Earthquake prediction

Prediction: specifies that an earthquake of a specific magnitude will occur in a defined region during a particular time period:

"There will be a M 7 or larger earthquake in southern California in March of 2015"

Forecast: provides a probability of the above, usually over 10 to 100 year timescales

"21% chance of a M 6.5 to M 7 earthquake on the San Andreas Fault in the next thirty years"

"62% chance of a M 6.5 or greater earthquake in the San Francisco Bay Area in the next thirty years"

Earthquake prediction: animals?

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Toad is a telltale for impending quakes: scientists

AFP

Mar 30 07:22 PM US/Eastern

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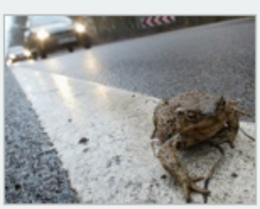


A toad sitting on a road in Germany. For ages, mankind has craved a tool th...

For ages, mankind has craved a tool that can provide early warning of that terrifying moment when the earth begins to shake.

But if a scientific paper published on Wednesday is confirmed, we may at last have found one.

The best hope yet of an earthquake predictor could lie in a small, brown, knobbly amphibian, it suggests.

The male common toad (Bufo bufo) gave five days' warning of the earthquake that ravaged the town of L'Aquila in central Italy on April 6, 2009, killing more than 300 people and displacing 40,000 others, the study says.

R. Grant, J. Zoology, 2010

Earthquake prediction: animals?

- when?
- where? how big?

Toads (L'Aquila, Italy) Maybe - but just one anecdote

Catfish experiment (Japan, 16-year study) inconclusive

Ant, rodent experiments (Mojave desert CA) FAIL

Lost pet ads in San Jose Calif newspaper FAIL

Dogs, birds, cats... ...cattle MANY anecdotes, but NO systematic correlation

Successful 1976 China quake prediction was based on foreshocks (which do not always occur), not on animals.

What about prediction based on other precursors?

Changing well water levels, ground-hugging fog, low-frequency electromagnetic emission, "earthquake lights", magnetic field anomalies up to 0.5% of the Earth's dipole field, temperature anomalies by several degrees over wide areas as seen in satellite images, changes in the plasma density of the ionosphere, radon and helium emission, methane emission and formation of colored clouds, changes in seismicity patterns, bulging of the Earth's surface...

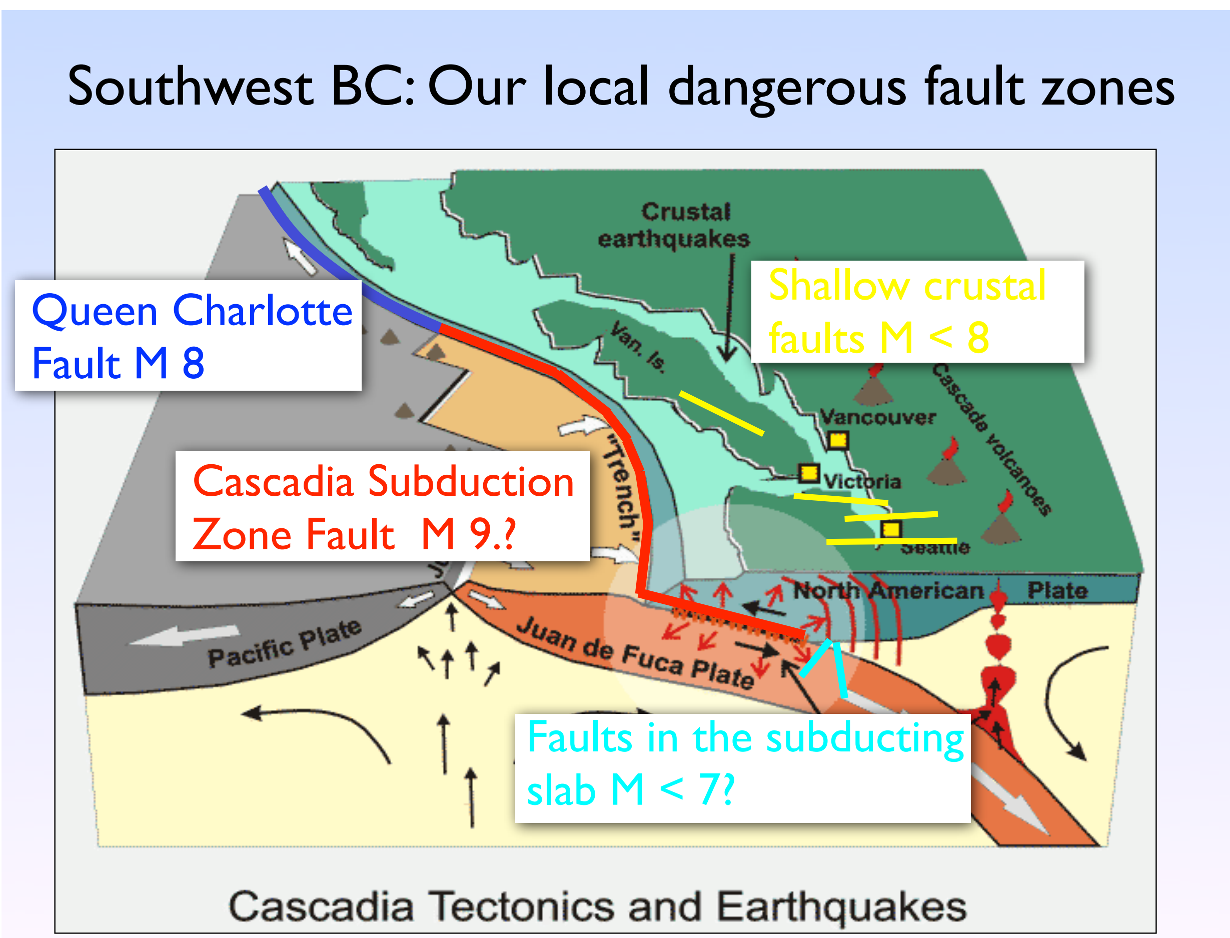
Some of these are seen for some quakes but not for all (or even for many) quakes. Studies of these precursors fail to address cases where the phenomenon <u>wasn't</u> followed by a major quake).

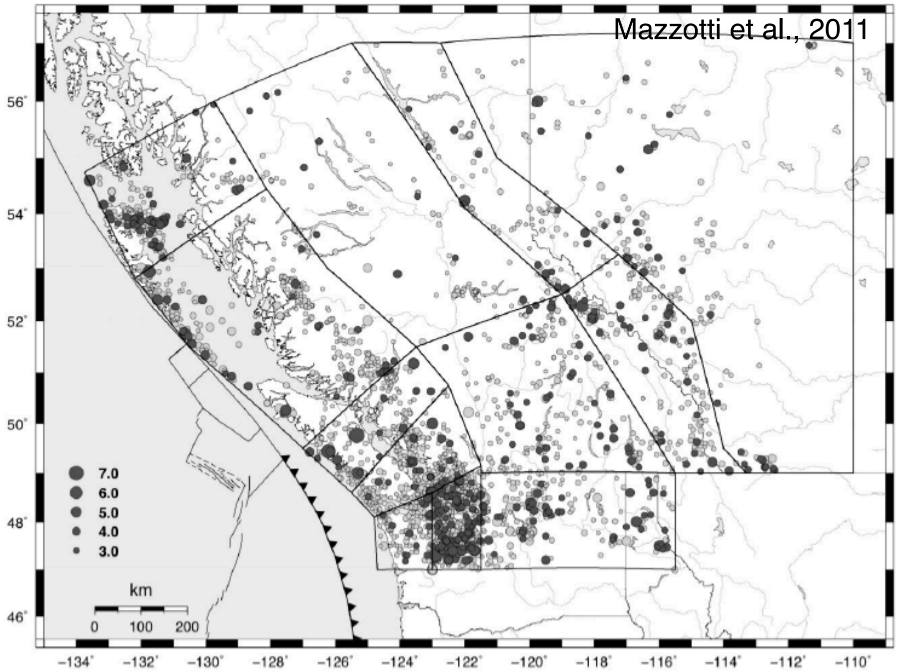
Most earthquake forecasting is based on statistics of past earthquakes (how often, magnitude, how regular, when was the last one...)

In western Canada we know something about:

- The Queen Charlotte Fault
- The Cascadia Subduction zone Fault

In other BC regions we must use seismicity catalogues and the Gutenberg-Richter relationship, together with <u>assumptions</u> about the maximum earthquake size, to forecast probability of damaging earthquakes.



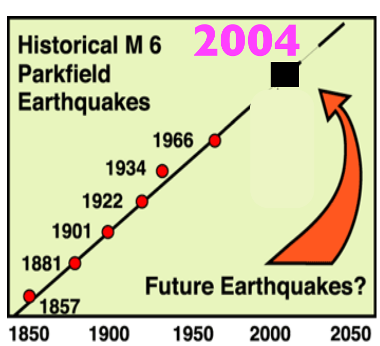


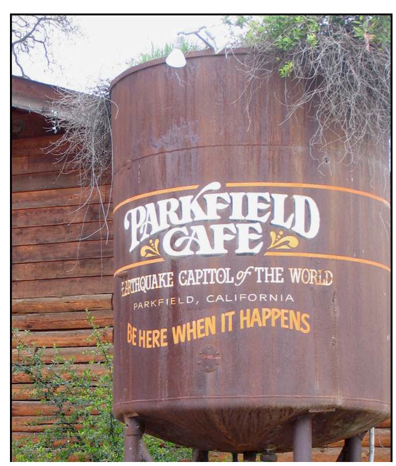
In the BC interior and in the subducting slab, active faults are not mapped and earthquake hypocenter locations are imprecise.
We do not know where the faults are.
For forecasting all we have is seismicity data, but these data are incomplete.

Figure 2. Earthquakes and seismic source zones. Continental crustal earthquakes from GSC catalog, magnitude M ≥ 2.0, 1899-2009 (light gray circles). Dark gray circles show earthquakes M ≥ 3.0 that pass completeness test. Oceanic plate, plate-boundary, and induced earthquakes are omitted.

Forecasting when a large earthquake is likely to happen, if you DO know something about the fault and its past large earthquakes

- earthquakes do not happen at regular time intervals
  (even at Parkfield CA, famous for "regular" SAF earthquakes, of M 6, the time spacing is not actually regular)
- but earthquakes are not perfectly random, either

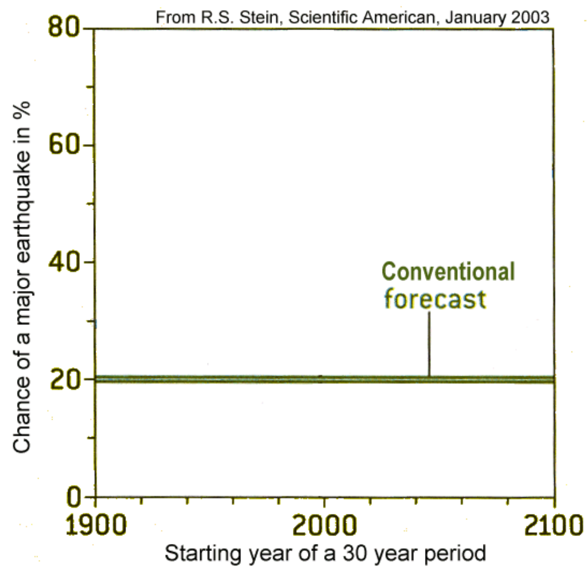




“Conventional Forecast”

Say all we know is an **average** recurrence interval. We have no clue how regular or random the large quakes are. In this case, the estimated probability is constant.

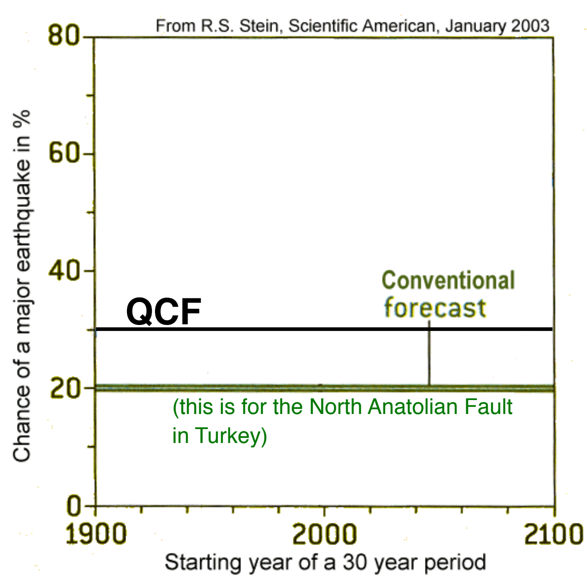
Example: a fault has earthquakes **on average** every 150 years. That means that each year, there is a 1 in 150 chance of an earthquake. In 30 years, there is a 30 in 150, or 20% chance.



“Conventional Forecast”

Queen Charlotte Fault: **average** recurrence interval for M 8 earthquakes is “about every 100 years, as little as 50, as much as 200”.

Thus, conventional forecast is about a 1% chance per year, or a 10% chance per decade (30% in 30 years).

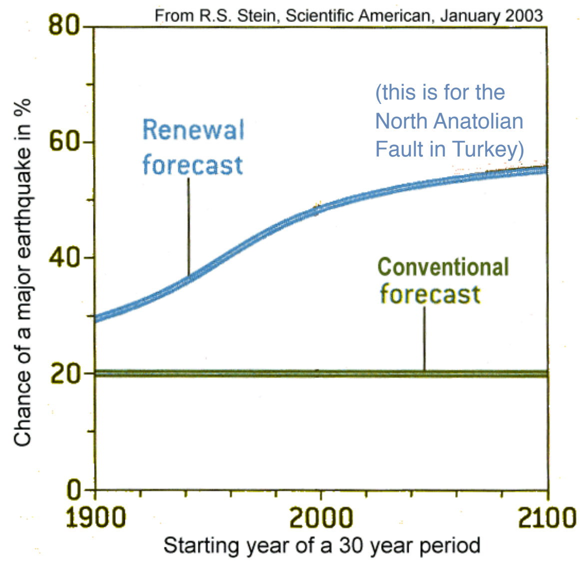


Renewal forecast

Elastic stress on the fault increases gradually, so the chance of a big earthquake grows with time.

In this case the probability in 1900 was “30% in the next 30 years” but the probability in 2000 was “48% in the next 30 years”

We have **renewal forecasts** for the Casadia Subduction Zone fault.



We need to know:

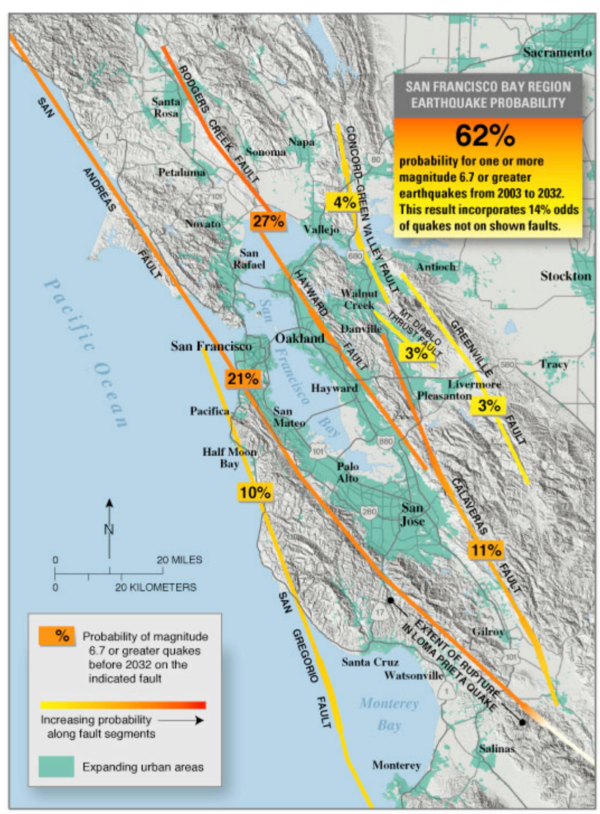
- mean recurrence interval
- **standard deviation of the recurrence interval**
- **time since the last large earthquake**

Renewal Forecast in the SF Bay Area

Probability of a M 6.7 or larger earthquake in the San Francisco Bay Area between 2003 and 2032

Probability of a large quake in a region includes probabilities on all of the local faults

This is one place where all of the major faults are mapped and their recurrence intervals and most recent events are known.



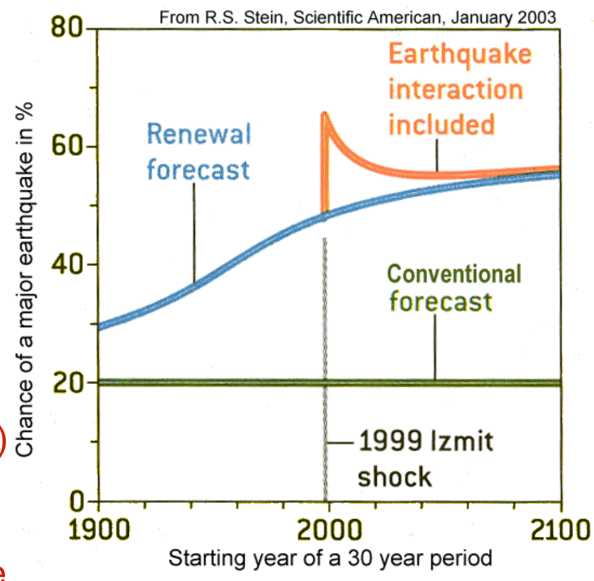
http://pubs.usgs.gov/fs/2003/fs039-03/

Renewal forecast with earthquake interaction

Effects of stress changes caused by nearby earthquakes may cause probabilities of another shock to **rise *or fall* temporarily**.

These stress changes can be from permanent deformation of the ground **or** from passing seismic waves.

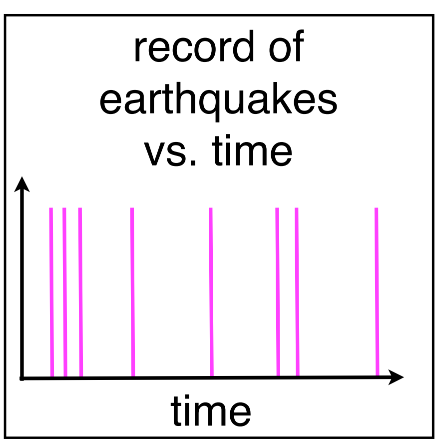
In this case (NAF in the Marmara Sea) the probability increased from 48% in 30 years to 65% in the next 30 years due to stresses from the 1999 Izmit, Turkey earthquake.



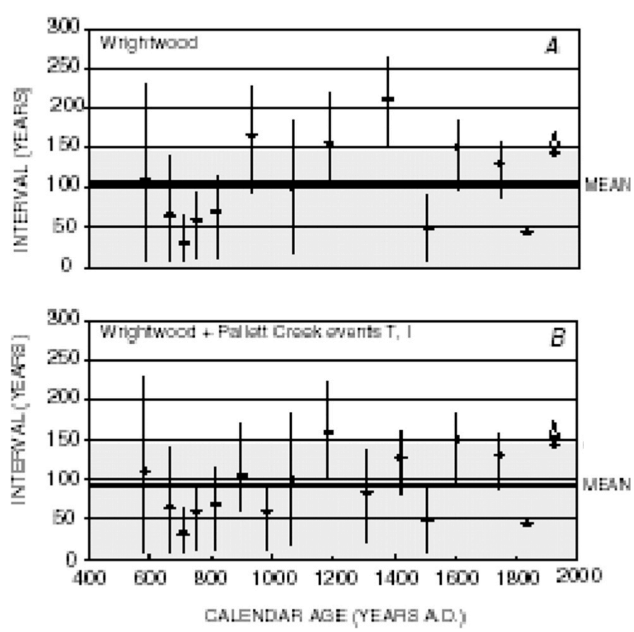
This is the most sophisticated type of forecasting and it is not very common.

Renewal forecast requires

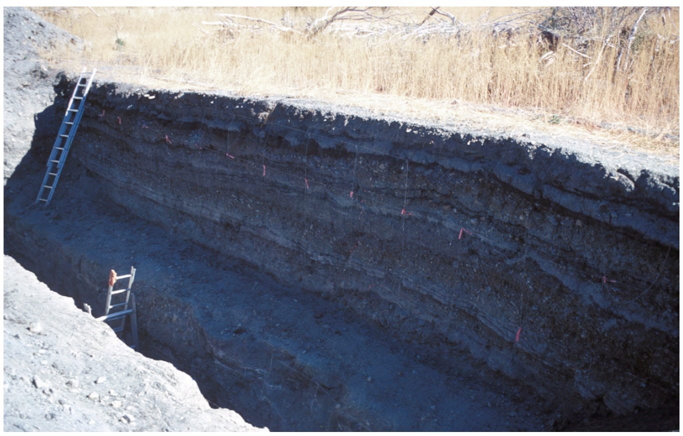
- mean recurrence interval
- standard deviation of recurrence interval
- time since the last earthquake



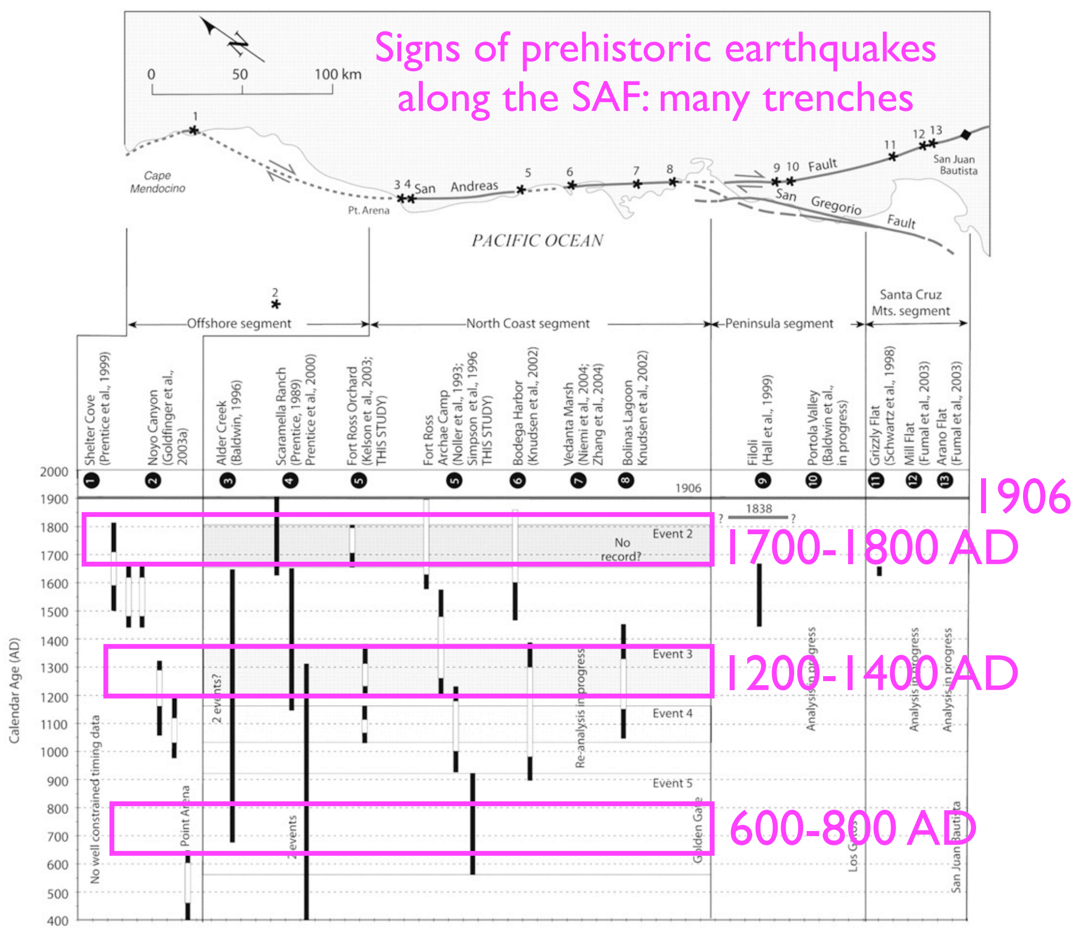
Who tells us this?



Geologists.



Trenching across active faults, dating offset former ground surfaces and getting a time history of large earthquakes



Cascadia Subduction Zone Fault

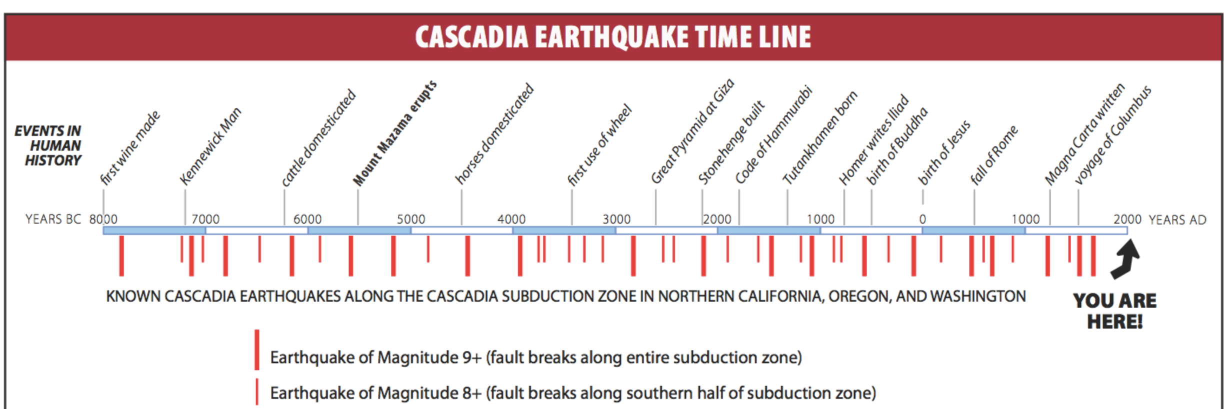
M9+ earthquakes every (200 to 1300) years

drowned ancient stumps from tress killed by sudden subsidence in a Cascadia earthquake

wood fragments sandwiched between sand layers where land surface dropped suddenly and killed a mature forest

Also, dates of catastrophic undersea debris flows (submarine landslide deposits)... trenching these is not possible, core samples are obtained by drilling. We can also see uplift of Van. Island, showing that stresses are building up.

From many data sources up and down the Pacific coast:

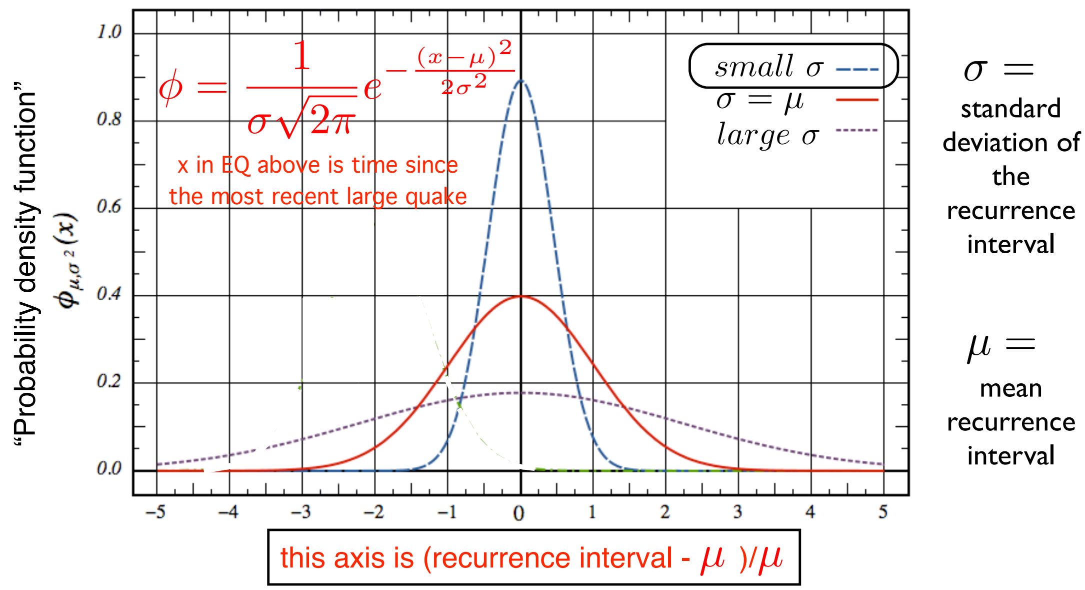


Comparison of the history of subduction zone earthquakes along the Cascadia Subduction Zone in northern California, Oregon, and Washington, with events from human history. Ages of earthquakes are derived from study and dating of submarine landslides triggered by the earthquakes. Earthquake data provided by Chris Goldfinger, Oregon State University; time line by Ian P. Madin, DOGAMI.

From Saanich Inlet drill cores (Stevens et al., 2011):

18 DFDs (310, 410–435, 493–582, 767–887, 874–950, 1001–1133, 1163–1292, 1238–1348, 1546–1741, 1694–1811, 1859–2104, 2197–2509, 2296–2483, 2525–2844, 2987–3298, 3164–3392, 3654–4569, 3989–4284 yrs ago from A.D. 2010 datum) were correlated among two or more cores during this time period, suggesting an average return period of strong shaking from earthquakes of about 220 yr. Nine of the DFDs overlap with the age ranges for great plate-boundary earthquakes that have been determined by other paleoseismic studies: coastal subsidence and offshore turbidity deposits. The remaining nine events give an average return period of about 470 yr for strong shaking from local earthquakes. ("DFD" = debris flow deposit - EHH)

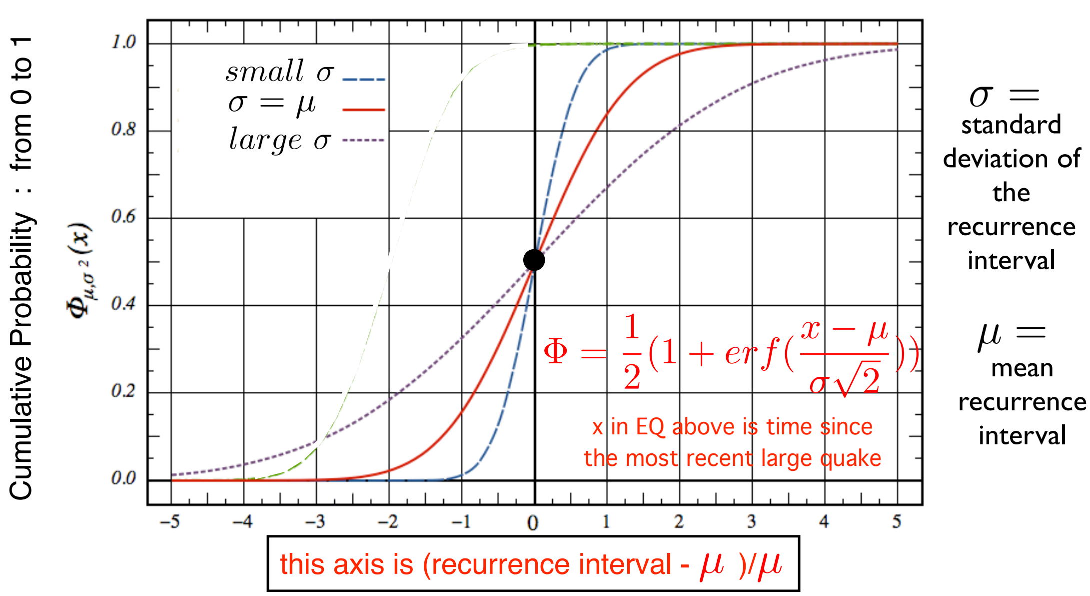
Make a bar chart of the recurrence intervals - they sort of fit a Gaussian (normal) distribution



- 0 if recurrence interval = mean interval
- negative if recurrence interval is less than mean interval
- positive if recurrence interval is greater than mean interval

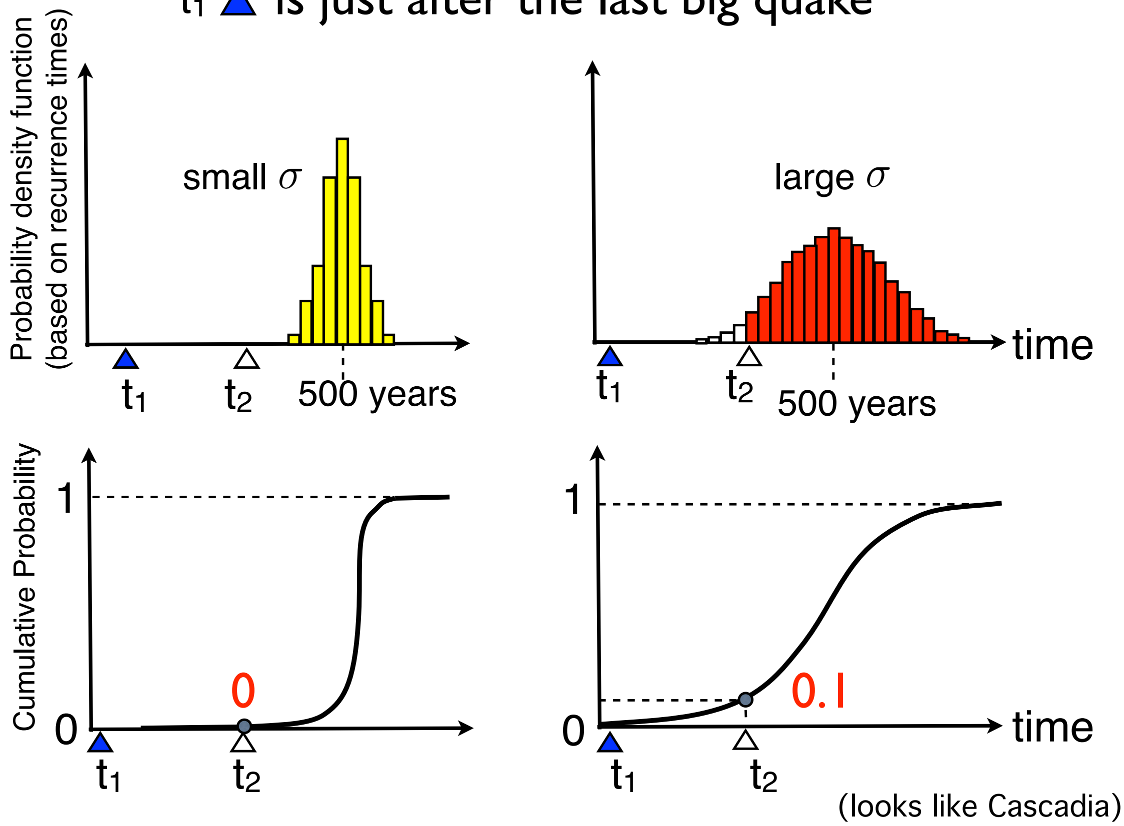
Integrate this Gaussian function to get the probability of an earthquake over a time interval

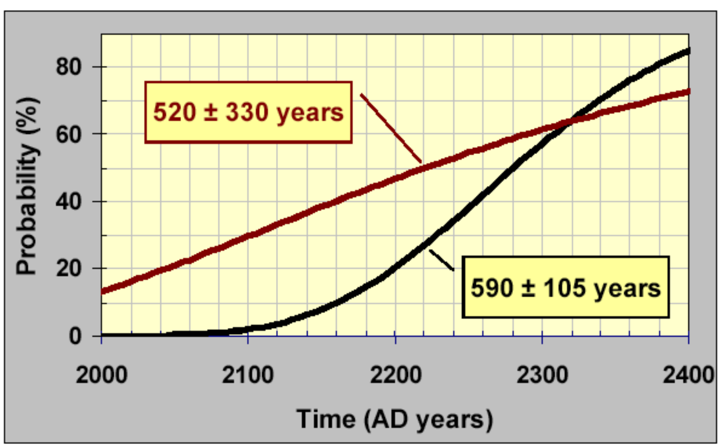
(area under the curves on the previous slide)



For all: 50% chance it has happened by the time the mean recurrence time has elapsed

t_1 ▲ is just after the last big quake





last one: January 1700, based on Japanese tsunami records

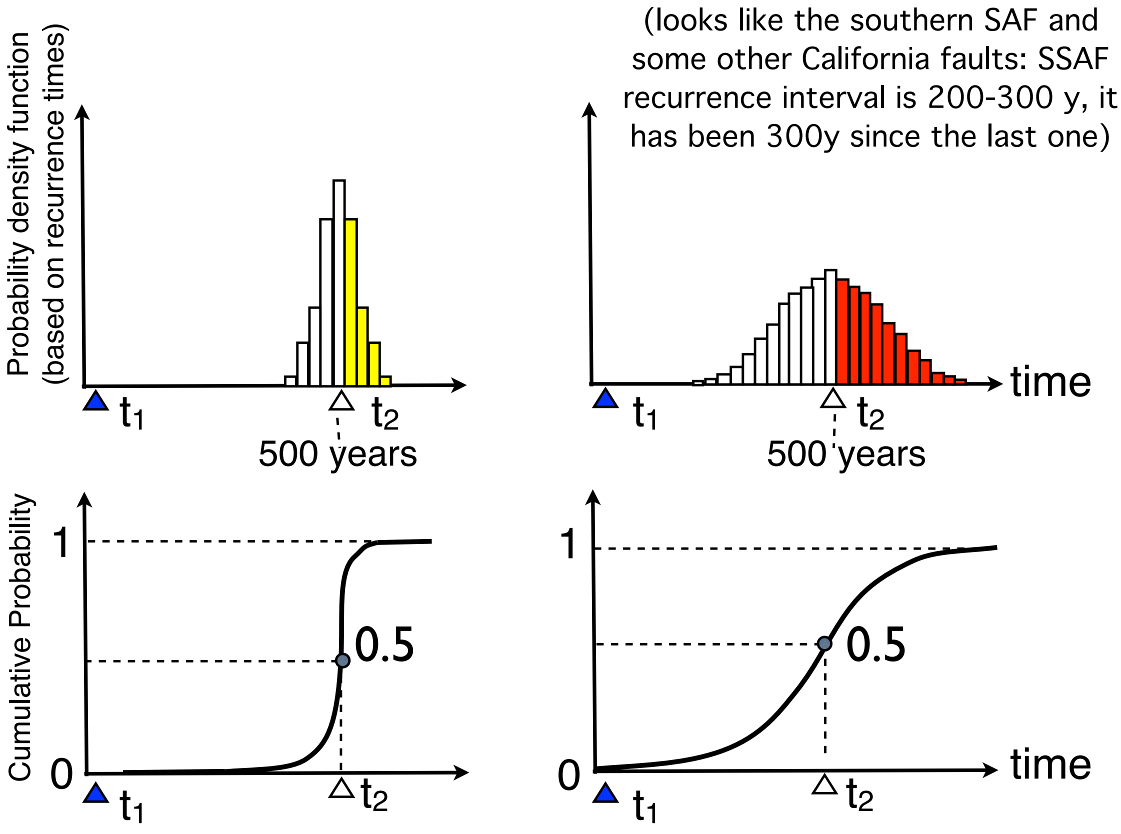
Table 4. Probabilities of a Cascadia megathrust earthquake within the next 10, 50, and 100 years

Cascadia megathrust earthquake occurrence probability (%) within the next:								
10 years			50 years			100 years		
Lower	Best	Upper	Lower	Best	Upper	Lower	Best	Upper
0.034	7.5	15	0.31	11	22	2.3	17	31

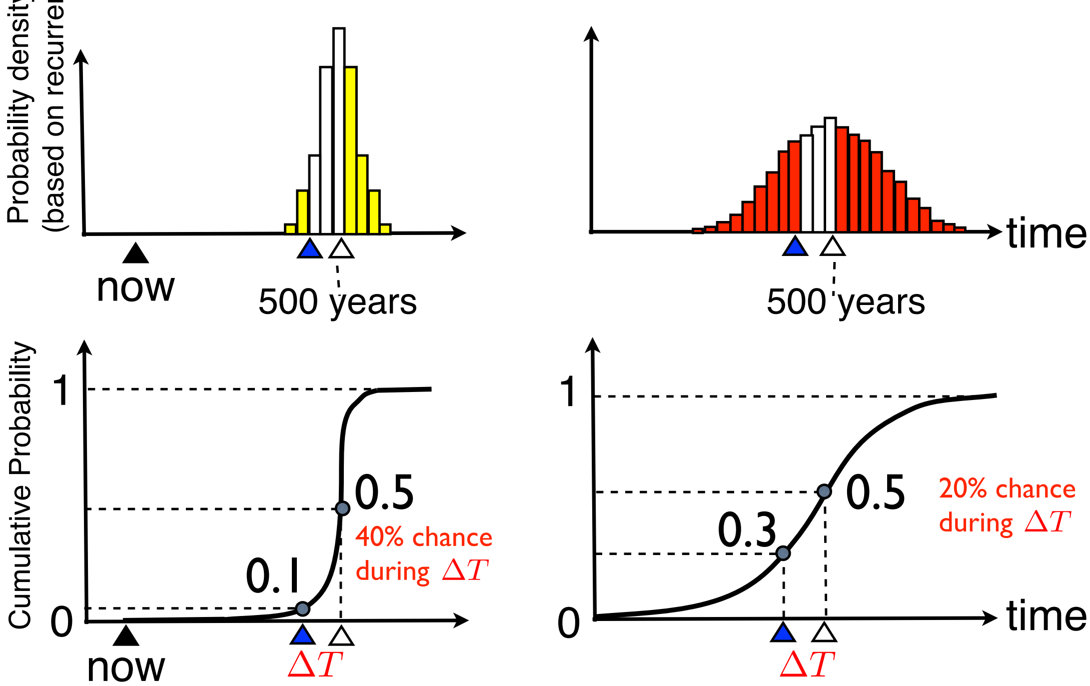
13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1065

PROBABILITIES OF SIGNIFICANT EARTHQUAKE SHAKING IN COMMUNITIES ACROSS BRITISH COLUMBIA: IMPLICATIONS FOR EMERGENCY MANAGEMENT

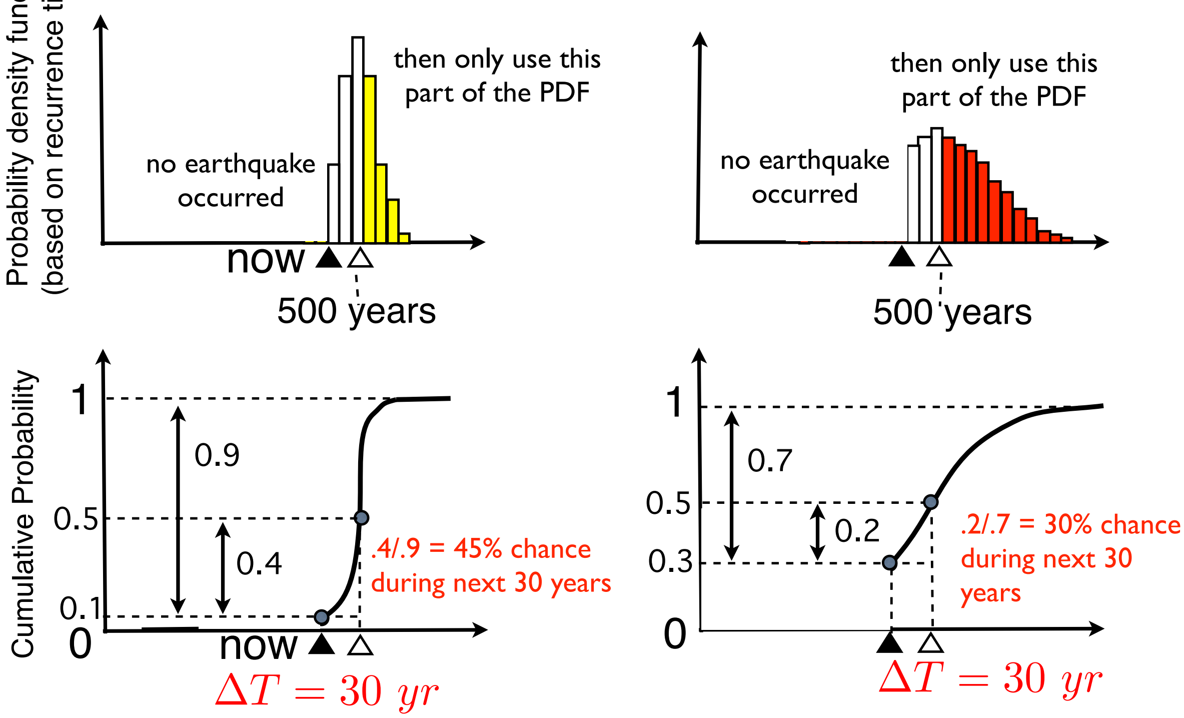
Tuna ONUR, and Mark R. SEEMANN



Predicting the probability for a time interval <u>in the future</u> - just integrate between the two times



If we know the quake has not happened yet…
and we are at time "▲" then probability is higher



Earthquake forecasting summary

We can usually forecast where damaging earthquakes will be (seismic gaps on known faults) but we are still often surprised (e.g., blind faults, intraplate faults)

We can usually forecast their effects (e.g., strength and duration of shaking, tsunami genesis)

We cannot predict the timing of earthquakes very well (though we can forecast *probabilities* over long time periods if we have enough statistical data on earthquakes along the fault)