



## Global tour of quakes

- California
- Rest of country
- Biggest quakes
  - 1960 Chile, 1964 Alaska, 2004 Sumatra
- Rest of world
  - Japan, Turkey, India
  - 1755 Lisbon

## International quakes

- Japan
  - 1923 Tokyo quake, horrific casualties
  - 1995 Kobe most expensive, \$150 billion
- China - 1975 Haichang & 1976 Tangshan
  - Most fatalities, prediction experiment
- India - very active
- Europe - somewhat active

Great Kanto Earthquake. Destruction of Kokugikan (National Sumo Wrestling arena), Ryogoku district.

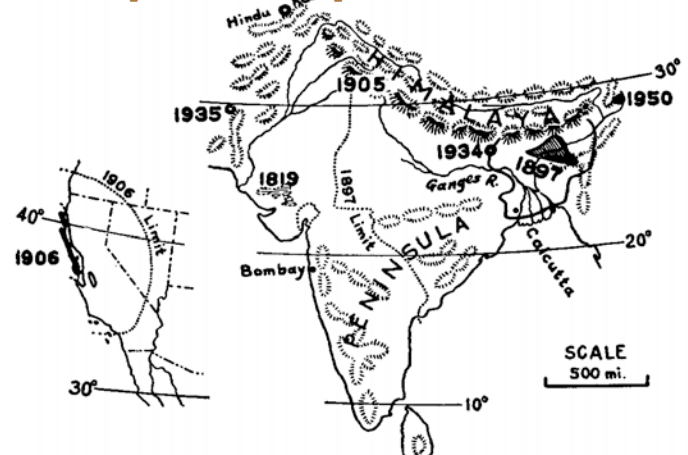
## Tokyo 1923

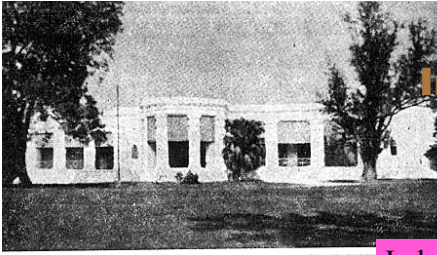


## India

- Quakes are the result of the India-Asia collision
- California quakes pale in comparison
- Many great quakes
  - 8.7 in 1897
  - 8.6 in 1905
  - 8.4 in 1934
  - 8.7 in 1950
- Prototype for intensity XII shaking

## Map: Indian quakes





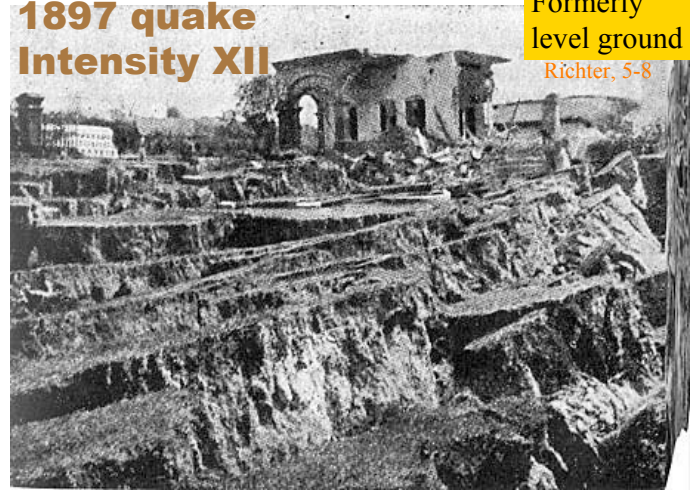
## 1897: Intensity XII



Judge's house:  
Before and after

Richter, 5-6

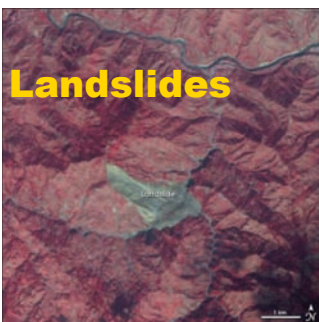
## 1897 quake Intensity XII



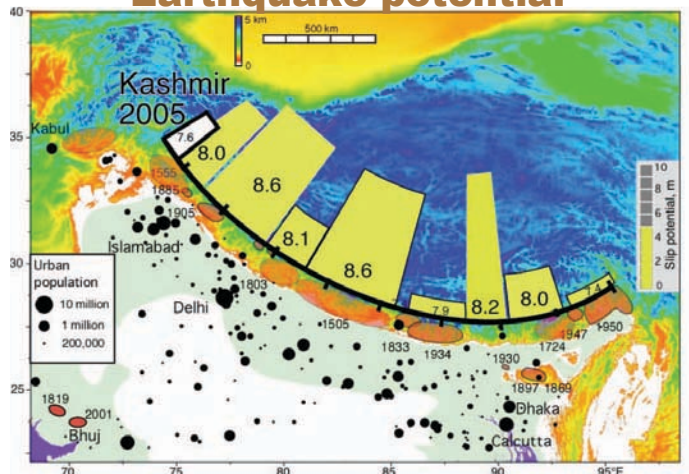
Formerly  
level ground  
Richter, 5-8

## Deadly quake in Pakistan, October 8, 2005

- M7.6, a shade bigger than Landers
- 9am, 70,000+ fatalities
- Losses about \$5,000,000,000
  - Had to talk at dawn on MSNBC
    - Earbrow trim, make-up, Godiva choc
    - 8:30am east coast time

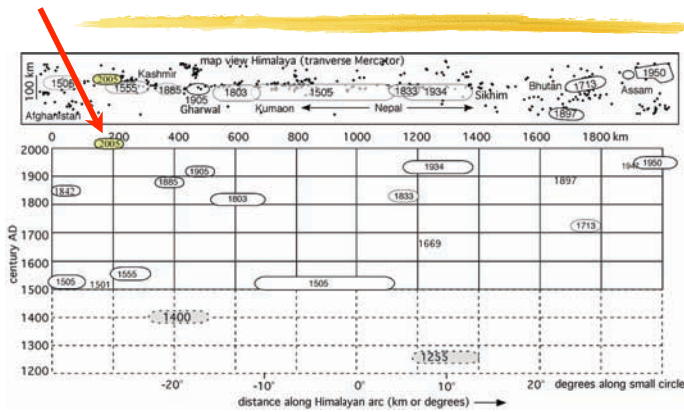


## Earthquake potential





## Space-time EQ's across Tibet



## Poor construction



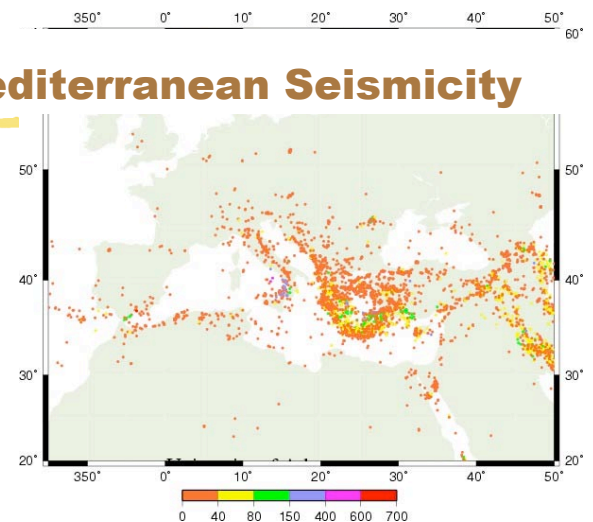
## Cracked hilltop, and damage



## Quakes in Europe

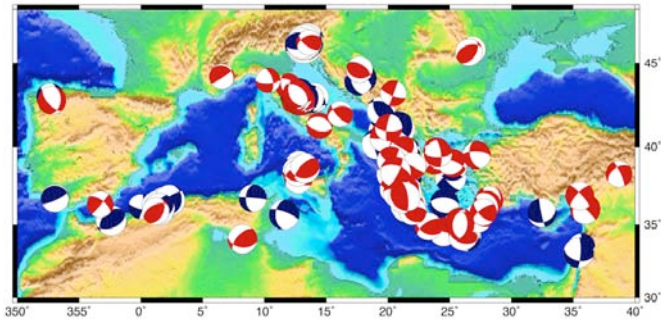
- Plate boundaries complicated
- Italy and Greece
  - Some damaging moderate quakes
    - Old buildings, in 2000, there was \$1 billion M=5.
  - Volcanoes also a hazard, like Etna
- Turkey and Israel like California
  - Big strike-slip quakes
  - Sequence in 1940's showed alarming series of events marching along Anatolian Fault
- Lisbon 1755 an important event

## Mediterranean Seismicity





## Focal mechanisms



### 1980 Naples, Italy quake

4000 killed  
250,000 homeless



### Deadly quake in Turkey, August 17, 1999

- M7.4, like Landers
- 20,000 to 30,000 fatalities
- Losses about \$10,000,000,000
- Govt. heavily criticized for slow response
- Sumatran earthquake well reported



### Offset wall



### Faulted barn





??



The figure consists of three parts: an inset map (a), a main graph (b), and a geological cross-section (c).

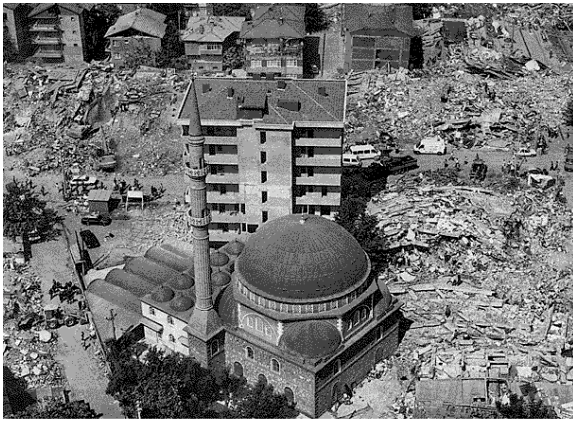
- Inset map (a):** Shows the location of the study area in Turkey, with a red line indicating the North Anatolian Fault.
- Main graph (b):** A line graph showing cumulative right-lateral slip (m) versus distance east of 35°E longitude (km). The x-axis ranges from -500 to 600 km, and the y-axis ranges from 0 to 10 m. The graph shows a series of peaks corresponding to earthquakes in 1939, 1942, 1943, 1944, 1951, 1957, 1967, 1966, 1969, 1971, and 1992. The slip increases from west to east, reaching a maximum of about 10 m near 400 km.
- Geological cross-section (c):** A map showing the North Anatolian Fault system, including the Black Sea, Marmara Sea, and various cities and towns. The fault is labeled as the North Anatolian Fault, and the slip is indicated by arrows. The map shows the fault extending from the Black Sea to the east, with various cities and towns marked along the fault line.

- Fault much like California

- M6 in 1939
  - M8 in 1939
  - M7.3 in 1942
  - M7.6 in 1943
  - M7.6 in 1944
- What if this happened in California?

The map illustrates the geological features of Turkey and California. In Turkey, the Izmit Fault is shown with a red circle indicating the 1999 earthquake epicenter. The 1939-1992 earthquake sequence is marked with a double-headed arrow. The Ankara Fault shows the 1939-1944 progression. The Erzinjan Fault is also depicted. The fault slip rate for the Izmit Fault is given as  $24 \pm 4$  mm/yr. In California, the San Andreas Fault is shown with the 1857 earthquake near Los Angeles and the 1906 earthquake near San Francisco. The fault slip rate for the San Andreas Fault is given as 20-34 mm/yr. A scale bar indicates 500 km. The text 'T U R K E Y' and 'C A L I F O R N I A' are spread across their respective regions.

- Similar slip rate, age, length and straightness



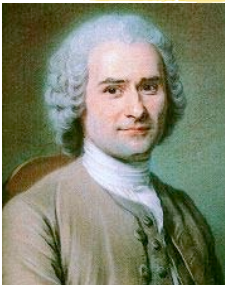
A mosque stood with a few other structures amid the rubble of collapsed buildings in the town of Golcuk, 60 miles east of Istanbul.

Associated Press Photo by Enric Martí  
Taken from New York Times, August 20, 1999

## 1755 Lisbon quake

- $M = 8.5?$ , felt across most of Europe
- We still don't know what fault it was on
- Timing unlucky, 9:30 am on Nov. 1
  - All Saint's Day, people were in church
  - Also brought fires and a big aftershock at noon
- Tsunami - water receded then smashed boats
  - 10 m waves
  - As high as 3 m in Holland and the Caribbean

## Rousseau concluded "Live Outdoors!"

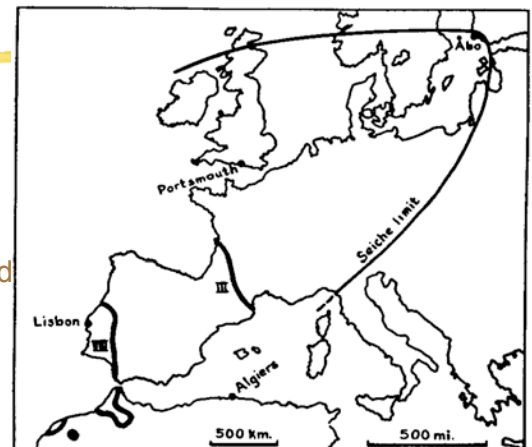


## Effects of 1755 Lisbon quake

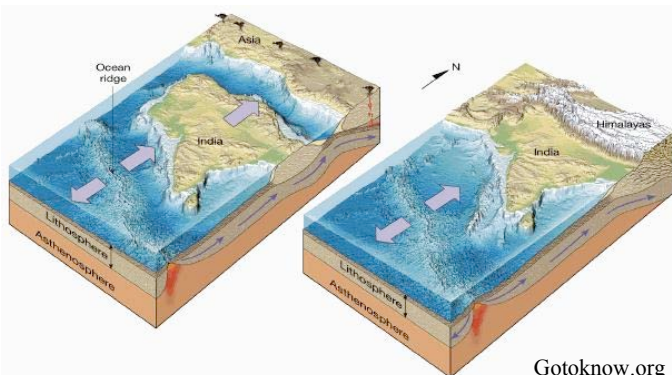
60,000  
killed

Portugal  
devastated

Richter, 9-1

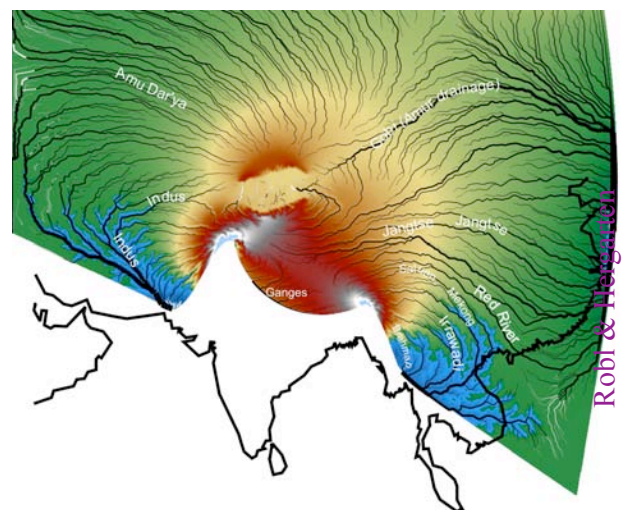


## Tectonic bumper cars



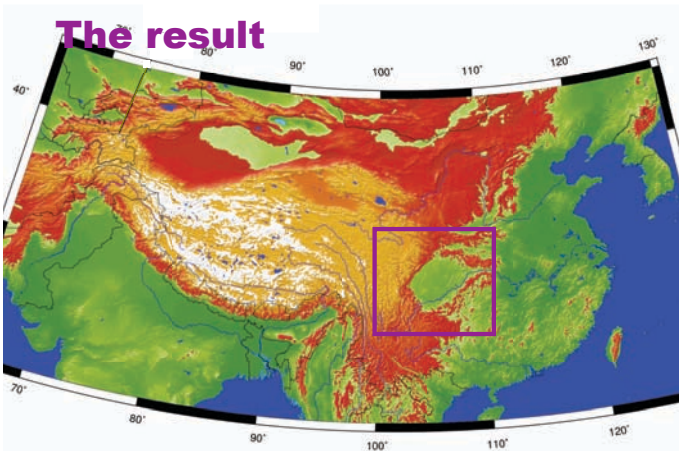
Gotoknow.org

A numerical model

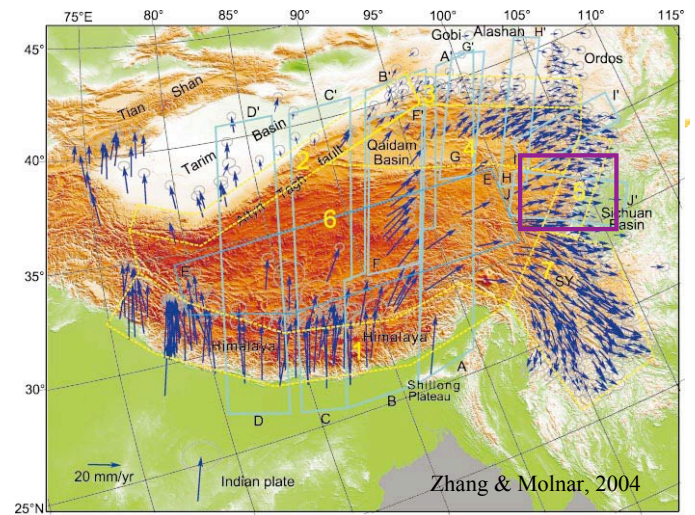




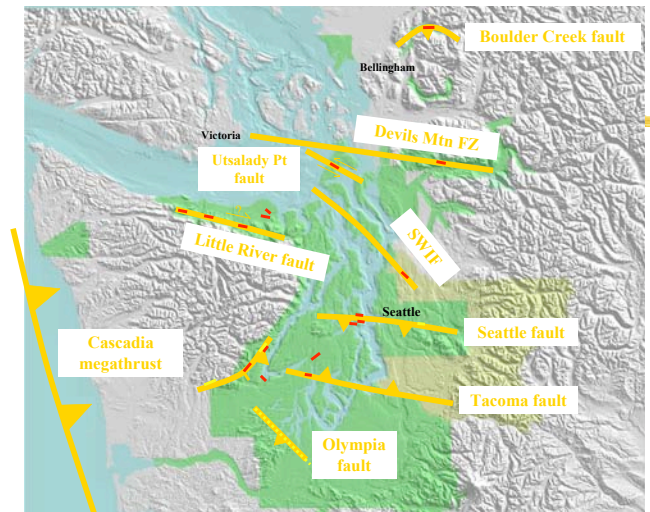
## The result



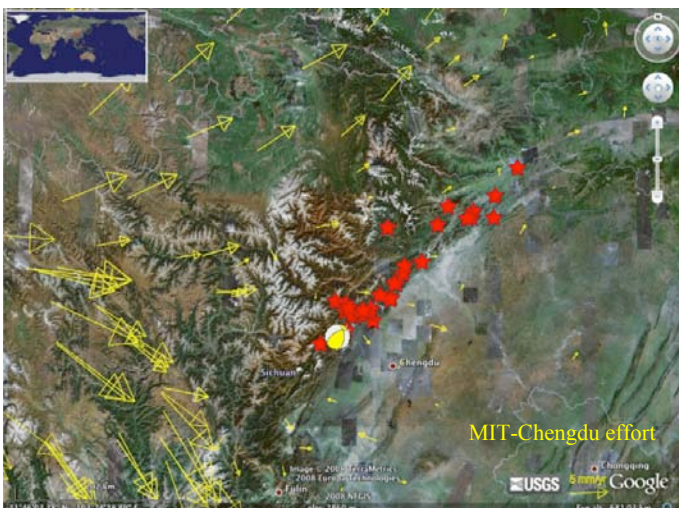
Arrowsmith & Strecker, 1999



## The landscape



Courtesy R. Haugerud, USGS

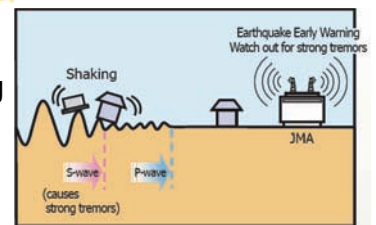


## Problems

- Buildings
- Ill-founded rumors
- Monitoring
- Not enough mapping

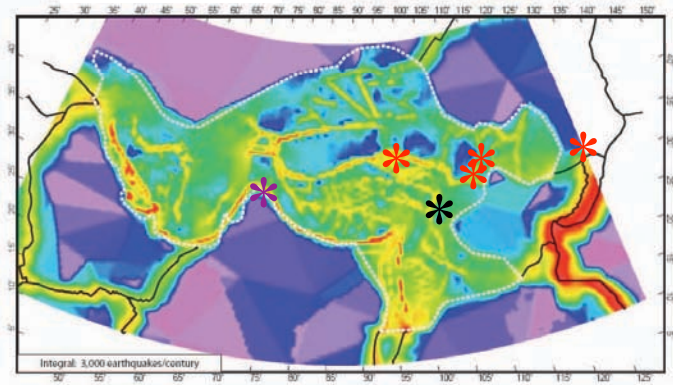
## Progress

- Growing monitoring
- Continued fault mapping
- Possible "early warning"
  - 20s warning for Chengdu, for example





## Not unique



Previous quakes in China, with 200K+ fatalities:

1556, 1920, 1927, 1976

Pakistan, 2005, 80K

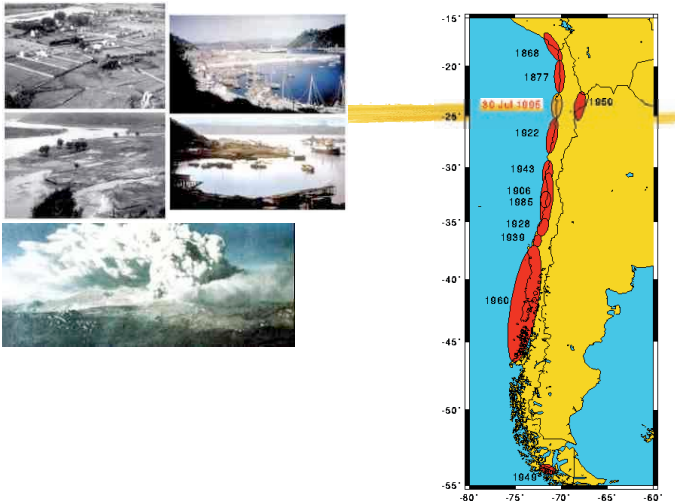
Quake risk across Asia, Liu & Bird, 2008

## 1960 Chile earthquake

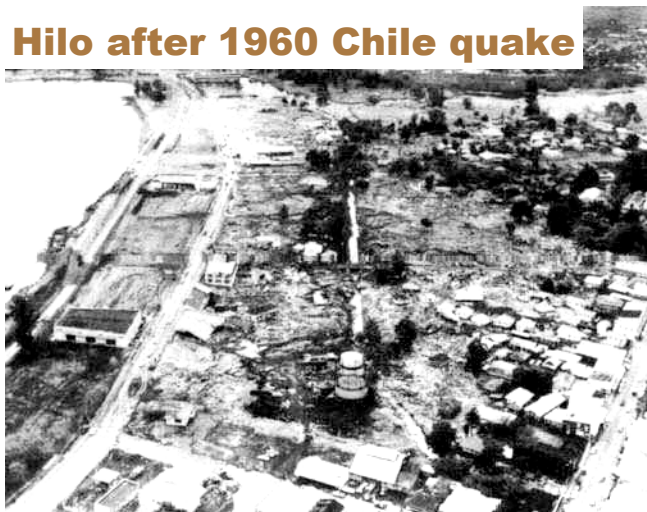
- M 9.5!!
- 160,000 square km fault
- 21 meter average slip
- Loss of life and property in Chile, Hawaii, and Japan



## Isla Chiloe, Chile



## Hilo after 1960 Chile quake



## 1964 Alaska

- M 9.2 !
- Several meters of uplift over a huge fault area
- 119 deaths in Alaska and California
- 2-7m waves along open California coast
- Crescent City hardest hit
  - Thirty blocks of Crescent City were devastated
  - Gas truck smashed into electric wires
  - Texaco tank fire burned for three days





## 1964 Alaska displacement

No wonder there was a large tsunami.

USGS Prof. Paper 5460



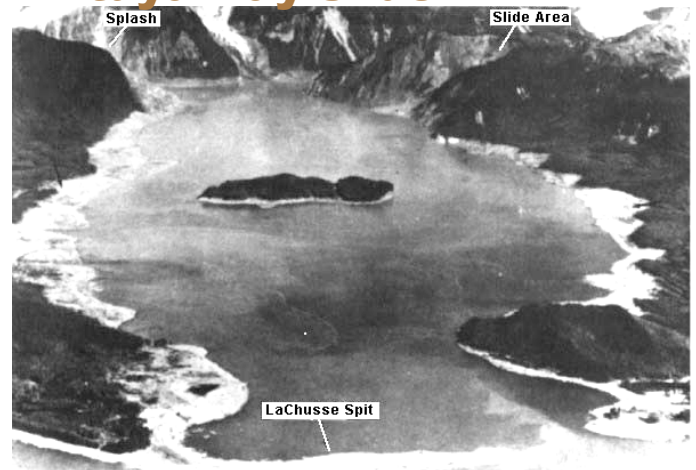
## Port



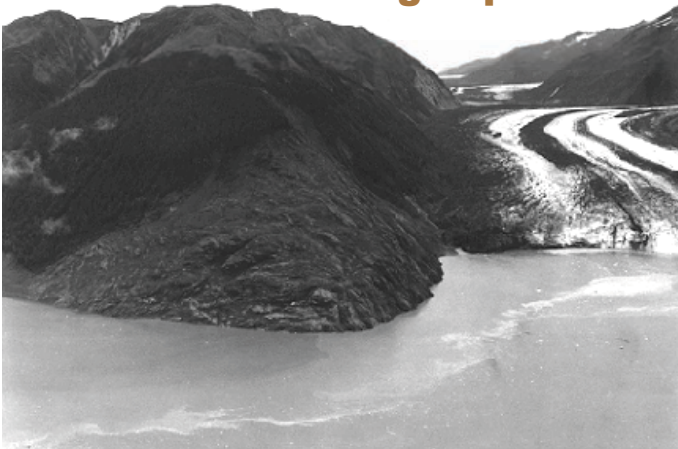
## Lituya Bay

- This image shows Lituya Bay, Alaska, after a huge, landslide-generated tsunami occurred on July 9, 1958. The earthquake-induced rockslide, shown in upper right-hand corner of this image, generated a 525 m splash-up immediately across the bay, and razed trees along the bay and across LaChausse Spit before leaving the bay and dissipating in the open waters of the Gulf of Alaska. Source: Lander, and P. Lockridge

## Lituya Bay slide



## 1720 ft high splash!



## Tsunami from impact





## Chain of impact spots on the surface of Jupiter

Shoemaker-Levy comet, 1994, hours after impacts

## Meteorites

- Roughly once a year, a meteorite 2-3 meters across hits Earth.



## Powerful meteorites

- A former asteroid pierces the atmosphere and releases the energy equivalent of five kilotons (5,000 tons) of TNT about **once a year**. In comparison, the explosive power is almost half that of the bomb dropped on Hiroshima, Japan during World War II.

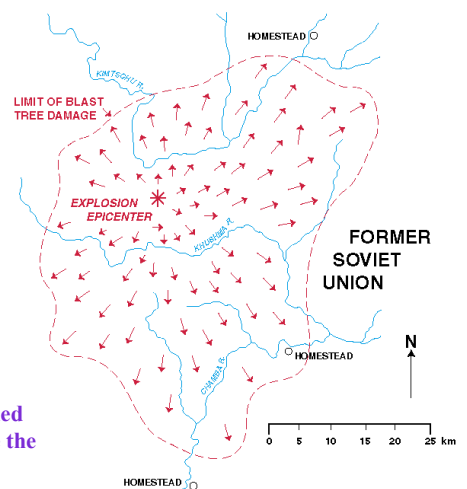


## Tungushka in 1908

- An object big enough to cause destruction, like the approximately 60-meter-wide asteroid or comet that exploded over Tungushka, Siberia in 1908, hits about once a millennium.
- (Conspiracy theorists think otherwise.)
- The blast, equivalent to 10 megatons of TNT, flattened 500,000 acres (2,000 square km) of uninhabited forest. Had the bull's-eye been on New York City, it would have been destroyed.

## Tree Fall

Probably exploded about 6 km above the ground





## Meteor crater, Arizona



## King of known impacts

- Cretaceous-Tertiary boundary impact
- Probably 10 km radius meteorite
- Caused the downfall of the dinosaurs
  - Many other animals and plants
- Global fires?
- Greenhouse effect?
- Darkness for days? Years?
- Sprayed a lot of vaporized rock across the western hemisphere

## King of suspected impacts

- Moon-forming impact
- Probably collision of two Mars-sized objects
- More than 4 billion years ago
- Sprayed out large amounts of pulverized and melted rock and iron
- Much of spray captured in orbit
- Collected to form the Moon
- King of possible impacts
  - Colliding super-massive black holes ...

## Chicxulub impact crater

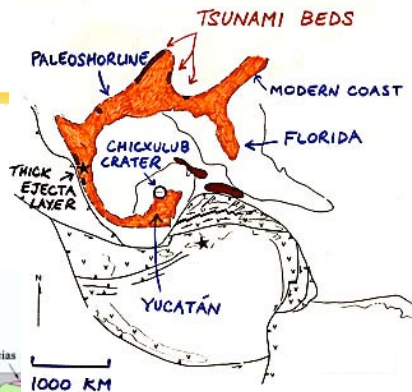
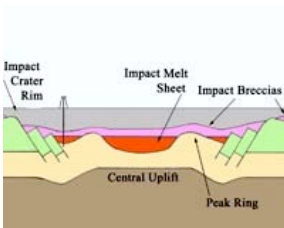
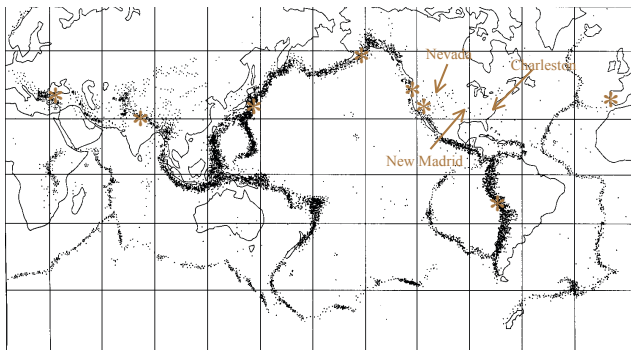


DIAGRAM FROM HILDEBRAND AND OTHERS  
GEOLOGY, SEPTEMBER 1991.

## Earthquakes M>5, 1963-1988

Quakes that we've discussed



Keller, 1-5