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Real-time Prediction of Earthquakes: State-of-the-art and Perspectives

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Real-time prediction of earthquakes: State-of-the-art and Perspectives

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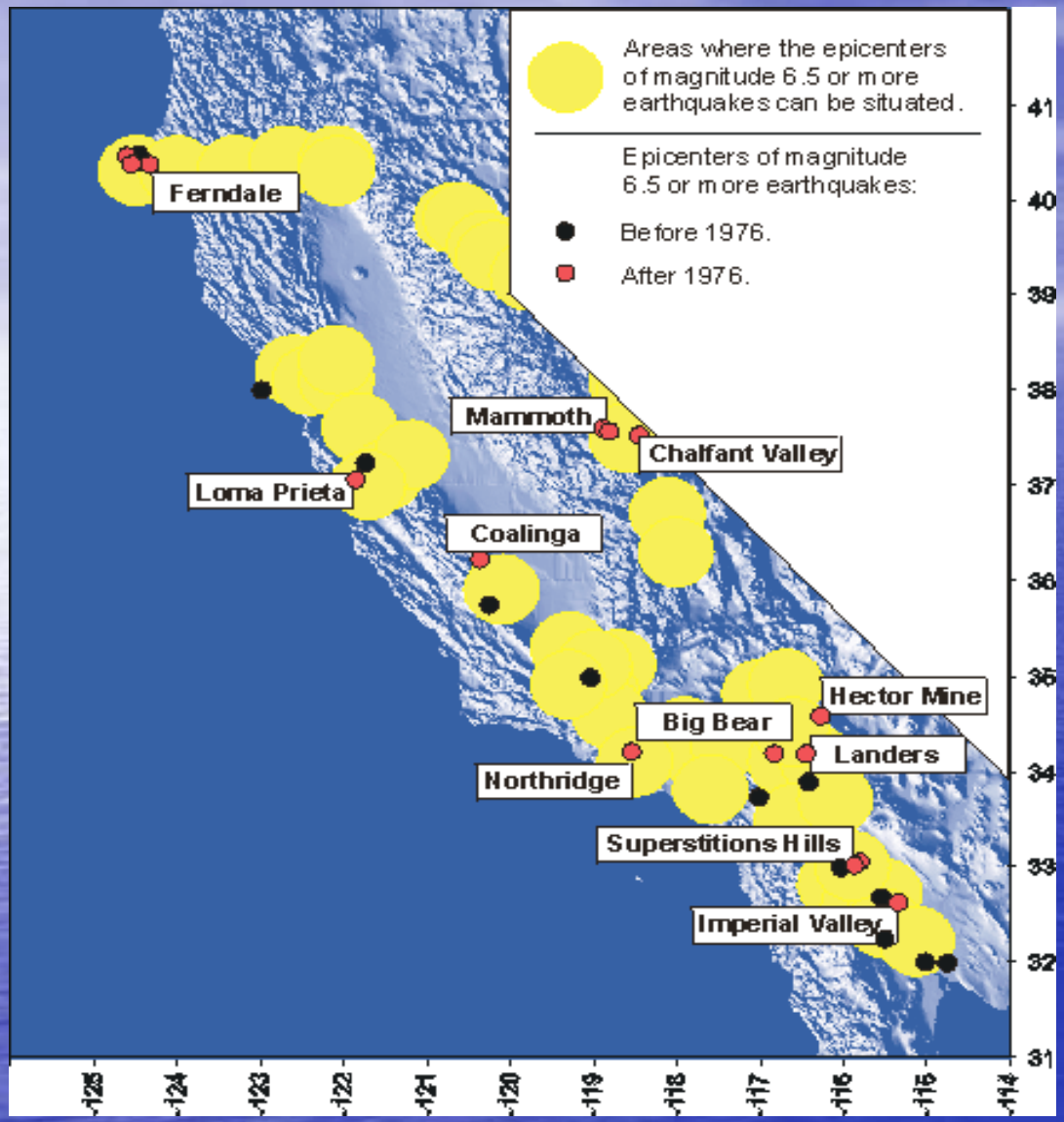
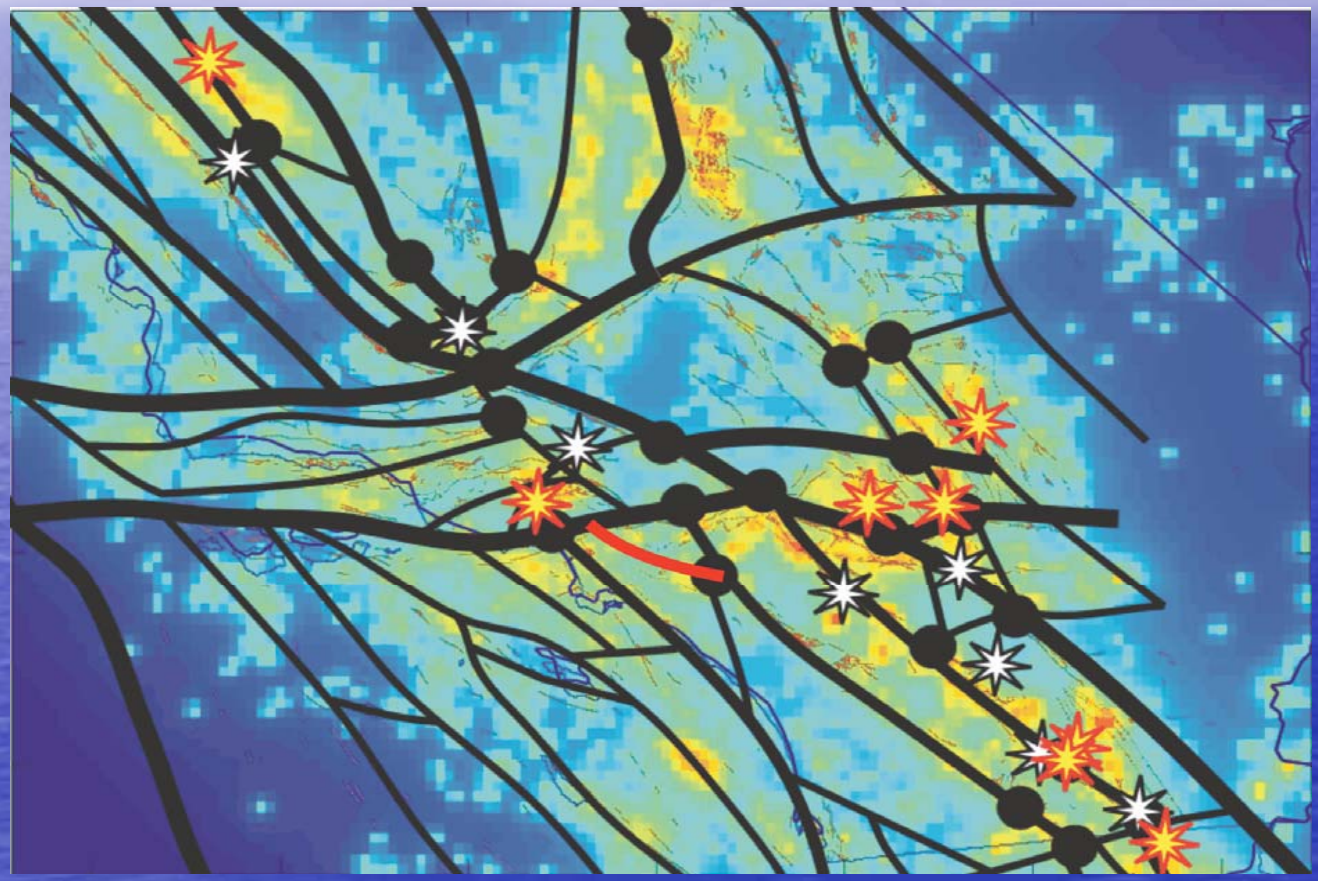


Term-less approximation:

- The 73 D-intersections of morphostructural lineaments in California and Nevada determined by *Gelfand et al.* (1976) as earthquake-prone for magnitude 6.5+ events. Since 1976 fourteen magnitude 6.5+ earthquakes occurred, all in a narrow vicinity of the D-intersections

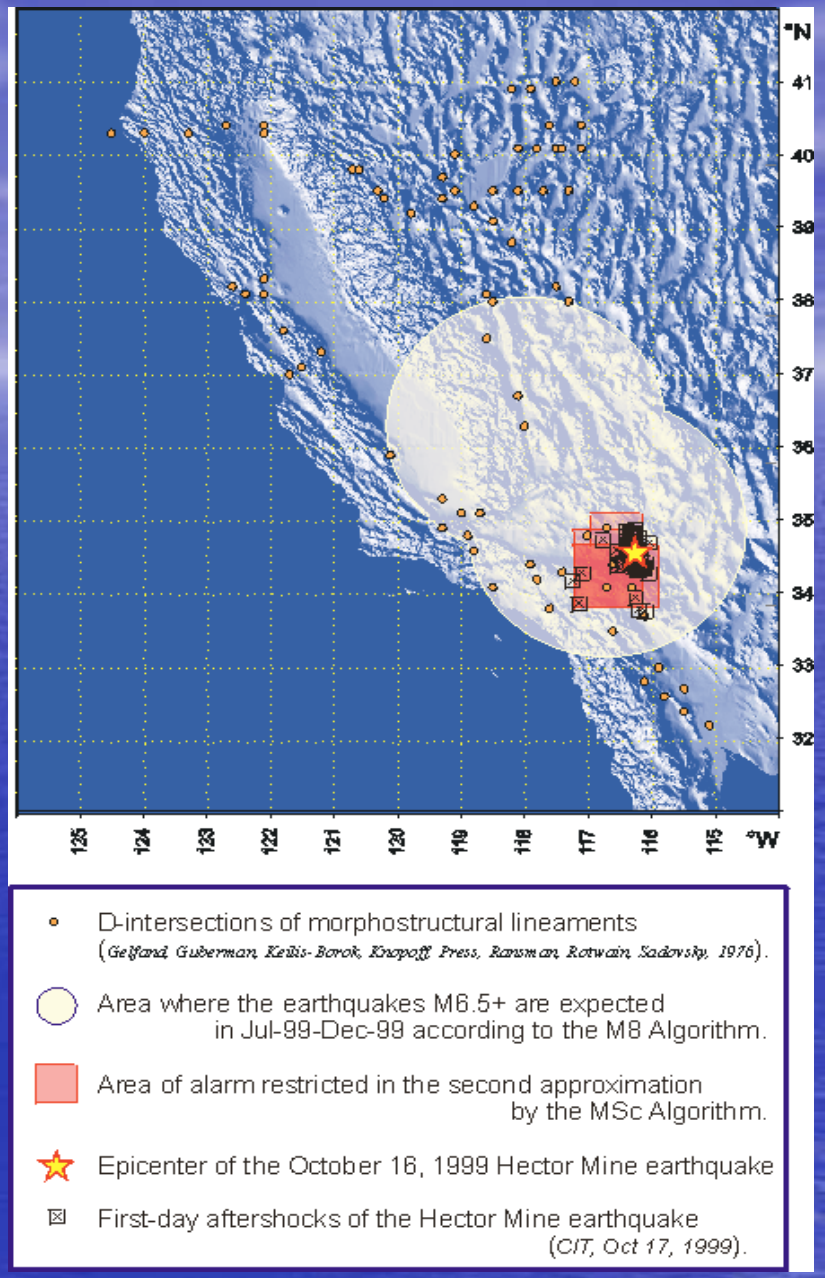
At least one of the newly discovered faults, i.e., the Puente Hills thrust fault (J.H. Shaw and Shearer P.M., 1999. An elusive blind-thrust fault beneath metropolitan Los Angeles. *Science*, **238**, 1516-1518), **coincides exactly with the lineament drawn in 1976.**



16/10/1999 Hector Mine, CA Ms7.4 earthquake

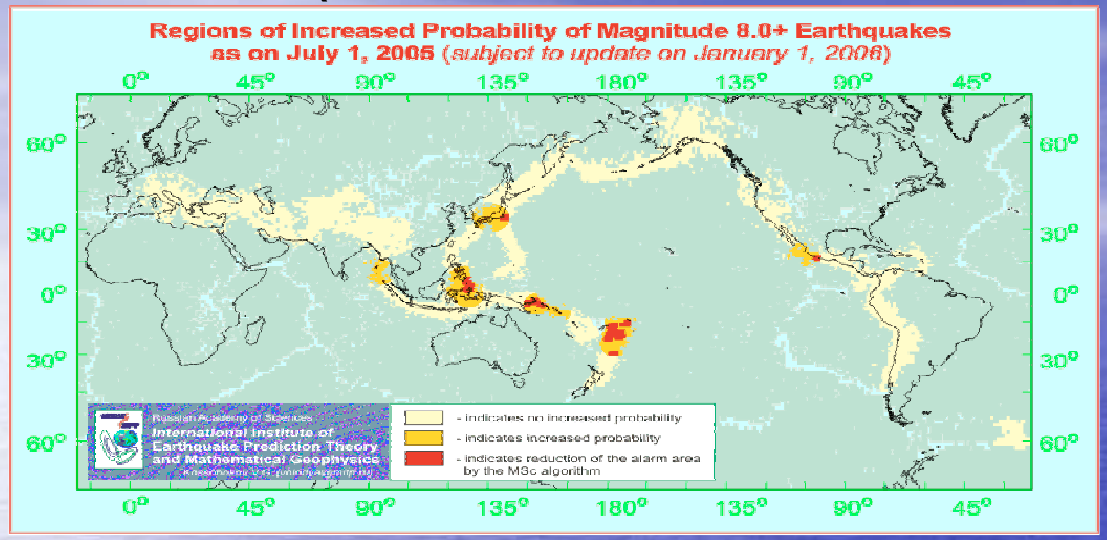
First approximation: The M8 algorithm in circles of investigation centered at the 73 D-intersections and run on July 1, 1999 determined alarms in two of them.

Second approximation: The MSc algorithm narrowed the prediction to a location between 34.68N-33.82N and 117.23W-116.17W, where the epicenter of the Hector Mine earthquake and most of its aftershocks occurred on October 16.

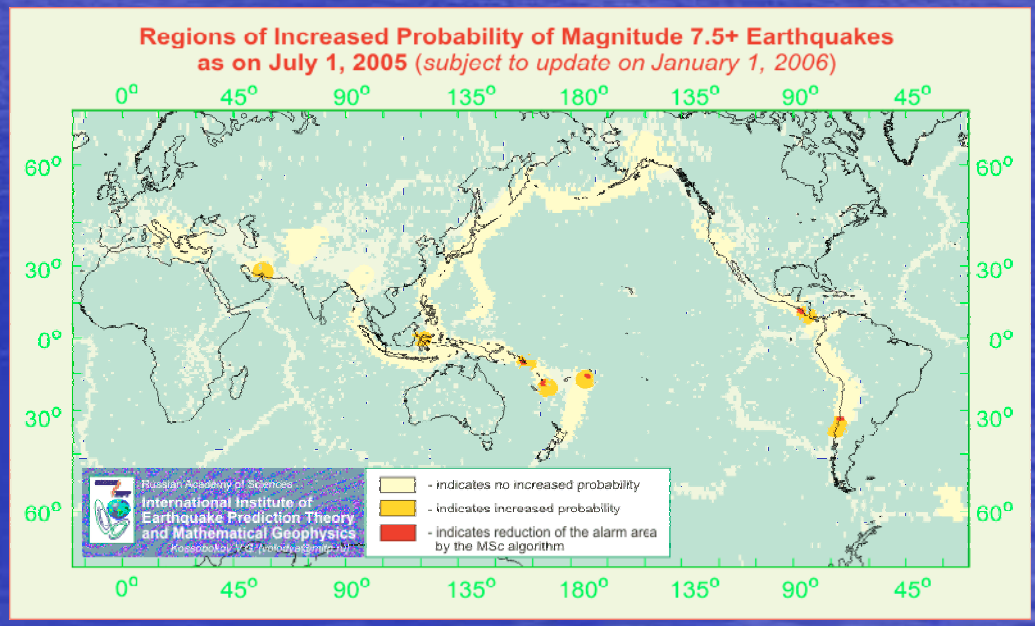


Real-time prediction of the world largest earthquakes

(http://www.mitp.ru or http://www.phys.ualberta.ca/mirrors/mitp)



Although the M8-MSc predictions are intermediate-term middle-range and by no means imply any "red alert", some colleagues have expressed a legitimate concern about maintaining necessary confidentiality. Therefore, the up-to-date predictions are not shown here, although available on web-pages of restricted access provided to about 150 members of the Mailing List.



Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: Magnitude 8.0+.

Test period	Large earthquakes Total	Predicted by M8	Predicted by M8-MSc	Measure of alarms,% M8	Measure of alarms,% M8-MSc	Confidence level, % M8	Confidence level, % M8-MSc
1985-present	11	9	7	$33._{24}$	$17._{14}$	$99._{87}$	$99._{92}$
1992-present	9	7	5	$28._{42}$	$14._{37}$	$99._{69}$	$99._{54}$

The significance level estimates use the most conservative measure of the alarm volume accounting for empirical distribution of epicenters.

To drive the achieved confidence level below 95%, the Test should encounter four failures-to-predict in a row.

Worldwide performance of earthquake prediction algorithms M8 and M8-MSc: Magnitude 7.5 or more.

Test period	Large earthquakes Total	Predicted by M8	Predicted by M8-MSc	Measure of alarms,% M8	Measure of alarms,% M8-MSc	Confidence level, % M8	Confidence level, % M8-MSc
1985-present	53	30	16	$34._{35}$	$11._{05}$	$99._{93}$	$99._{98}$
1992-present	40	19	10	$28._{77}$	$10._{45}$	$99._{07}$	$99._{31}$

The significance level estimates use the most conservative measure of the alarm volume accounting for empirical distribution of epicenters.

The prediction for M7.5+ is less effective than for M8.0+. Nevertheless, we continue testing the algorithms for this and smaller magnitude ranges.

Conclusions – The Four Paradigms

Statistical validity of predictions confirms the underlying paradigms:

- Seismic premonitory patterns exist;
- Formation of earthquake precursors at scale of years involves large size fault system;
- The phenomena are similar in a wide range of tectonic environment…
- … and in other complex non-linear systems.

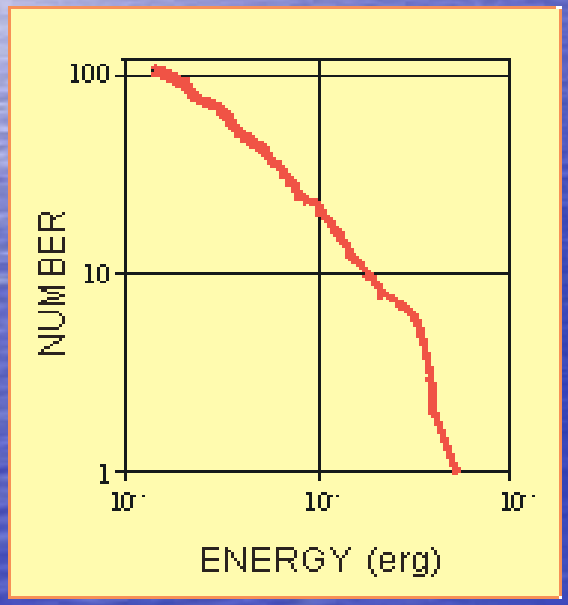
SGR1806-20 sequence

Soft-Gamma-Repeater 1806-20 is the source in Sagittarius, from which more than a hundred X-ray pulsations have been detected. Its location on the sky (1806-20 refer to celestial coordinates: 18 hours 06 minutes right ascension, -20 degrees declination) is near the Galactic center, which is 25,000 light years away.

The energy of one burst varies from $1.4 \cdot 10^{40}$ erg to $5.3 \cdot 10^{41}$ erg (the largest earthquakes release about 10^{26} erg).

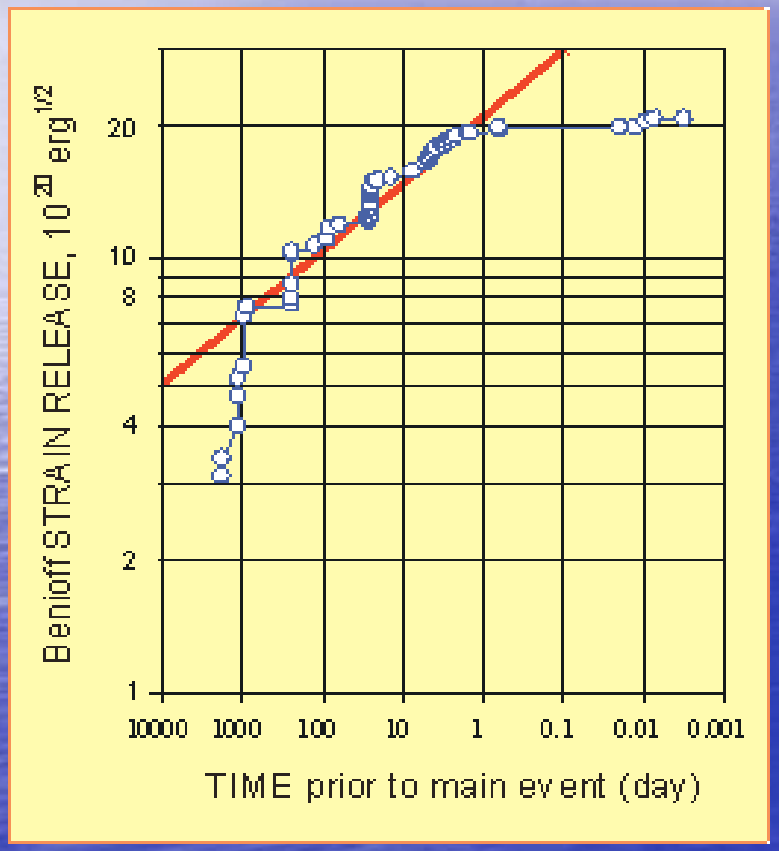
Common general features

A fundamental property of multiple fracturing is the power-law distribution of energy $\log_{10} N(E) = a + b \cdot \log_{10} E$



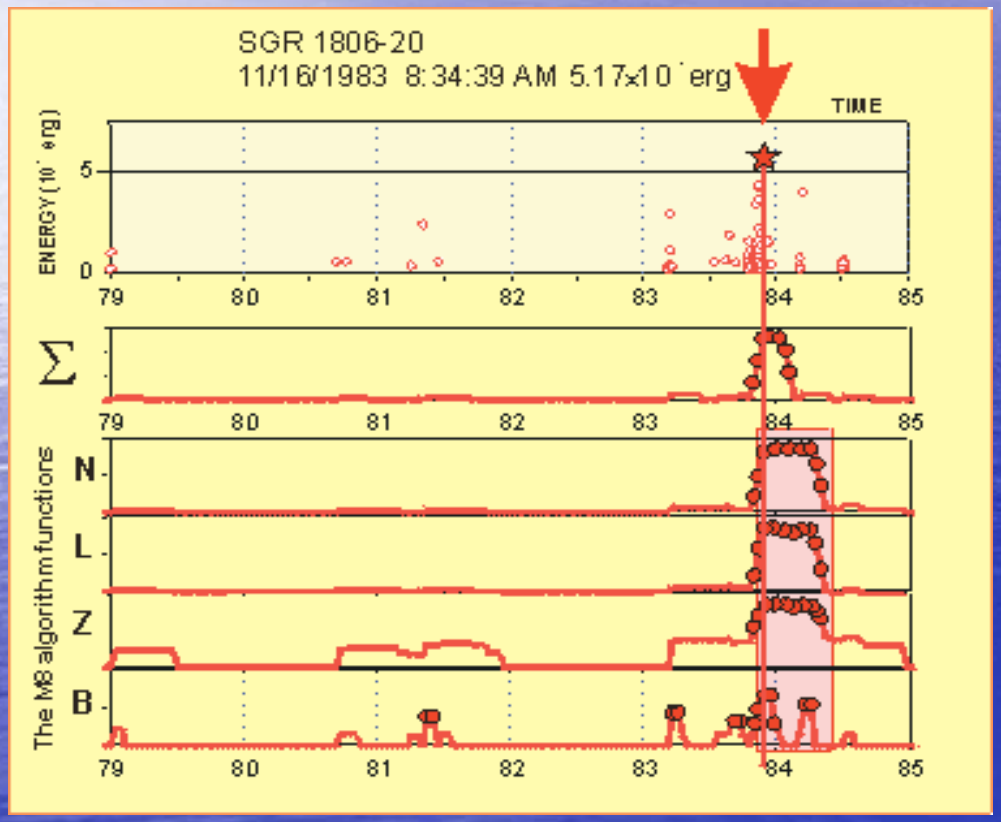
(Gutenberg-Richter relation)

Symptoms of transition to the main rupture



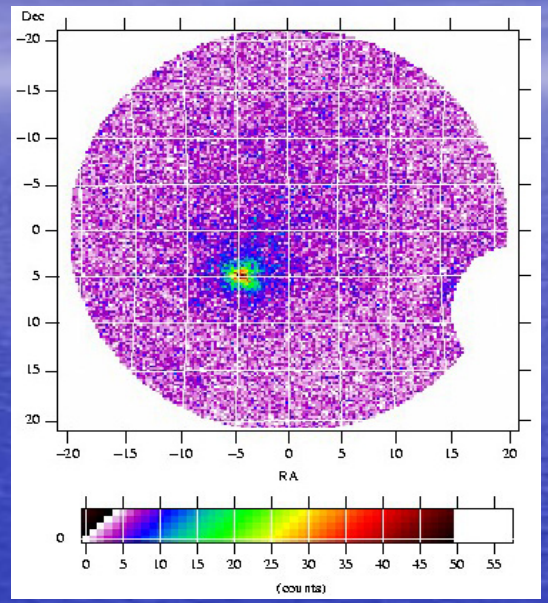
- Escalation of fracturing lasting nearly 1000 days and culminated with the largest starquake on November 16
- The power-law increase of activity, e.g. Benioff strain release $\varepsilon(t)$, with a possible trace of the four log-periodic oscillations.

Seismic premonitory patterns



- Pattern $\Sigma \sim E^{2/3}$ *Keilis-Borok & Malinovskaya, 1964*
- Pattern B *Keilis-Borok, Knopoff & Rotwain, 1980*
- M8 algorithm *Keilis-Borok & Kossobokov, 1990*

Similarity of starquakes and earthquakes



Qualitative so far

- Gutenberg-Richter relation
- Premonitory changes
- Decay of "aftershocks"

– Omori power-law

Starquakes evidence drastic expansion of the Realm of Multiple Fracturing previously observed from the lithosphere of the Earth to laboratory samples

Kossobokov, Keilis-Borok & Cheng, 2000

How to explain such similarity?

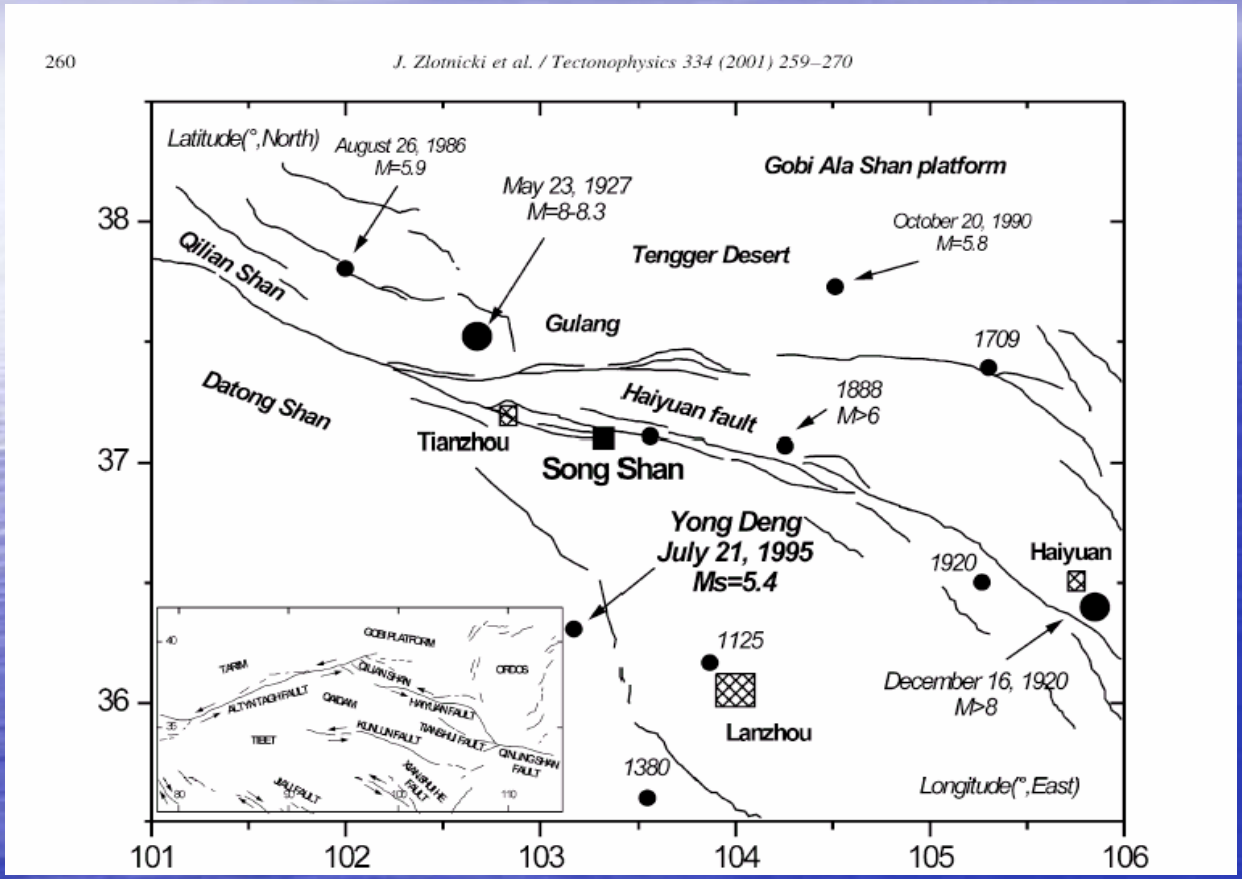
The simplest answer is –

- Multiple fracturing reflects scenarios of critical transition, common for a broader class of non-linear systems

Turcotte, 1995. Fractals and Chaos in Geophysics.

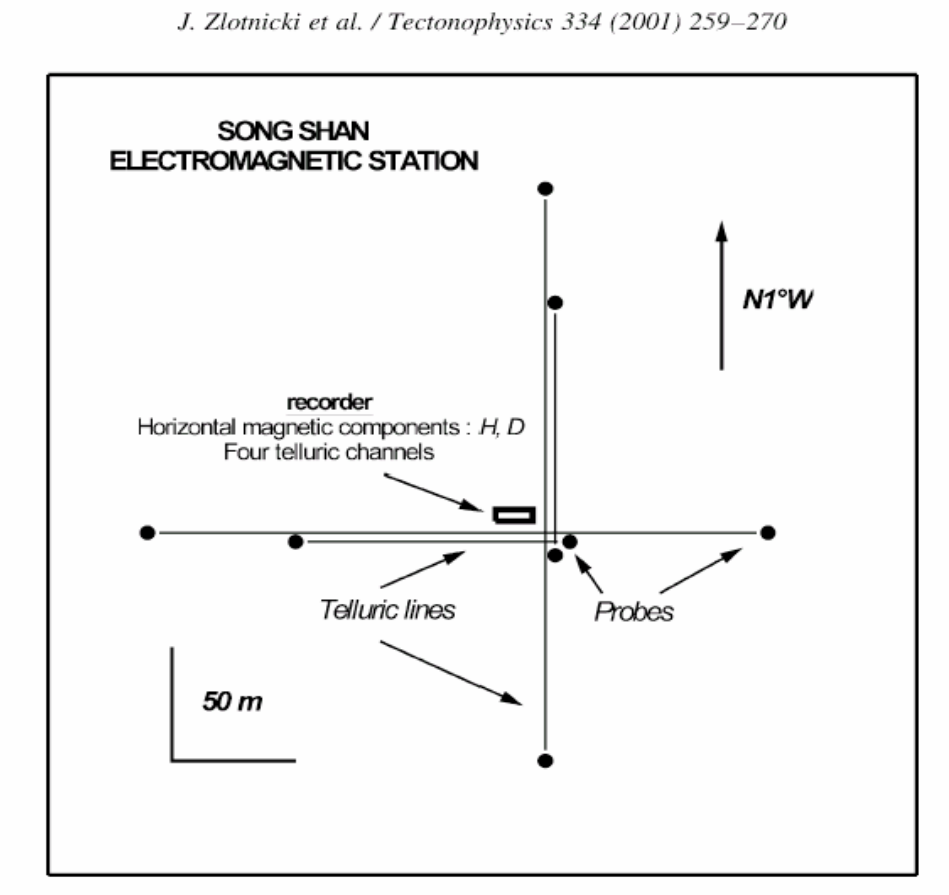
Newman, Gabrielov, & Turcotte, editors. 1994. Nonlinear Dynamics and Predictability of Geophysical Phenomena.

One example from ENE off Tibet



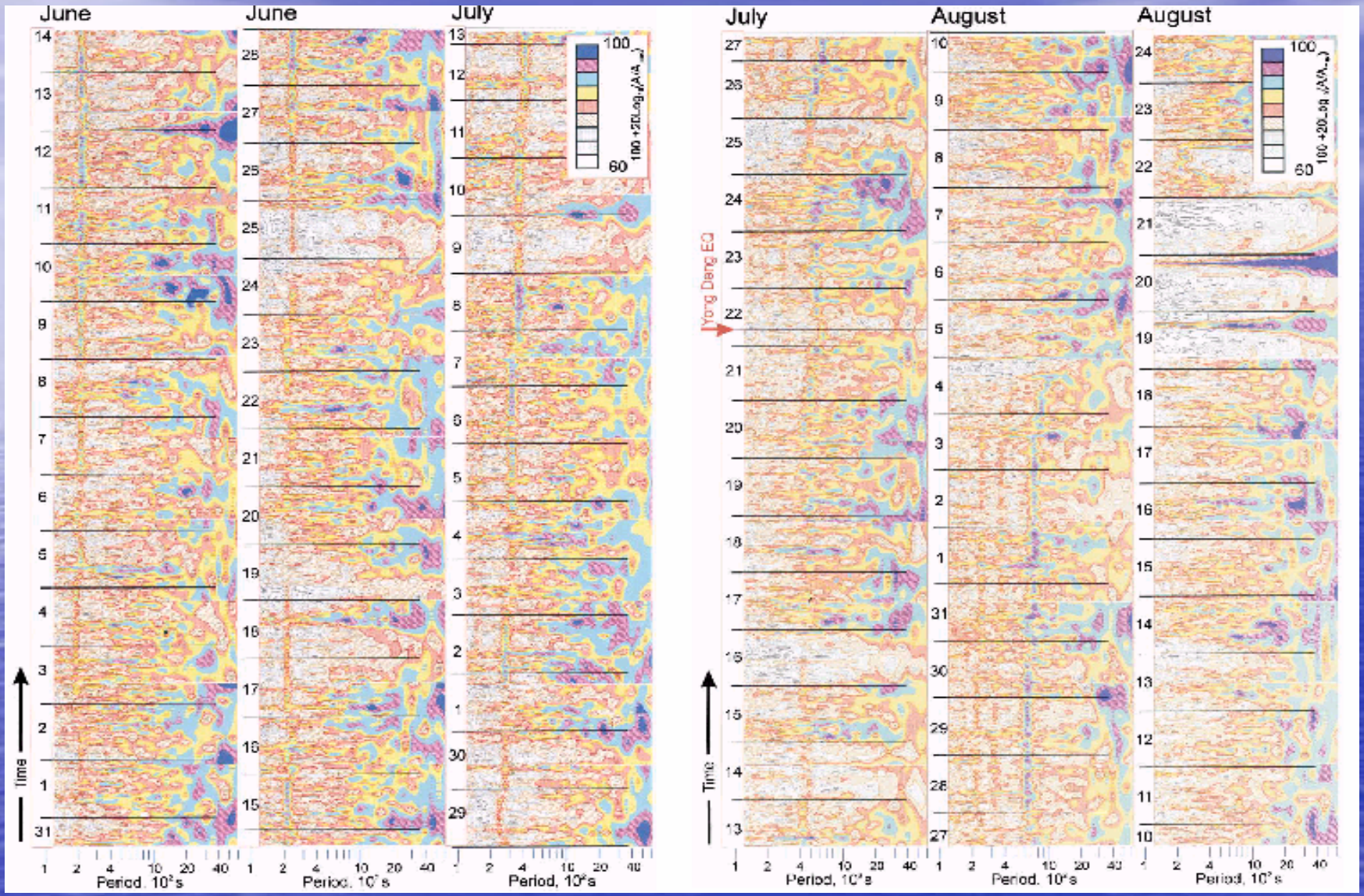
- An ULF electromagnetic signal around 21 July 1995, M5.7, Yong Deng (China) earthquake

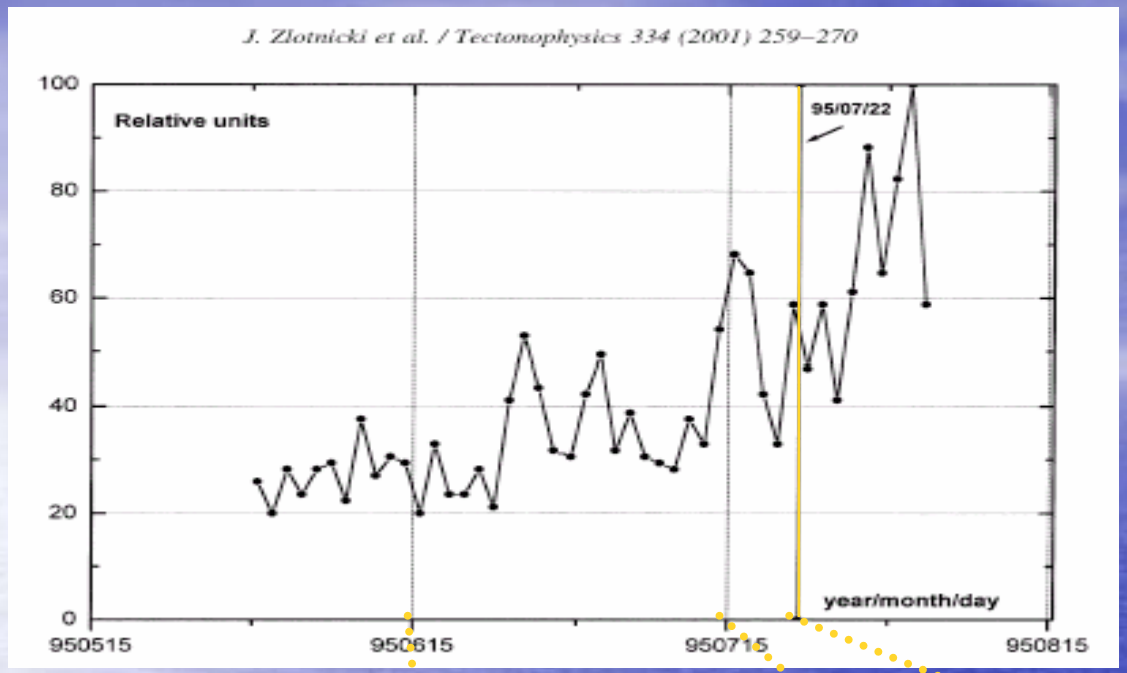
Schematic representation of the electromagnetic station at Song Shan



- Two independent, 110 and 250 m long, lines

Frequency-Time diagrams for the NS 250 m line



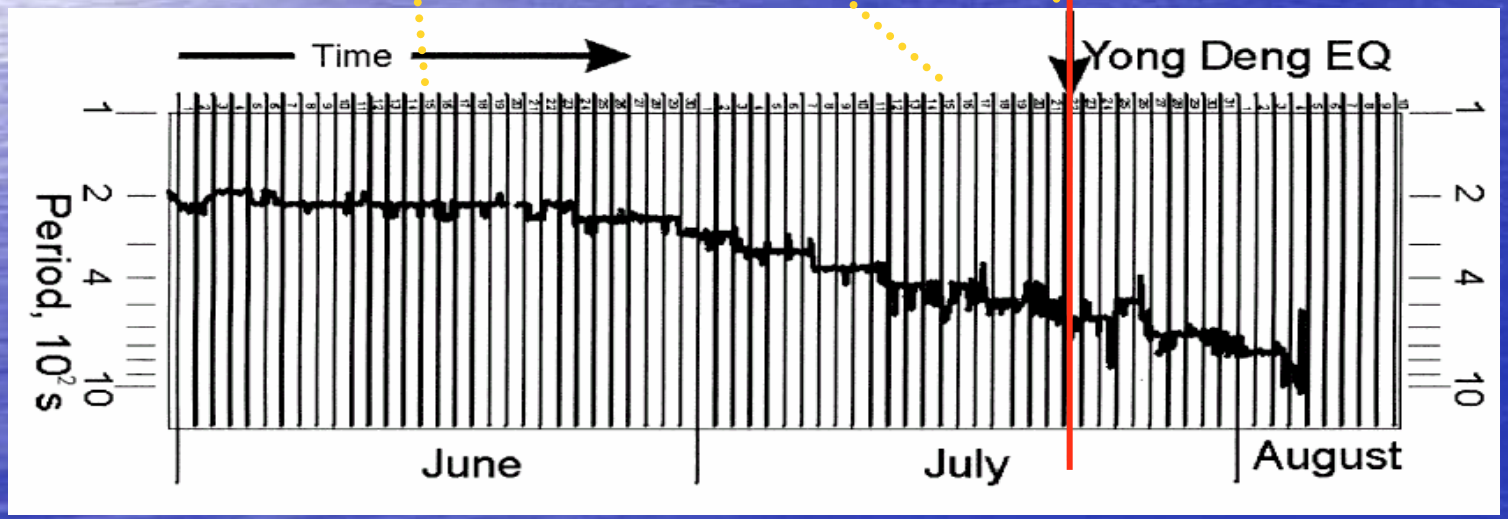


Signal evolution

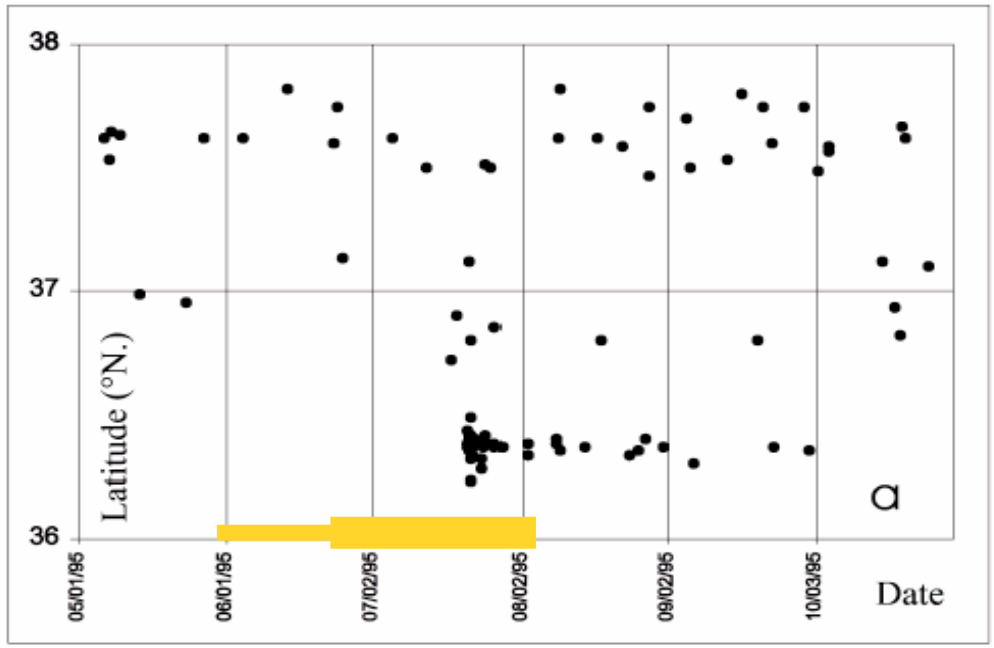
Both

- Intensity and
- Period

GROW



The signal start and collapse

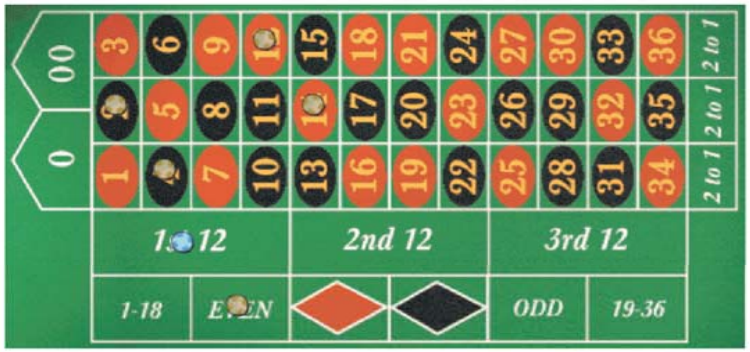


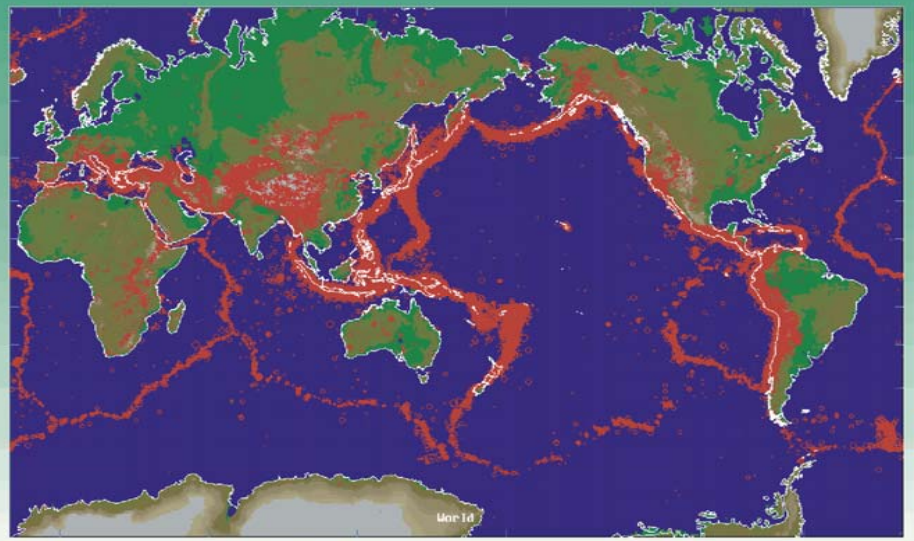
The Yong Deng earthquake has occurred in a near vicinity of electromagnetic observations at the time when *the characteristic ULF* and/or its exponential show decrease, on the component pointing at epicenter.

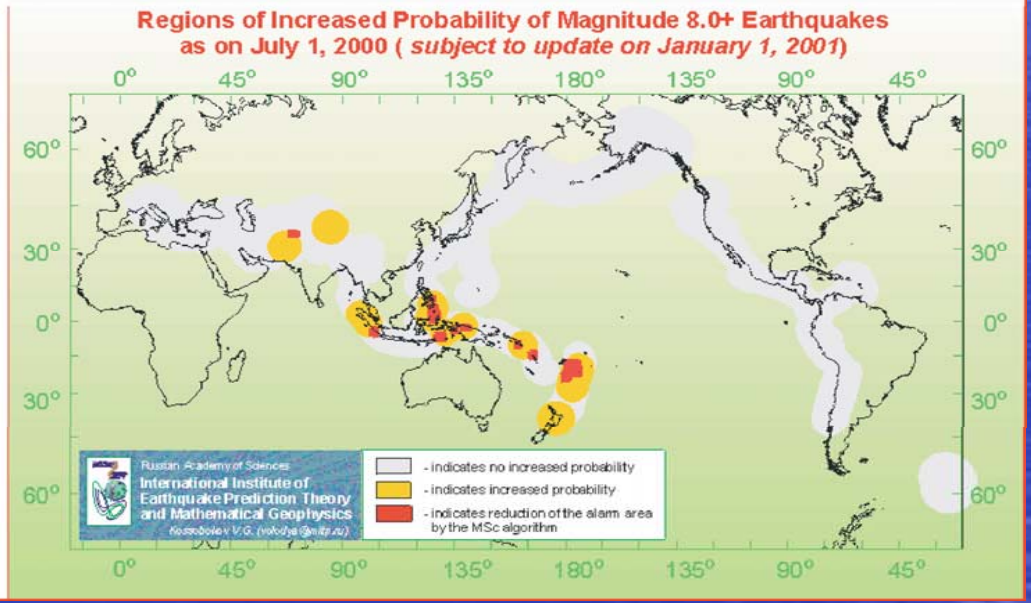
The start of the ULF *decrease* was accompanied with a seismic activation of associate segment of Haiyuan fault system.

The collapse of the characteristic ULF happened just before the Yong Deng aftershocks vanished exponentially.

Seismic Roulette







Conclusions – Seismic Roulette is not perfect

Are these predictions useful?

- Yes, if used in a knowledgeable way.
- Their accuracy is already enough for undertaking earthquake preparedness measures, which would prevent a considerable part of damage and human loss, although far from the total.
- The methodology linking prediction with disaster management strategies does exist (*Molchan, 1997*).

Kofi Annan:

Introduction to Secretary-General's Annual Report on the Work of the Organization of United Nations, 1999 - A/54/1

"More effective prevention strategies would save not only tens of billions of dollars, but save tens of thousands of lives. Funds currently spent on intervention and relief could be devoted to enhancing equitable and sustainable development instead, which would further reduce the risk for war and disaster. Building a culture of prevention is not easy. While the costs of prevention have to be paid in the present, its benefits lie in a distant future. Moreover, the benefits are not tangible; they are the disasters that did NOT happen."

The consequences of the recent disasters (*26 Dec 2004 Indian Ocean earthquake and tsunami, hurricanes Katrina and Rita, 8 Oct 2005 Muzaffarabad, Pakistan earthquake*) have risen the understanding of the necessity to pay forward for mitigation of the catastrophes.

Conclusions – Implications for Physics

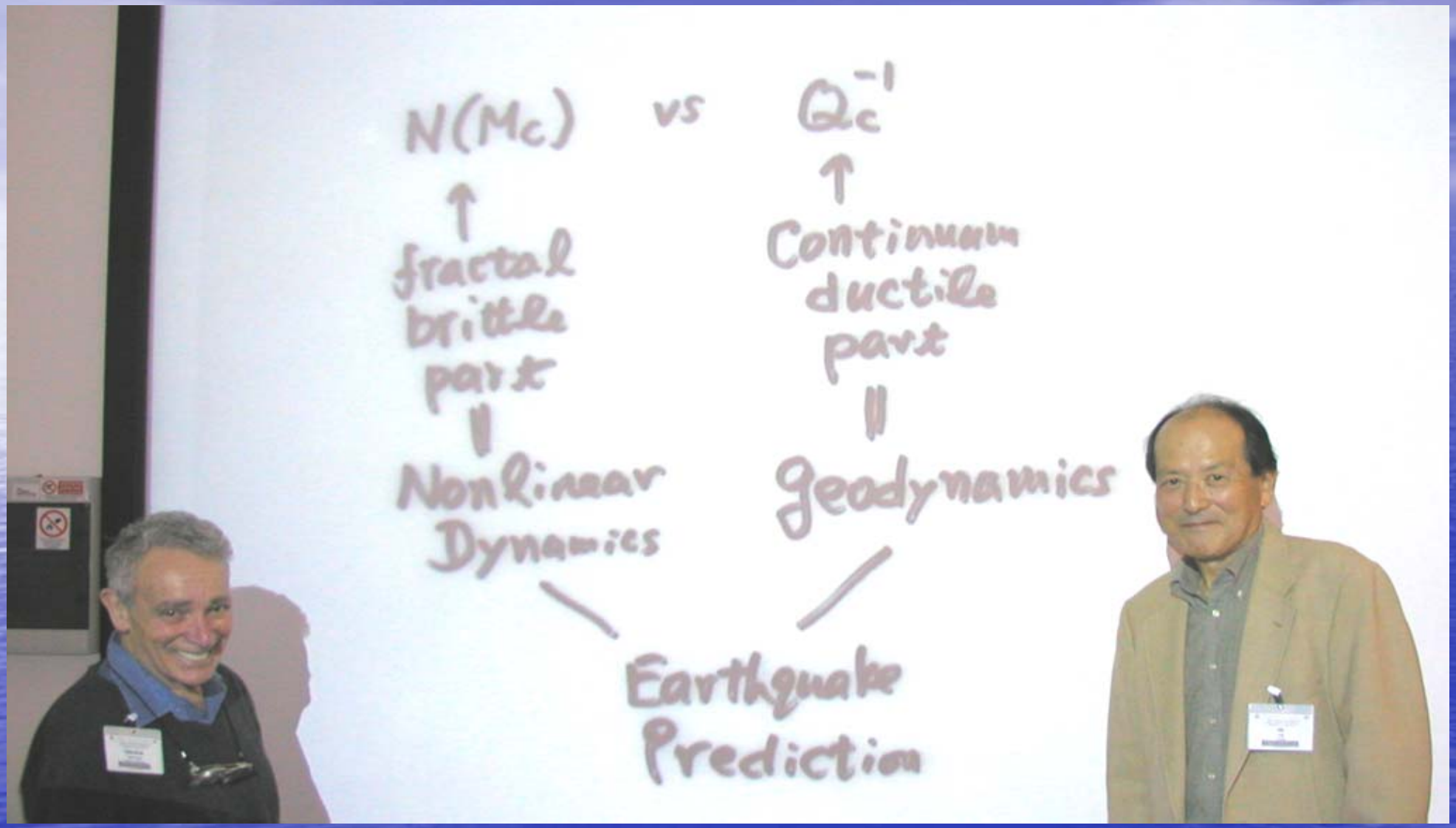
- The predictions provide reliable empirical constrains for modeling earthquakes and earthquake sequences.
- Evidence that distributed seismic activity is a problem in statistical physics.
- Favor the hypothesis that earthquakes follow a general hierarchical process that proceeds via a sequence of inverse cascades to produce self-similar scaling (*intermediate asymptotic*), which then truncates at the largest scales bursting into direct cascades (*Gabrielov, Newman, Turcotte, 1999*).

What are the Next Steps?

- The algorithms are neither optimal nor unique (CN, SSE, Vere-Jones "probabilistic" version of M8, etc.). The accuracy could be improved by a systematic monitoring of the alarm areas and by designing a new generation of earthquake prediction technique ("Seismic Reversal" - SR, ROC, Accord, RTP, etc.).

... and an obvious general one -

- More data should be analyzed systematically to establish reliable correlations between the occurrence of extreme events and observable phenomena.


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