EARTHQUAKES PREDICTION: HOW OT START

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"Of course, things are complicated….
But in the end every situation can be reduced to a simple question: Do we act or not? If yes, in what way?"
/E. Burdick/

The problem **of earthquake prediction consists of consecutive, stage-by-stage, narrowing down the time interval, area, and magnitude range where a strong earthquake has to be expected.**

Prediction stages *fuzzily divided*	***Characteristic duration of alarms, years***
Long-term	10^{1}
Intermediate-term	**1**
Short-term	$10^{-1} – 10^{-2}$
Immediate	10^{-3} **or less**

Such division is dictated both by:

- **multiscale nature of lithosphere dynamics, ripening of strong earthquakes included**

and

- **the needs of earthquake preparedness**

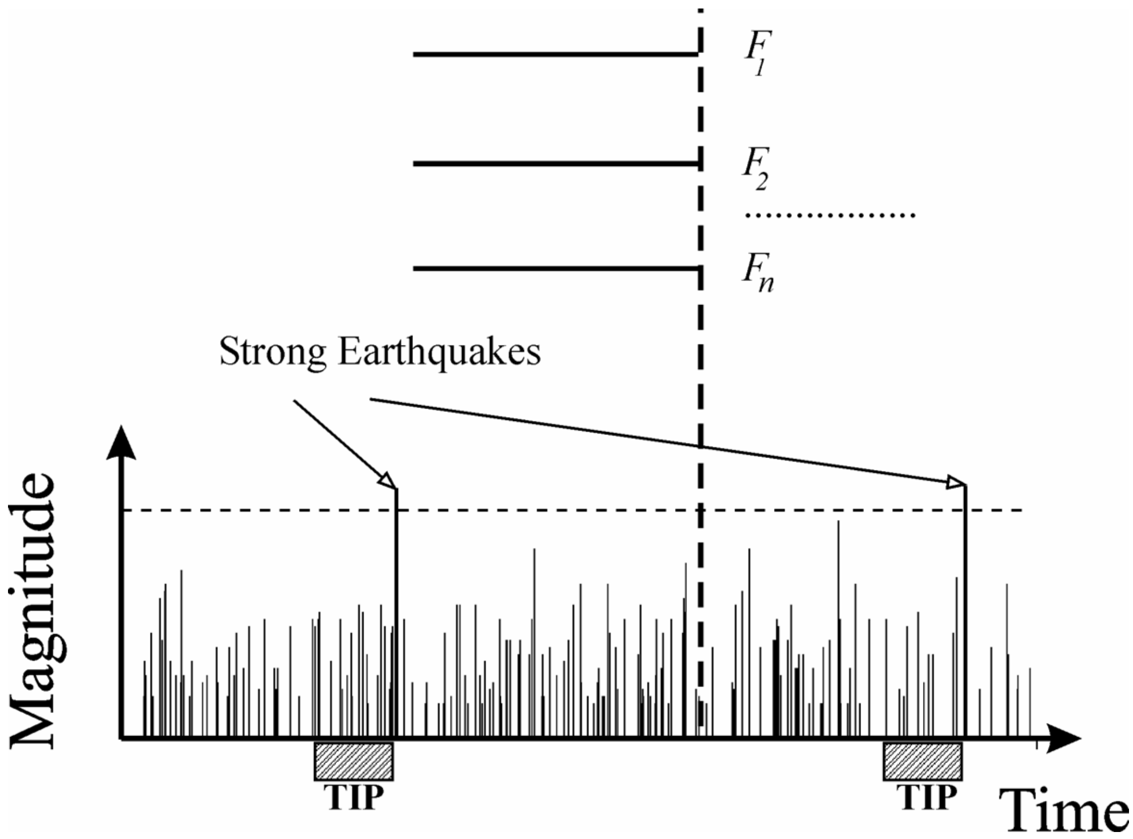
PREDICTION BY ANALYSIS OBSERVED TIME SERIES (e.g. of earthquake sequences)

(i) This sequence is robustly described **by the functionals $F_p(t)$, p=1,2, …, each depicting certain premonitory seismicity pattern P.**

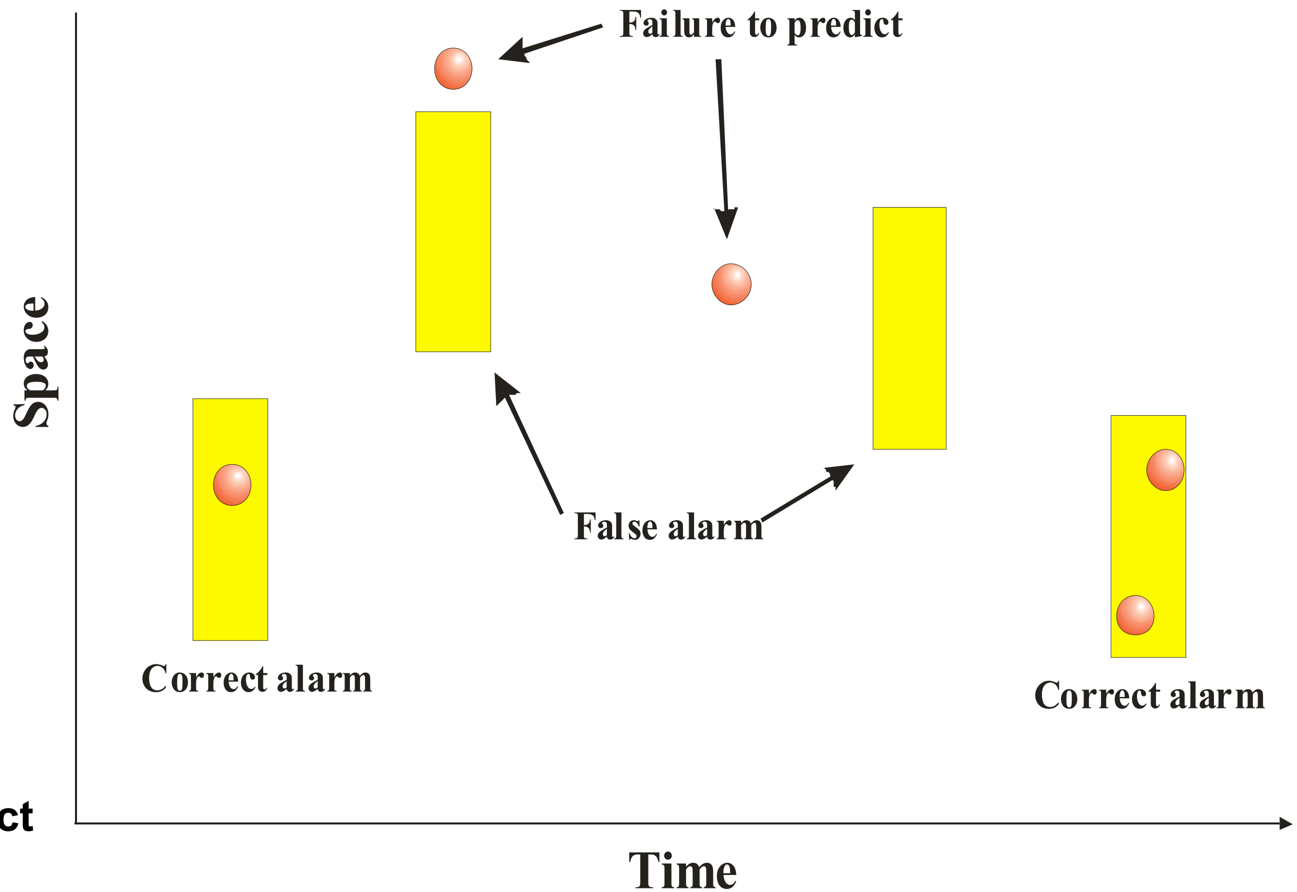
(ii) Emergence of a pattern P **is defined by condition $F_p(t) \geq C_p$. The threshold C_p is usually defined as a certain percentile of the functional F_p.**

(iii) An alarm is triggered **when a single pattern or certain combination of patterns emerges. That combination is determined by pattern recognition.**

An alarm lasts for a time interval τ.



POSSIBLE OUTCOMES OF PREDICTION



Probabilistic component of prediction is represented by probability gain and rates of false alarms and failures to predict

This is prediction of *extreme point events*, with predictor being a discrete sequence of alarms. This is different from Kolmogorov-Weiner prediction of continuous functions where predictor is also continuous.

PROBLEMS: CHOOSING FUNCTIONALS; STATISTICAL SIGNIFICANCE; and LINKING PREDICTION WITH DISASTERS PREPAREDNESS

WHERE ARE WE?

***Good news*: *earthquakes are predictable*: prediction algorithms based on earthquakes sequences (t, M, hypocenter) do provide statistically significant predictions. That is not trivial for extreme events ("low probability, large consequences")**

***Bad news: accuracy of predictions is limited*. Better validated algorithms indicate time intervals of years and areas 10L(m) in diameter where a target quake will occur (L is the size of its source).**

***Don't sell this short:* These algorithms enhanced our fundamental understanding of earthquakes. And on the applied side they allow the prevention of a considerable part of the damage, by undertaking temporary preparedness measures, like simulation alarms, out of turn enforcement of high risk objects, stocking vital supplies, etc. (Non-trivial prediction is useful if its accuracy is *known*, but not necessarily *high*; such is the case with many disasters, war included).**

But remaining damage still might be unacceptable, to put it gently.

Good news*: there is plenty of yet untapped data, models, and theories. This is a *"paradox of want amidst plenty" **(contemporaries' view of the Great Depression):**

YET UNTAPPED DATA exist in all geosciences:

Seismology itself - source mechanisms, slow earthquakes, wave spectra, slow deformations, etc.
Other geophysical fields
Geology **Geomorphology**
Geochemistry **Fluid regime**

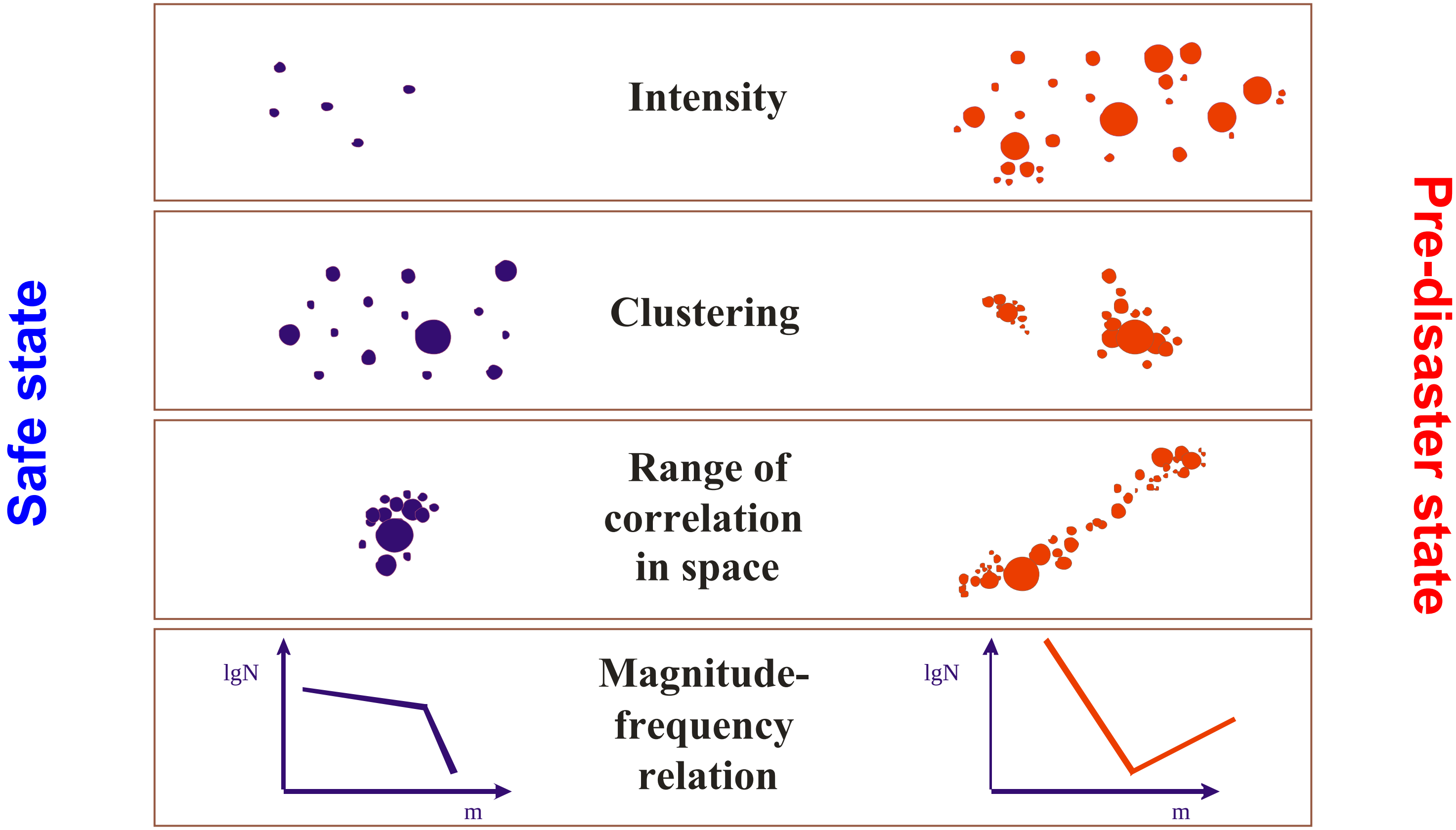
They are connected by the common origin – lithosphere dynamics

FOUR PARADIGMS IN EARTHQUAKE PREDICTION suggest *how to use these data at least for a start.*
They are established by modeling of complex systems; modeling of fault networks and data analysis (pattern recognition)

WHAT PRECURSORS TO LOOK FOR?

Paradigm I. BASIC TYPES OF PREMONITORY PHENOMENA

A strong earthquake is preceded by the following changes in observed fields:



These phenomena are reminiscent of asymptotics near the phase transition of second kind. However, we consider not the equilibrium, but the growing disequilibrium, culminated by an extreme event.

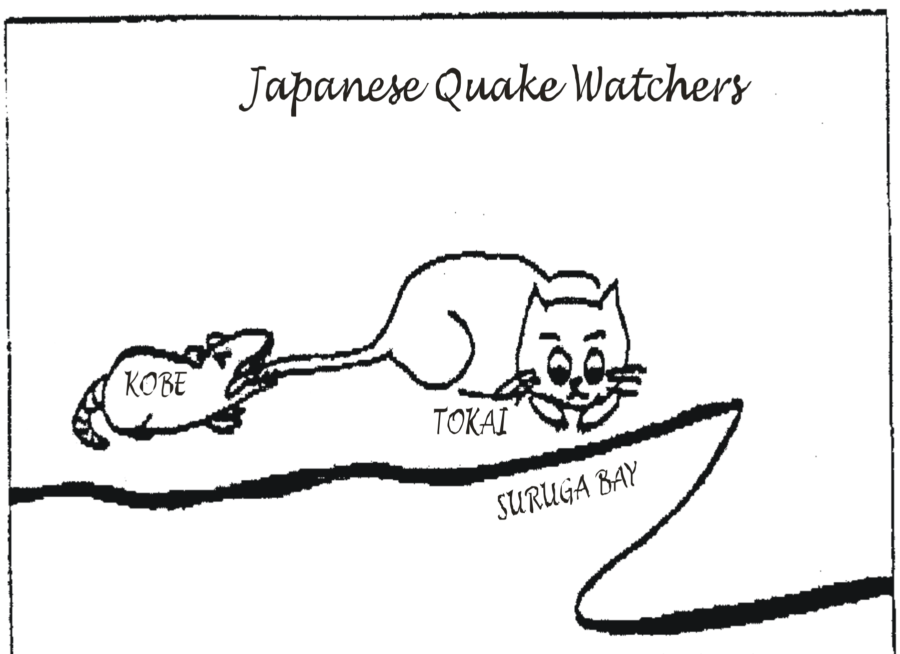
PROBLEMS: LOW-PARAMETRIC DEFINITION OF THAT SET and MERGER OF PRECURSORS INTO SCENARIOS

WHERE TO LOOK FOR PRECURSORS?
Paradigm II. LONG-RANGE CORRELATIONS

The generation of an earthquake is not localized around the its future source. A flow of earthquakes is generated by a lithosphere, rather than each earthquake – by a segment of a fault.

In the time scale up to tens of years, precursors to an earthquake with linear source dimension L(M) are formed with the fault network of the size 10L to 100L.

This is inevitable due to the impact of large-scale processes: perturbations in mantle flow and plates movement; invasion of fluids, etc.



Ch. Scholz, Geotimes, March '97

Up to 10L:
Pattern Σ (Malinovskaya, KB 1964); long-range aftershocks (Prozoroff, 1975; clusters (Caputo et al, 1977, Knopoff et al, 1980); Benioff strain release (Varness, 1989); algorithms CN (Rotwain et al, 1990), M8 (Kossobokov et al, 1986, 1990), SSE (Vorobieva and Levshina, 1992)

Up to 100L:
Interaction of large earthquakes (Romanovicz, 1993). Alternation of source mechanisms (Press, Allen, 1995).

Scholz, 1997

SELF-ADJUSTMENT OF PRECURSORS TO ENVIRONMENT
Paradigm III. SIMILARITY

Premonitory phenomena are similar (identical after normalization) in the extremely diverse conditions and in a broad energy range.

That similarity was observed for:

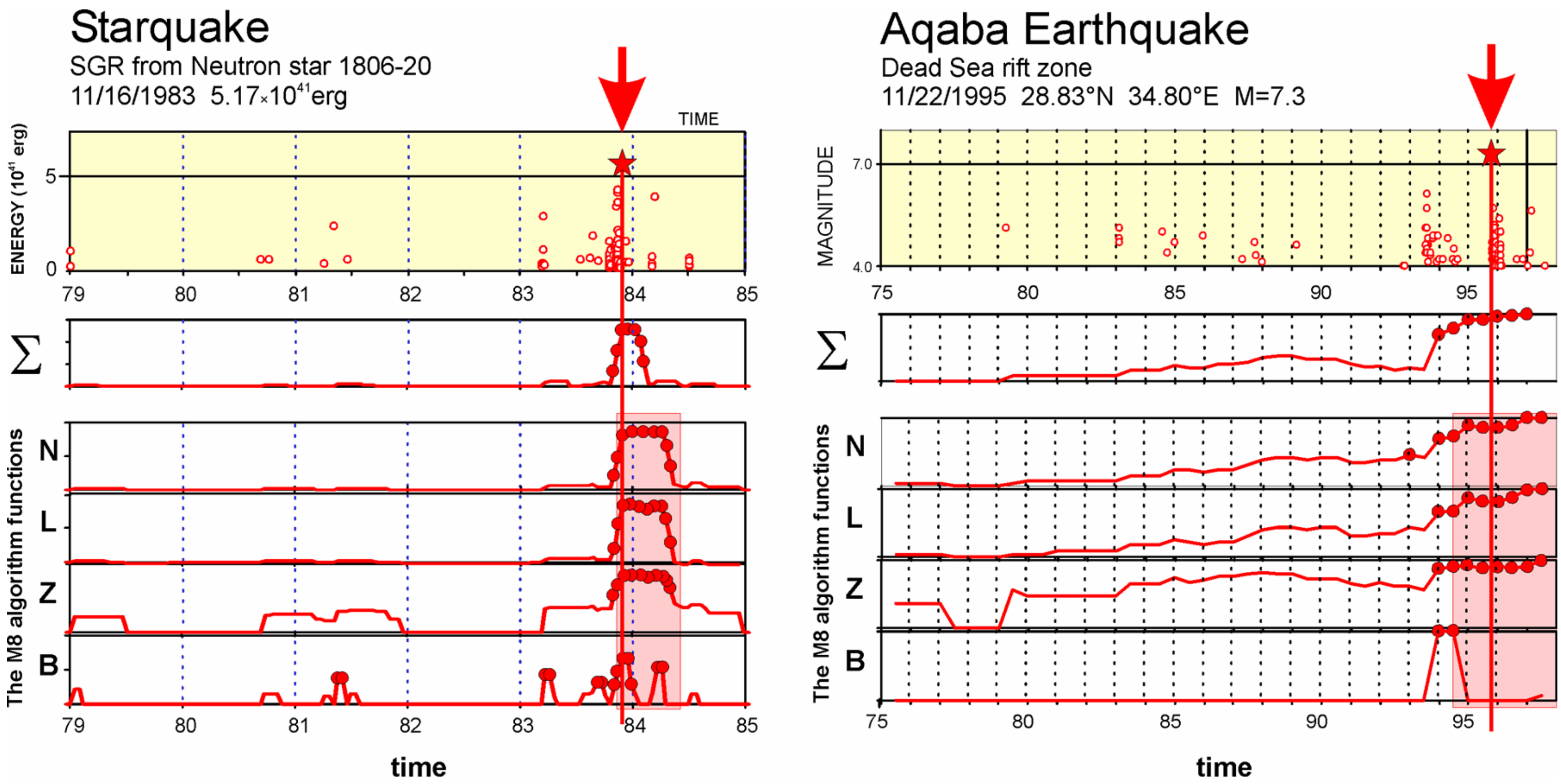
Breakdown of laboratory samples ⇒
⇒ Rockbursts in mines ⇒
⇒ Earthquakes with magnitude from 4.5 to 8+ worldwide ⇒
⇒ Possibly, starquakes, magnitude about 20, ⇒

in the energy range from erg to 10^{23} erg, and possibly 10^{41} erg.

The similarity holds only after a robust coarse-graining, and is not unlimited: on its background some regional variations of premonitory phenomena emerge.

PROBLEMS: RENORMALIZATION and
RELATION BETWEEN TIME, SPACE, and ENERGY SCALES

FRONTIERS OF SIMILARITY

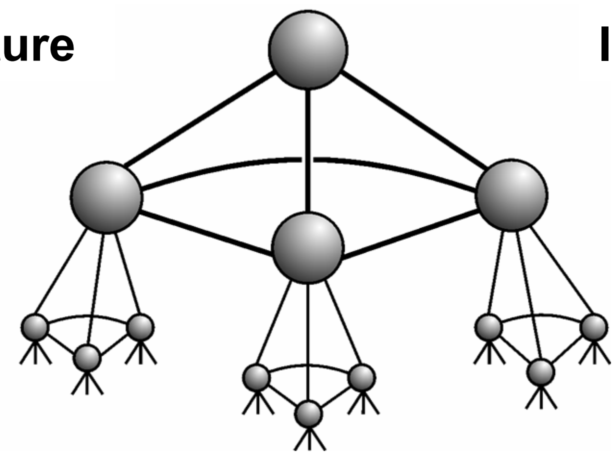


WHERE IS PHYSICS?
Paradigm IV. DUAL NATURE OF PREMONITORY PHENOMENA

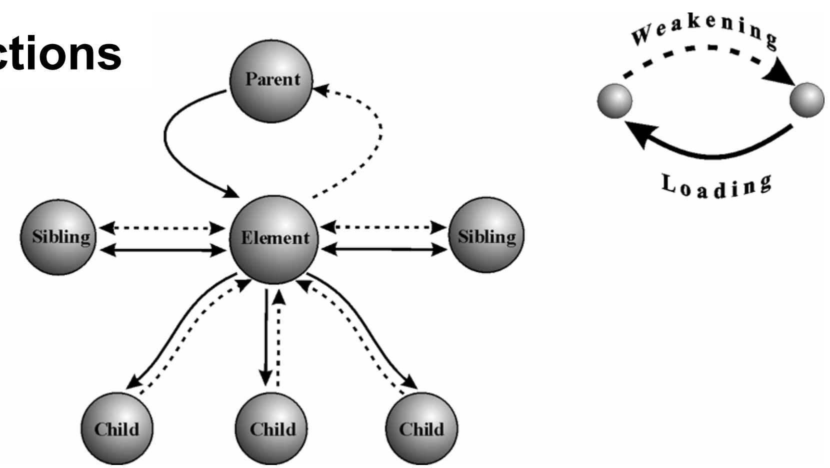
Some are "universal", common for hierarchical complex non-linear systems of different origin.

Example: Colliding Cascades/BDE Model reproducing major premonitory seismicity patterns

Structure

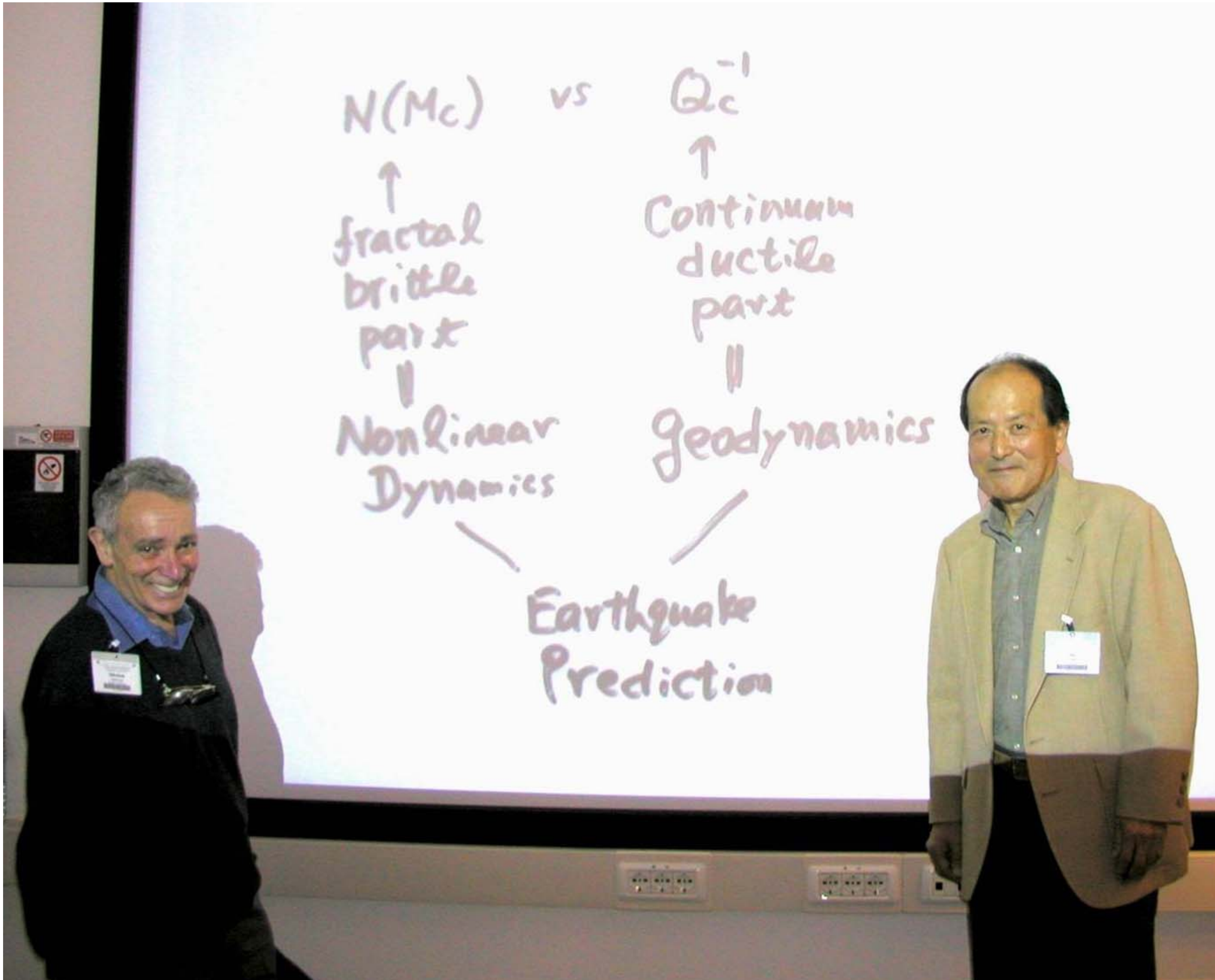


Interactions



Some phenomena are specific to the geometry of the faults' network, or to a certain mechanism like stress corrosion, stress transfer, heat flow, etc.

PROBLEMS: SIMILAR PRECURSORS TO OTHER GEOLOGICAL / GEOTECHNICAL DISASTERS

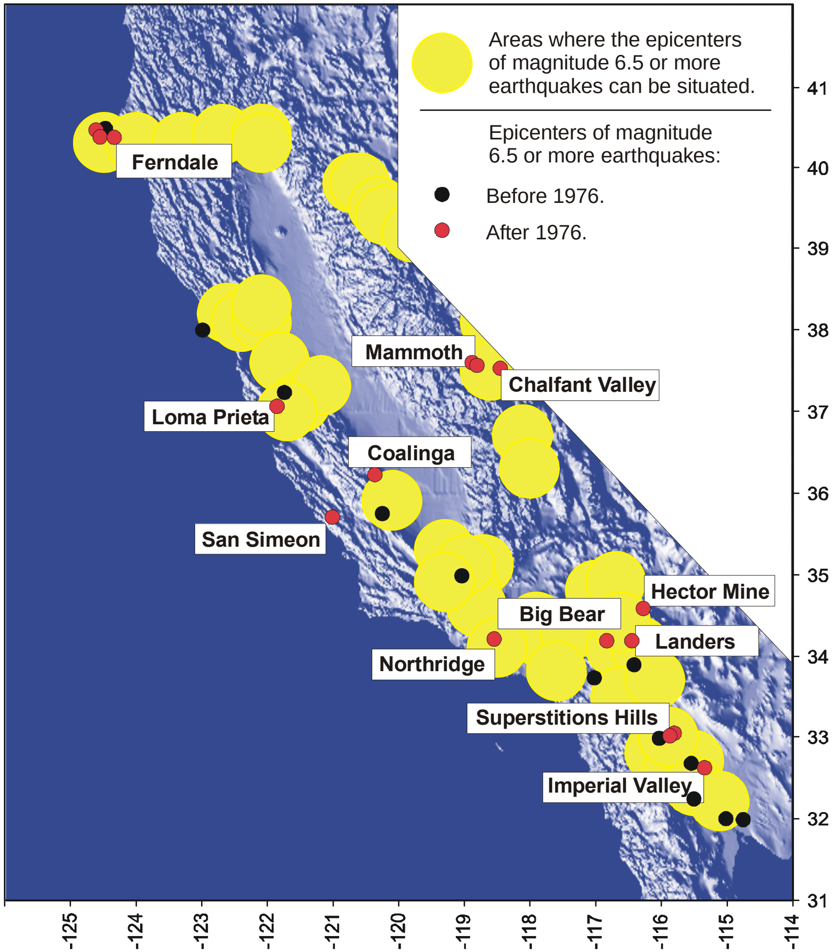

N(Mc) vs Q_c^{-1}
fractal brittle part
Nonlinear Dynamics
Continuum ductile part
geodynamics
Earthquake Prediction

STRONG EA-S NUCLEATE IN THE NODES AND ONLY IN SOME NODES "D" WHICH CAN BE PATTERN RECOGNIZED BY AN ENSEMBLE OF DATA

California and adjacent parts of Nevada.

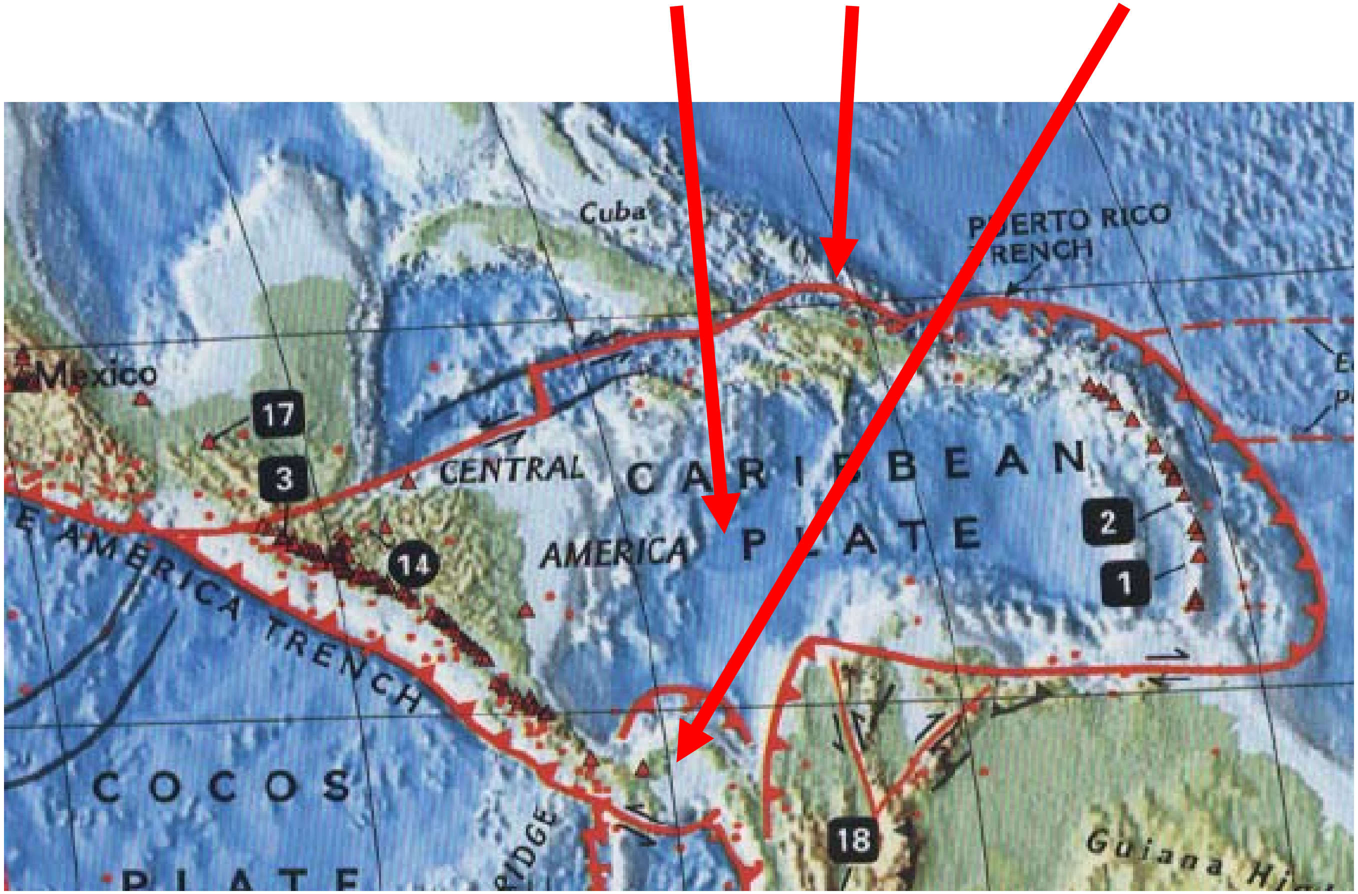
From: ***Gelfand, I.M., Guberman, Sh.A., Keilis-Borok, V.I., Knopoff, L., Press, F., et al., 1976. Pattern recognition applied to earthquake epicenters in California. Phys. Earth Planet. Inter. 11:227–83***

Data for recognition are taken from generally available maps and satellite images



More untapped possibilities:
INTEGRATING FAULT NETWORK INTO PREDICTION - 1

Different precursors in blocks, faults, and nodes.

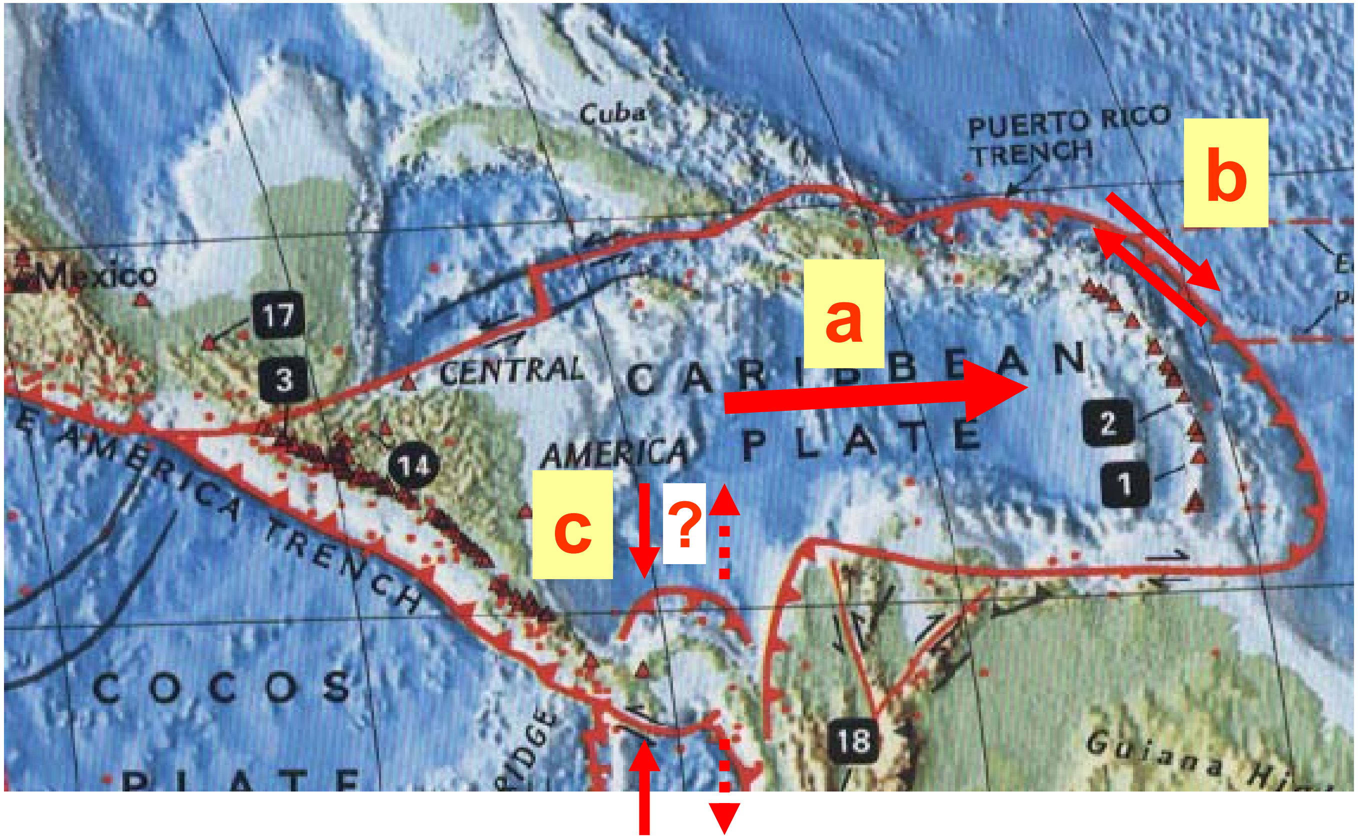


More untapped possibilities:

INTEGRATING FAULT NETWORK INTO PREDICTION - 2

Using satellite data

a) absolute displacement averaged over blocks;
b) relative displacement on the faults
c) Compression vs. tension in the nodes.
d) Heat flow at the faults and nodes.



MINI-PROJECT: HOW TO START?

Pour commencer il faut commencer ("to start one should start", French proverb)

Questions ask for an initial guess, to be modified or rejected during the analysis

Problem: Extreme events that you want to predict ____________________

Qualitatively (e.g. strong earthquakes) __________________________________

Quantitatively (e.g. magnitude, territory, lead time) ______________________

Available time series possibly containing precursors (one at a time)

____

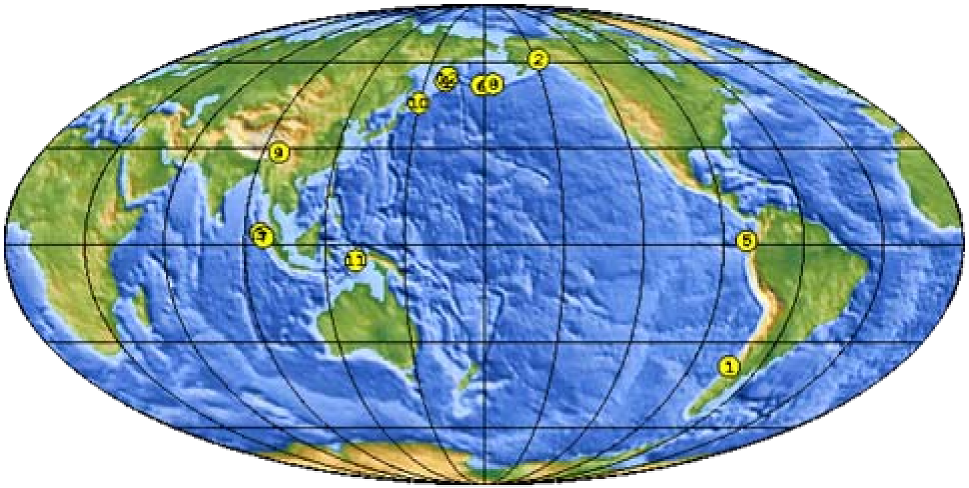
Premonitory phenomenon (one at a time)

____

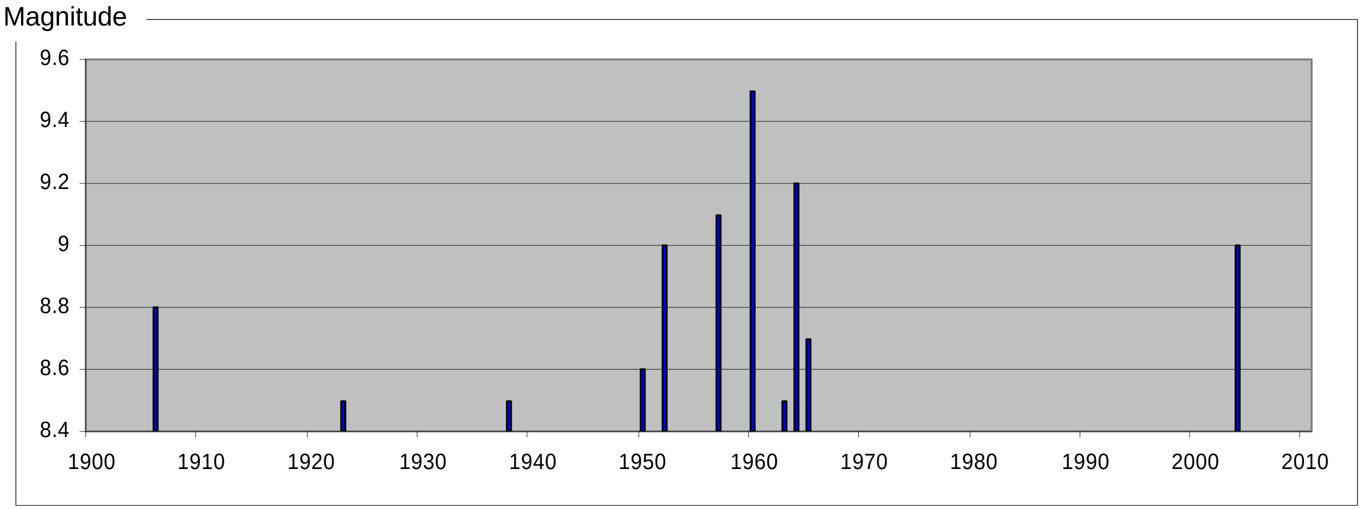
A possibility: Analyze time series generated by a model

Clustering exists in multiple time- and space-scales. The whole seismicity is unraveling as a cascade of clusters.

Example: Extreme earthquakes in the world



USGS National Earthquake Information Center



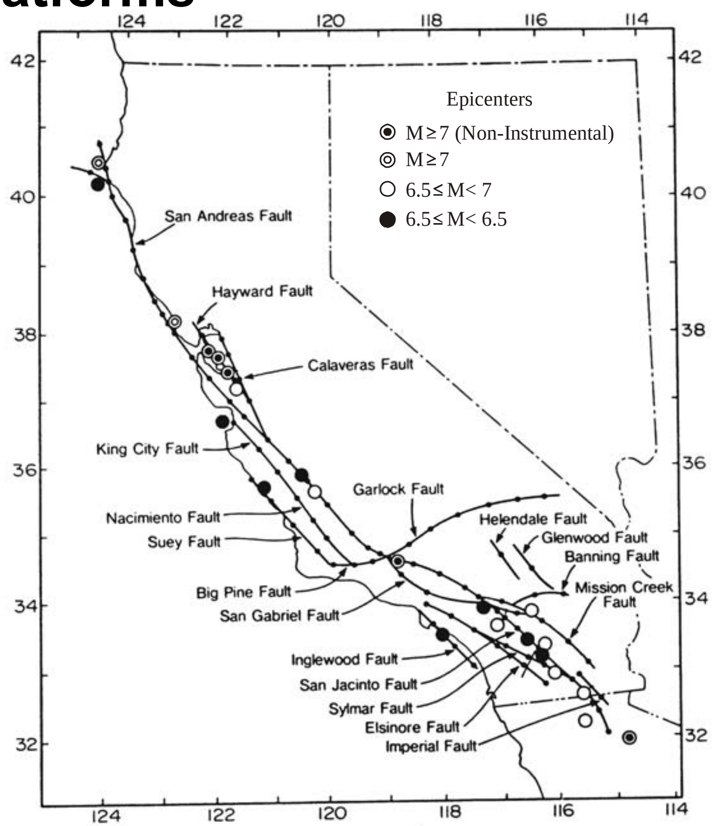
More untapped possibilities:
INTEGRATING FAULT NETWORK INTO PREDICTION - 3

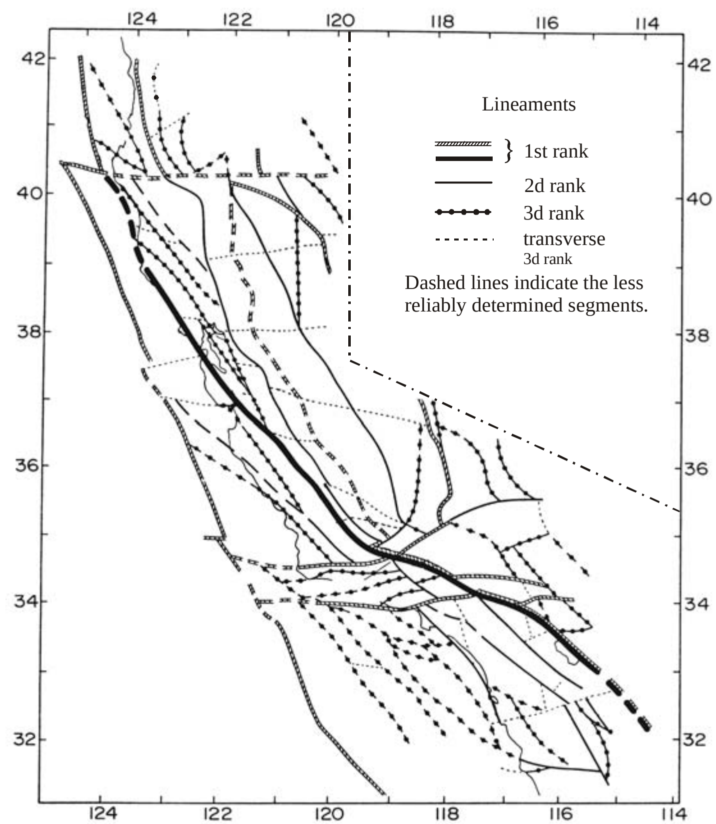
Awareness gap: Many significant faults/boundary layers remain unrecognized in seismotectonics, although they would be routinely mapped in structural geology and mineral prospecting. After the earthquake they are called “blind faults”.

More faults-more intersections-more nodes-more instability-more precursors.

Ditto – platforms

Example:





Gelfand, I.M., Guberman, Sh.A., Keilis-Borok, V.I., Knopoff, L., Press, F., Ranzman, E.Ya., Rotwain, I.M., Sadovsky, A.M., 1976. Phys. Earth Planet. Inter. 11:227–83

More untapped data: PRECURSORY PERTURBATIONS in:

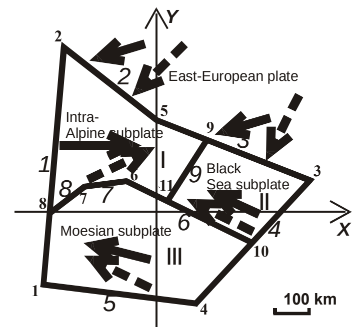
-- Ductile lower crust (Aki)
-- Plate movements (Press, Allen)
-- Mantle flows (Schubert, Turcotte, Ismail-Zadeh, Soloviev)
-- Chandler wobble, Earth rotation, drift of magnetic field (Press, Briggs)

An example

RECONSTRUCTION OF DRIVING FORCES FROM SPATIAL DISTRIBUTION OF SEISMICITY:
BLOCK MODEL OF VRANCEA REGION

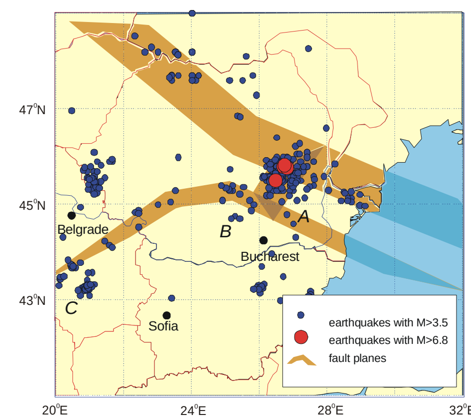
(Soloviev, Ismail-Zadeh, 2003.)

Geometry of the block system

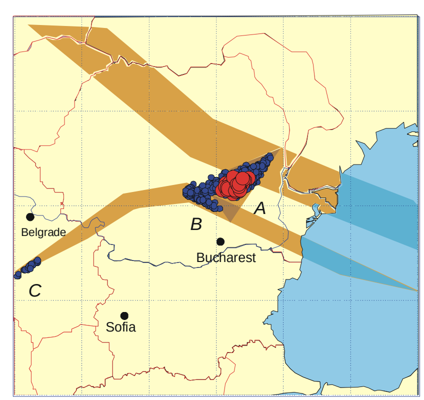


Arrows indicate driving forces:
Solid ones correspond to synthetic seismicity on the left figure below, dashed ones correspond to synthetic seismicity on the right figure below

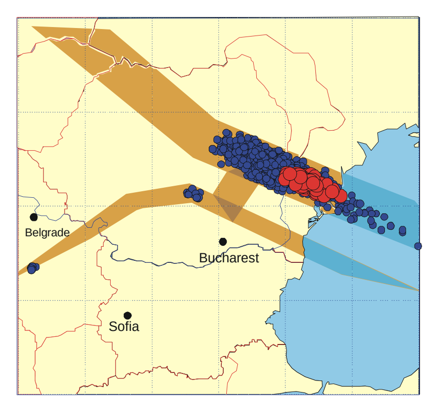
Observed seismicity, 1900-1995

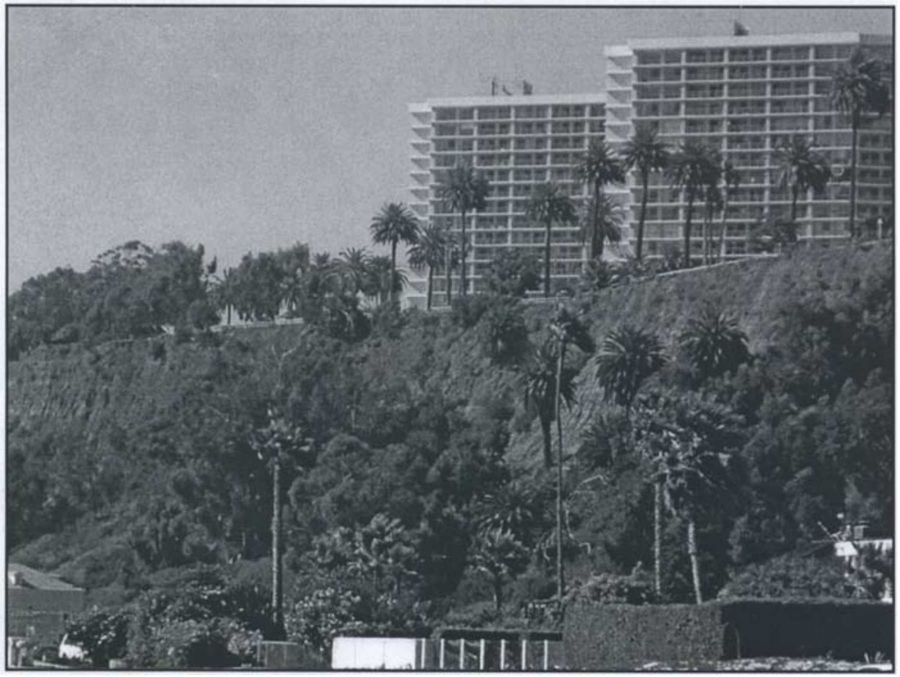


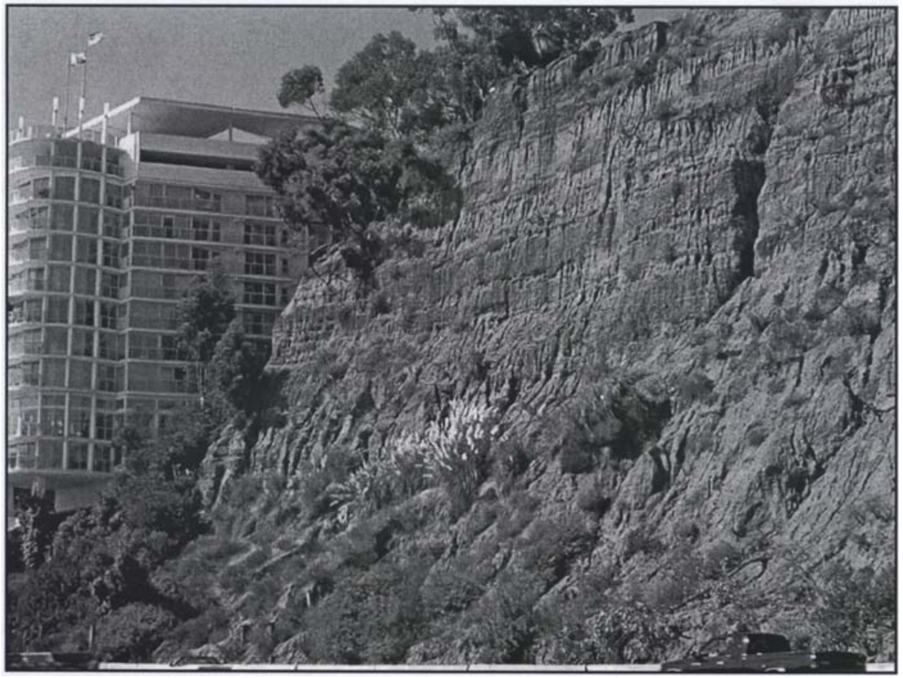
Synthetic seismicity (solid arrows)



Synthetic seismicity (dashed arrows)







PROJECTS SUGGESTED SINCE MARCH:

GOAL

Prediction: ea-s, landslides, volcanic eruptions……

– Observations available: For earthquake prediction following have been mentioned
Time series - seismicity; source mechanism; (GPS and heat flow); fluid regime; geochemistry (e.g. radon); and microseisms.
Maps of fault network and nucleation areas

– Prediction targets: (Magnitude range, territory, lead time (years – months – weeks???)

Reconstruction of fault network

– Data available

– Scale of product

Responding to a prediction – combinatorics approach

– Vulnerable objects ⇒ possible actions ⇒ their reasonable combinations (scenarios of response)

– Preparedness – staff excersizes, simulation alarms

Common goals with fluid dynamics and plasma physics

Initial teams: leader, 3-5 members, international setting, learning by doing