The Abdus Salam
International Centre
for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2464-36

Earthquake Tectonics and Hazards on the Continents

17 - 28 June 2013

Regional synthesis: Middle East Tectonics and hazard

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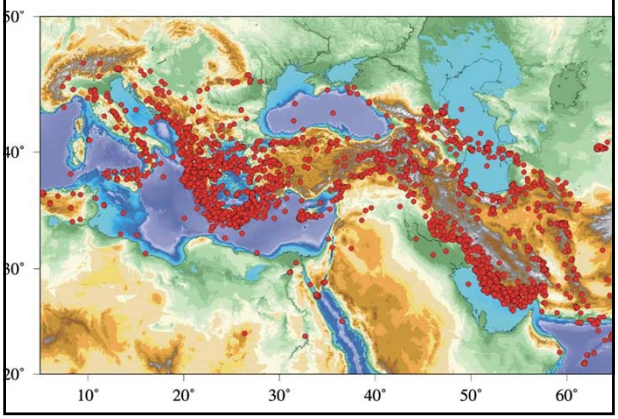
Tectonics and Hazard in the Middle East



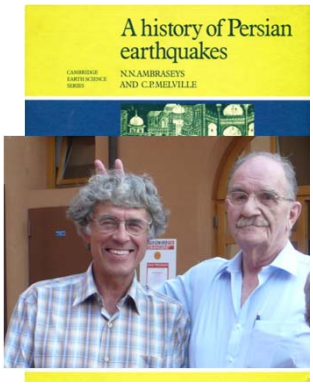
Historical earthquake catalogue?

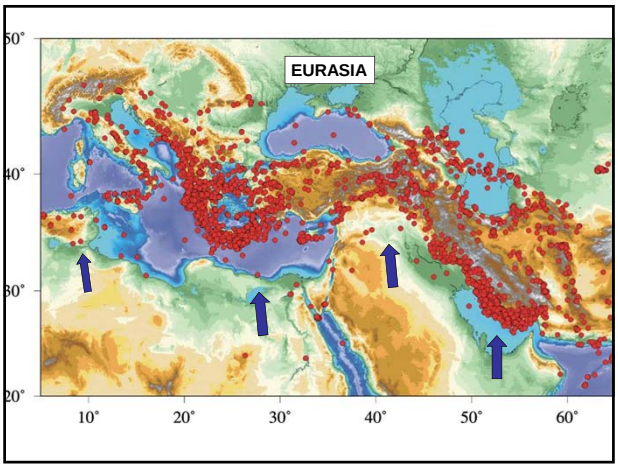
Is it complete? Above what magnitude?
How to interpret silence?

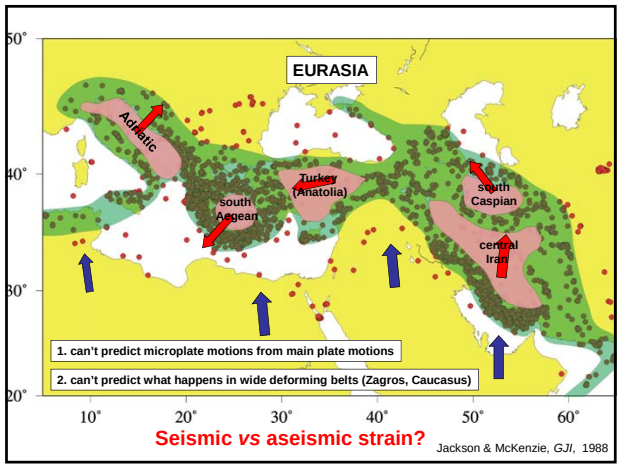
Is it accurate:
dates? locations? magnitudes?

How to interpret the historical accounts:
are they plausible? exaggerated?

Necessary skills:
Languages
History
Engineering/seismology
Geology

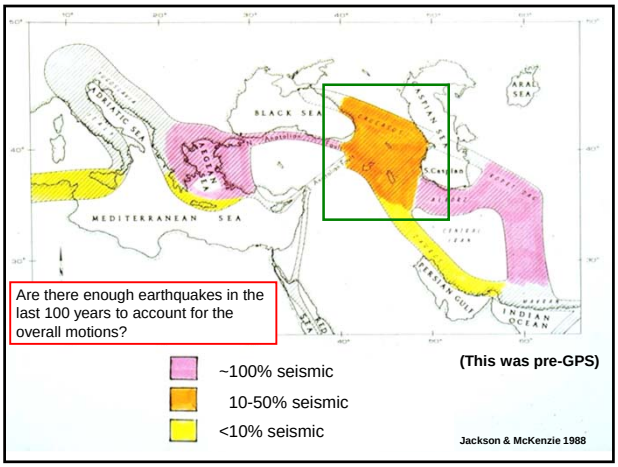


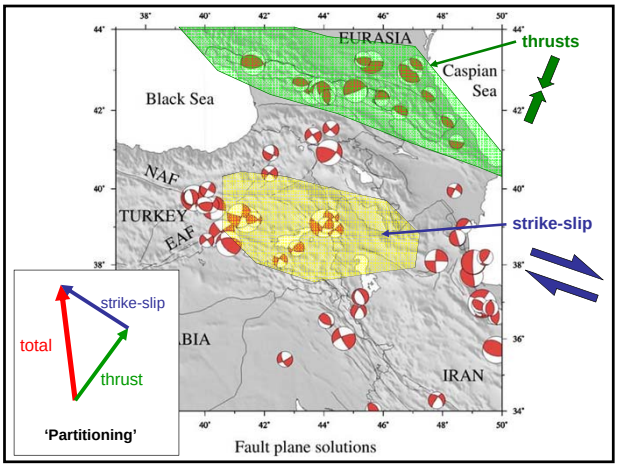


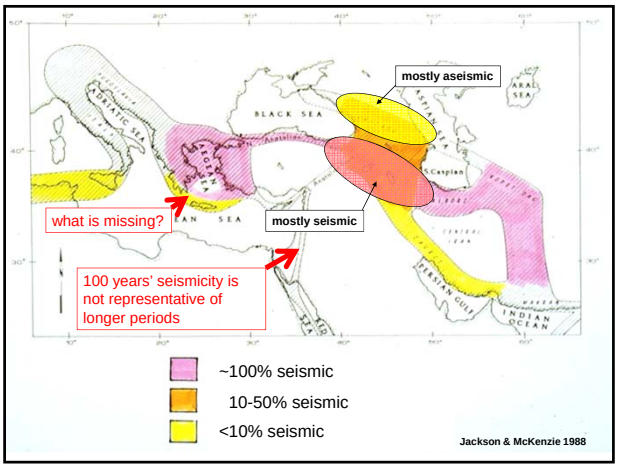


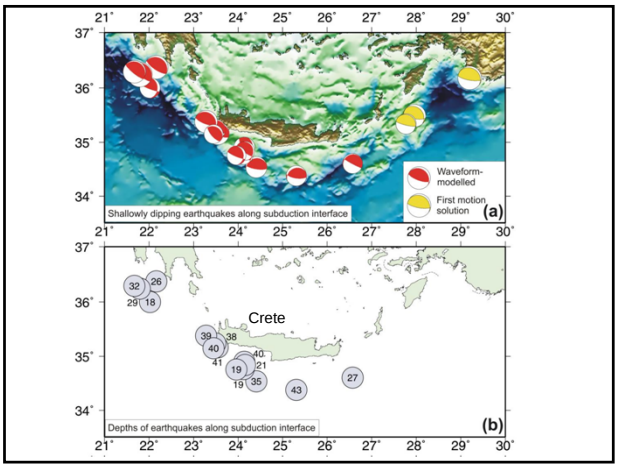
Seismic *vs* aseismic strain?

Jackson & McKenzie, *GJI*, 1988


Are there enough earthquakes in the last 100 years to account for the overall motions?
~100% seismic
10-50% seismic
<10% seismic
(This was pre-GPS)
Jackson & McKenzie 1988


EURASIA
thrusts
Caspian Sea
Black Sea
NAF
TURKEY
EAF
strike-slip
total
strike-slip
thrust
'Partitioning'
IRAN
Fault plane solutions


mostly aseismic
what is missing?
mostly seismic
100 years' seismicity is not representative of longer periods
~100% seismic
10-50% seismic
<10% seismic
Jackson & McKenzie 1988


Waveform-modelled
First motion solution
Shallowly dipping earthquakes along subduction interface
(a)
Crete
Depths of earthquakes along subduction interface
(b)

Calculations: Hellenic Trench

Length = 600 km; down-dip width = 40/sin 15° = 160 km; velocity = 40 mm/yr

Expected moment rate = 115 x 10^{18} Nm/yr
Earthquakes over last 100 years account for 9 x10^{18} Nm/yr or 3 mm/yr

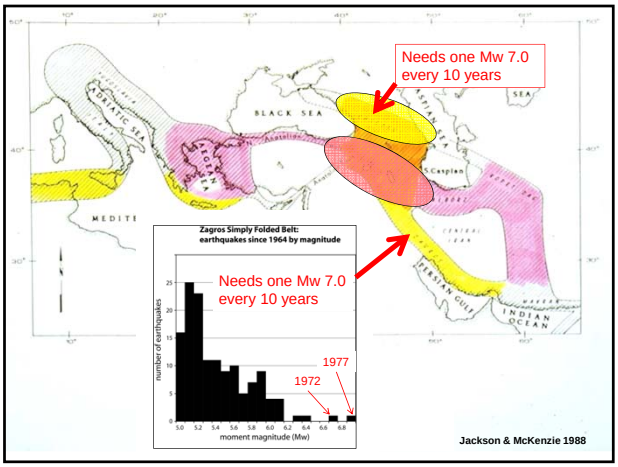
Earthquakes in 20th century account for <6 mm/yr or <15% of the convergence

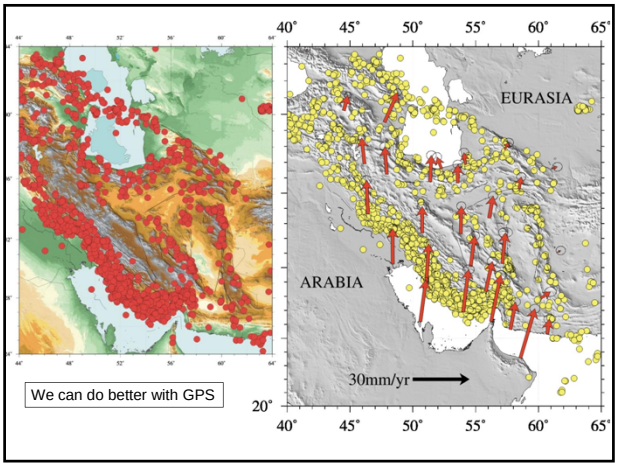
Either: most of the convergence is aseismic
Or: there are occasional very large earthquakes

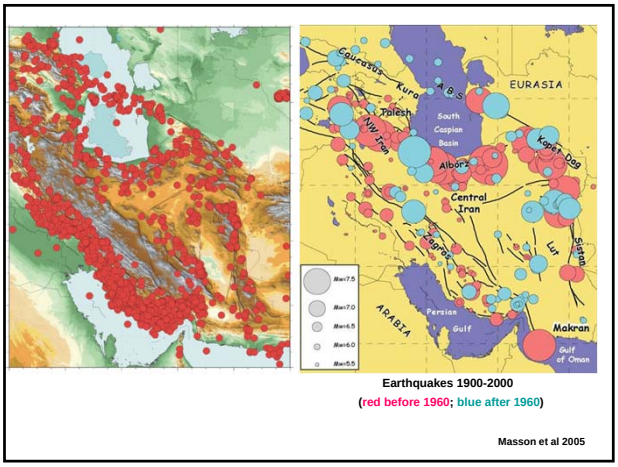
The deficit: one M_w 7.3 every year or
one M_w 8.0 every 15 years

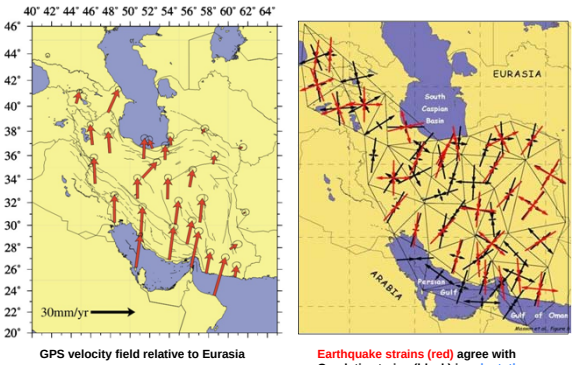
In the last 100 years there were 5 earthquakes of M_w > 7.0 (biggest M_w 7.1)
Only two known candidates for earthquakes of M_w ~ 8.0 (AD 365 and 1303)

The bulk of the convergence must be aseismic





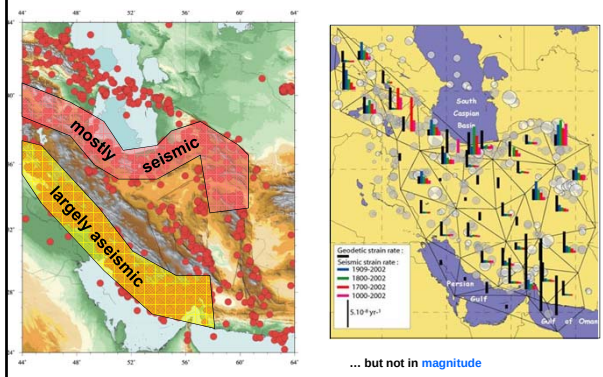




GPS velocity field relative to Eurasia

Earthquake strains (red) agree with Geodetic strains (black) in orientation

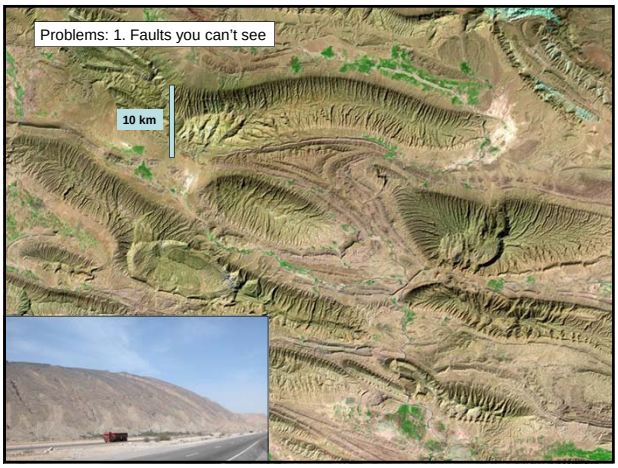
Masson et al 2005

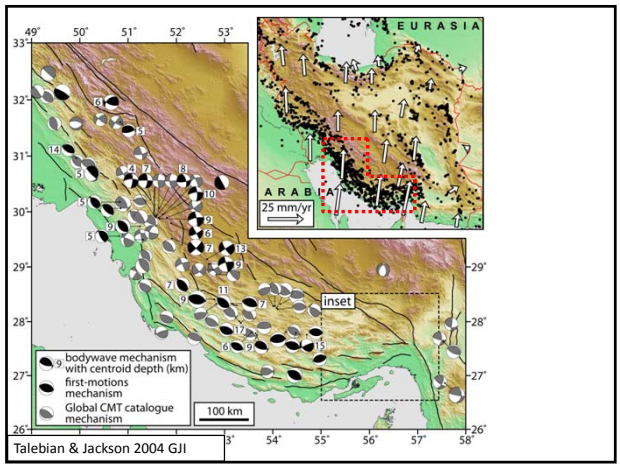


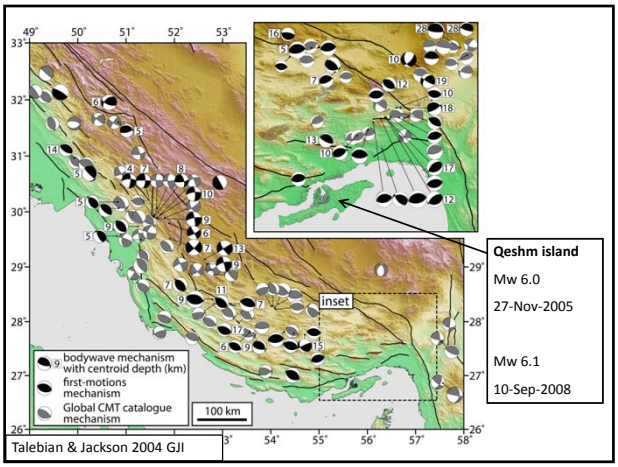
… but not in magnitude

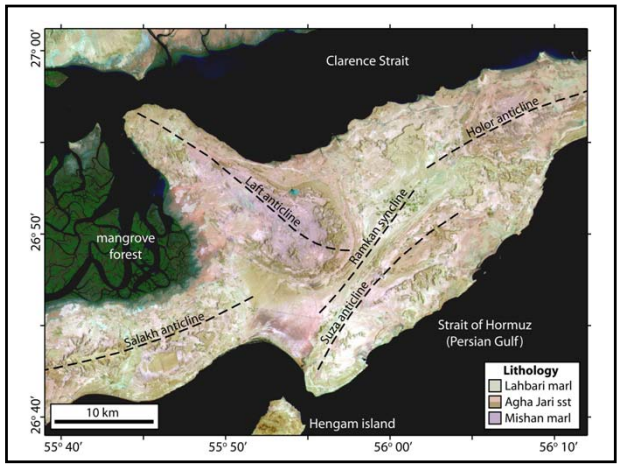
But largely aseismic does not mean SAFE

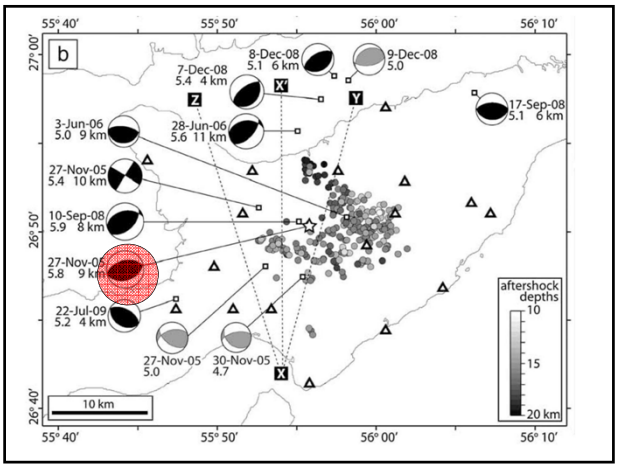
Masson et al 2005

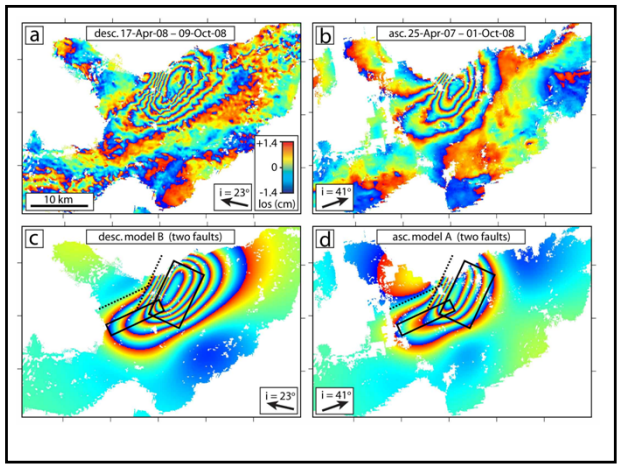


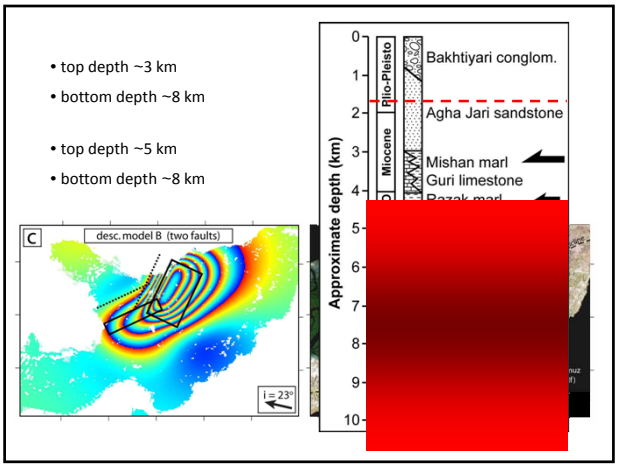


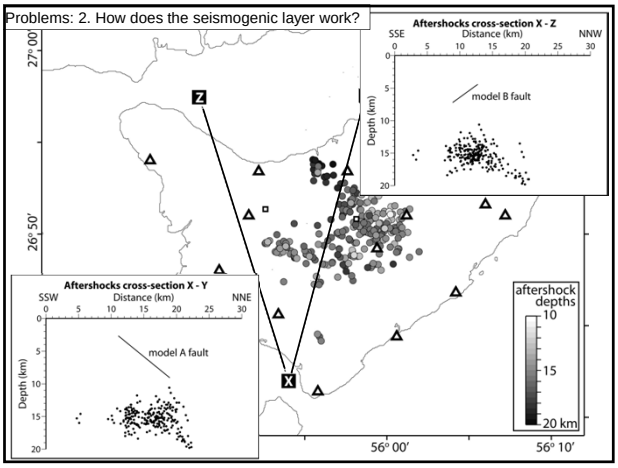

Qeshm island
Mw 6.0
27-Nov-2005
Mw 6.1
10-Sep-2008
inset
bodywave mechanism with centroid depth (km)
first-motions mechanism
Global CMT catalogue mechanism
100 km
Talebian & Jackson 2004 GJI

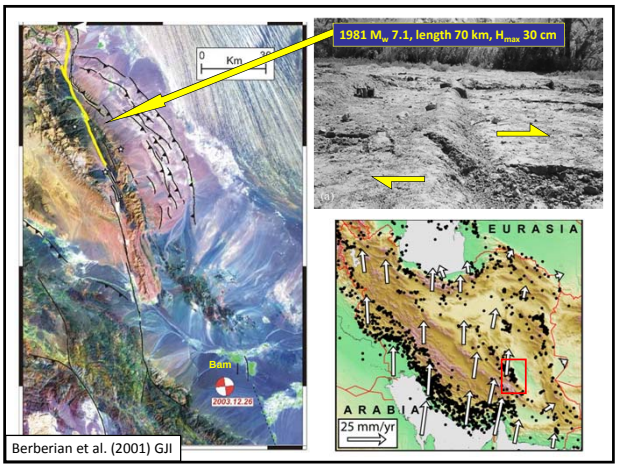

Clarence Strait
Holor anticline
Laft anticline
Ramkan syncline
Siza anticline
Salakh anticline
mangrove forest
Strait of Hormuz (Persian Gulf)
Lithology
Lahbari marl
Agha Jari sst
Mishan marl
10 km
Hengam island

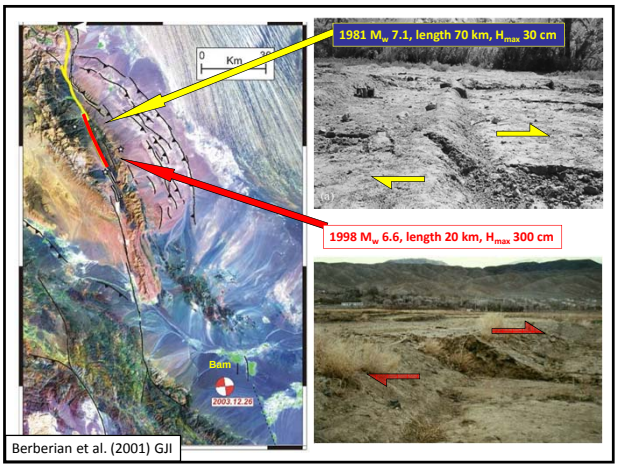

b
8-Dec-08 5.1 6 km
9-Dec-08 5.0
7-Dec-08 5.4 4 km
17-Sep-08 5.1 6 km
3-Jun-06 5.0 9 km
28-Jun-06 5.6 11 km
27-Nov-05 5.4 10 km
10-Sep-08 5.9 8 km
27-Nov-05 5.8 9 km
22-Jul-09 5.2 4 km
27-Nov-05 5.0
30-Nov-05 4.7
aftershock depths
10 km
15
20 km
10 km

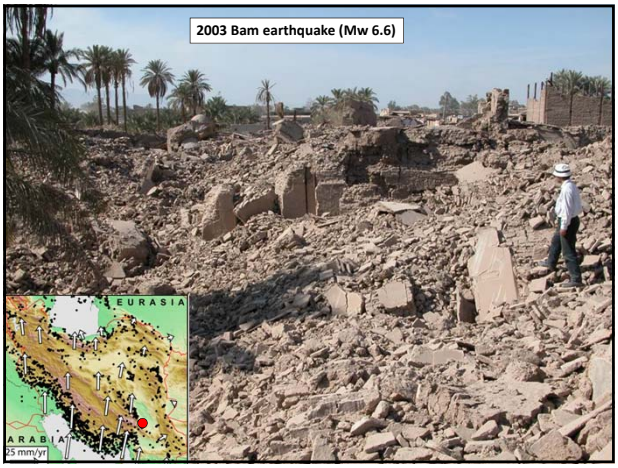

a
desc. 17-Apr-08 – 09-Oct-08
+1.4
0
-1.4
los (cm)
10 km
i = 23°
b
asc. 25-Apr-07 – 01-Oct-08
i = 41°
c
desc. model B (two faults)
i = 23°
d
asc. model A (two faults)
i = 41°

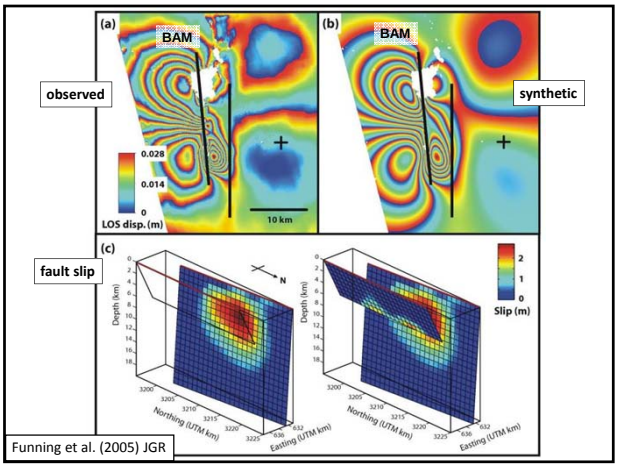

• top depth ~3 km
• bottom depth ~8 km
• top depth ~5 km
• bottom depth ~8 km
Bakhtiyari conglom.
Agha Jari sandstone
Mishan marl
Guri limestone
Plio-Pleisto
Miocene
Approximate depth (km)
desc. model B (two faults)
i = 23°

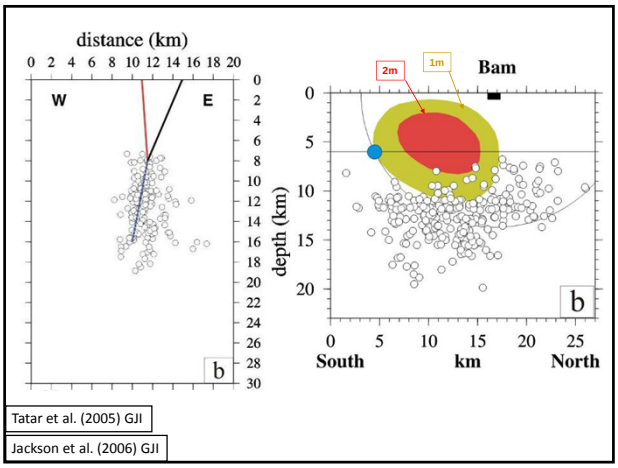

Problems: 2. How does the seismogenic layer work?
Aftershocks cross-section X - Z
SSE
Distance (km)
NNW
model B fault
Depth (km)
Aftershocks cross-section X - Y
SSW
NNE
model A fault
aftershock depths
10
15
20 km
Z
X
27° 00′
26° 50′
56° 00′
56° 10′

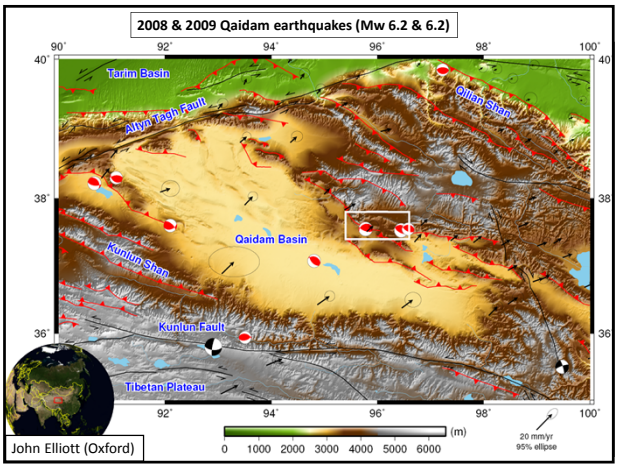

1981 Mw 7.1, length 70 km, Hmax 30 cm
Km
Bam
2003.12.26
EURASIA
ARABIA
25 mm/yr
Berberian et al. (2001) GJI


1981 Mw 7.1, length 70 km, Hmax 30 cm
1998 Mw 6.6, length 20 km, Hmax 300 cm
Km
Bam
2003.12.26
Berberian et al. (2001) GJI


2003 Bam earthquake (Mw 6.6)
EURASIA
ARABIA
25 mm/yr


observed
synthetic
fault slip
(a)
(b)
(c)
BAM
BAM
0.028
0.014
0
LOS disp. (m)
10 km
N
Depth (km)
Northing (UTM km)
Easting (UTM km)
Slip (m)
2
1
0
Funning et al. (2005) JGR


distance (km)
0 2 4 6 8 10 12 14 16 18 20
W
E
b
depth (km)
2m
1m
Bam
South
km
North
Tatar et al. (2005) GJI
Jackson et al. (2006) GJI


2008 & 2009 Qaidam earthquakes (Mw 6.2 & 6.2)
Tarim Basin
Altyn Tagh Fault
Qilian Shan
Qaidam Basin
Kunlun Shan
Kunlun Fault
Tibetan Plateau
(m)
0 1000 2000 3000 4000 5000 6000
20 mm/yr
95% ellipse
John Elliott (Oxford)

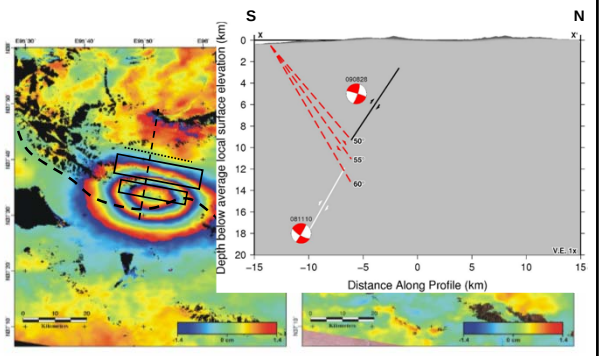
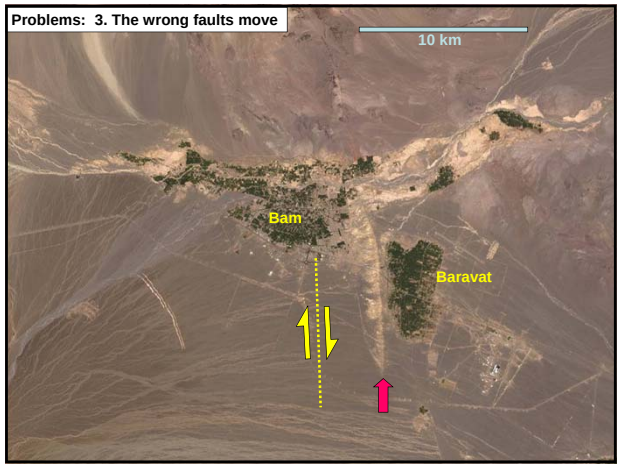
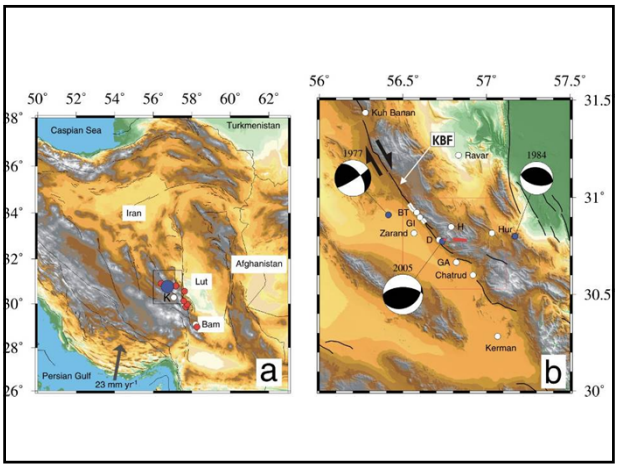


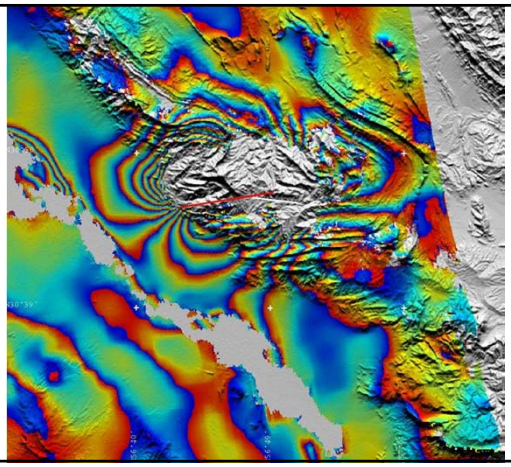
Figure 8: (left) Descending interferogram for the first earthquake on the 10th November 2008. Interferogram, wrapped to +/-1.4 cm. with positive indicating motion away from the satellite. (right) Descending interferogram for the second earthquake on the 28th August 2009.

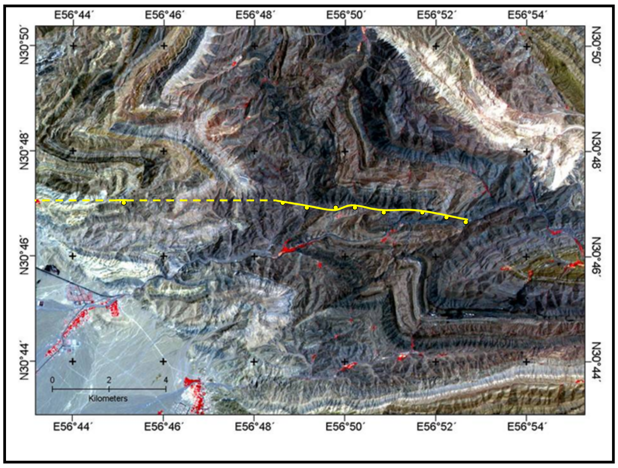
John Elliott (Oxford)

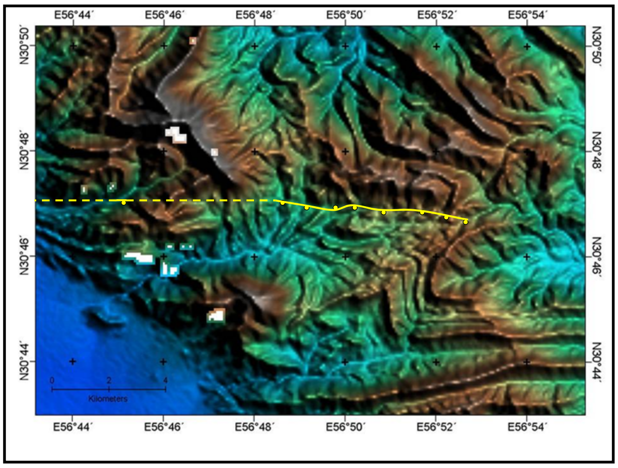
Problems: 3. The wrong faults move

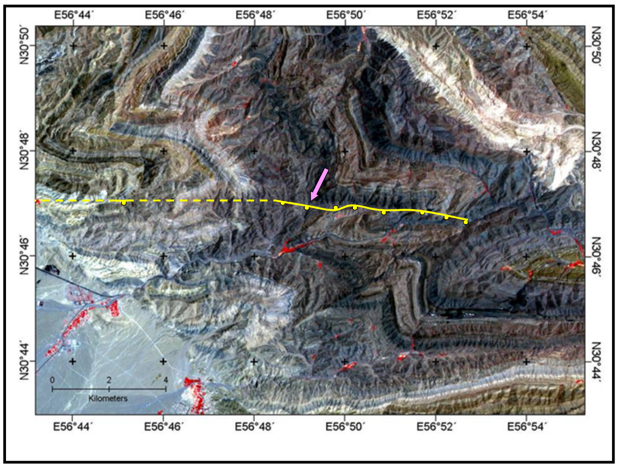


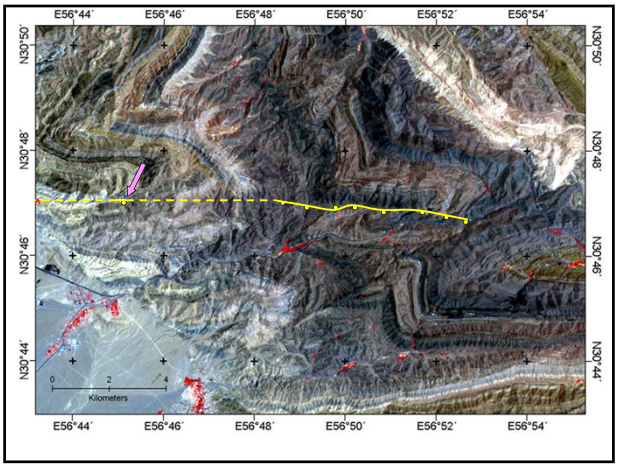


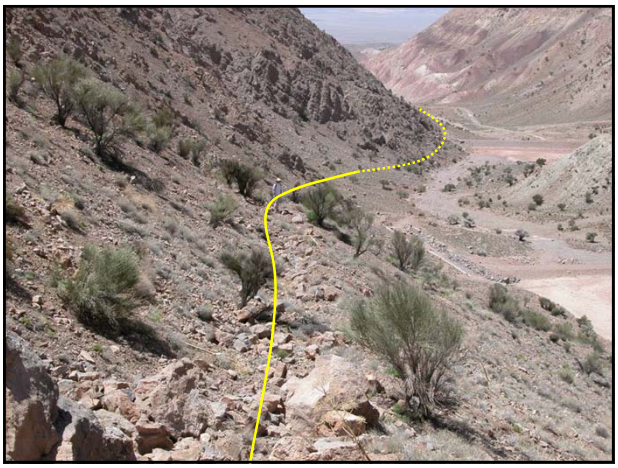


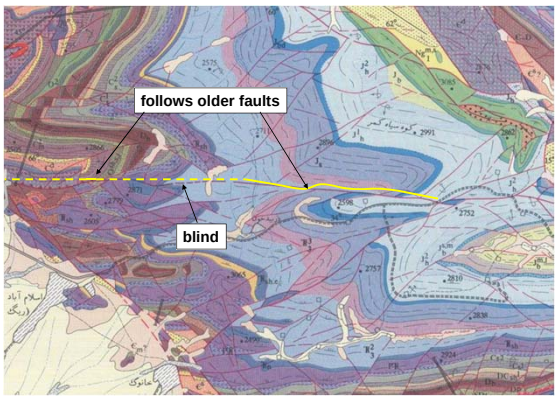

E56°44′
E56°46′
E56°48′
E56°50′
E56°52′
E56°54′
N30°50′
N30°48′
N30°46′
N30°44′
0
2
4
Kilometers

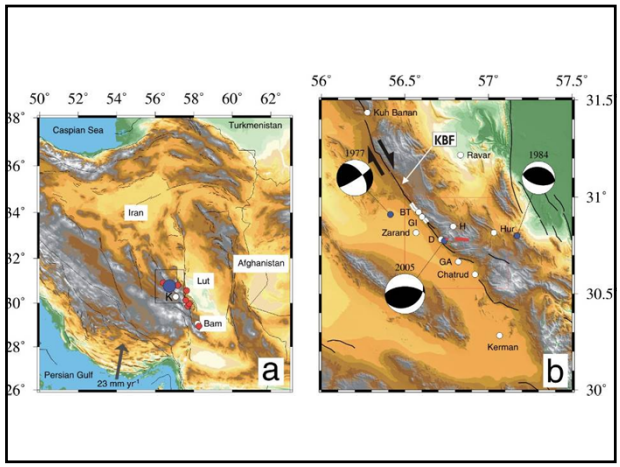

E56°44′
E56°46′
E56°48′
E56°50′
E56°52′
E56°54′
N30°50′
N30°48′
N30°46′
N30°44′
Kilometers

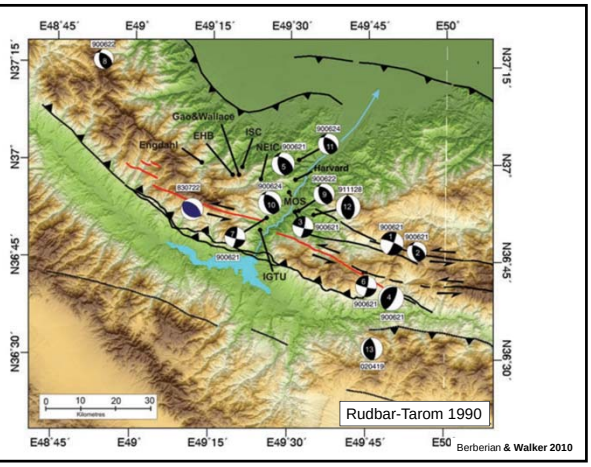

E56°44′
E56°46′
E56°48′
E56°50′
E56°52′
E56°54′
N30°50′
N30°48′
N30°46′
N30°44′
0
2
4
Kilometers

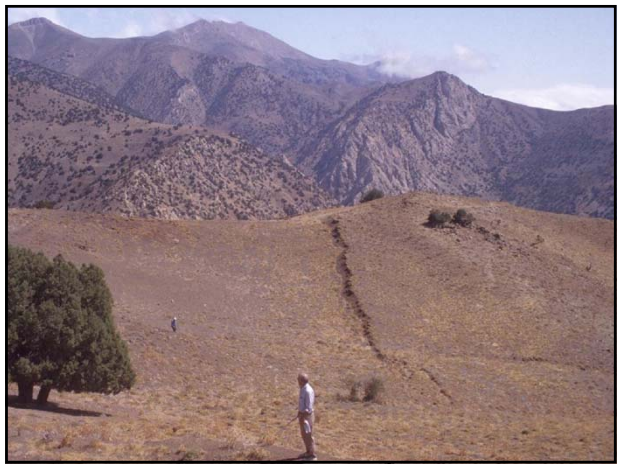

E56°44´
E56°46´
E56°48´
E56°50´
E56°52´
E56°54´
N30°50´
N30°48´
N30°46´
N30°44´
0
2
4
Kilometers

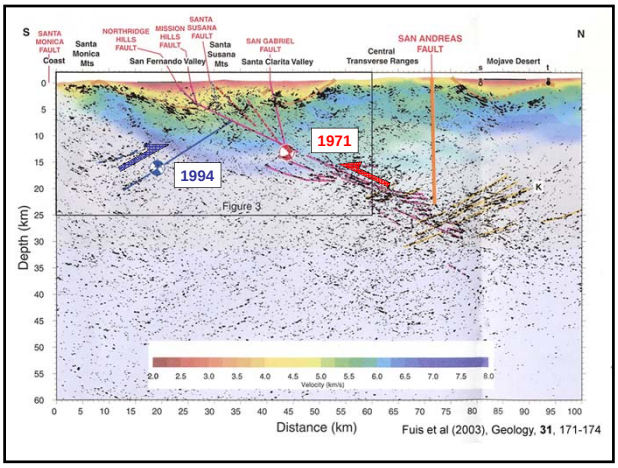


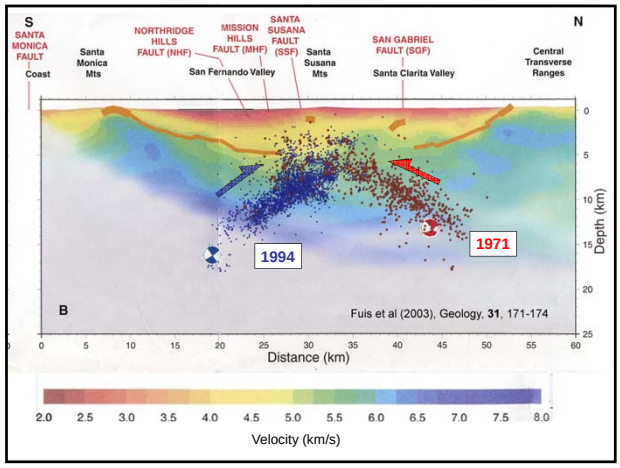

follows older faults
blind

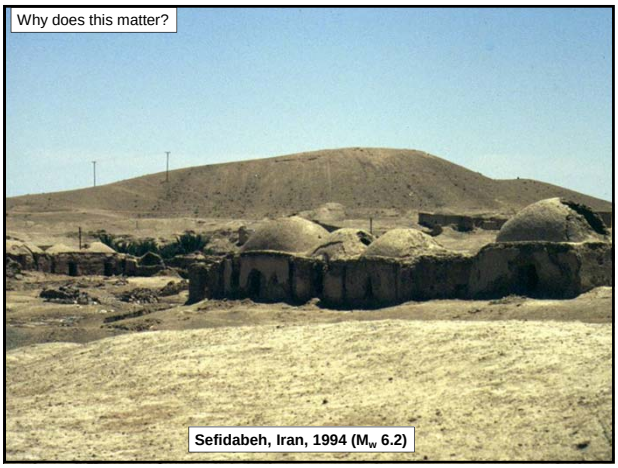

50° 52° 54° 56° 58° 60° 62°
Caspian Sea
Turkmenistan
Iran
Afghanistan
Lut
Bam
Persian Gulf
23 mm yr⁻¹
a
56° 56.5° 57° 57.5°
31.5
31°
30.5
30°
Kuh Banan
KBF
Ravar
1977
1984
BT
GI
Zarand
H
Hur
D
2005
GA
Chatrud
Kerman
b


E48°45′
E49°
E49°15′
E49°30′
E49°45′
E50°
N37°15′
N37°
N36°45′
N36°30′
Gao&Wallace
EHB
ISC
NEIC
Engdahl
Harvard
MOS
IGTU
0 10 20 30
Kilometres
Rudbar-Tarom 1990
Berberian & Walker 2010



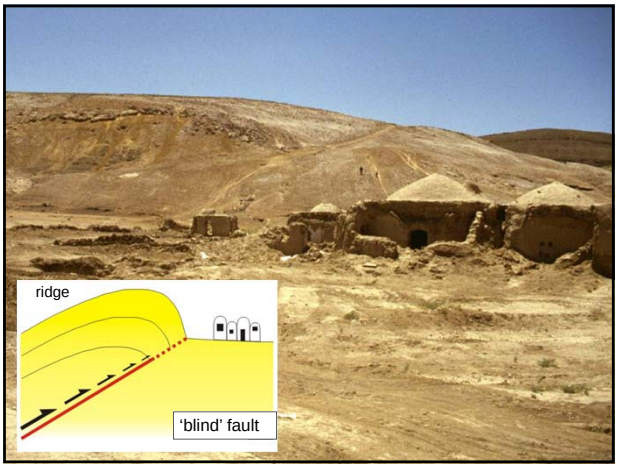

S
N
SANTA MONICA FAULT
Coast
Santa Monica Mts
NORTHRIDGE HILLS FAULT
MISSION HILLS FAULT
SANTA SUSANA FAULT
San Fernando Valley
Santa Susana Mts
SAN GABRIEL FAULT
Santa Clarita Valley
Central Transverse Ranges
SAN ANDREAS FAULT
Mojave Desert
1971
1994
Figure 3
Depth (km)
Distance (km)
Velocity (km/s)
Fuis et al (2003), Geology, 31, 171-174

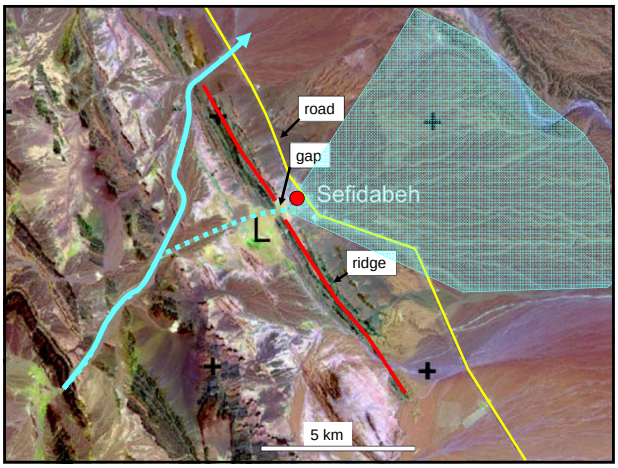

S
N
SANTA MONICA FAULT
Coast
Santa Monica Mts
NORTHRIDGE HILLS FAULT (NHF)
MISSION HILLS FAULT (MHF)
SANTA SUSANA FAULT (SSF)
San Fernando Valley
Santa Susana Mts
SAN GABRIEL FAULT (SGF)
Santa Clarita Valley
Central Transverse Ranges
1971
1994
B
Fuis et al (2003), Geology, 31, 171-174
Depth (km)
Distance (km)
Velocity (km/s)

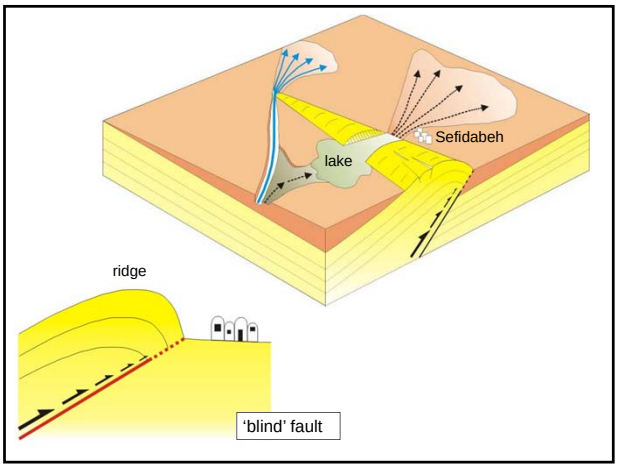

Why does this matter?
Sefidabeh, Iran, 1994 (M_w 6.2)

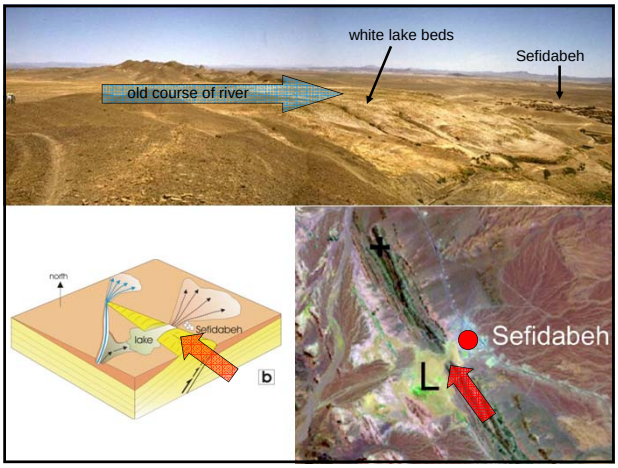

Dasht-e-Margo

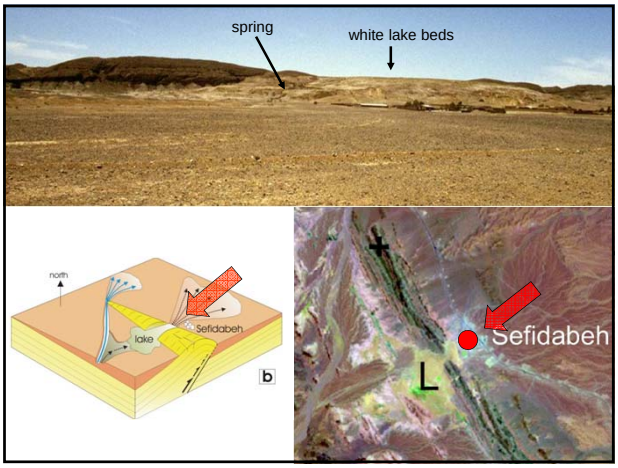

Dasht-e-Lut

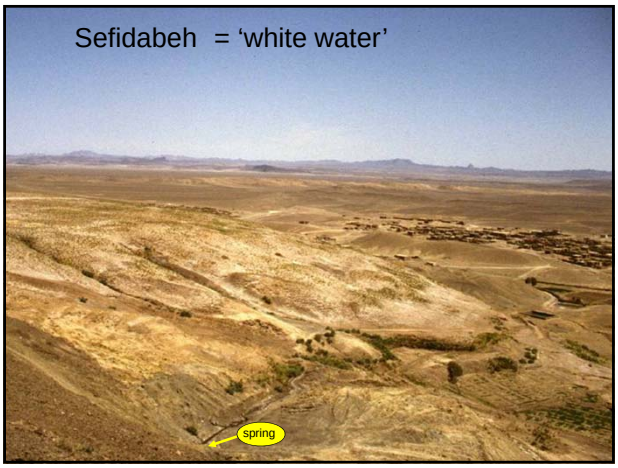

ridge
'blind' fault


road
gap
Sefidabeh
ridge
5 km

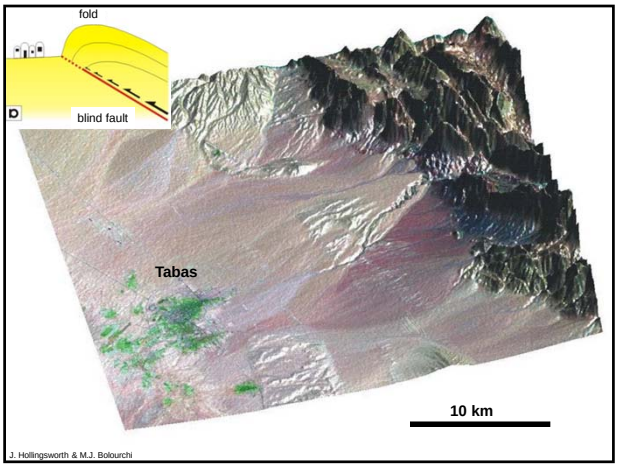

Sefidabeh
lake
ridge
'blind' fault

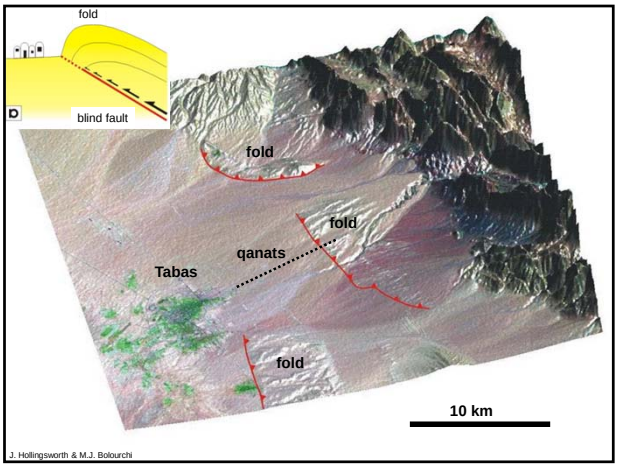

white lake beds
Sefidabeh
old course of river
north
lake
Sefidabeh
b
Sefidabeh
L

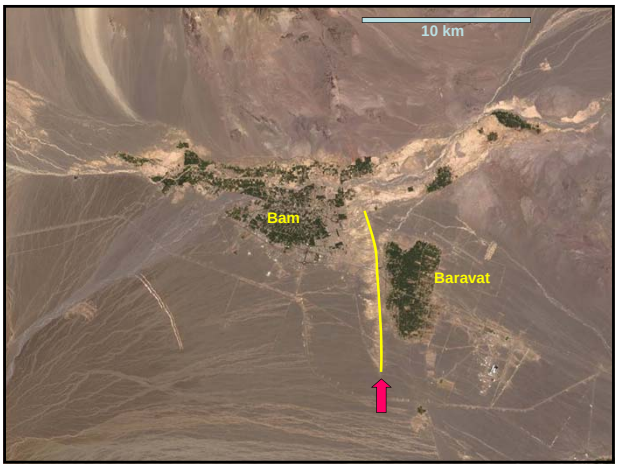

spring
white lake beds
north
lake
Sefidabeh
b
Sefidabeh
L

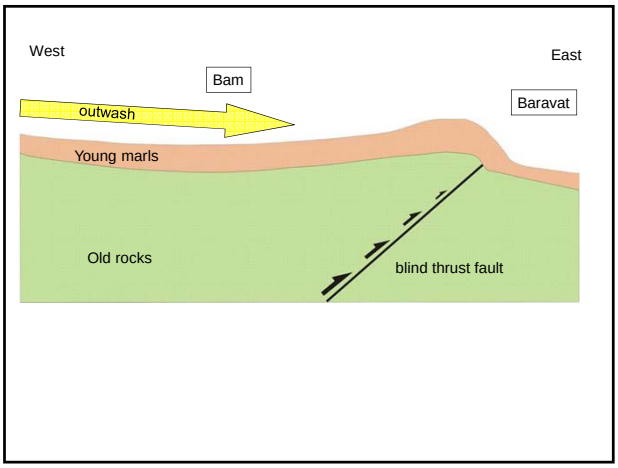

Sefidabeh = 'white water'
spring

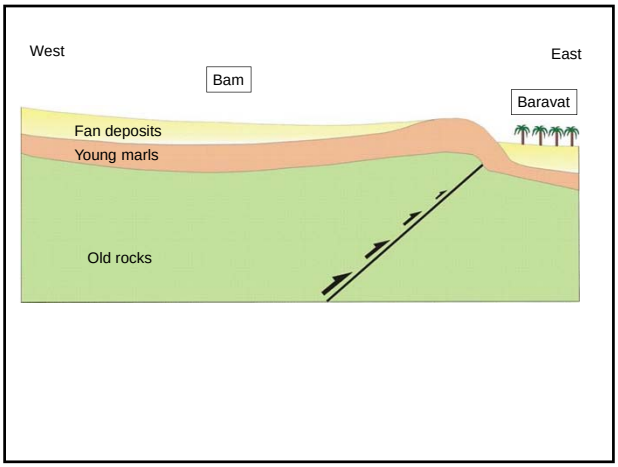

13,000 population
11,000 dead
Tabas-e-Golshan, 1978

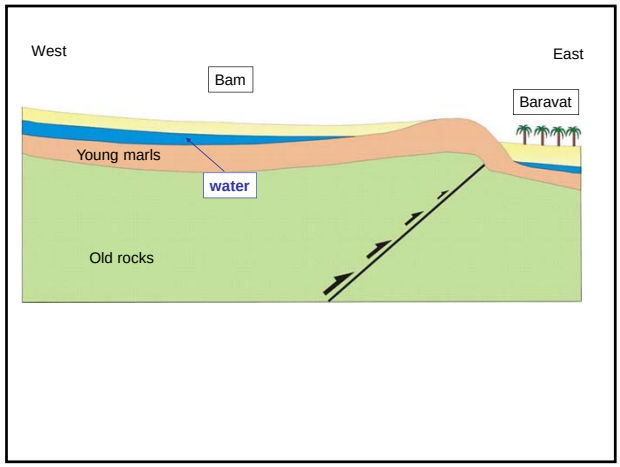

fold
blind fault
Tabas
10 km
J. Hollingsworth & M.J. Bolourchi

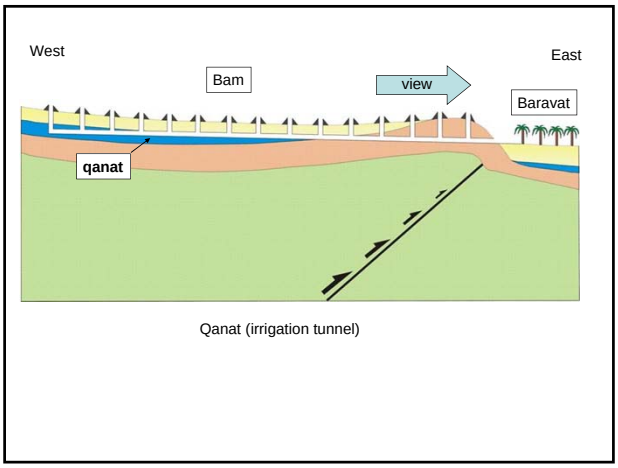

fold
blind fault
fold
fold
qanats
Tabas
fold
10 km
J. Hollingsworth & M.J. Bolourchi


10 km
Bam
Baravat

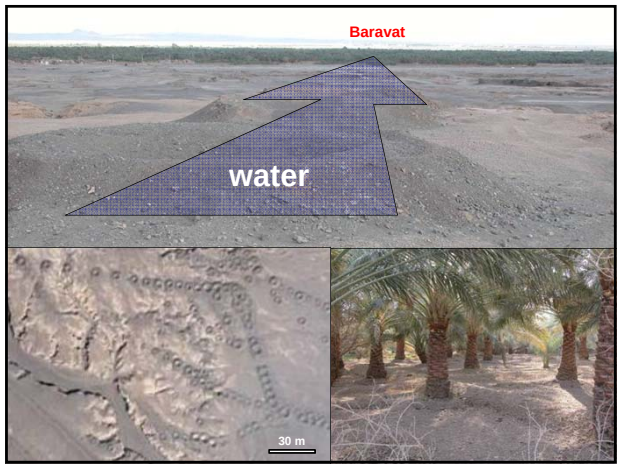

West
East
Bam
Baravat
outwash
Young marls
Old rocks
blind thrust fault

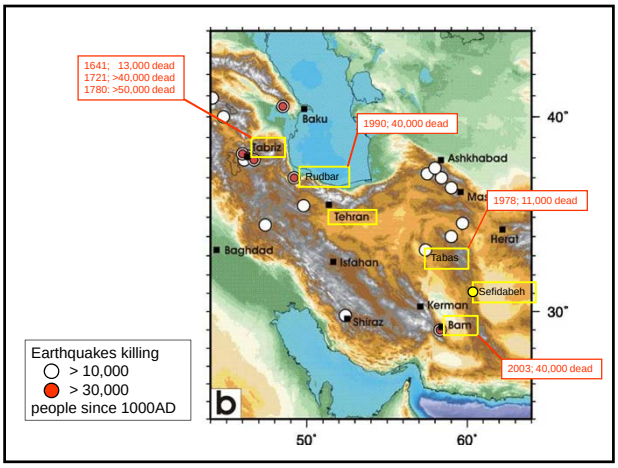


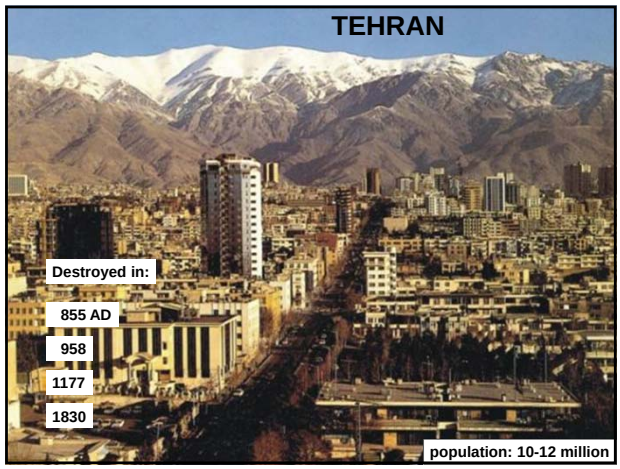


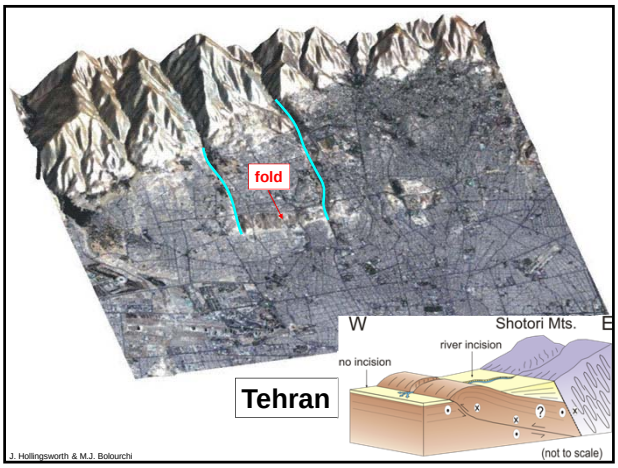


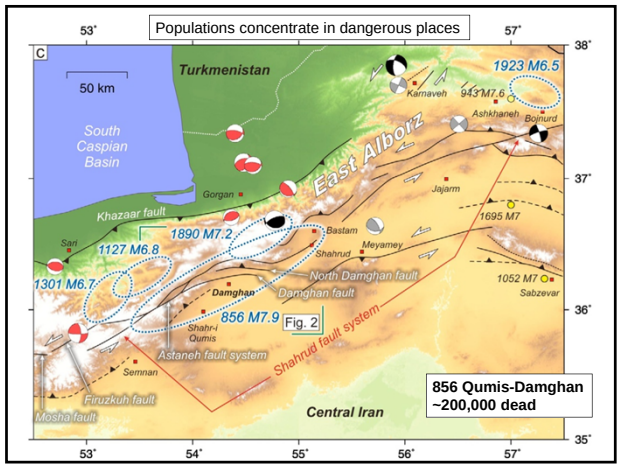
Qanat (irrigation tunnel)

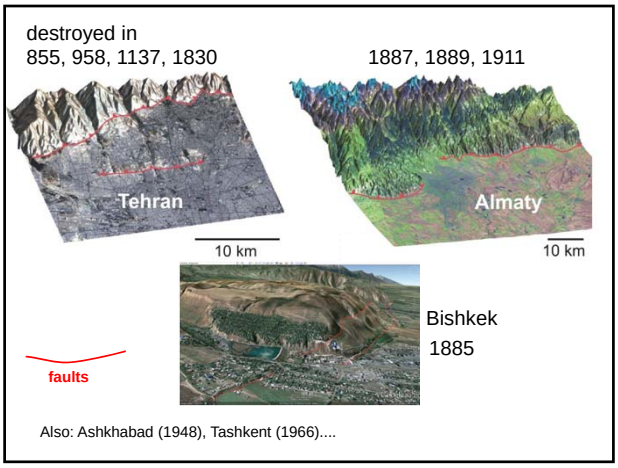


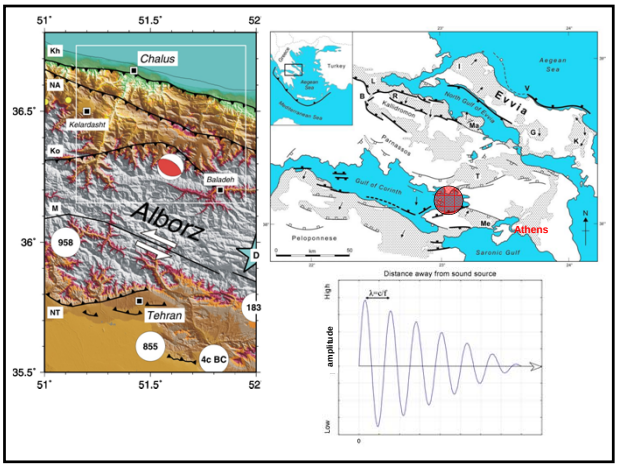

1641; 13,000 dead
1721; >40,000 dead
1780: >50,000 dead
1990; 40,000 dead
1978; 11,000 dead
2003; 40,000 dead
Baku
Tabriz
Rudbar
Tehran
Ashkhabad
Herat
Tabas
Baghdad
Isfahan
Sefidabeh
Kerman
Shiraz
Bam
40°
30°
50°
60°
b
Earthquakes killing
> 10,000
> 30,000
people since 1000AD

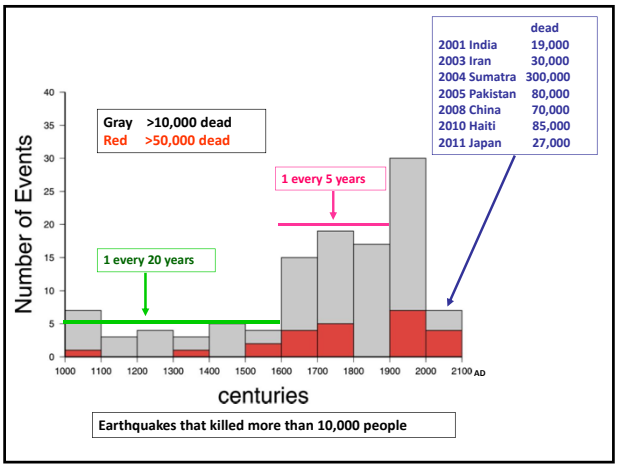

TEHRAN
Destroyed in:
855 AD
958
1177
1830
population: 10-12 million


fold
W
Shotori Mts.
E
river incision
no incision
Tehran
J. Hollingsworth & M.J. Bolourchi
(not to scale)


Populations concentrate in dangerous places
C
50 km
Turkmenistan
South Caspian Basin
East Alborz
Khazaar fault
Gorgan
Karnaveh
Ashkhaneh
Bojnurd
Jajarm
Bastam
Meyamey
Shahrud
Sari
1923 M6.5
943 M7.6
1695 M7
1052 M7
Sabzevar
1890 M7.2
1127 M6.8
1301 M6.7
856 M7.9
Fig. 2
Damghan
Damghan fault
North Damghan fault
Shahrud fault system
Shahr-i Qumis
Astaneh fault system
Semnan
Firuzkuh fault
Mosha fault
Central Iran
856 Qumis-Damghan
~200,000 dead
53°
54°
55°
56°
57°
38°
37°
36°
35°


destroyed in
855, 958, 1137, 1830
1887, 1889, 1911
Tehran
Almaty
10 km
10 km
faults
Bishkek
1885
Also: Ashkhabad (1948), Tashkent (1966)....


Chalus
Kelardasht
Baladeh
Alborz
Tehran
958
855
4c BC
183
Evvia
Athens
Peloponnese
Distance away from sound source
amplitude


dead
2001 India 19,000
2003 Iran 30,000
2004 Sumatra 300,000
2005 Pakistan 80,000
2008 China 70,000
2010 Haiti 85,000
2011 Japan 27,000
Gray >10,000 dead
Red >50,000 dead
1 every 5 years
1 every 20 years
Number of Events
centuries
Earthquakes that killed more than 10,000 people