

# La previsione dei terremoti non solo è impossibile, ma è anche inutile

Dario Slejko

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale



利用动物搞预报 简便易行好办到

地震前，地下的各种变化，动物的某些器官往往可以敏锐地感觉到，据历史记载以及近年对地震的调查，均证实动物有前兆反映。

# Cosa significa fare una previsione sismica?

Bisogna indicare:

1. Tempo
2. Luogo
3. Magnitudo
4. Margini di incertezza
5. La previsione deve essere verificabile
6. Terremoti avvengono comunque



# Tipi di previsione

Breve termine da minuti a settimane

Medio termine da mesi a 10 anni

Lungo termine > 10 anni

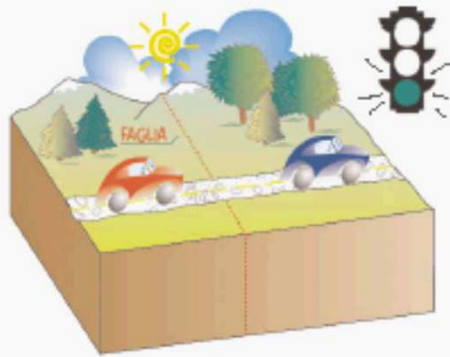


Namazu, il pesce gatto responsabile dei terremoti

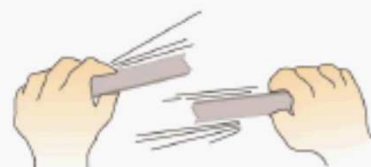
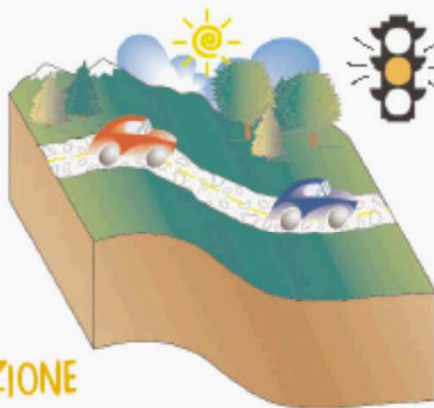




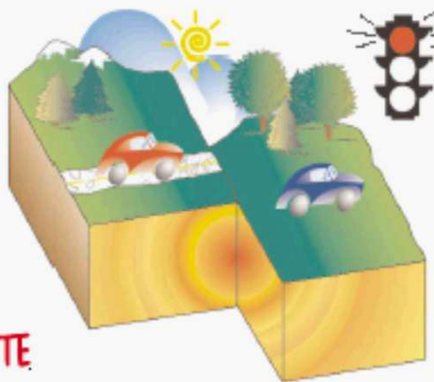
posizione originale:  
**SENZA DEFORMAZIONE**



accumulo di energia:  
**PROGRESSIVA DEFORMAZIONE**

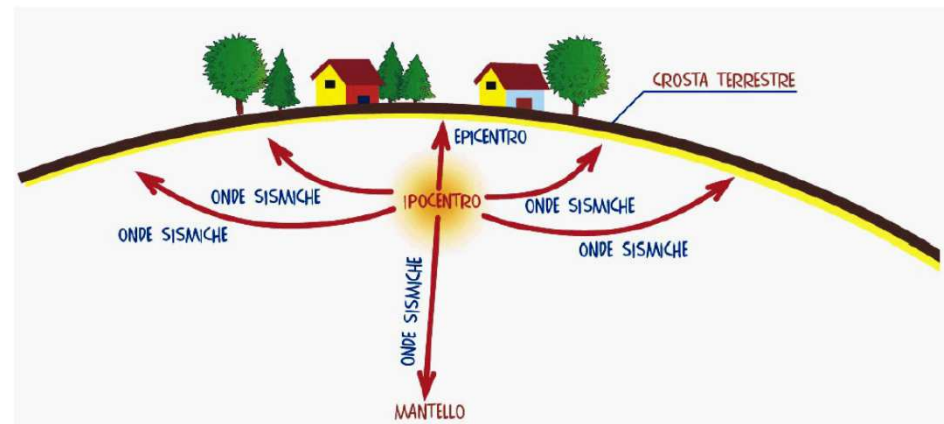


rottura con rilascio di energia:  
**TERREMOTO**  
**SPOSTAMENTO PERMANENTE**



# Cos'è il terremoto?

## Un rilascio di energia elastica

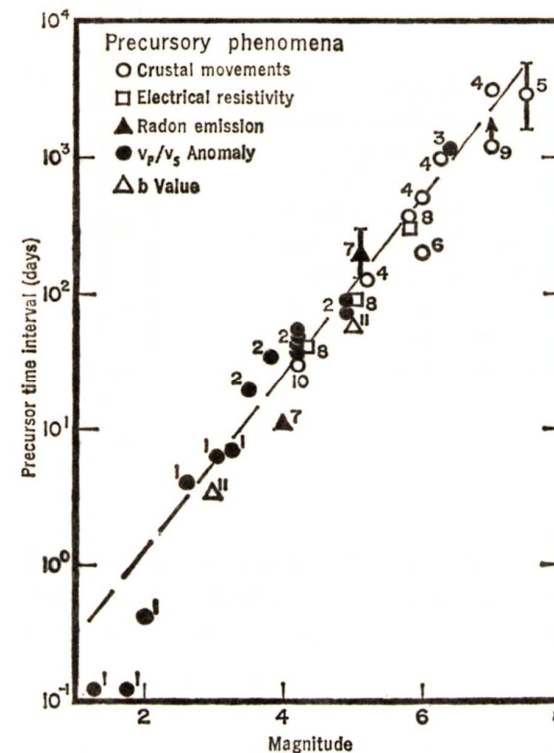


# Possibili fenomeni premonitori

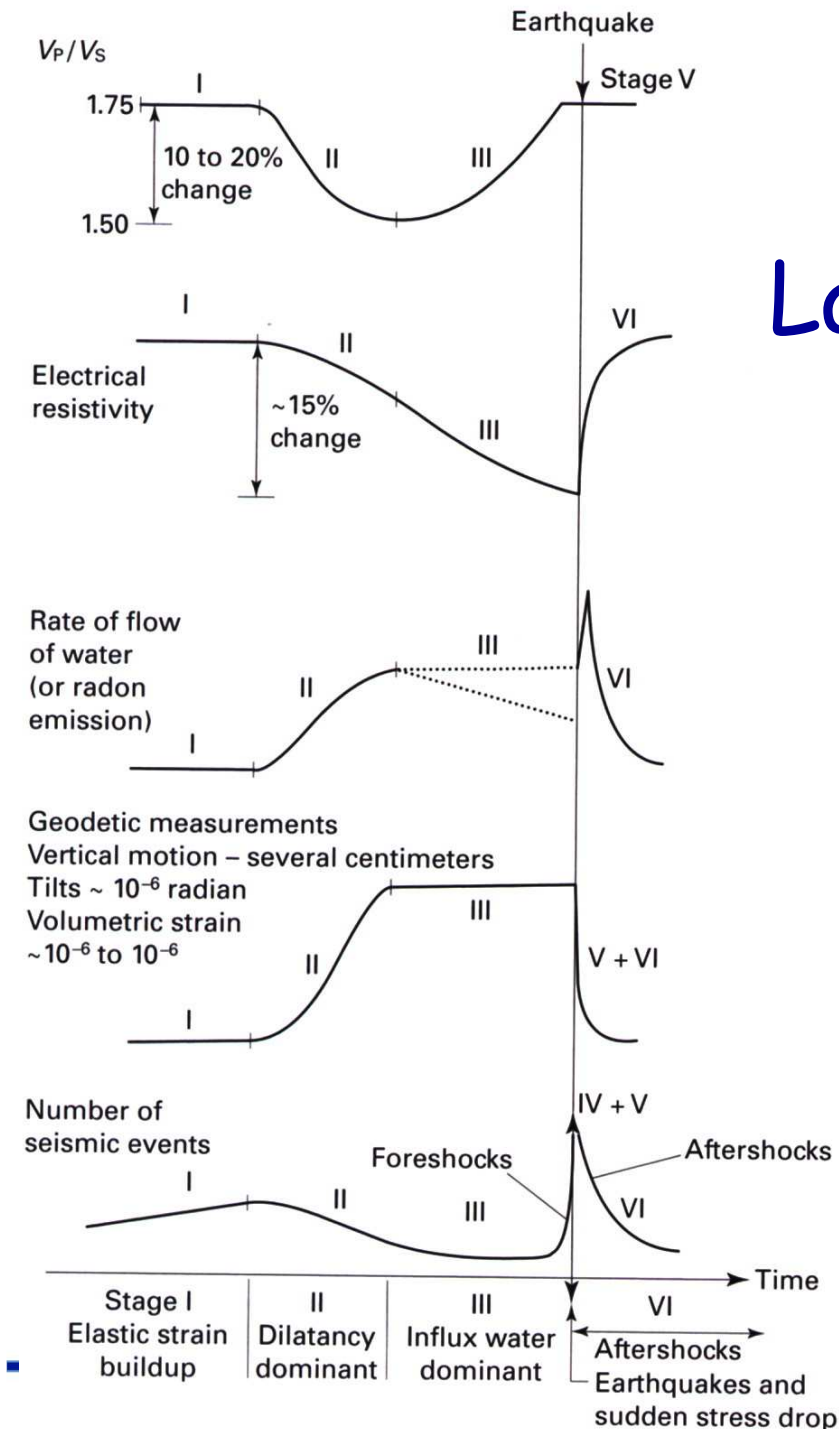
## Problemi:

1. Si verificano solo alcuni fenomeni
2. Si verificano solo in alcuni luoghi
3. Si verificano solo alcune volte

TABELLA INDICATIVA DEI FENOMENI PRECURSORI E DEI LORO PERIODI DI MANIFESTAZIONE	
■ = precursori a lungo periodo	
● = precursori a medio periodo	
★ = precursori a breve periodo	
Deformazione ed inclinazione del suolo	■ ●
Variazioni magnetiche	●
Maree terrestri	●
Rapporto fra scosse di magnitudo diversa	■
Spostamento degli ipocentri	■
Sismicità di bassa magnitudo	● ■
Tipo di rottura della crosta	■ ●
Scosse premonitrici	★
Velocità delle onde sismiche	■ ●
Livello dell'acqua nei pozzi	●
Correnti elettriche spontanee nel suolo	● ★
Resistività delle rocce	★ ●
Emissioni di gas	●
Emissioni di rado	■ ●
Emissioni luminose	★
Comportamento degli animali	★ ●



# Perchè dovrebbero esserci precursori? La teoria della dilatanza



Le rocce si dilatano prima di un terremoto e, con l'aumento del loro volume, la superficie del terreno si gonfia leggermente (misurabile con livellazioni geodetiche), la densità delle rocce diminuisce, si aprono crepe e la successiva introduzione di acque sotterranee modifica la resistività elettrica delle rocce. L'apertura di fessure facilita la fuoriuscita di  $R_n$ , prodotto dal decadimento radioattivo in rocce nel sottosuolo, e produce un picco nelle misure di  $R_n$  in superficie.

# Successi e Fallimenti

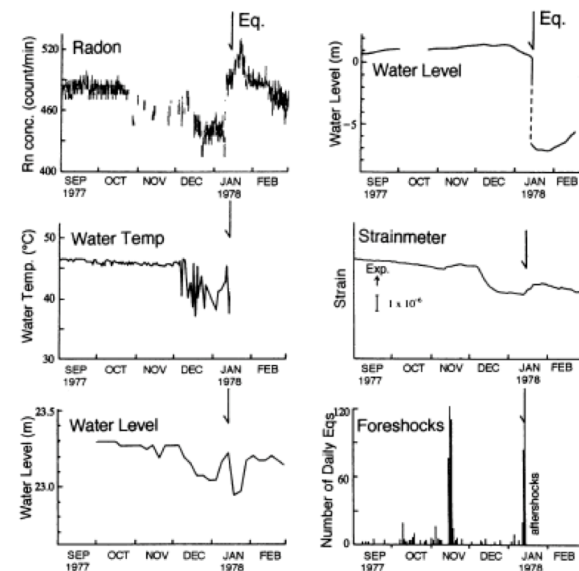
## *Terremoti previsti*

- 1973 Blue Mountain Lake (simili osservazioni non furono in seguito confermate)
- 1975 Haicheng, Cina
- 1978 Oaxaca, Messico (lo studio ipotizzava solo la possibilità di un evento)
- 1978 Izu, Giappone (non una previsione ma un avvertimento sulla base di una

sequenza in atto)

## *Terremoti non previsti*

- 1976 Tangshan, Cina  
(M7,7 650.000 morti stimati)
- 2004 Parkfield, California



# Perchè i precursori non sono stati osservati con successo?

- Gli esperimenti con gli animali sono falliti
- I premonitori sono stati individuati solo a posteriori (dopo il terremoto)
- Richiedono ampia dotazione strumentale
- Dipendono dalle condizioni geologiche (specialmente luci ed effetti piezoelettrici)
- Gli algoritmi predittivi non hanno funzionato (almeno per la previsione a breve termine)
- I terremoti non si ripetono mai in maniera uguale
- Non esiste alcuna correlazione con le maree terrestri o l'allineamento dei pianeti
- La psicologia non ha mai fatto previsioni attendibili





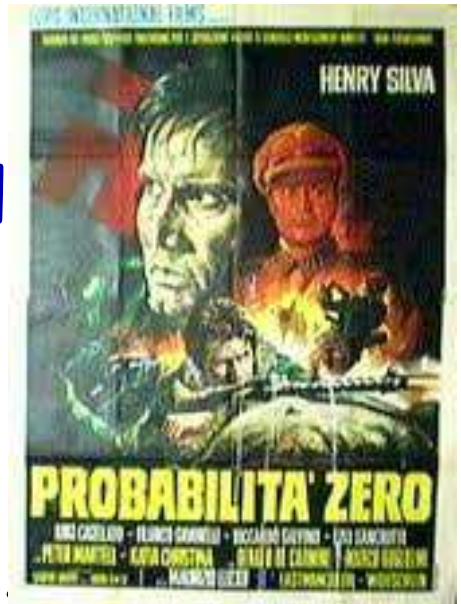
# Frase forte 1: la previsione a breve - medio termine **OGGI** è impossibile

- Molti precursori vengono individuati solo dopo che il terremoto è avvenuto
- L'unico allarme seguito da terremoto è stato quello di Haicheng, basato su una particolare sequenza sismica in



## Frases forte 2: la previsione a breve - medio termine può essere inutile

- La probabilità che una previsione sia esatta è bassissima e, comunque, potrebbe evitare perdite umane solo nel caso di terremoto forte e non eviterebbe i danni
- Una previsione sbagliata (cosa frequente) può provocare danni maggiori anche di quelli causati da un terremoto (se debole)



# Ma allora non possiamo prevedere nulla?

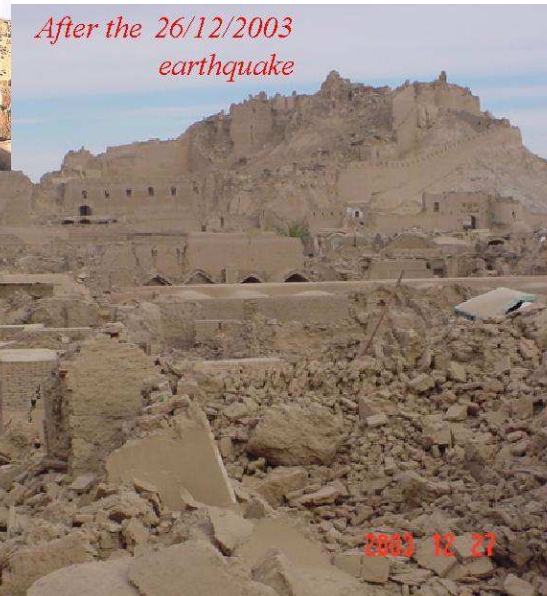
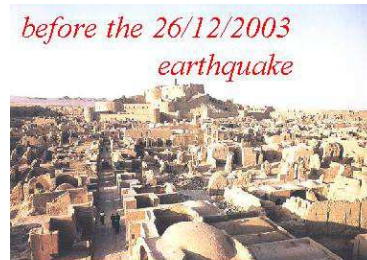
- Esiste la previsione a lungo termine che non dice quando un terremoto avverrà ma che in una regione esiste la probabilità che un sisma avvenga nelle prossime decine d'anni: dunque **PREPARIAMOCI**



## Frases forte 3

“Costruire una cultura di prevenzione non è facile perchè i benefici non si vedono subito: i benefici sono i disastri che non si verificheranno”

Kofi Annan,  
segretario delle Nazioni Unite  
dopo il terremoto di Bam

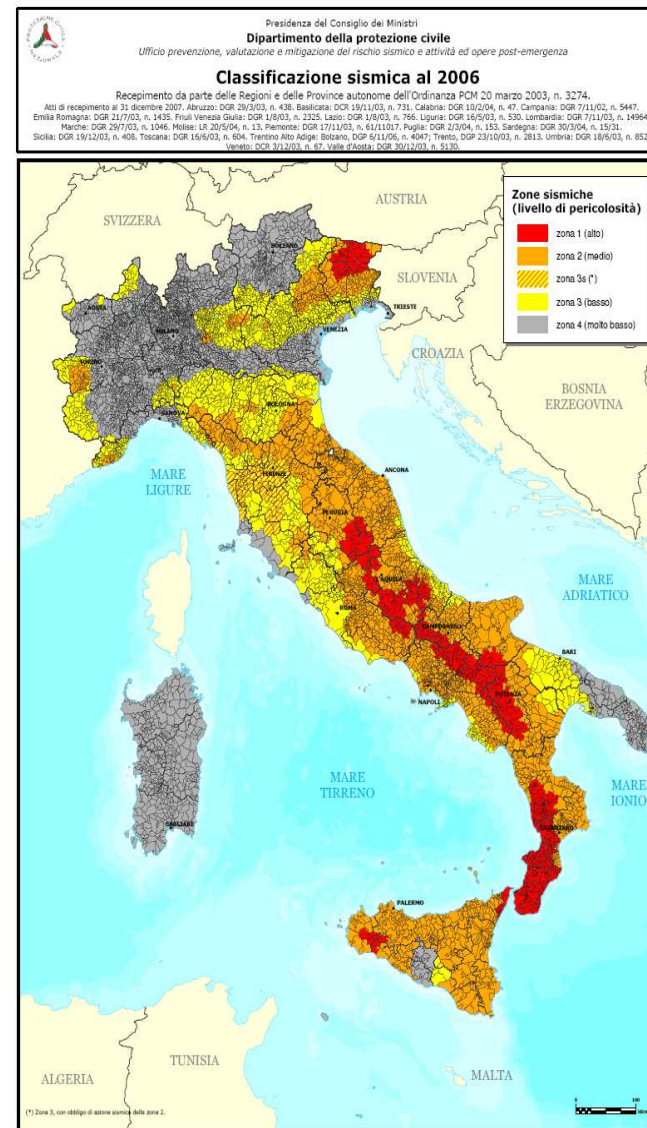
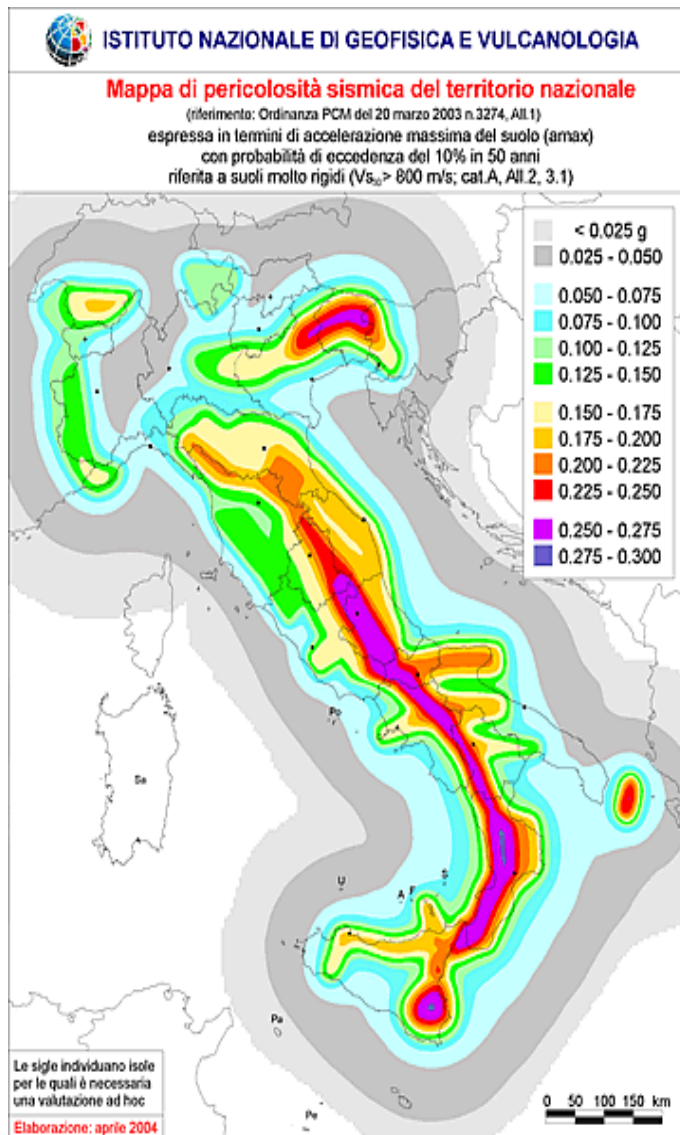


# Qual è la strada giusta?



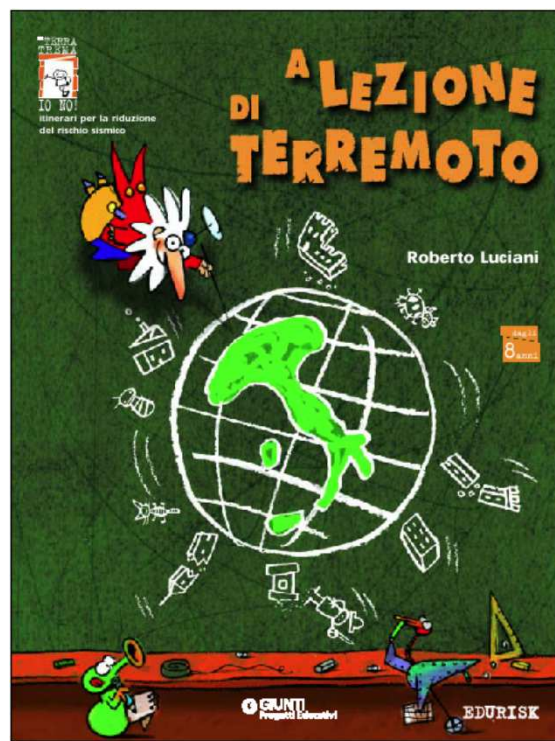
- Prevenzione  
perchè la nostra casa non ci crolli sulla testa
- Istruzione  
per sapere cosa fare nel caso di terremoto

# Mappa di pericolosità sismica nazionale a seguito dell'OPCM 3274 e classificazione





Kit per bambini da 4 a 7 anni  
(materna, 1° ciclo elementare)



Quadernone attivo per la fascia 8-10 anni  
(2° ciclo elementare)

Libro ad uso di ragazzi 11-13 anni  
(scuola media)



# Fine della presentazione



- That's all folks!





# La domanda delle 100 pistole

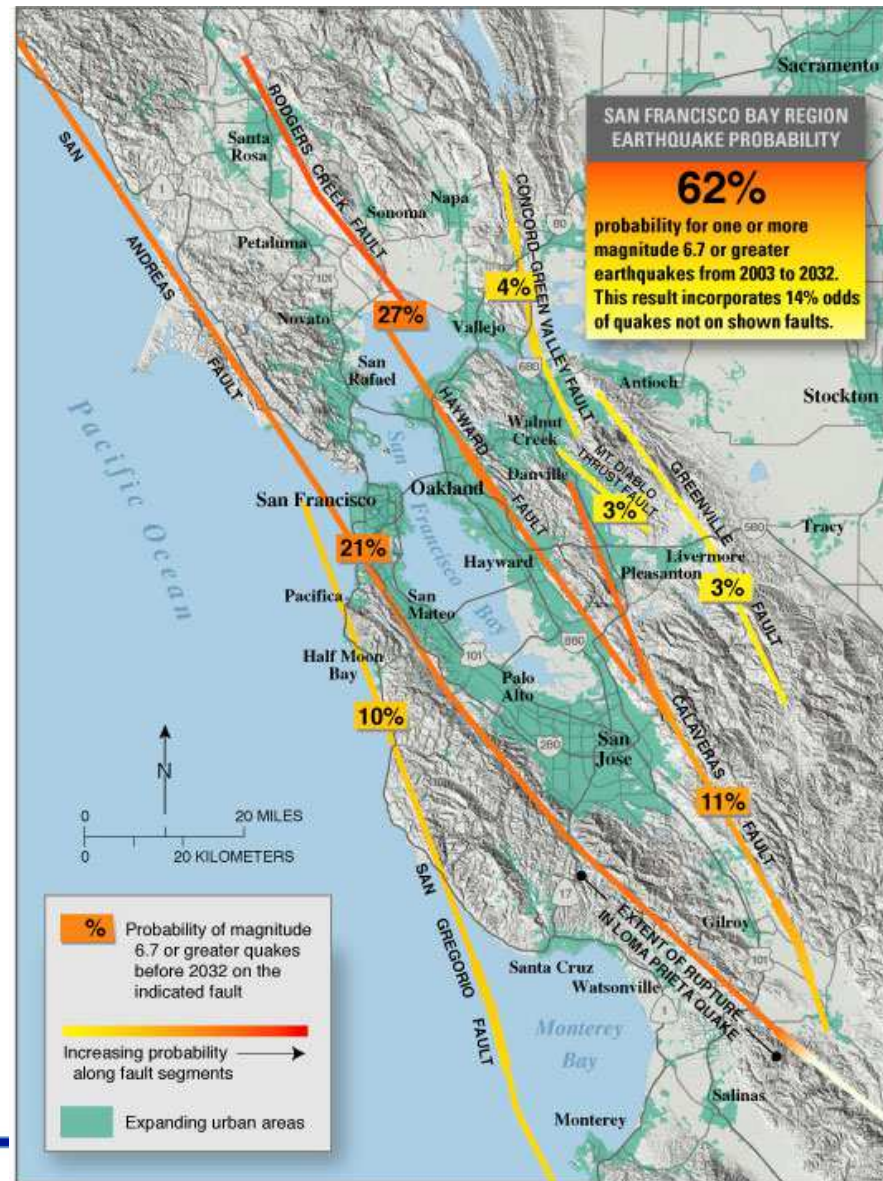


Si possono prevedere i terremoti?

# Earthquake occurrence probabilities

USGS seismic hazard map showing the probability of an **M6.7 or greater earthquake occurring in the San Francisco Bay Area between 2003 and 2032.**

Recent (January 2008) assessments (San Jose Mercury News: Hayward fault might be more dangerous than scientists thought) suggest that the Hayward, Rodgers Creek, and northern Calaveras faults may be more likely to fail in the next few decades than previously thought (more so than is indicated on this map).



## TABELLA INDICATIVA DEI FENOMENI PRECURSORI E DEI LORO PERIODI DI MANIFESTAZIONE

- = precursori a lungo periodo
- = precursori a medio periodo
- ★ = precursori a breve periodo

Deformazione ed inclinazione del suolo ■ ●

Variazioni magnetiche ●

Maree terrestri ●

Rapporto fra scosse di magnitudo diversa ■

Spostamento degli ipocentri ■

Sismicità di bassa magnitudo ● ■

Tipo di rottura della crosta ■ ●

Scosse premonitrici ★

Velocità delle onde sismiche ■ ●

Livello dell'acqua nei pozzi ●

Correnti elettriche spontanee nel suolo ● ★

Resistività delle rocce ★ ●

Emissioni di gas ●

Emissioni di rado ■ ●

Emissioni luminose ★

Comportamento degli animali ★ ●

### I DUE PIÙ FAMOSI ESEMPI CINESI

Questa è la sintetica cronistoria di due previsioni, quella viene riferita da missioni scientifiche americane, giapponesi e neozelandesi.

Il terremoto di Haicheng avvenuto il 4 febbraio 1975

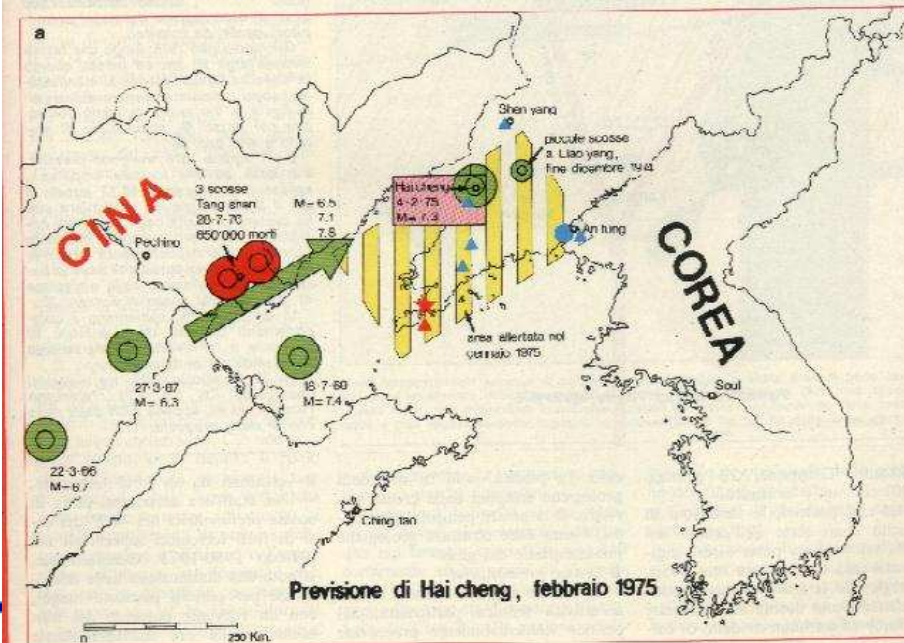
Provisione di medio-lungo periodo: nel giugno 1974 viene giudicato probabile un terremoto forte a nord della baia di Pohai (fig. a) entro il 1976, sulla base di una tendenza dei terremoti a spostarsi verso Nord-Est (cerchi ● o treccia verde, nella stessa fig. a). Questo andamento verrà però clamorosamente contraddetto nel 1975 con i tremendi terremoti di Tangshan (epicentri indicati da cerchi rossi ● nella figura a, in basso).

Giugno-dicembre 1974: variazioni di livello nell'acqua nei pozzi e comportamenti anomali di animali ●, ad Antung. Serie di piccole scosse sismiche nei dintorni di Liao-Yang.

Gennaio 1975: è posta in allarme l'area tratteggiata in giallo. In essa si verificano anche piccoli cambiamenti di quota ed inclinazione del suolo [★], anomalie magnetiche [▲], variazioni di livello dell'acqua nei pozzi [●] e comportamenti strani di animali, uniti ancora ad esaltazioni di rado [▲].

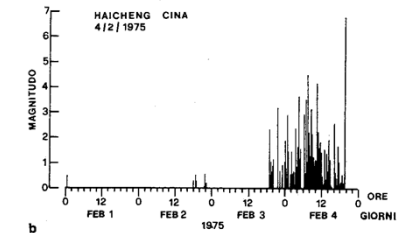


Fine gennaio 1975: le anomalie sono sparse ancora in un'area di circa 32.000 chilometri quadrati. 3 febbraio 1975, ore 18.00: inizia una intensa serie di scosse (466 fino alle 13.00 del 4 febbraio), nella zona di Haicheng. Otto scosse superano l'intensità del IV-V Mercalli. La popolazione



La previsione sismica:  
un argomento, ancora,  
di ricerca scientifica

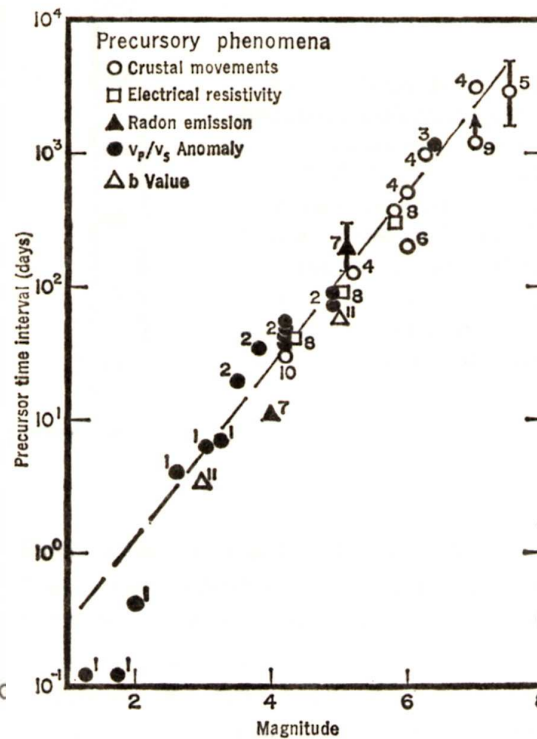
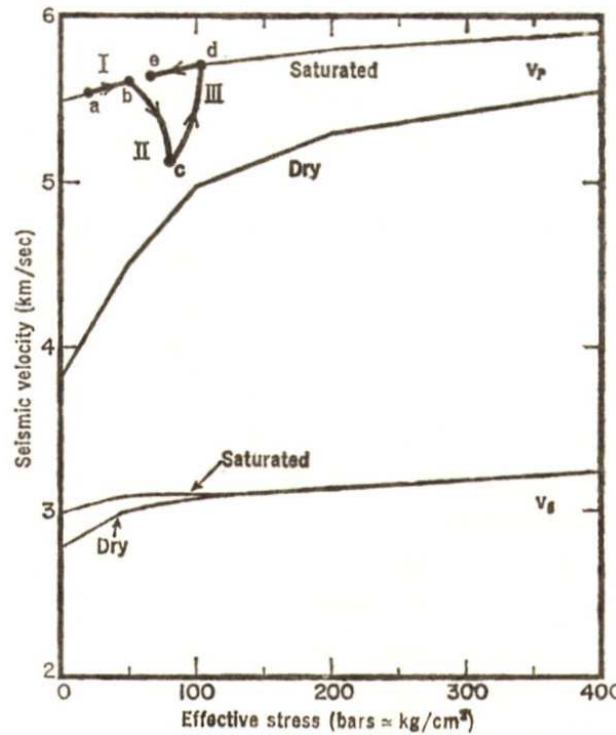
Haichen feb. 1975: previsto  
Tanshang lug. 1976: 255.000 mort



b



# The theory of dilatancy (1)



Proposed in spring 1973

## SCIENCE

Vol. 181, 803-810

### The Dilatancy Model

Observations for a number of earthquakes made at Garm, U.S.S.R., and in the New York Adirondacks and observations of the San Fernando earthquake show that, prior to each of these earthquakes, the ratio of seismic velocities  $v_p/v_s$  decreased to anomalously low values. In each of these cases, earthquakes occurred shortly after the return of  $v_p/v_s$  to its normal value.

Nur (4) and Aggarwal *et al.* (2) independently put forward a model that would explain this phenomenon. The model is based on laboratory fracture studies which show that rock

### Earthquake Prediction: A Physical Basis

Rock dilatancy and water diffusion may explain a large class of phenomena precursory to earthquakes.

Christopher H. Scholz, Lynn R. Sykes, Yash P. Aggarwal



# Earthquake Predictions vs. Forecasts

Predictions have specific times, locations, and magnitudes for future earthquakes.

Forecasts are more long-term estimates of earthquake occurrences with probability information.



# Types of forecasts

## *Forecast*

Short-term (minutes to weeks)

Intermediate (months to 10 years)

Long-term (> 10 years)

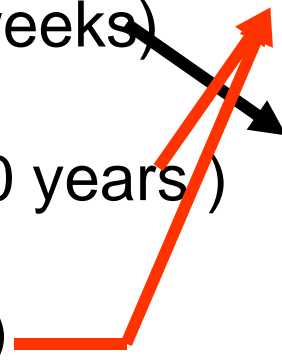
## Loading Cycle

Interseismic

Preseismic

Coseismic

Postseismic



# Optimism in the 1960s and 1970s

*'Now, when will earthquake prediction be possible and an efficient Forewarning service available ? ...if we start the project presented here we should be able to answer the question with sufficient certainty within ten years.'*

The Japanese Blueprint (Tsuboi et al., 1962)

*'Based on an assessment of worldwide observations and findings over the past few years, it is the panel's unanimous opinion that the development of an effective earthquake prediction capability is an achievable goal. ...with appropriate commitment and level of effort, the routine announcement of reliable predictions may be possible within ten years...'*

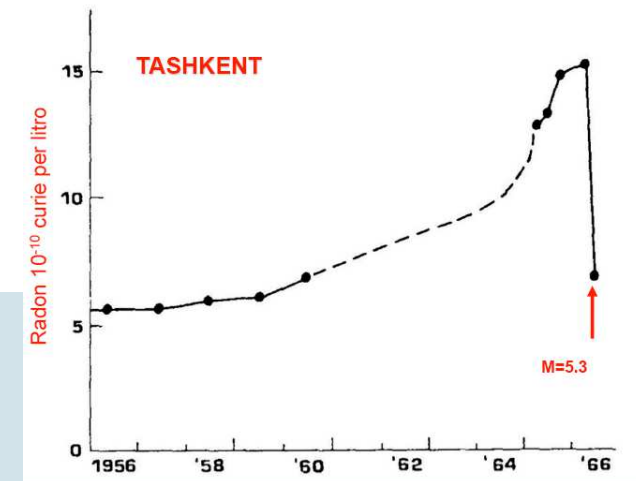
Panel of the US National Research Council (Allen et al., 1976)



# Radon anomalies

## Changes in radon concentration in geothermal water in relation to earthquakes in South Iceland

P.Einarsson, A.R. Hjartardóttir, P. Theodórsson, G.Jónsson, 2005



Radon anomalies were observed before **30 of 98** significant seismic events, and **35%** of all observed anomalies were related to seismicity.

Three types of change could be identified:

1. Pre-seismic decrease of radon at all stations. Anomalously low values were measured **101-167** days before the earthquakes.
2. Pre-seismic increase. Spikes appear in the time series at 6 stations **40-144** days prior to the earthquakes. These anomalies were large and unusual if compared to a 17 years history of radon monitoring in this area.
3. Co-seismic step, most likely related to the co-seismic change in ground water pressure observed over the whole area.



# Blue Mountain Lake, NY, prediction

NATURE VOL. 241 JANUARY 12 1973

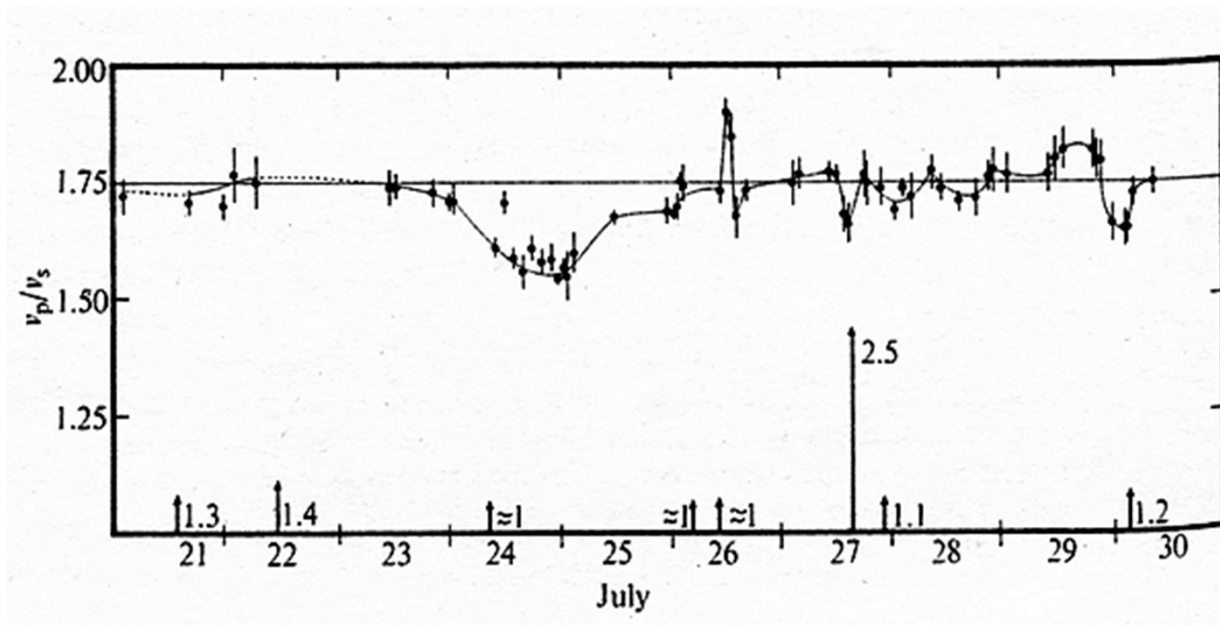
101

## Premonitory Changes in Seismic Velocities and Prediction of Earthquakes

YASH P. AGGARWAL, LYNN R. SYKES,  
JOHN ARMBRUSTER & MARC L. SBAR

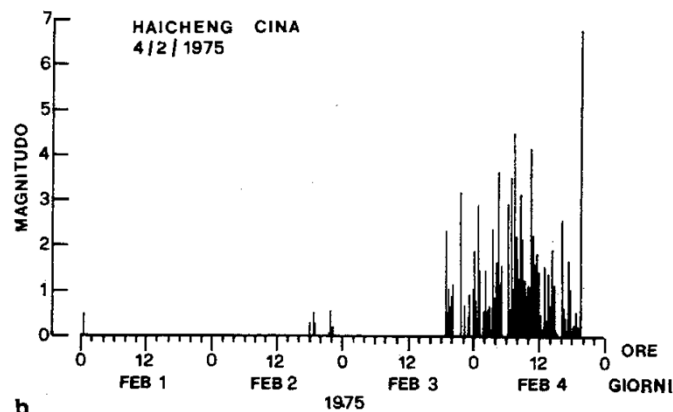
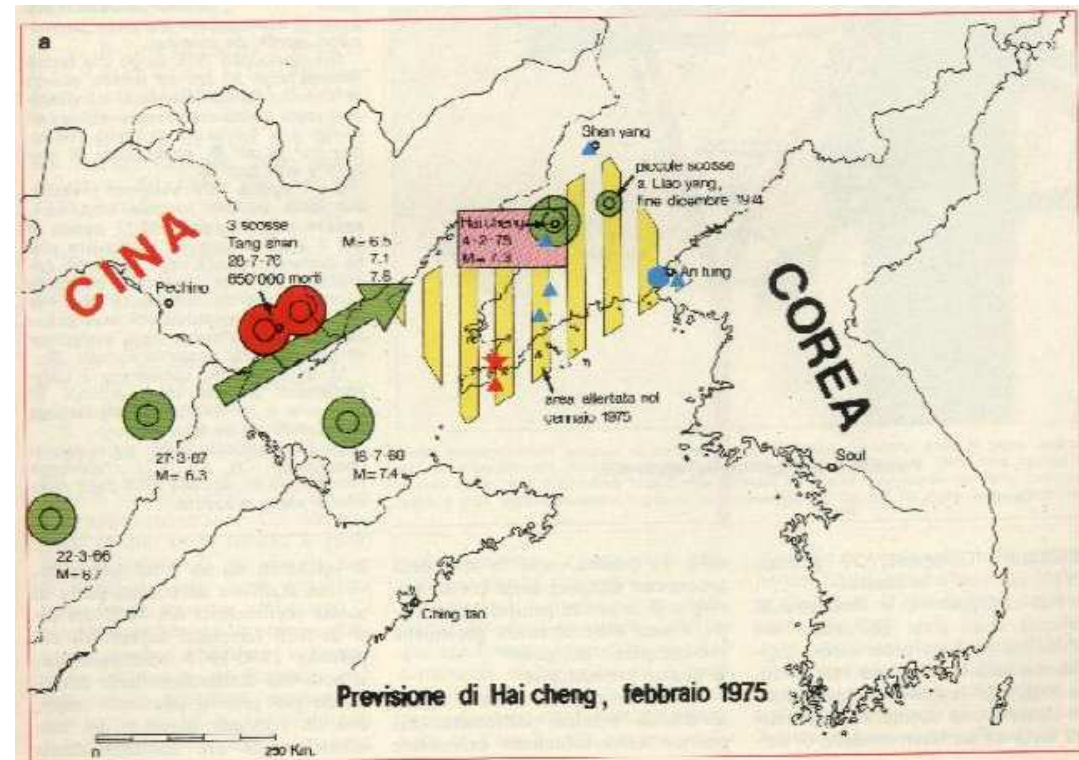
Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964

$v_p/v_s$  variations were observed by Soviet seismologists since the 1960s in the Garm region of Tajikistan.



# The steps of the Heicheng earthquake prediction

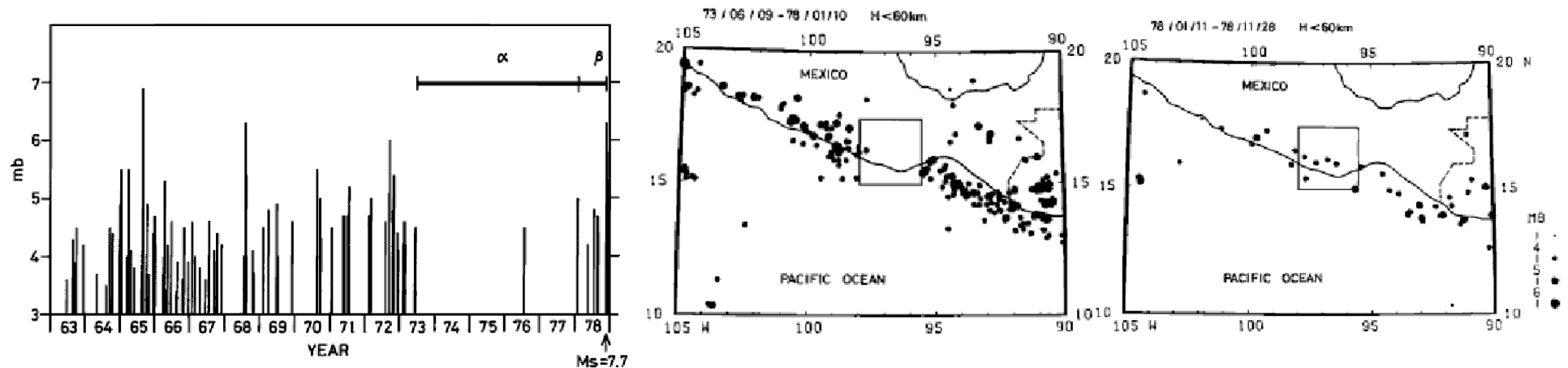
- A seismicity migration towards the Heicheng area was observed in **1966** (green circles and arrow).
- Seismicity around Heicheng increased from **1974** with several M5.0 earthquakes and soil deformation (red stars) was observed.
- Level variations in the wells and strange animal behaviour (blue dots), radon emissions (blue triangles), magnetic anomalies (red triangles) were observed in **January 1975** and the ground started to crack downtown Heicheng.
- The area dashed in yellow was alerted in January 1975.
- 500 earthquakes in the M range 1 to 3.5 were recorded between **February 1 and 4**, 1975.
- Heicheng population was evacuated on **February 1**.
- Seismic activity stopped on **February 4**.
- An M7.2 earthquake occurred during the night from **February 4 to 5**.



# M7.8 Oaxaca (Mexico) earthquake of November 29, 1978

The epicenter location and magnitude of the 1978 Oaxaca earthquake were successfully predicted based on the premonitory **seismic quiescence and the seismic gap** of the past large earthquakes. From a scientific point of view, it is important that the rupture zone of the main shock was accurately predicted.

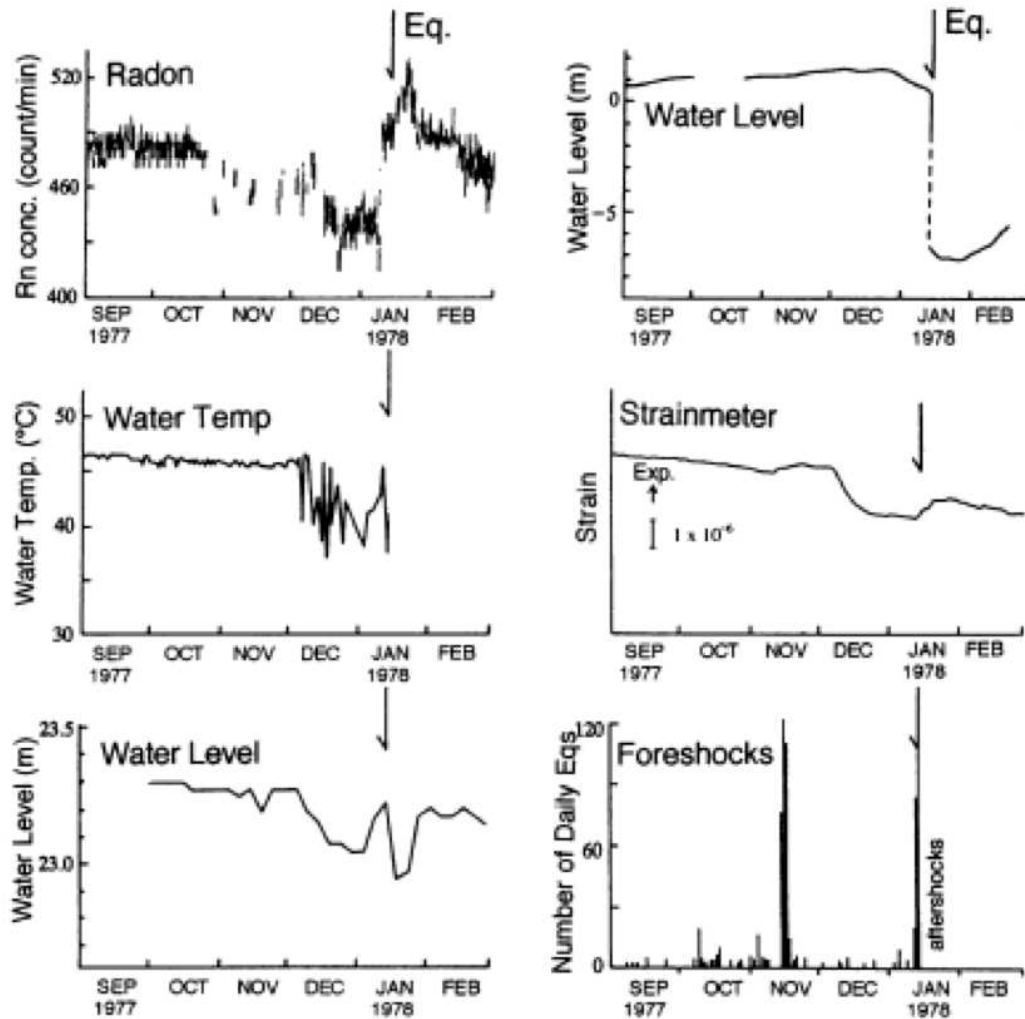
Aftershocks of the Oaxaca earthquake define a rupture area of about 6000 km<sup>2</sup> along the boundary of the Cocos sea-plate subduction. This area had not ruptured in a large ( $M_s \geq 7$ ), shallow earthquake since the years 1928 and 1931 and had been designated a seismic "gap." The region has also been seismically quiet for small to moderate ( $M \geq 4$ ), shallow (depth  $\leq 60$  km) earthquakes since 1966; this quiet zone became about six times larger in 1973. A major earthquake ( $M_s = 7.5 \pm 0.25$ ) was forecast at this location on the basis of the quiescence that began in 1973. The aftershock data indicate that an area approximately equivalent in size to the seismic gap has now broken.



The 43 foreshocks of magnitude  $M > 2.8$  were recorded by the network in a period of 20 days prior to the mainshock. These events show an interesting spatial and temporal pattern, which culminates in the last 1.8 days of the sequence with an apparent migration of activity towards the epicenter of the impending earthquake. This pattern can be interpreted as a buildup of stress or migration of stress towards a fault zone asperity.



# M7.0 Izu earthquake of January 14, 1978



Among others, **precursory changes in the Rn** concentration of groundwater were observed prior to the M7.0 Izu earthquake. The distance from the epicenter to a continuous radon-monitoring station at Nakaizu was about 25 km. A sudden drop and a subsequent increase in the Rn concentration recorded on 9 January 1978 were significant. The size of the spike-like change was about 15%. After the earthquake, a remarkable increase in the Rn concentration occurred.

Wakita, 1996



For short-term prediction, there have been more negative results than positive results:

*Not Predicted*

- 1976 Tangshan, China  
(M7.7 650,000 est. casualties)
- 2004 Parkfield, California

*Other precursors have not been consistently seen*



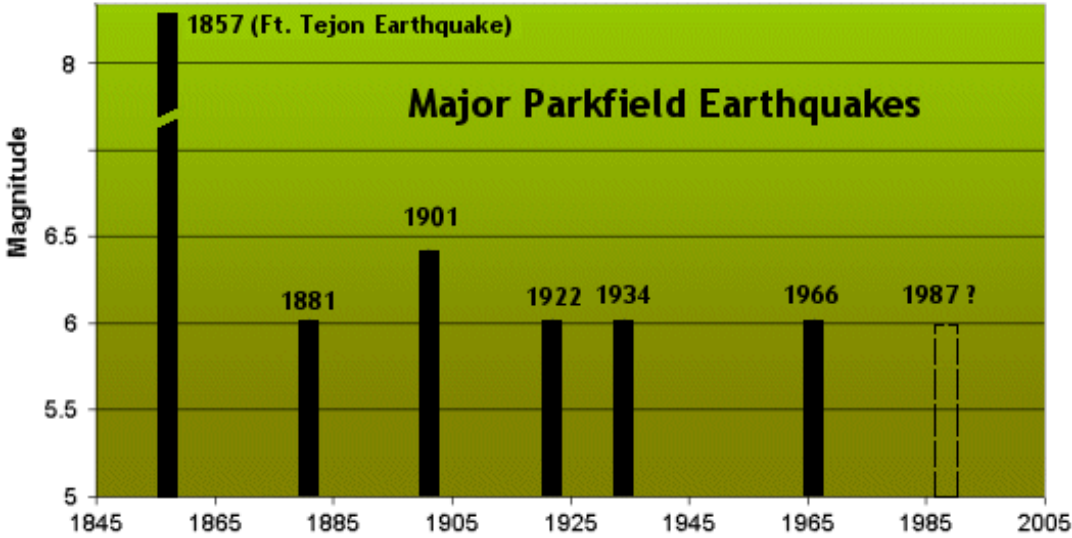
# The Parkfield experiment (1)



ANNO	M
1857	6.0
1881	5.8
1901	6.0
1922	6.0
1934	6.0
1966	6.0

1985 USGS forecast: 95% chance of an M5.5-6.0 earthquake before 1993

2004: an M6.0 earthquake occurred without any precursors

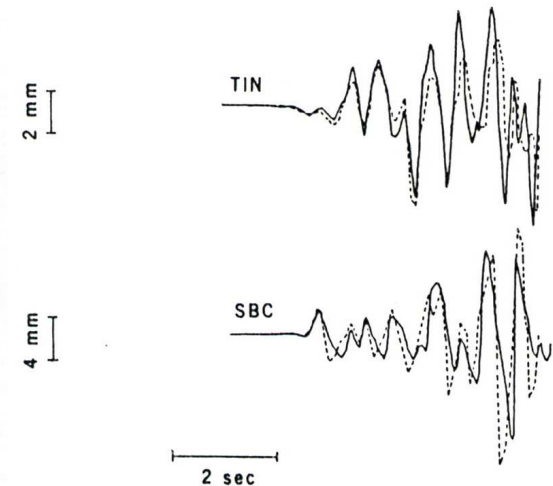
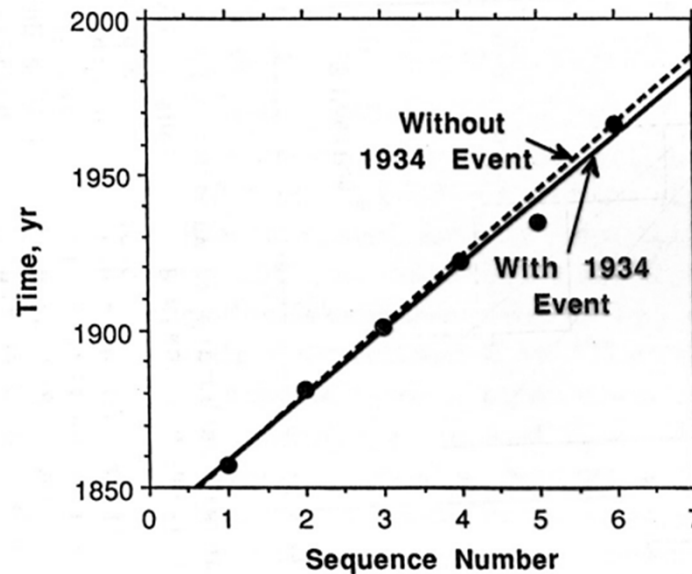
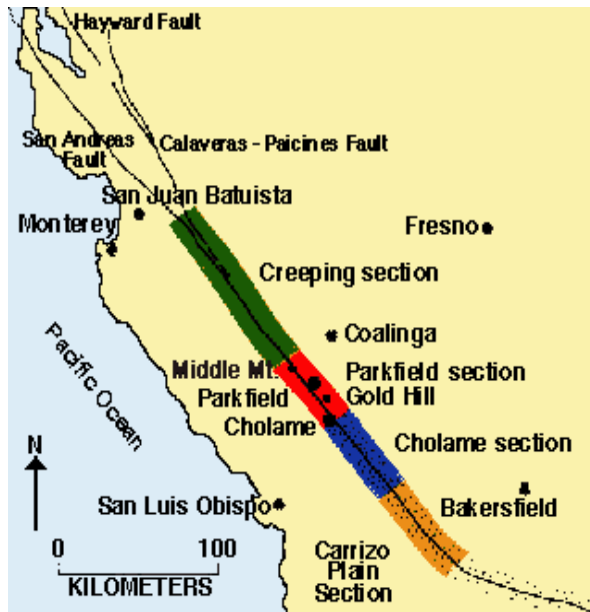


# The Parkfield experiment (2)

95% probability that M5.5 to 6 will occur 1985-1993

Based on

- Recurrence pattern
- Characteristic waveforms
- M5 foreshock 17 minutes before 1934 and 1966 events



Bakun and McEvilly, 1979

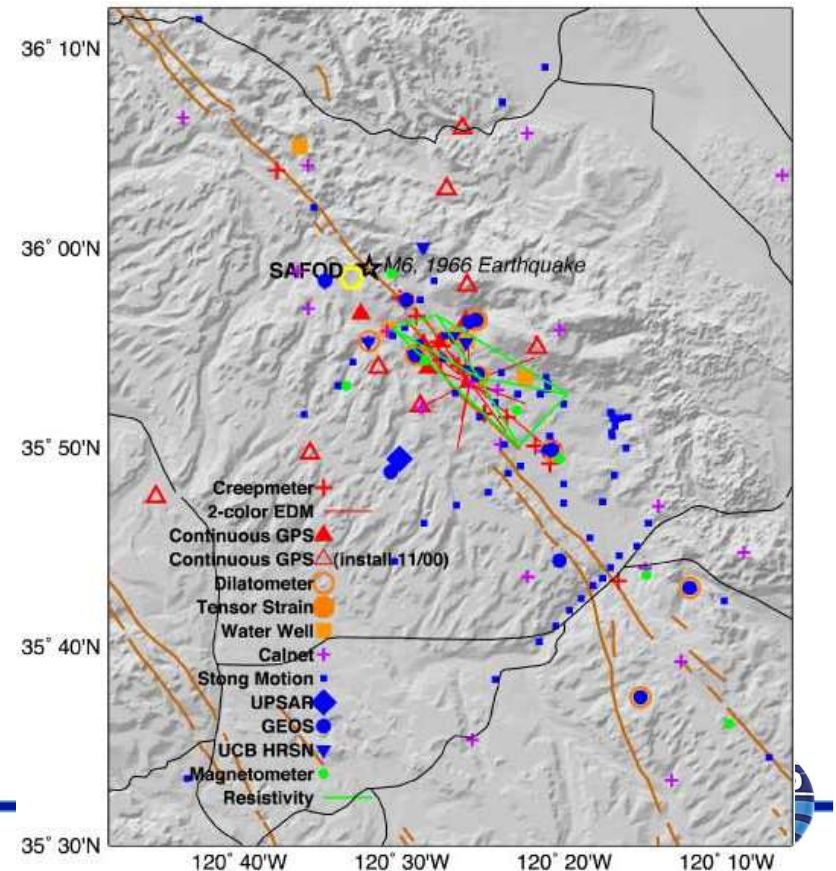


# The Parkfield experiment

## (3)

In the mid 1980s the USGS and several California universities initiated an intensive seismic monitoring program at Parkfield. The program includes the following instrumentation:

- 12 creep meters (to measure slow aseismic slip on the fault);
- 2 electronic distance measurement instruments (to monitor displacement);
- 12 GPS stations (to monitor displacement);
- 8 dilatational strain meters (to assess strain build-up in rocks);
- 3 tensor strain meters (to assess strain build-up in rocks);
- 12 short-period seismometers;
- 10 bore-hole seismometers;
- 30 strong motion sensors (to measure the ground motion associated with a large earthquake);
- a 2.2 km deep borehole with various instrumentation (SAFOD project started in 2004);
- a proposed 4 km deep borehole with various instrumentation.

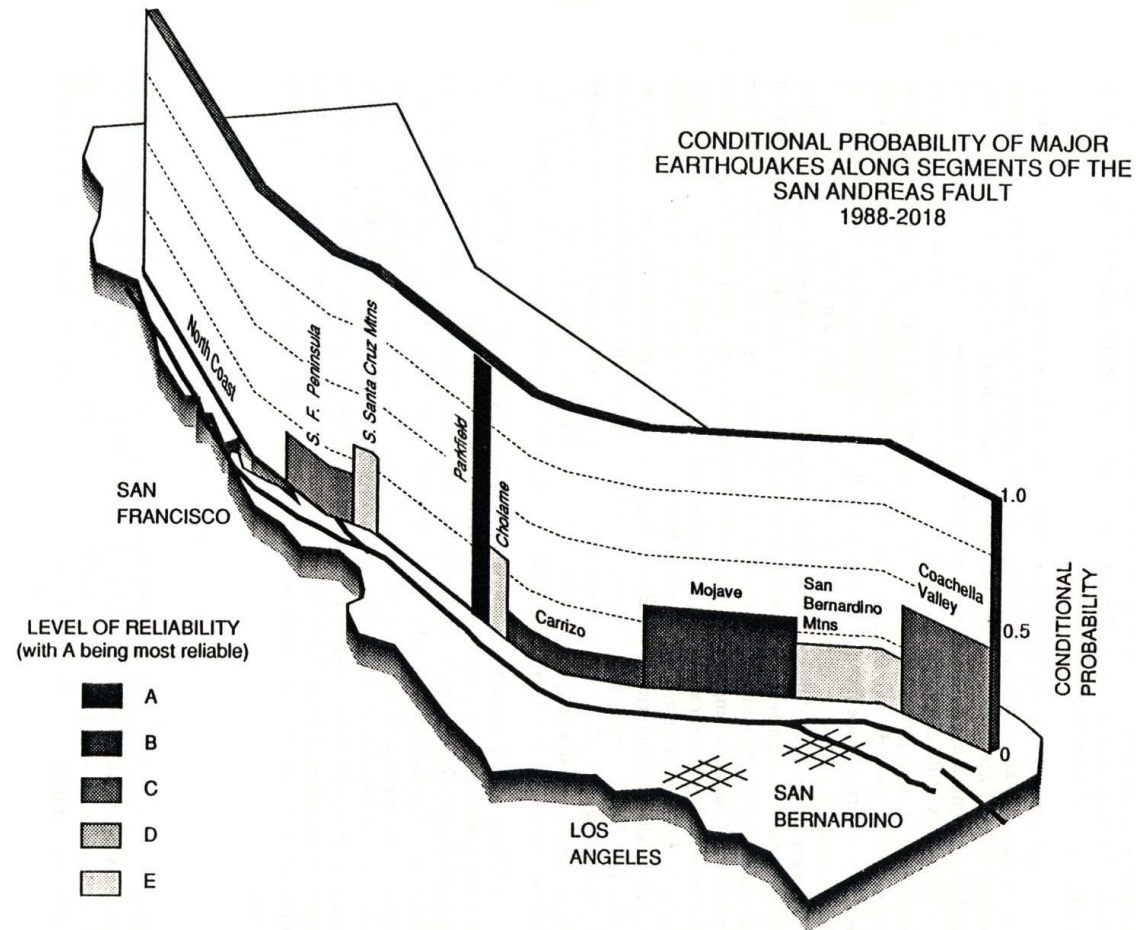




# Probabilistic Earthquake Forecasting for California

Recurrence times of earthquakes to forecast future earthquakes

- Using historic data
- Using geologic data



# Short-Term Crustal Deformation Precursor (M 8.1 Tonankai Earthquake 1944)

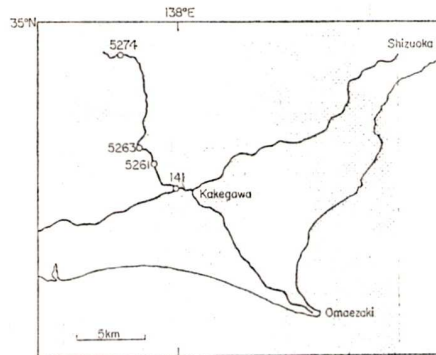
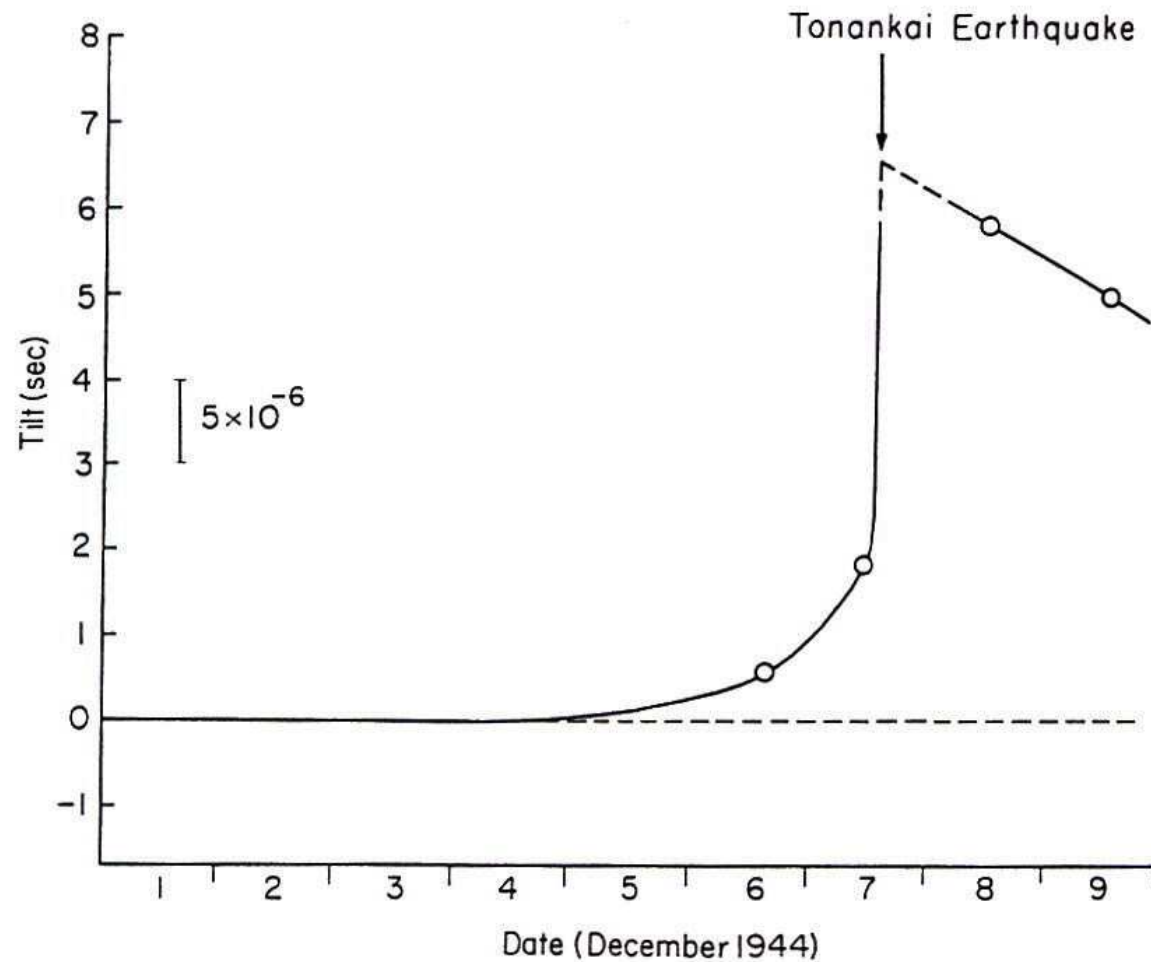


Fig. 1. Leveling routes in the Tokai region surveyed before and after the 1944 Tonankai earthquake.



# Short-Term Electromagnetic Precursor 1989 Loma Prieta Earthquake

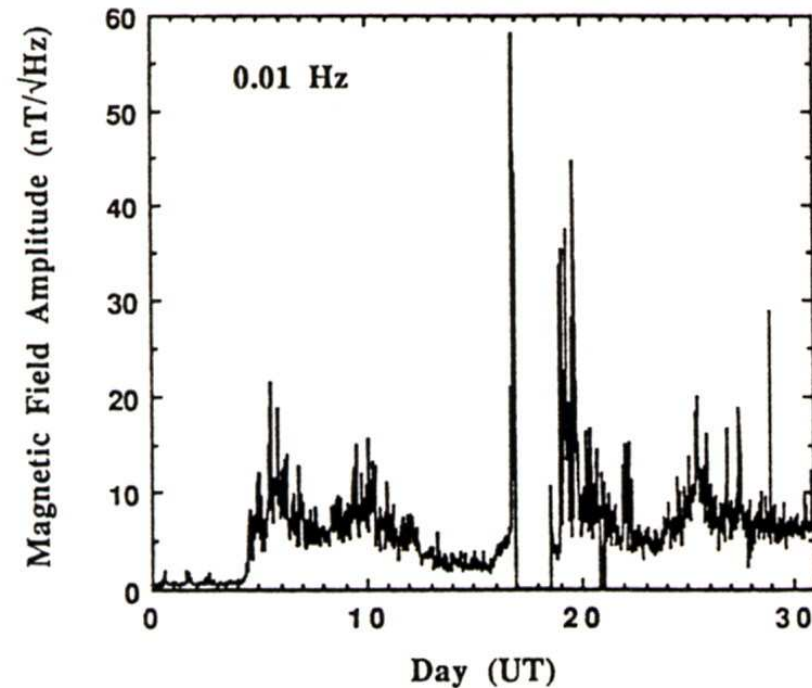
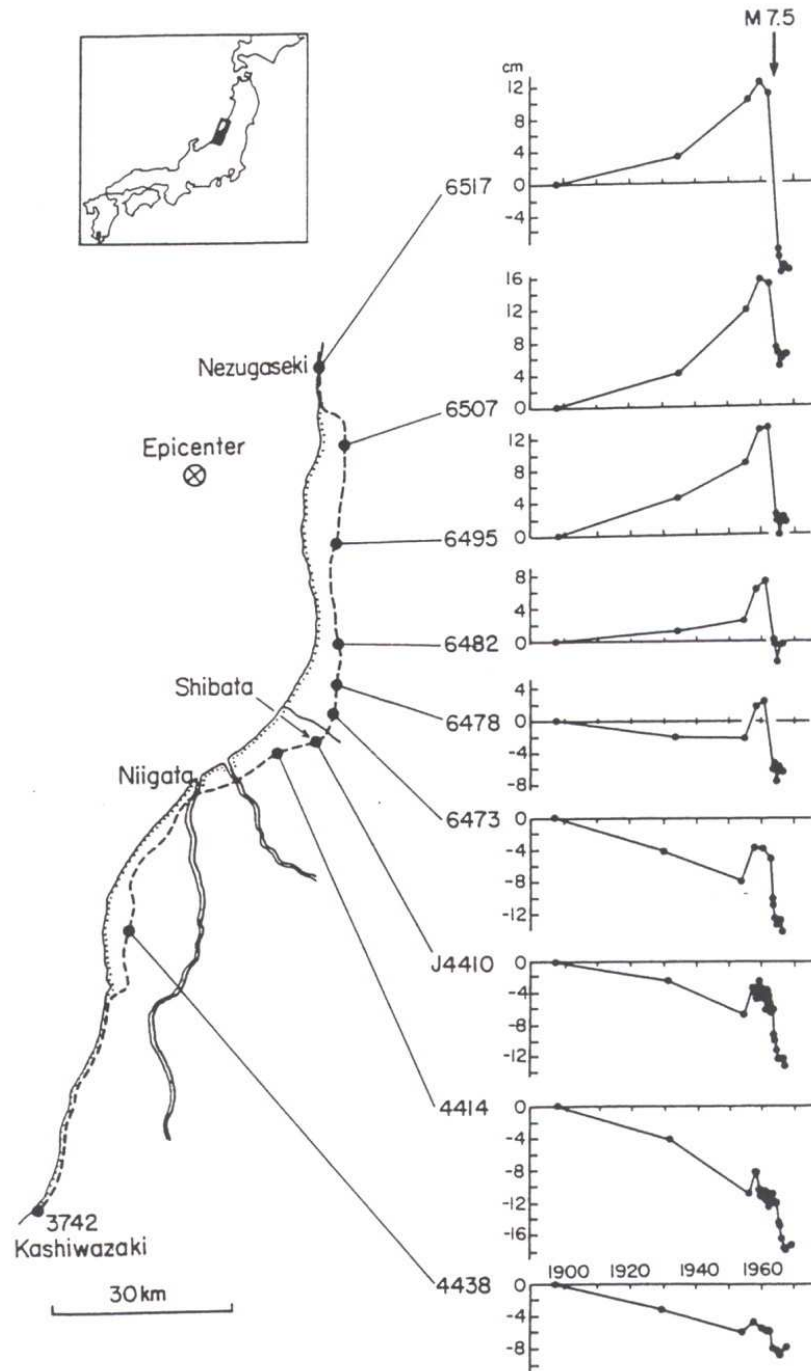


Fig. 3. Variation of the Corralitos 0.01 Hz magnetic field measurements during October 1989. The Loma Prieta earthquake started just after 0004 UT on October 18 and a power failure occurred almost immediately, whereupon the magnetic field measurements went to zero. The large peaks following the earthquake include many aftershocks as well as a magnetic storm that peaked October 20–21. The amplitudes can be converted to nT units (where 1 nT = 1000 pT) by multiplying by  $\sqrt{0.00732}$ , or 0.0855.



## *Intermediate-Term: Crustal Deformation*

*1964 Niigata earthquake*

Mogi, 1985

