INTERNATIONAL ATOMIC ENERGY AGENCY
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SMR/107 - 22

WORKSHOP ON PATTERN RECOGNITION AND ANALYSIS OF SEISMICITY

(5 - 16 December 1983)

PHYSICAL CAUSES OF AFTERSHOCKS

L. Knopoff

IV Aftershocks

Time scale —— minutes (or less) to years

Rate $n \sim 1/t$ Omori (1892)

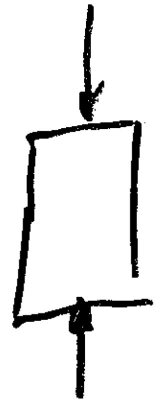
⟶). Possibility of very long time aftershocks
– Intraplate seismicity

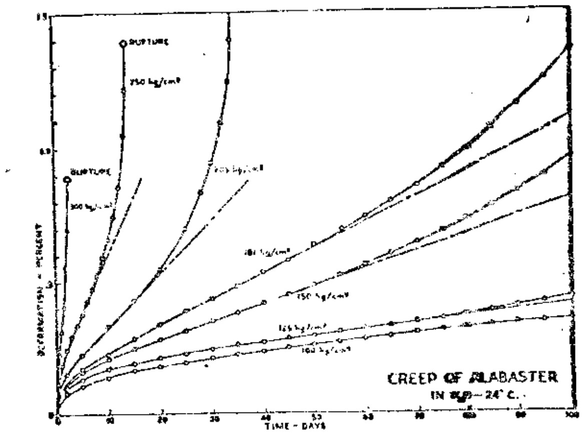
Tripped by main earthquake
stress relaxation or stress diffusion important
if Diffusion processes may be dissipative

Processes in time interval between shock diffusion
Processes at times of aftershocks are elastic
Examples of stress relaxation / diffusion in laboratory
Processes in rocks accelerated by energy water
Rate of accel. energy change not fast enough.

$t_f = t_0 e^{-\sigma \alpha V/kT}$

Time lakin
recrystallization





$t_f = t_0 e^{-E/kT}$. $E = \sigma \alpha V$

a large number of references:

Glasses: Preston et al., Nature 156, 1946
J. App. Phys. 17, 1946

Metals: Zhurkov, Int. J. Fract. Mech. 1, 1965

Rock(s): Griggs, Bull. G.S.A. 51, 1940

Plastics, Ionic Solids: Zhurkov, loc. cit.

Metals: Cherepanov, Mech. of Brittle Fract. (McGraw-Hill) 1979.

TABLE 1.—*Properties of alabaster in wet creep tests at different stresses*

(Gypsum in each experiment subject to constant load, in the presence of its own saturated aqueous solution, at [illegible] C., $\sigma_2=\sigma_3=0$)

Compressive stress ($\sigma_1-\sigma_3$ in kg/cm²) σ	Steady-state velocity (millionths per day) v_s	Deformation before fracture (per cent) S	Duration of test (to fracture) (days) t_f	Equivalent viscosity (poises) × 10¹⁶ η
300	2000	.89	2.45	.42
250	440	1.39	13.58	1.60
205	219*	2.5*	48*	2.64
181	100	3.0	133	5.11
165	77.0	3.6	285	6.04
150	66.5	>1.05	>110	6.36
125	24.5	3.3	308	14.4
103	~~7.0~~ 7.6	~~>.71~~ >6.1	~~>520~~ 7190	~~41.0 (?)~~ 42.2

* Average of three duplicate tests.

Properties of same gypsum when dry:
Strength (short-time) = 520 kg/cm²
Deformation before fracture = 35% (primarily elastic)
Equivalent viscosity = > 5. × 10¹⁹ at 420 kg/cm²

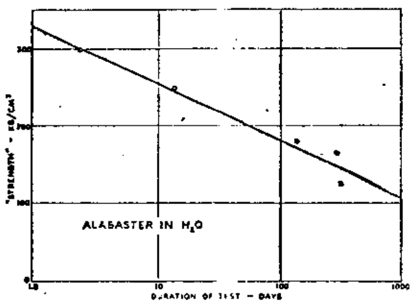


FIGURE 10.—*Strength of alabaster as a function of duration of test*
Data from experiments of Figure 6.

Viscosity? Viscoelasticity?

Seismological evidence for creep
1. Aseismic slip before & after earthquakes
2. Silent earthquakes
3. Aftershock swarms (no clusters).

Linear viscoelasticity

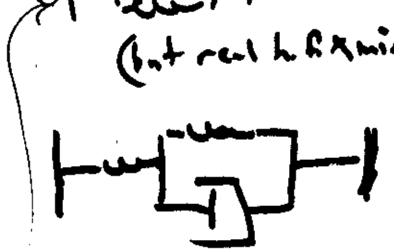
Maxwell [redacted] body

creep under static load

Kelvin body

inf. resistance
inf atten. at $\omega=\infty$
(but real h.f. transmission v.g.)

Std viscoel. solid



$$\tau = \mu\varepsilon + \eta\dot{\varepsilon}$$

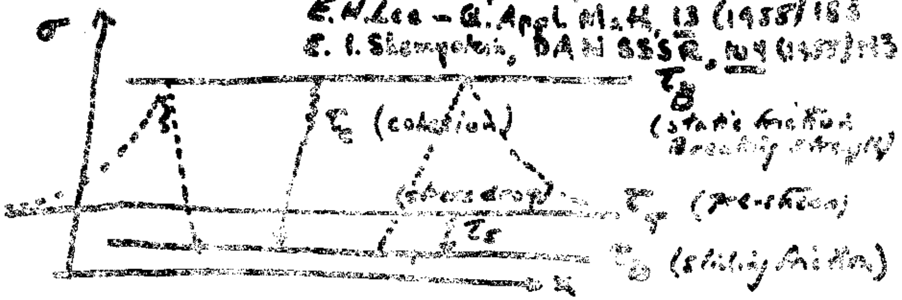
Consider a pre-existing crack in

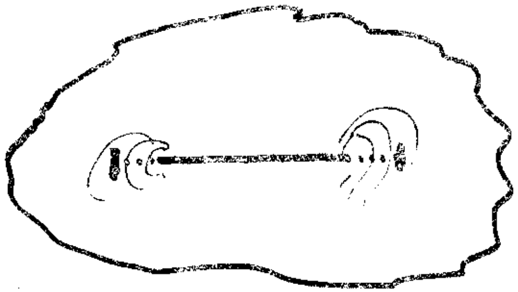
1) a uniform stress field and
2) the medium has the properties of a standard viscoelastic body

We separate the problem into two regimes

a) quasistatic → correspondence principle
b) seismic

E.H. Lee – Q. Appl. Math. 13 (1955) 183
E. I. Shemyakin, DAN SSSR, 104 (1955) 193

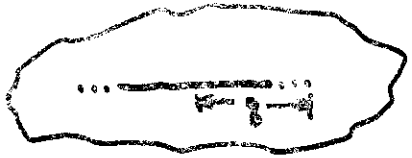


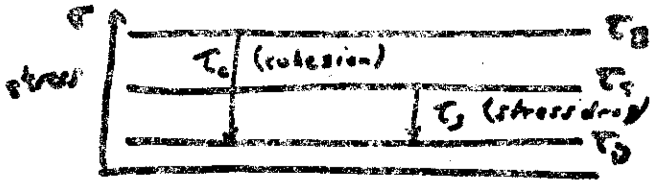


2-D

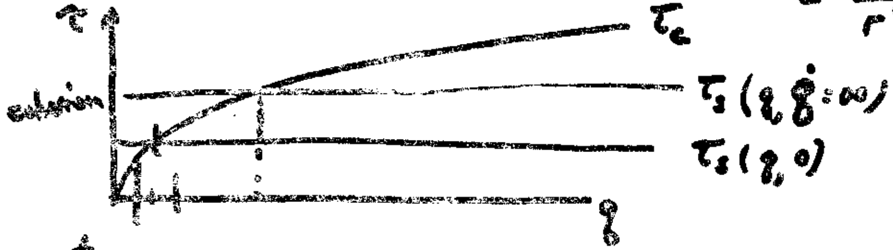
$V \approx \sqrt{\frac{\mu}{\rho}}$

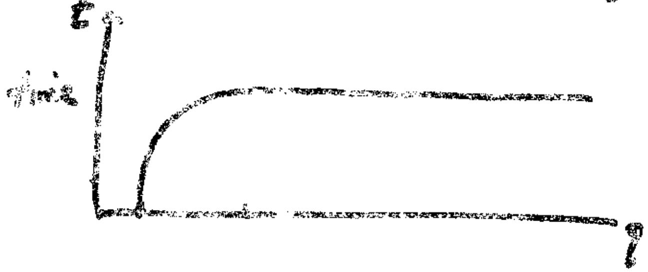
This crack will undergo accelerated extension quasistatically for a finite time; when its velocity of extension reaches velocity comparable to $\beta = V_S$ it starts to radiate seismic waves. This crack never stops



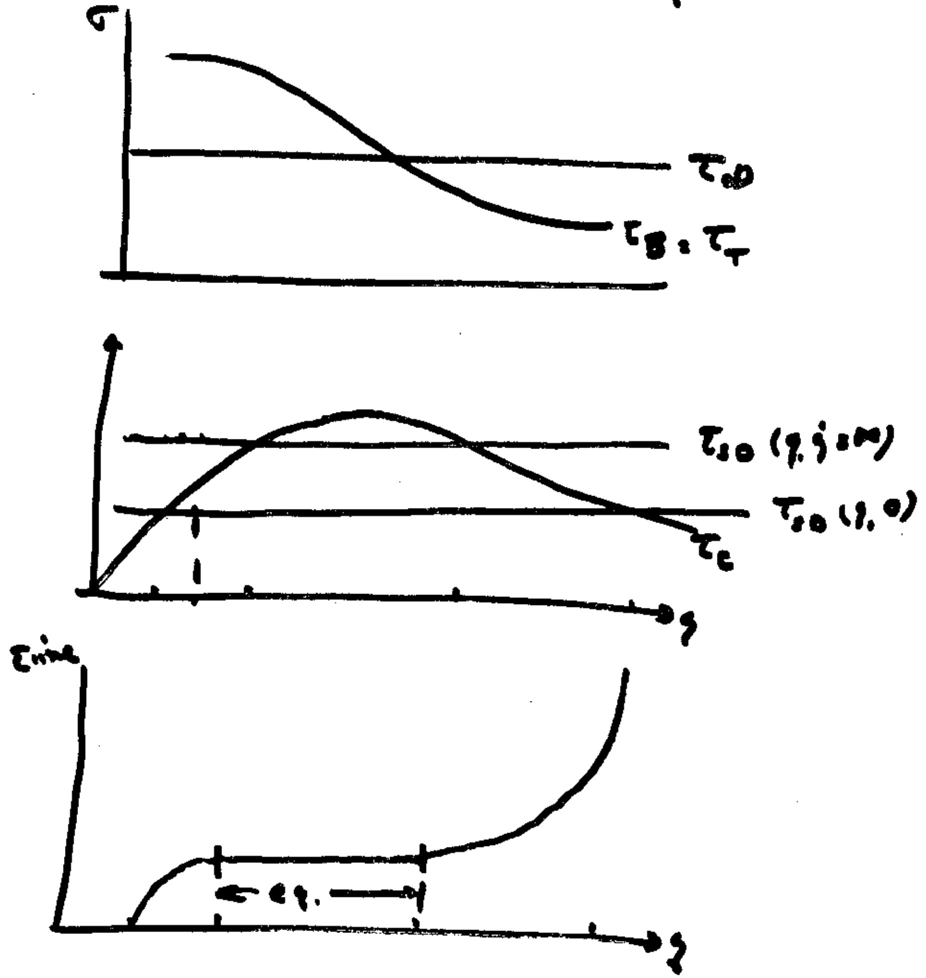


$\tau_c \sim \frac{L^{1/2} \tau_s}{r^{1/2}}$

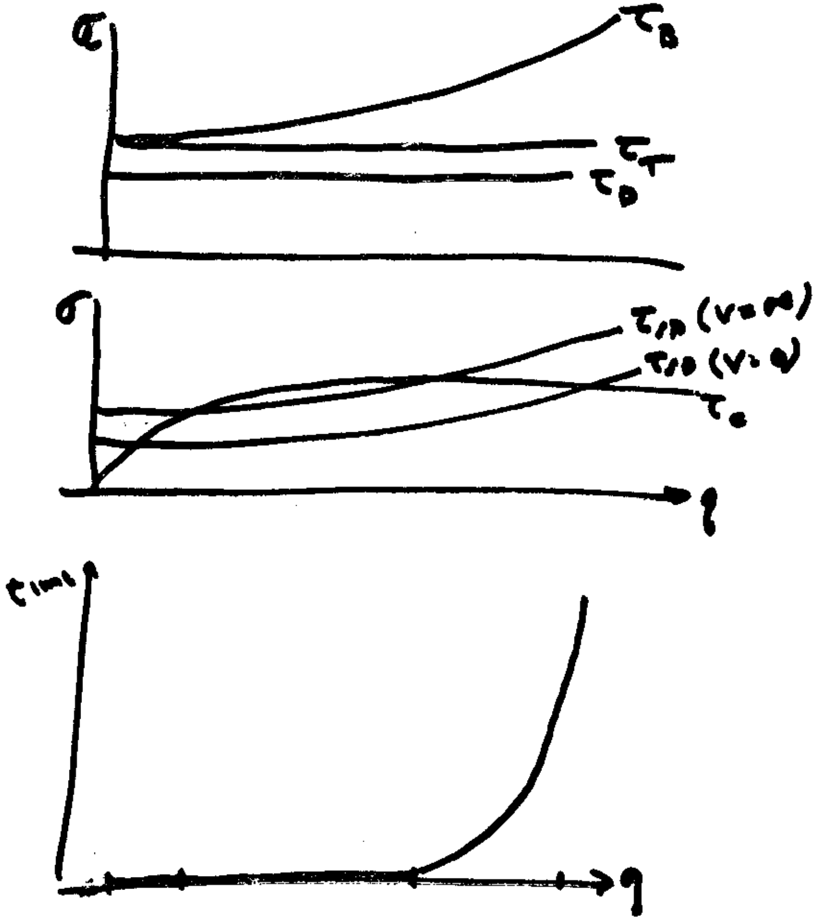


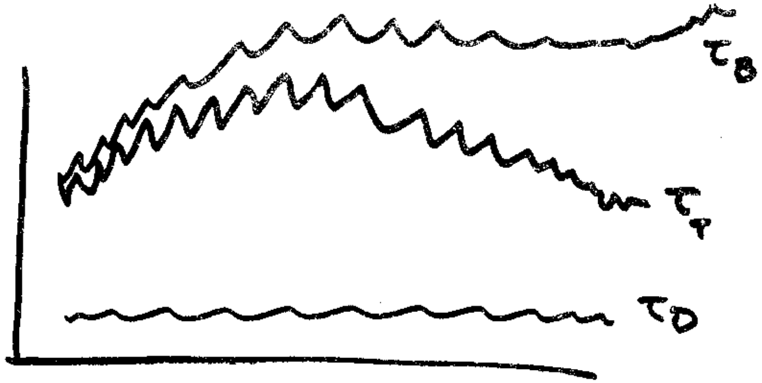


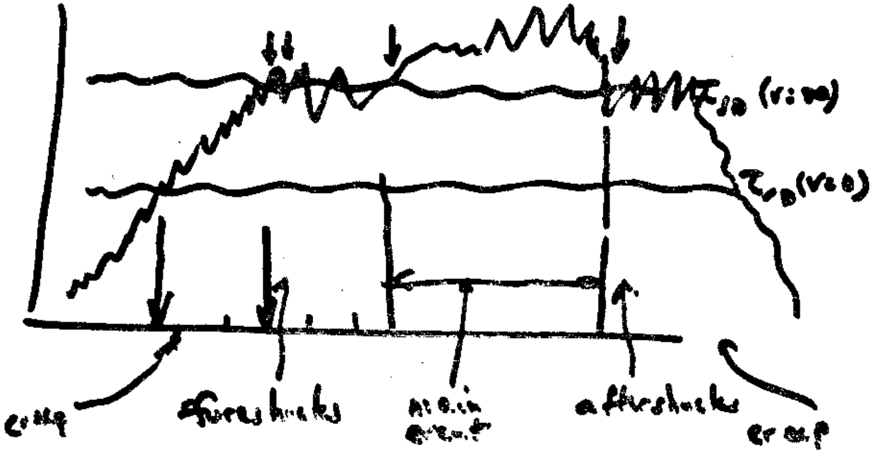
reversal of stress drop [redacted] as method of stopping a crack

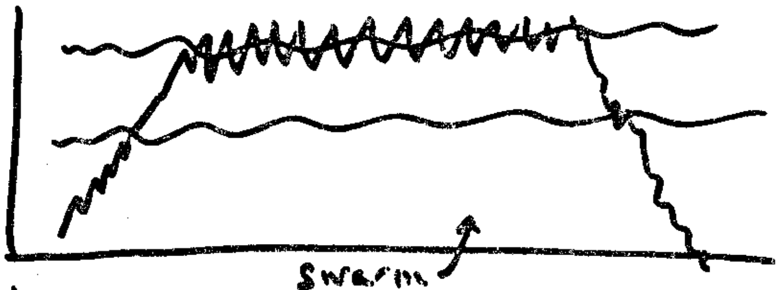


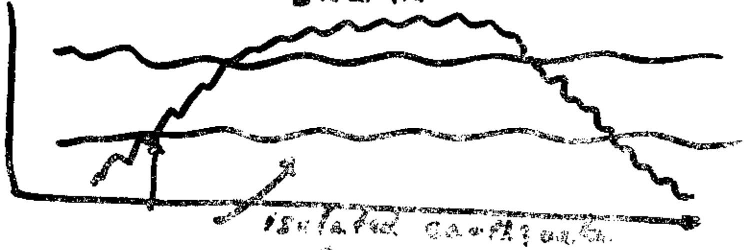
Elevated breaking strength as method of stopping a crack



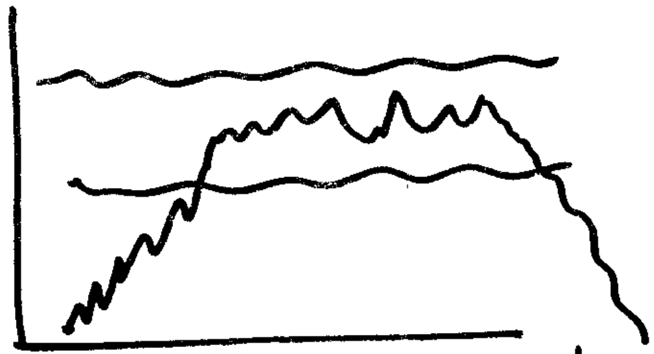




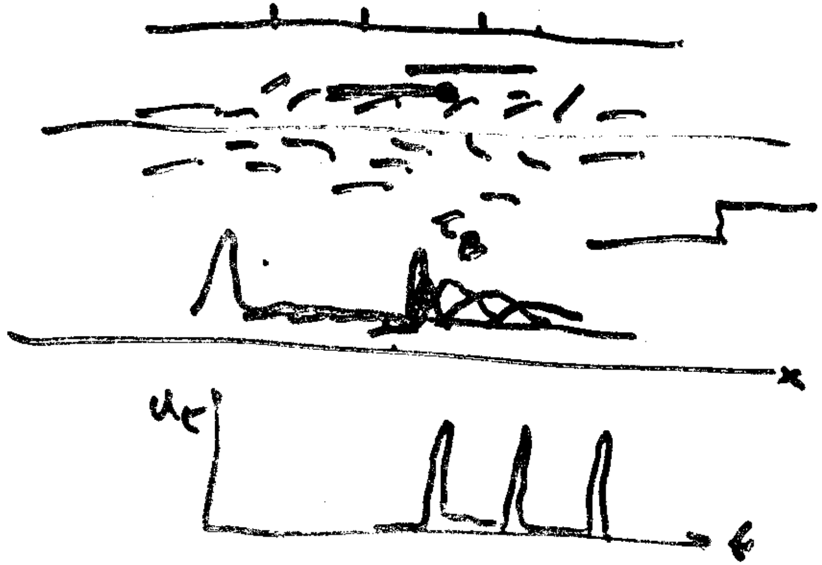




isolated earthquake



silent earthquake



References Aftershocks

Experimental: See text

Fracture Dynamics: See Lecture III

T. Yamashita, J. Phys. Earth, 28 (1980) 309

T. Yamashita, J. Phys. Earth, 29 (1981) 283

Y. T. Chen and L. Knopoff: 1. Static shear crack with a zone of slip weakening.

2. Quasistatic extension of a shear crack with a zone of slip-weakening in a viscoelastic medium.

3. Simulation of earthquake sequences.

All three of these are "in preparation"