Geophysical Environment of the Indian Subcontinent:

Hazard challenges and mitigation

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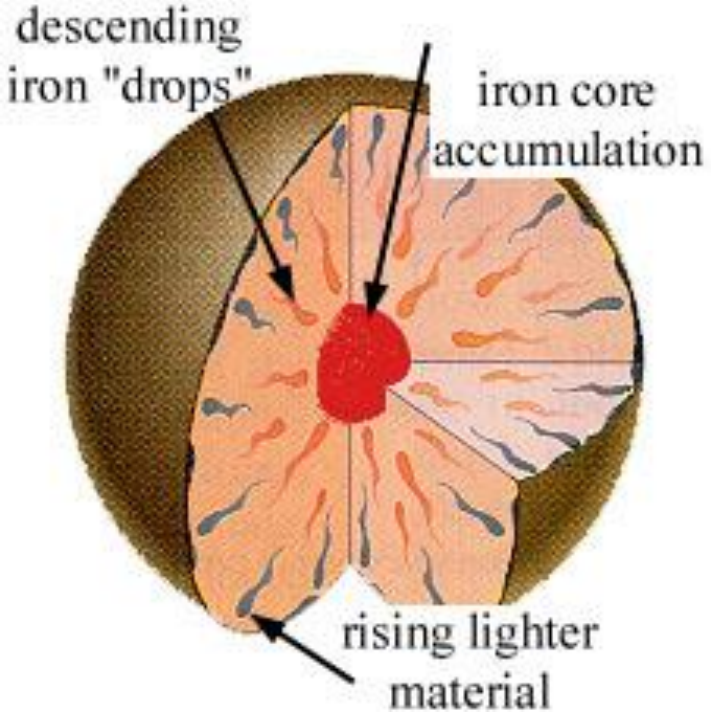
Indian Institute of Science, Bangalore

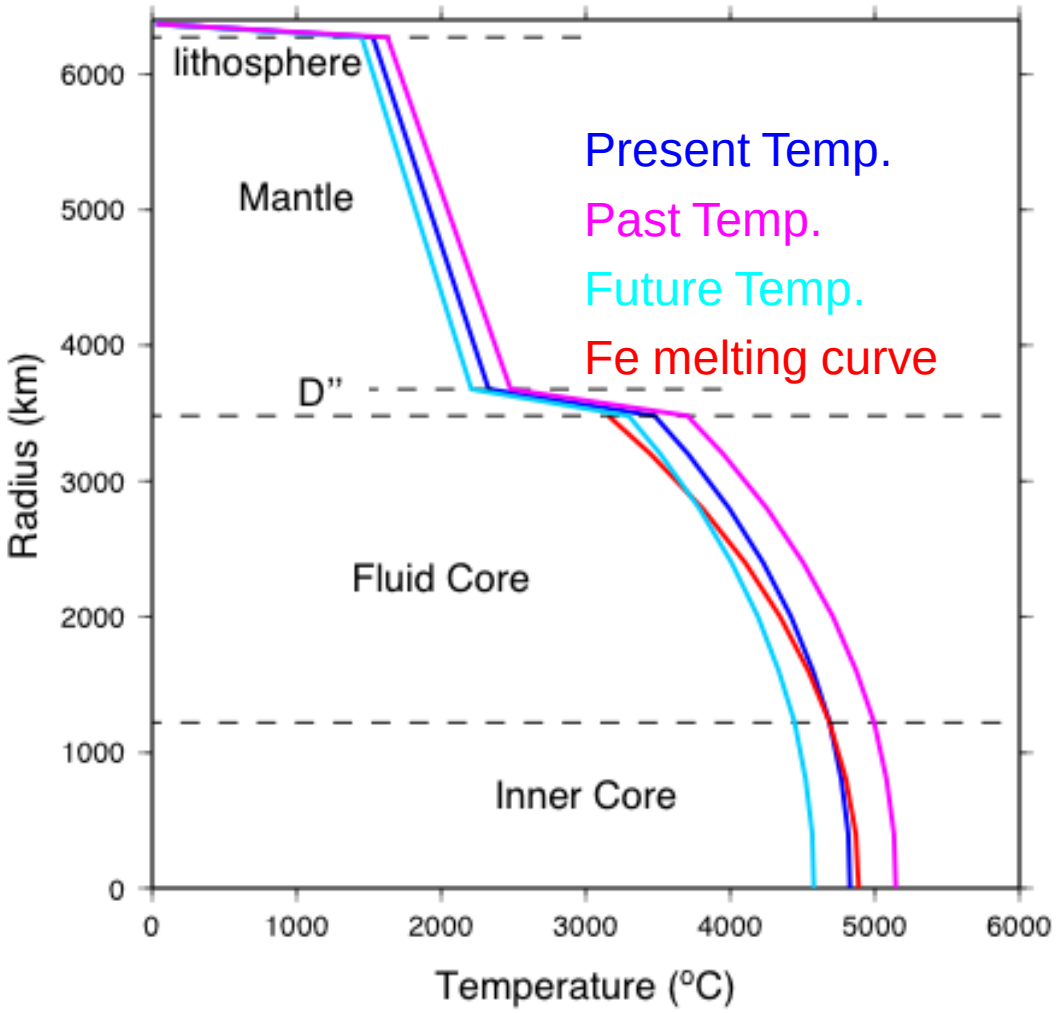
Earthrise, as seen by the Apollo astronauts on the Moon. Ironically, it has only been since we left our planet that we have really begun to understand it.

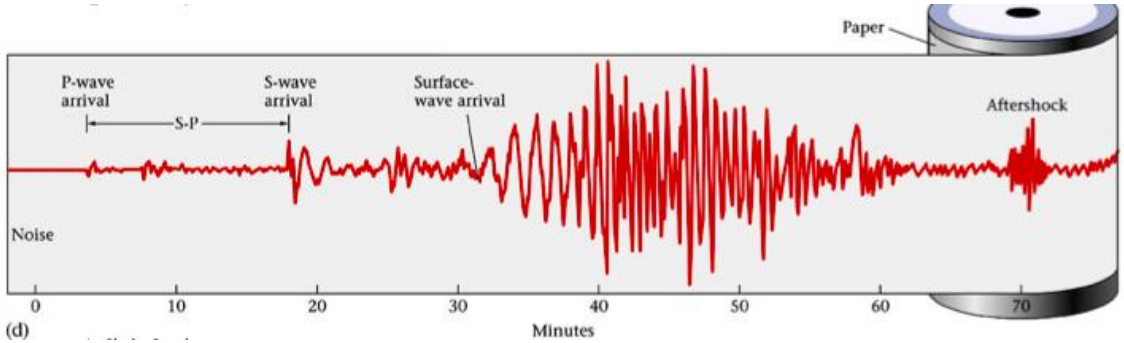
Gravitational differentiation



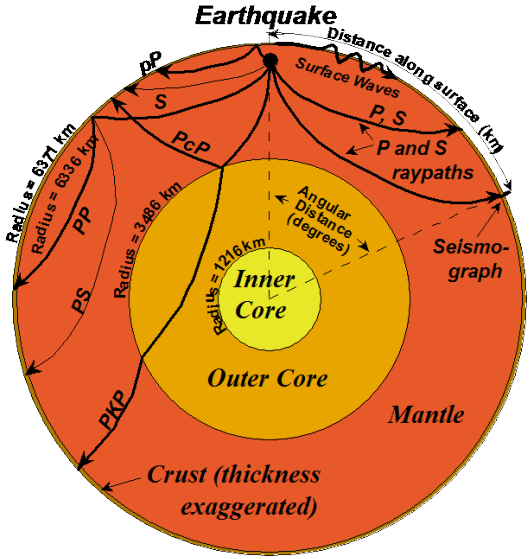
Iron "drops" follow gravity and accumulate towards the core. Lighter materials, such as silicate minerals, migrate upwards in exchange.

Thermal evolution

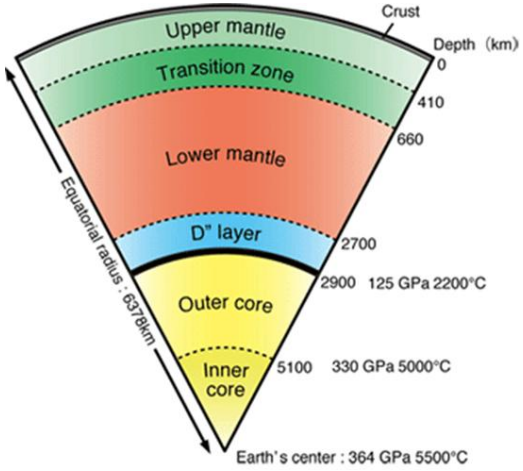


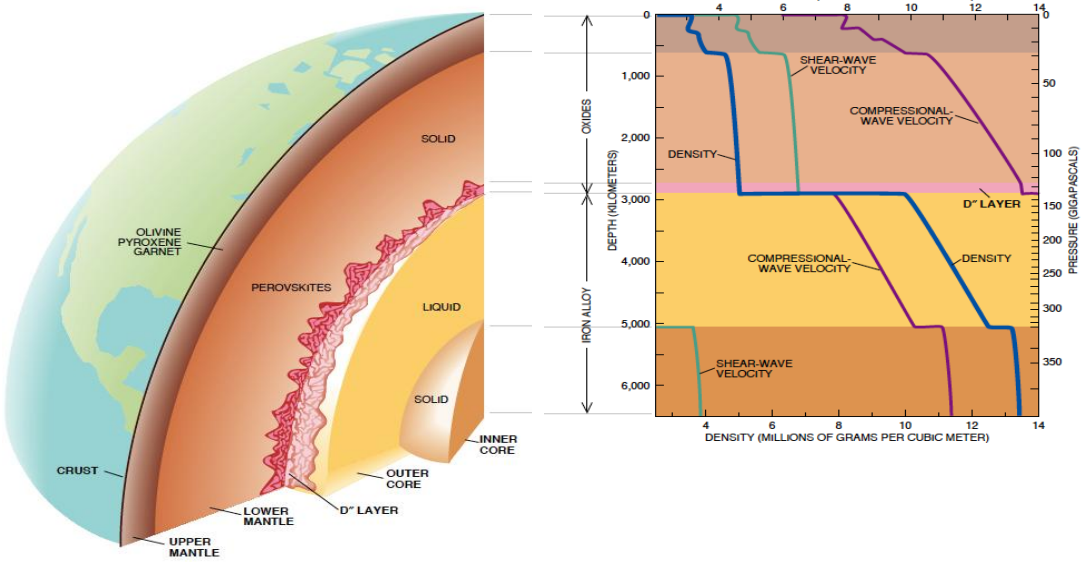


Probing the earth using earthquake waves

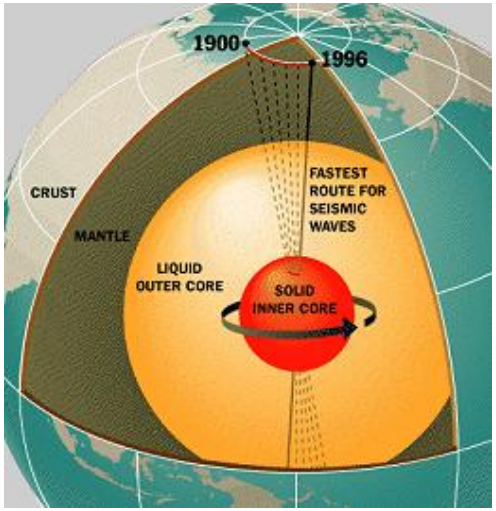


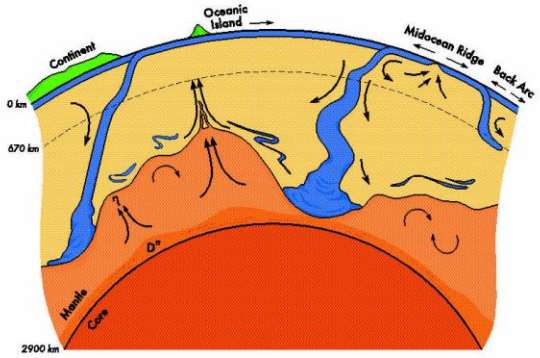
Earthquake waves tells us about the internal structure, boundaries between different layers and their velocities





Magnetic field

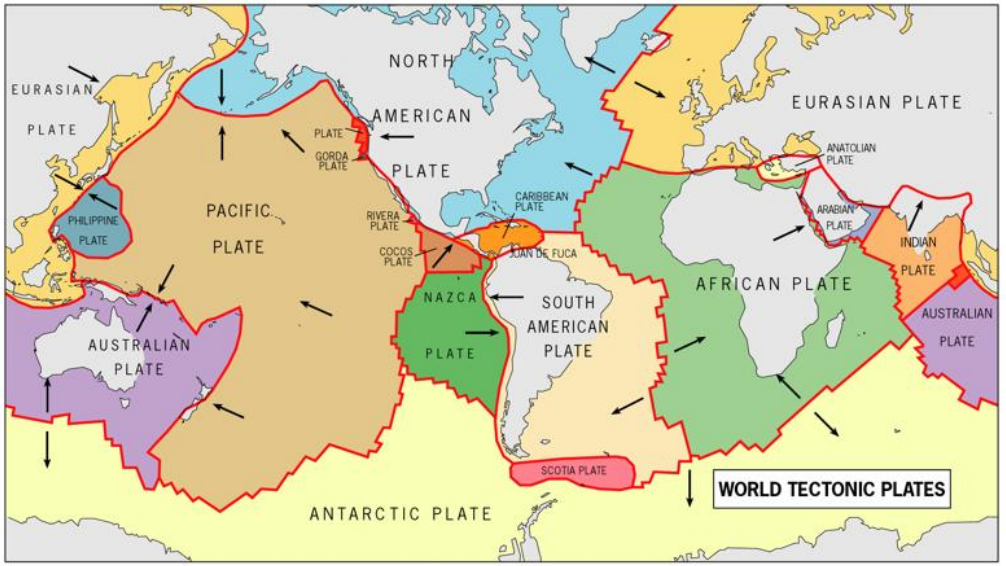




Earth's magnetic field is generated by fluid motions in the core, much like a self-sustaining dynamo that.

Two important consequences of the thermal structure- both essential for life

Plate Tectonics



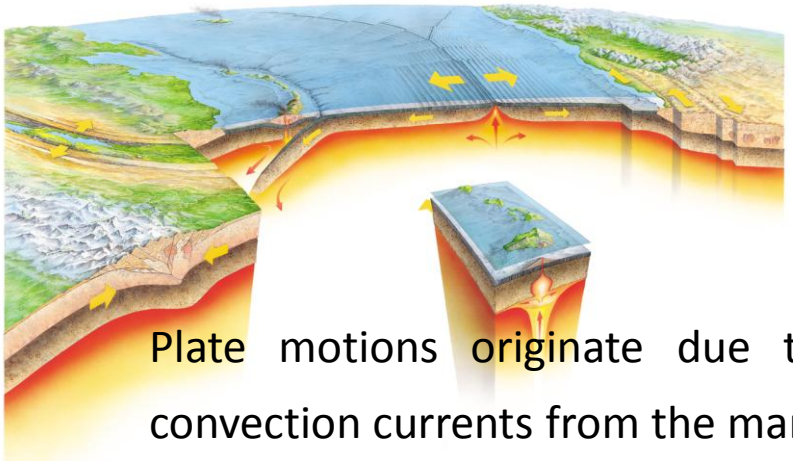


Plate motions originate due to the convection currents from the mantle.

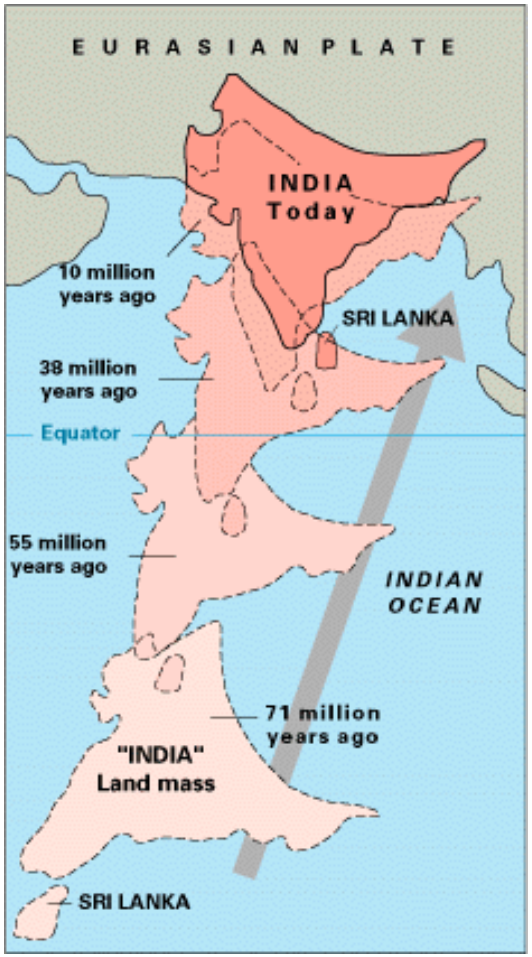
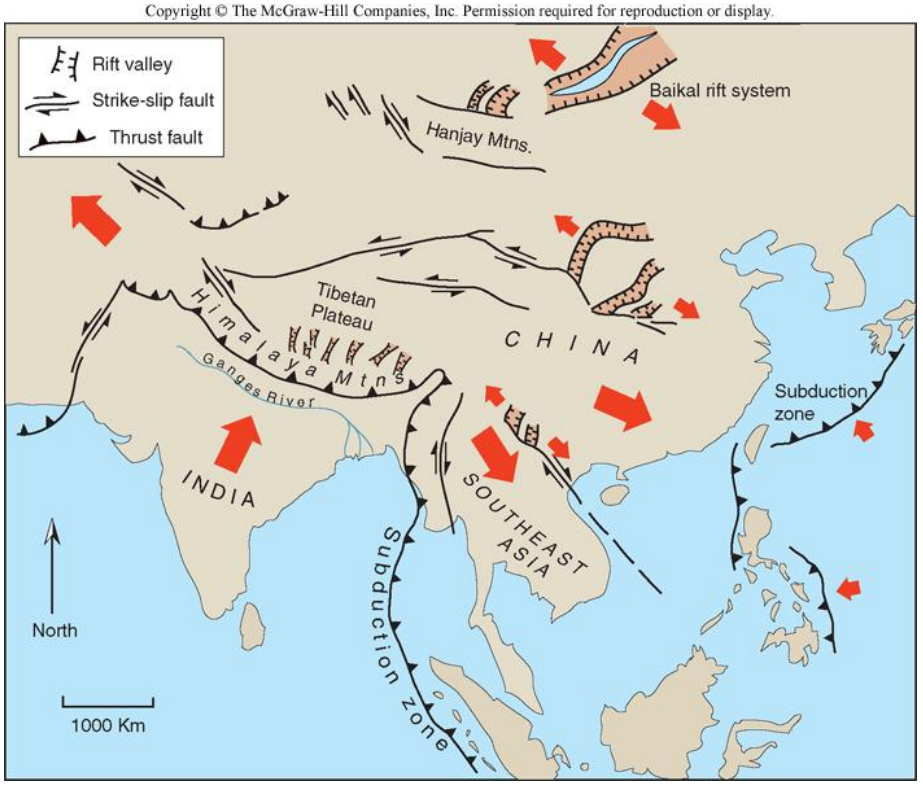
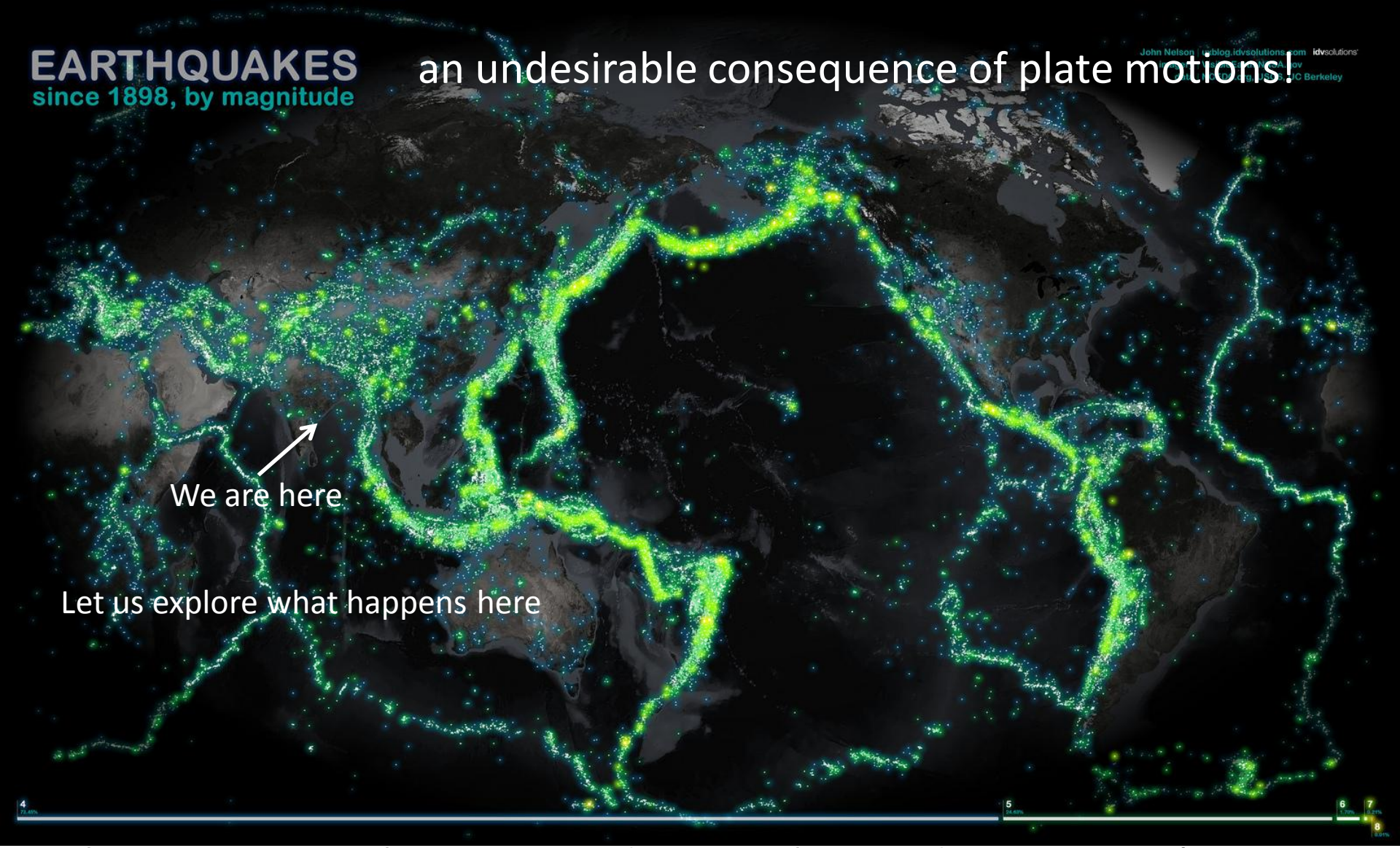


Plate motions lead to collision of plates, where they converge and such convergent margins generate large earthquakes.



The northward movement of India and collision ~ 40 million years ago has given rise to the Himalaya. Movement continues at the rate of ~20 mm/year, giving rise to frequent large earthquakes. These estimates are based on GPS vectors.



The *U.S. National Oceanic and Atmospheric Administration's National Geophysical Data Center* (NGDC): "significant earthquakes" between 2150 BC and AD 2013

In this presentation we will look at…

- Some specific examples where recent earthquakes have given insights on the mechanisms on earthquake source processes and tsunami generation.

- Source models are based on teleseismically recorded global data (displacement records). Assumptions made on material properties.

- Outcome: source models that provide magnitude, depth, rupture direction, spatial pattern of slip, moment rate function etc…

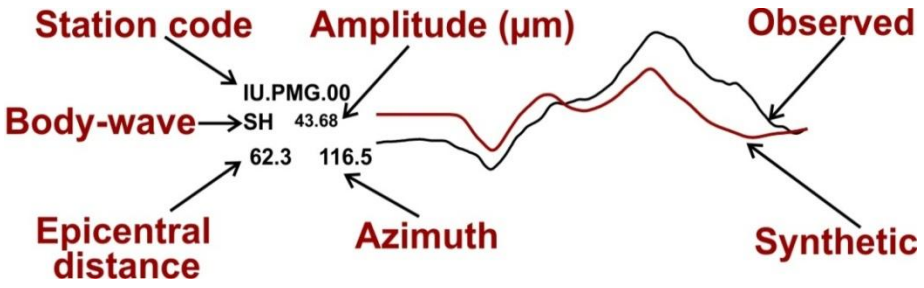
- Tsunami modeling used displacement field modelled from seismologic data and shallow water equations.

Nature of data used

Expected Results from source modeling:

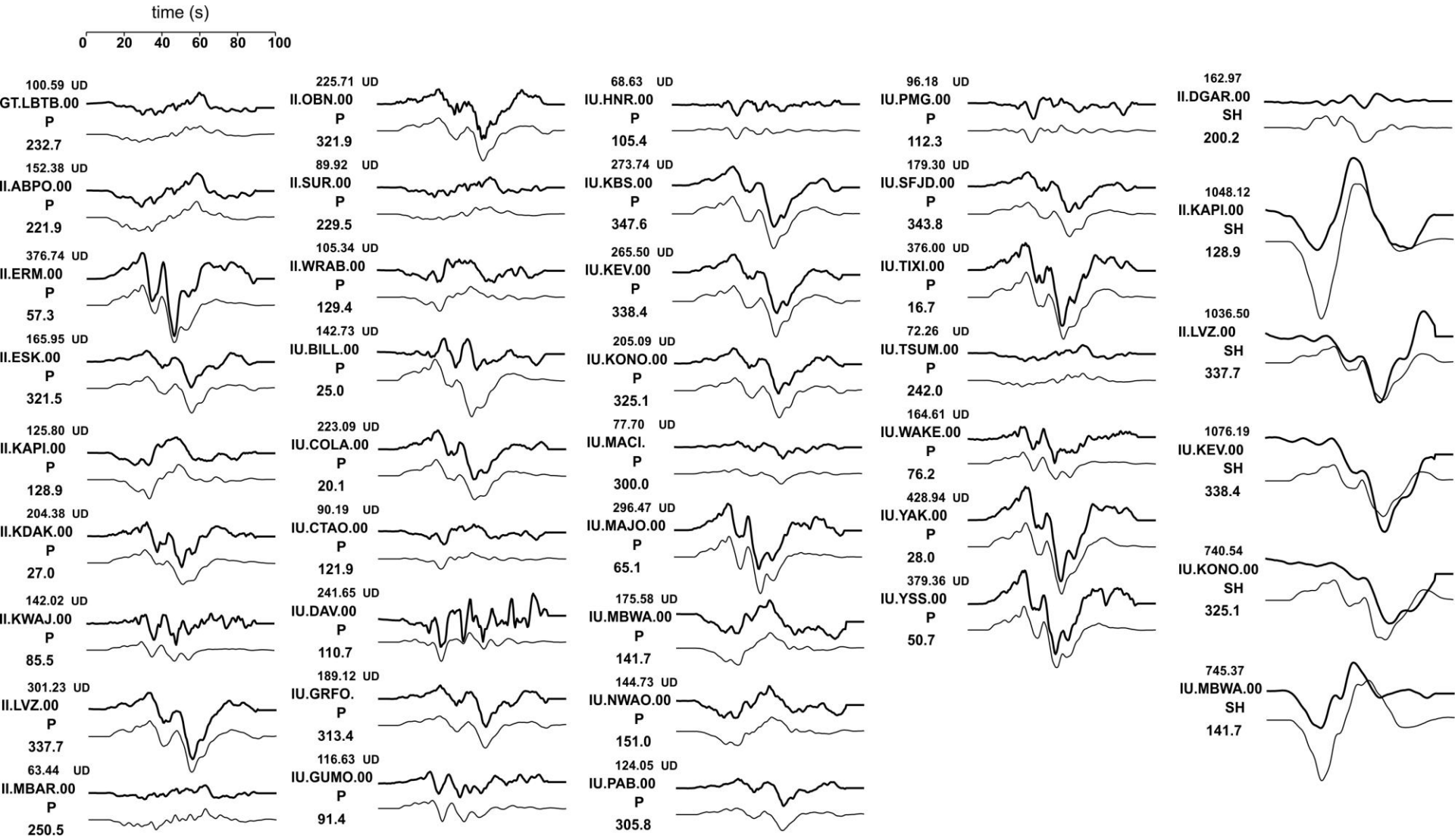
- Source parameters, magnitude, moment release and slip history
- Orientation and geometry of faults
- Depth distribution of slip
- Fault interactions (static stress changes)

Moment inversion output: waveform match

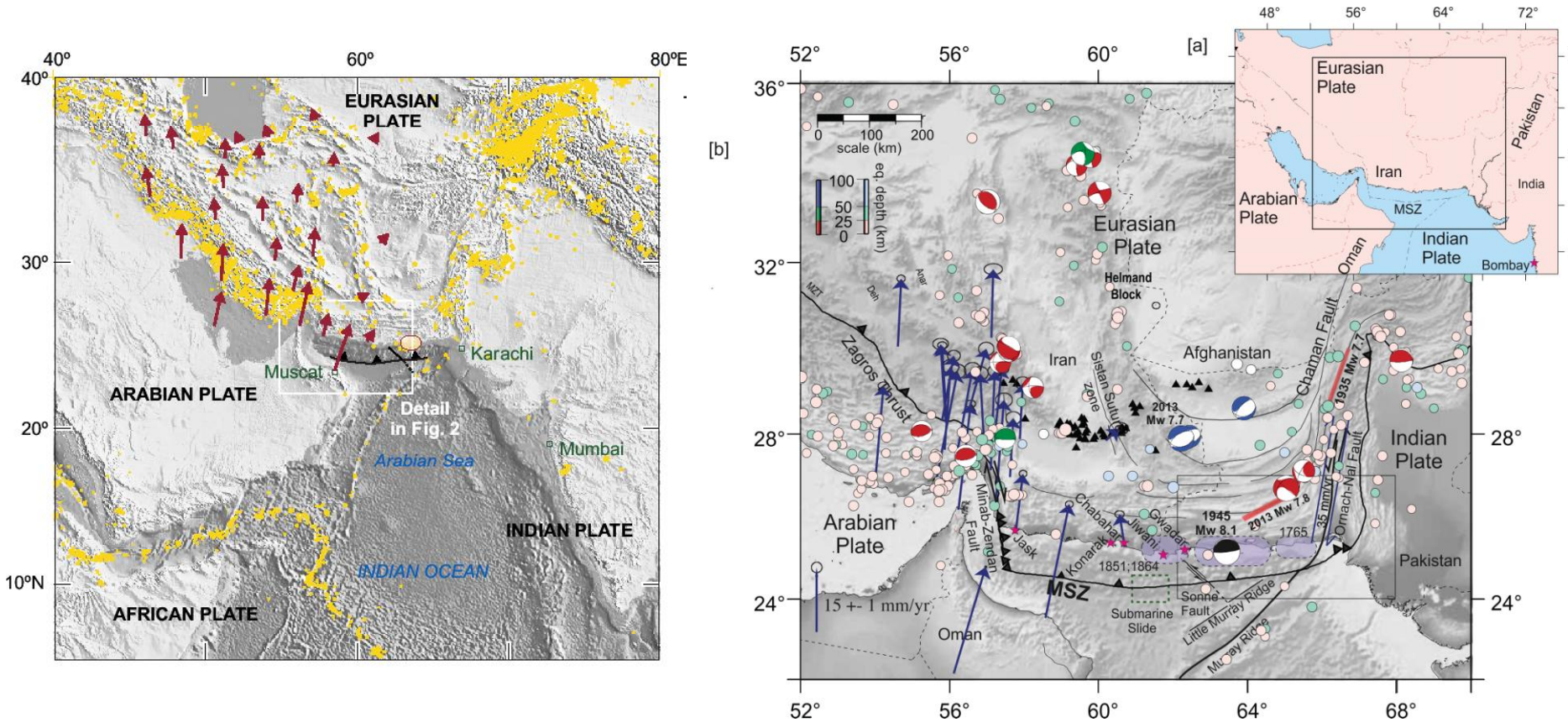


Ref: Kikuchi and Kanamori, 1991, 2003

Essence of waveform modeling



The Makran Subduction Zone



1945, M 8.0 is the largest known recent earthquake. It generated tsunamis that are reported to have attained 8-10 m height in the Gulf of Kutch (based on models by Tad Murthy)

Surroundings of Bombay were affected by the 1945 tsunami

The Times of India, Thursday, Nov 28, 1945

CO., LTD., BOMBAY

CAPITAL

LIFE · FIRE · MARINE · MOTOR · ACCIDENT

The Time

NO. 263. VOL. CVII. BOMBAY: T

TIDAL WAVE HITS BOMBAY SHORE

Entire Family Washed Away

THREE WOMEN DROWNED IN VERSOVA CREEK

FIFTEEN persons were washed away when a huge tidal wave, the like of which, according to eye-witnesses, has not been experienced in living memory, hit Bombay's seashore at 8-15 on Wednesday morning. Of those, two were saved, three were picked up dead and the fate of the remaining ten is unknown.

Four women and one man, all fisherfolk, were overtaken while fishing in knee-deep water at the mouth of the Versova creek, at the northern end of Juhu, and were washed away within the twinkling of the eye.

Fishermen in the vicinity tried to save the victim by launching their boats, but with great difficulty they could save only one woman. The dead bodies of three women were picked up later. The man could not be traced.

Exactly at the same moment, an entire Muslim family, consisting of one Rahimtulla, his wife, three children and two servants, was swept away while returning from Haji Ali "dargah" at Mahalaxmi.

They had gone to the dargah the previous night and were returning home when the tragedy occurred. Only one servant reached the shore to narrate the incident. He reported that three other men, proceeding towards the mosque, had been also swept away.

"Fakirs" at the mosque and also fishermen at Juhu say that the phenomenon was strange and unusual. A huge mass of water rose and rolled with such rapidity and

'Quake Spends Fury In Sea

TIDAL WAVE IN KARACHI

From Our Staff Correspondent

POONA, November 28.

Weather experts here believe that the earthquake which was felt early on Wednesday morning in many parts of India spent its fury in the sea and

"No Change In U. S. China Policy"

U. S. SECRETARY'S STATEMENT

WASHINGTON, November 28.

In a statement following swiftly on the sensational resignation of General Patrick Hurley and the substitution of General George Marshall as Envoy to China, the Secretary of State, Mr. James Byrnes, told a Press conference today that there has been no change in the United States policy in China.

The United States, he said, was carrying out the terms of surrender by moving troops in North China, and he affirmed that the United States would be happy to use its good offices in bringing the two Chinese factions together.

Mr. Byrnes disclosed that he telephoned General Hurley when the news of his resignation was published, and discovered that the General was determined to resign after reading the critical speeches made in Congress on Monday.

Mr. Byrnes said that General Hurley felt the State Department had supported the Congressional attacks on him.

Asked for comment on General Hurley's allegation that some elements in the State Department were supporting Communists and Imperialists, Mr. Byrnes referred the questioner to previous changes in the Press that the State Department was filled with anti-Russians.

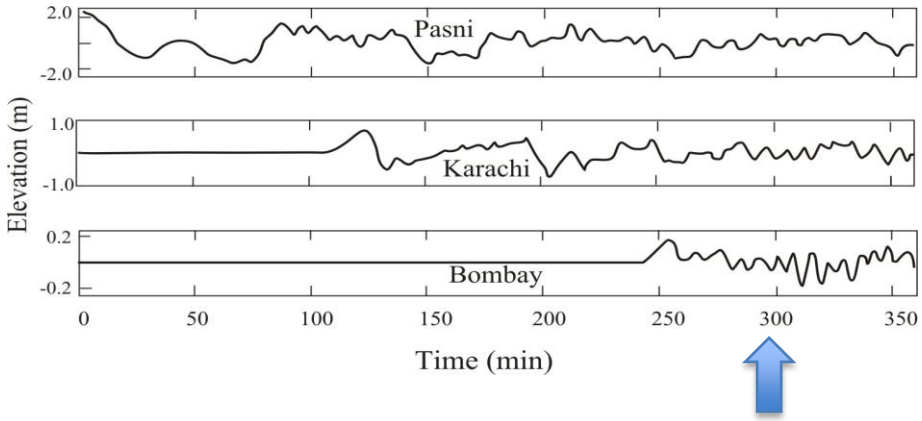
He said he imagined there were all kinds of opinion in the Department and this might not be such a bad thing.

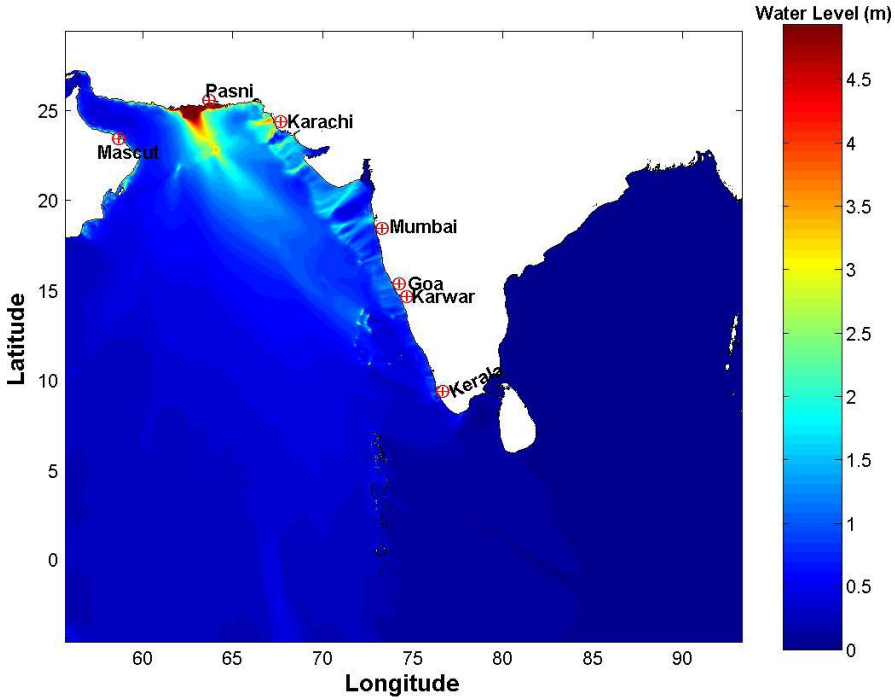
Mr. Byrnes declared there was no evidence to support the Congress charge that General Hurley had attempted to reverse the American policy in China.

Mr. Byrnes, who earlier in the day had an hour's meeting with President Truman and General Marshall, said no agreement had been reached on what General Marshall was leaving for China.

Over a month ago, said Mr. Byrnes, General Hurley had mentioned two

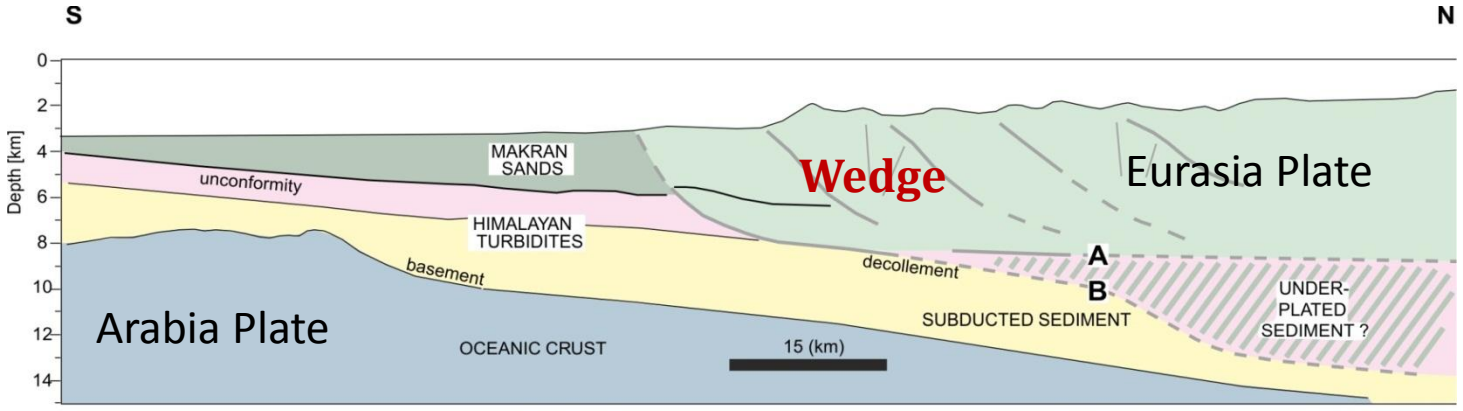
Versova Creek is the Present Malad Creek





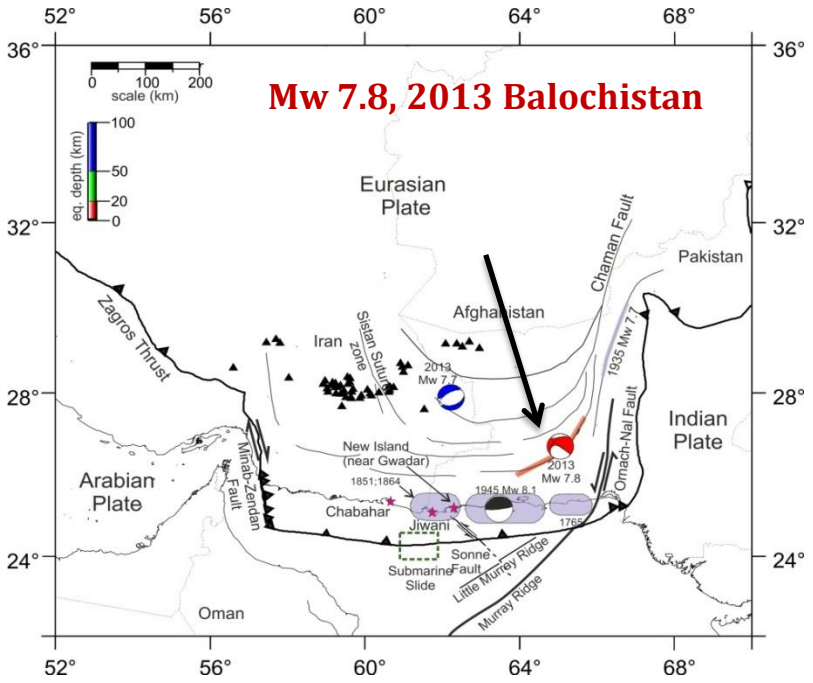
Computed and observed (Tide gauges) arrival times misfit: 17-29 min. A landslide triggering mechanism has been suggested (Rajendran et al., 2008)

Destabilization of wedge, a potential mechanism?

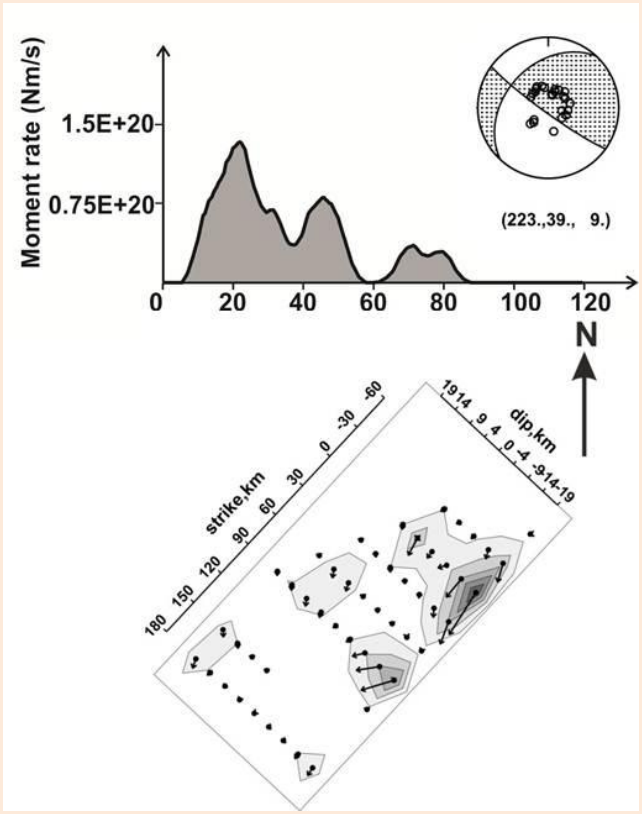


modified from C. Kopp et al. / Tectonophysics 329 (2000)

Source model for Mw 7.8, 2013 Balochistan earthquake



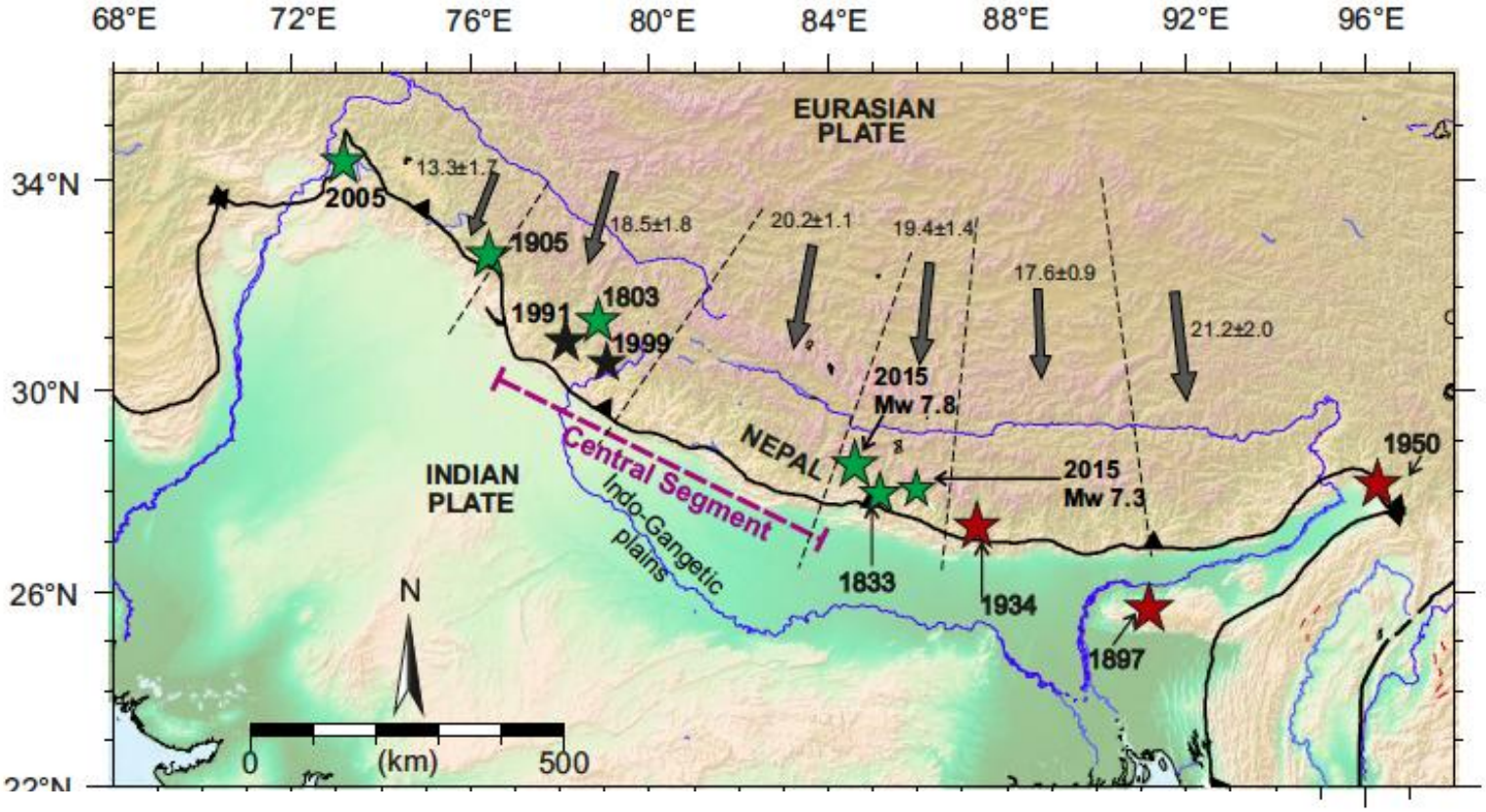
- ~ 200 km from the MSZ trench; ~ 12 km depth (Harvard CMT).
- Generated a tsunami ~500 km from the epicentre; source believed to be a submarine slide ~ 60 km off the coast of Jiwani (Heidarzadeh and Satake, 2014; Hoffmann et.al., 2014)

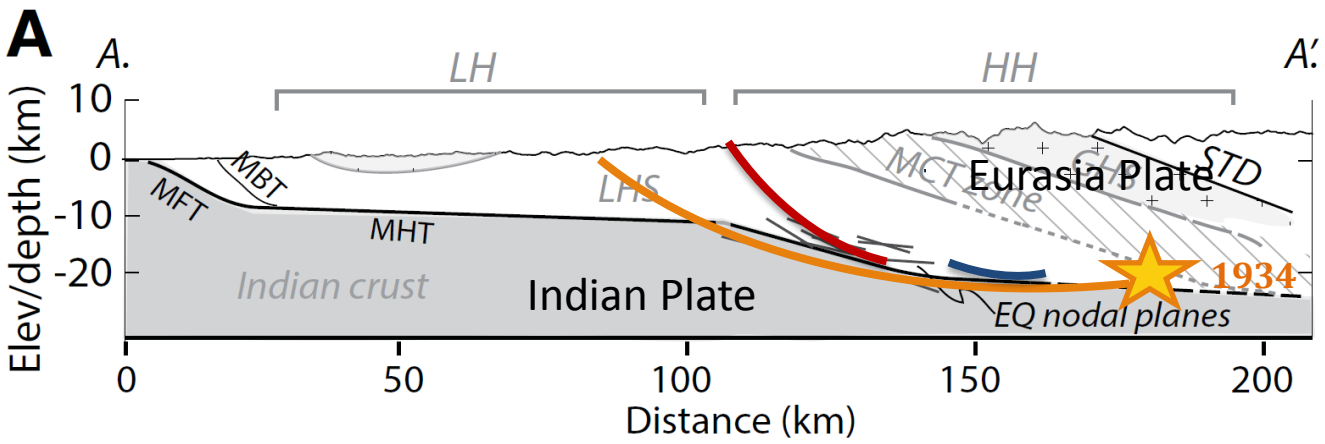


- Pure thrust (Mw 7.71); Fault planes: strike 223°, dip 39°, rake 9°
- Net moment of 0.455E+20 Nm; released in just over ~80 seconds; Multiple bursts of energy; possible subevents
- Maximum up-dip slip: ~4.0 m

Influence on the wedge?

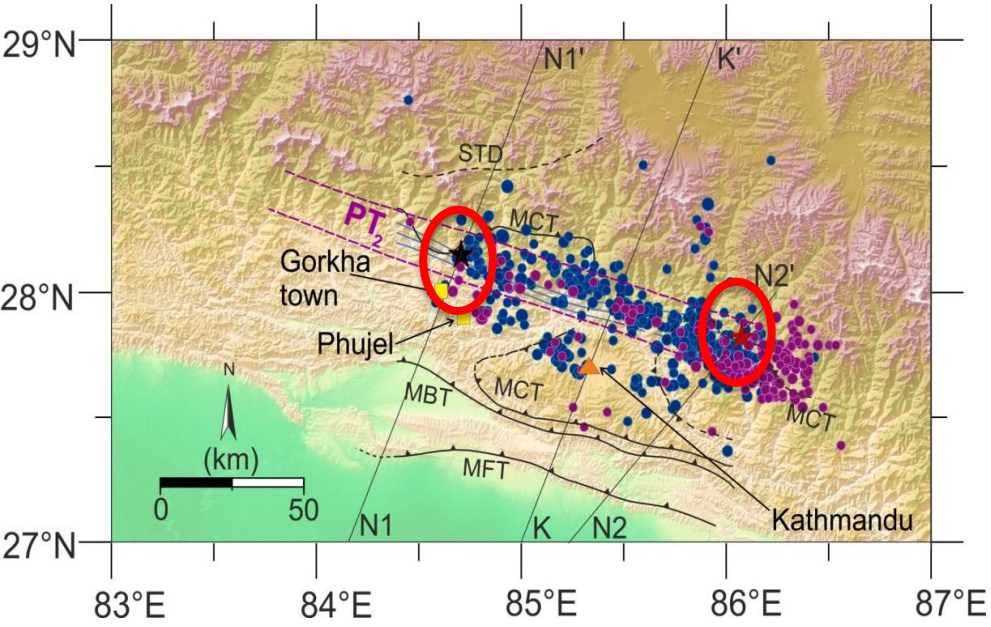
Significant earthquakes in the Himalaya and GPS convergence rates

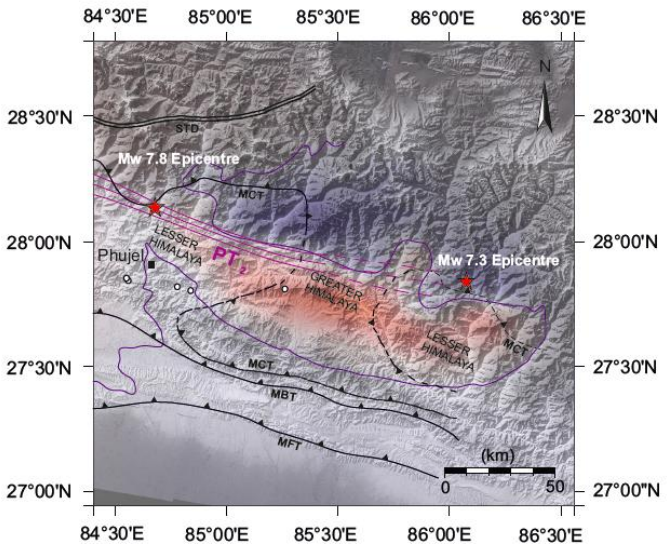




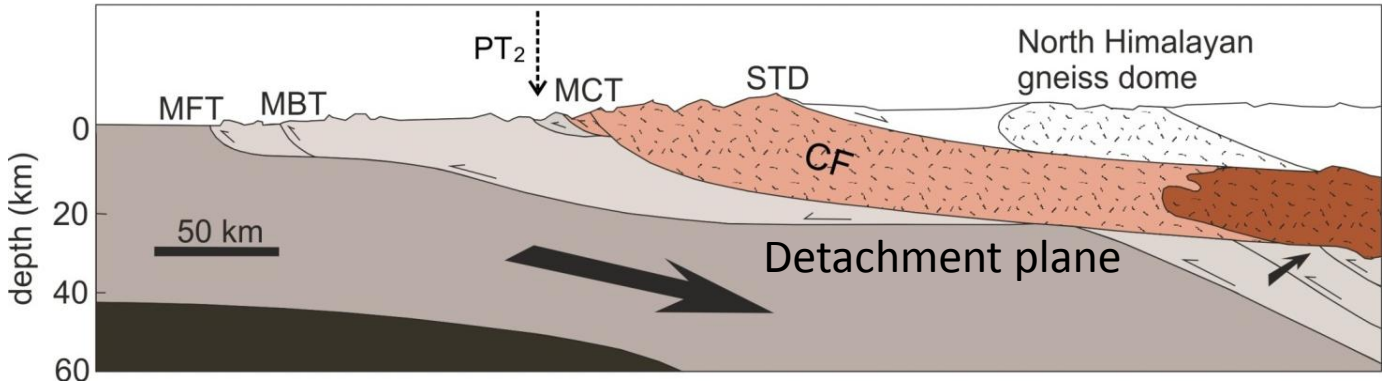
MHT is the detachment plane where great earthquakes originate and rupture propagates to the south

2015 Nepal earthquakes (Mw 7.8, Mw 7.3, 2015)



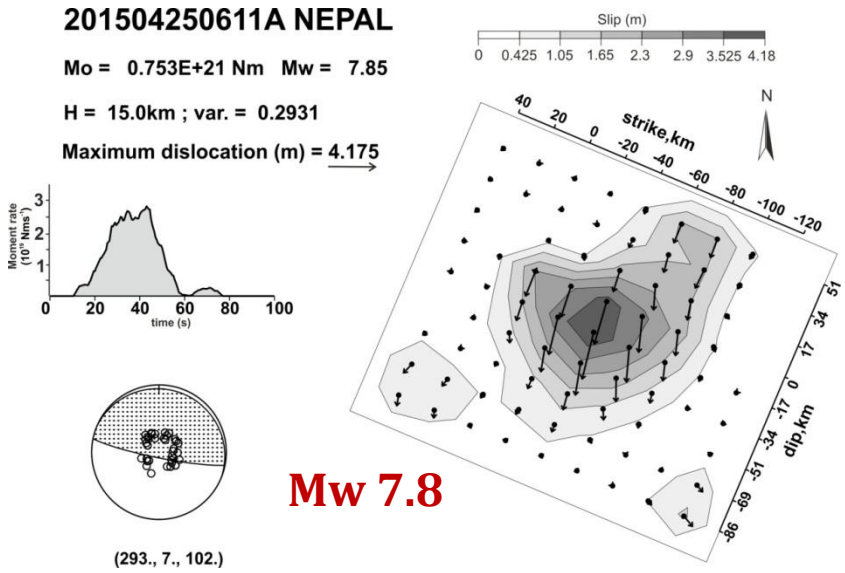


- **South eastward propagation of aftershocks; abrupt termination ~86°E.**
- **Major fault lines and the trace corresponds with InSAR deformation**



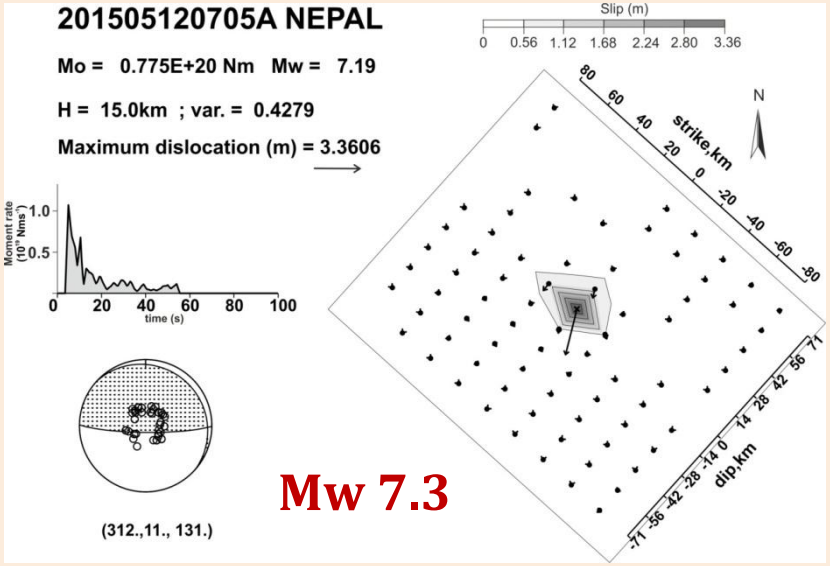
But this time there was no southward rupture, but southeastward

Constraining ruptures through source models: Wave form inversion



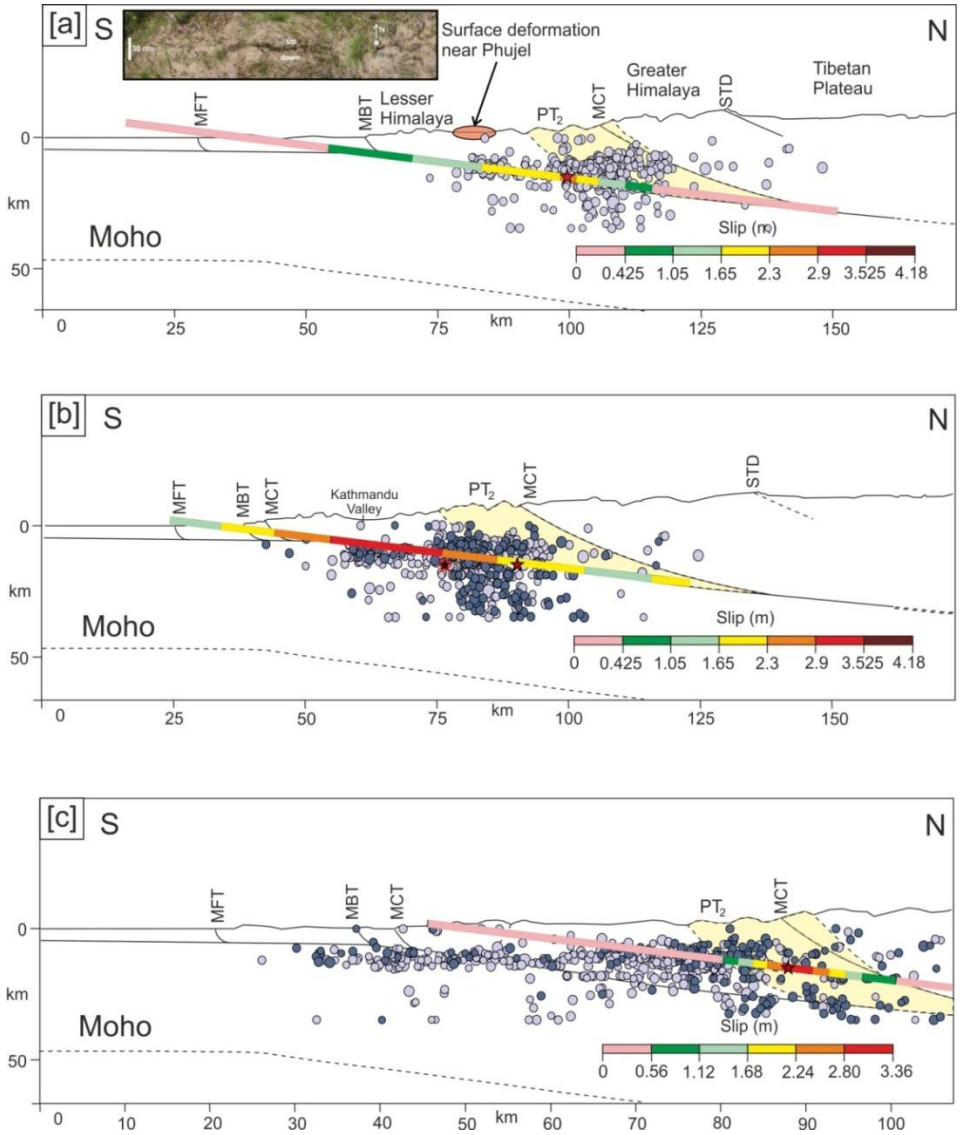
- Pure thrust ; Mw 7.85; Fault plane; strike 293°, dip 7°, rake 103°
- Net moment release of 0.753E+21 Nm; release over 70-80 s
- Maximum slip: 4.175 m, ~40 km southeast of the epicenter
- Average slip: 0.1003 m
- Slip vectors directed up-dip

Parameswaran and Rajendran, 2016



- Pure thrust; Mw 7.19; Fault plane: strike 312°, dip 11°, rake 131°
- Net moment of 0.775E+20 Nm; released in ~50 seconds
- Slip distribution is highly localized (40 x 28 km^2) around the source
- Maximum up-dip slip: 3.36 m.

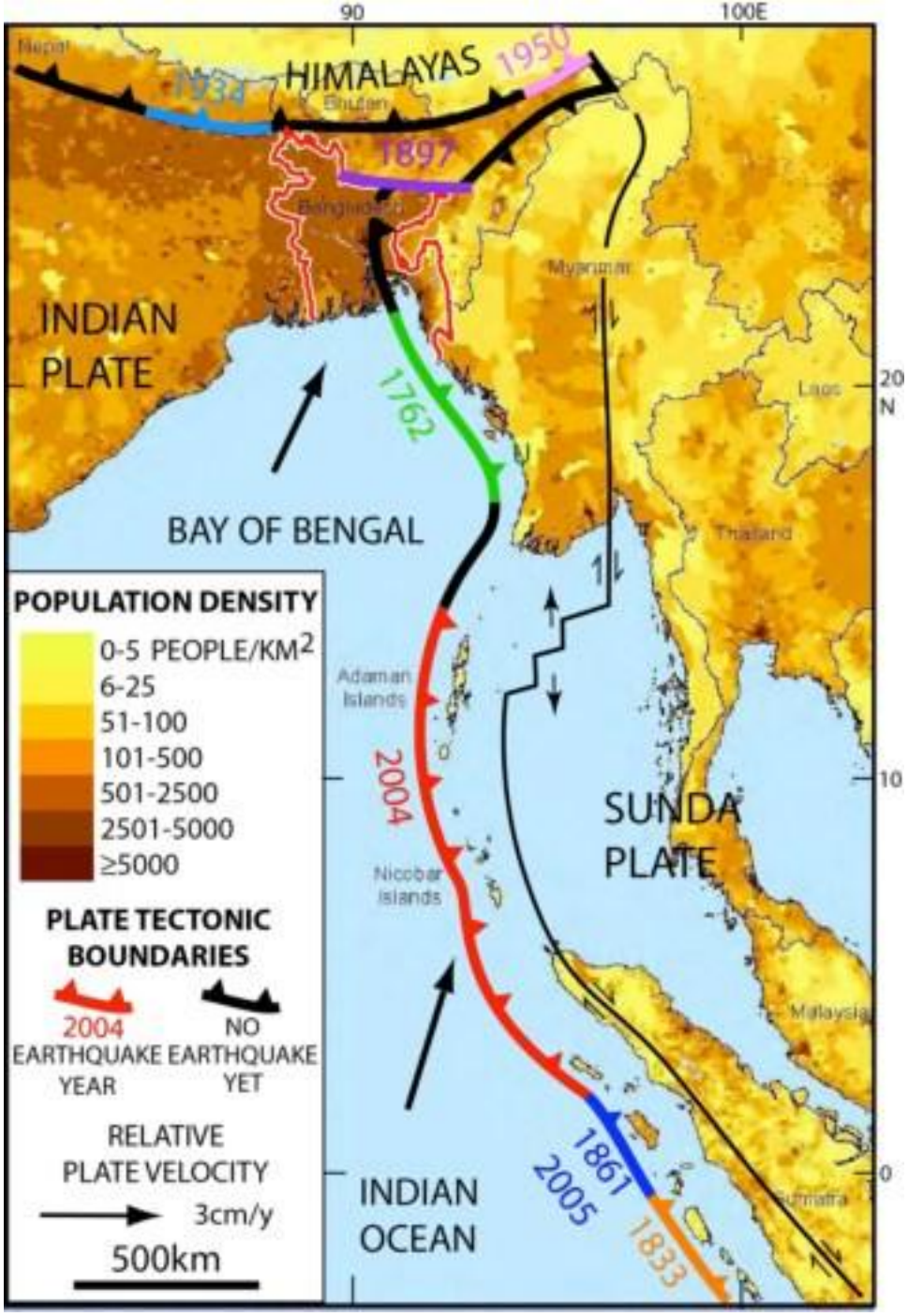
Slip models and aftershock growth



Slip models of the 2015 earthquakes suggest diverse styles of faulting for the two earthquakes.

The first one showed a southeastward propagating rupture. The second one had a highly localized rupture.

Overall, neither the aftershocks, nor the rupture reached the MFT, which is why there was no damage in the Indian Plains.



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LETTERS
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Locked and loading megathrust linked to active subduction beneath the Indo-Burman Ranges

Michael S. Steckler[1]*, Dhiman Ranjan Mondal[2,3], Syed Humayun Akhter[4], Leonardo Seeber[1], Lujia Feng[5], Jonathan Gale[1], Emma M. Hill[5] and Michael Howe[1]

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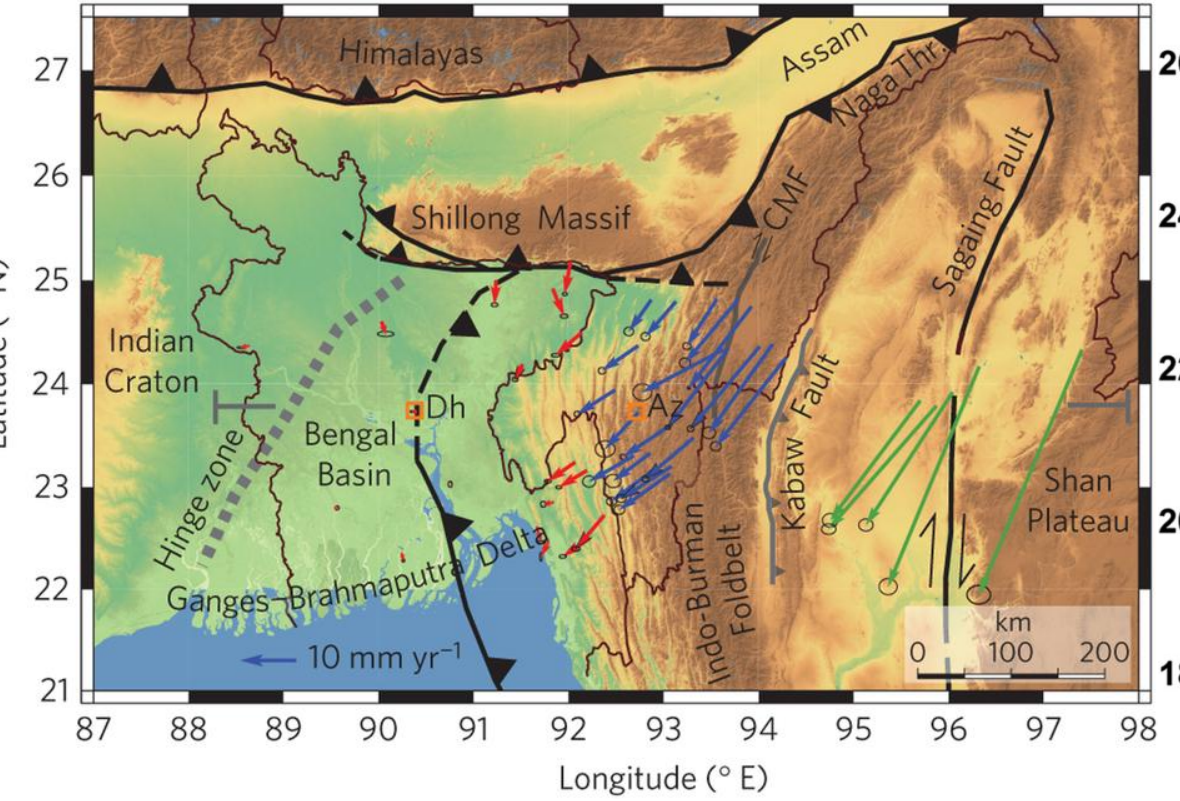
DHAKA, July 12, 2016

Updated: July 12, 2016 17:13 IST

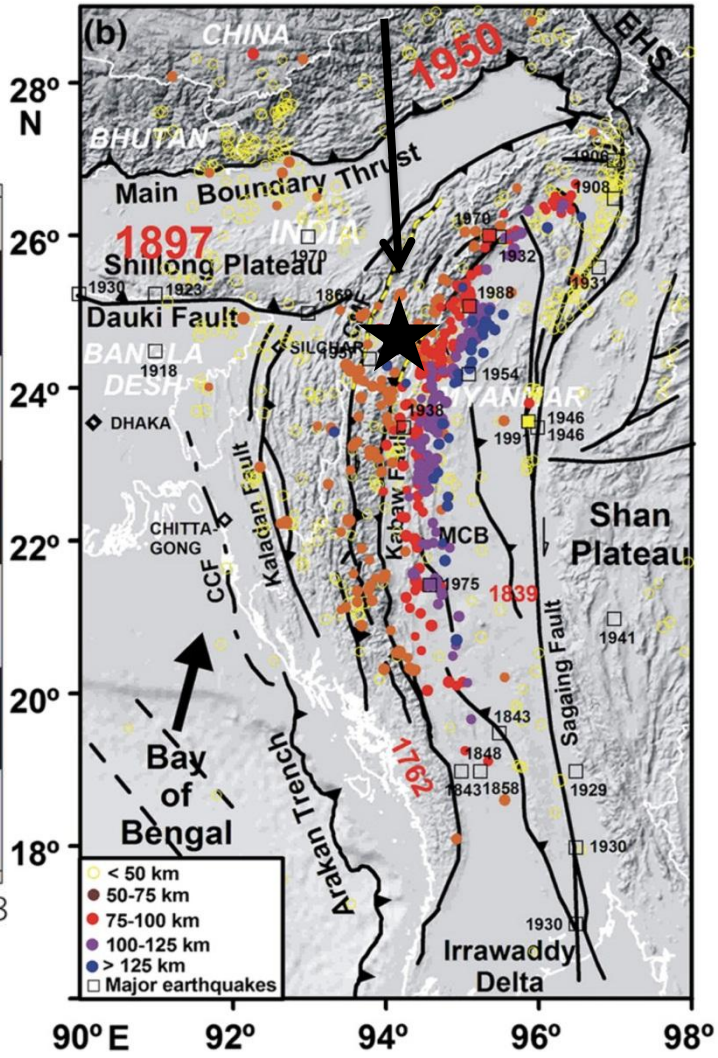
Major earthquake lurking under India, Bangladesh: study

Indo-Burman Range (IBR): Prediction of a great earthquake

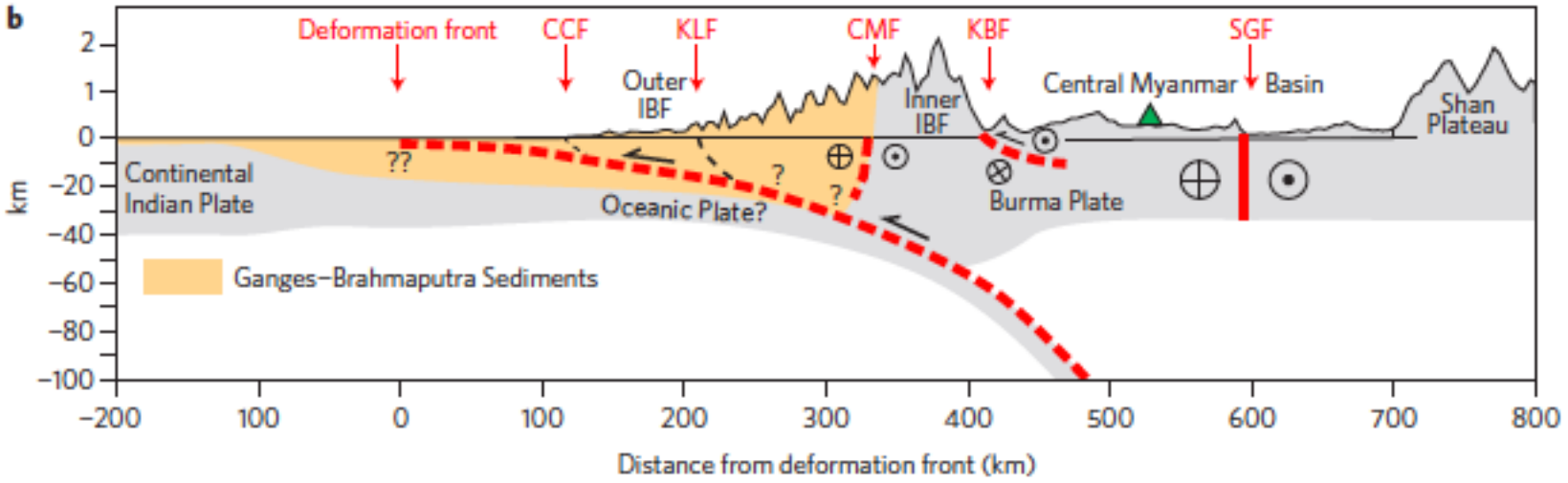


Geodetic slip vectors assuming that the plate boundary Is locked.

Mw 6.7, 2016



No great earthquakes on the IBR in the recent/historic times.

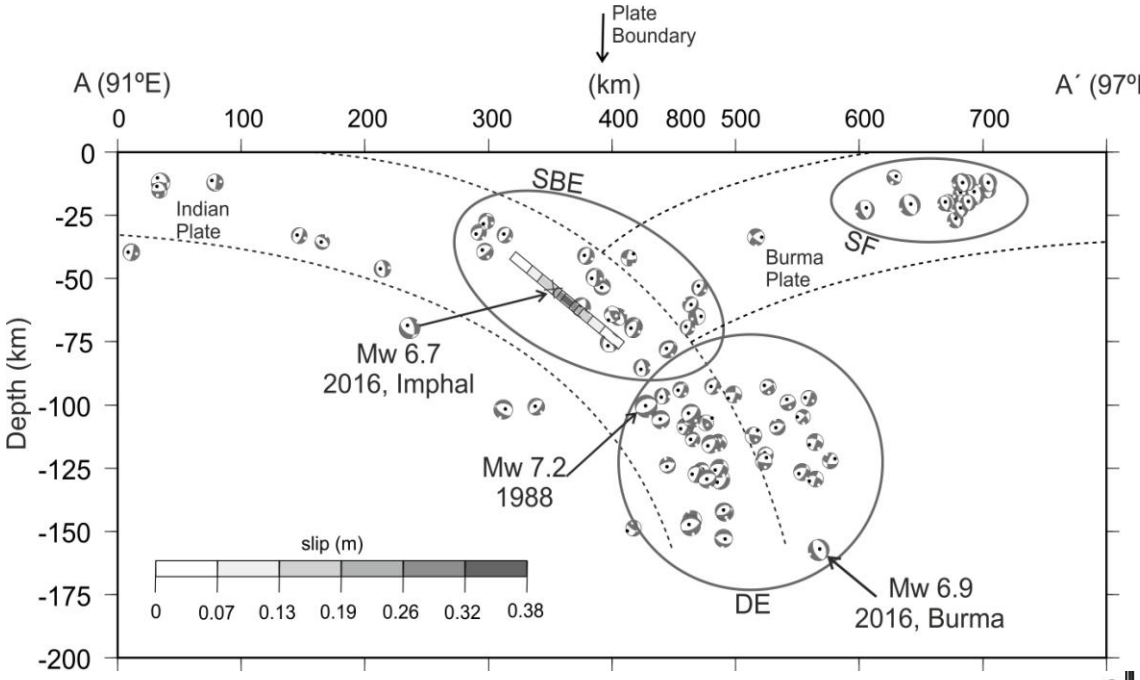


The important question here is if the subduction zone is locked or if is aseismically slipping?

Can the sediments be assumed to follow the same deformation as the basement?

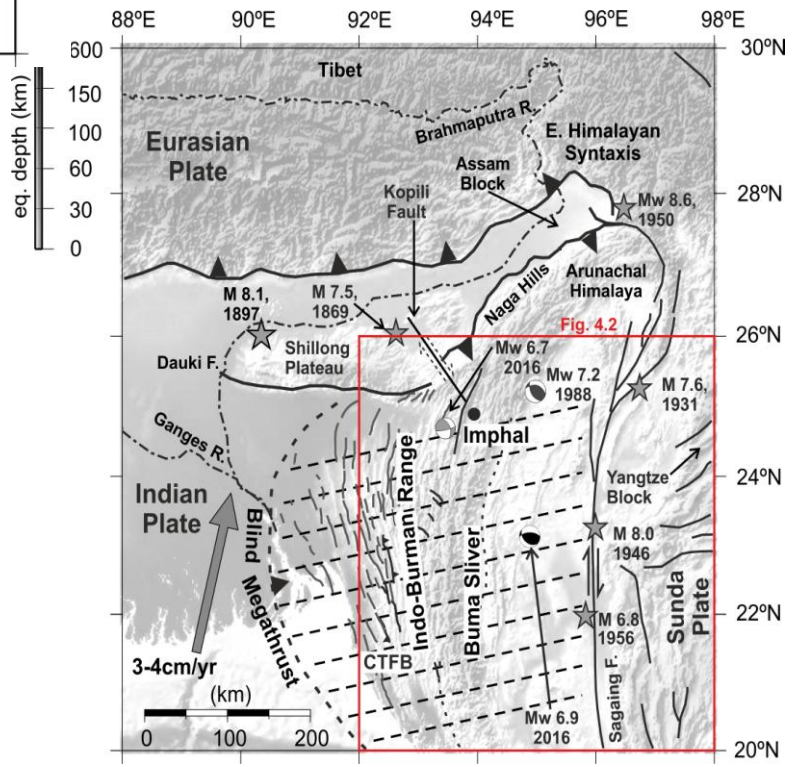
Model assumes active E-W convergence.

(Steckler et al., 2016)

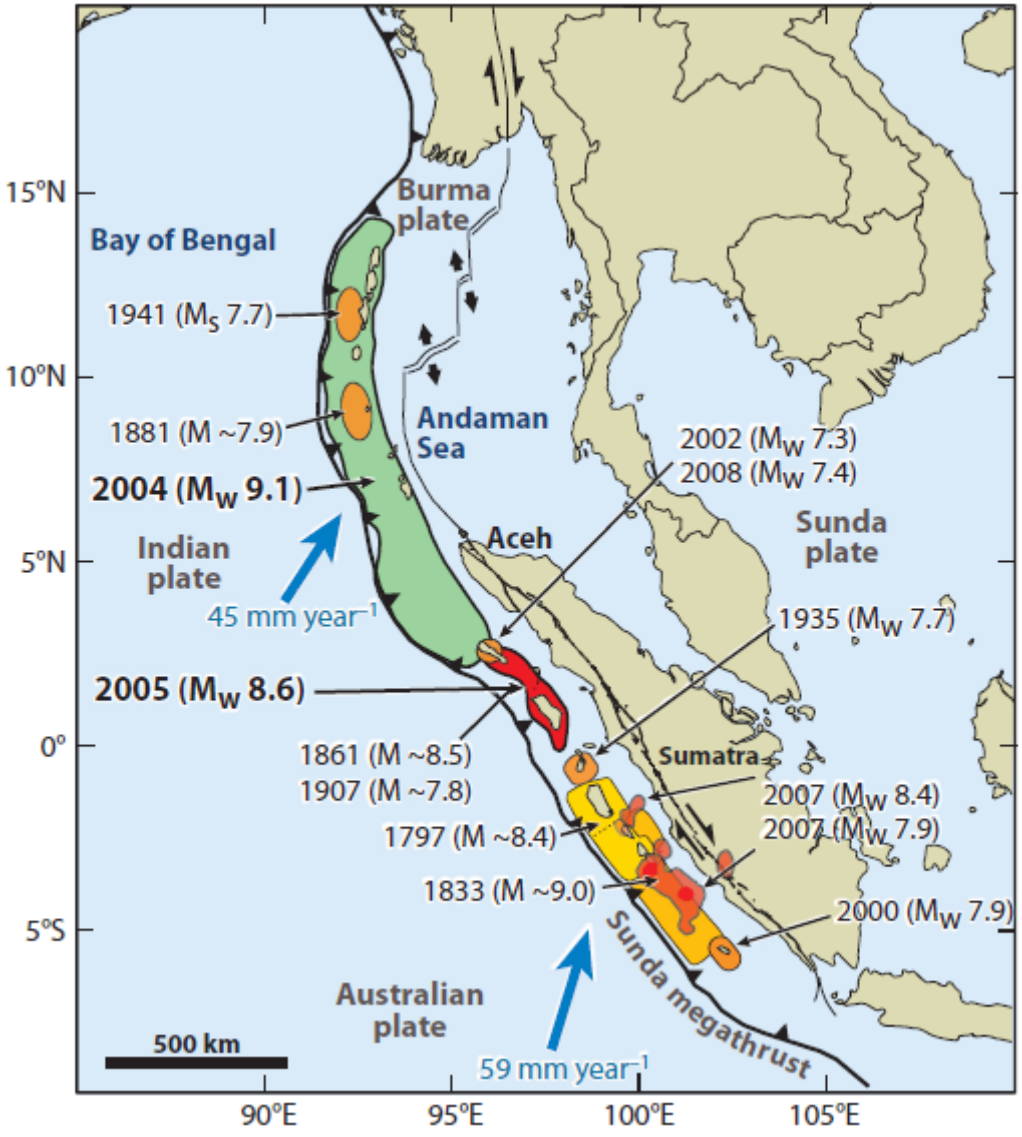


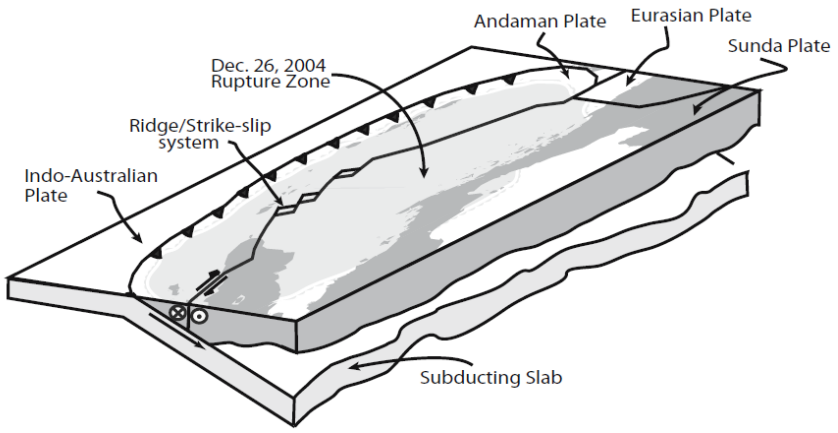
Occasional moderate earthquakes mostly sly from bending events at (25-75 km). Direction of compression, NE-SW and nor E-W as would be expected for India-Burma convergence

Seismological evidence does not support active convergence



The 2004 Sumatra-Andaman (SA) Earthquake



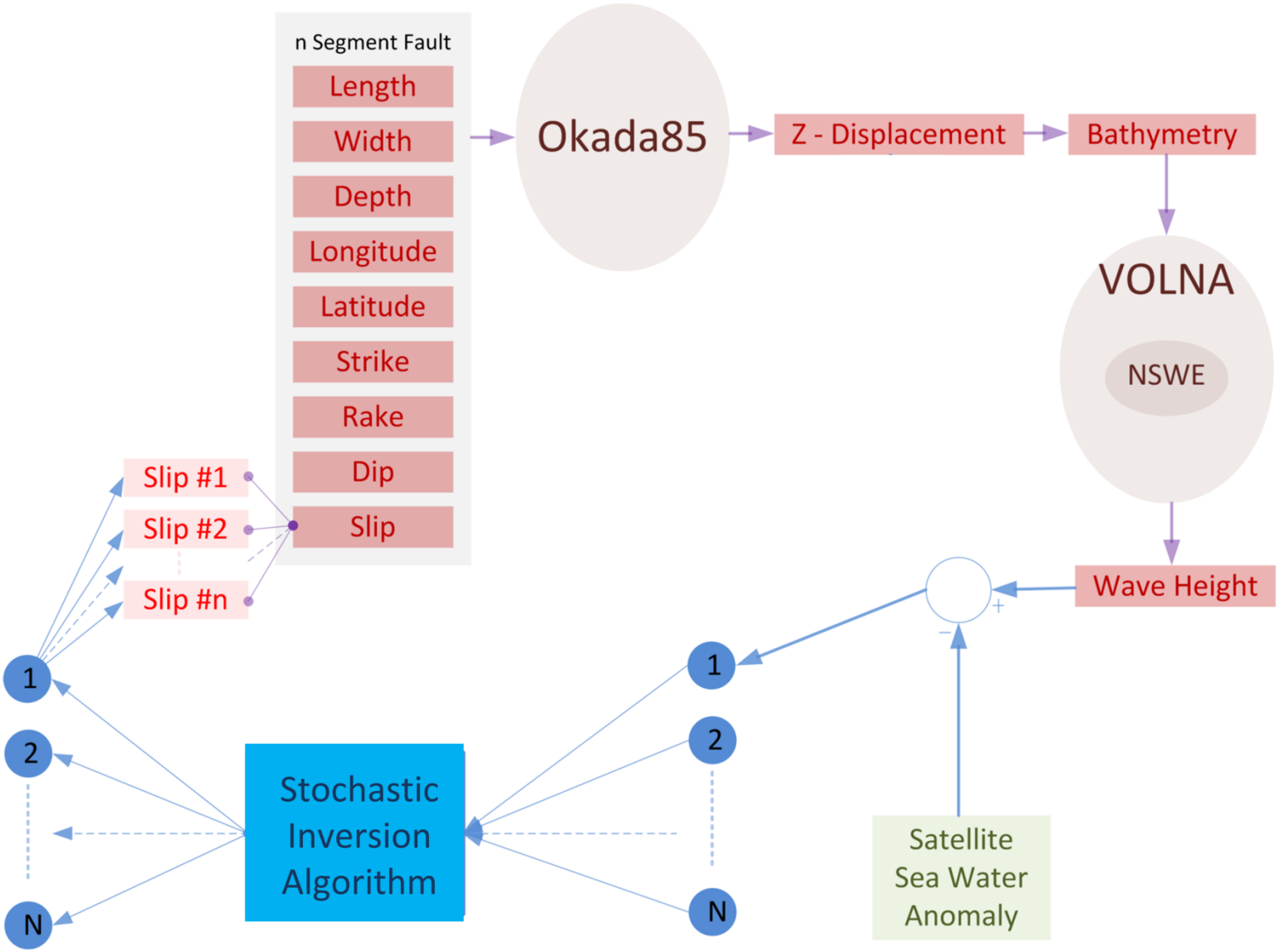


Generated a transoceanic tsunami.

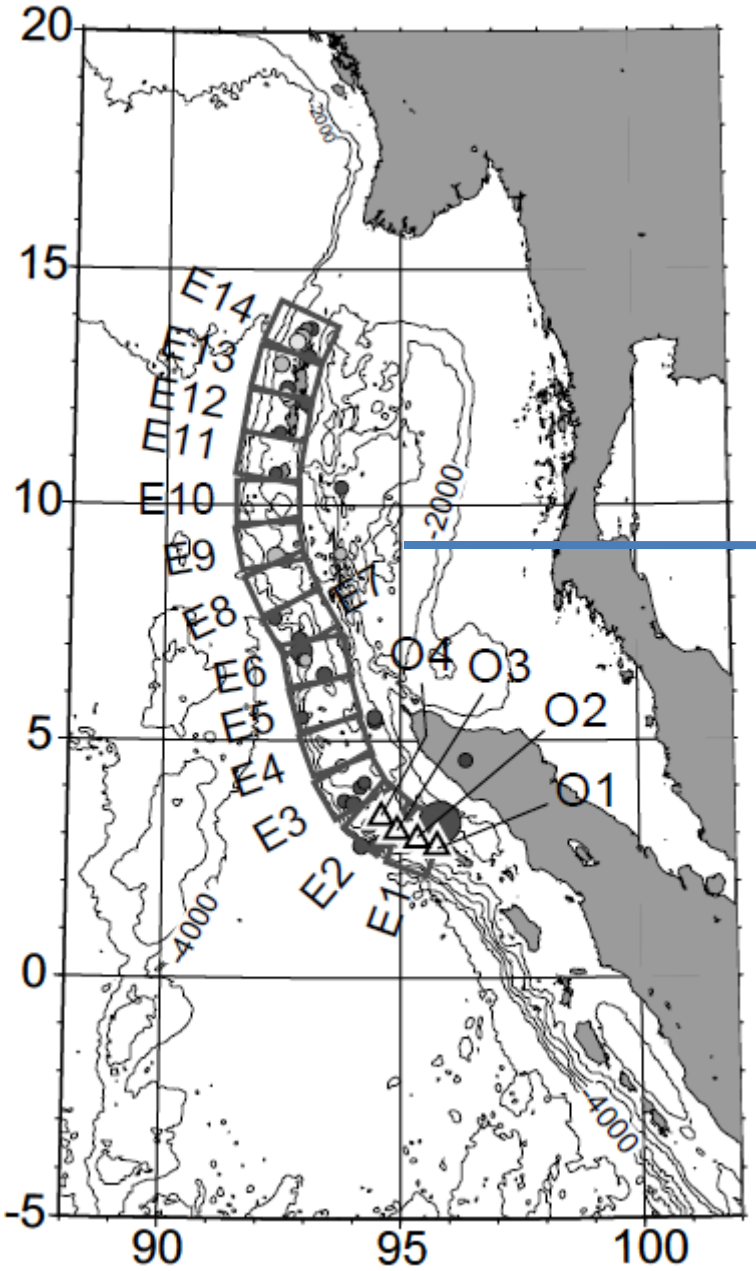
Challenge here is to use the recorded wave forms to model the source

Initial models start with displacements inferred from seismologic evidence

INVERSION OVERVIEW



Uplift/Ocean Bottom Deformation



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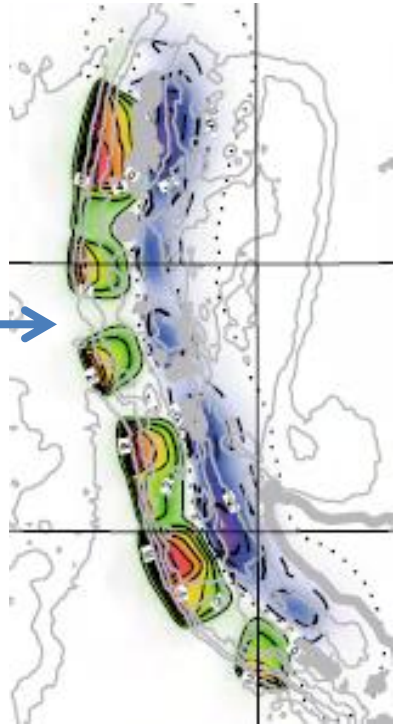
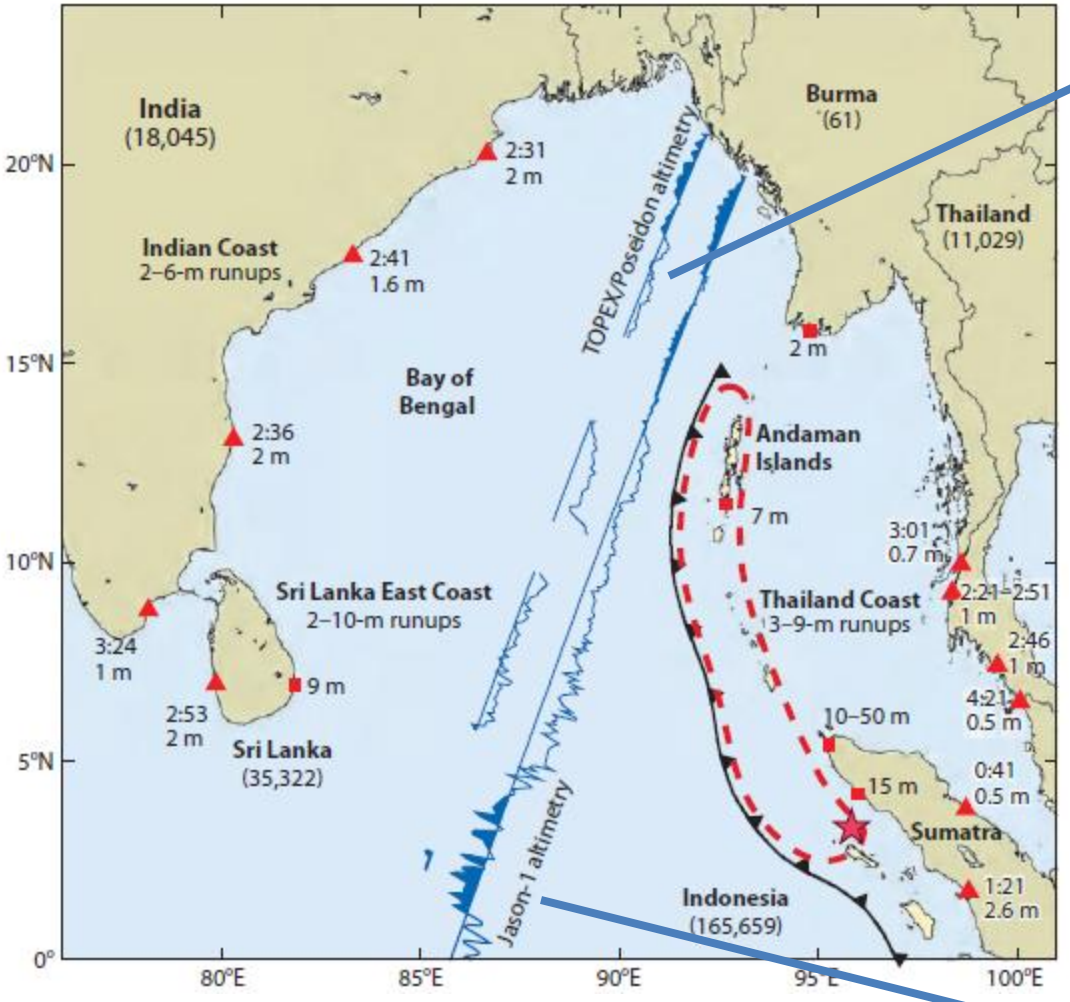
Vertical Displacement

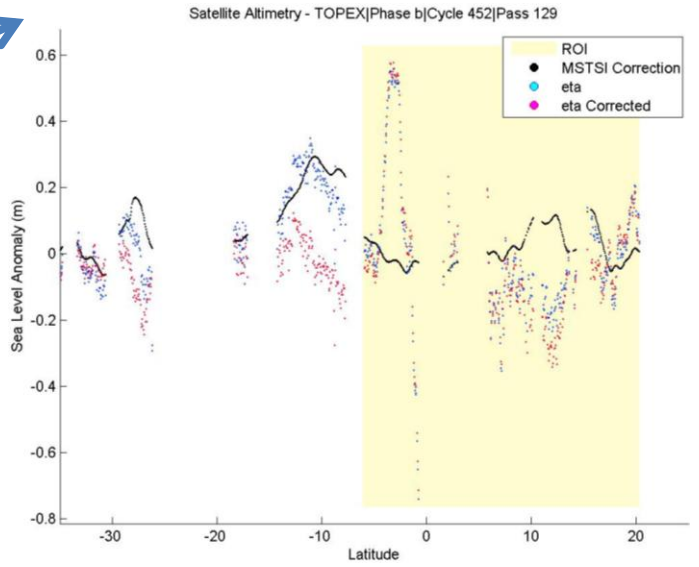


Note : Horizontal Displacement need for high Bathymetry gradient regions

Figures from *Hirata et al.,* 2006

Satellite Altimetry





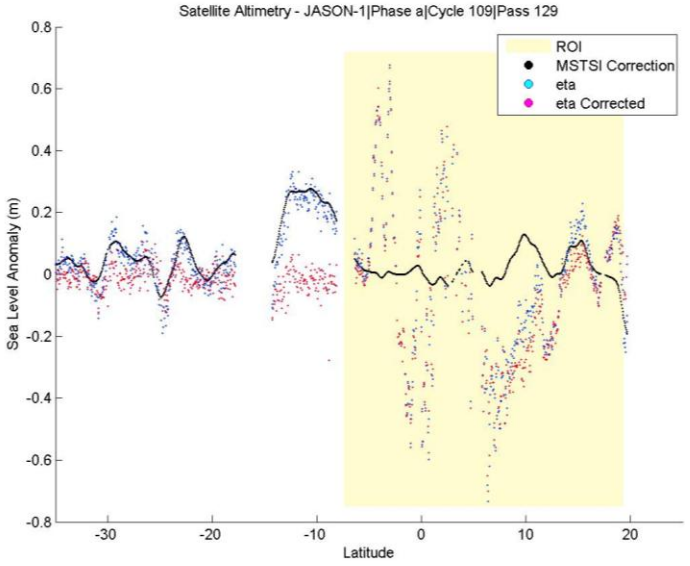
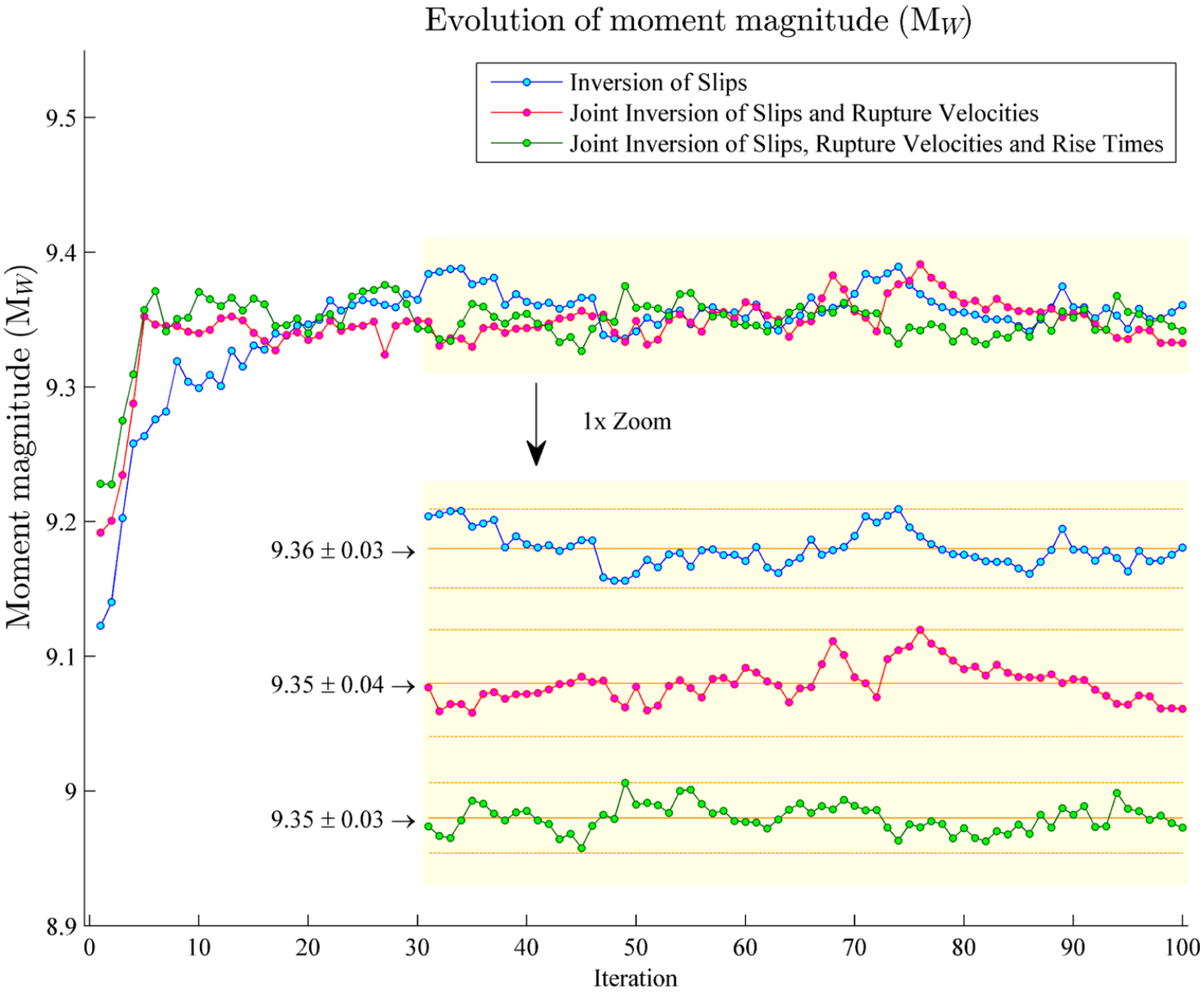


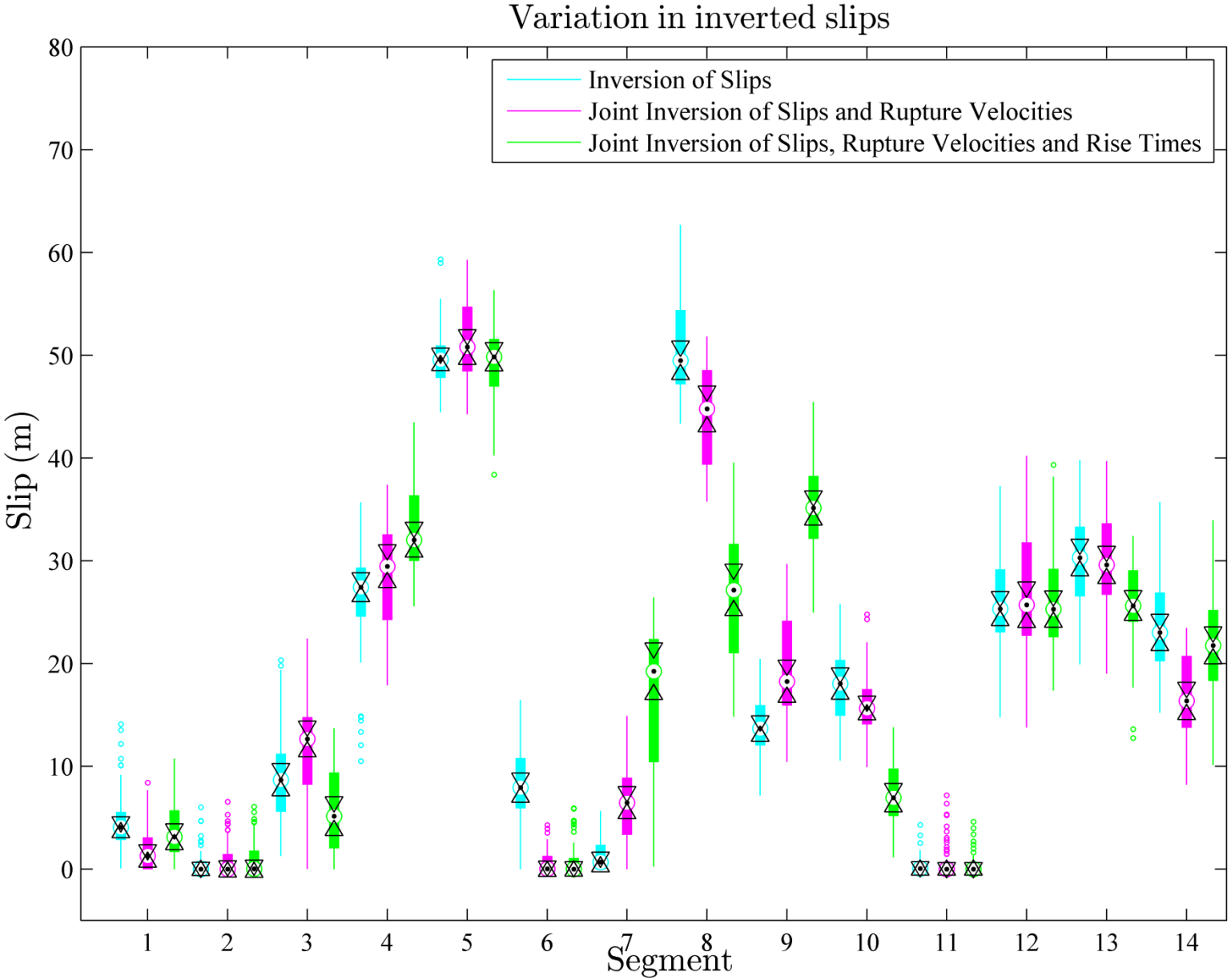
Figure from *Shearer and Bürgmann,* 2010

Evolution : Moment Magnitude

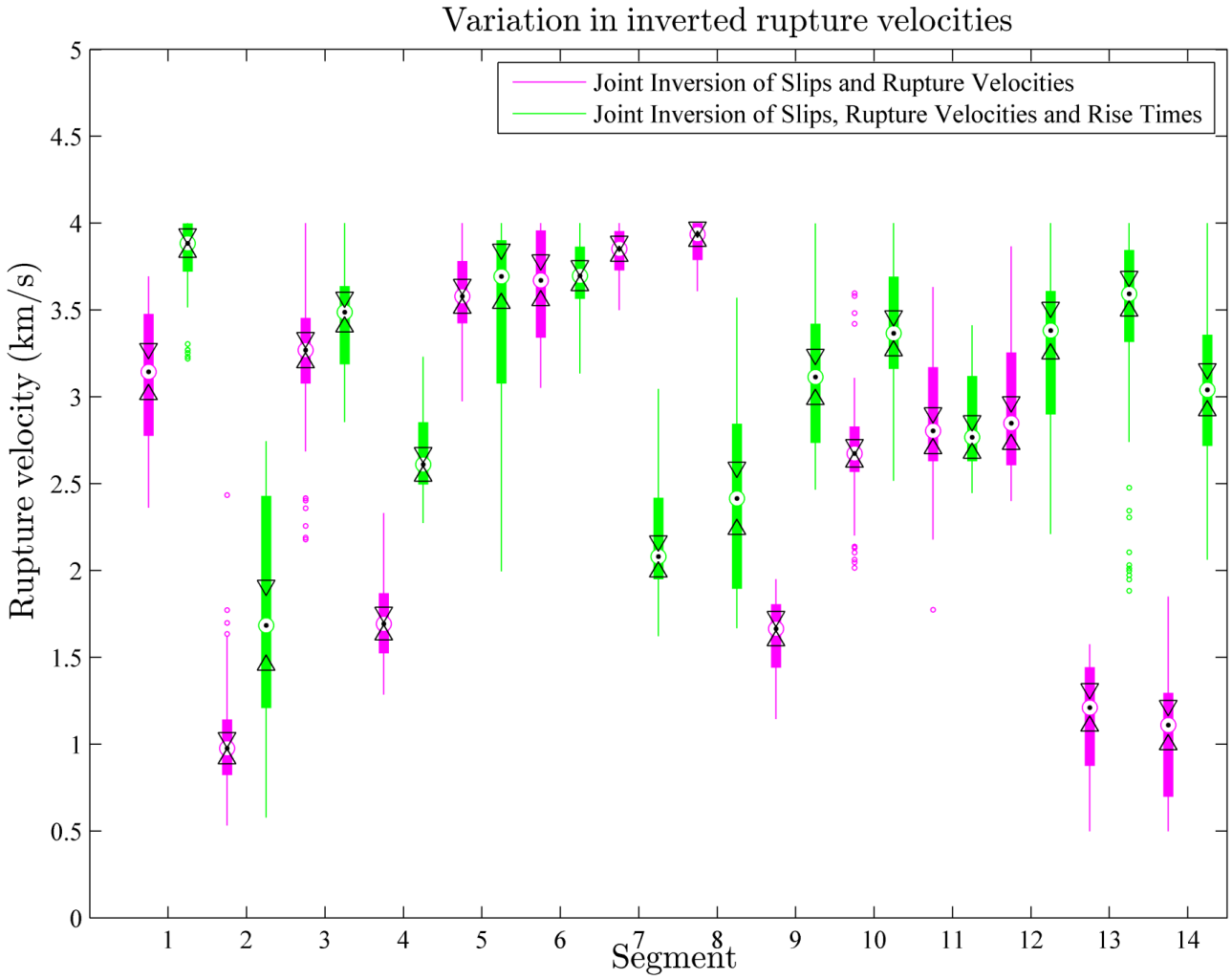


Evolution : Seismic Moment

Variances : Slip



Variances : Rupture Velcoity



Summary

- The Geopohysical environment defined mostly by the India-Eurasia collision poses several modeling challenges

- Models that can explain slip/strain transfer across boundaries can possibly help explain movement of the sediment wedges, locked/unlocked status of collision zones. These would refine the geodetic slip models

- Tsunami source inversion from satellite altimetry or tide gauges (prone to more errors die to near shore amplification) provide inputs for tsunami warning systems

The presentation here is based on the work of :

Ms. Revathy Paramesawaran (PhD student at CEaS)

Mr. G. Devaraj (Ph. D Student, CE Department; collaborative work with Prof. Debaisish Roy)

Thank you