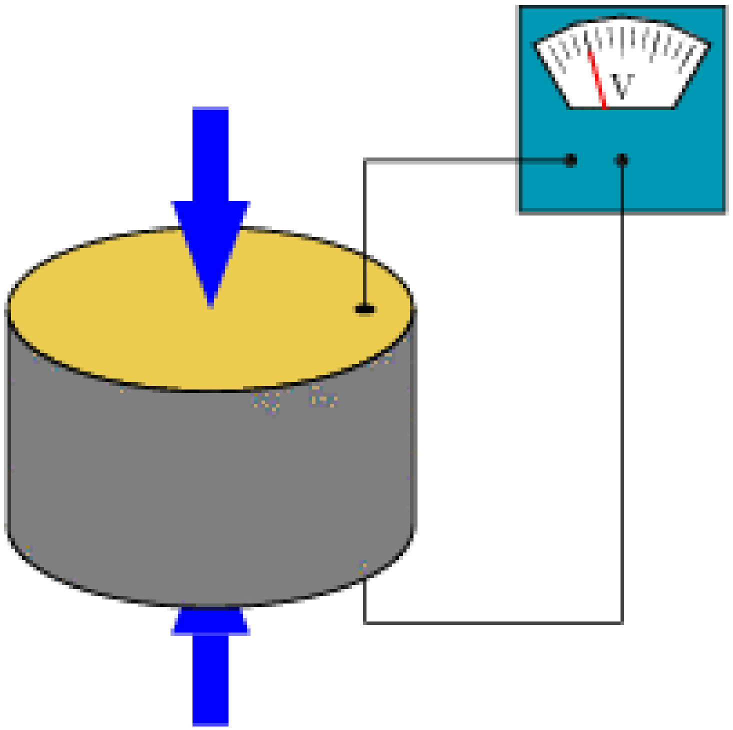
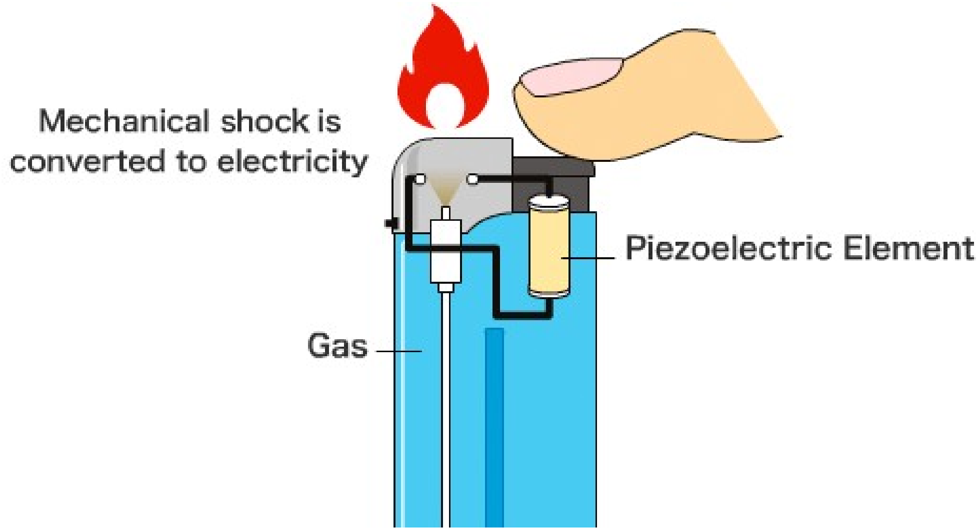
Contents

Piezoelectric Solids I



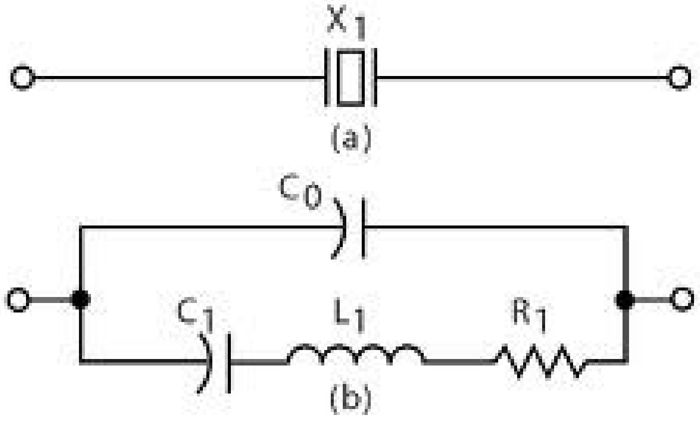
Strains in a crystal produce voltages across the crystal and vice versa.

Piezoelectric Solids II



The strain Produces a voltage.
The voltage produces a spark.

Piezoelectric Solids III



In the equivalent circuit, C_0 represents the geometric capacitance of the upper arm. C_1 represents the quartz oscillator spring constant and L_1 represents the oscillator mass in the mechanical lower arm circuit element. The resistance R_1 represents the slight mechanical oscillator damping due to mechanical viscosity.

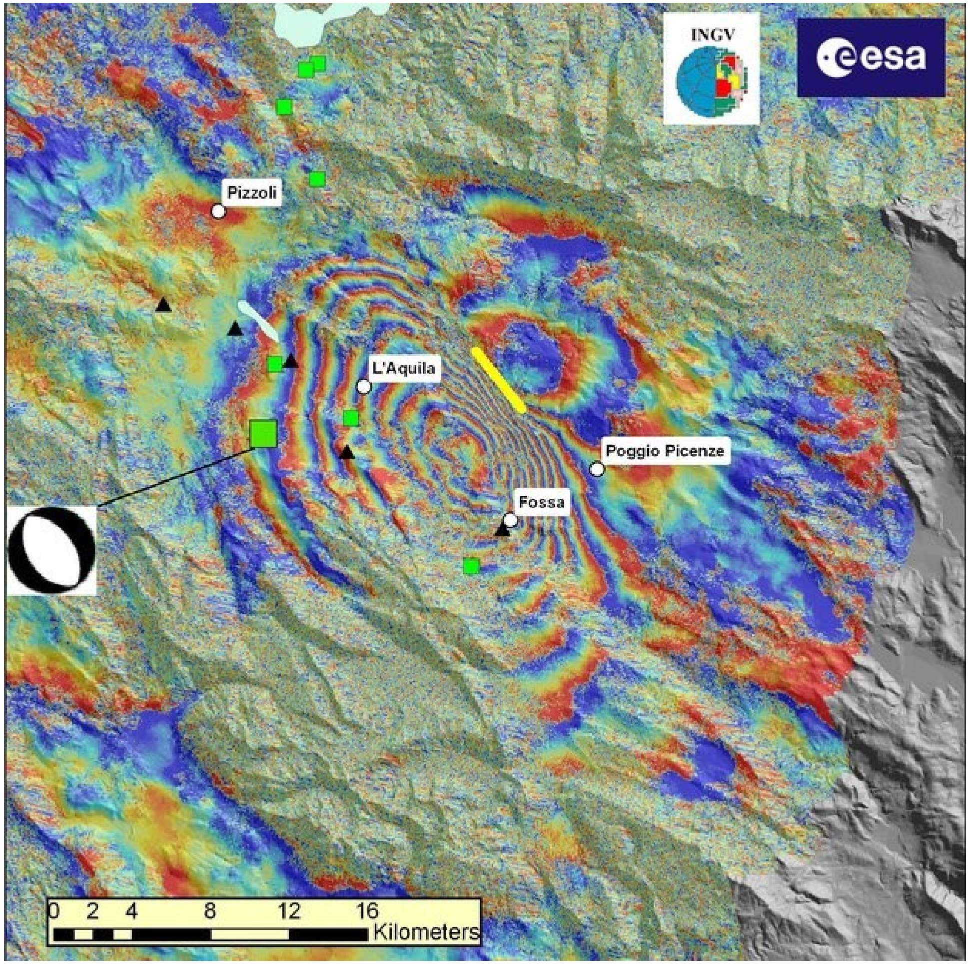
Earthquake Lights I

Japanese Earthquake Takes Place around the times the light is emitted.

Earthquake Lights II

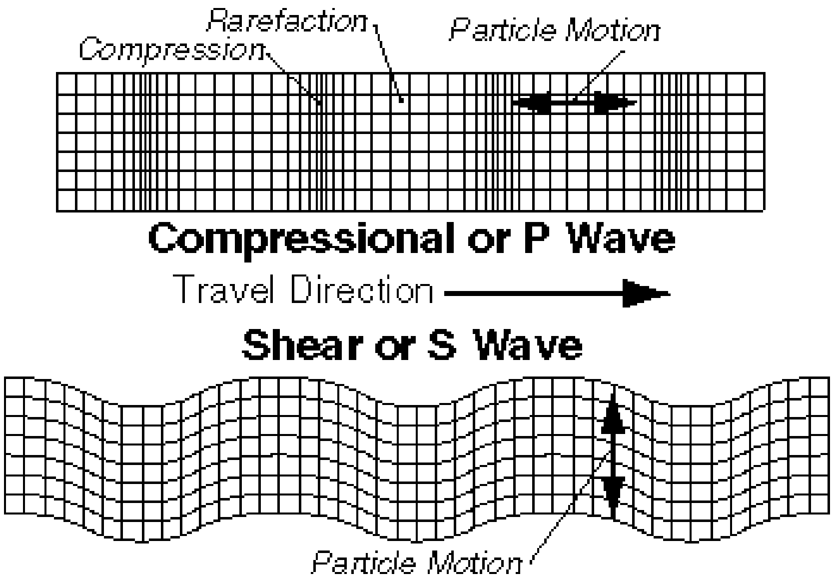
Day and Night Earthquake Lights

Earthquake Lights III



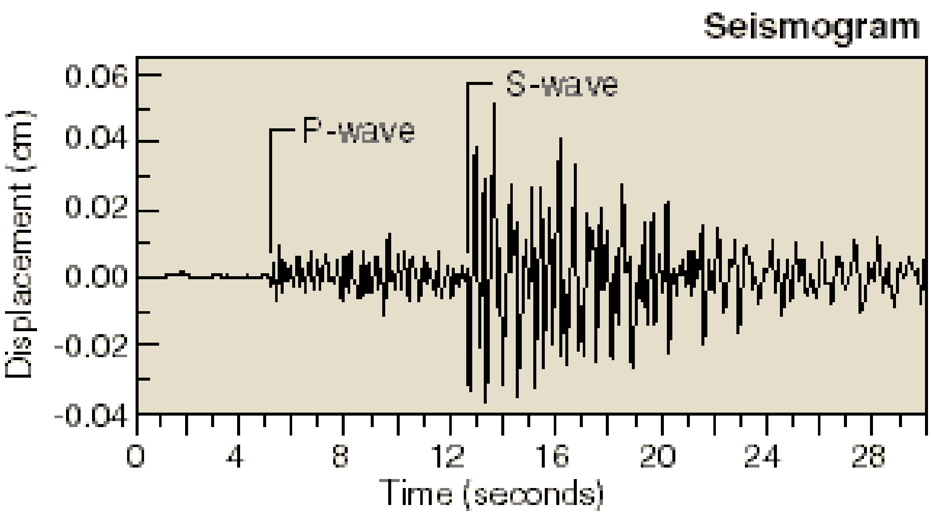
Satellite Pictures of the L'Aquila Region Around the Time of the 2009 Earthquake

Earthquake Sounds and Seismic Waves I

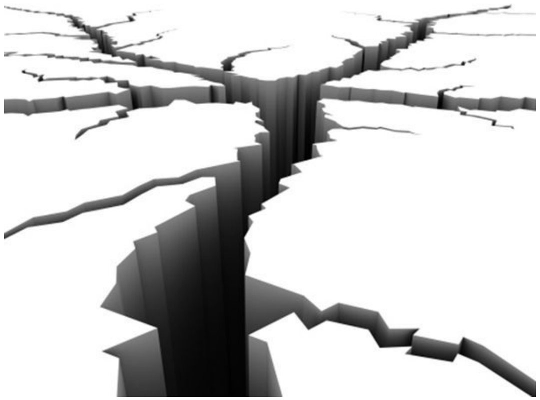


Seismic Waves can describe compression (P wave) strain or shear (S wave) strain.

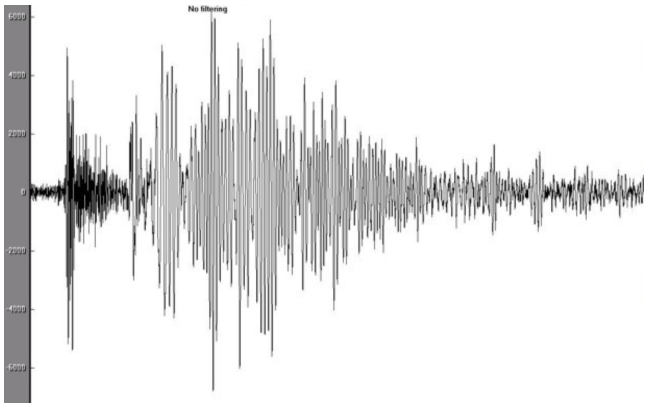
P waves travel faster than do S waves.



Earthquake Sounds and Seismic Waves II

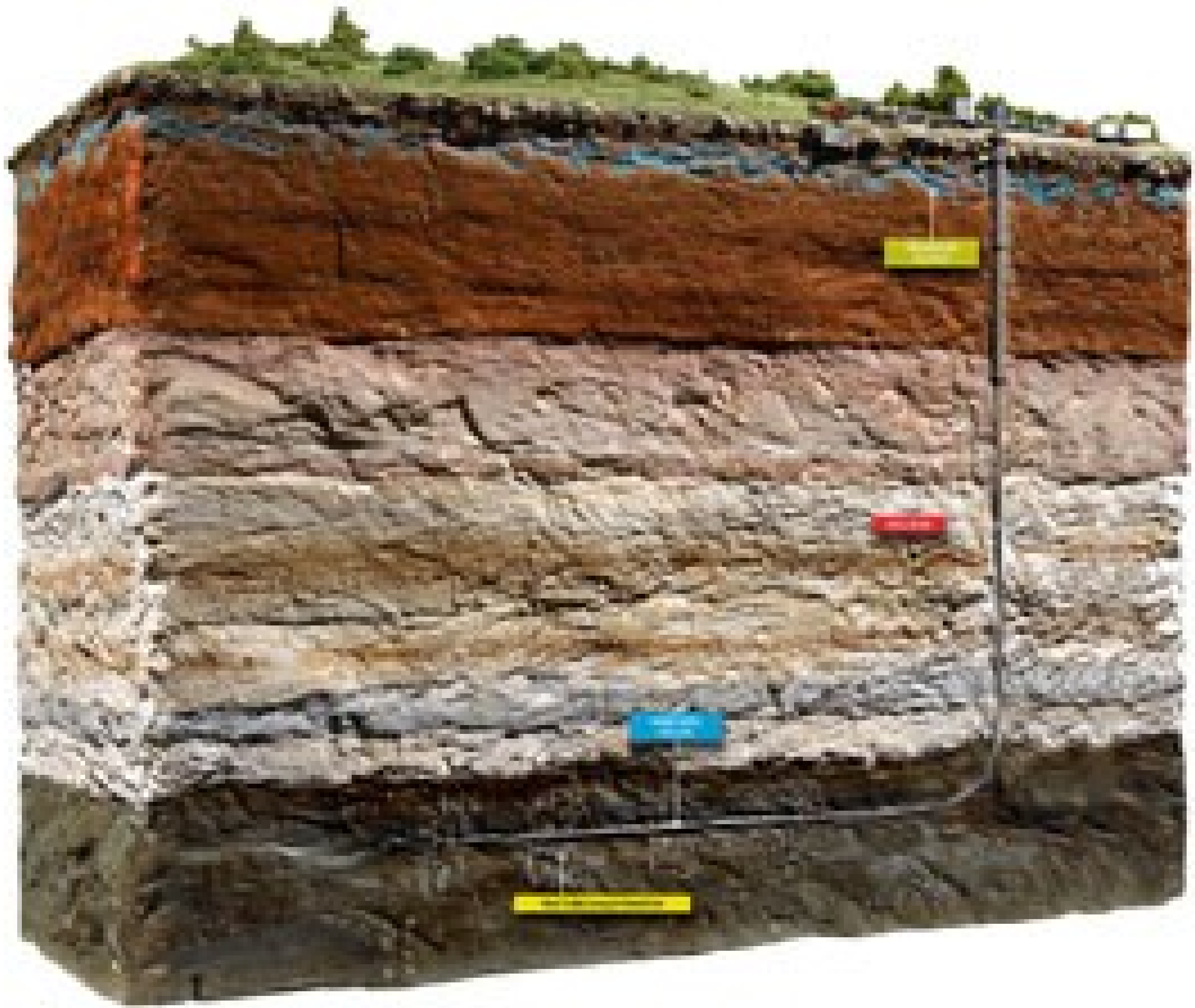


Fracture produced sound.

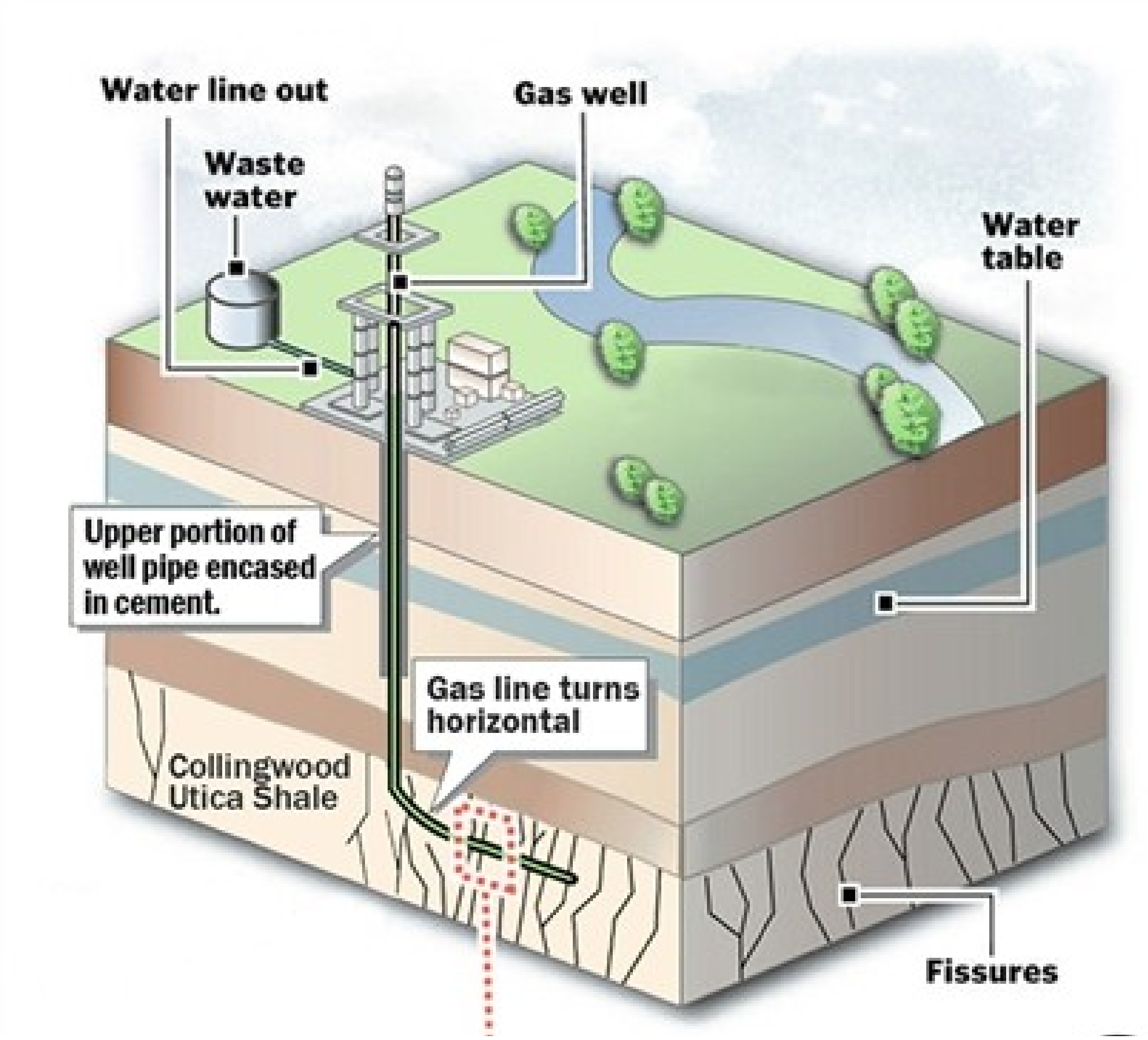


Fractured Granite Stone from a Mechanical Engineering Laboratory

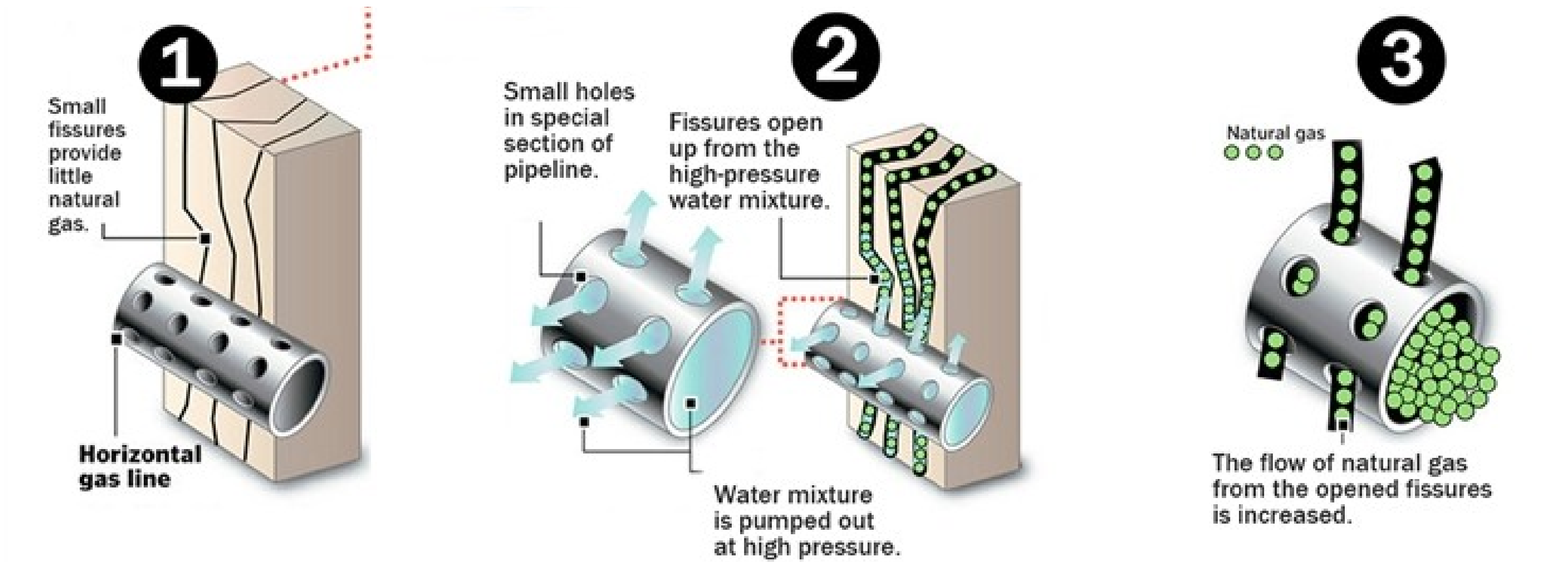
Hydraulic Fracturing I



Hydraulic Fracturing II



Hydraulic Fracturing III



1. Drilling for maximum effect
The drilling turns horizontal at about 9,000 feet, hitting multiple fissures and increasing the volume of available natural gas.

2. Putting the Pressure On
A mixture of water, sand and chemicals is pumped into the pipe-line, which has small holes through which the mixture is forced.

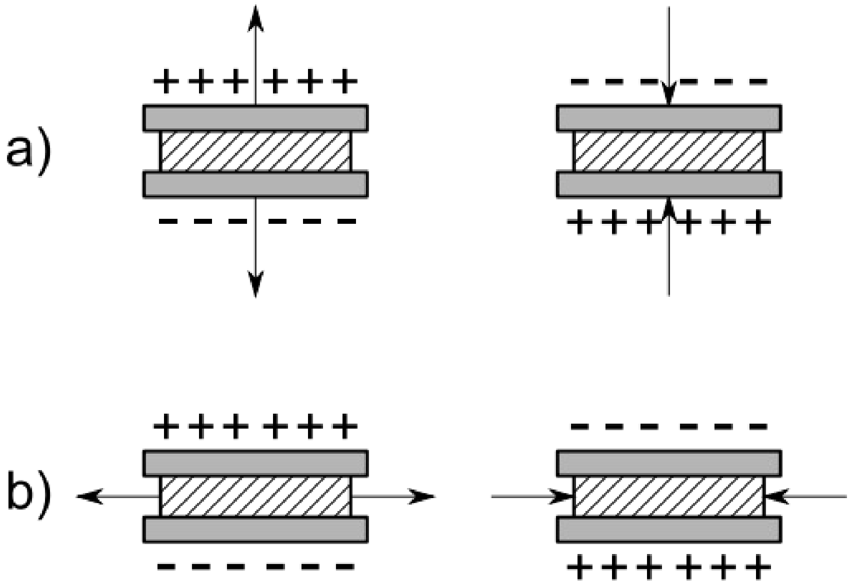
3. Increase Gas Flow
The small fissures are widened by the pressure. The water mixture is pumped back out of the well and natural gas follows back up the pipeline to the wellhead.

Thermodynamics I

$$du = T\,ds - \mathbf{P}\cdot d\mathbf{E} - \boldsymbol{\sigma} : d\mathbf{w}$$

$$\beta_{i,jk} = \left(\frac{\partial P_i}{\partial w_{jk}}\right)_{\mathbf{E},s} = \left(\frac{\partial \sigma_{jk}}{\partial E_i}\right)_{\mathbf{w},s}$$

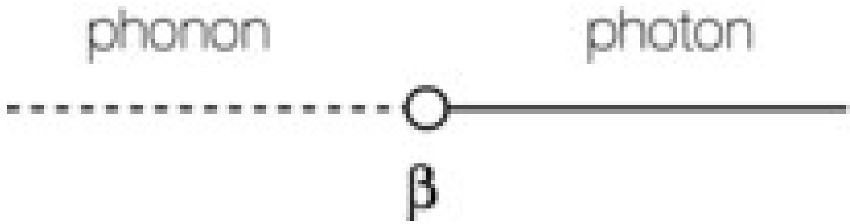
u = energy per unit volume
T = temperature
s = entropy per unit volume
$\mathbf{P}$ = polarization
$\mathbf{E}$ = electric field
$\boldsymbol{\sigma}$ = stress tensor
$\mathbf{w}$ = strain tensor
$\boldsymbol{\beta}$ = piezoelectric coefficient



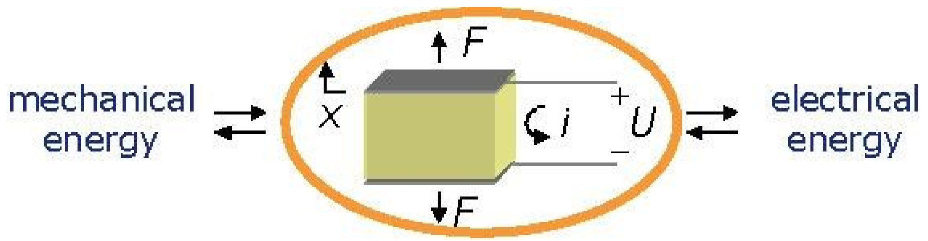
Thermodynamics II

$$\beta_{i,jk} = \left(\frac{\partial P_i}{\partial w_{jk}}\right)_{\mathbf{E},s} = \left(\frac{\partial \sigma_{jk}}{\partial E_i}\right)_{\mathbf{w},s}$$

Feynman Diagram



Engineering Diagram



$$\text{Mechanical Power} = Fv = F\frac{dx}{dt}$$

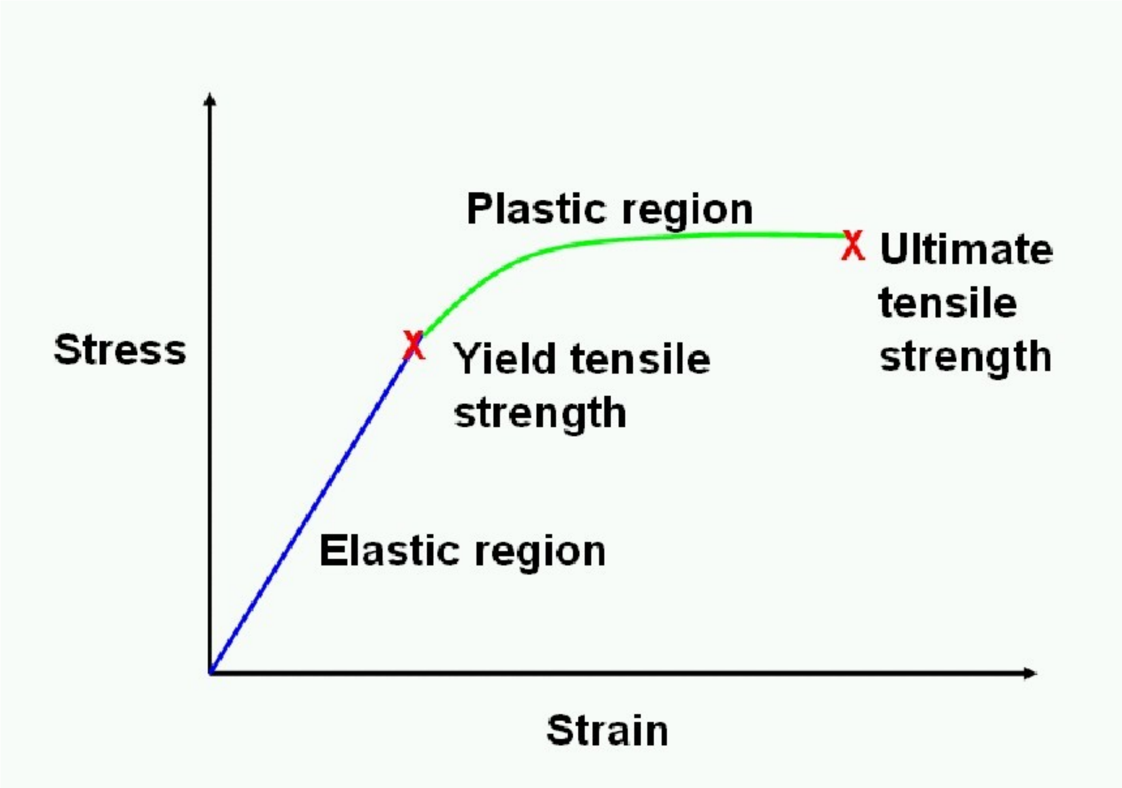
$$\text{Electrical Power} = Ui = U\frac{dq}{dt}$$

Tensile Strength I

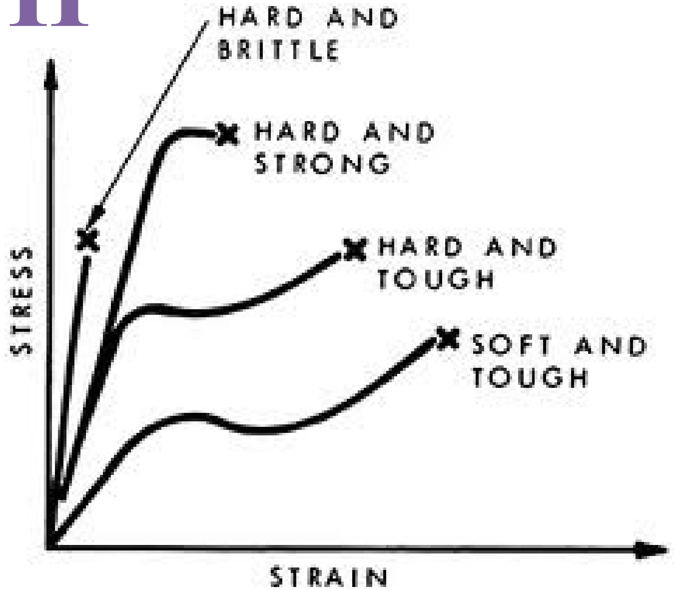
σ_F = tensile strength of a material beyond which the material fractures

If the matter is held together by Coulombs law, then in order of magnitude the electric fields E_F associated with fracture is determined.

$$\sigma_F = \frac{E_F^{\,2}}{4\pi}$$

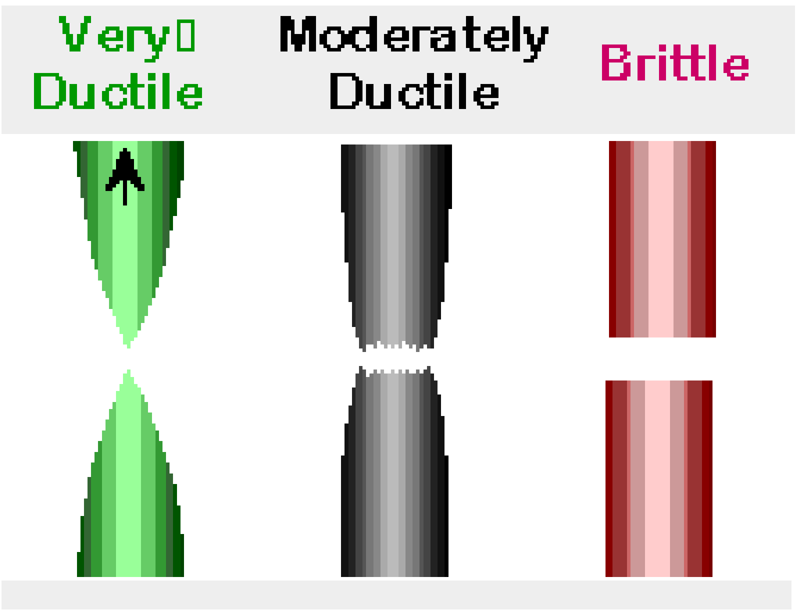


Tensile Strength II



Brittle Fracture Tensile Stress

$$\sigma_F = \frac{E_F^{\,2}}{4\pi}$$

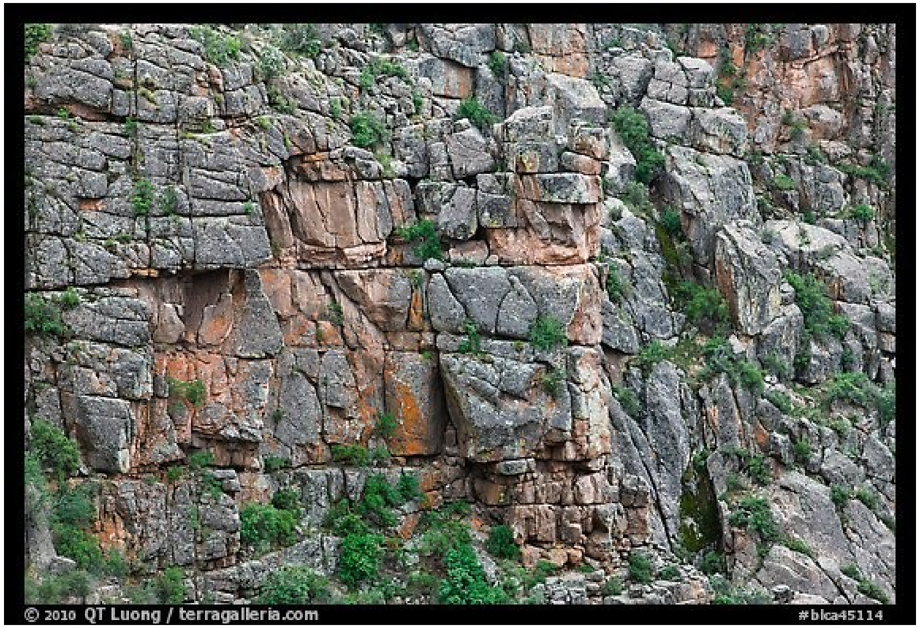


Micro-Cracks and Brittle Fracture I

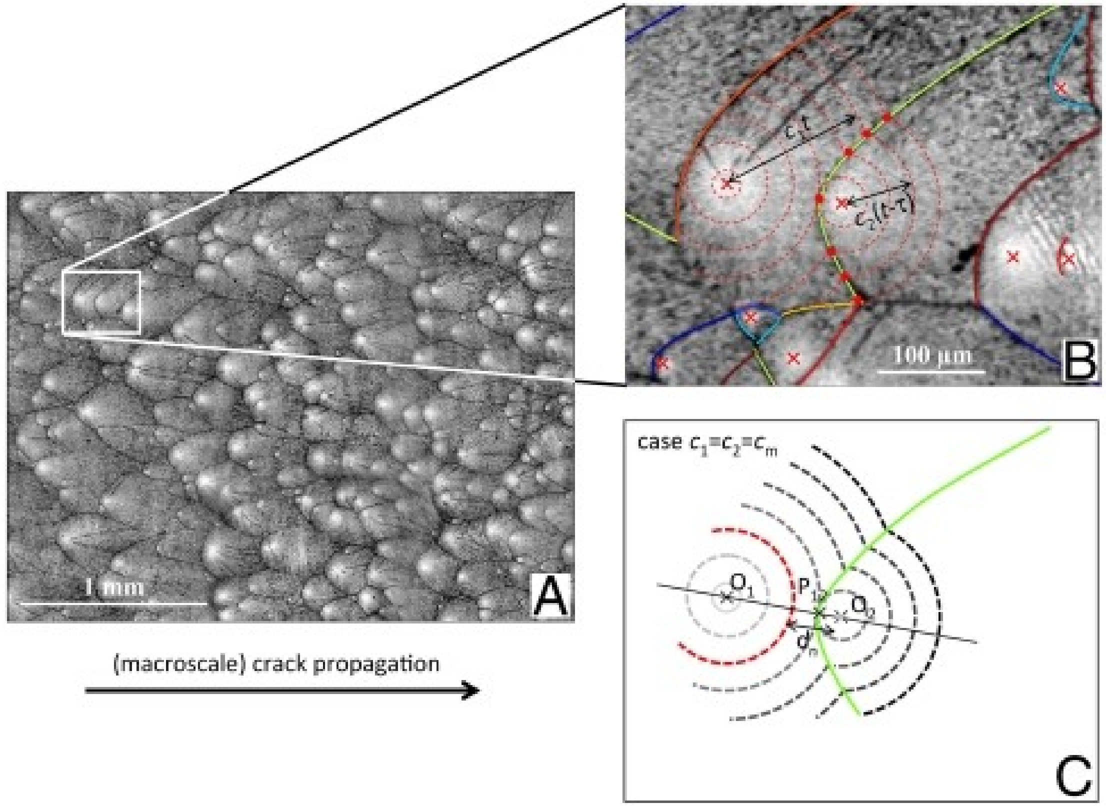
Understanding fast macro-scale fracture from micro-crack post mortem patterns

C, Guerra, J.Scheibert, D. Bonamy, D. Dalmas

Proc Natl Acad Sci USA **109,** 190 (2012)

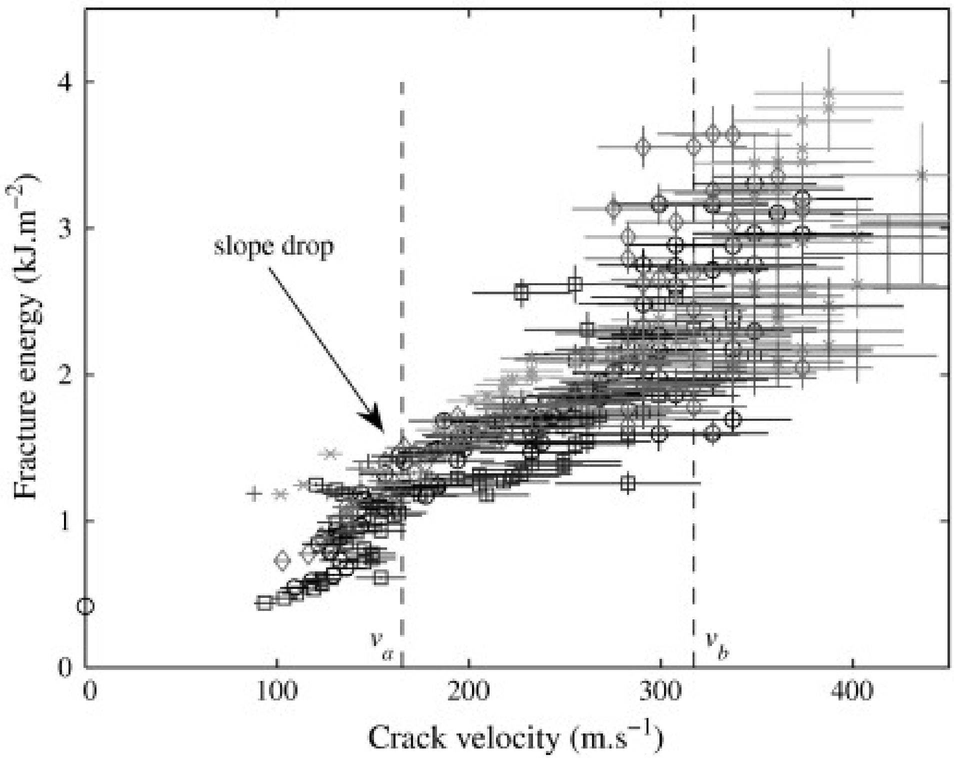


Micro-Cracks and Brittle Fracture II



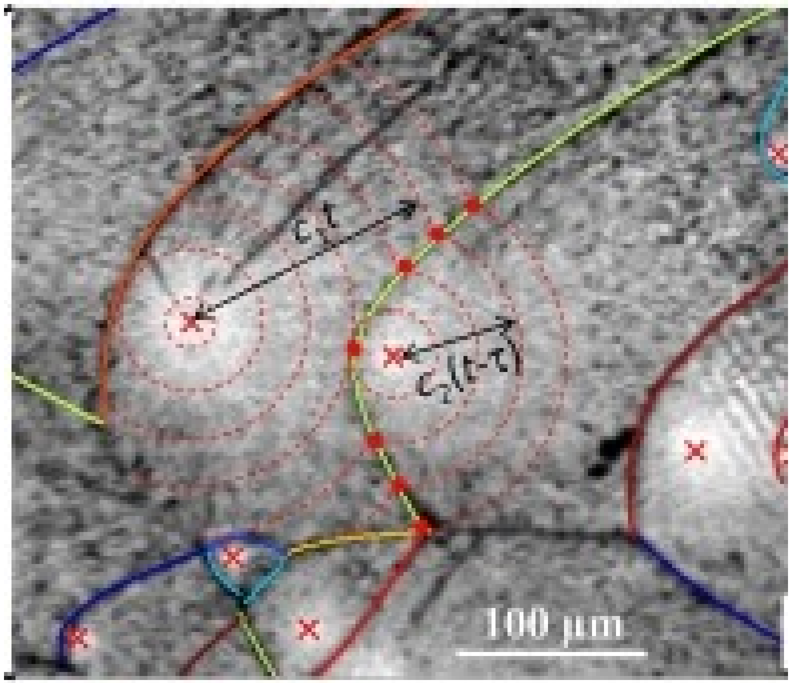
Micro Cracks on a Length Scale of 100 microns

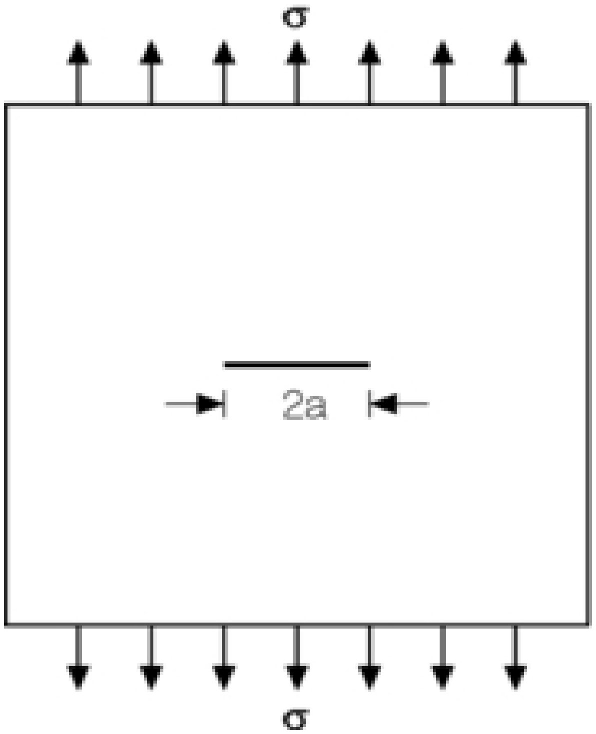
Micro-Cracks and Brittle Fracture III



Micro Crack Energy per Unit Area is Related to The speed of Micro Crack Propagation Speed

Micro-Cracks and Brittle Fracture IV





Physical Micro Crack

Cartoon Drawing

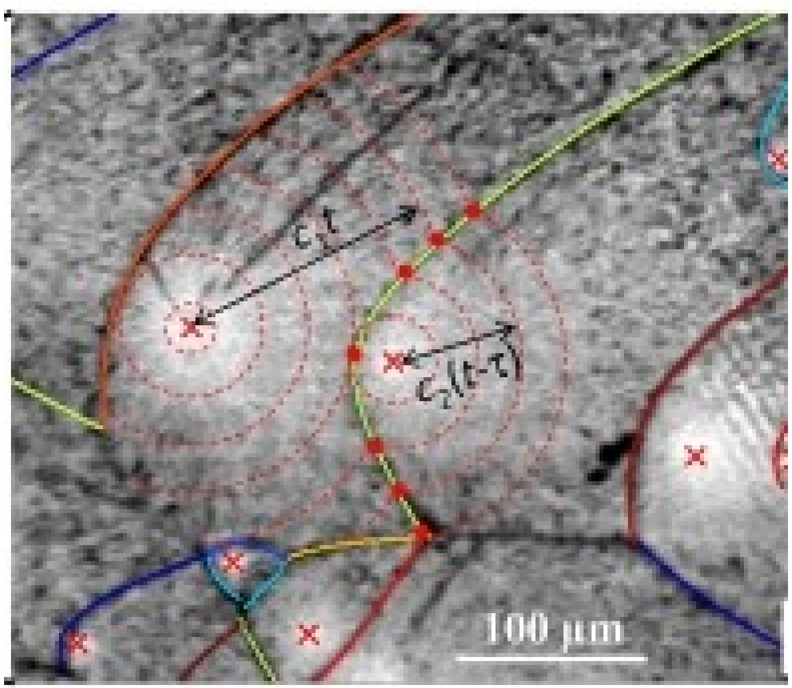
Micro-Cracks and Brittle Fracture V

Y = Young's Modulus
ν = Poisson Ratio
γ_s = surface tension
a = crack width
σ_F = tensile fracture stress

$$u = \gamma_s a = Min_b \left(4\gamma_s b - \pi b^2 \left[\frac{(1-\nu^2)\sigma_F^2}{Y} \right] \right)$$

$$a = \frac{2\gamma_s}{\pi} \left(\frac{Y}{(1-\nu^2)\sigma_F^2} \right)$$

$$\sigma_F = \sqrt{\frac{2\gamma_s Y}{\pi (1-\nu^2) a}}$$



Neutron Production Within Micro Cracks I:

Indian Academy of Sciences Sa dhana **37.** 59 (2012).

Electromagnetic and neutron emissions from brittle rocks failure: Experimental evidence and geological implications

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Neutron Production Within Micro Cracks II:

J. Phys. G: Nucl. Part. Phys. **40,** 015006 (2013).

Neutron production from the fracture of piezoelectric rocks

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Neutron Production Within Micro Cracks III:

$$\dot{\mathbf{p}} = e\mathbf{E}$$

$$\overline{p^2} = \frac{e^2 E^2}{\omega_0^{\ 2}}$$

$$Mc^2 = m^2 c^4 + c^2 \overline{p^2}$$

$$M = m\sqrt{1 + \left(\frac{E^2}{E_0^{\ 2}}\right)}$$

$$E_0 = \left(\frac{mc^2}{|e|}\right)\frac{\omega_0}{c} = \frac{(mc^2/|e|)}{\text{🖓}}$$

p = electron momentum
e = -|*e*| = electron charge
E = field
m = vacuum electron mass
M = Electron renormalized mass within the micro-crack
ω_0 = resonant field frequency
E_0 = threshold electric field

Forces on an Electron in a Micro-Crack

Neutron Production Within Micro Cracks IV:

$$M = m\sqrt{1 + \left(\frac{4\pi\sigma_F}{E_0^{\,2}}\right)}$$

$$N = m\sqrt{1 + \left(\frac{E}{E_0}\right)^2}$$

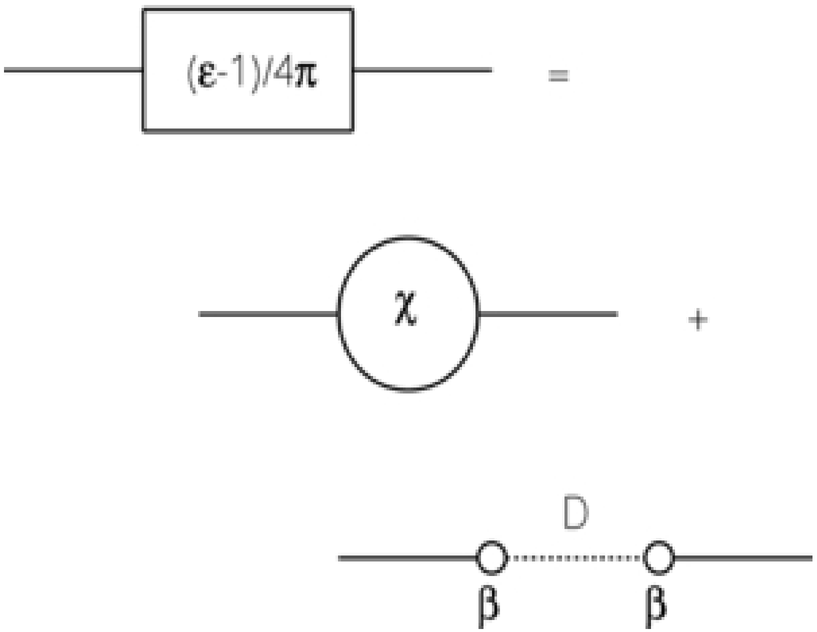
$$E_0 = \left(\frac{mc^2}{|e|}\right)\frac{\omega_0}{c}$$

$$\sigma_F \sim 10^8 \ \frac{\text{erg}}{\text{cm}}$$

$$E \sim 10^5 \ \text{Gauss}$$

$$E_0 \sim 10^3 \ \text{Gauss}$$

Piezoelectric Sound Coupling to Electromagnetic Fields determines the frequency ω_0 .



The electron mass renormalization is very large. (M/m)~10^2 .

Neutron Production Within Micro Cracks V:

The large mass enhancement of the electrons in the neighborhoods of the micro-cracks allow for the production of neutrons via the reaction

$$e^- + p^+ \rightarrow n + \nu_e$$

There Should be Considerable Microwave Radiation

Conclusion

Granite is a Piezoelectric Solid
Earthquake Lights and Sound Depend on Piezoelectricity
Laboratory Rock Fracturing is a Small Scale Earthquake
Hydraulic Fracturing Depends on Granite Rock Crushing
Micro-Cracks are Formed During Brittle Fracture
There is Neutron Production and Microwave Radiation