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 - TELEPHONES: 224281/2/3/4/5-6
CABLE: CENTRATOM - TELEX 460392-I

SMR/107 - 19

WORKSHOP ON PATTERN RECOGNITION AND ANALYSIS OF SEISMICITY

(5 - 16 December 1983)

STOCHASTIC MODELING

L. KNOPOFF

L. Knopoff

STOCHASTIC MODELING:

Physical Model of Earthquake Process with random elements.

more physics

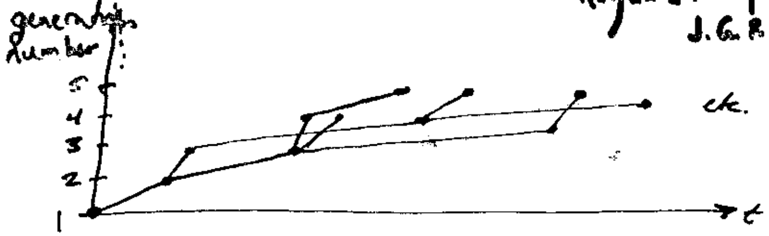
1. Branching Process
2. Kolmogorov/Feller Model with continuous states.
3. Two-dimensional Friction grid models.

To undisciplined statistics we try to add a little physics.
This makes statistical analysis difficult
↓
computers (Monte Carlo)

→ We need a model!

1. Critical Branching Process

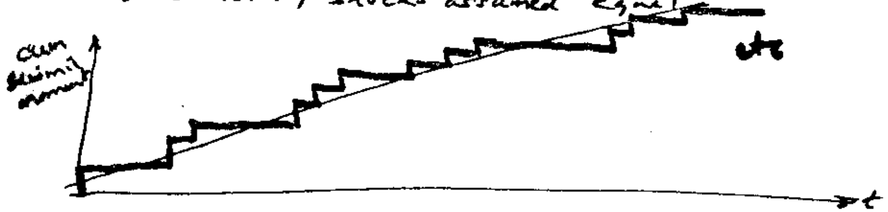
Ref. Kagan & Knopoff, J.G.R. 86 (1981) 2853.



Prob. that one event gives "birth" to another event in time interval dt is

$$\phi(t)dt = 0 \qquad 0 < t < t_0 \quad *$$
$$= (1-K)\theta t_0^{\theta} \frac{dt}{t^{1+\theta}} \qquad t > t_0.$$

All elementary shocks assumed equal



If $K=0$ then each event gives rise to one offspring (critical process) on the average in infinite time.
If $0<K<1$ the process is subcritical.

For critical process we can have many since total no. of shocks may be ∞.
For subcritical process, finite no. of shocks.

* Self-similarity!

If $\theta \sim 0.5$ (shallow eqs)
~ 0.8 (intermed. eqs.)

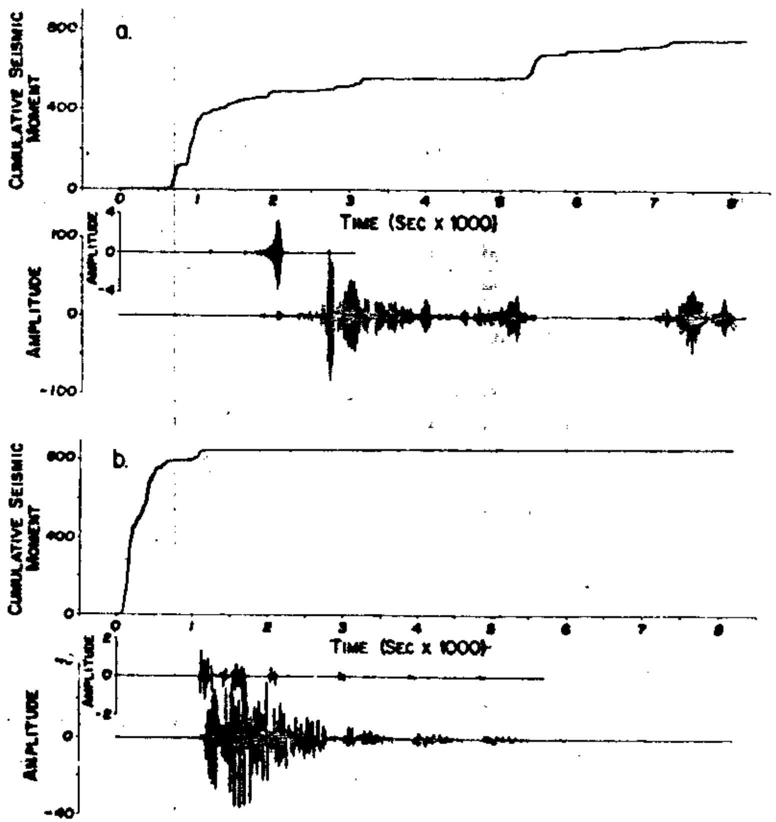
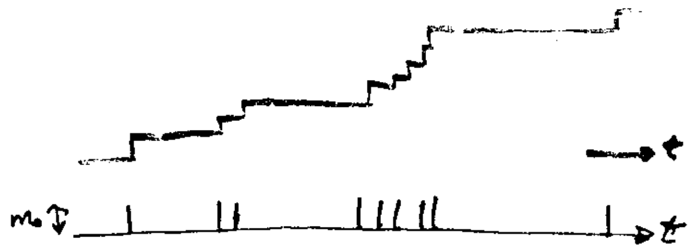


Fig. 3. Simulated source-time functions and seismograms for shallow (a) and intermediate (b) earthquake sources. The upper trace in each plot is a synthetic source-time function. The middle plot is a theoretical seismogram described in the text, and the lower trace is a convolution of the derivative of source-time function with the theoretical seismogram.



(I)

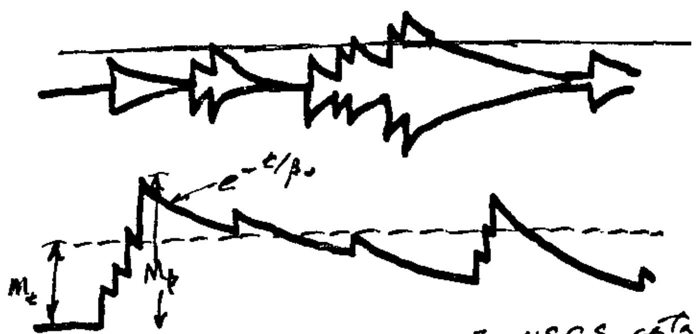
identify M_0 with threshold ~~magnitude~~ moment of detectability of network (i.e. threshold of homogeneity).

If $M_0 \sim 10^5$, $t_0 = 1$ sec (NOAA catalog)

$M_0 \sim 10^1$, $t_0 = 10^{-2}$ sec (USGS central California)

Now convolve (I) with Green's function for elastic medium

(Synthetic Seismogram)



For USGS catalog, we use

$\beta_0 \sim 400$ sec ($\Delta \simeq 2000$ km) WWSSN 15-100 LPZ seismograph

$M_t \approx 10^{4/2}$

Dimensionless Variables: β / t_0 → (decay const. of instrument) / (characteristic time of probability function)

M_0 / M_t → unit moment / threshold moment

K ($\sim 10^{-2}$)

Input parameters → (as above)

$\beta / t_0 \simeq 4 \times 10^4$ (M_{p} (max) 2.7 to 4.0)

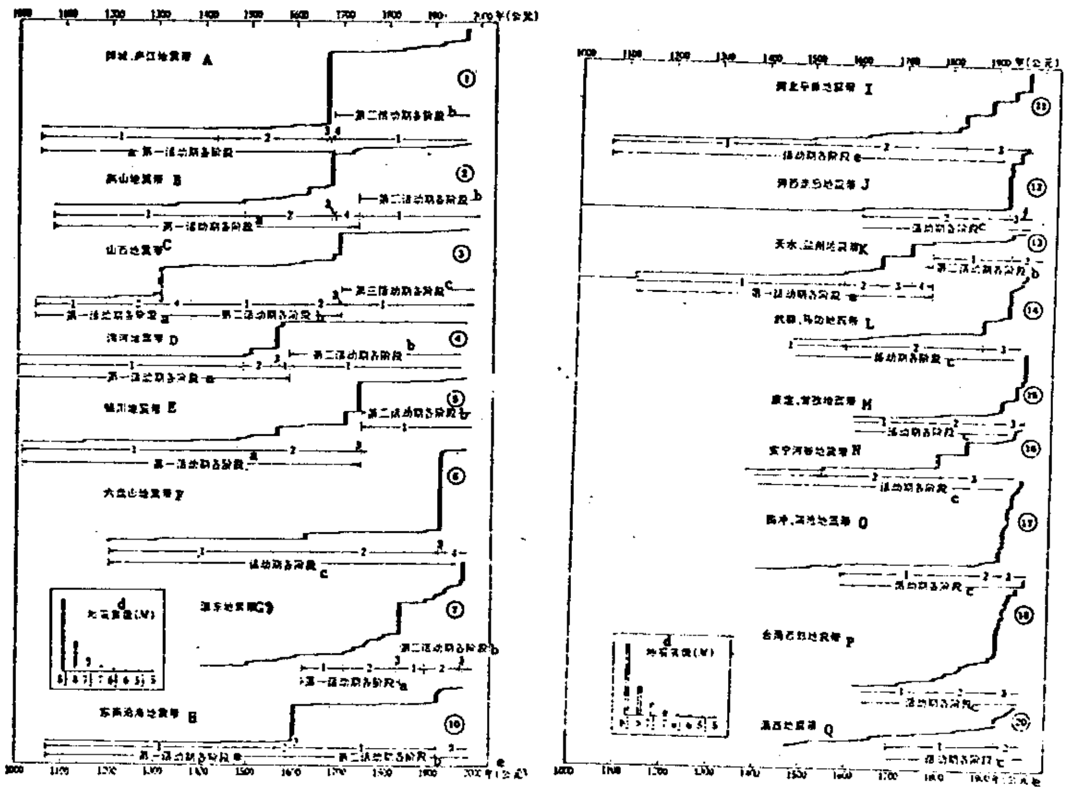
$M_0 / M_t \approx 3.$

$K \sim 10^{-2}$

Input assumption of pairwise power law probability ($1/t$ rule)

We get
1). magnitude - frequency law
2). Omori (1894) law of aftershocks
3). Magnitude - crack length law
4. Earthquakes non-stationary process
5. Earthquakes may occur in superclusters whose length exceed time span of most catalogs.*

* Chinese, Middle East seismicity (catalogs)



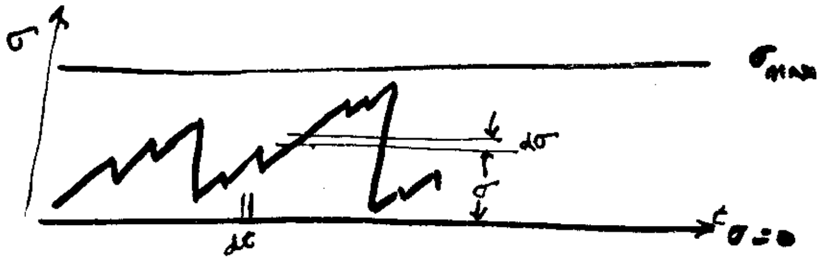
strain release curves for the seismic zones of China.

a. Stages of the first seismic period.
b. Stages of the second seismic period.
c. Stages of the third seismic period.
d. Magnitude.
e. Year (AD).

A. Tancheng-Lujiang seismic zone.
B. Yanshan seismic zone.
C. Shansi seismic zone.
D. Weihe seismic zone.
E. Yinchan seismic zone.
F. Liupanshan seismic zone.
G. Eastern Yunnan seismic zone.
H. Southeast coast seismic zone.

I. Hopei plain seismic zone.
J. Hosi corridor seismic zone.
K. Tienshu-Lanzhou seismic zone.
L. Wudu-Mabian seismic zone.
M. Kangding-Ganzi seismic zone.
N. Anning valley seismic zone.
O. Tengcong-Langcong seismic zone.
P. Western Taiwan seismic zone.
Q. Western Yunnan seismic zone.

05



Assume no viscosity (or other anelasticity)

$P(\sigma,t)\,d\sigma$ is prob. that stress (strain) is between σ and $\sigma+d\sigma$

$\lambda(\sigma)\,dt$ " " " an eq. will occur in time int. between t & $t+dt$ if we are in the state σ.

$T(x,\sigma)\,d\sigma$ " " (cond)" if we are in state x & eq. occurs, then stress drops to interval σ & $\sigma+d\sigma$.

$$\lambda(\sigma)P(\sigma,t) + \alpha\frac{\partial P(\sigma,t)}{\partial\sigma} + \frac{\partial P(\sigma,t)}{\partial t} = \int_{\sigma}^{\sigma_{max}} P(x,t)\,\lambda(x)\,T(x,\sigma)\,dx$$

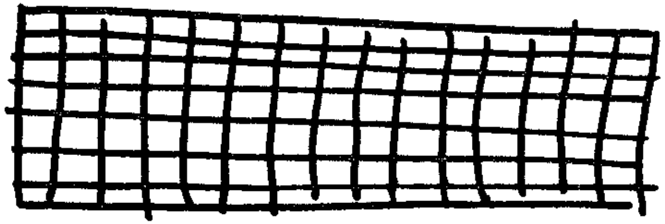
Normalization $\int_0^{x} T(x,\sigma)\,d\sigma = 1$

$$\int_{\sigma_0}^{\sigma_{max}} P(\sigma)\,d\sigma = 1$$

We find system is stable and stationary.

We expect introduction of time delays $\lambda(\sigma(t-\tau))$ will produce clustering of (aftershocks!)

Model of fracture:



1 at each point (asperity, barrier), we have a critical threshold of stress B (breaking strength) $B(x,y)$

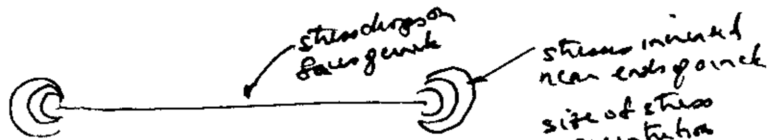
2. To each point we apply an external force $F(x,y)$

3. Between events, $F(x,y)$ increases linearly with time (plate tectonics).

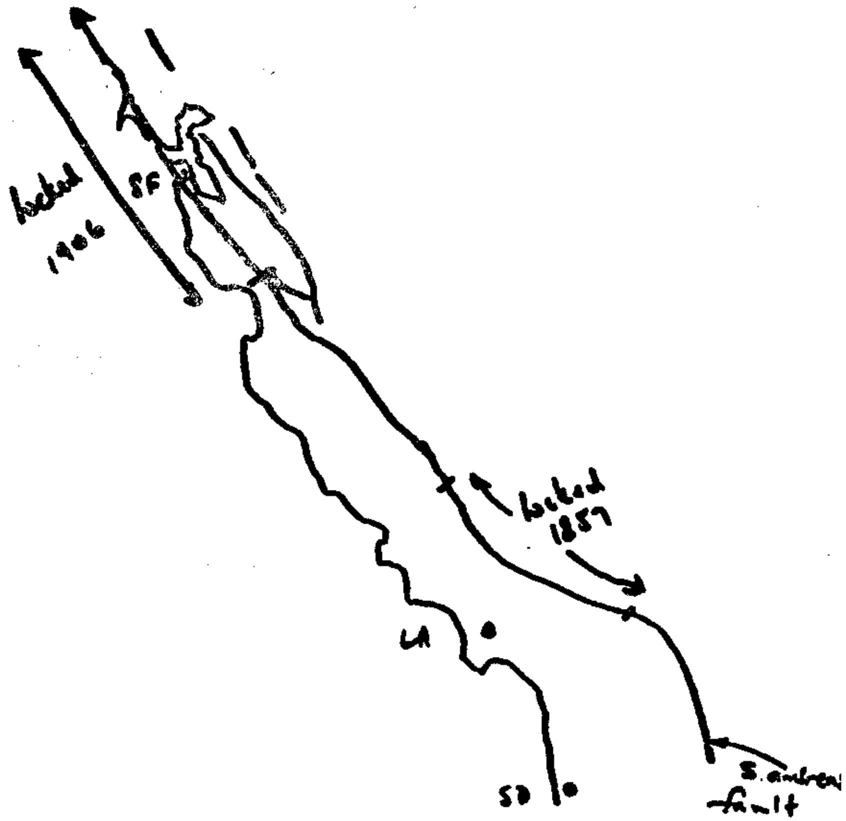
4. When fracture occurs crack grows quasistatically.

- crack initiates some time $F(x,y)$ after $B = F$ at some point
- Nearest neighbors searched to see if redistributed stress, added to local value of F exceeds local value of B
- etc.

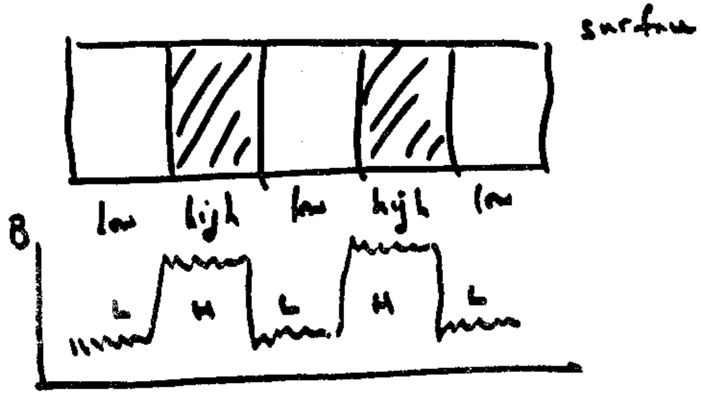
When crack reaches its maximum size, stress in entire plane has been redistributed.



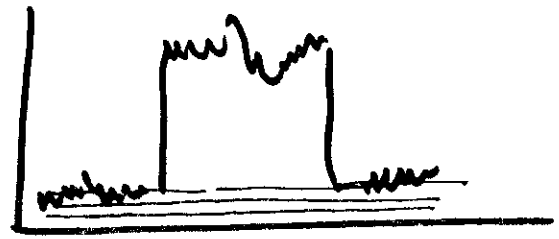
size of stress concentration depends on stress drop on faces of crack to size of crack



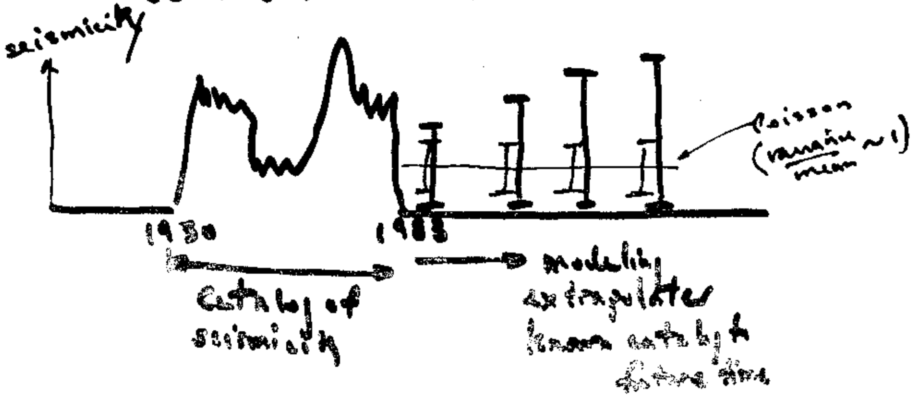
CALIFORNIA



1. Time delays necessary to simulate magnitude – frequency law.
2. For model above, 99.5% of all events occur in L regions with correct mag– freq. law.
3. no events in L break completely across an L zone.
4. 0.5% of all events occur at an L–H boundary and tear completely across an H zone.
5. there are no small events in H.



Seismic Risk Prediction



(if seismicity interactive (non-independent), then mean predictions are about the same as for Poisson model, but variances grow. In many of our models (branching process) variances may be more than two times as large)

References

Stochastic Modeling

Sawtooth Model (Kolmogorov (Feller)

1. L. Knopoff, Rev. Geophys. & Space Phys., 9 (1971) 175.

Branching Process

2. Y. Y. Kagan & L. Knopoff, J. Geophys. Research,

Chinese Seismicity

3. ~~[illegible]~~ Ma, ??, in *Chinese Geophysics* publ. by A.G.U.