UMFIE : UNIFIED MODEL FOR INTRAPLATE EARTHQUAKES

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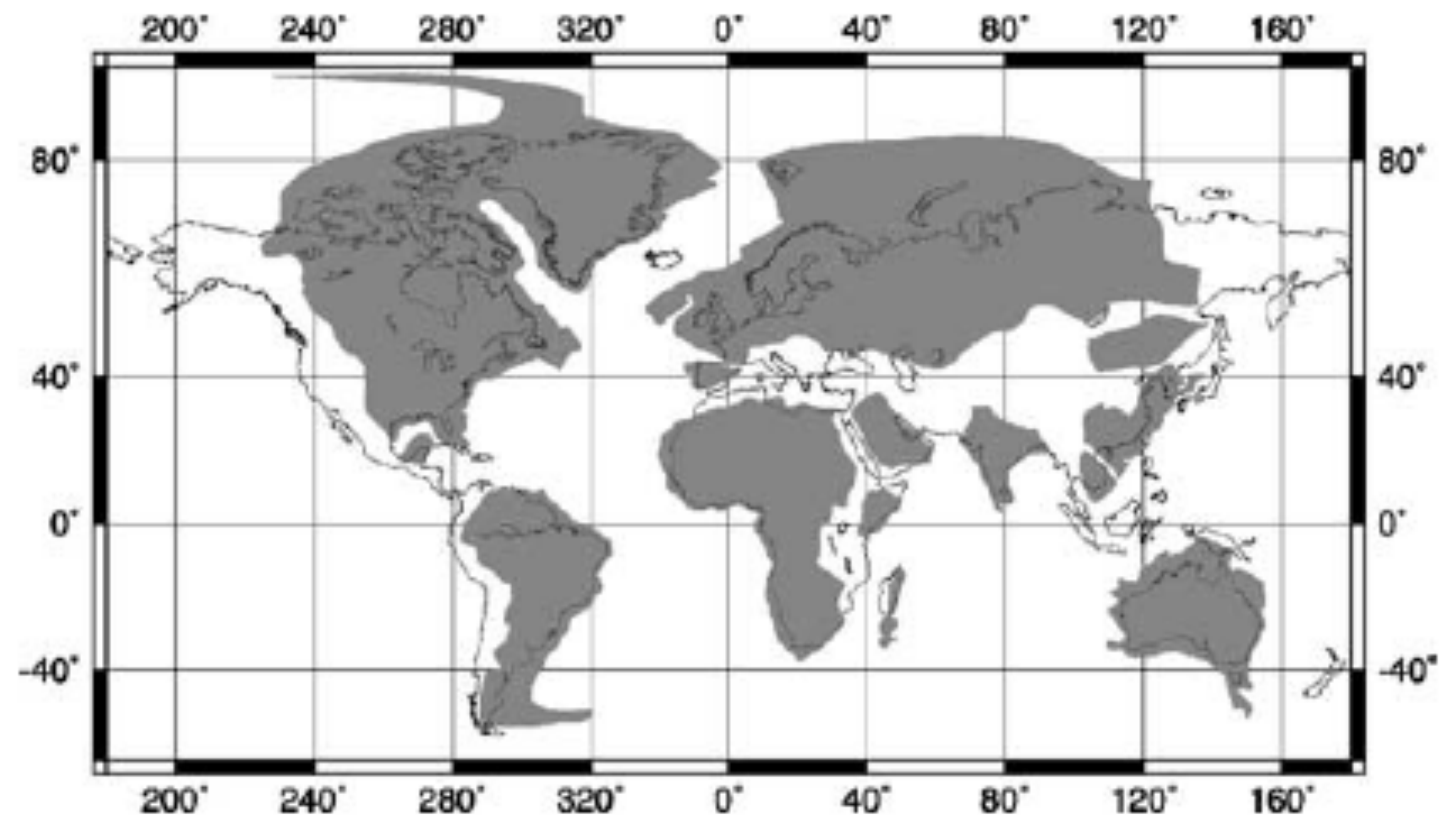
OUTLINE

- UMFIE
- Comparison with two case histories of IPE
- Evidence of local stress perturbation
- Finding potential locations of IPE
- Unanswered questions.

Schulte and Mooney (2005) compared the location of IPE with ancient rifts within SCR (gray)



IPE CORELATED WITH ANCIENT RIFTS

- More than 80% of seismic energy within Stable Continental Regions by is released in the rifted crust and taphrogens.

Johnston and Canter (1990)

Schulte and Mooney (2005)

- 12 rifts and taphrogens account for 74% of all events and 98% of total seismic moment release.

Schulte and Mooney (2005)

Review of observations and compilations of IPE case histories

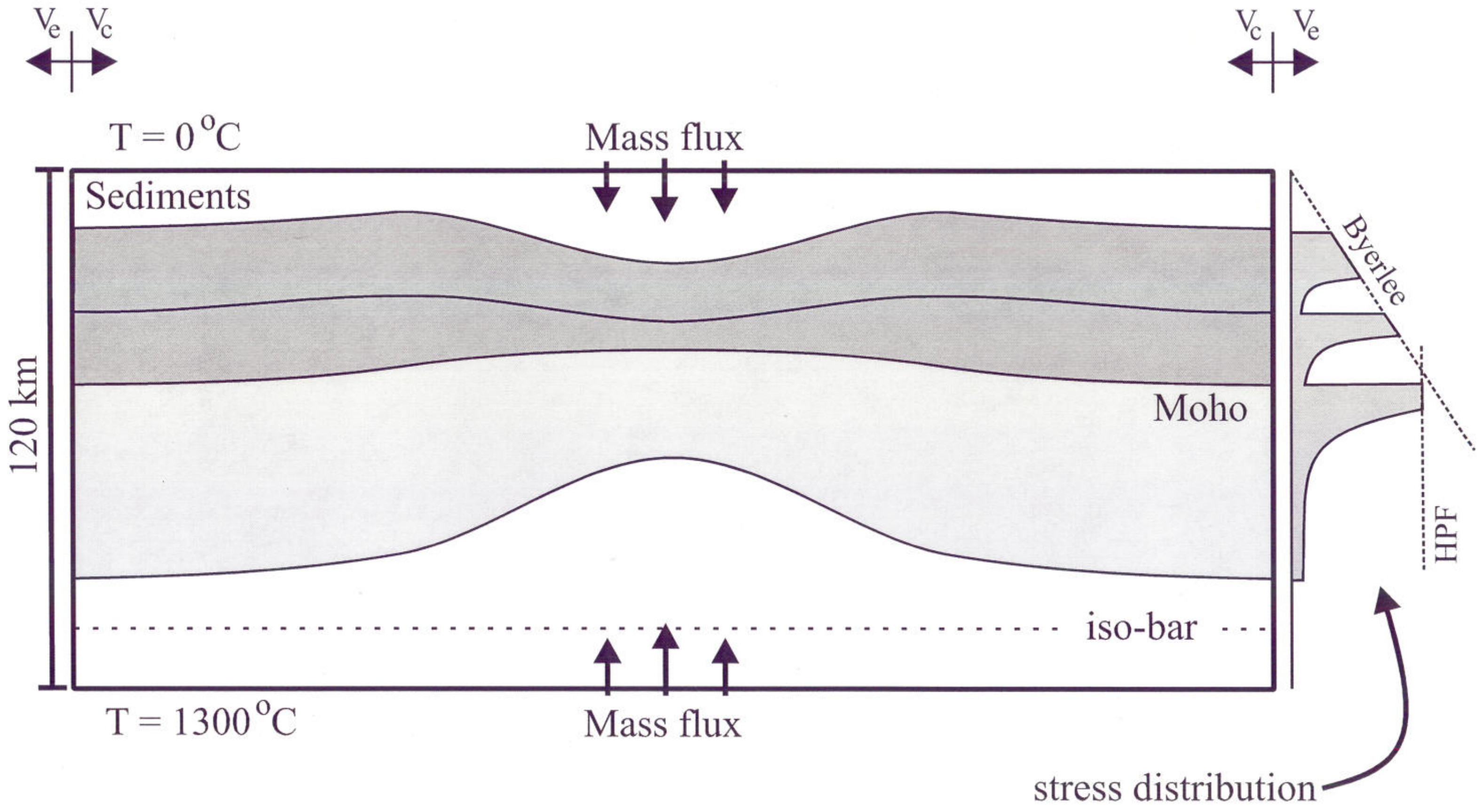
- IPE located in inverted rift basins
- IPE occur at Local Stress Concentrators.
- Evidence of perturbation of plate tectonic stress field on regional and local scales

Insights from modeling.

- Hansen and Nielsen (2003) presented dynamic thermo-mechanical models of compressional inversion of a sedimentary basin with permanent a priori crustal weakness.
- We will compare the results of these models with observations and explanations of intraplate earthquakes.

Model set up

D.L. Hansen, S.B. Nielsen / Tectonophysics 373 (2003) 5–24



Effective strain rate at three stages of extensional evolution

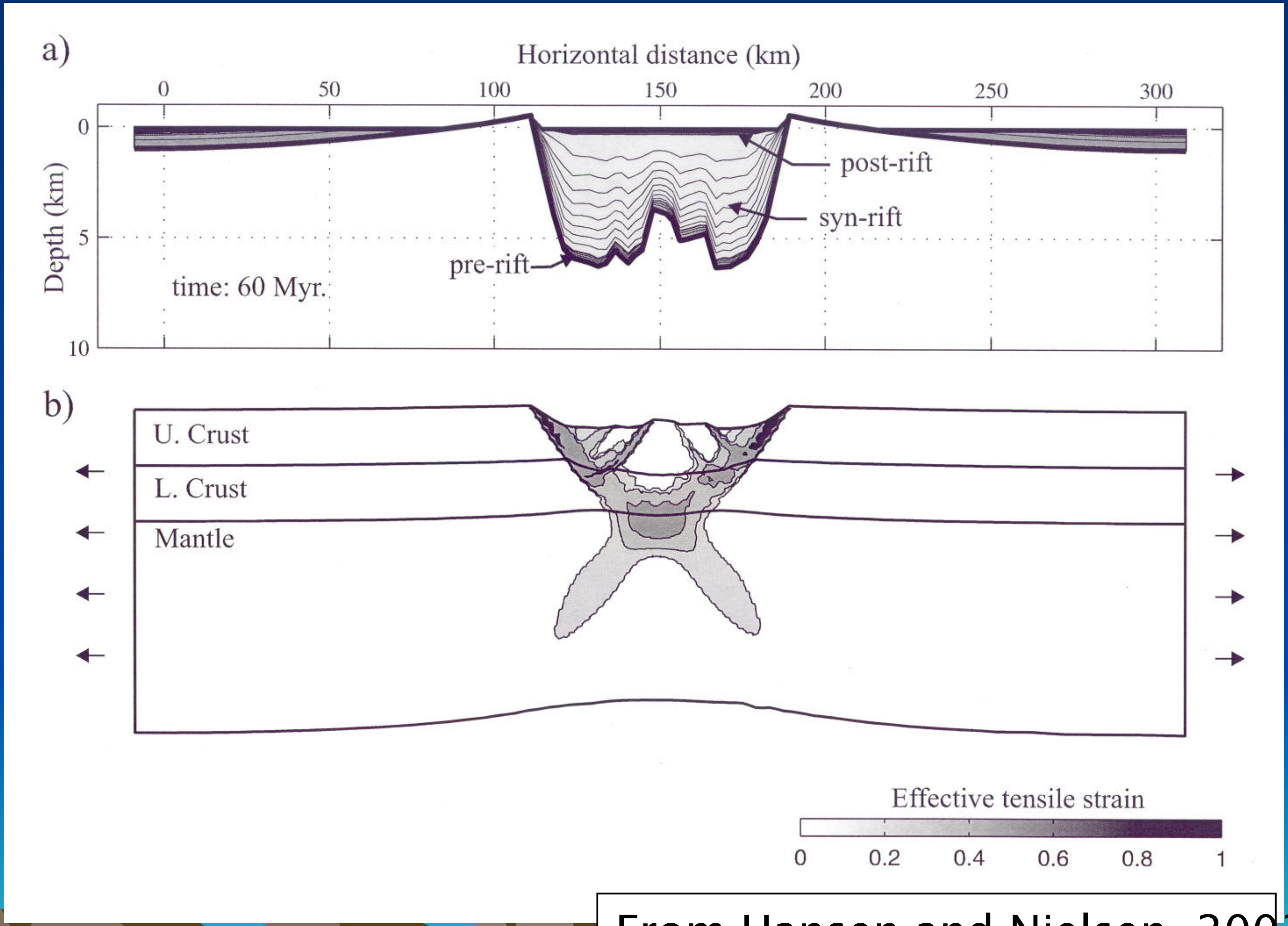
1 Ma

2 Ma

7 Ma

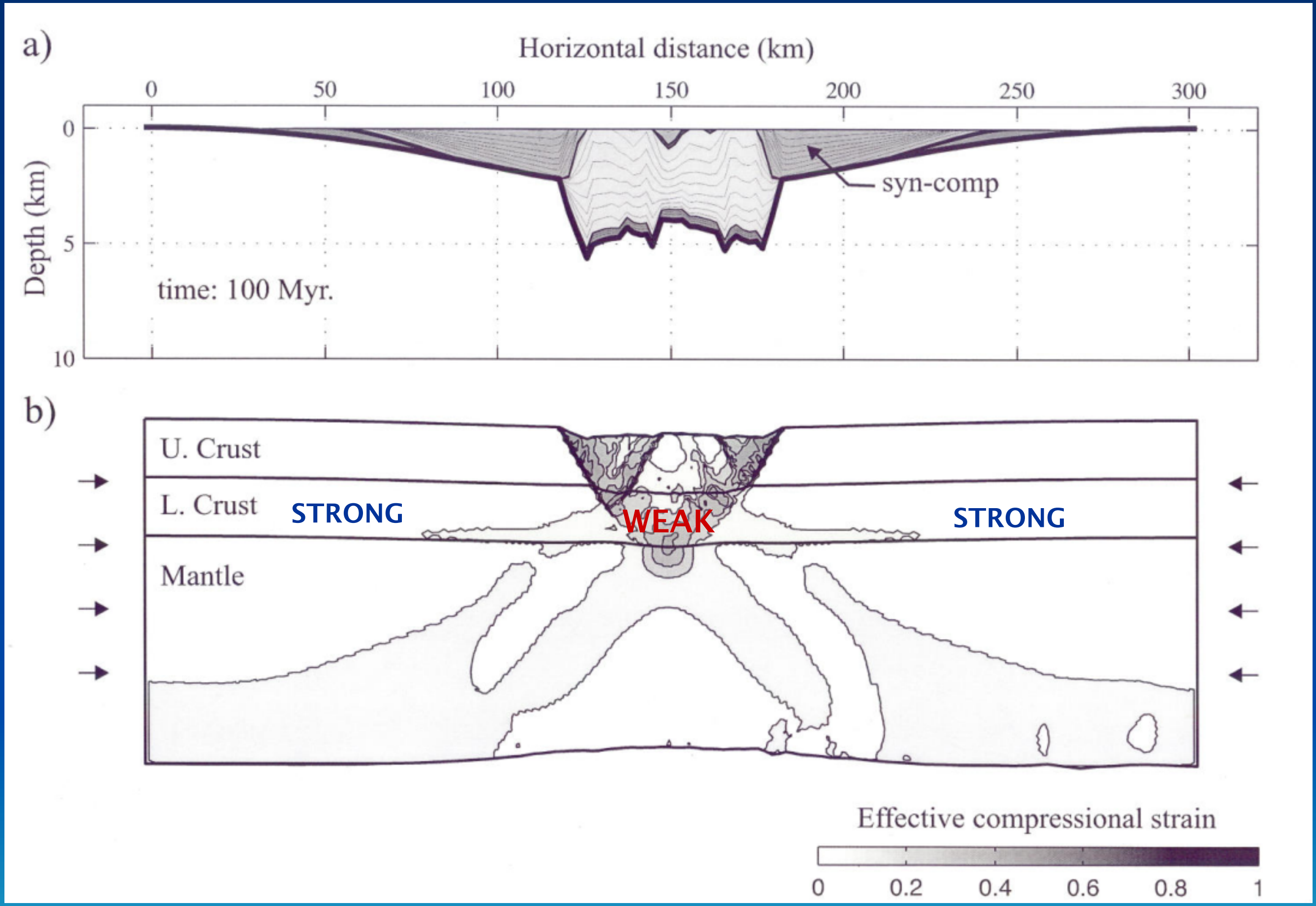
- 1 Ma. Two sets of conjugate faults develop, intersecting at brittle–ductile transition in upper crust.
- 2 Ma. Part of lower crust becomes brittle. New faults form.
- 7 Ma. Fault network established. Further deformation in shear zones with rigid subsidence and rotation

Just before compression, 60Ma



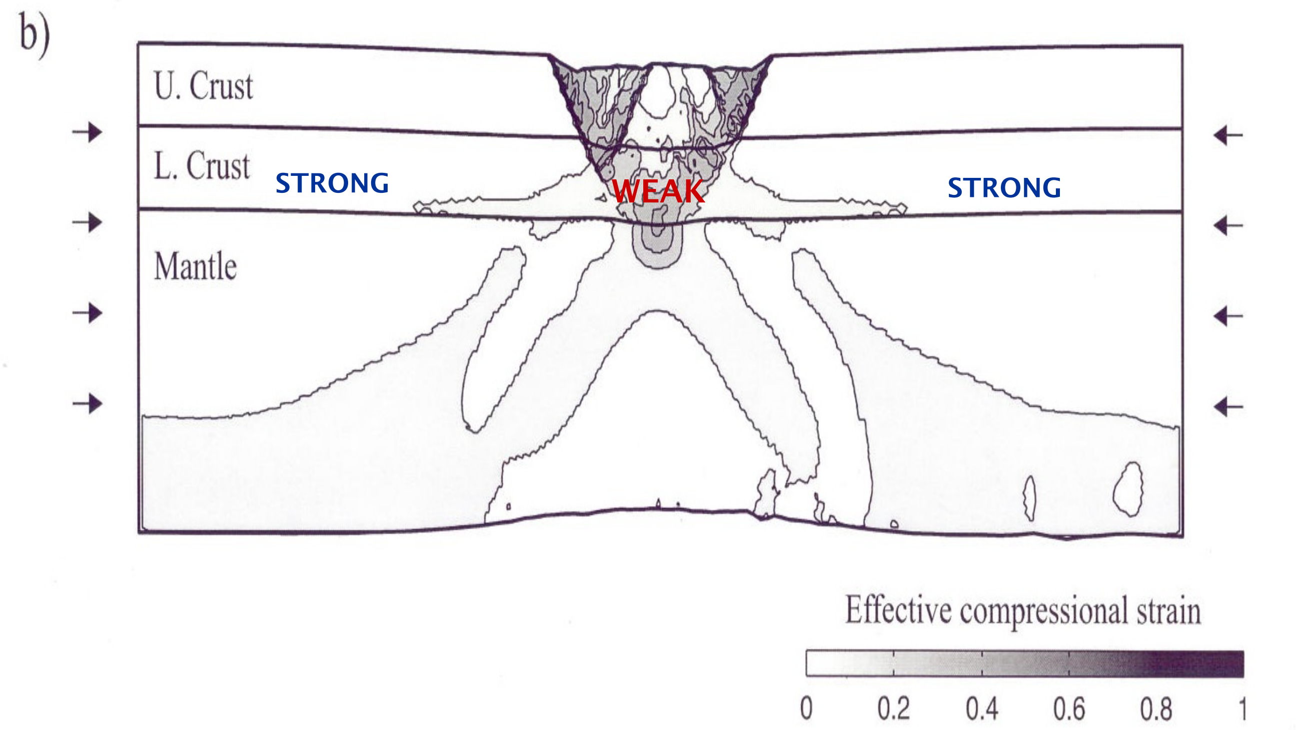
From Hansen and Nielsen, 2003

After compression, 100Ma



From Hansen and Nielsen, 2003

Distribution of compressional strain rates



From Hansen and Nielsen, 2003

Inference of strong and weak crust/mantle from Mooney and Ritsema, 2009

Insights from modeling of stress inversion in rifted basins.

Stress inversion of rifted sedimentary basin results in

- Formation of weak conjugate and boundary faults.
- Higher **local** strain rates on these faults and in up welled lower crust… rift pillows
- Weak upper mantle-lower crust within rift structure.

COMBINING evolving ideas and results of the two papers

IPE occur in ancient rifts

Stress inversion of rifts produces local stress concentrators

IPE occur at local stress concentrators

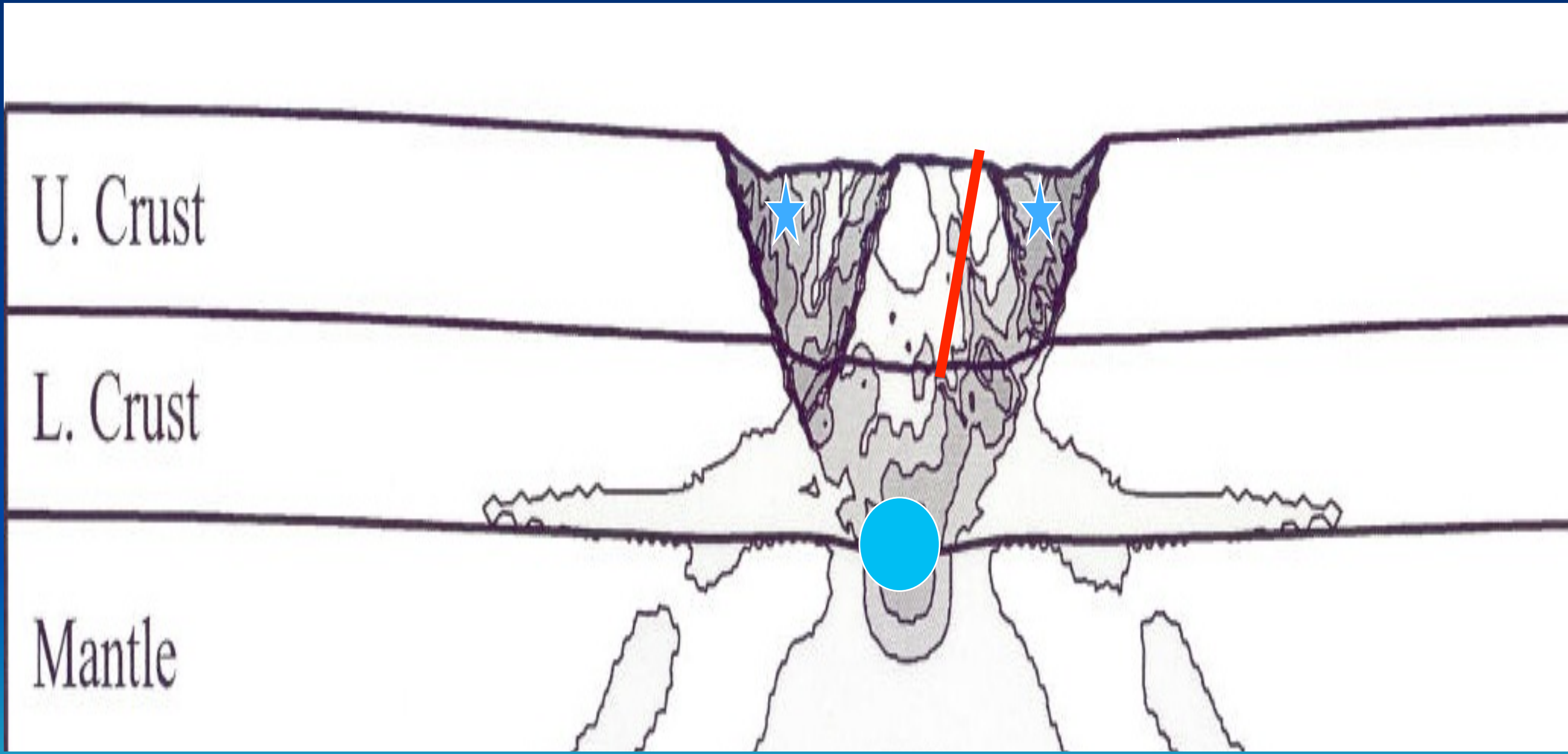
We get

UMFIE the Unified Model For Intrapalte Earthquakes

Unified model for IPE

- Most of the seismic energy release occurs in former rifts.
- IPE are associated with local stress concentrators in the upper and lower crust within rifts.
- Fault intersections at shallow depths and rift pillows at mid-crustal depths are the most common stress concentrators.
- These localized seismicity regions are associated with discernable, high strain rates.

Local stress concentrators within an ancient rift



Caveat

Individual seismogenic faults and strain rates depend on

the tectonic history of the rift basin

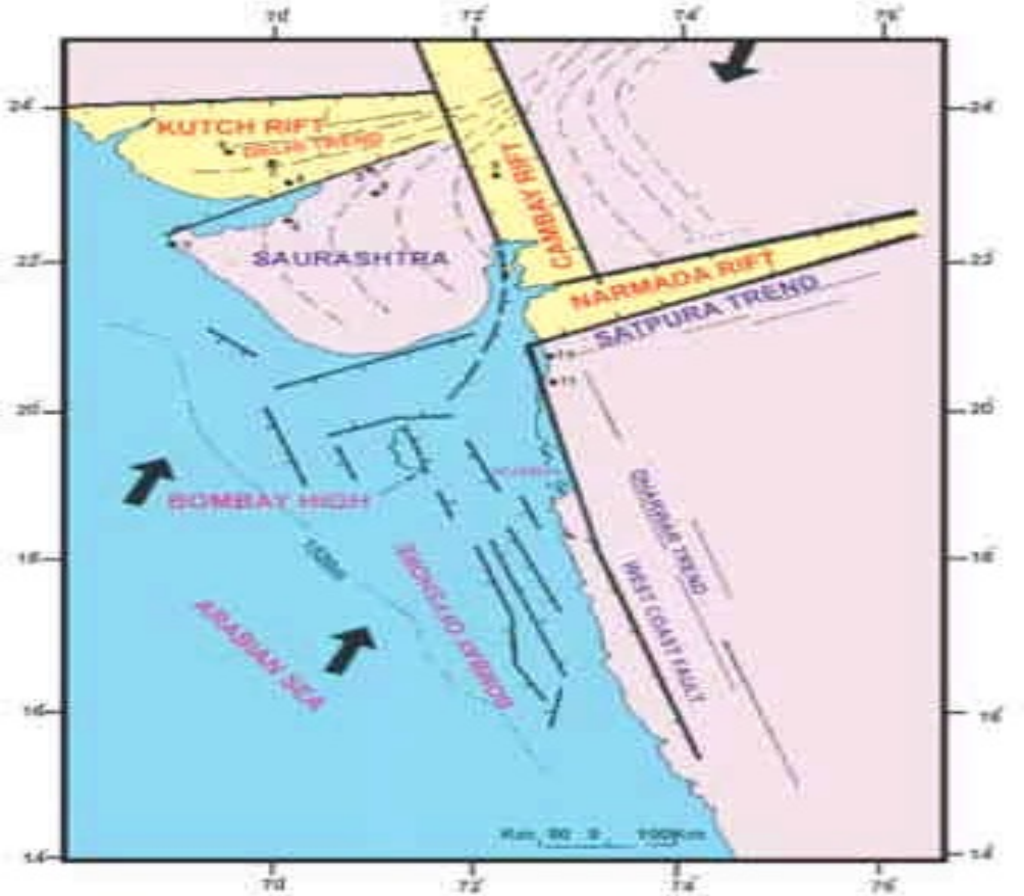
and its orientation with respect to the modern stress field

Comparison of UMFIE with two examples of Intraplate earthquakes

Kutch rift basin, India

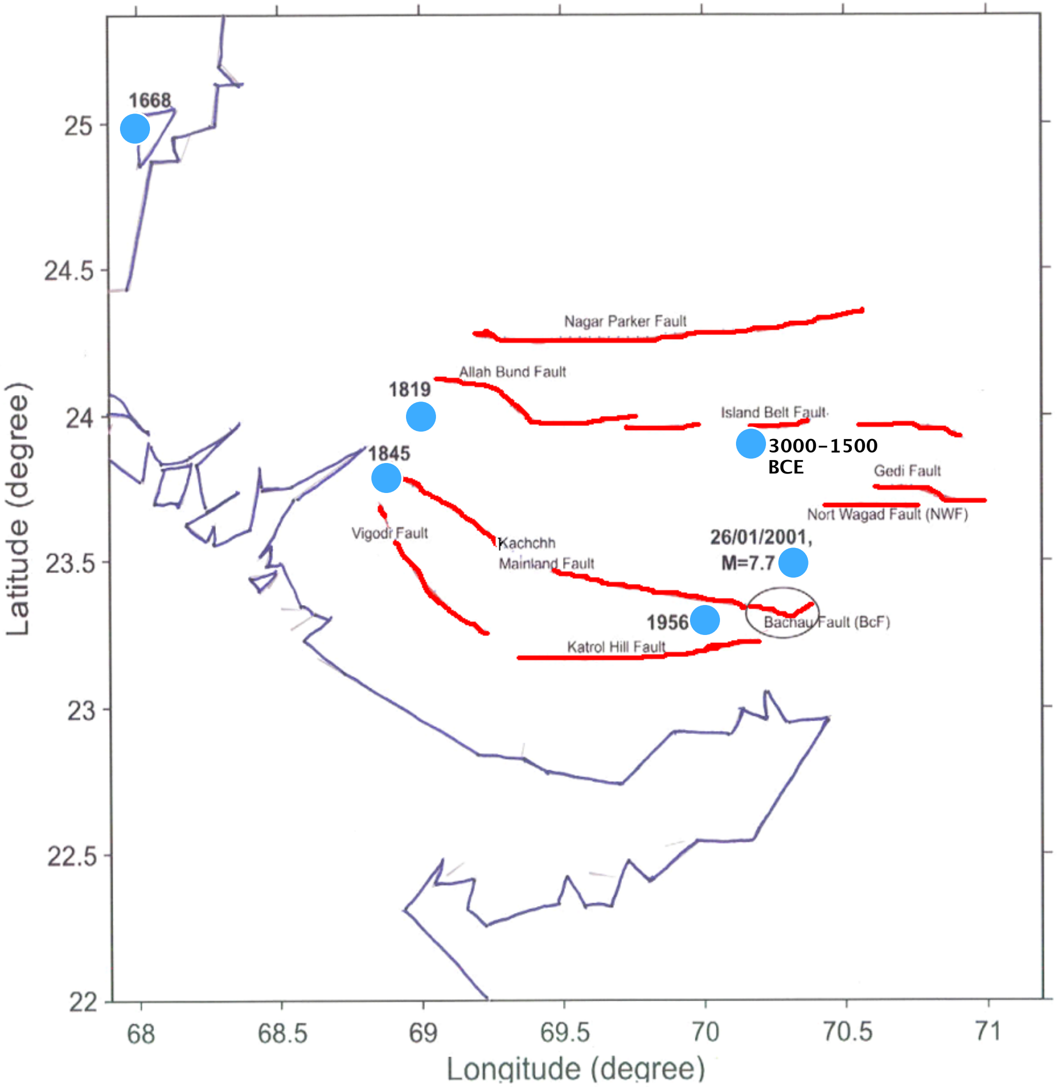
Sea of Japan

Kutch Rift Basin, India



From Biswas (2005)

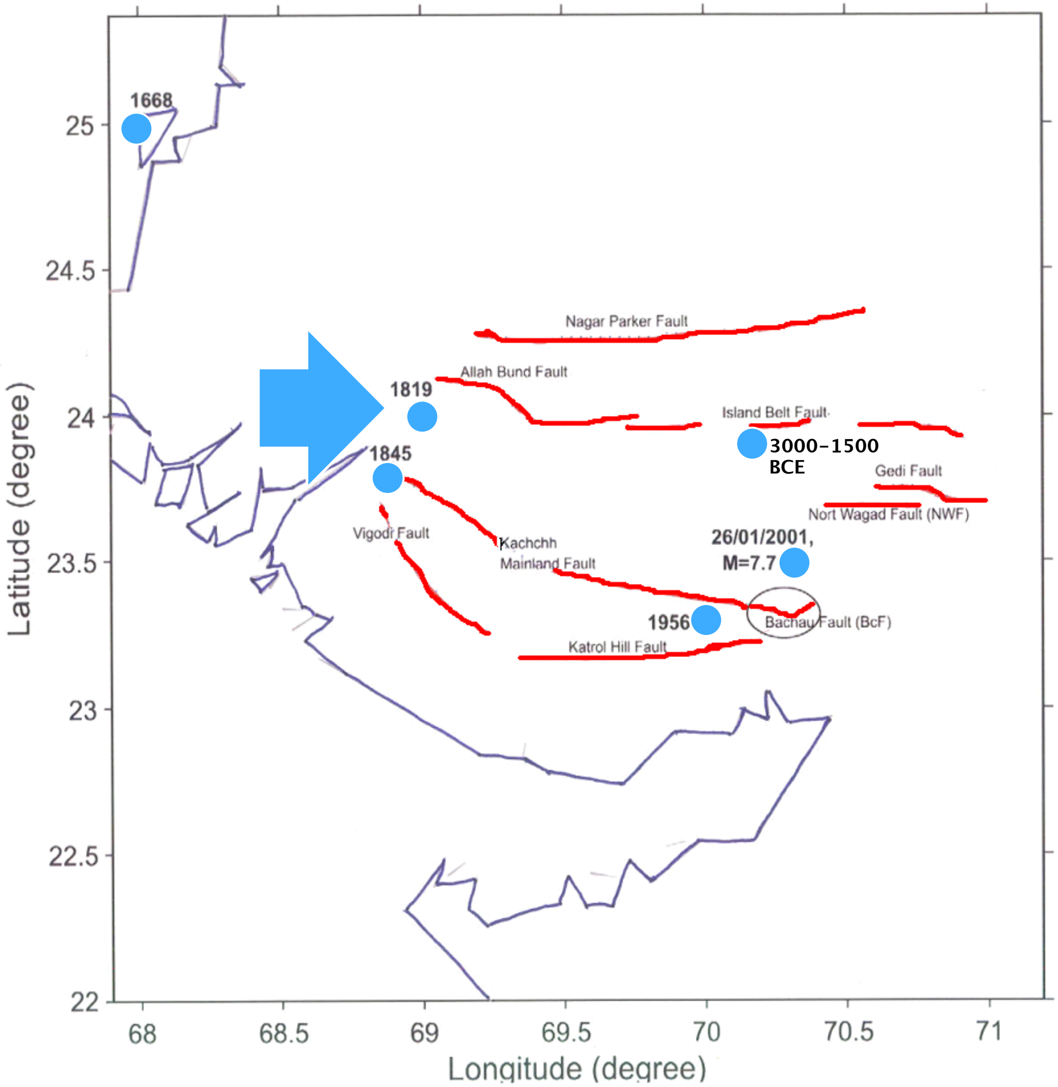
Major historical earthquakes in Kutch and associated faults



Modified from Bhatt et al., 2009

Major historical earthquakes in Kutch and associated faults

1819 Allah Bund Earthquake



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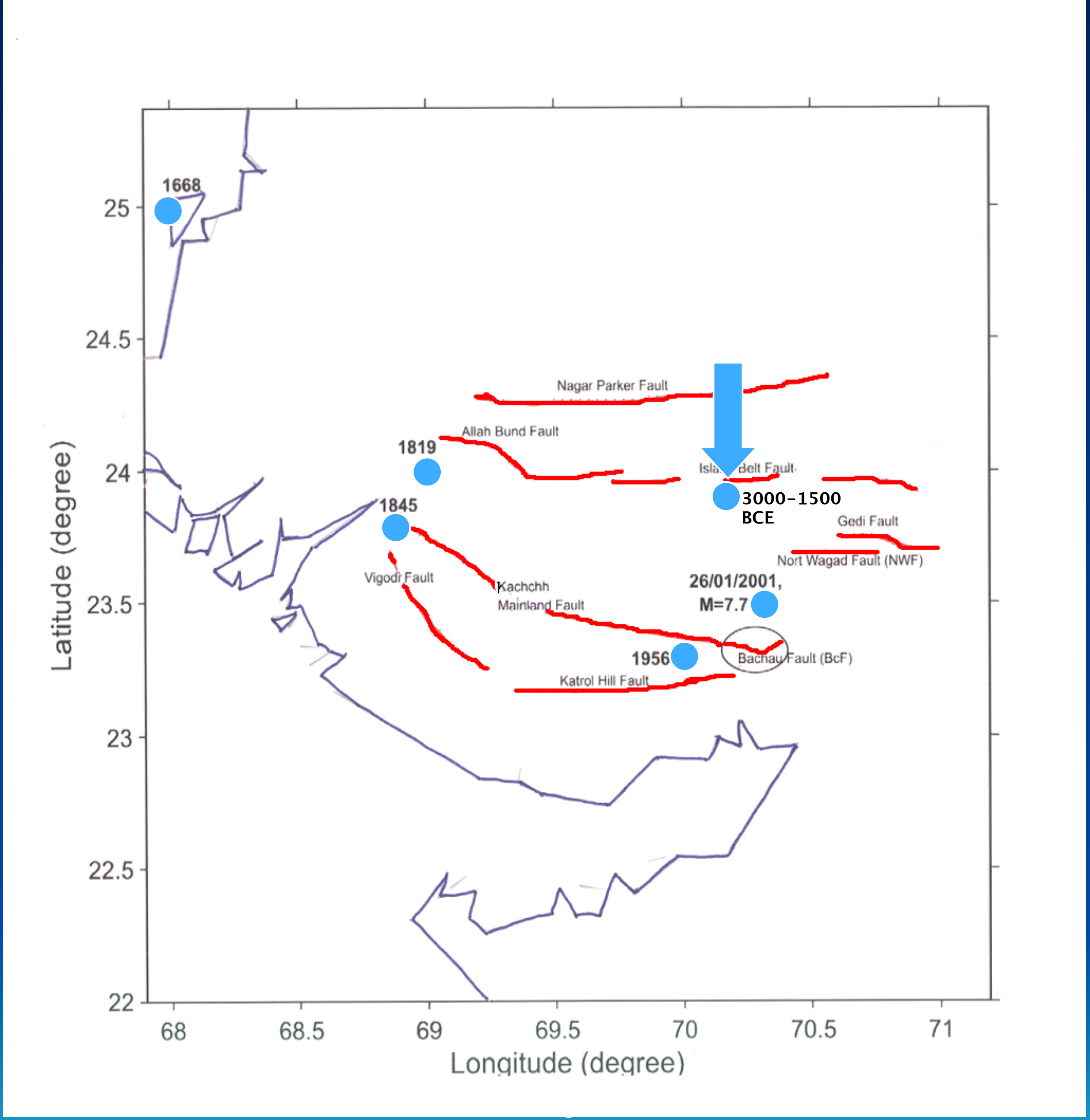
Allah Bund, 1819

Major historical earthquakes in Kutch and associated faults

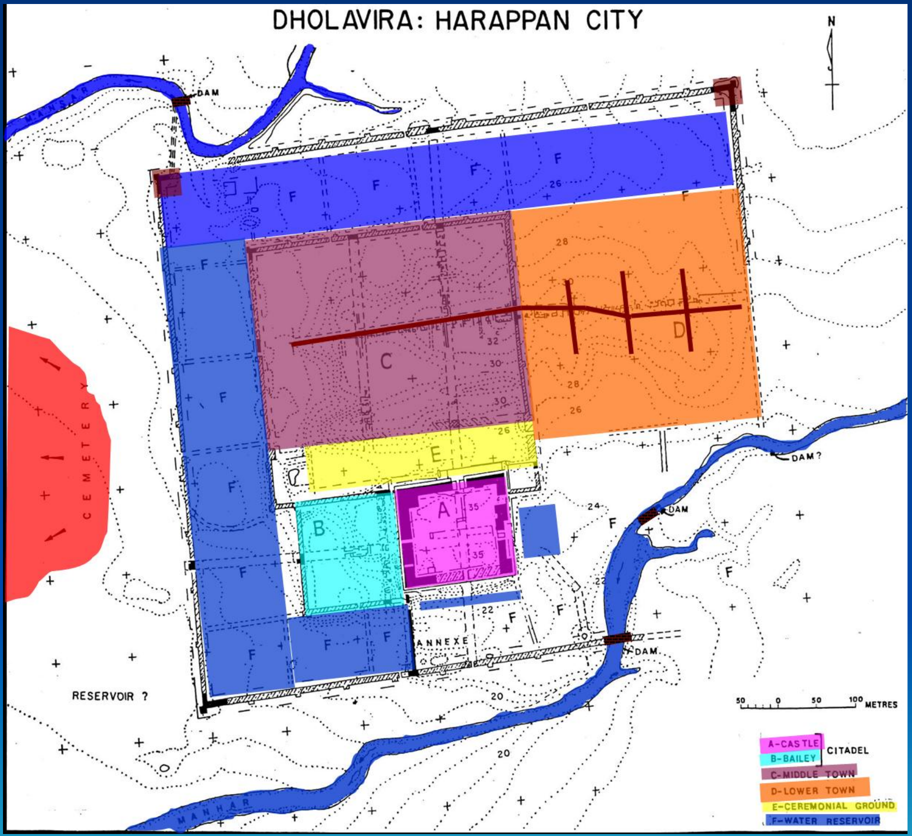


Dholavira
Three eq.
~2900,~ 2700 and ~2100-2000 BCE

Modified from Bhatt et al., 2009

Dholavira, 3000 to 15000 B.C.E

Archeo-seismological evidence of three earthquakes

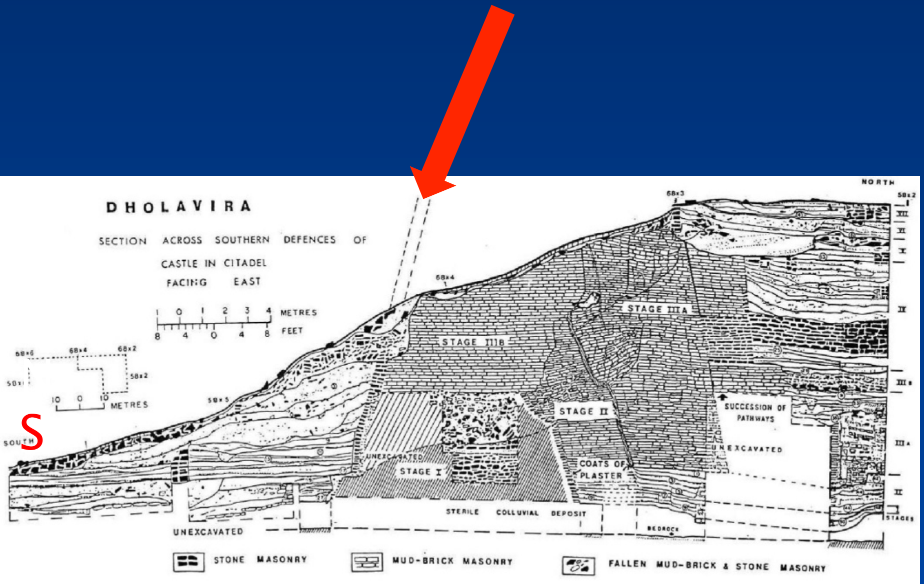


- ~ 2900 BCE
- Effects observed in southern wall of the Citadel
- ~2700 BCE –the largest
- ~2100-2000 BCE--

  the last one before abandonment

Courtesy Dr. R.S. Bisht, 2010

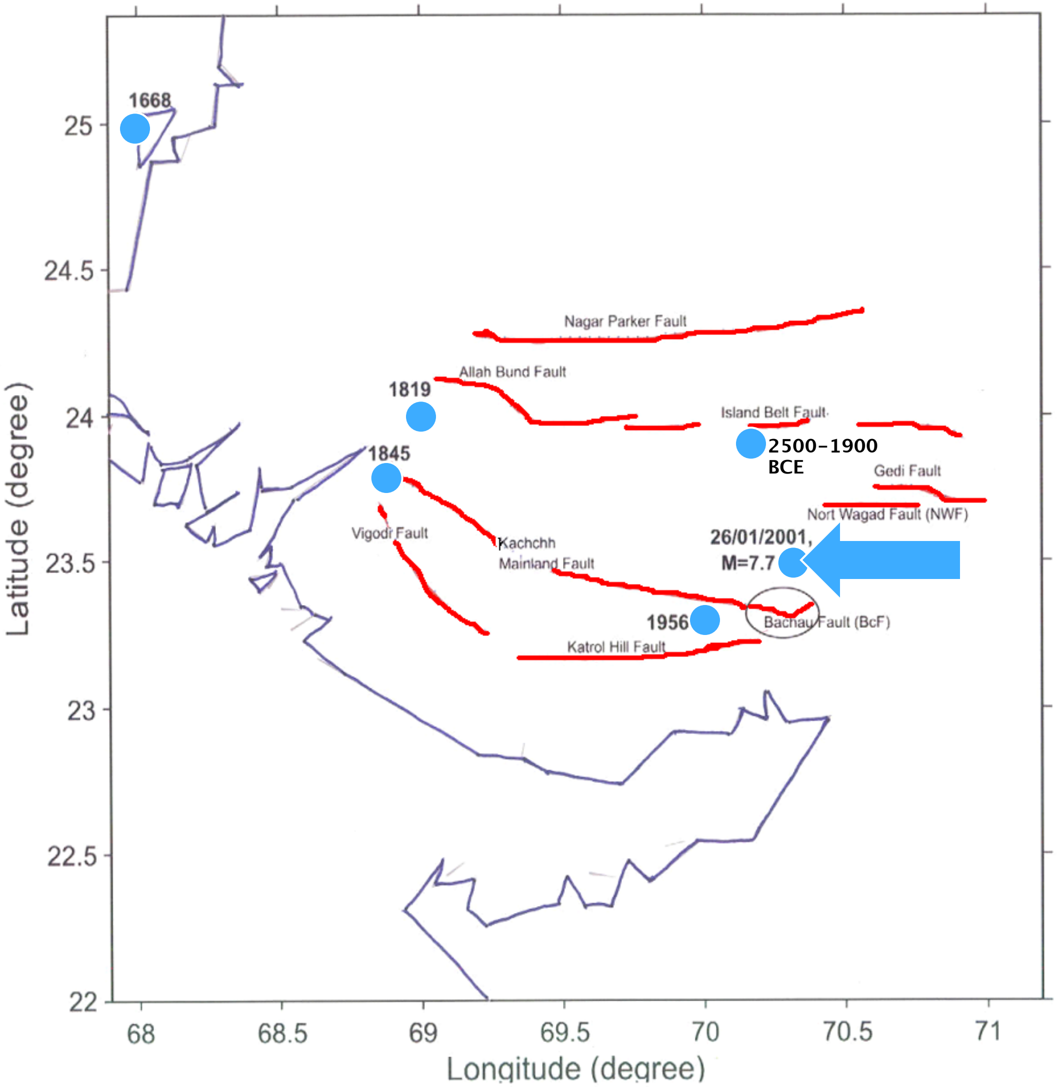
Southern wall of the Citadel damaged in 2900 BCE



Courtesy Dr. R. S. Bisht

Major historical earthquakes in Kutch and associated faults

The 2001 Bhuj earthquake



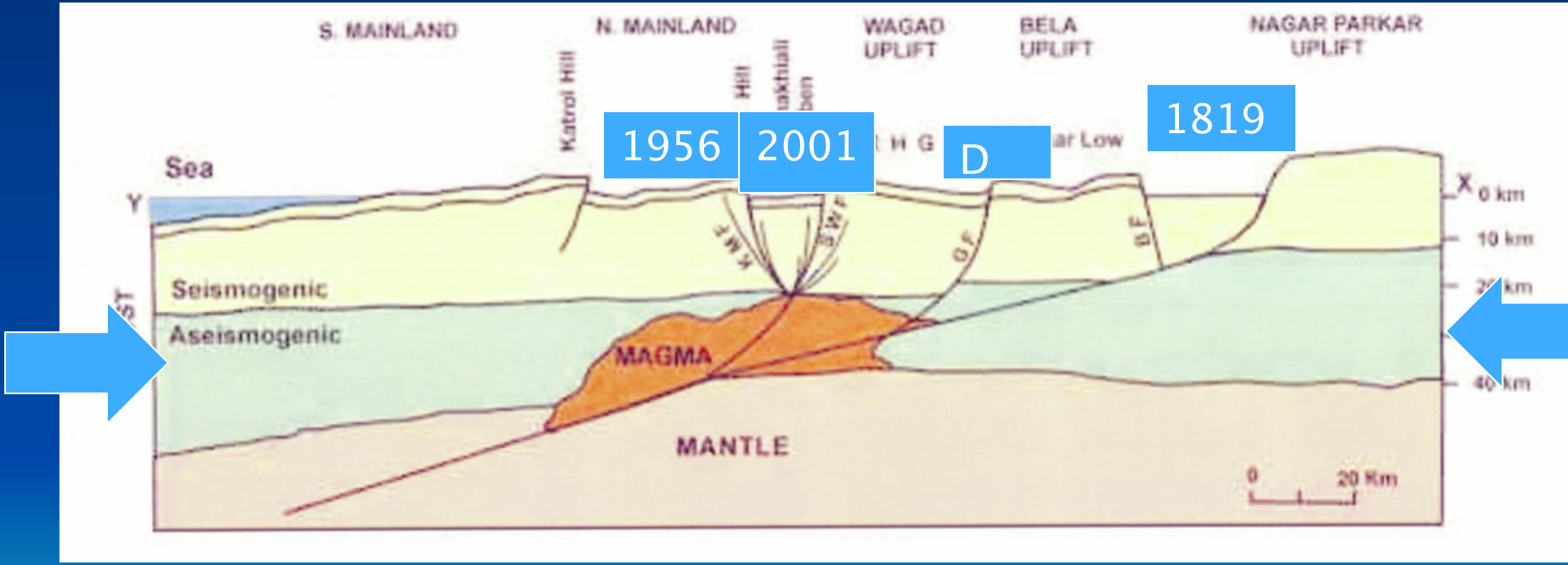
Modified from Bhatt et al., 2009

Analysis of 2001 Bhuj aftershocks revealed

- Seismicity occurs on N and S dipping faults that extend to mid-crustal depths
- Seismic tomography revealed the presence of a massive intrusive body – ‘rift pillow’ and fluids
- Moho shallower within the rift.
- Ongoing uplift ~ 2-4 mm/yr (InSAR), ~1-2mm/yr (GPS)

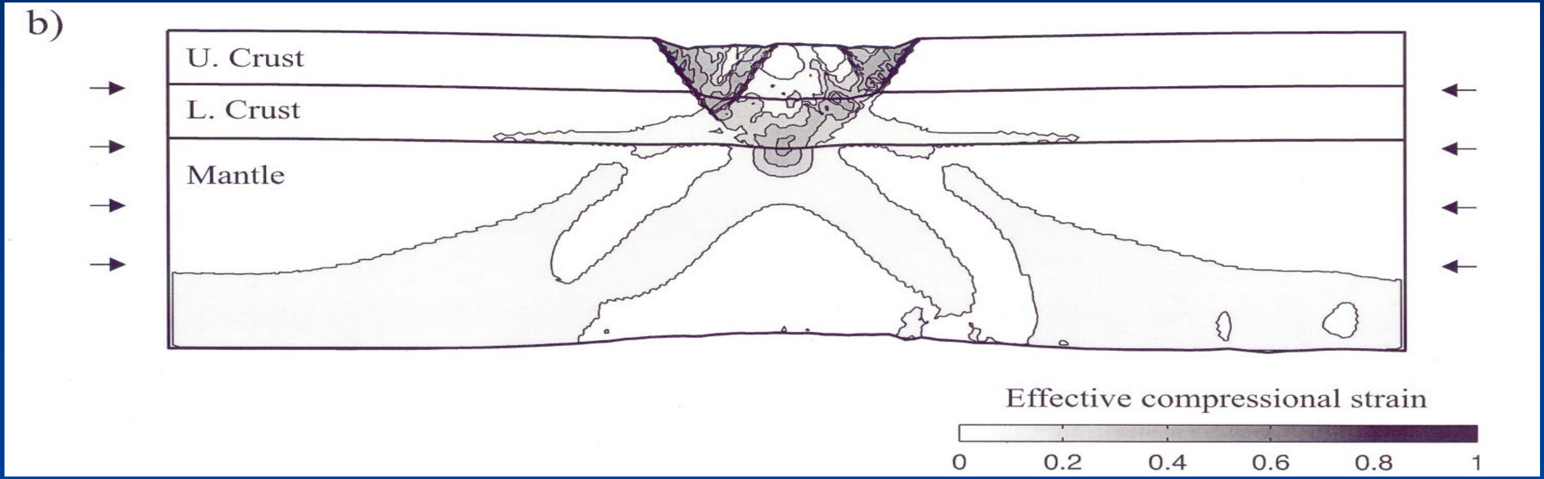
Mandal et al., 2004 Bhatt et al. 2009, Chopra et al., 2010 , Rastogi, 2010

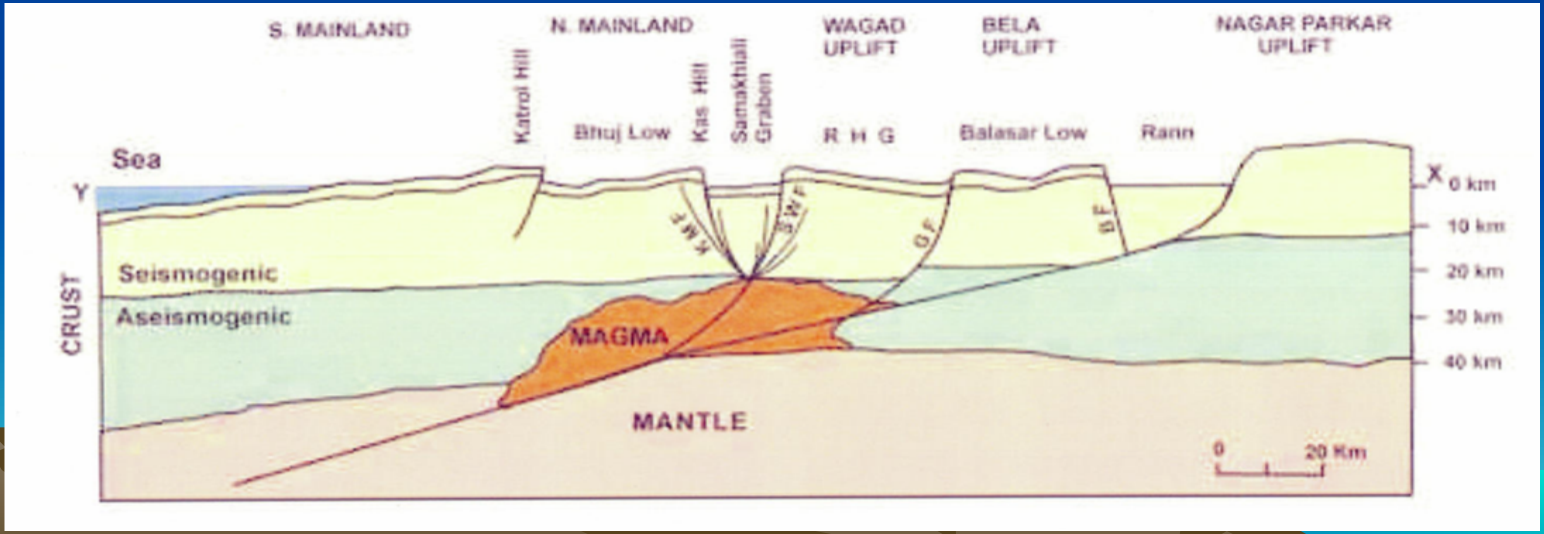
Deeper Geological Cross Section showing Rift Pillow and inferred Seismogenic Faults



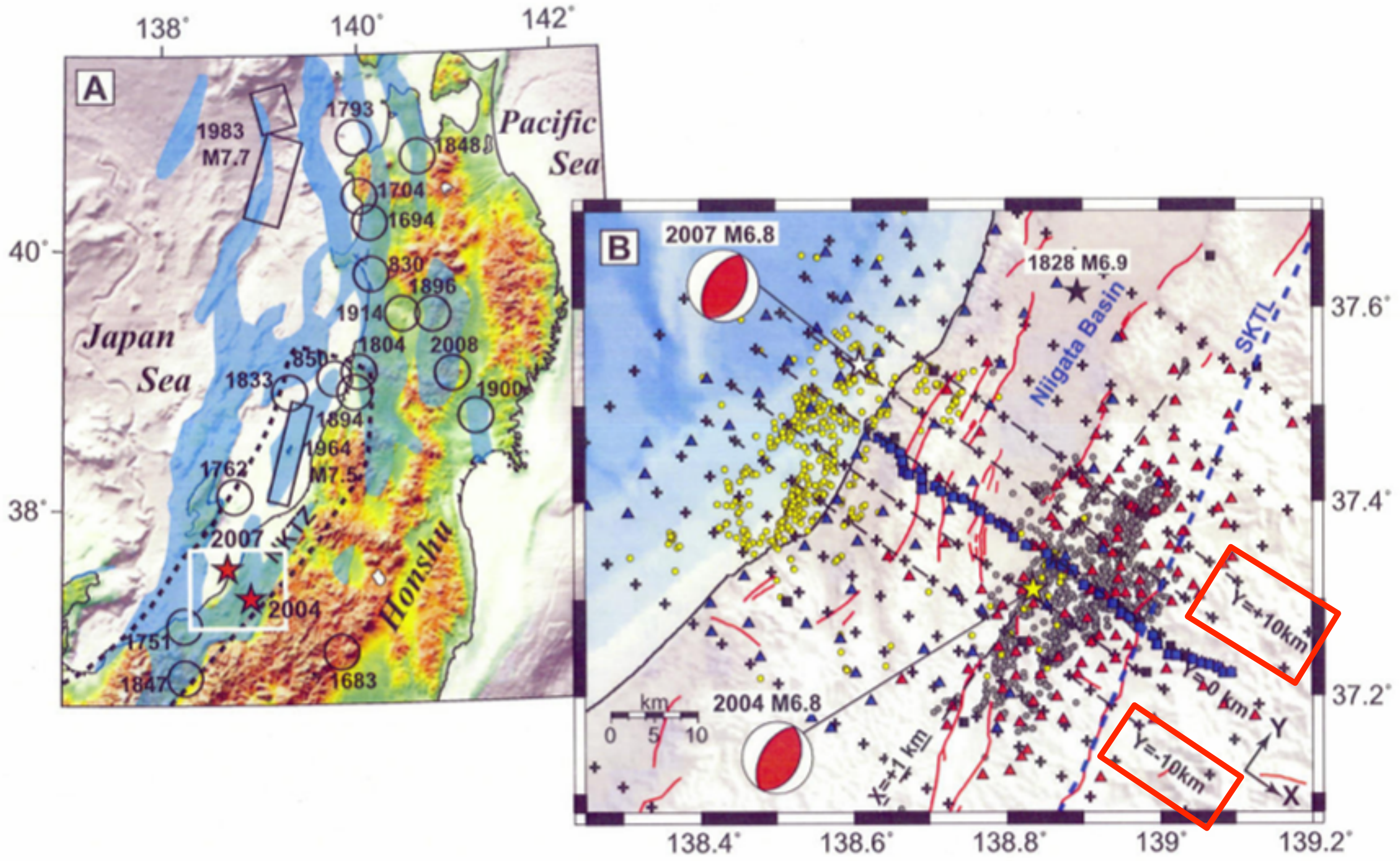
Modified from Biswas, 2005

Comparison with modeling results



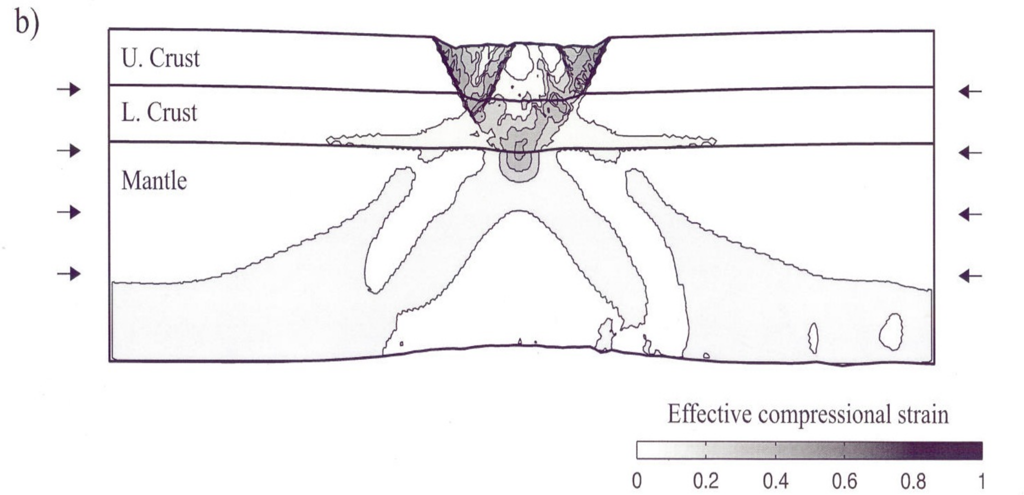


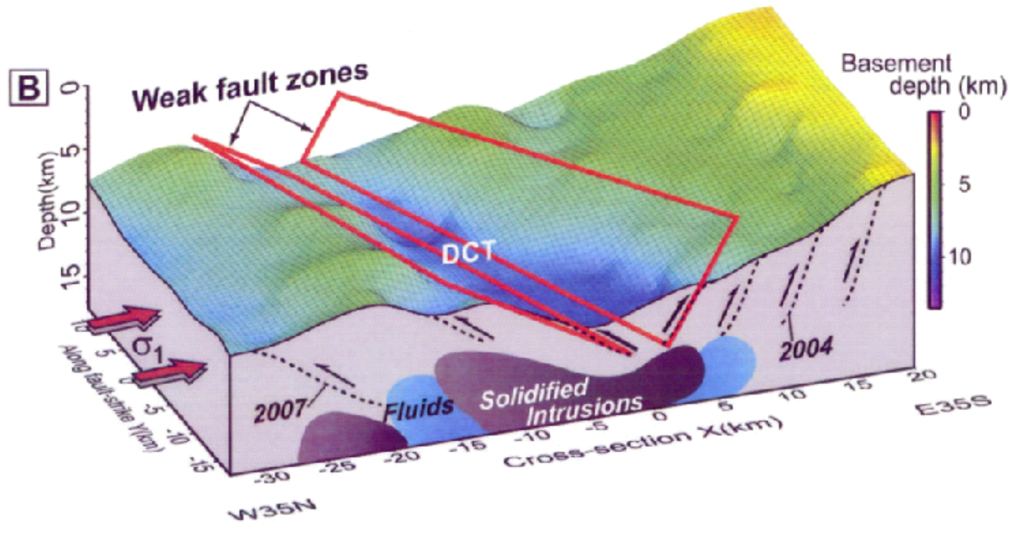
Sea of Japan



From Kato et al., 2009

Comparison with modeling results

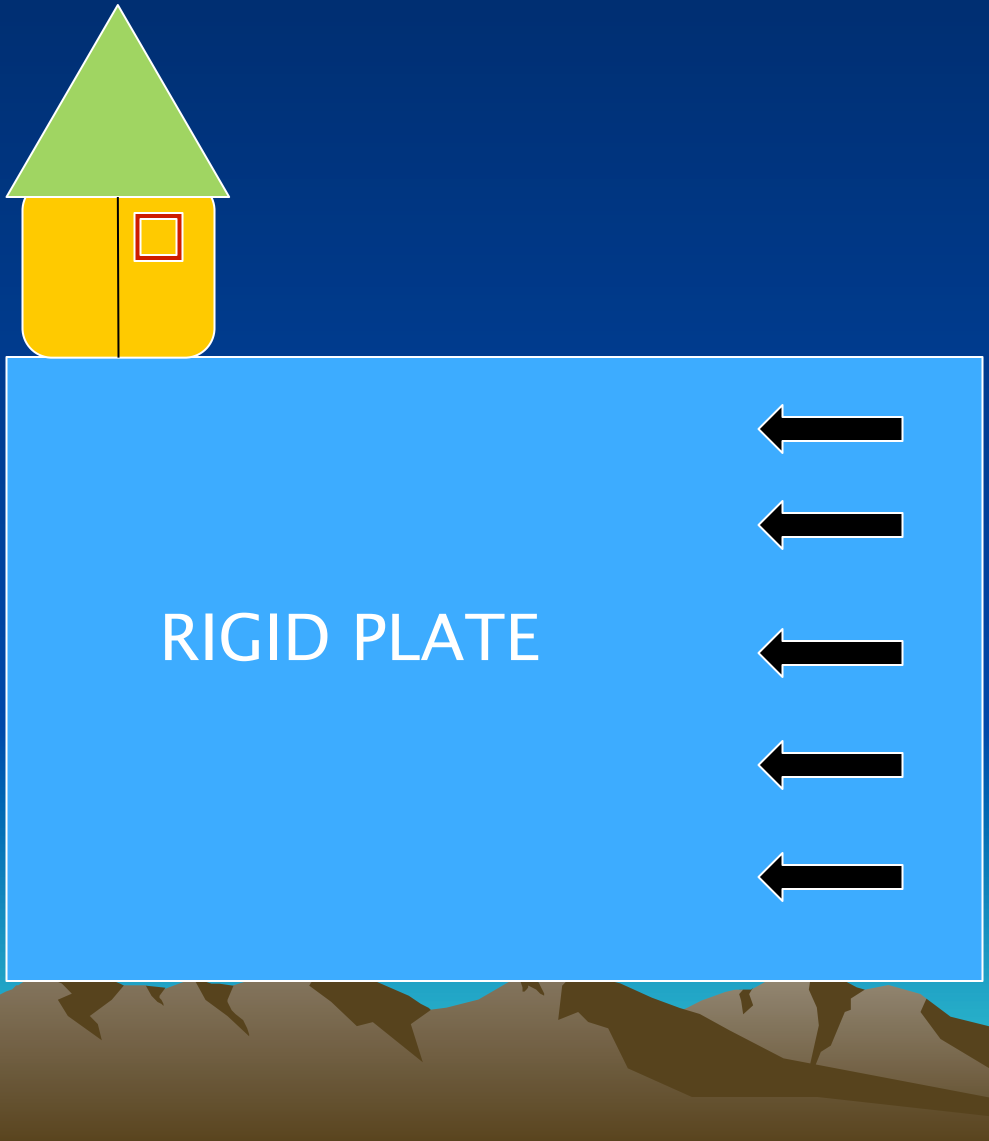




Model by Kato et al., 2009

SUMMARIZING

Normal Intraplate setting



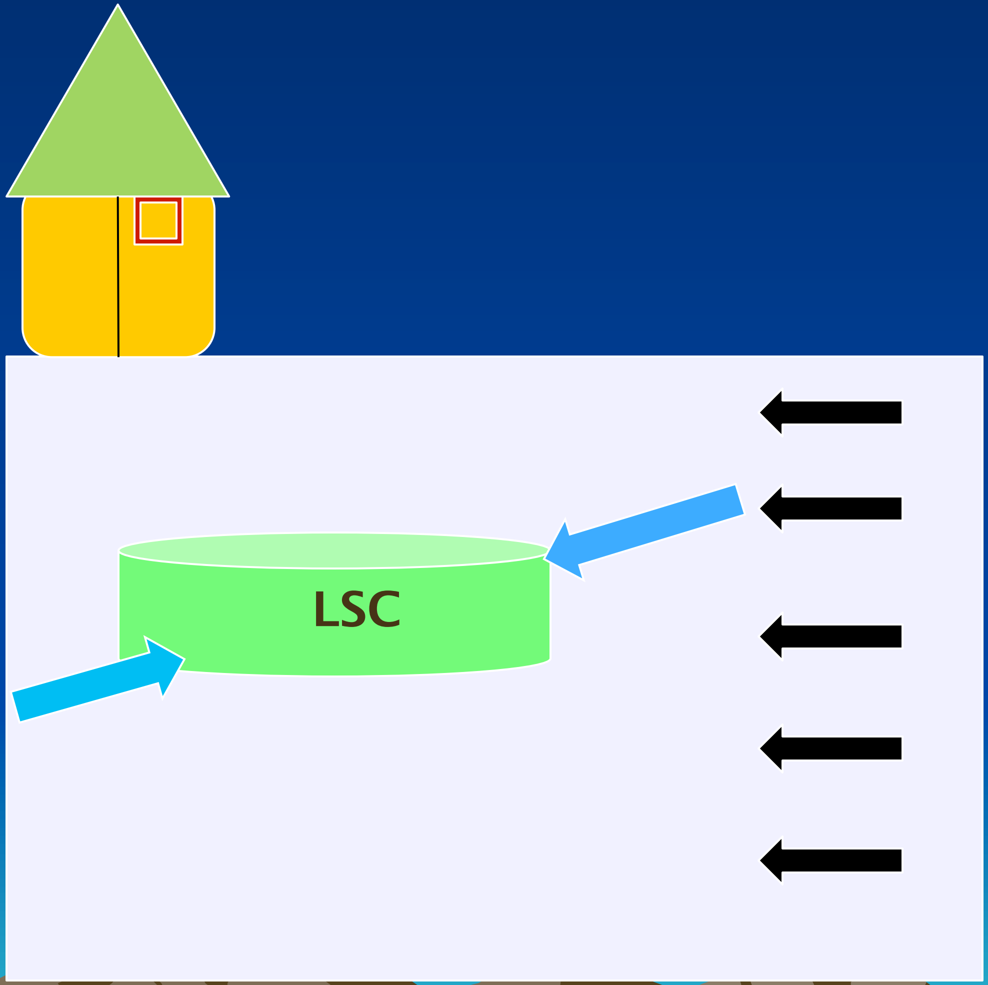
Asesimic

$S_1 = S_{Hmax}$

$S_2 = S_v$

$S_3 = S_{hmin}$

Local perturbation of tectonic stress field due to LSC (blue)



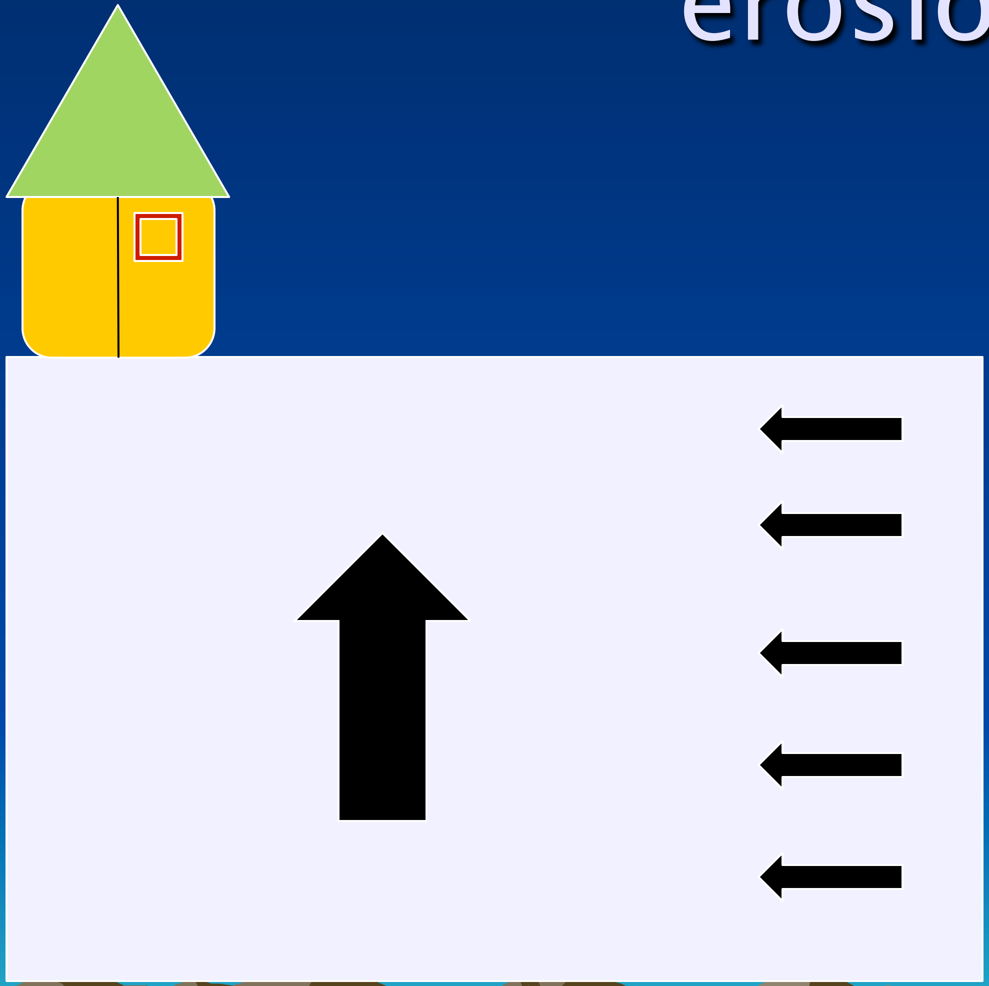
Grows with time and leads to IPE

Localized near LSC

Perturbs regional stress field

Perturbation detected by inversion of seismicity data.

Regional perturbation of stress field due to glacial rebound or erosion



$S_1 = S_{Hmax}$

$S_2 = S_{hmin}$

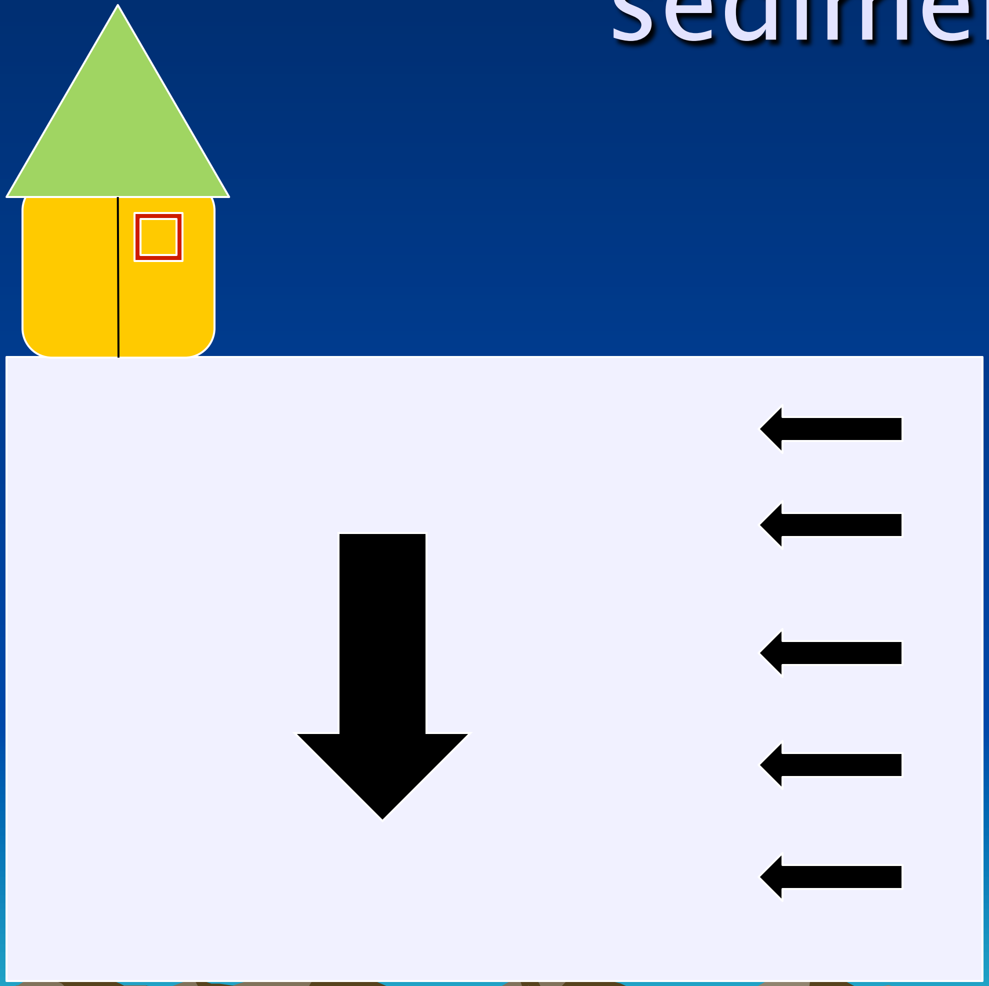
$S_3 = S_v$

Influences pattern and timing of seismicity

E.g. NE Canada and USA, Fennoscandia

Talwani and Rajendran, 1991

Regional perturbation of stress field due to deposition of sediments



$S_1 = S_v$

$S_2 = S_{Hmax}$

$S_3 = S_{hmin}$

Influences pattern and timing of seismicity

E.g. Gulf of Mexico

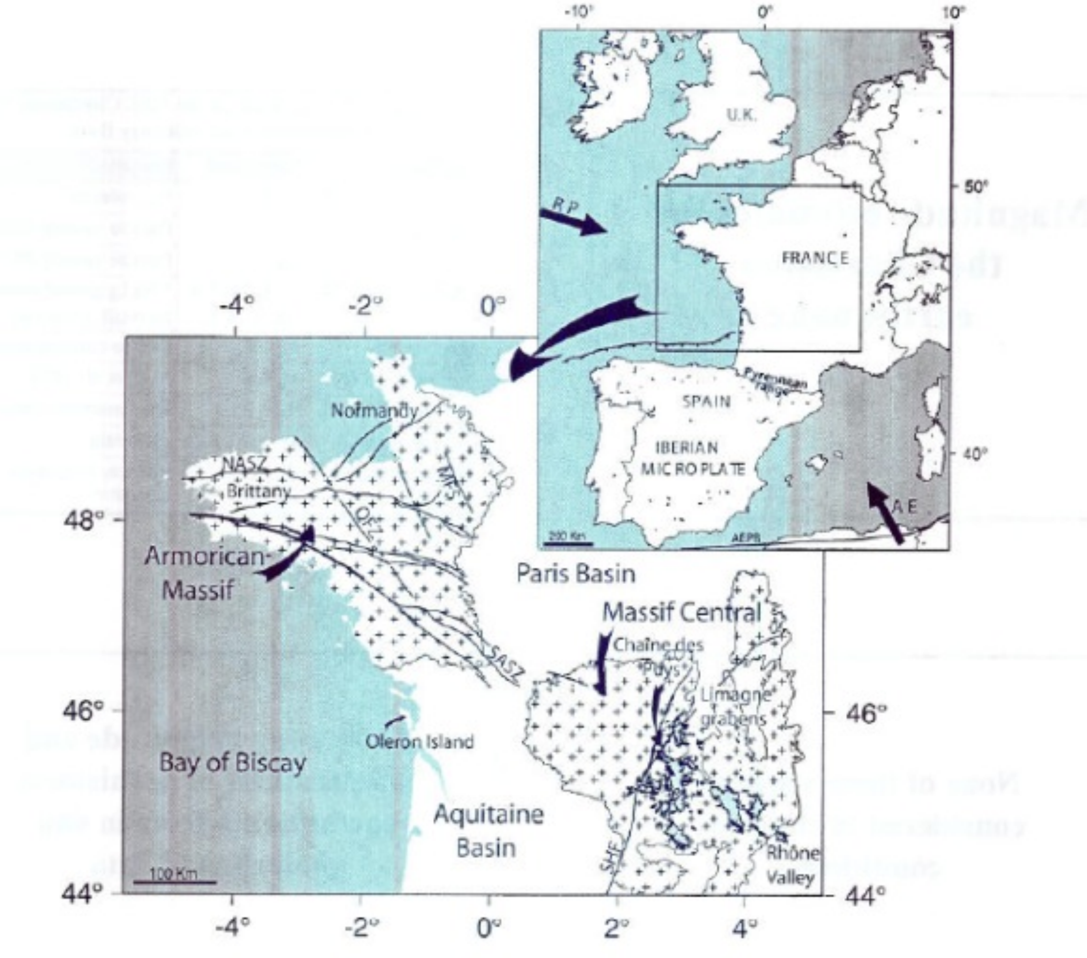
Talwani and Rajendran, 1991

Local stress perturbation of regional stress field from an analysis of seismicity data

Central –Western France

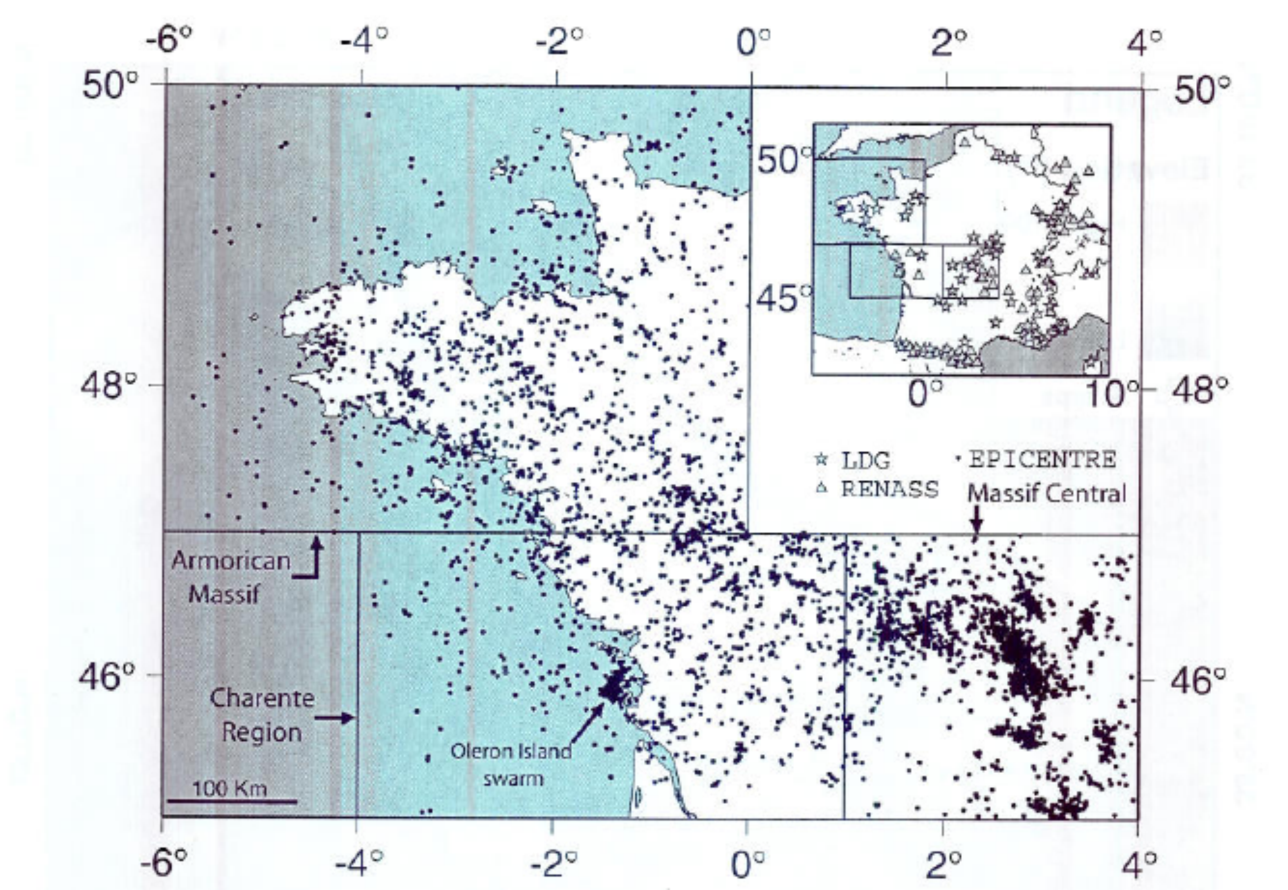
Sea of Japan Seismic belt

Location of Amorican Massif and Massif Central in central-western France



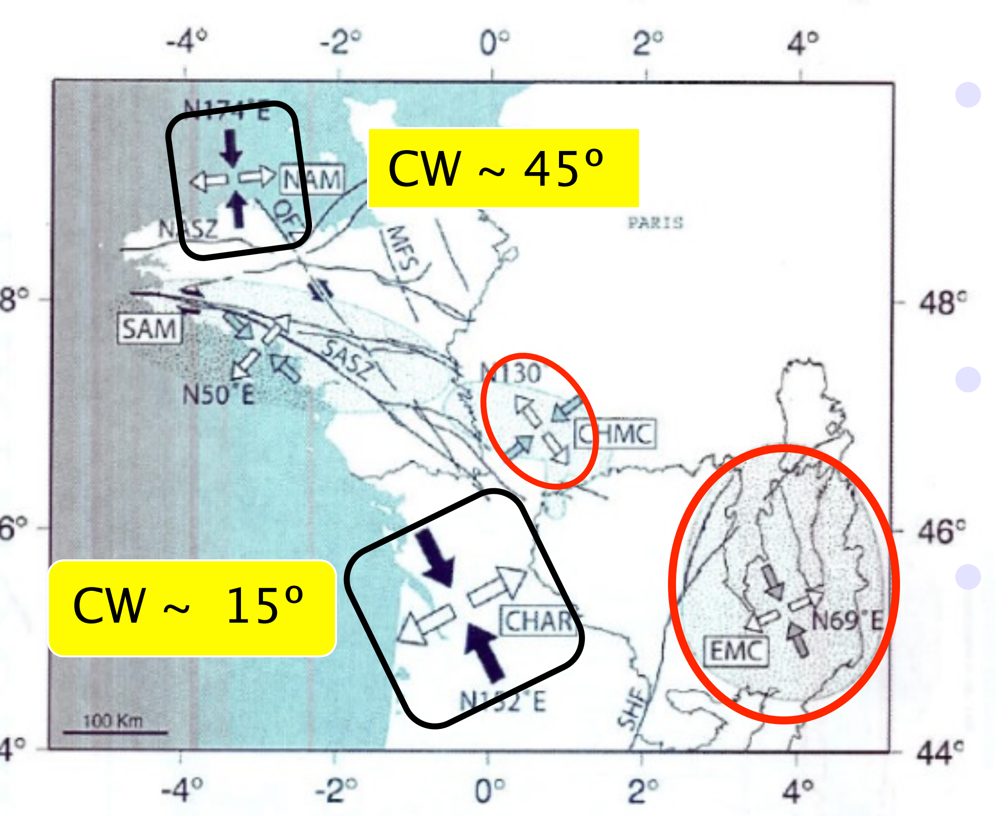
Mazabraud et al.,2005

Seismicity data inverted to obtained local stress orientations (1962-2002)



Mazabraud et al, 2005

Regional NW–SE compressional stress field is perturbed locally



CW ~ 45°

CW ~ 15°

- Extensional in Eastern massif Central (EMC) and CHMC(red)
- Related to ascent of hot mantle plume
- Compressional stress fields rotated in Charente (CHAR) and Northern Armorian Massif (NAM)

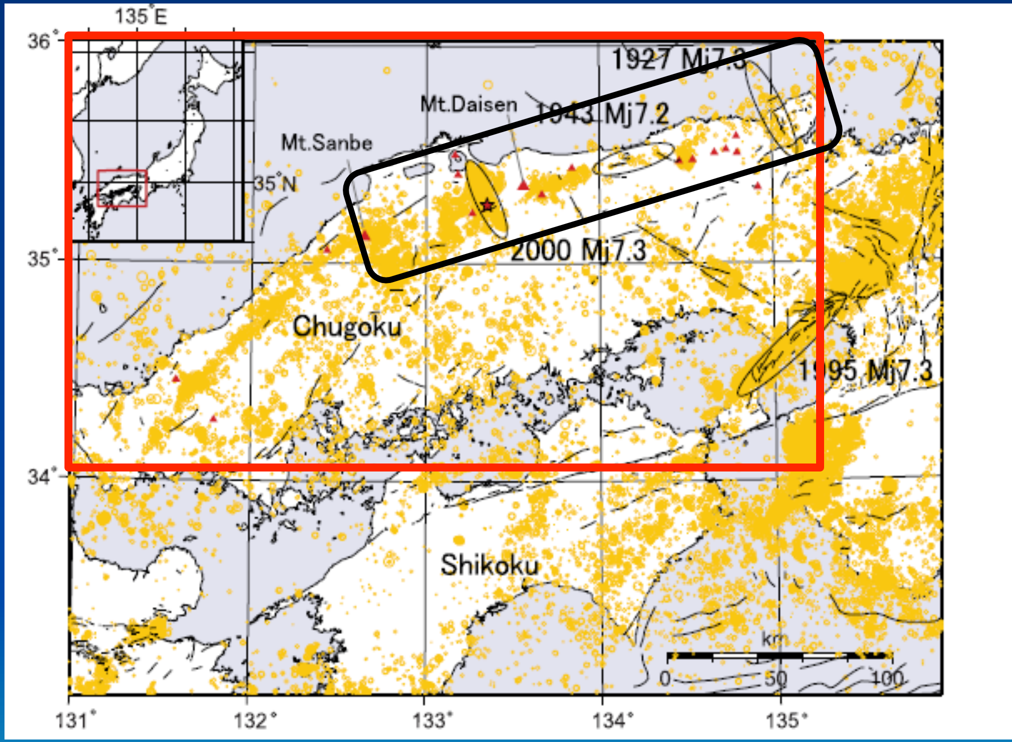
Mazabraud et al., 2005

Eastern margin Sea of Japan earthquakes

- Both the 1964 Niigata M 7.5 and 1983 Japan Sea M7.7 earthquakes occurred in a E-W contractional zone with GPS strain rates greater than 10^{-7} per year.
- Two recent earthquakes, both with M 6.8 occurred in this zone in Oct. 2004 and July, 2007. on reactivated normal faults

Intraplate Seismicity in Choguku district, SW Japan

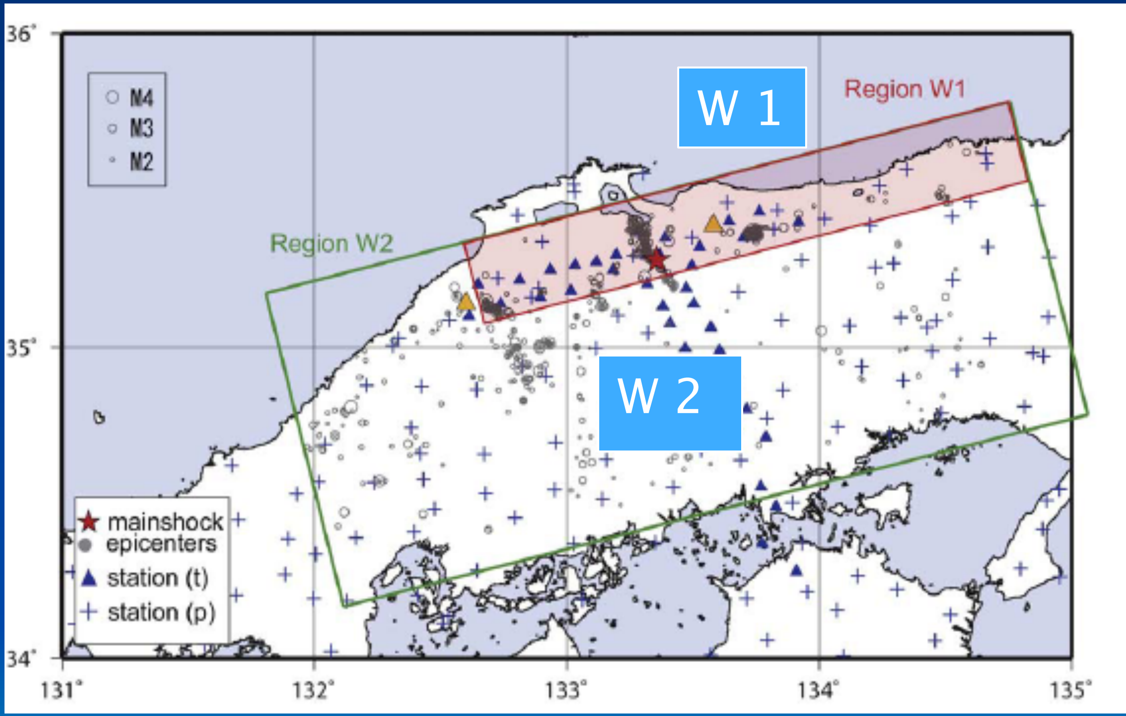
- $M \geq 1.0$
- $Z \leq 30$ km
- M> 7.0 events in the past 100 years shown by ellipses
- Linear seismicity pattern parallel Sea of Japan named “Seismicity belt”



Kawanishi et al., 2009

Two regions chosen for stress inversion

- 766 events with M≥ 1.5 (4/02–5/04)
- W1–Eastern part
- W2–Sorrounding region
- Blue triangles and crosses—station locations



Kawanishi et al., 2009

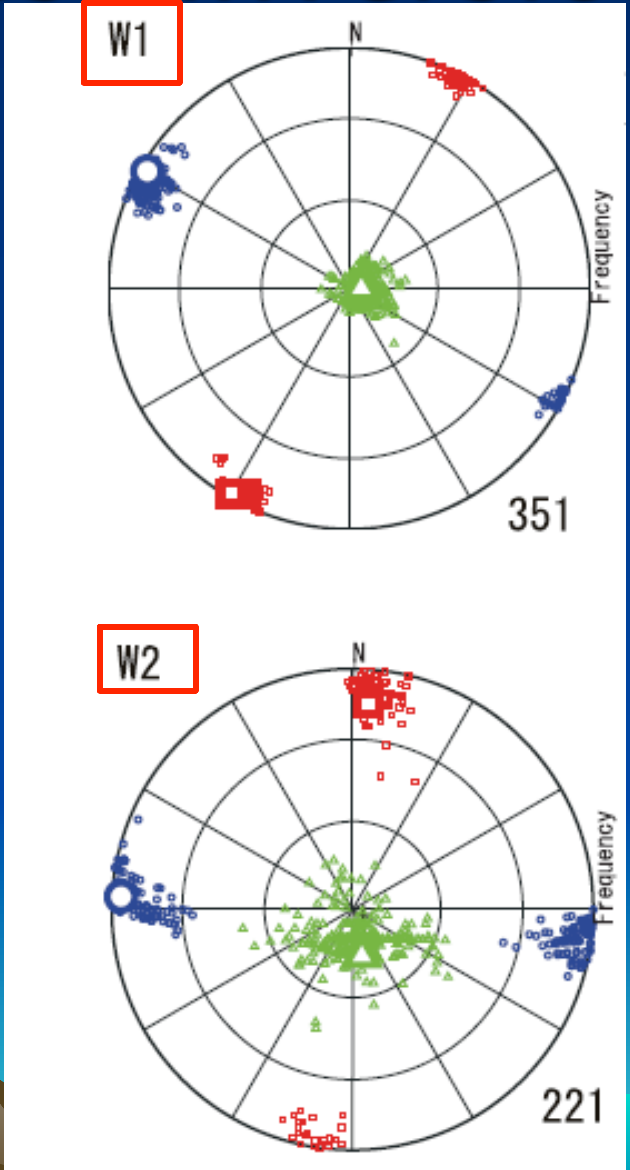
Results of Stress Inversion

- S_1 orientation (blue)

W1 N110° E–N130°E

W2 N82° E–N113°E

- ~20° cw rotation of S_1 below seismicity belt.



Kawanishi et al., 2009

INVERSION OF SEISMICITY DATA

Sea of Japan Seismicity belt

Stress rotated ~20° under seismic belt.

Stress accumulation due to deformation

in lower crust.

CONLUDE THAT

- The regional stress field is perturbed by a local stress field generated by the release of locally built up strains on local stress concentrators in the upper crust and in the lower crust and/or upper mantle.
- These local pockets of elevated strains are ~10s to perhaps ~100s km (?) in lateral extent.
- Are these localized strains detectable??

Finding potential locations of IPE

- Seek localized pockets of high strain rates with dense GPS surveys in areas of seismicity within rift basins.
- Outline weak lower crustal regions by seismic tomography.
- Determine seismogenic structures with the inversion of seismicity data complemented with geophysical investigations

Unanswered questions

- What is the strain rate due to LSC?
- Can it be detected with InSAR and/or GPS?
- How long will it take to get a meaningful signal?
- Why is there a large range of recurrence rates for IPE ?
- Why do many IPE occur as triplets?
- Do large IPE reoccur on the same or different faults?
- What is the cause of apparent migration of epicenters of large IPE ?

Thank you