INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392-1

H4.SMR/303 - 26

WORKSHOP
GLOBAL GEOPHYSICAL INFORMATICS WITH APPLICATIONS TO RESEARCH IN EARTHQUAKE PREDICTIONS AND REDUCTION OF SEISMIC RISK

(15 November - 16 December 1983)

CRACK FUSION MODELS OF SEISMICITY
CRACK GROWTH MODELS OF SEISMICITY

L. KNOPOFF

University of California
Los Angeles
U.S.A.

MODELING FOR UNDERSTANDING (CLUSTERING)

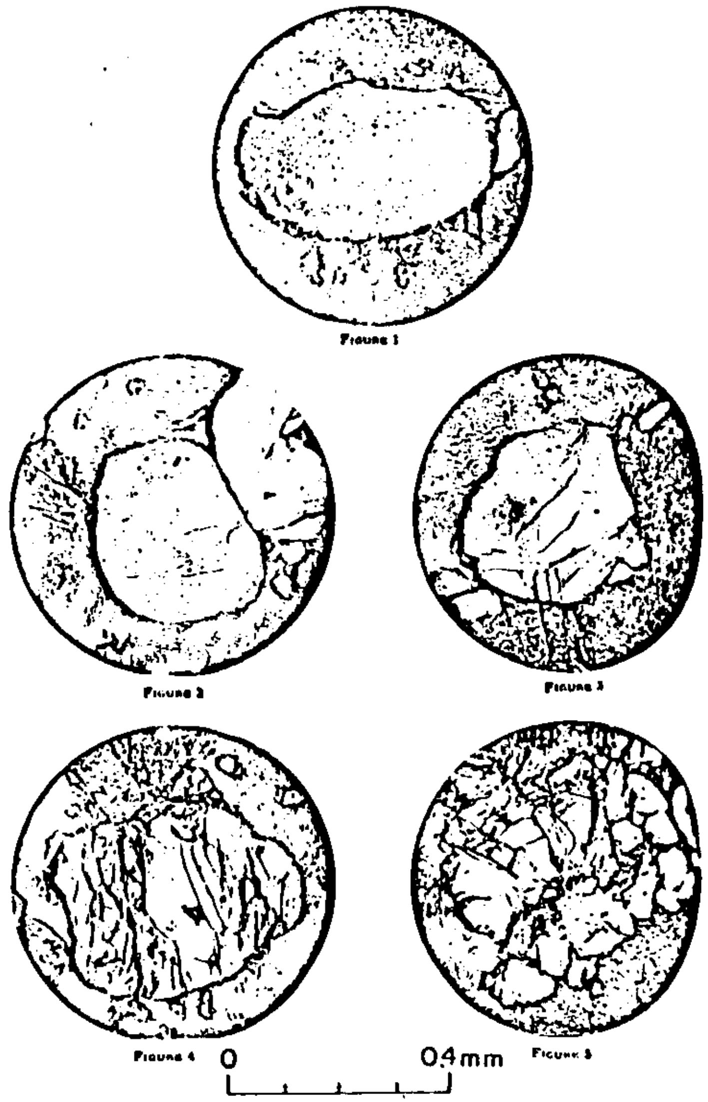
MAKES USE OF

- STRESS REDISTRIBUTION DUE TO FRACTURE
- PLATE TECTONICS
- GEOMETRY OF ALREADY FRACTURED (Damaged) MATERIALS
- CREEP RHEOLOGY
  STRESS CORROSION
  ⟹ TIME DELAYS

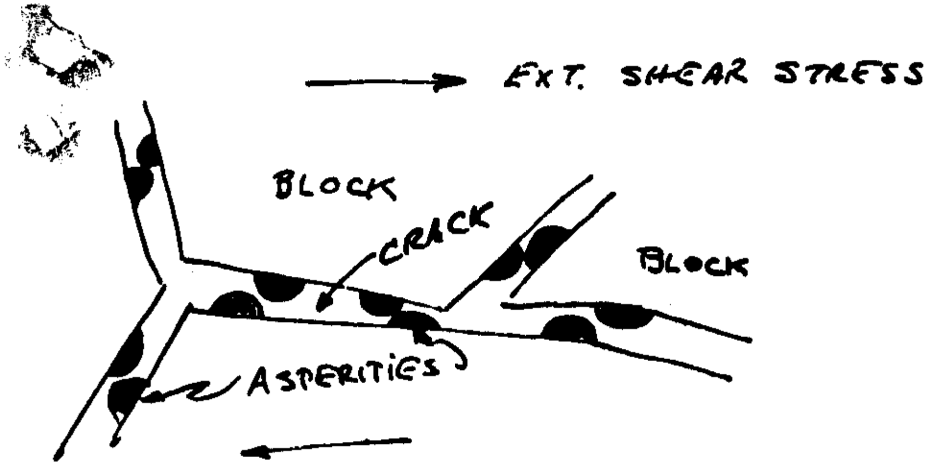
THEORETICIAN'S PHILOSOPHY:

The models should not be too complicated

i.e. THE NUMBER OF DEGREES OF FREEDOM (adjustable parameters) SHOULD BE SMALL

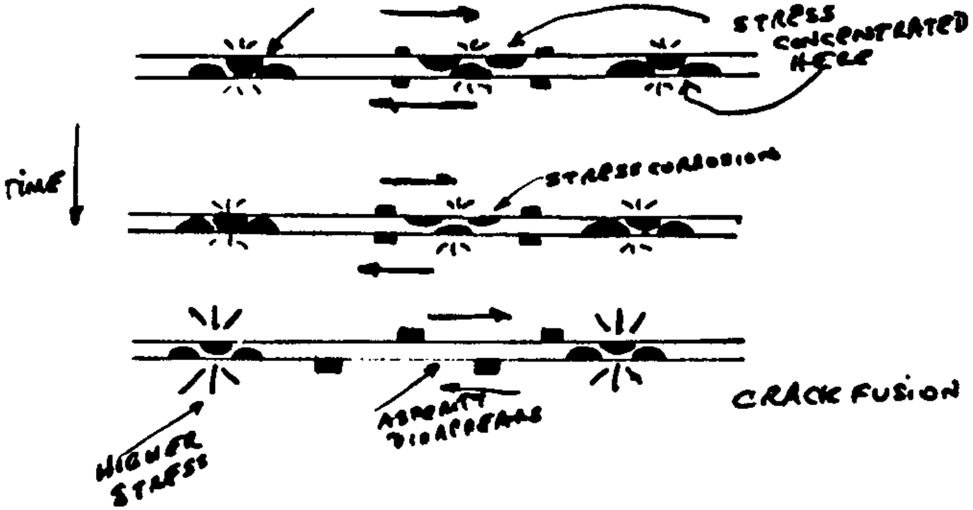


ST. PETER SAND SHOWING VARIOUS INTENSITIES OF FRACTURING



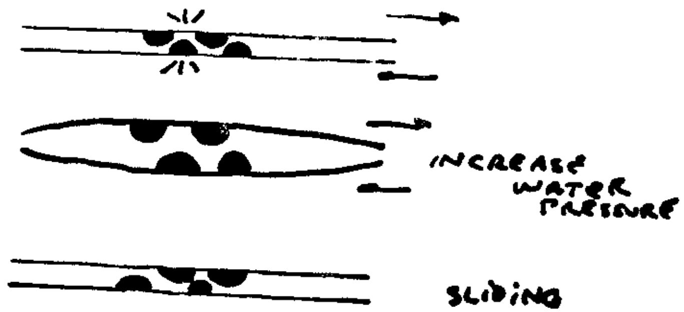
BLOCKS (3D) = TILES (2D) = CRACKS MODEL

. . . .

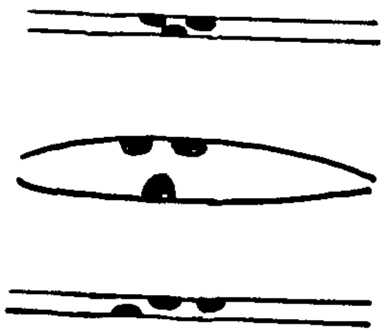


HOW DOES THE ASPERITY DISAPPEAR?

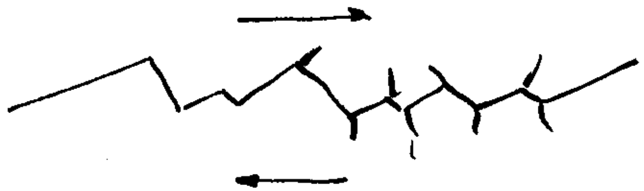
CLASSICAL (HUBBERT + RUBEY) MODEL



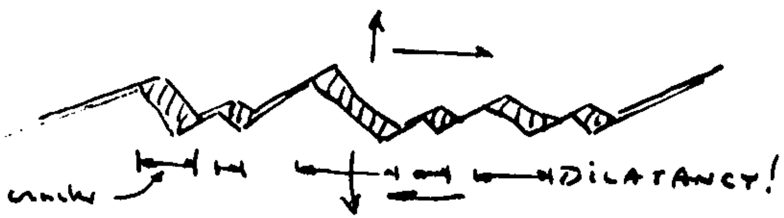
HEALING?



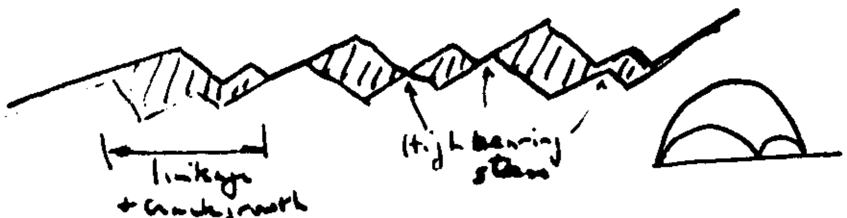
Consider an irregular crack surface which we model as a sawtooth. We subject the elastic medium to a shear stress.

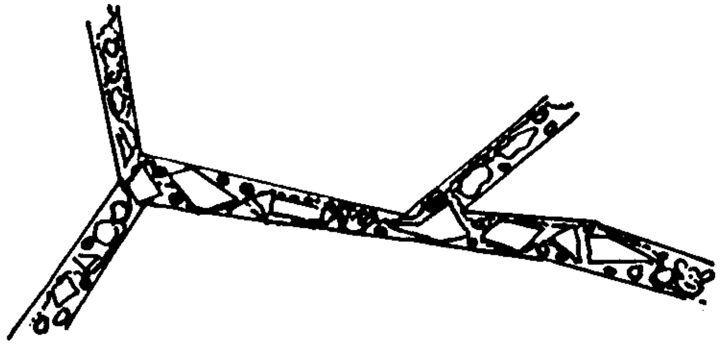


In order that lateral motion take place, one crack surface must "ride" upward over the other. Thus transverse motion must take place



When sliding becomes too large, cracks begin to link up.





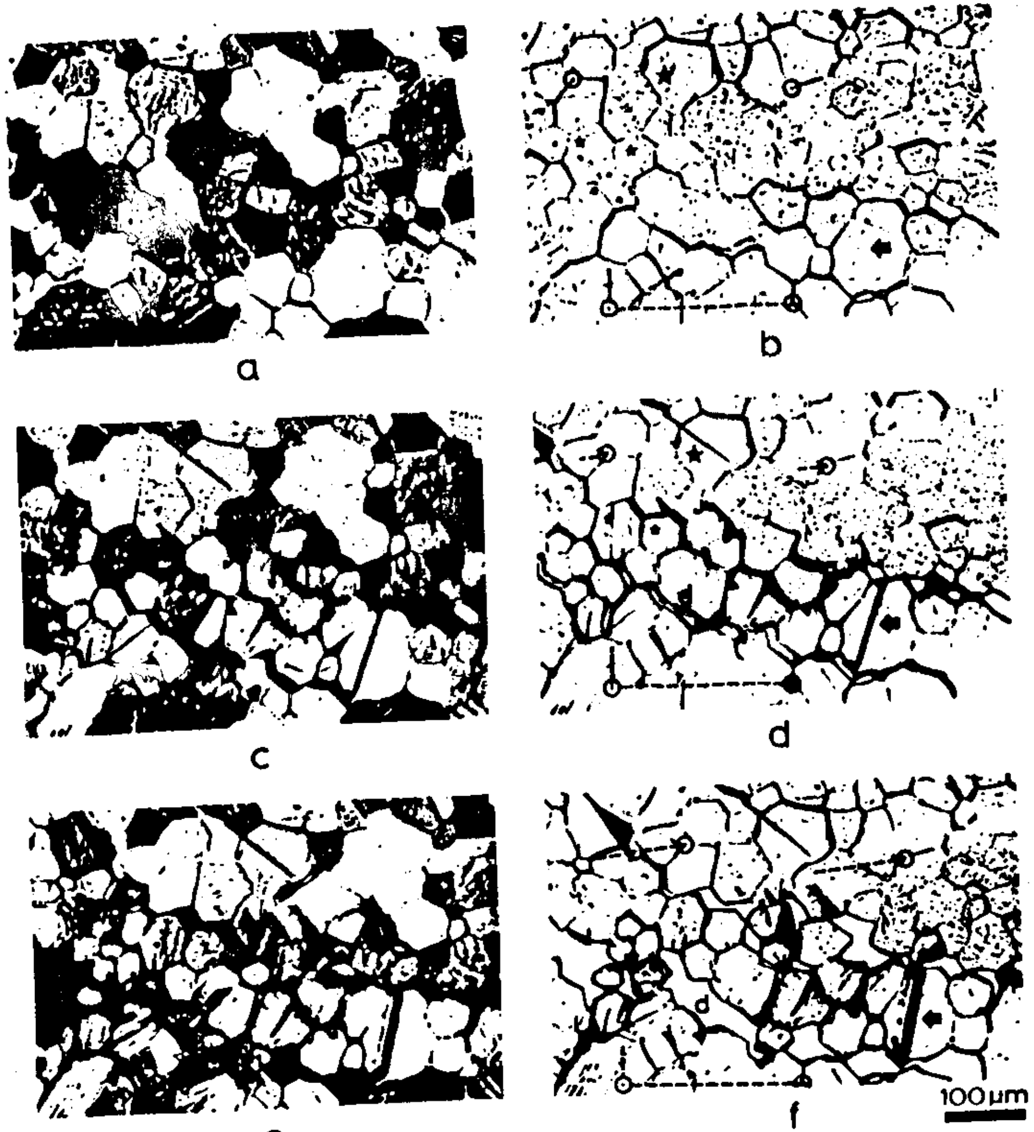
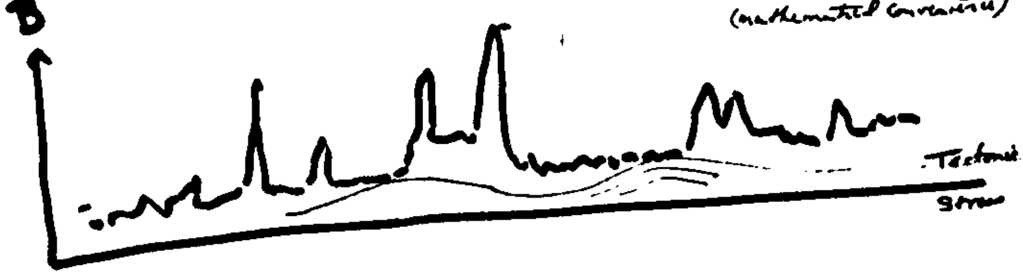


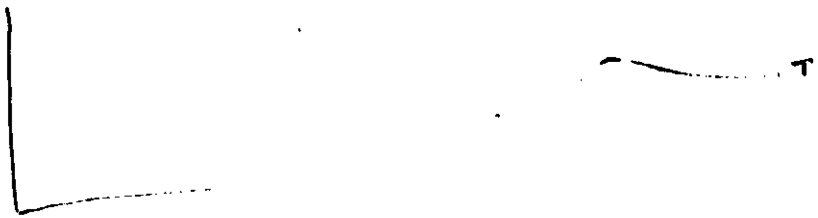
Figure 4. Cracking and twinning in sodium nitrate in dextral shear zone. Intergranular crack propagation and twin inception near small stars in b and d; twin widening at stubby arrow; microfracture dilation at d and elsewhere. Sample thickness is about 30 μm.

Geometry of Faulting

1 Dimensional Representation

(asperities, barriers)
(mathematical conveniences)

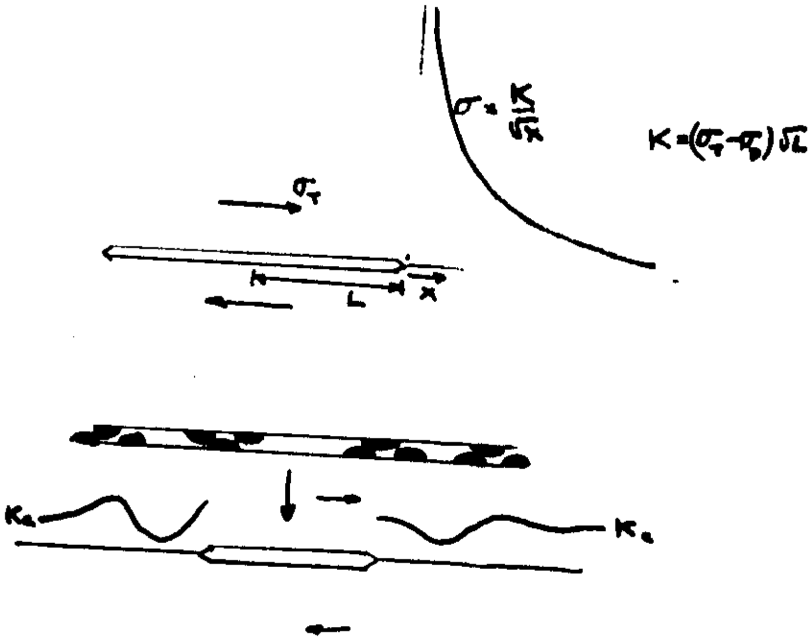


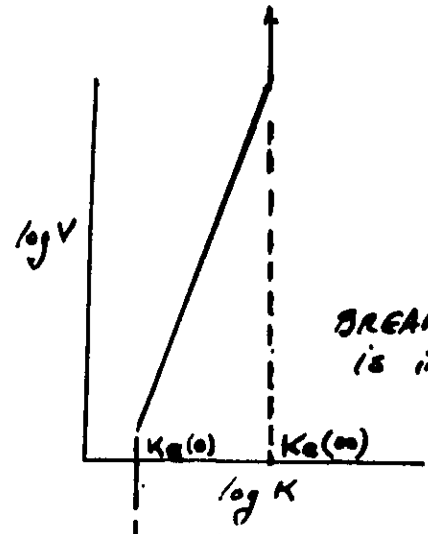


comp JS

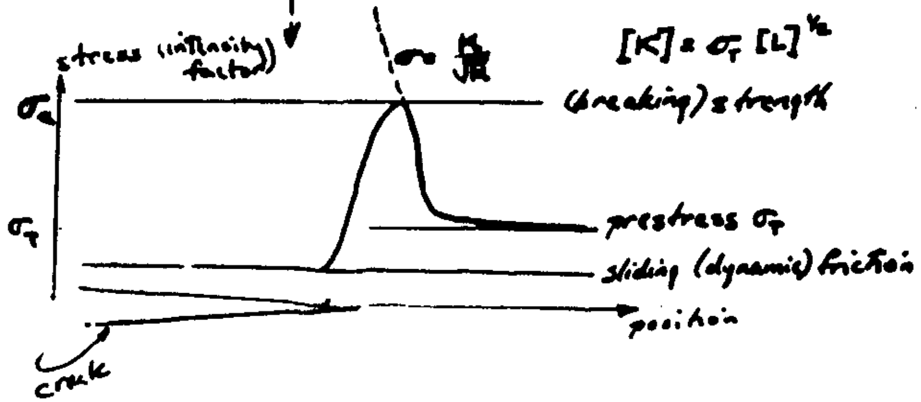
CRACK GROWTH MODEL

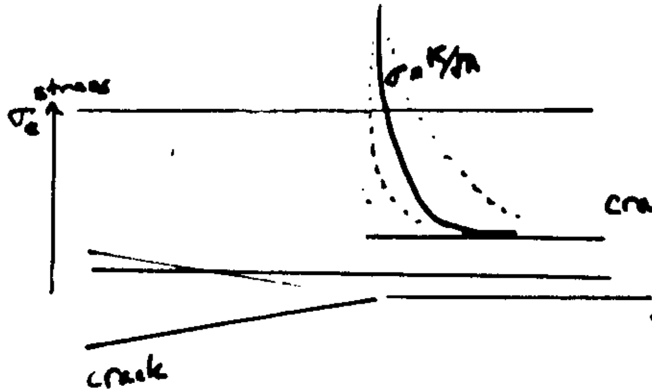
There is only one crack in the whole world (in this model)





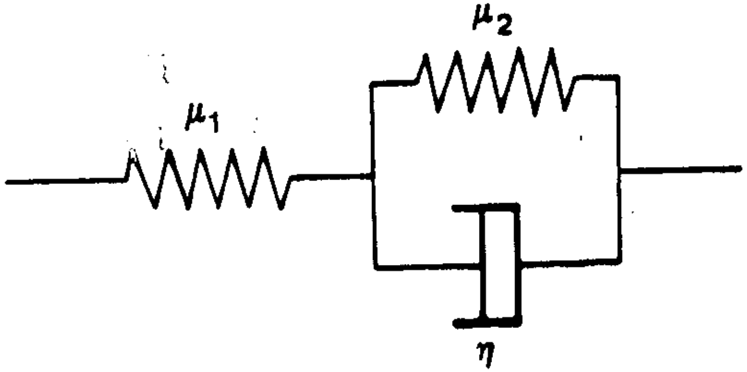
BREAKING (Fracture) is inevitable once $K > K_c(0)$



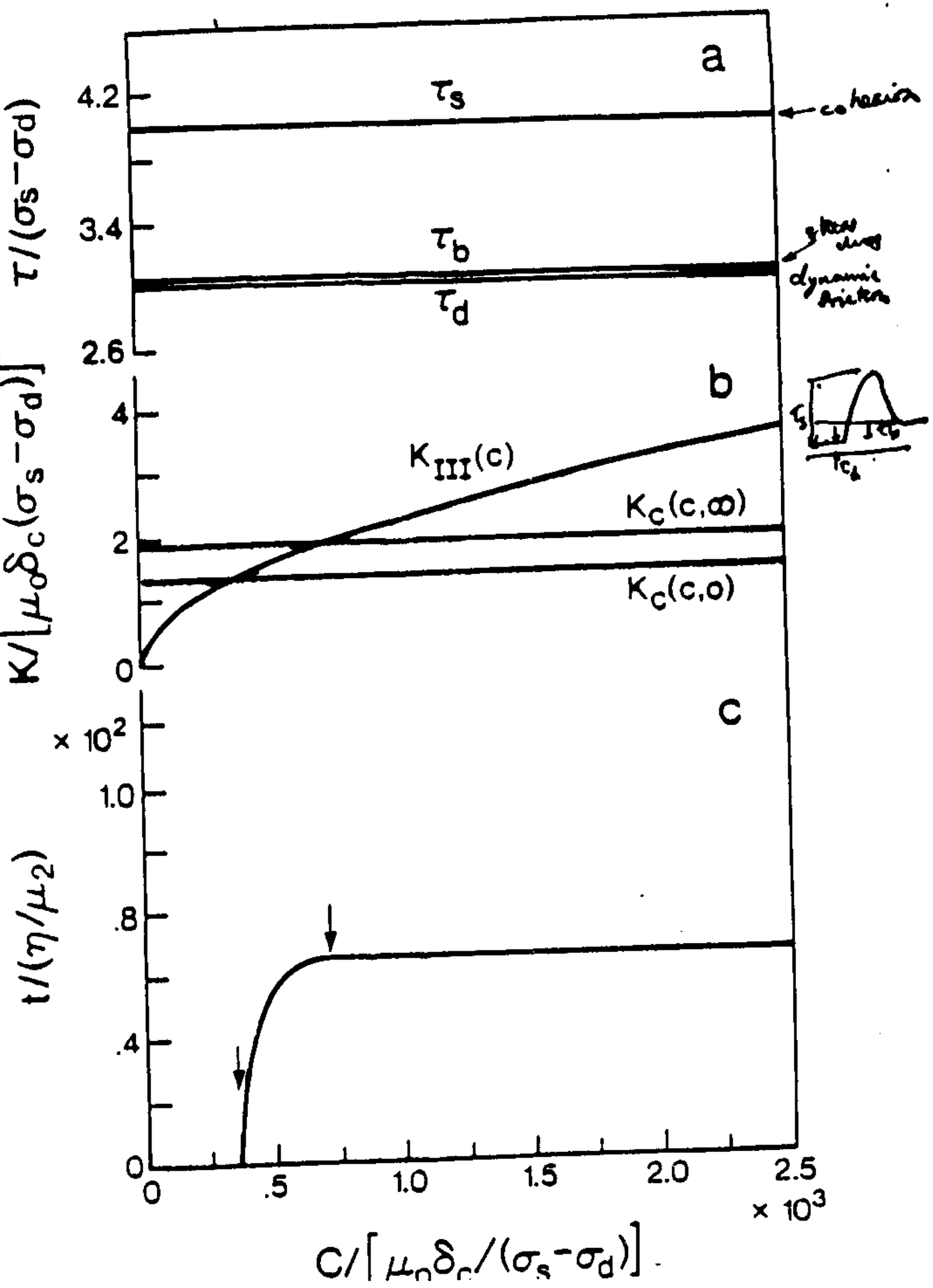


Define $K_c = \sigma_c L^{1/2}$

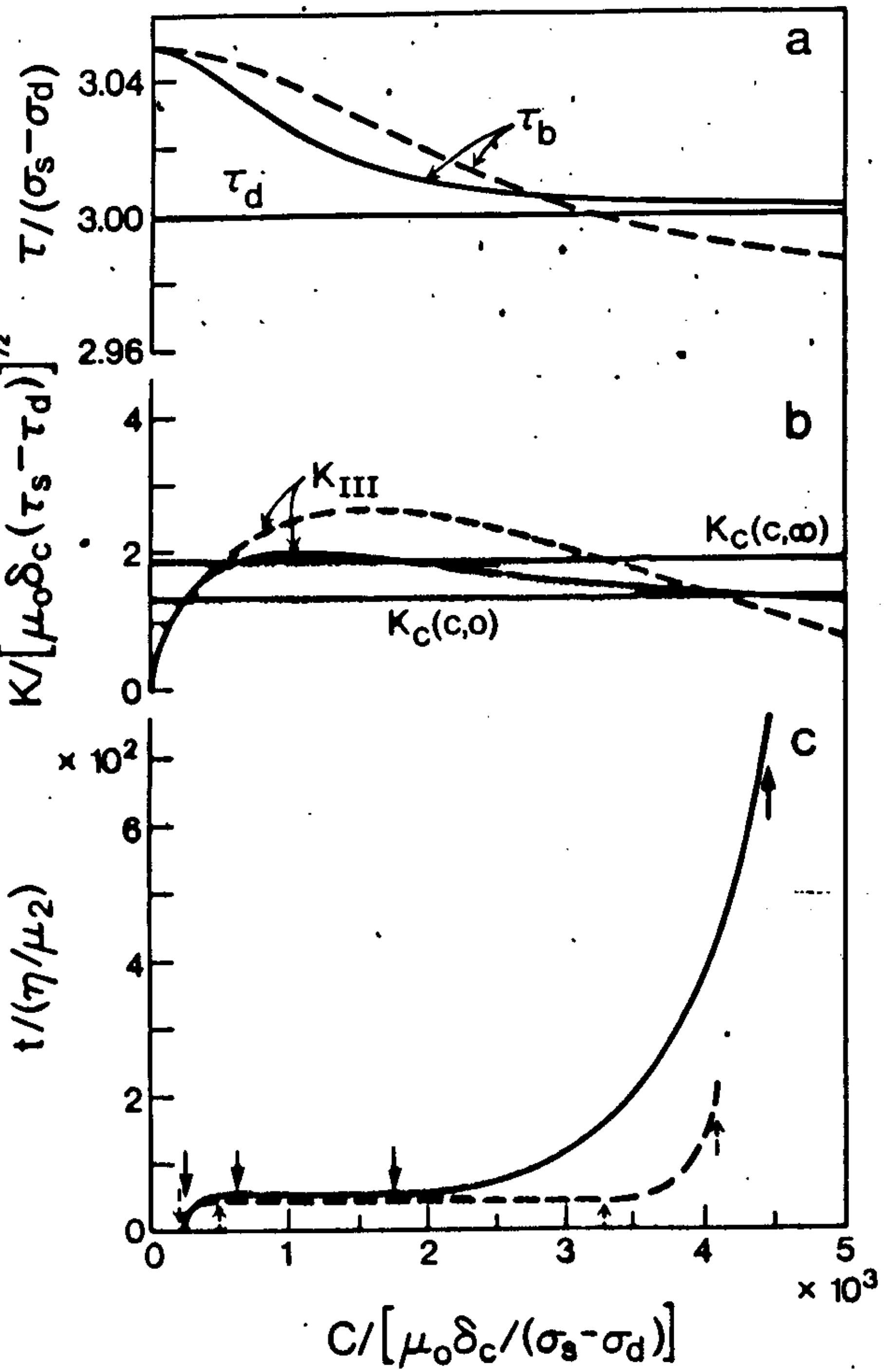
crack grows if $K > K_c$



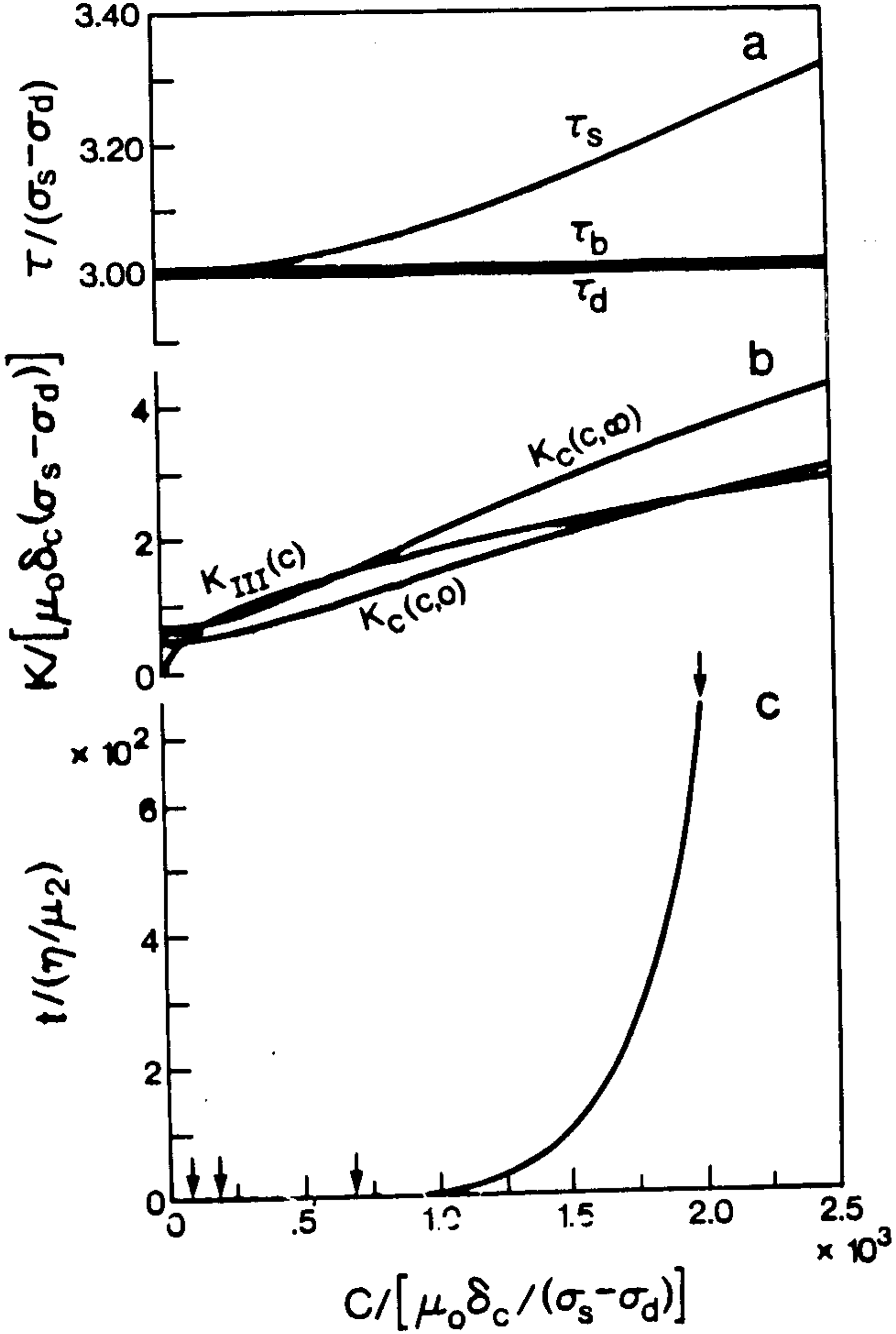
μ1
μ2
η



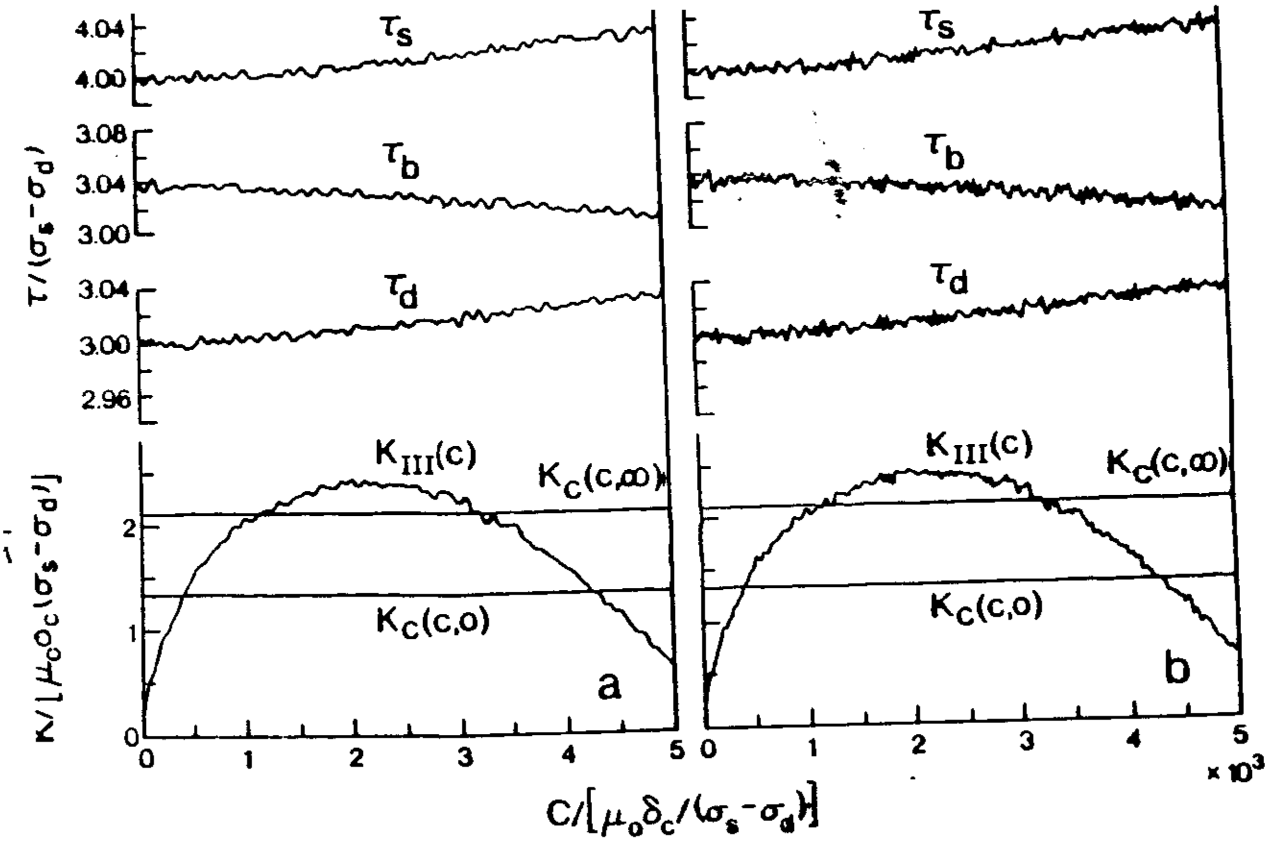
a
b
c
τs
τb
τd
cohesion
dynamic friction
KIII(c)
Kc(c,∞)
Kc(c,o)
τ/(σs−σd)
K/[μ0δc(σs−σd)]1/2
t/(η/μ2)
× 10²
× 10³
C/[μ0δc/(σs−σd)]
4.2
3.4
2.6
4
2
0
1.0
.8
.4
.5
1.5
2.0
2.5

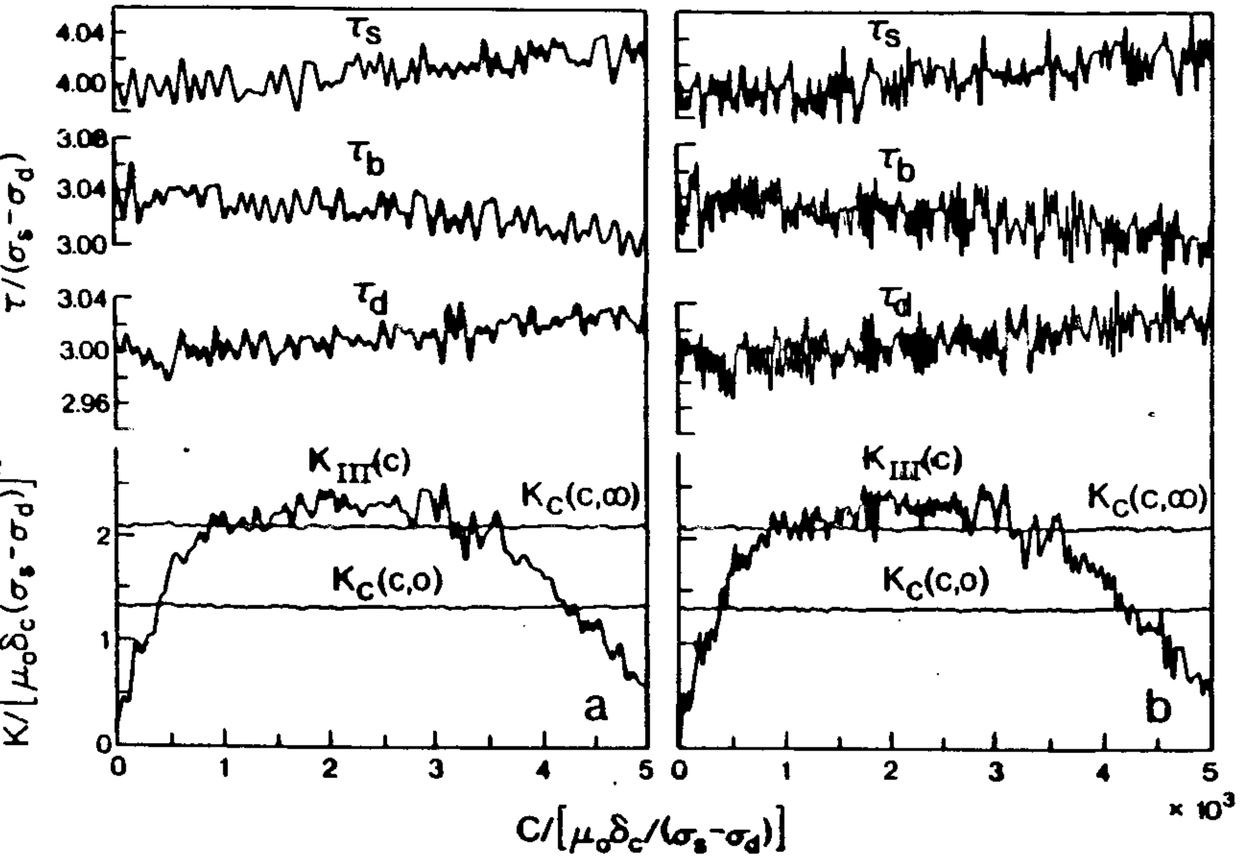


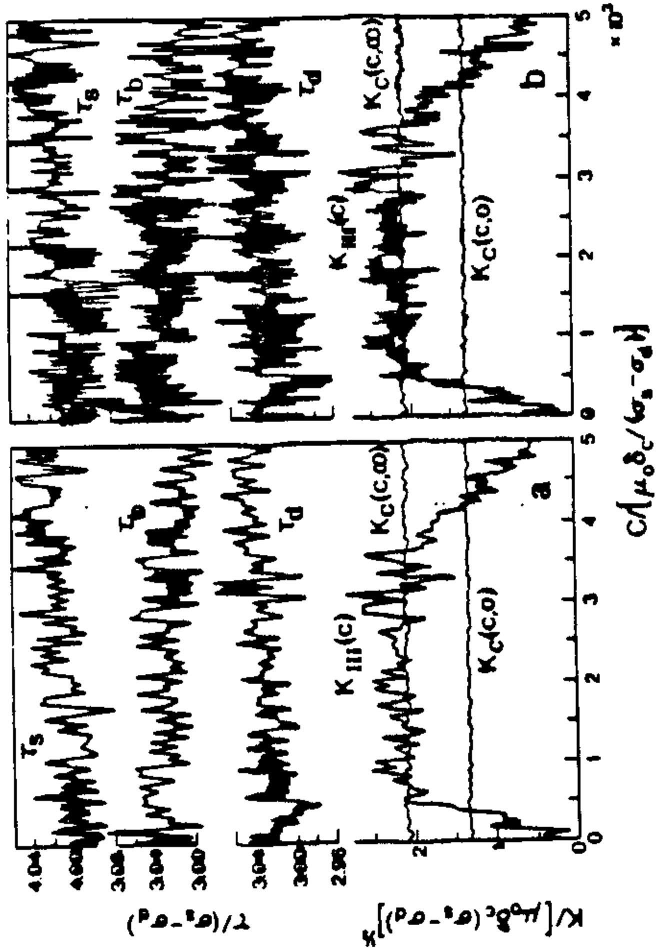
a
b
c
$\tau/(\sigma_s-\sigma_d)$
τ_b
τ_d
3.04
3.00
2.96
$K/[\mu_o\delta_c(\tau_s-\tau_d)]^{1/2}$
K_{III}
$K_c(c,\infty)$
$K_c(c,o)$
4
2
0
$t/(\eta/\mu_2)$
$\times 10^2$
6
4
2
0
0
1
2
3
4
5
$\times 10^3$
$C/[\mu_o\delta_c/(\sigma_s-\sigma_d)]$



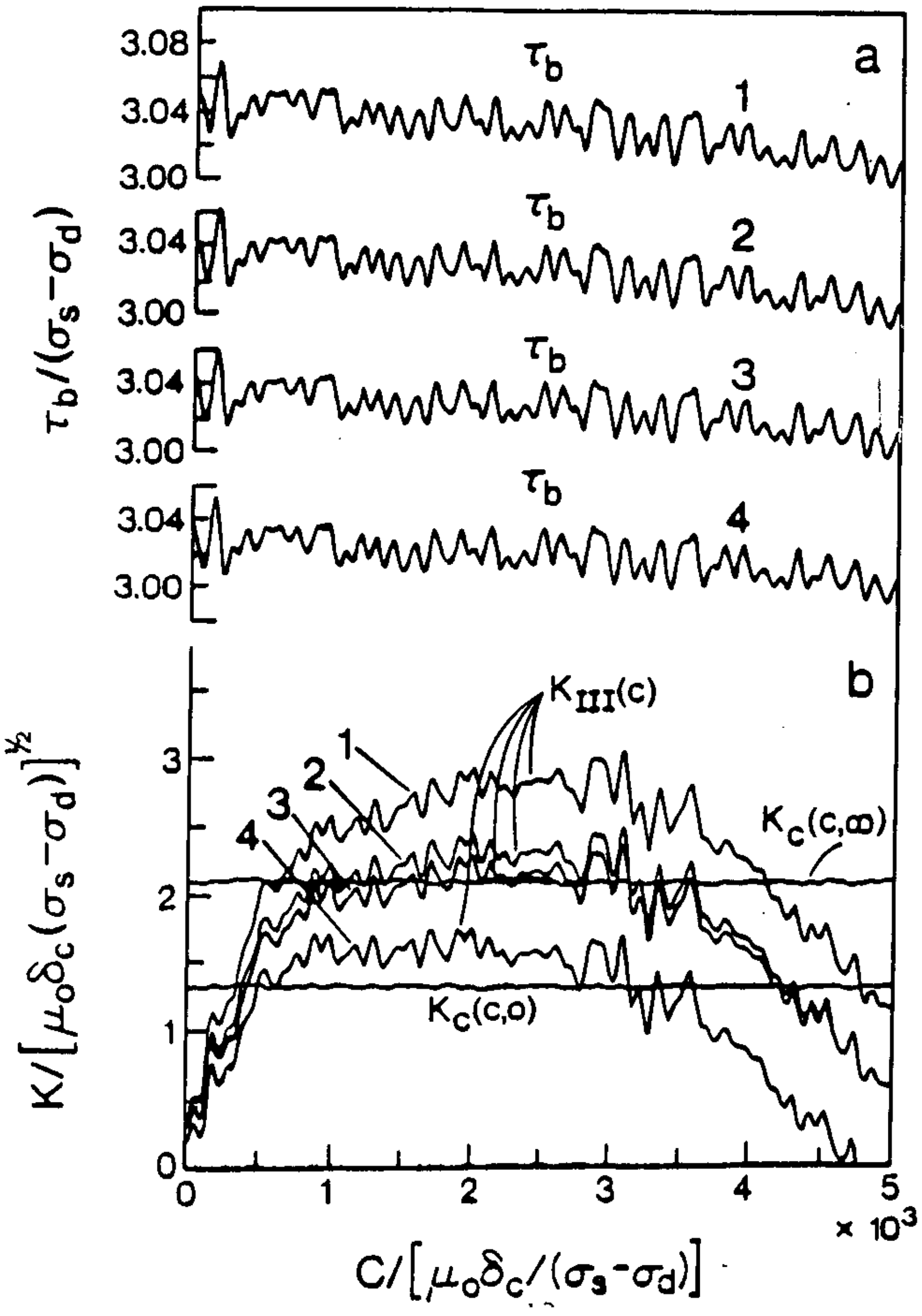
a
b
c
$\tau/(\sigma_s-\sigma_d)$
3.40
3.20
3.00
τ_s
τ_b
τ_d
$K/[\mu_o\delta_c(\sigma_s-\sigma_d)]$
$K_c(c,\infty)$
$K_{III}(c)$
$K_c(c,o)$
4
2
0
$t/(\eta/\mu_2)$
$\times 10^2$
6
4
2
0
0
.5
1.0
1.5
2.0
2.5
$\times 10^3$
$C/[\mu_o\delta_c/(\sigma_s-\sigma_d)]$


τ_s
τ_b
τ_d
$\tau/(\sigma_s-\sigma_d)$
4.04
4.00
3.08
3.04
3.00
3.04
3.00
2.96
$K/[\mu_o\delta_c(\sigma_s-\sigma_d)]$
$K_{III}(c)$
$K_c(c,\infty)$
$K_c(c,o)$
a
b
0 1 2 3 4 5
$\times 10^3$
$C/[\mu_o\delta_c/(\sigma_s-\sigma_d)]$

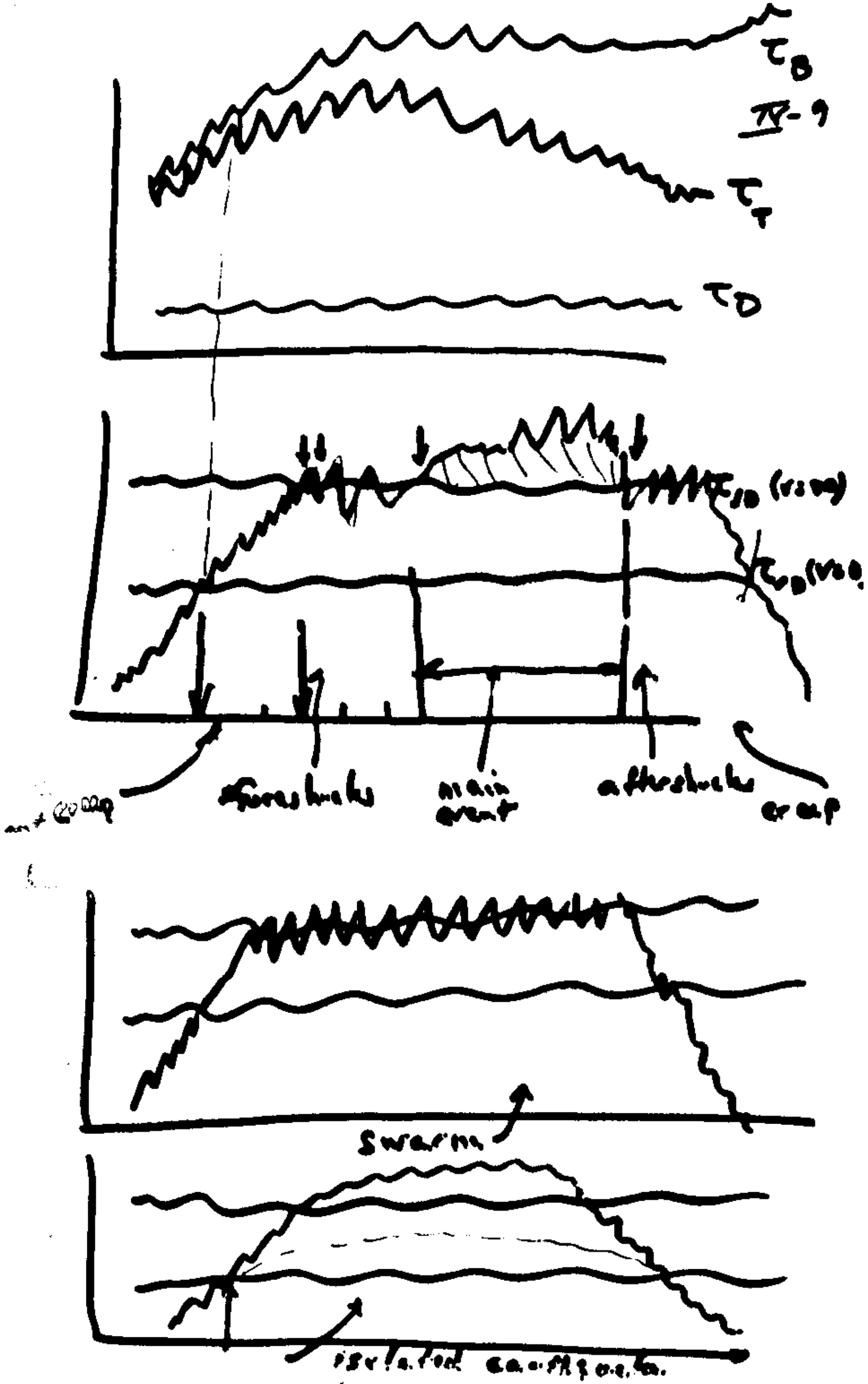

τ_s
τ_b
τ_d
$\tau/(\sigma_s-\sigma_d)$
4.04
4.00
3.08
3.04
3.00
3.04
3.00
2.96
$K/[\mu_o\delta_c(\sigma_s-\sigma_d)]^{1/2}$
$K_{III}(c)$
$K_c(c,\infty)$
$K_c(c,o)$
a
b
0 1 2 3 4 5
$\times 10^3$
$C/[\mu_o\delta_c/(\sigma_s-\sigma_d)]$



τ_s
τ_b
τ_d
$K_{III}(c)$
$K_c(c,\infty)$
$K_c(c,0)$
a
b
$\tau/(\sigma_s-\sigma_d)$
$K/[\mu_0\delta_c(\sigma_s-\sigma_d)]^{1/2}$
$C/[\mu_0\delta_c/(\sigma_s-\sigma_d)]$
$\times 10^3$



a
τ_b 1
τ_b 2
τ_b 3
τ_b 4
3.08
3.04
3.00
$\tau_b/(\sigma_s-\sigma_d)$
b
$K_{III}(c)$
$K_c(c,\infty)$
$K_c(c,0)$
1
2
3
4
$K/[\mu_0\delta_c(\sigma_s-\sigma_d)]^{1/2}$
0
1
2
3
4
5
$\times 10^3$
$C/[\mu_0\delta_c/(\sigma_s-\sigma_d)]$

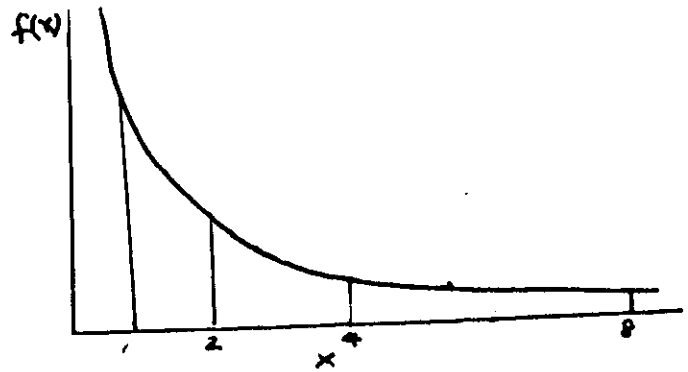


FRACTALS:

For our purposes, a *fractal* is a distribution that has a power law behavior

$$f(x)\,dx = x^{-\gamma}\,dx$$

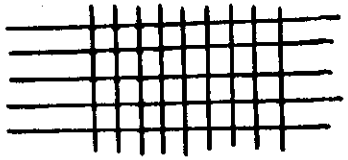
The distribution should be *homogeneous* i.e. the self-similarity implied by $x^{-\gamma}$ is valid "everywhere" in space.



The number of objects between 1 and 2
is the same as the " " " " 2 and 4
is " " " " " " " 4 and 8
etc.

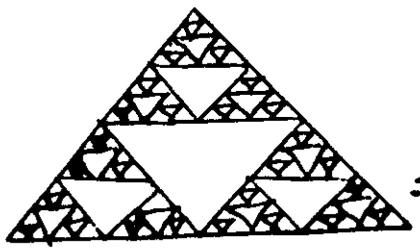
(There is no absolute unit of scale)

Diffusion on Lattices



S. Chandrasekhar (Revs. Mod. Physics 1943) showed that a random walk on a square homogeneous lattice has the ordinary linear diffusion equation as the asymptote,

$$K \nabla^2 \psi = \frac{\partial \psi}{\partial t}$$

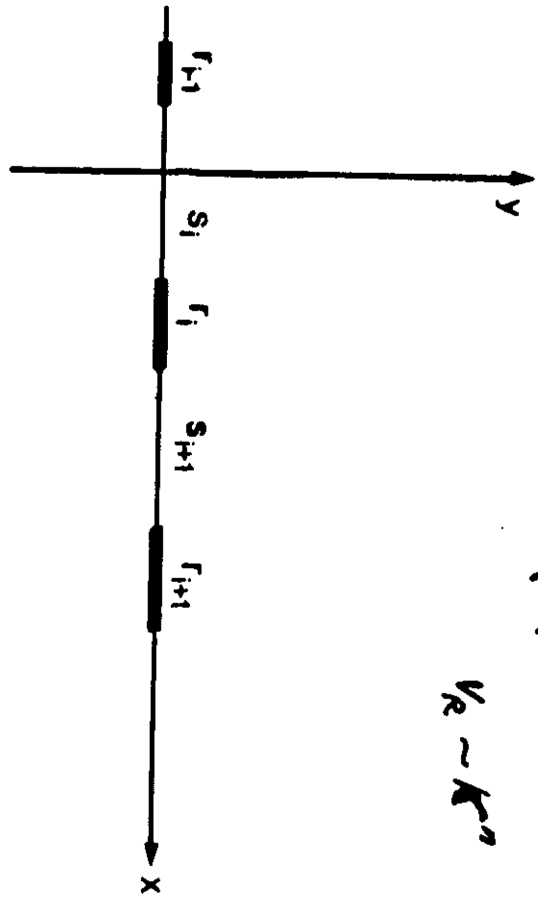


Sierpinski Carpet

Diffusion (random walk) on a fractal lattice leads to a diffusion equation with a scale dependent diffusion coefficient

$$\nabla \cdot K \nabla \psi = \frac{\partial \psi}{\partial t} \qquad K = K(\lambda)$$

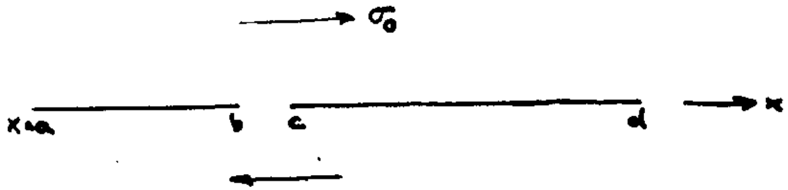
Refs: Gefen, Aharoni + Alexander Phys. Rev Letts
Orbach + Alexander, Phys. Rev. Letts
Orbach, Nature



$$p(r)\,dr = \sim r^{-\alpha}\,dr$$

$$p(s)\,ds = \sim s^{-\alpha}\,ds$$

$$V_R \sim R^3$$



Moment

$$\frac{2M}{\sigma_0(1-2\nu)} = \left\{\sqrt{\frac{a-c}{b-d}}\,(b-c)(a+b-c-d)K(k) + (b-d)(3c-a-b-d)E(k)\right\}$$
$$+ \frac{\pi}{2}\left\{(a-c+b-d)^2 - 4(a-c)(b-d)\frac{E(k)}{K(k)}\right\}(1-\Lambda_0(\theta,k))$$

$$\frac{\pi}{2}\Lambda_0(\theta,k) = E(k)F(\theta,k') + K(k)E(\theta,k') - K(k)F(\theta,k')$$

$$k'^2 = 1-k^2, \quad k'\sin\theta = \frac{a-d}{b-d}$$

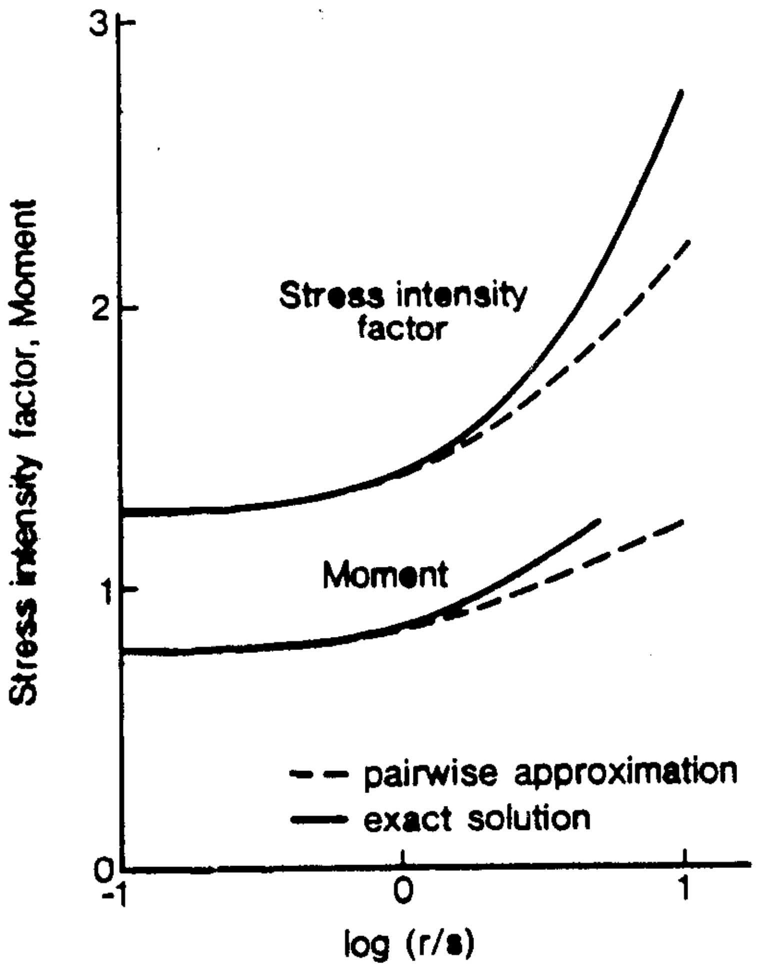
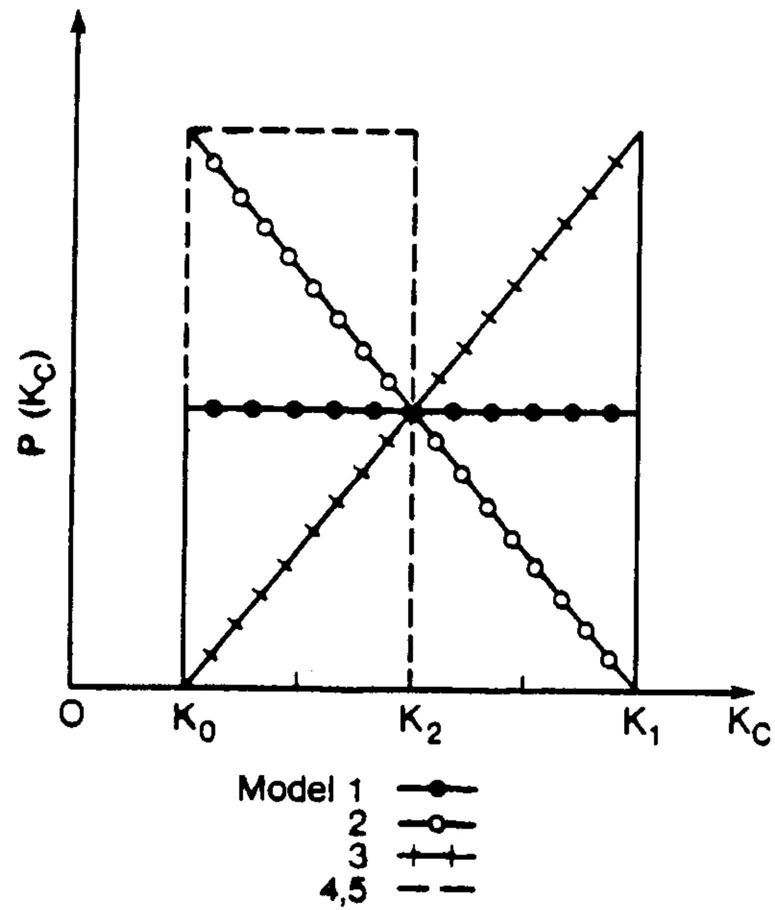


Figure 2


P (K_C)
O
K_0
K_2
K_1
K_C
Model 1
2
3
4,5

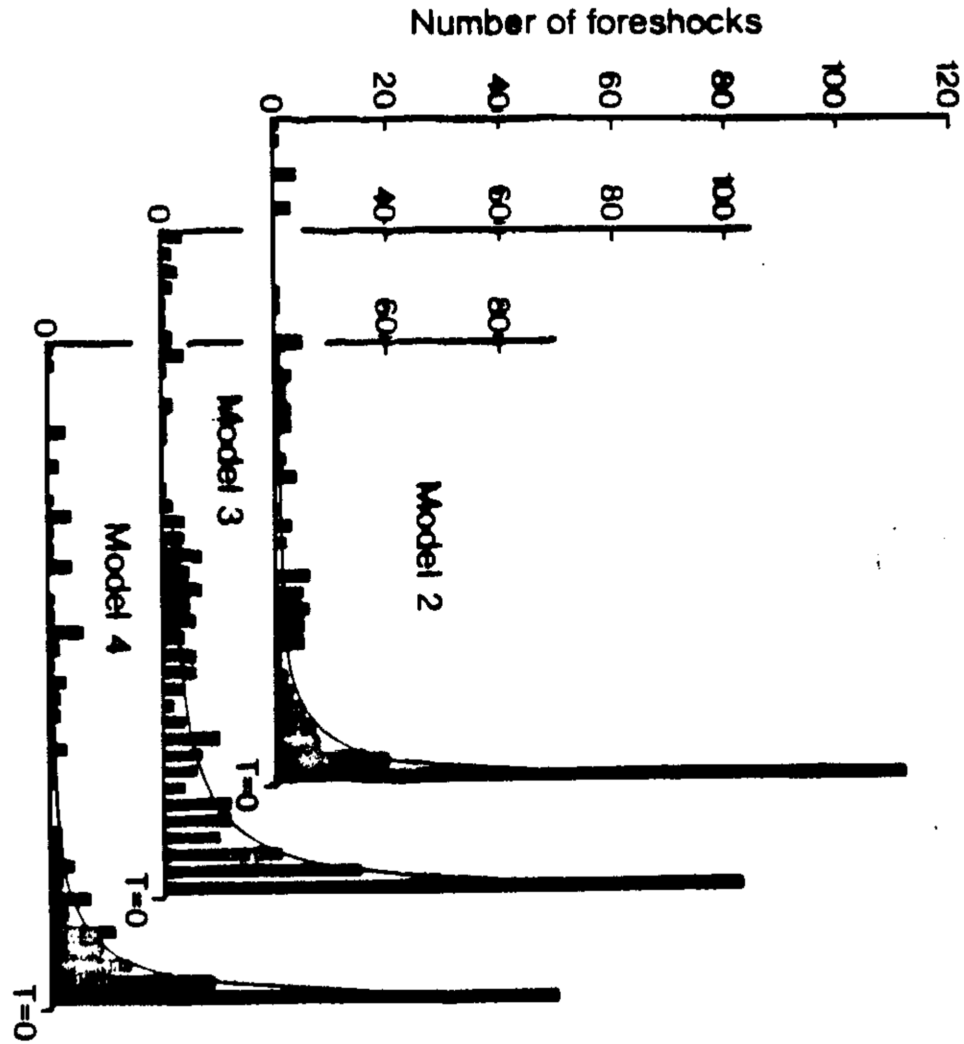
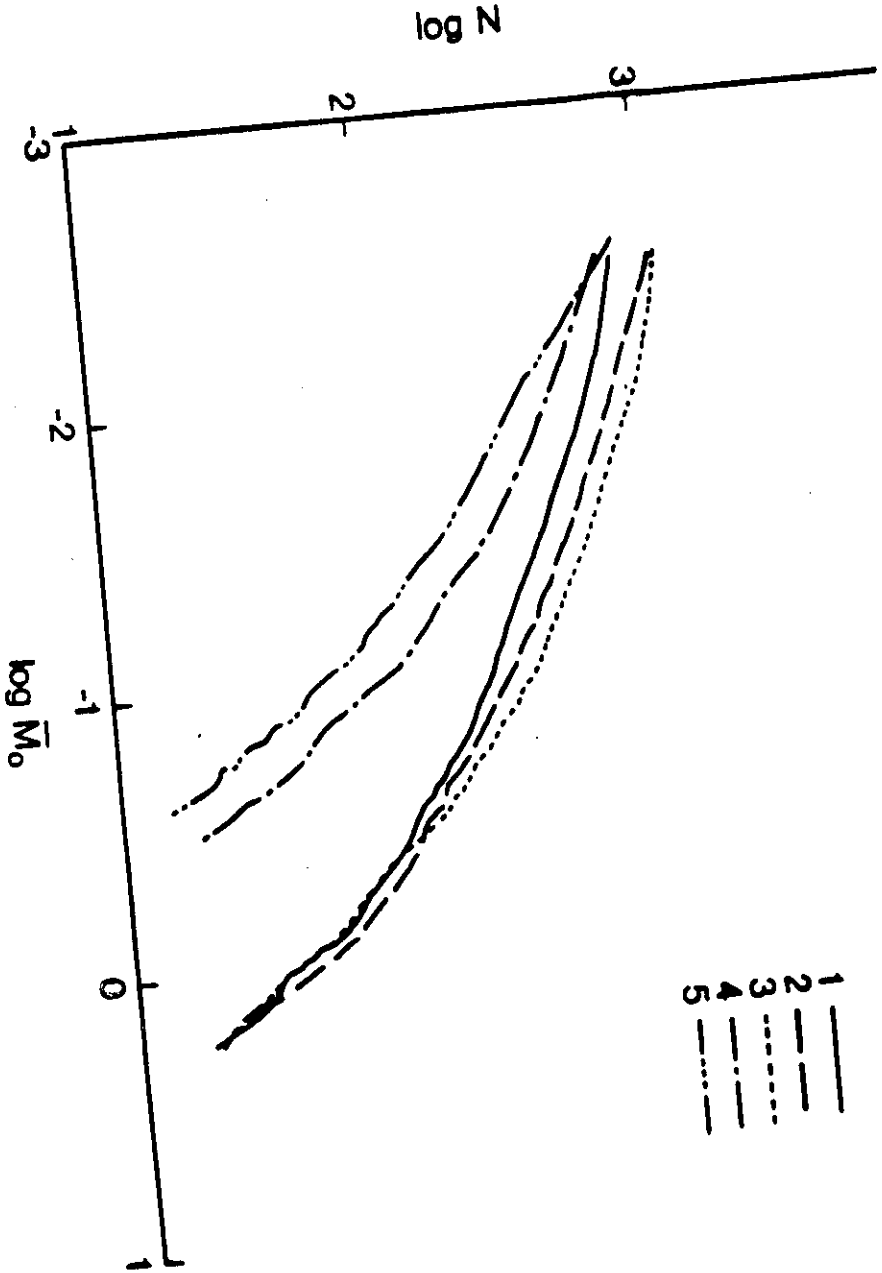

Number of foreshocks
0
20
40
60
80
100
120
40
60
80
100
60
80
0
0
Model 2
Model 3
Model 4
T=0
T=0
T=0

Figure 3


log N
2
3
-3
-2
-1
0
1
log $\bar{M}_o$
1
2
3
4
5

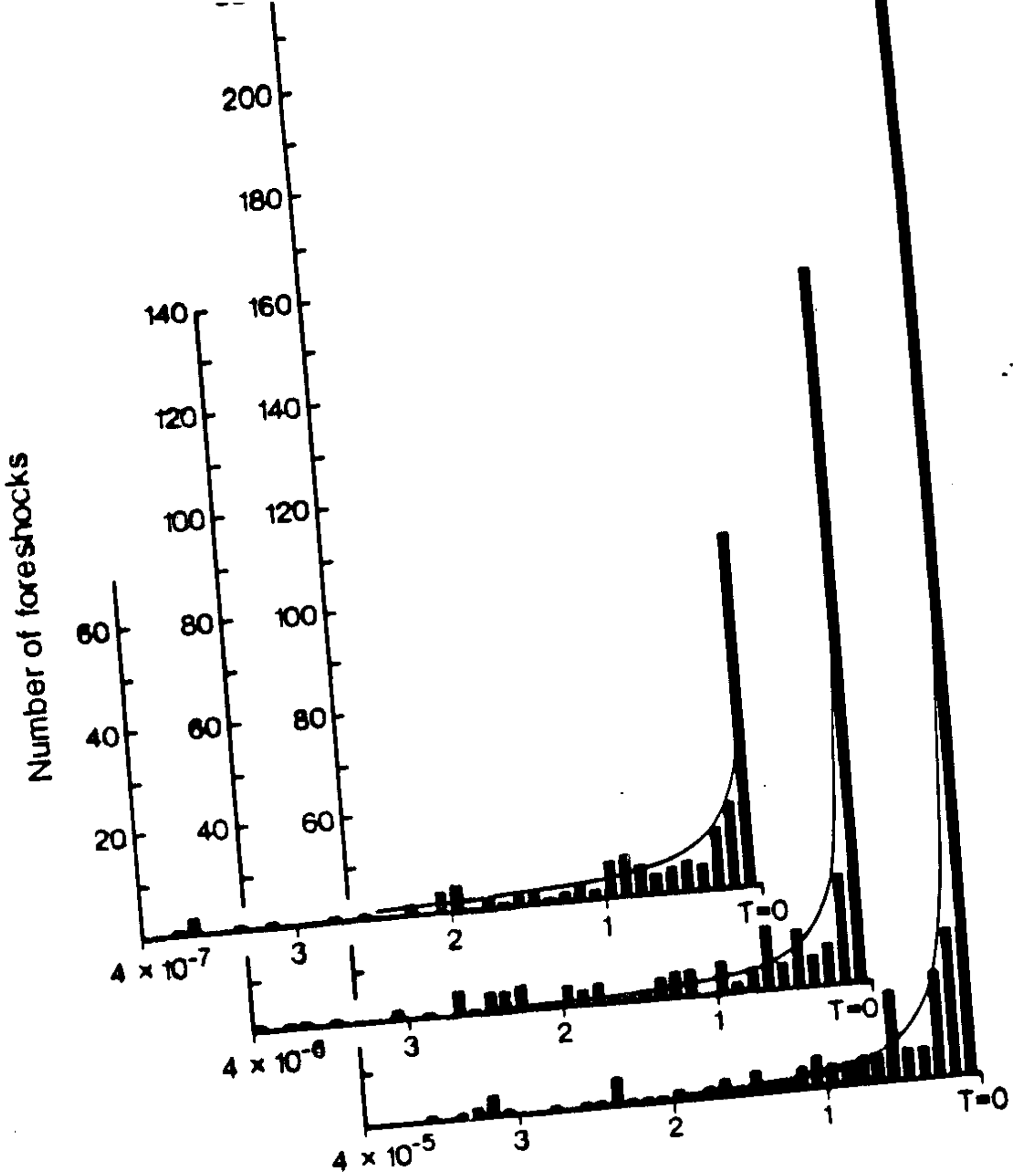
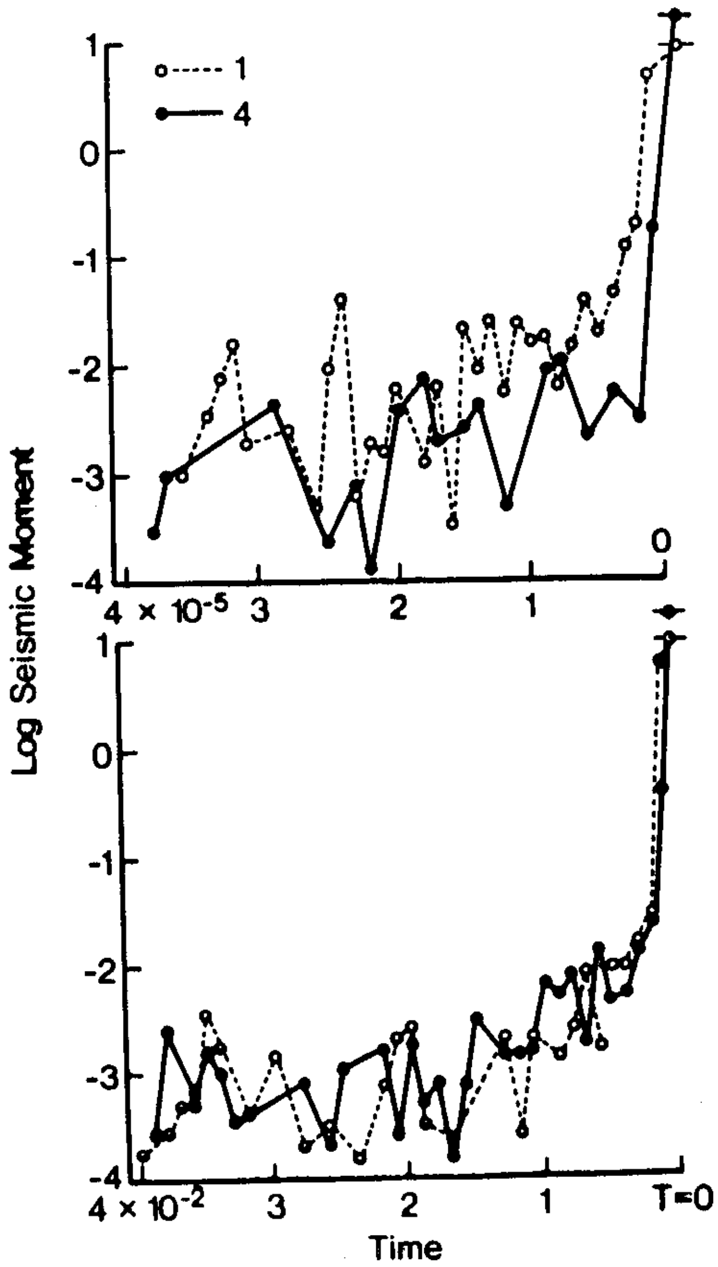
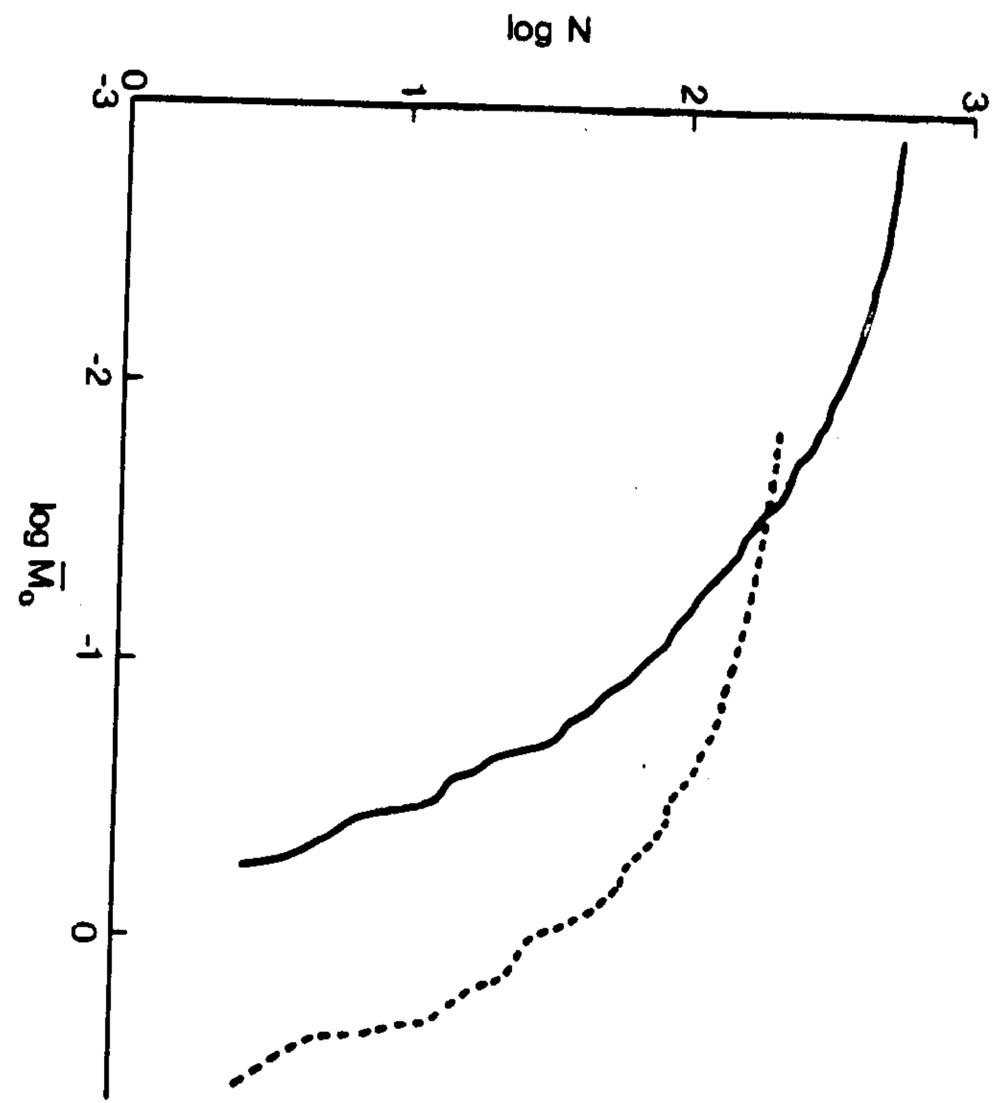

Number of foreshocks
200
180
160
140
120
100
80
60
40
20
T=0
4 × 10^{-7}
4 × 10^{-6}
4 × 10^{-5}
3
2
1

Figure 6a

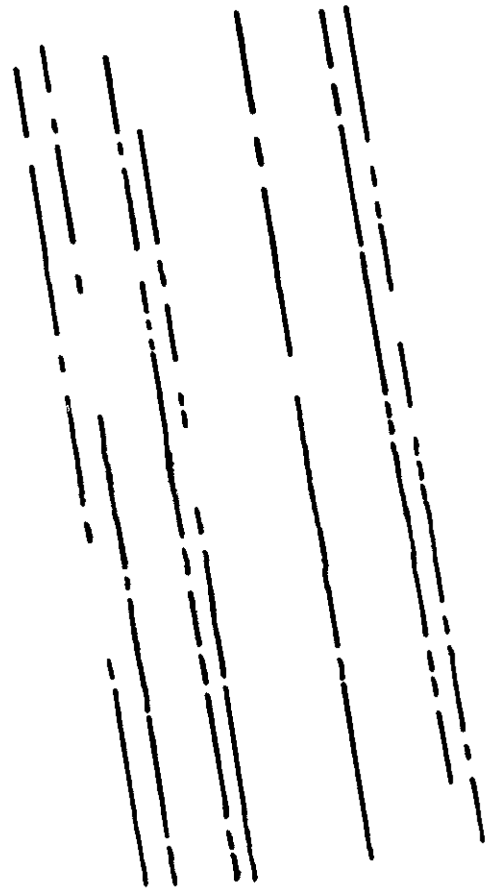


1
4
Log Seismic Moment
1
0
-1
-2
-3
-4
4 × 10⁻⁵ 3
2
1
0
4 × 10⁻² 3
T=0
Time

Figure 8a



log N
0
1
2
3
-3
-2
-1
0
log $\bar{M}_o$



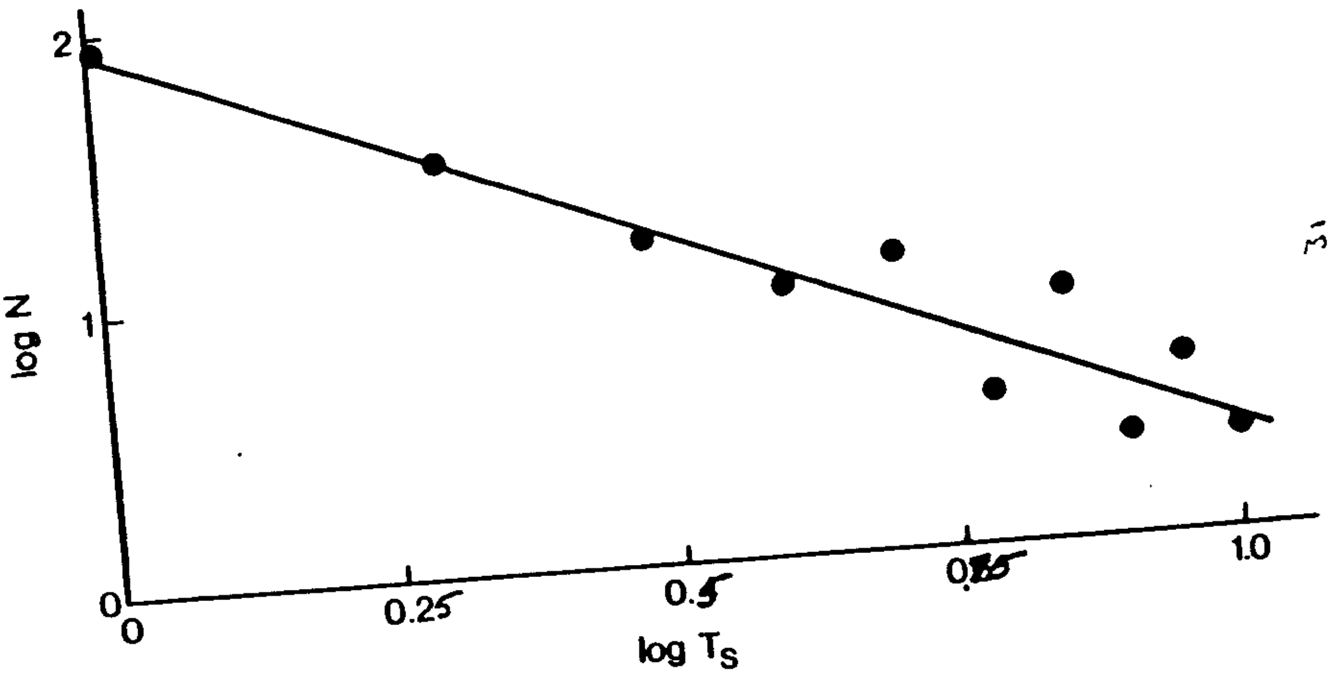
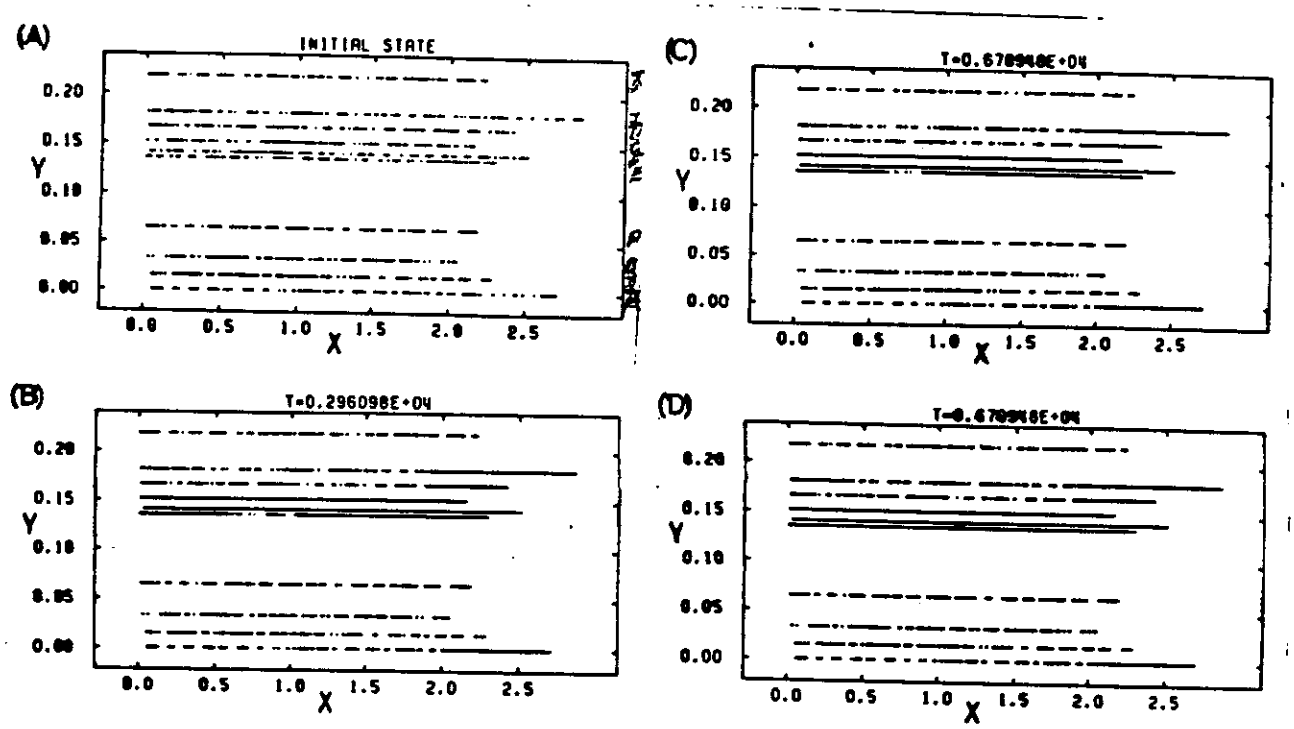
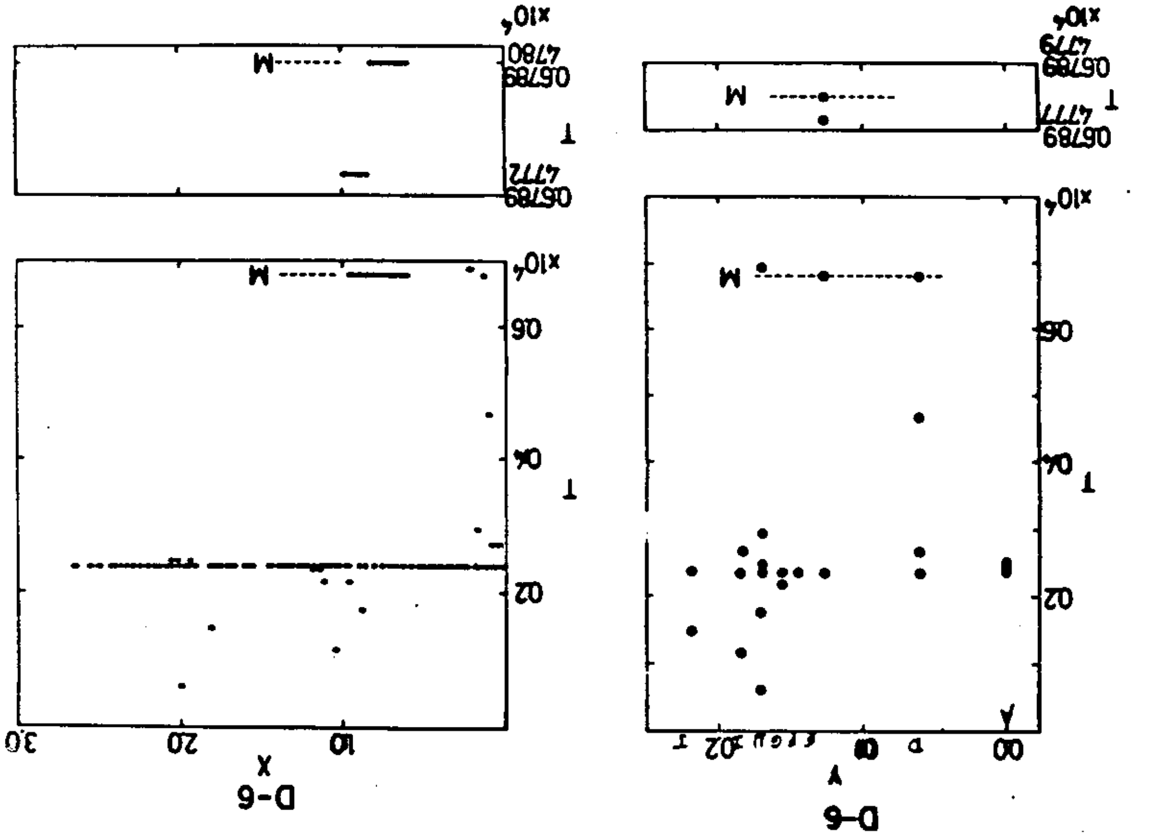
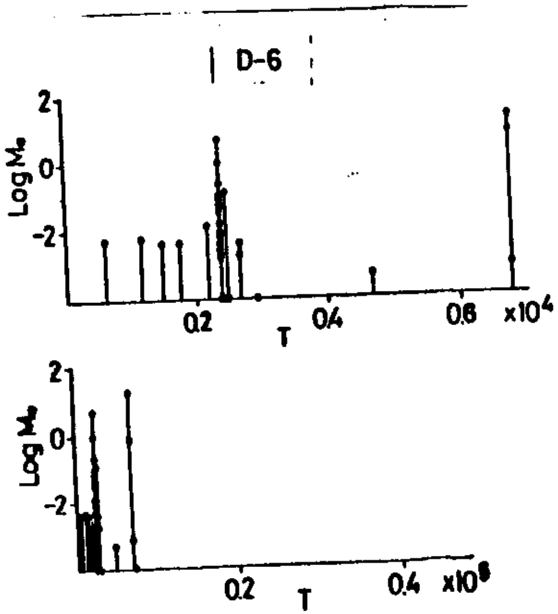


Figure 7

D-6


(A)
INITIAL STATE
(B)
T=0.296098E+04
(C)
T=0.670940E+04
(D)
T=0.670940E+04
Y
X


D-6
X
D-6
Y
T
M
x10⁴



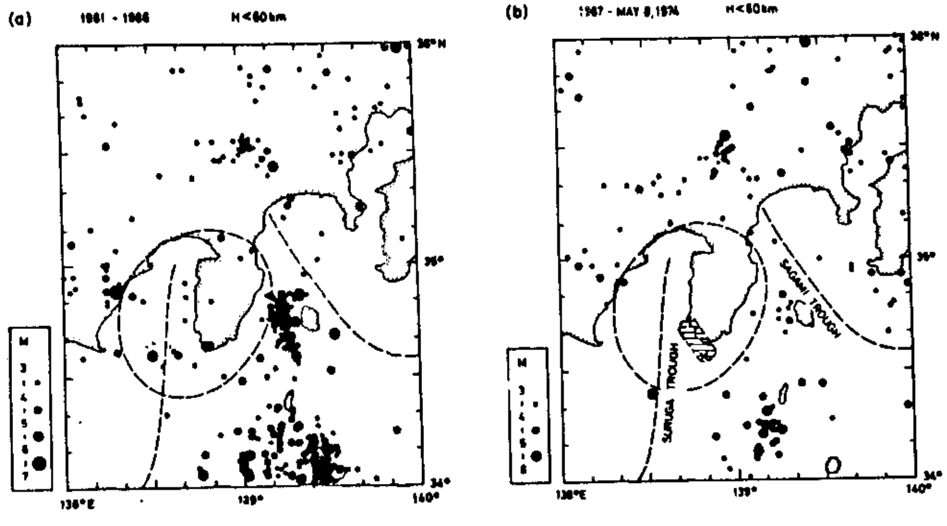


Figure 3

Seismicity in the Izu Peninsula and the adjacent regions for the periods: (a) 1961-1966, and (b) 1967-8 May 1974. Cross mark and shaded zone indicate the main shock and its aftershock zone after JMA, respectively. Large ellipse outlines aseismic area during the period (b).

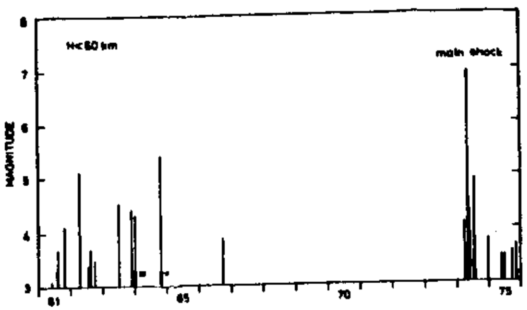


Figure 4

Time sequence of shallow earthquakes that took place in the elliptical area shown in Fig. 3. Those shocks of which magnitude is not reported are indicated by cross marks.

Ohtake:
PAGEOPH 114, 1083, 1976

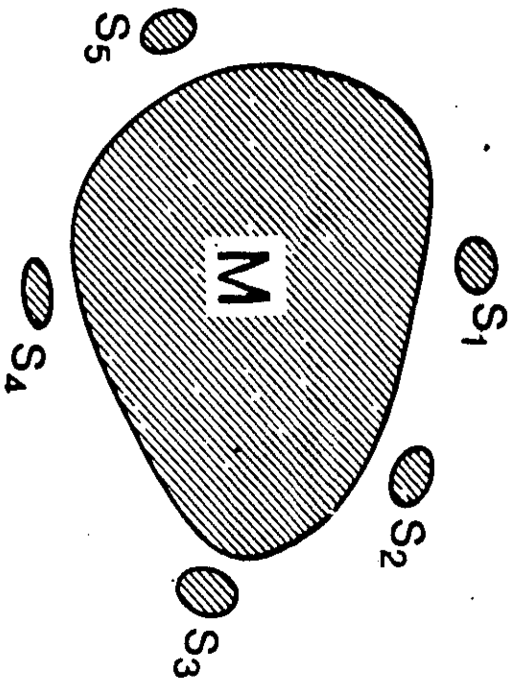
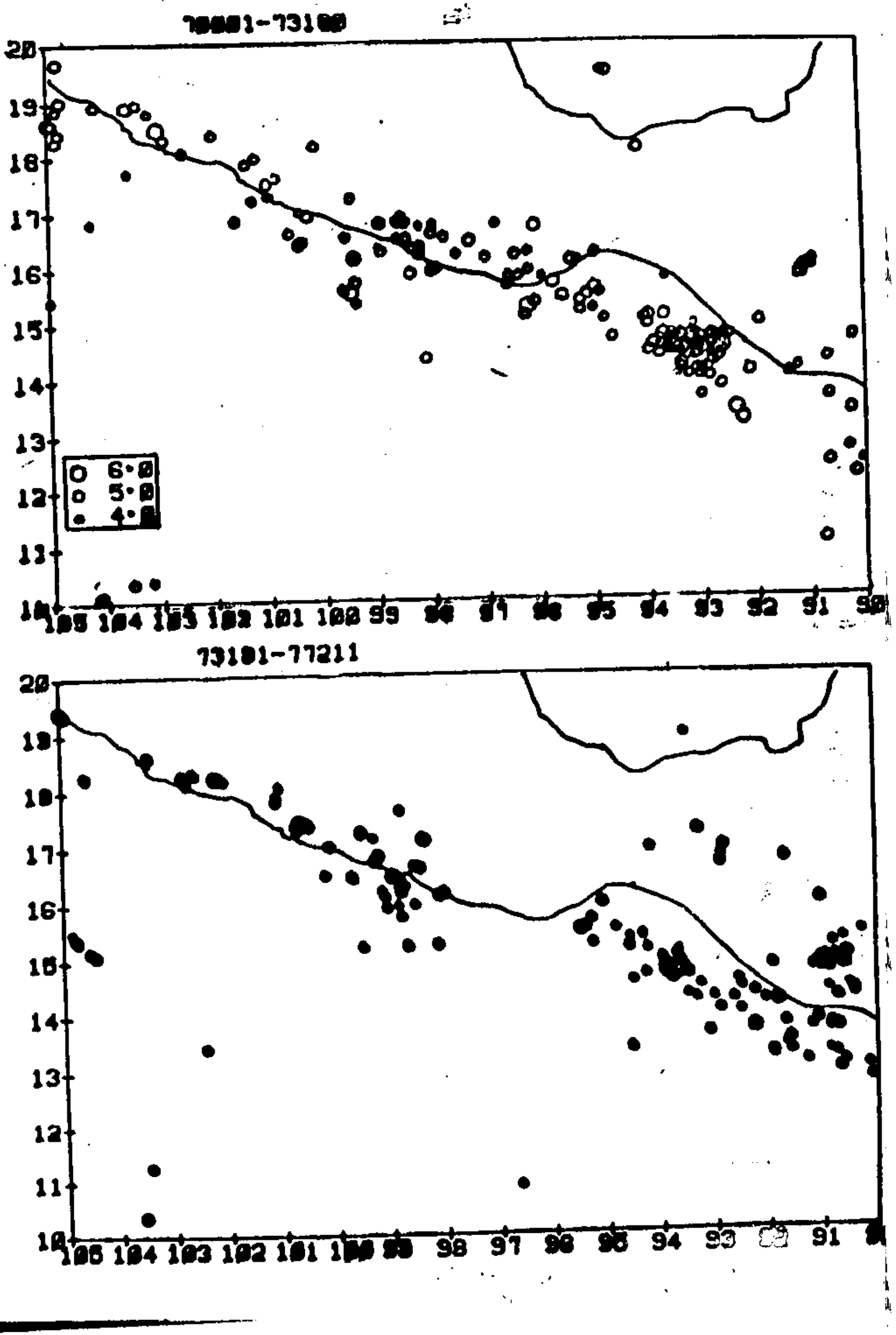
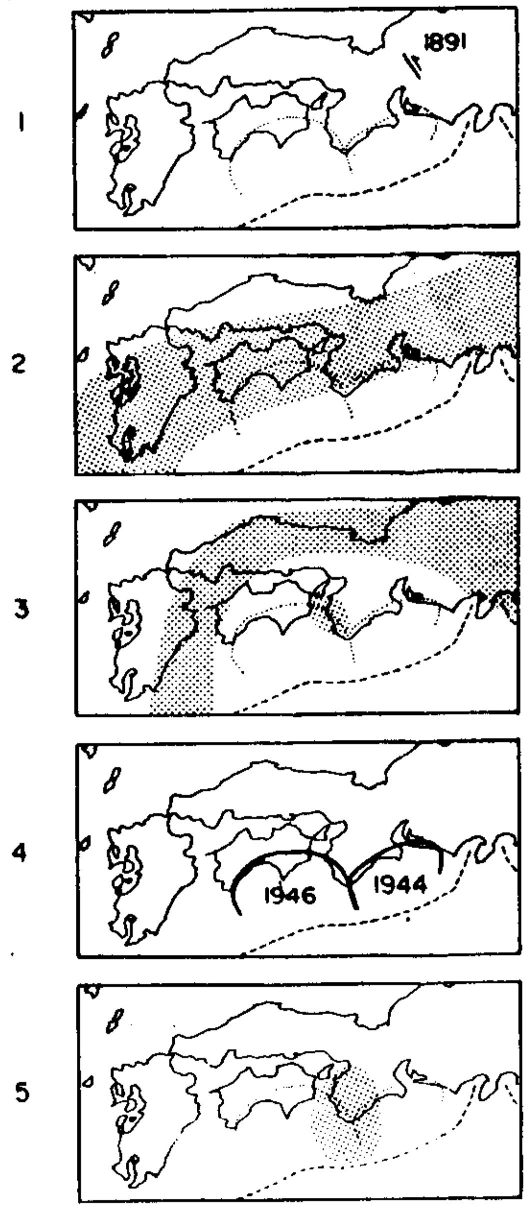
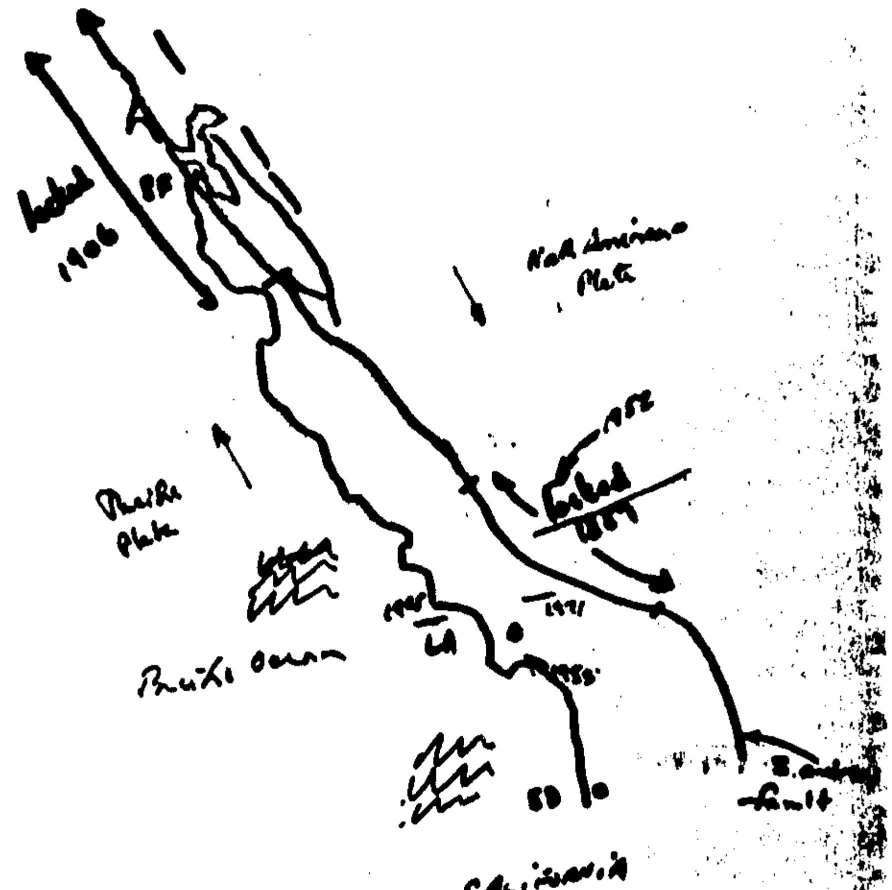


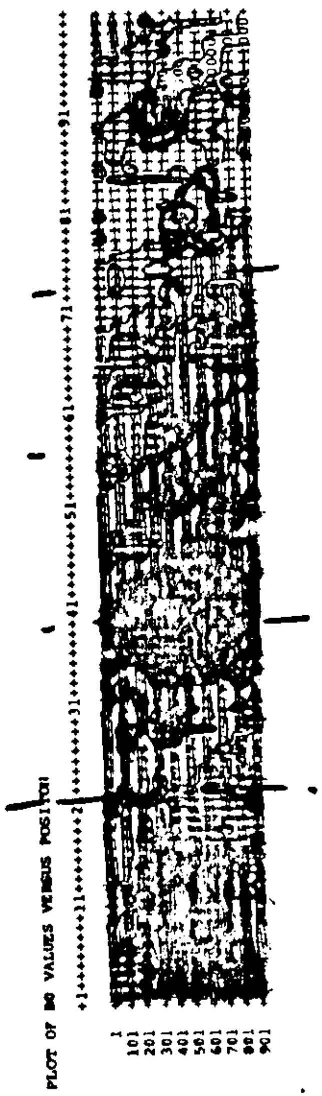
Fig. 2





Consider the practical anomaly of the San Andreas Fault of California, the two great earthquakes of 1906 and 1857 occurred on segments that have virtually no seismicity today (especially the southern break).



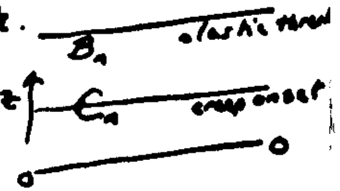


Quasistatic theory
Scalar modeling
(upper surface free)

rescaling of simulating studies

cellular automata $\overset{?}{\Longleftrightarrow}$ percolation

1-D Let z_n be stress at n^{th} site.



If $z_n \geq B_n$, $z_n \to 0 + R_n(n)$
$z_{n\pm1} \to z_{n\pm1} + P$

If $z_{n\pm1} \geq B_{n\pm1}$, $z_{n\pm2} \to z_{n\pm2} + P$
etc

if $B_n > z_n > C_n$, $z_n \to z_n + R$ $R > 1$

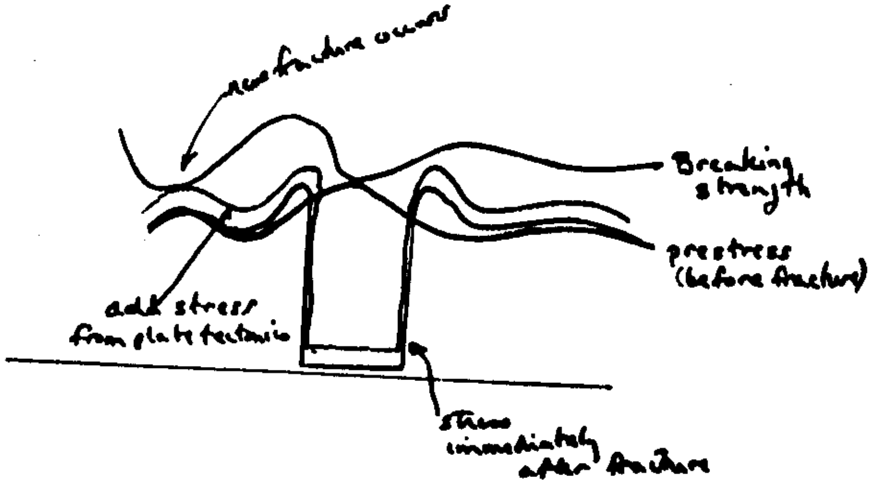
if $z_n < C_n$ $z_n \to z_n + 1$

typically, let B_n, C_n be fractals (Ran(N) ≥ 0).

Nearest-neighbor, 1-D structures cannot simulate seismicity adequately.

(1-D lattices in solid-state physics cannot develop phase transformations).

WHY?



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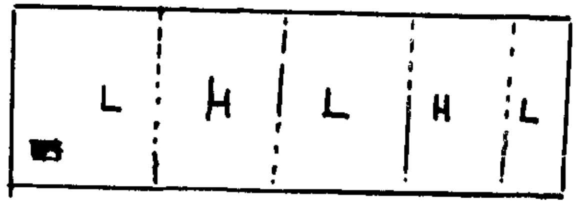
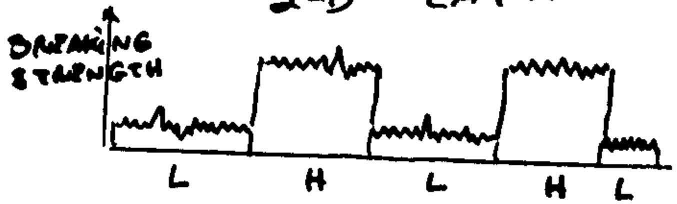


2-D LATTICE



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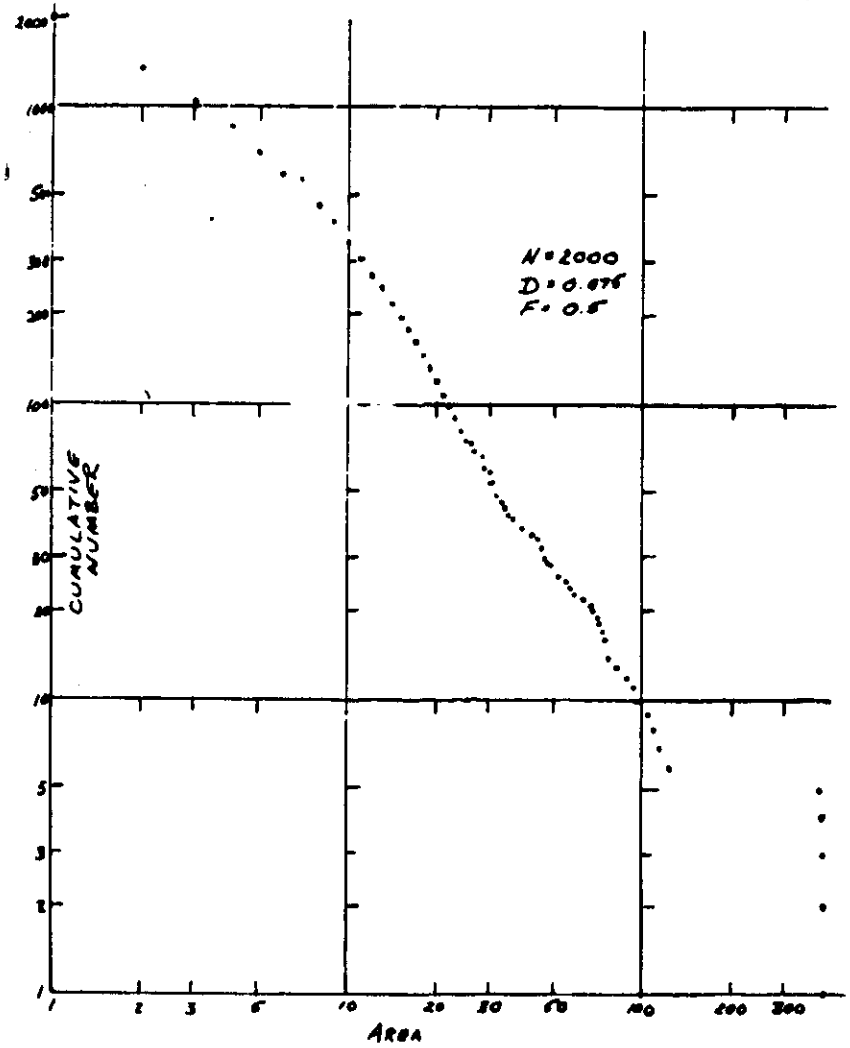
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D = 0.075
F = 0.5
CUMULATIVE NUMBER
AREA