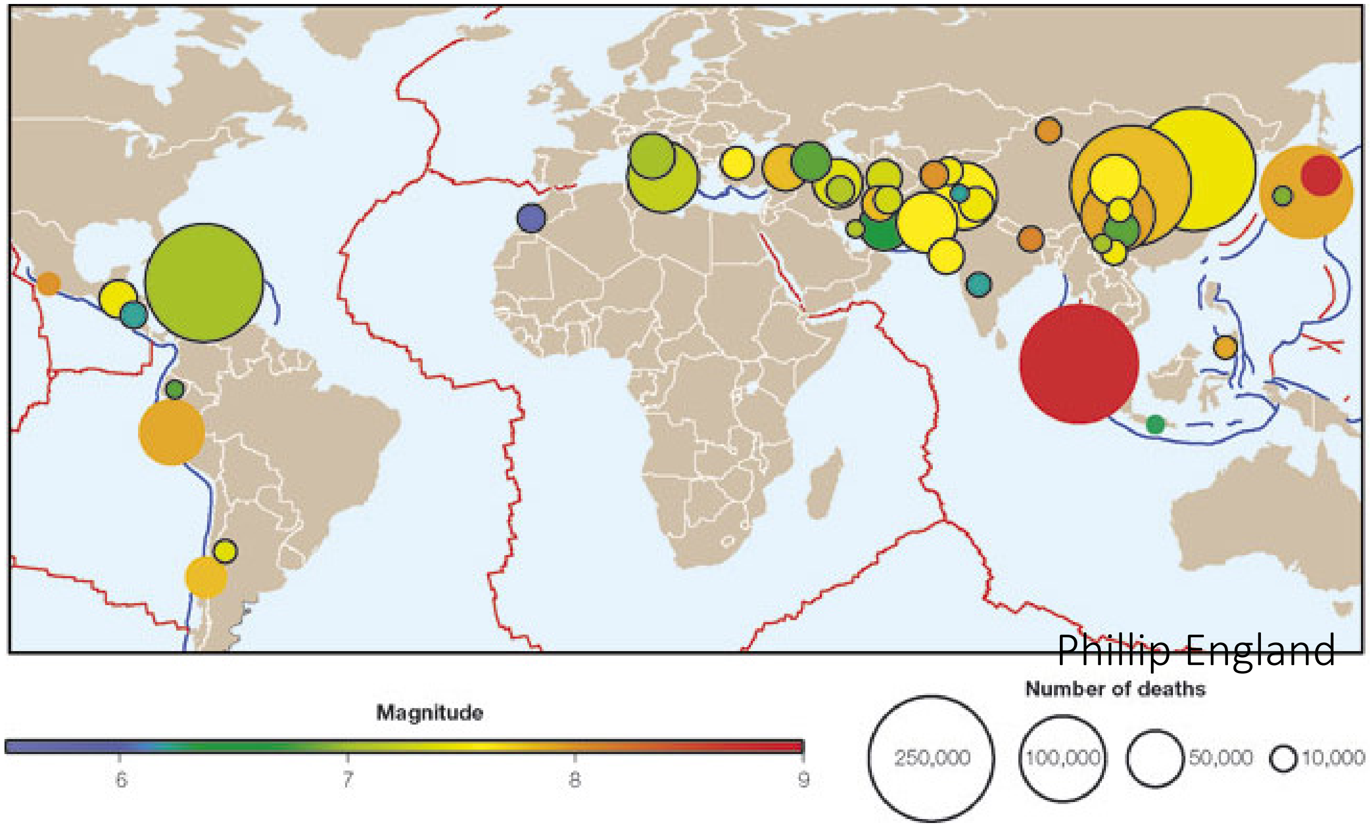
30-40*N Enchanting Lands, Exotic Endowments

Nature's Busiest Workshop on Earth

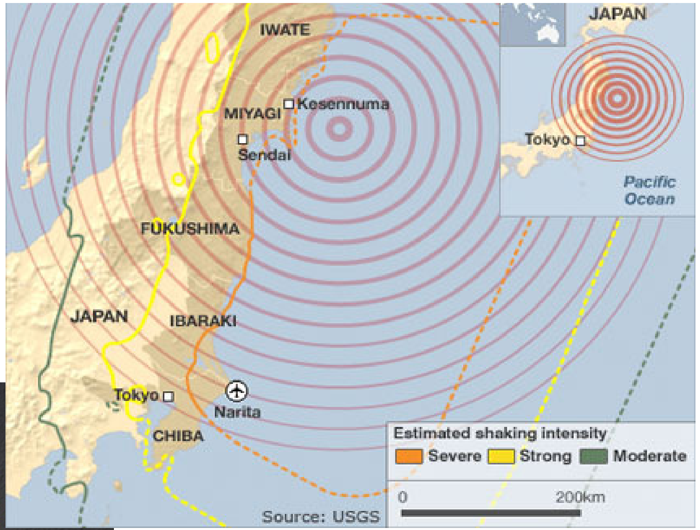
Great Civilizations – Tragic Encounters



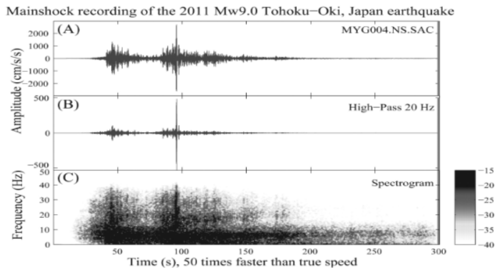
Himalaya a Piece of the Southern Eurasia Collision Zone

The Region Witnessed the highest Earthquake Fatalities (2009 -11)

The M8.9 TOHUKU EARTHQUAKE (2011)
SHIFTED HONSHU EAST BY 2.4 M
AND THE EARTH'S AXIS BY ~ 10 CM



BUILDINGS IN TOKYO SWAYED BY TENS Of CENTIMETRES BUT SURVIVED



Incisive Understanding of Nature's Works and Skilfully Negotiating Them - RESILIENCE

Design and Construction Practice

Abreast with the State of Knowledge

The Spectacular Himalaya

Wondrous diversity of Human-Natural ecosystems

Sensitively Balanced on High Gradients of

Topography, Climate, Biota and

Demands of the Designed World (Civil, Defence)

Vinod K Gaur

HIMALAYA BUILT METRE BY METRE OVER 40 MA

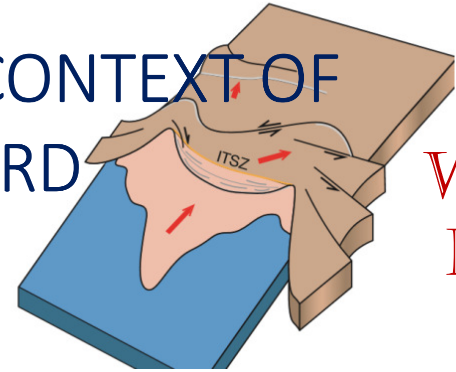
A High Hazard Abode FOR the Designed World

Key Issues FOR Sustaining Resilience:

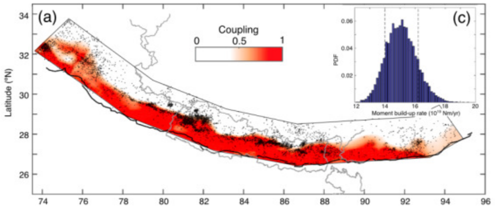
*Policy, Management & Work: ABREAST with State of Knowledge

*Science & Technology Initiatives: AHEAD of the State of Practice

THE PERSISTENT CONTEXT OF HIMALAYAN HAZARD

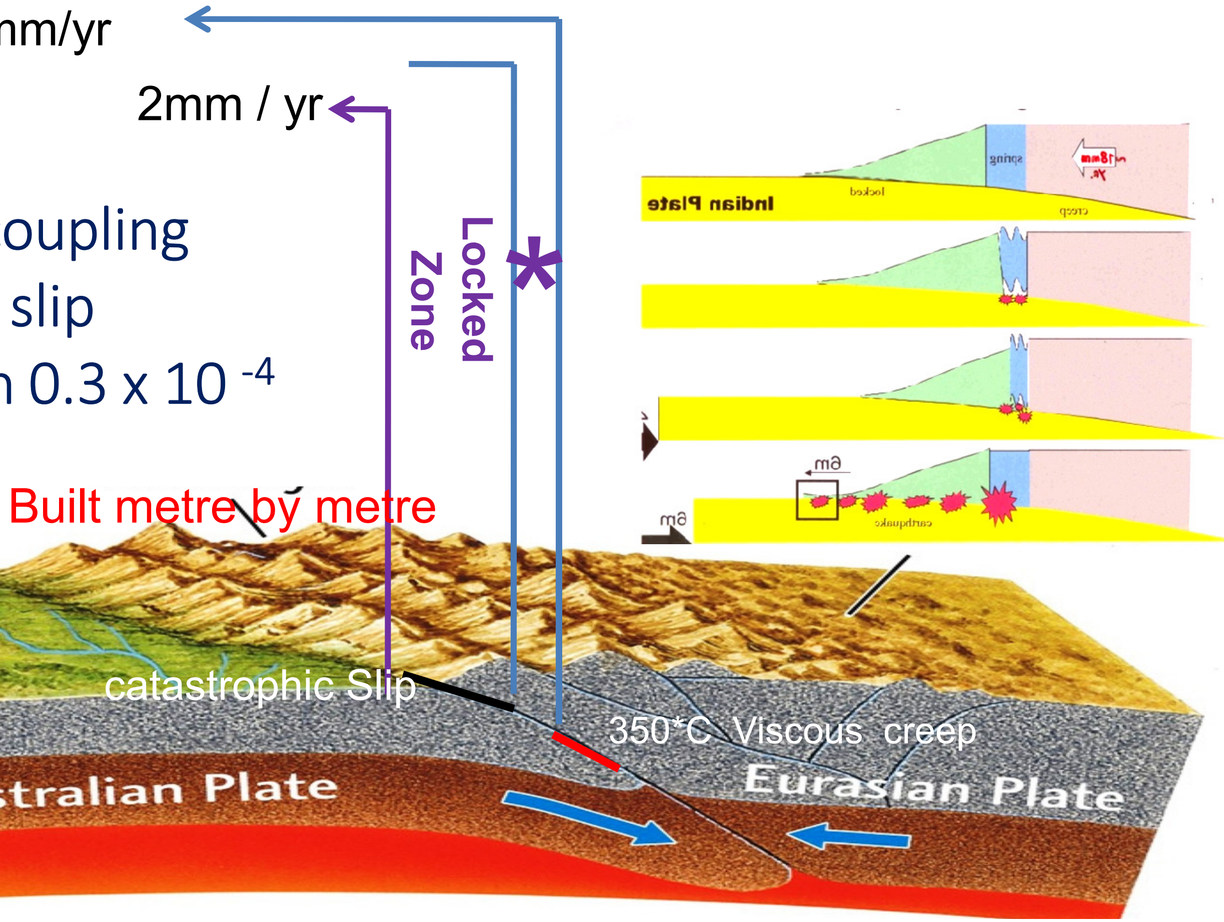


WE TOO CAN PREVENT HIMALAYAN HAZARD FROM TURNING INTO A DISASTER

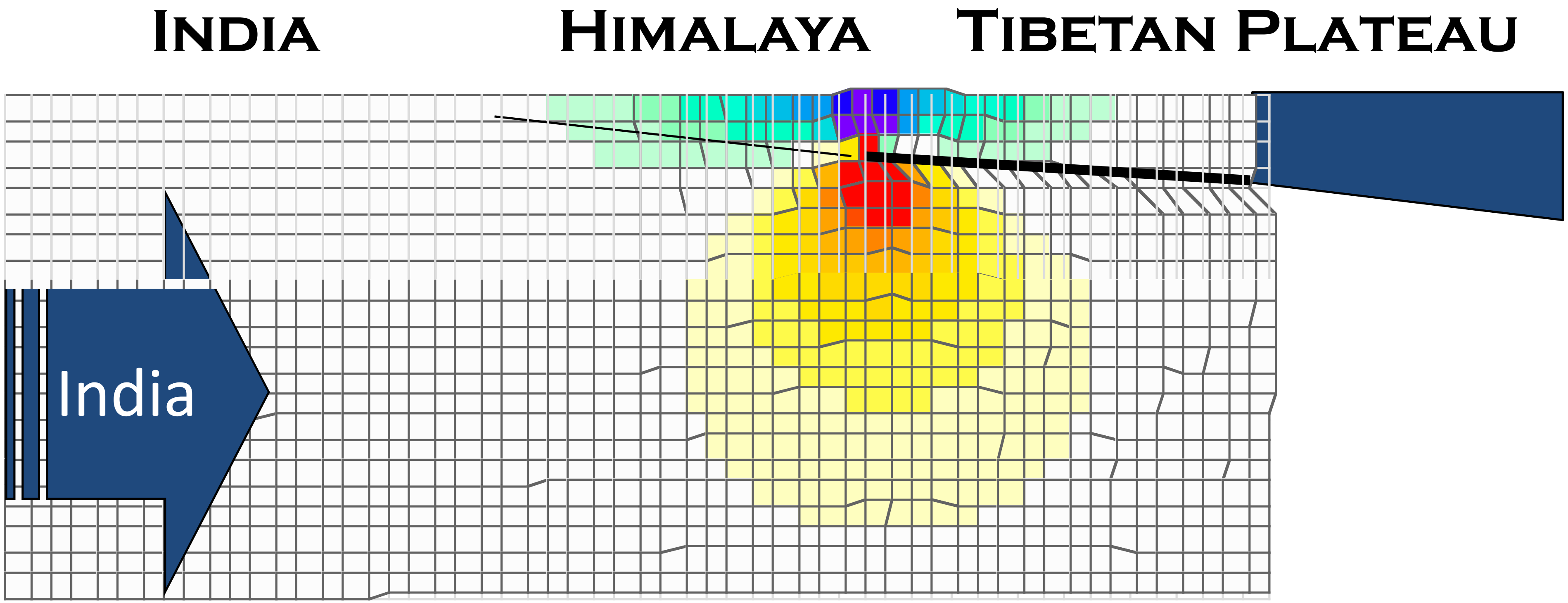


*The Interseismic Decoupling Zone Accumulates slip

@ ~ 1.5 m/century   Strain 0.3 x 10 $^{-4}$

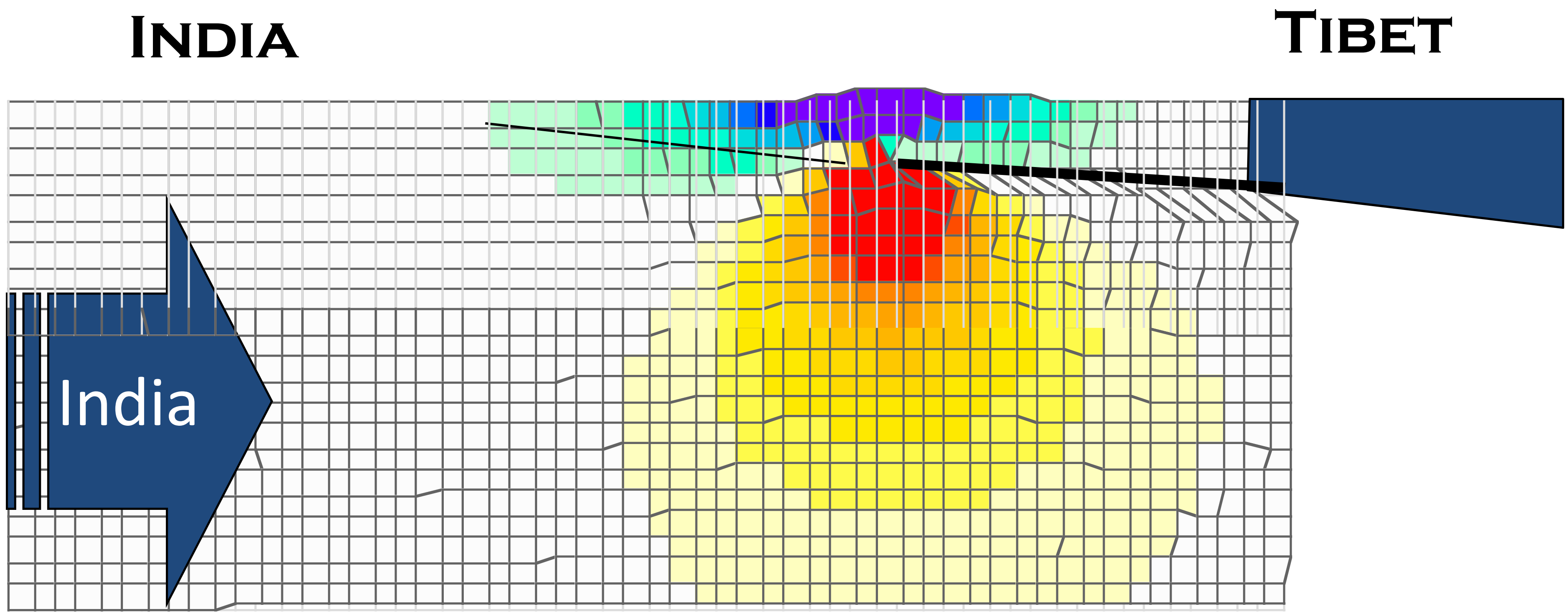


Evolution of the Strain Field in the Himalaya Between Major Earthquake Ruptures

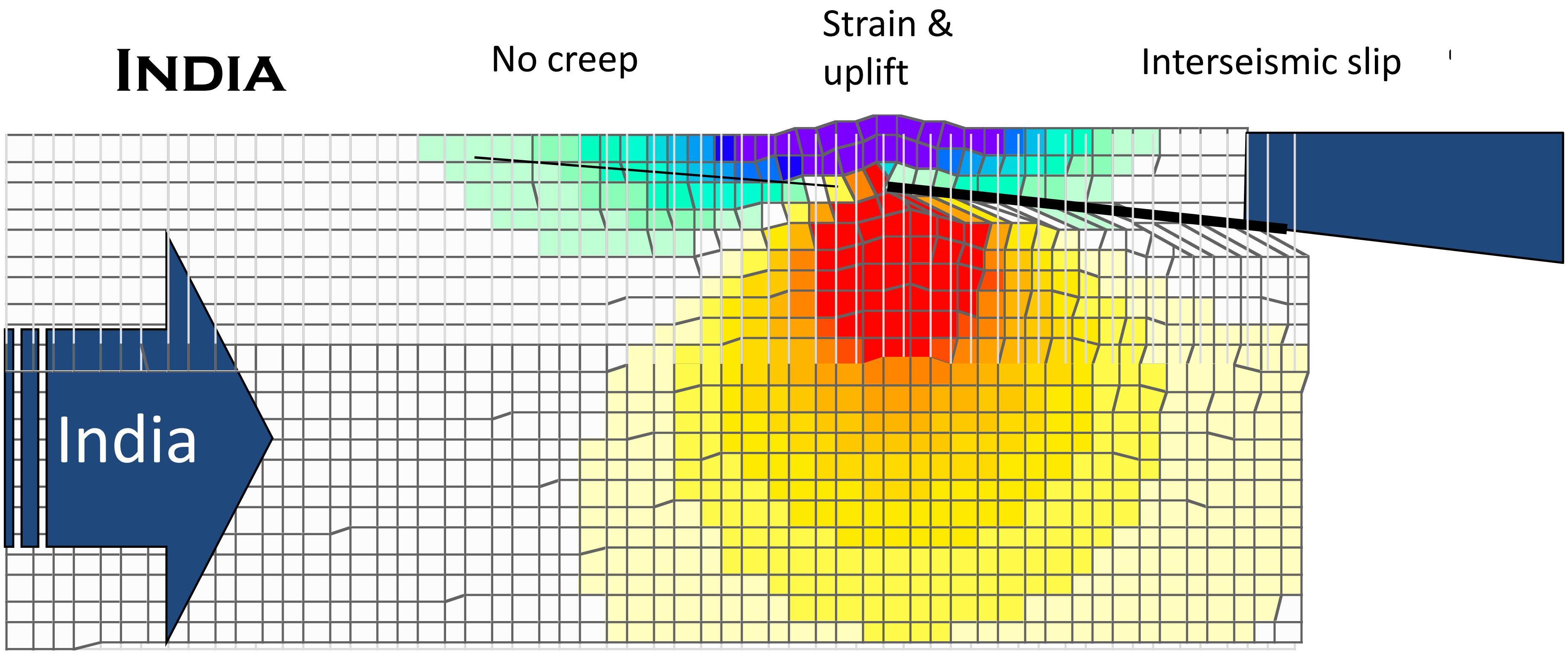


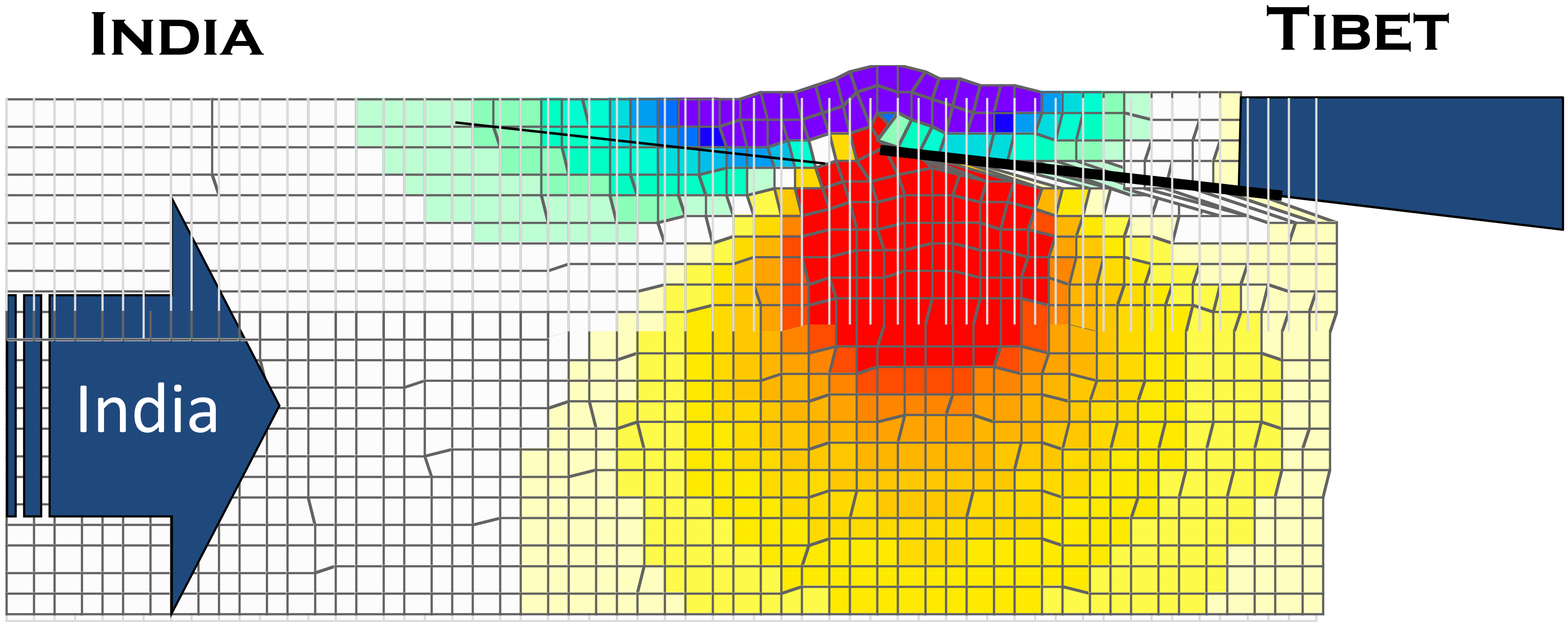
SOUTHWARD DRIVE OF TIBET OVER INDIA

BY ~2 CM/YR CREEP ON THE DEEPER > 15 KM PART OF THE DECOLLEMENT AND THEREAFTER BY STICK-SLIP : EXISTENCE OF A LOCKING LINE ?

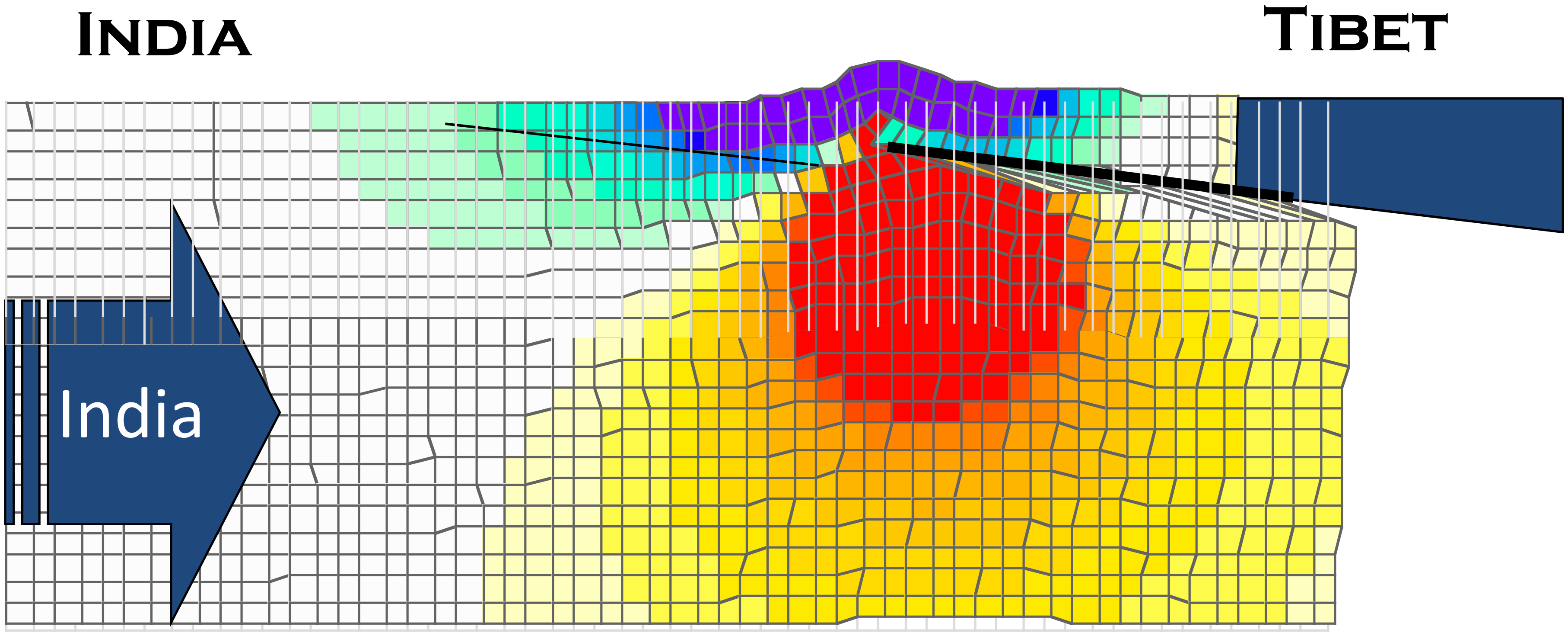

India
Tibet
India

Simple model for Himalayan earthquakes

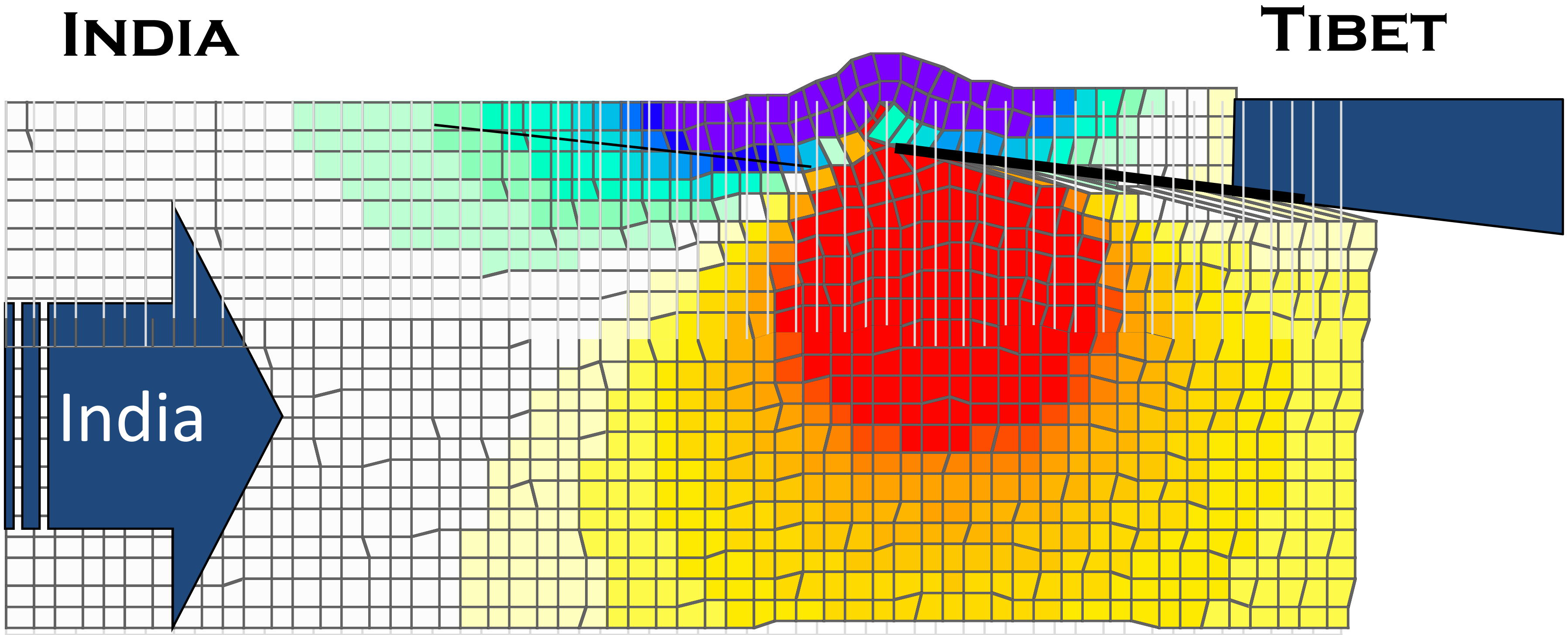


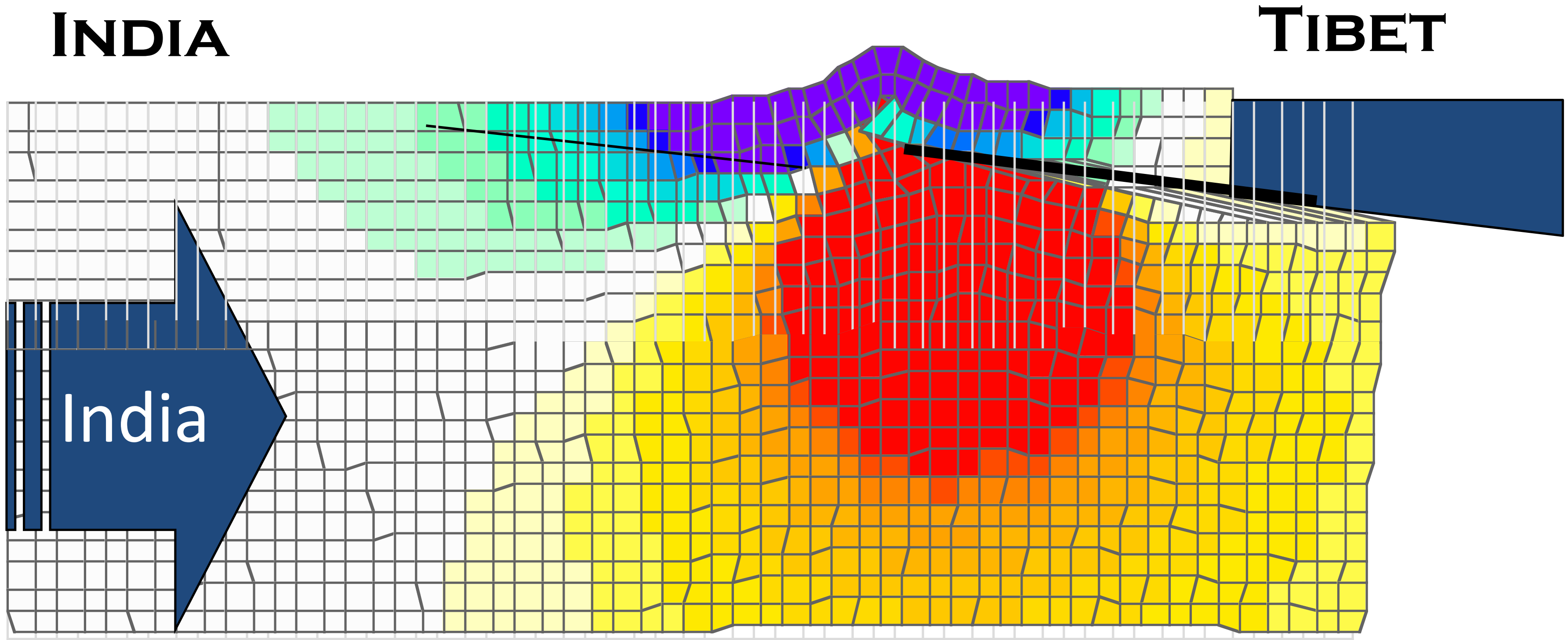


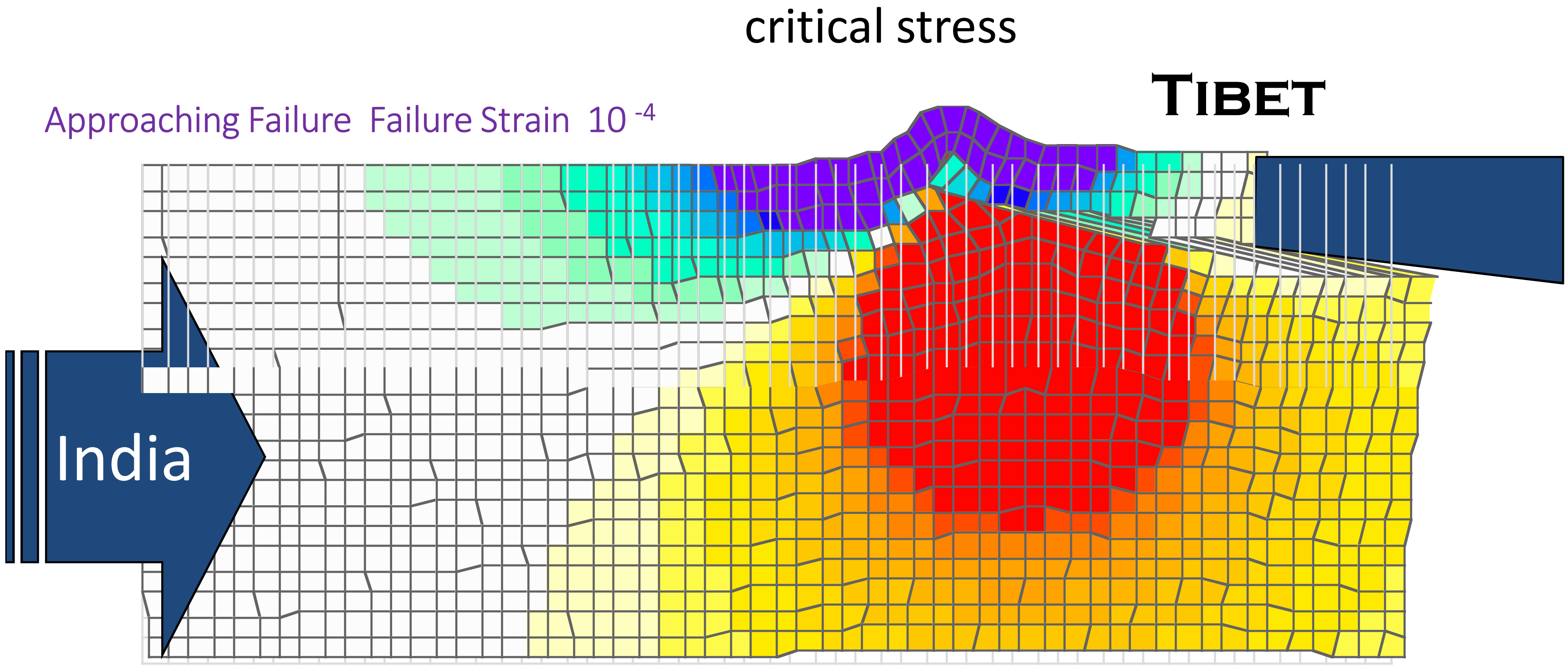
India
Tibet
India

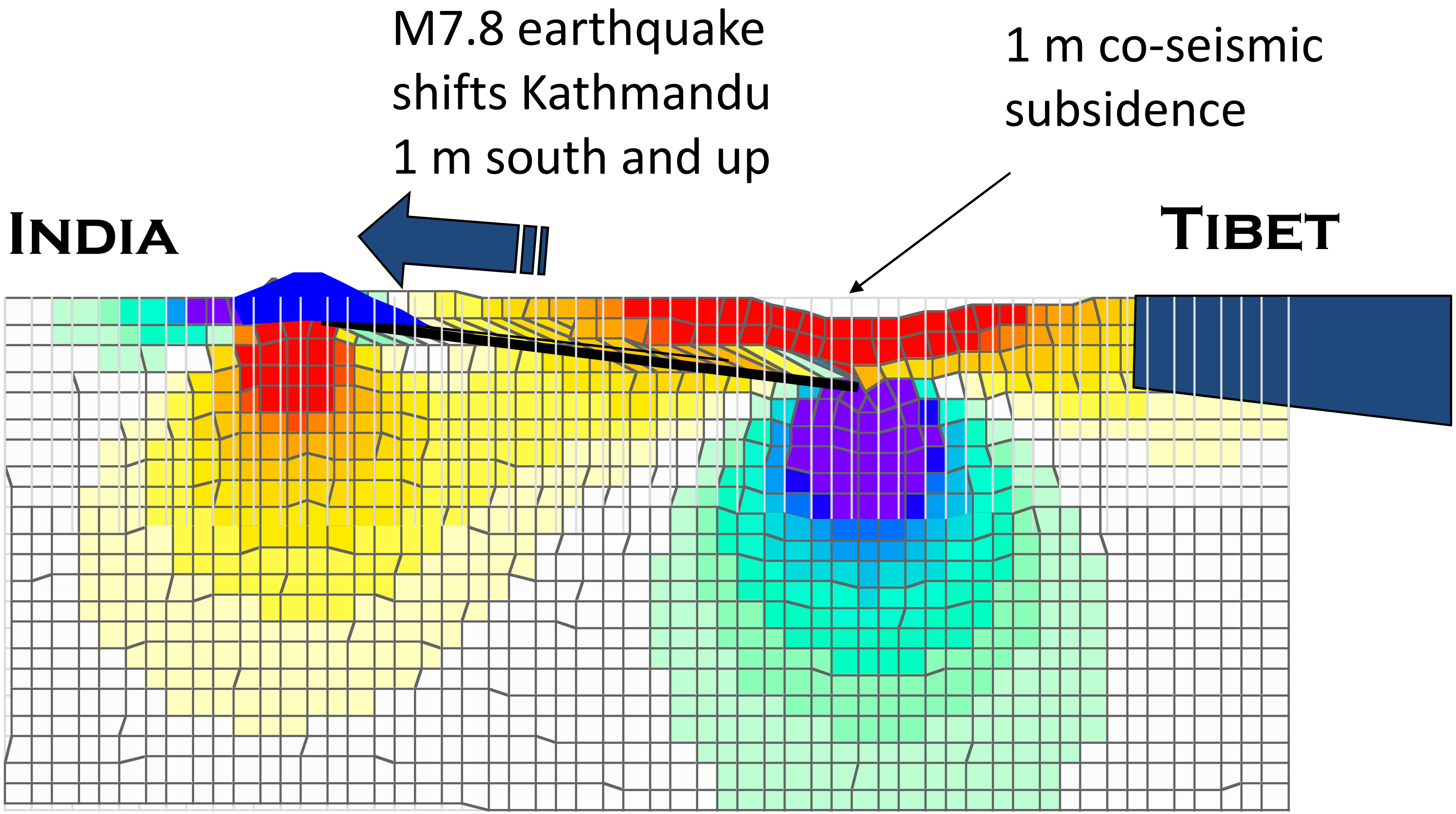


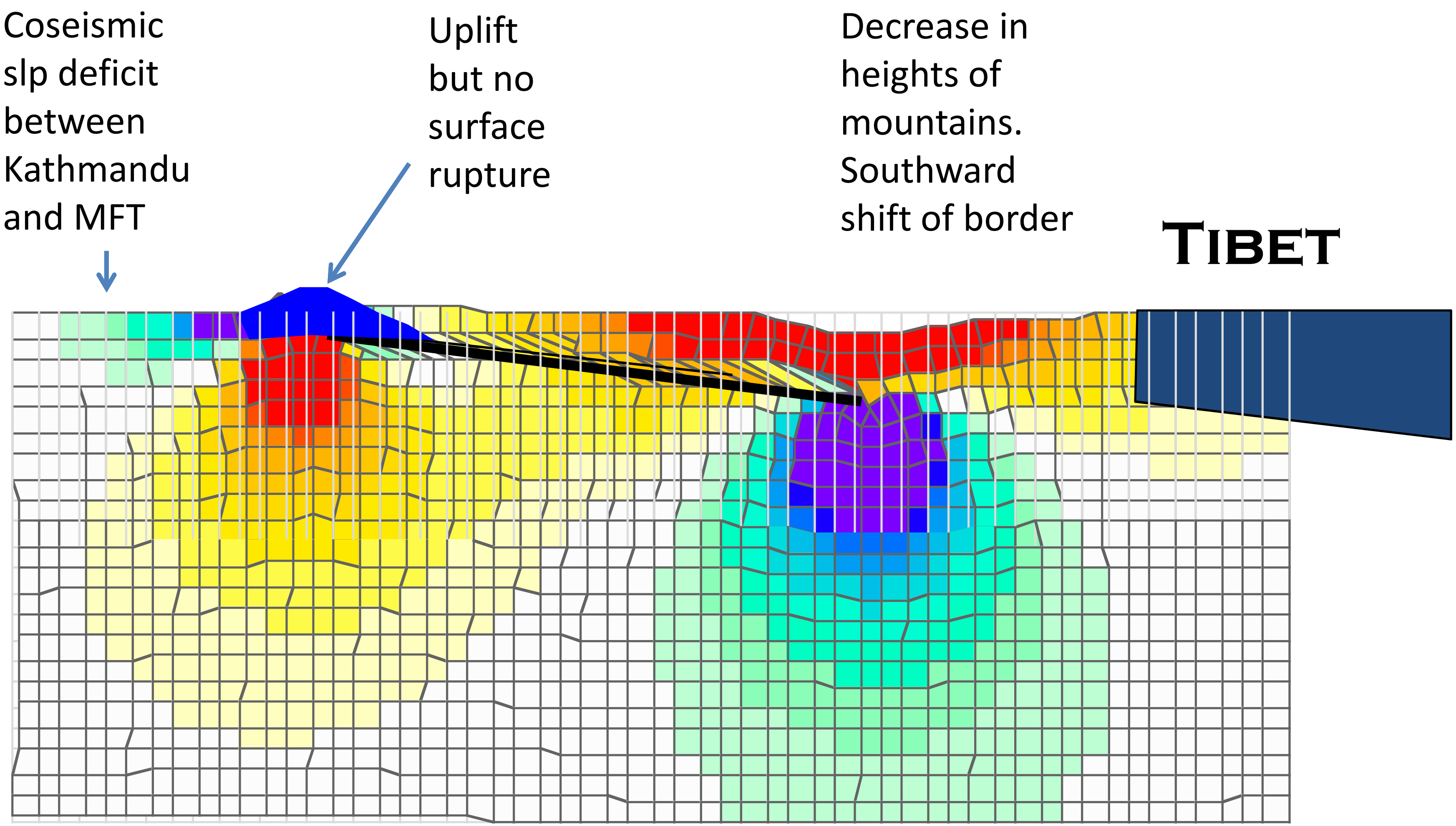
India
Tibet
India


India
Tibet
India


India
Tibet
India


critical stress
Tibet
Approaching Failure Failure Strain 10^{-4}
India


M7.8 earthquake
shifts Kathmandu
1 m south and up
1 m co-seismic
subsidence
India
Tibet

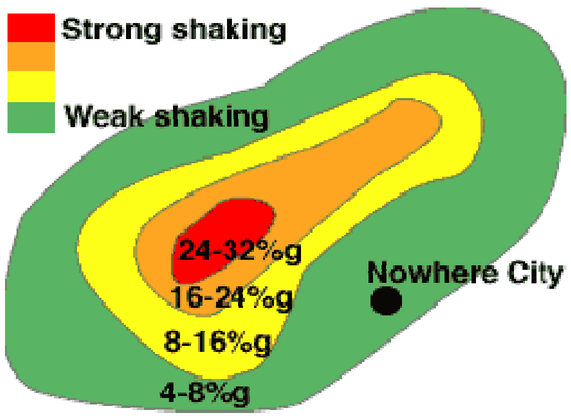


Coseismic slp deficit between Kathmandu and MFT
Uplift but no surface rupture
Decrease in heights of mountains. Southward shift of border
Tibet

To the Designed World

Earthquake Hazard (?)

$\mathcal{H} = p\{GM_{(X,Y,Z,..t)} \leq {}^{*}GM_{MAX}\}$



Earthquake Risk, $\mathcal{R} = \mathcal{H} * \mathcal{V}$

Natural Hazards $\mathcal{H}$ are Beyond Human Control

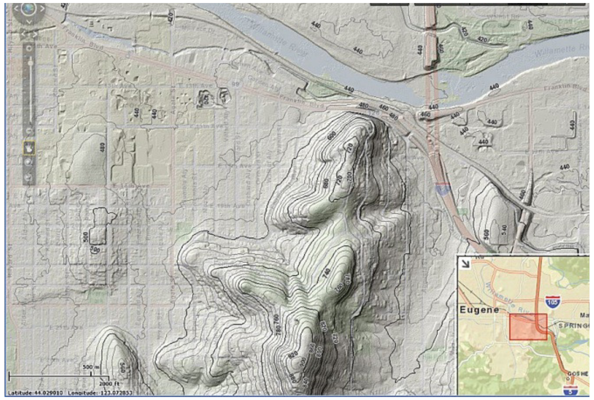
But, Risk Can Be Minimized By Reducing the Vulnerability $\mathcal{V}$

by Building Structures (Private, Public & Utilities)

capable of withstanding the calculated $\mathcal{H}$

What is the State of Knowledge today
Towards Making A Hazard Resilient Society

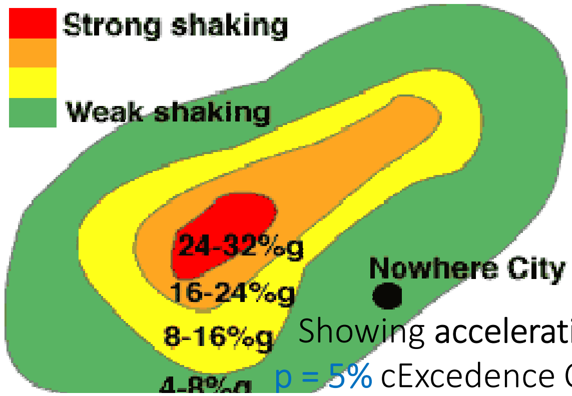
1,Ability to Construct Land Use Maps
that Maximize Resource Generation Potential
And Minimizee Risks Against
Quantitatively Evaluated Hazard Intensities



2. Ability to Design, construct a well as Retrofit
Buildings and Infra-strucutre to Withstand
Quantitatively Evaluated Hazard Intensities

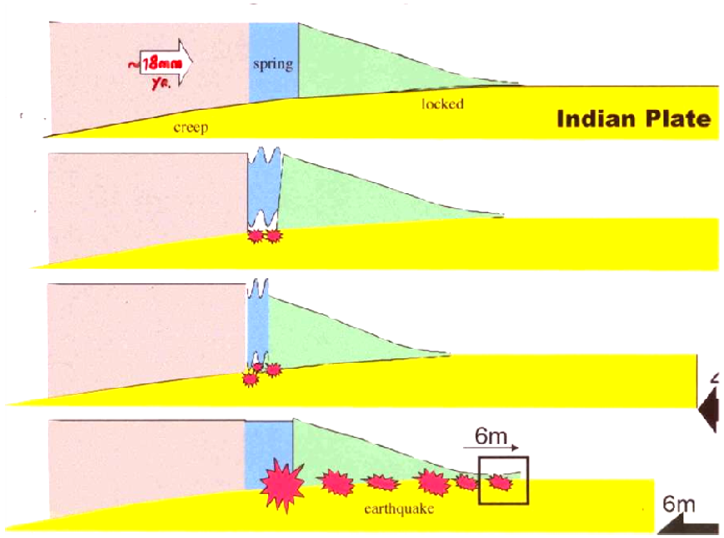
3. Ability to Construct Suites
of Q Hazard Intensity Maps
For Guiding the First two

$$H_{x,y,z,t} = P_{excedence}(I_{x,y,z,t})$$



Showing accelerations at I(x,y,z,t) that have a
p = 5% cExcedence Chance over the next 50 yrs

Critical Knowledge Products Pertaining to Himalayan terranes to construct Probabilistic Hazard Maps



*Long term shortening rate is entirely used up to drive slip(s) on MHT

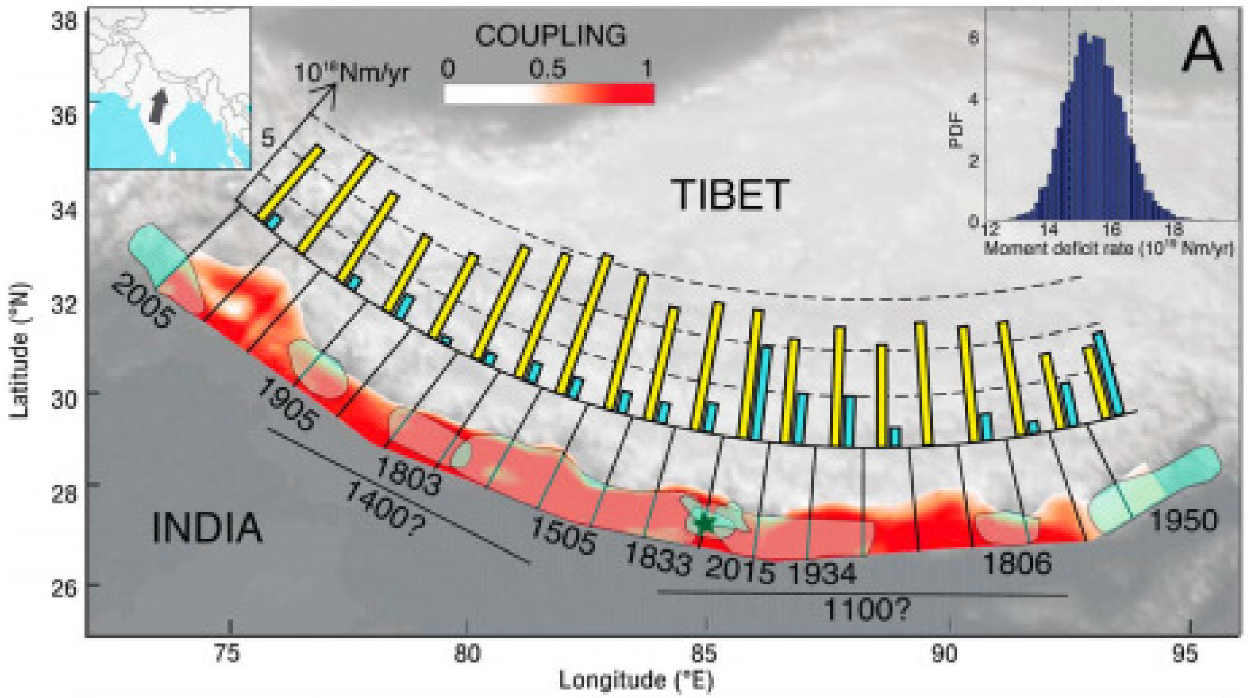
*Almost all (90%) of the Geodetic strain is elastically recovered in Earthquake Slips

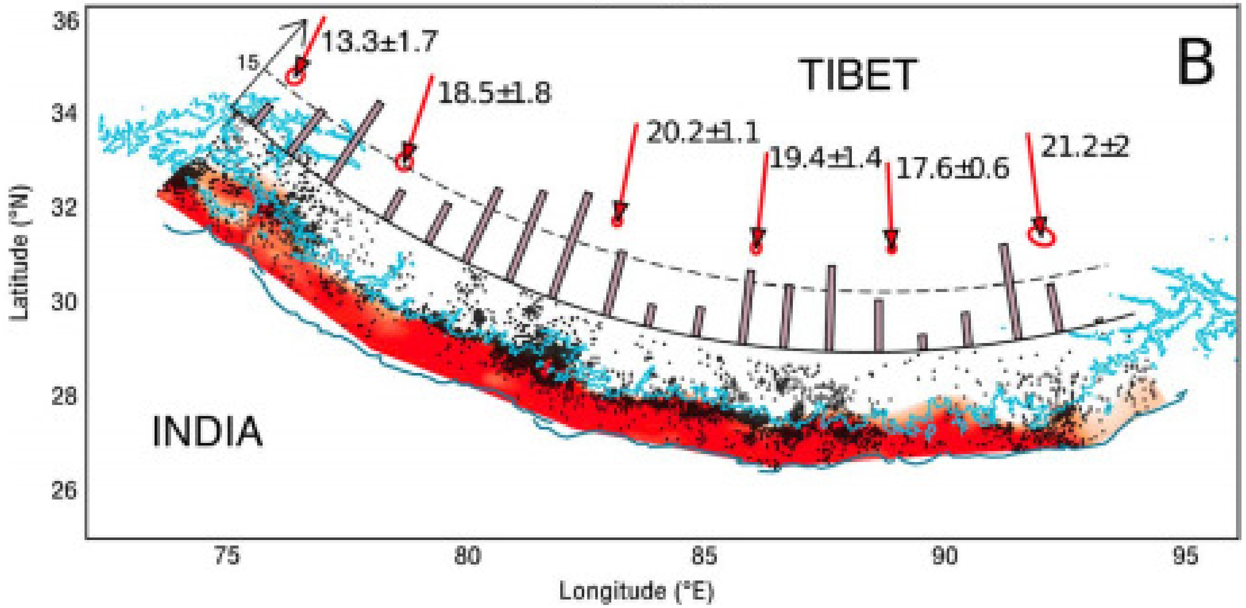
1. What is the available Strain Budget at the Present Epoch

2. Where, How wide and, How well locked are the Locked Zones ??

3. In How many different ways may these locked zones rupture

*What is the available Strain Budget





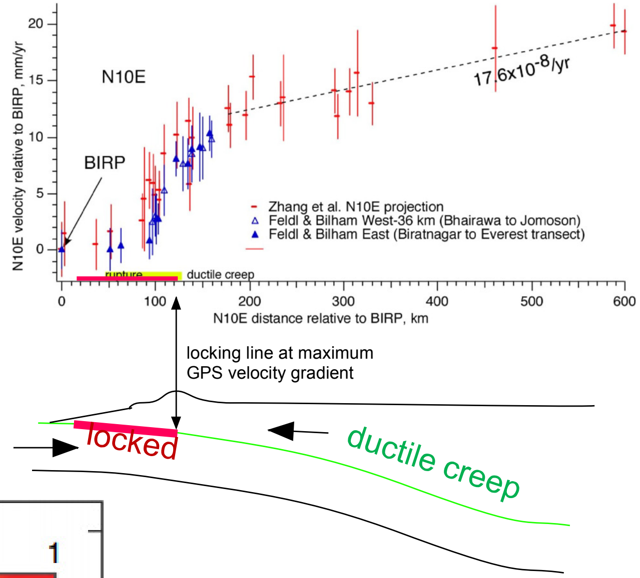
A. Shows patterns of coupling on the MHT, and earthquake Ruptures which were used to compute the total moment released by them (light blue bars) compared with that accumulated along the strike(yellow bars)

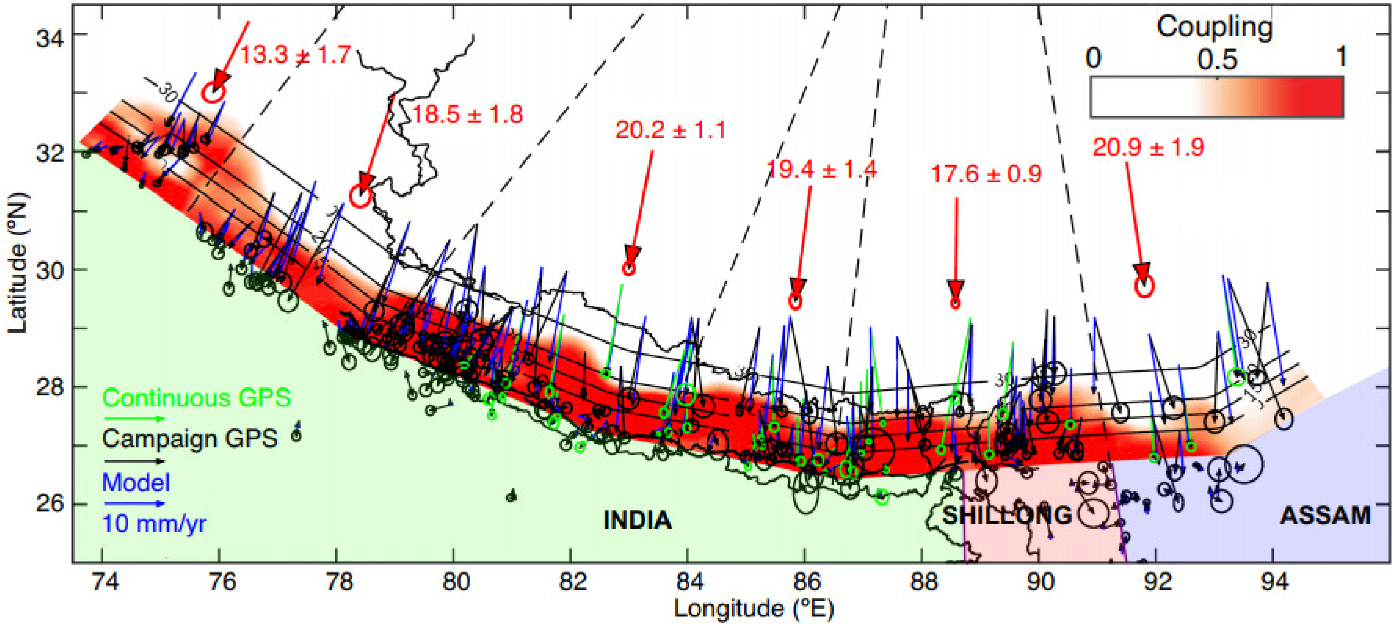
Note that Slip Deficit is only compensated in eastern Nepal @ 86*N, where Trenches revealed over 6 (>12m slip) during the past 3600 yrs.

B. Shows the MFT in dark blue & the 3.5 km contour in light blue. Red arrows mark the geologically constrained long term slip rates. Grey bars show the distribution & number of earthquakes > 4. 9

Stevens & Avouac GRL1960

*Where, How wide and How well locked are the Locked Zones ??





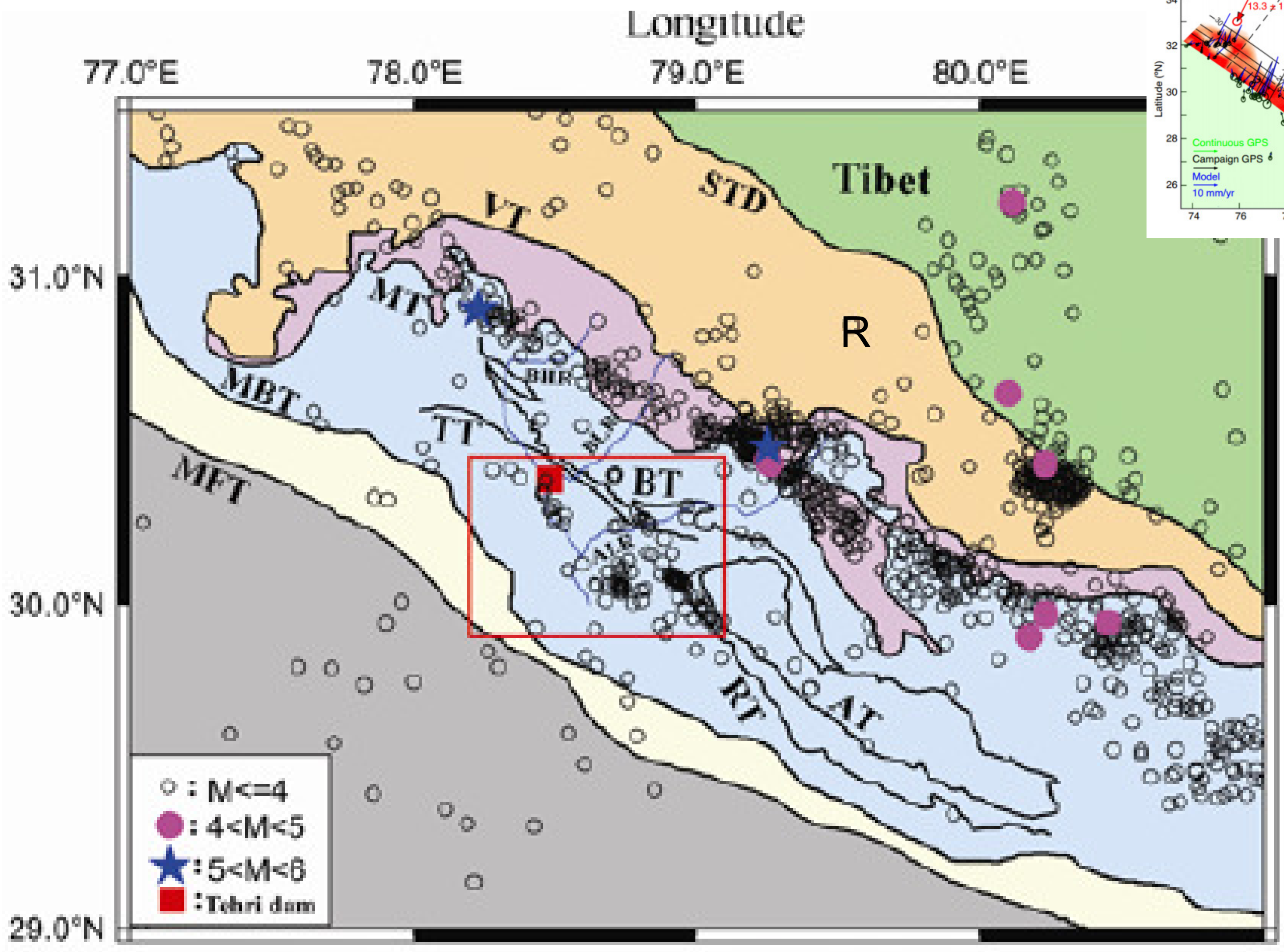
Interseismic coupling (slip deficit/long term slip) is in shades of red. Green and black arrows show continuous and campaign GPS velocities wrt Bangalore, whereas blue arrows are modelled velocities that fit the coupling coefficient

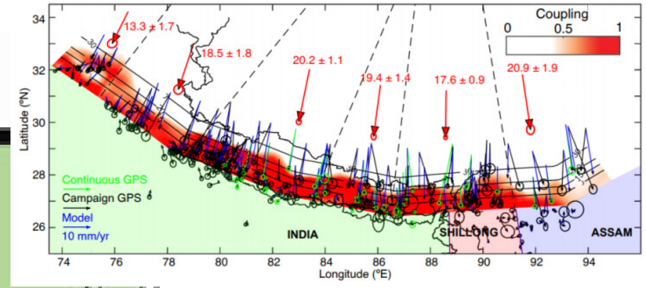
Bilham et al. Stevens & Avouac, GRL

The Uttaranchal Locking Line

Northern edge of the locked zone

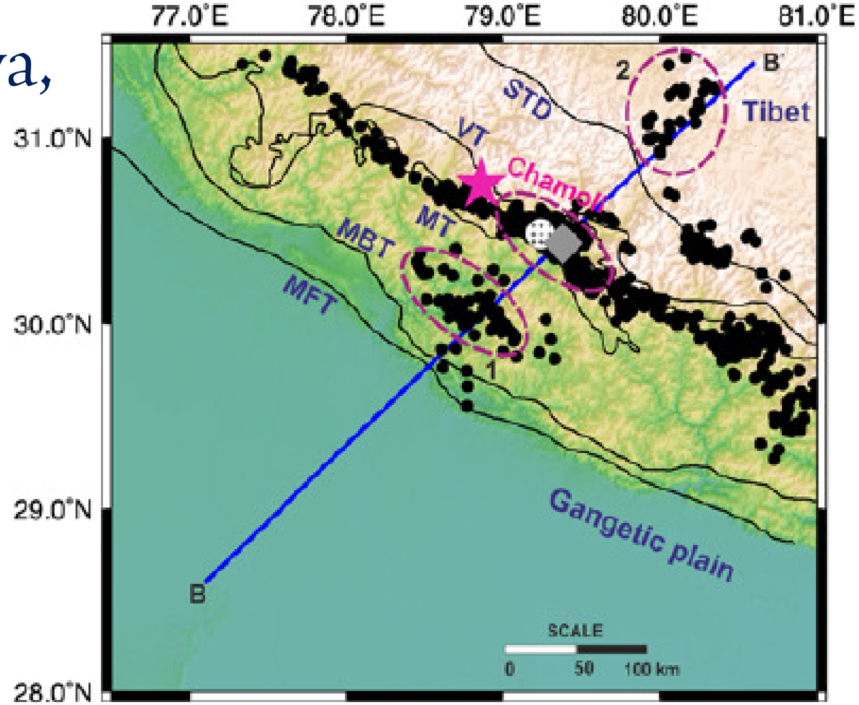
Coincides with High resolution Earthquake Epicentres

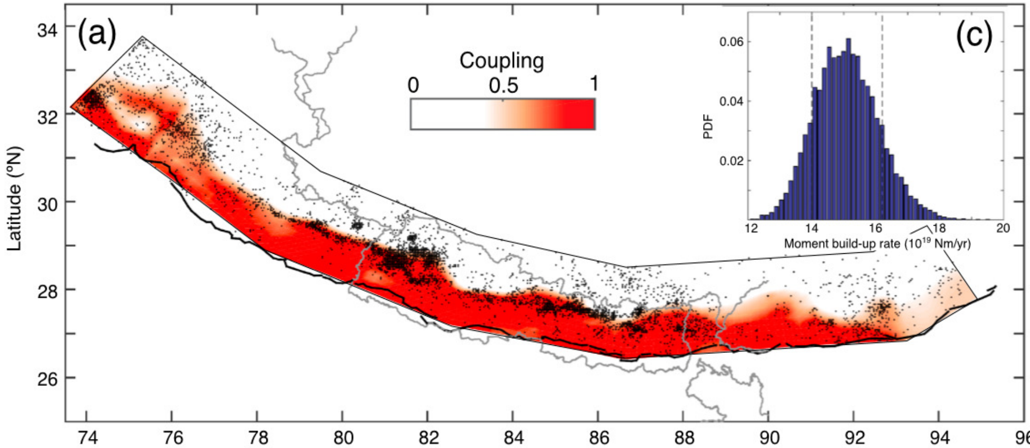


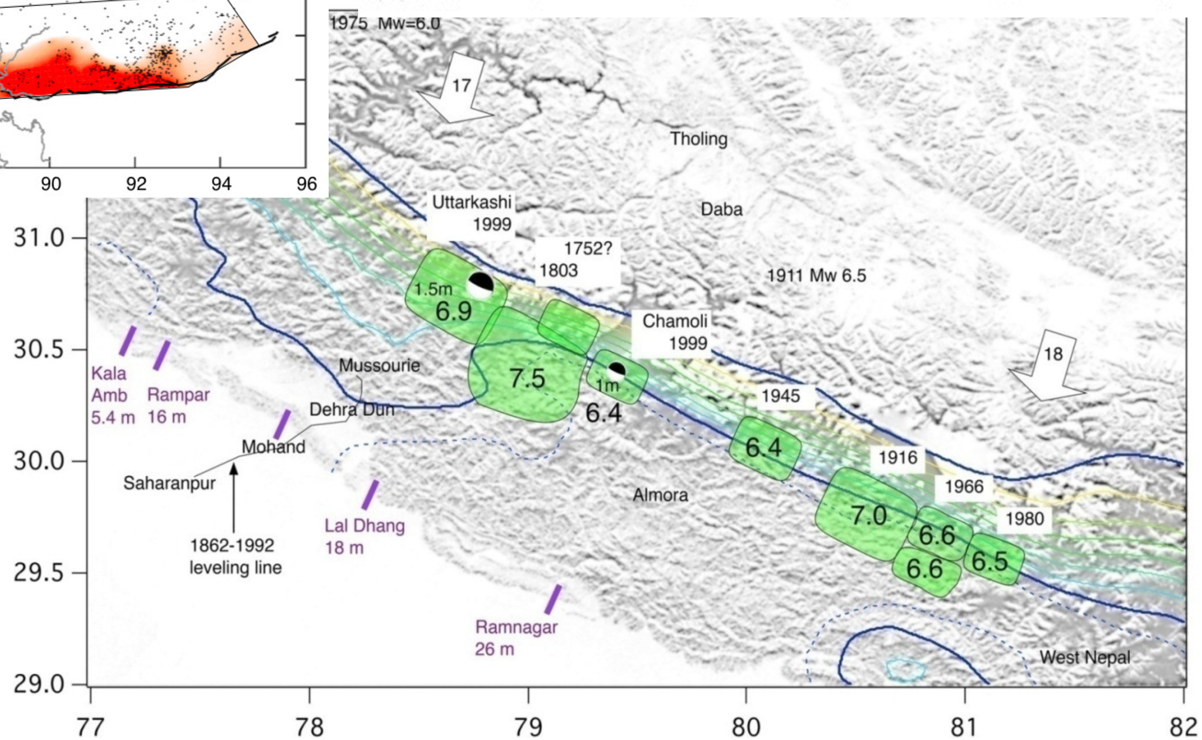


Shyam Rai et al., BSSA, 2008

Locked Zones Along the Himalaya, Locking Line in Uttaranchal, and Estimated Ruptures of Past earthquakes in Central Himalaya







Stevens et al, 2015;
Shyam Rai et al., 2013;
Bilham et al., 2017

IN HOW MANY DIFFERENT WAYS A FUTURE EARTHQUAKE RUPTURE MAY OCCUR AND WITH WHAT PROBABILITIES??

Important Research problem: Analysis of Potential leads

Potential Leads

(Incisive Analysis: Bayesian Inversion, Fractal Distribution, Hypothesis Tests)

*Rigorously Constrained Geological Faults
(both longitudinal & transverse)

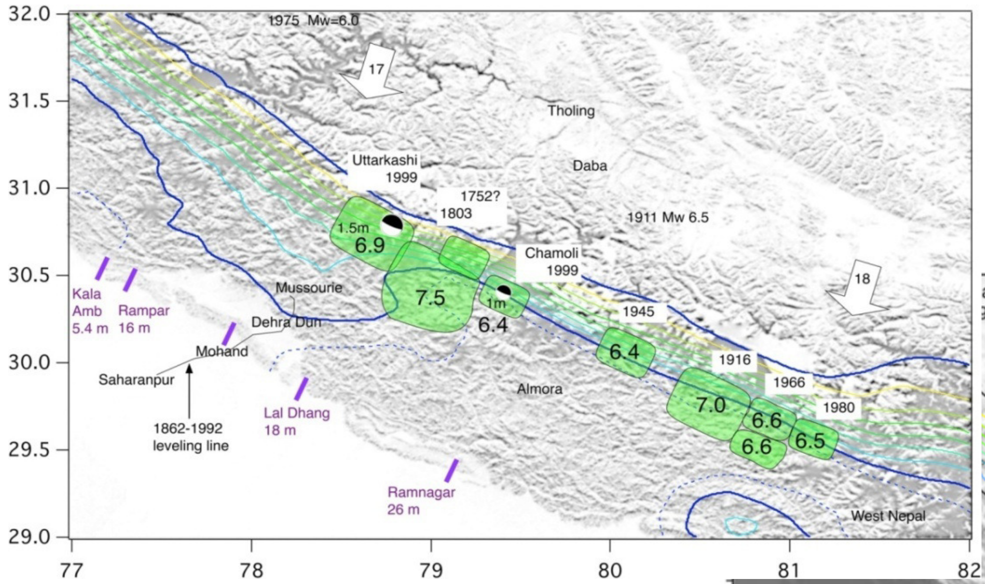
*Rigorously Constrained Past & current Rupture zones

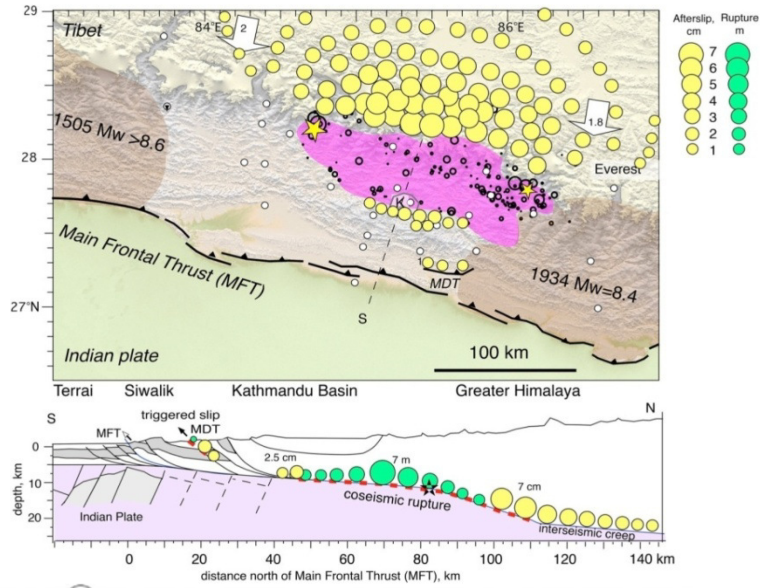
*Rigorously Constrained Earthquake Mechanisms & Coord.
(Both Small & Moderate Events)

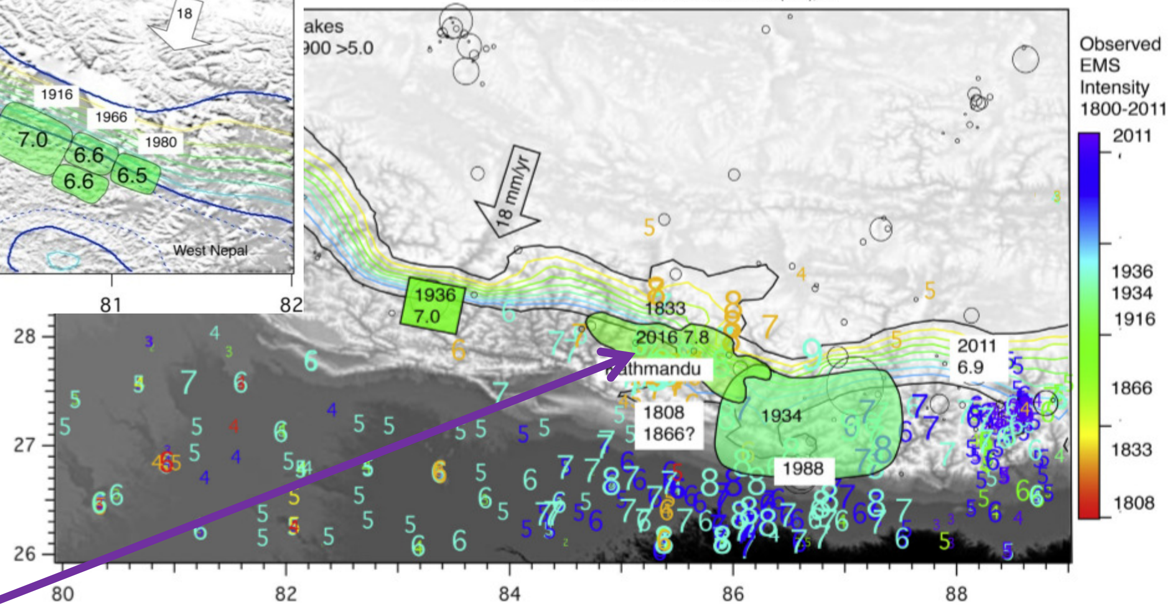
*Rigorously constrained Surface Deformation
(GPS, InSAR & Neotectonics)

*Rigorously Constrained Past Earthquake Slips

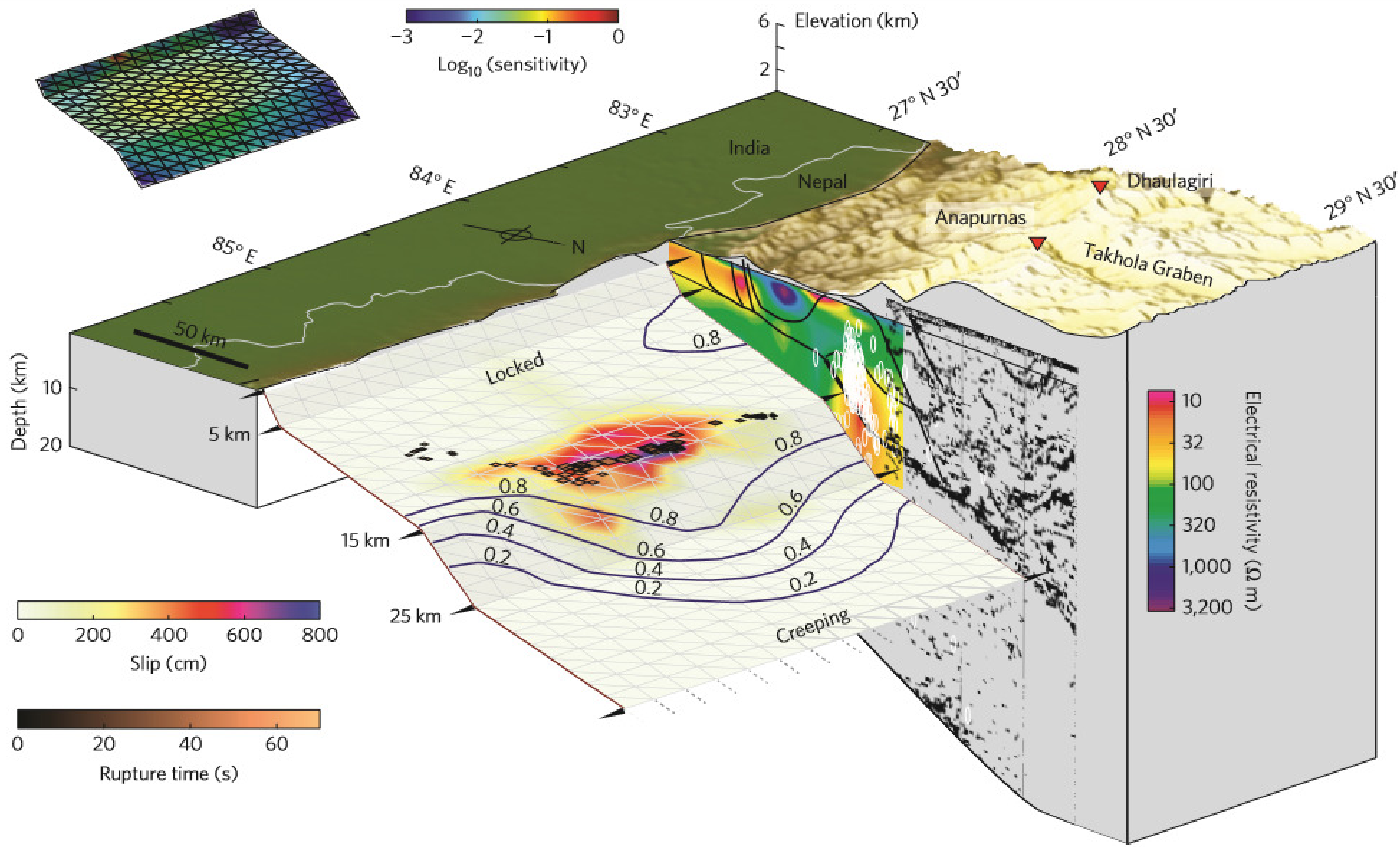
Best Estimated past ruptures in Uttaranchal and Nepal proceeded southward and updip from the locking line







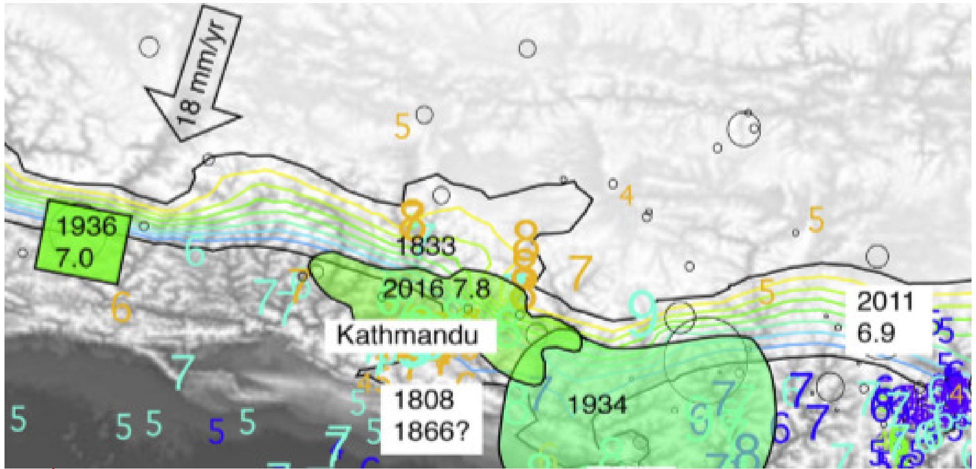
Implications of Incomplete Ruptures ??



The 3D Decollement shows high frequency earthquake sources running along the ramp-flat hinge line rupturing the MHT at ~ 15 km depth. The right wall shows the seismic reflection profile delineating faults & conducting (fluidized) zones   Elliot et al., 2017

I. Important Lessons From the Rupture Style of the April 2015 Gorkha Earthquake

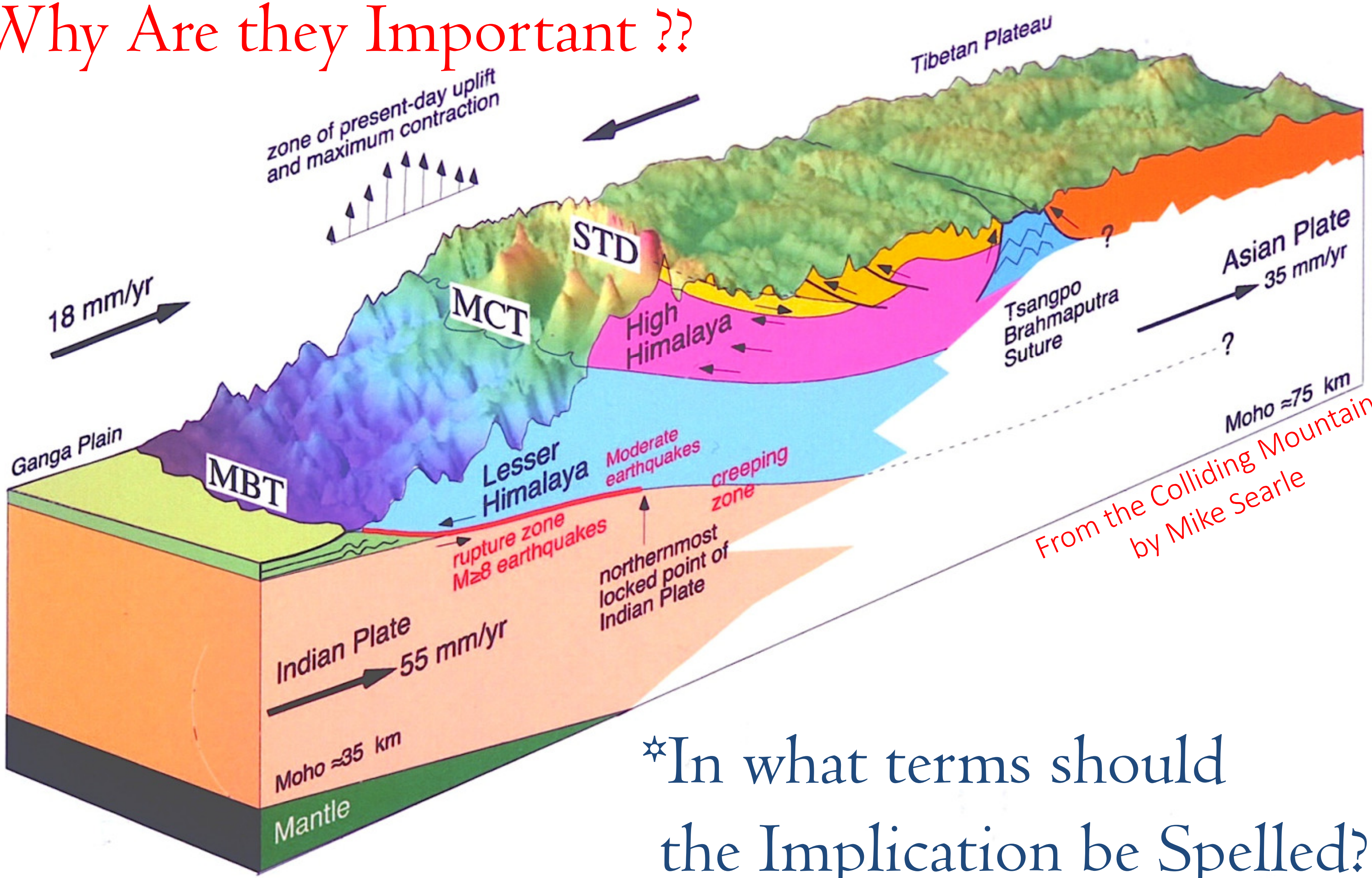
*Nuleated at the locking line. Also, marked by earthquake concentration
*Occurred in the seismic gap west of the1934 event,
*Ruptured Incompletely, piling slip at the unruptured LZ.
*Total Slips in Main & Aftershocks + Post slip creep only a fraction of that accumulated



Surface reaching rupture of MHT in Great Earthquakes, may generally occur in 2 stages after a few successive Incomplete ruptures jack up enough strain to Drive it.

Increased Strain At This Southern Boundary May Not, However, show Precursory seismic Activity Due To Colder Rheology

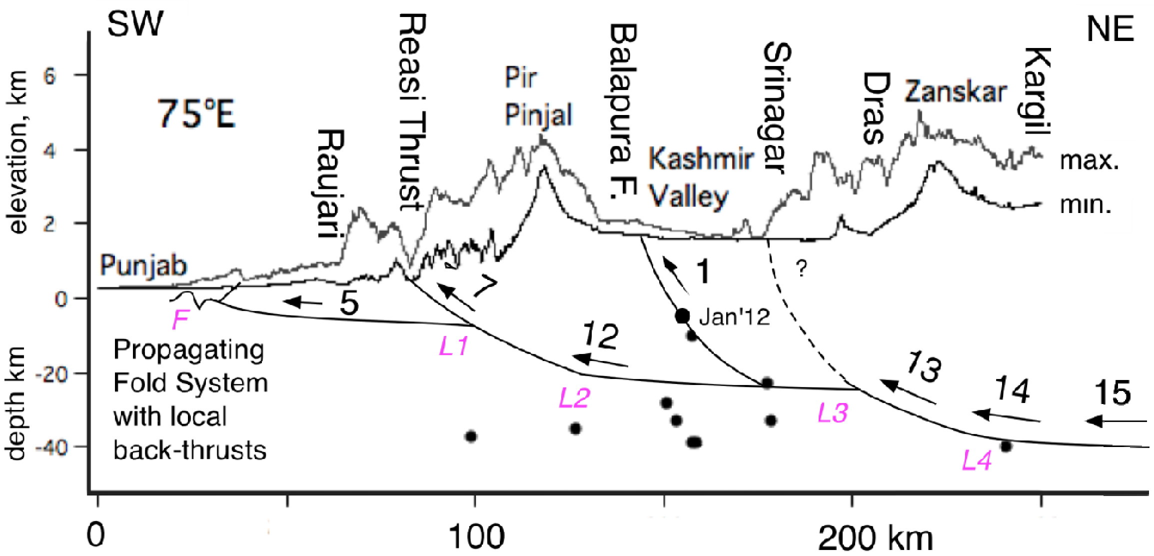
*What are Implications of Incomplete Ruptures and Why Are they Important ??



*In what terms should the Implication be Spelled??

Example For the Kashmir Gap

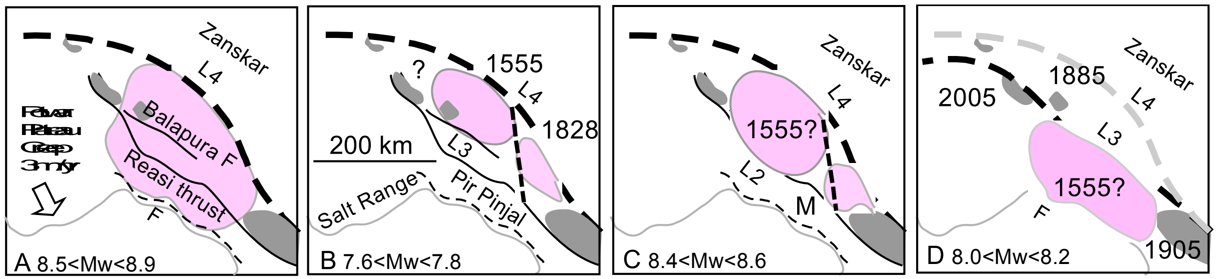
Bilham et al., GRL, 2013



Schematic section NE through Raujari/Srinagar/Kargil showing possible slip rates and inferred structure. Filled circles denote earthquake locations since 1960 (±20 km)

L1-L4 represent inflections of a master fault beneath Kashmir that may represent potential nucleation points for Future Events

Dashed line is a hypothetical thrust buried beneath sediments NE of the Kashmir Valley



Scenarios envisioned for historical and/or future earthquakes in the Kashmir gap. The dashed line represents a possible segment boundary recognized by Oldham (1888)

Hazard Quantification Requires Estimation of the Maximum Ground Acceleration at a Site over *t* yrs

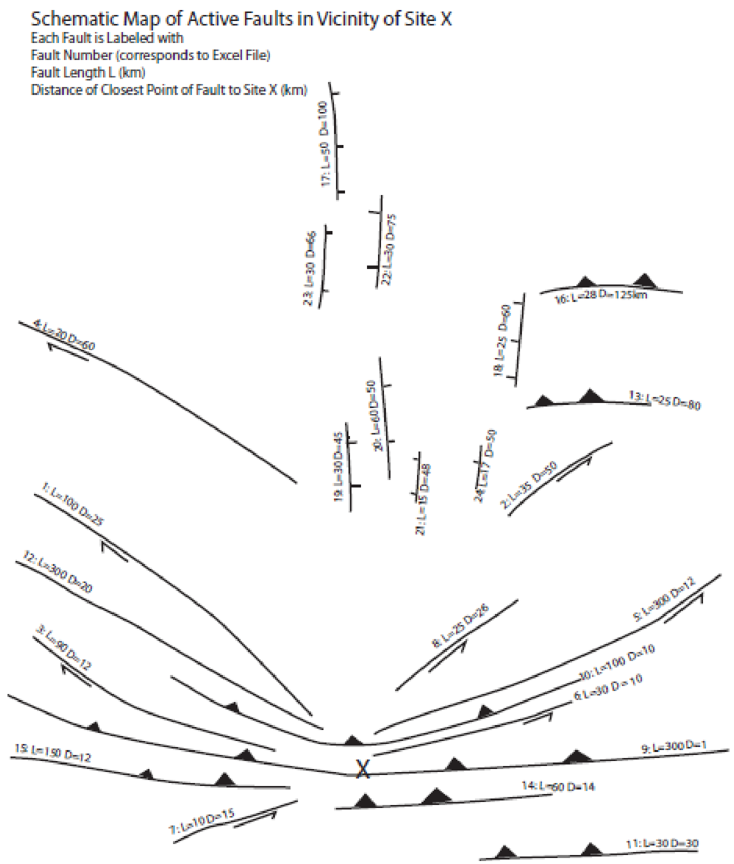
3 Steps

• **Identify** all **faults** within a few hundred km., capable of producing significant ground acceleration at the site. **Estimate** their dimensions (L)

• Compute ground acceleration at the site due to each fault

• Fuse all values to obtain a Bayesian probabilistic estimate

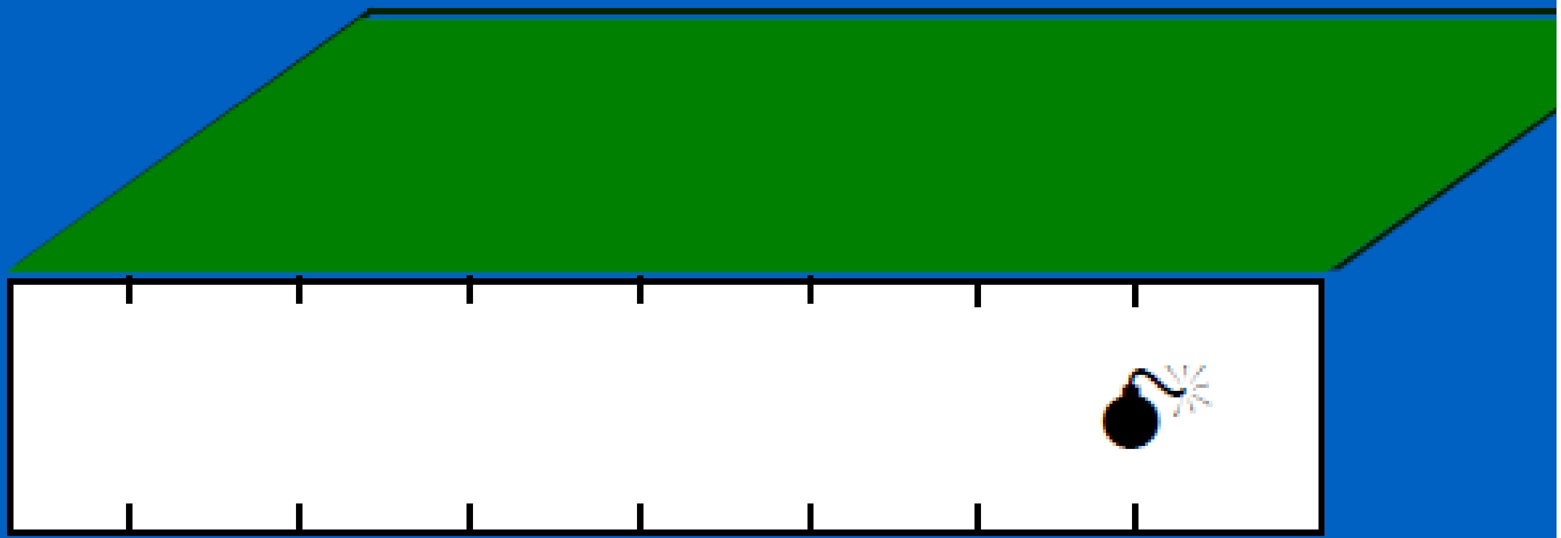
$$p\{GM_{(X,Y,Z,..t)} \leq GM_{MAX}\}$$



Slip on an earthquake fault

START

Surface of the earth



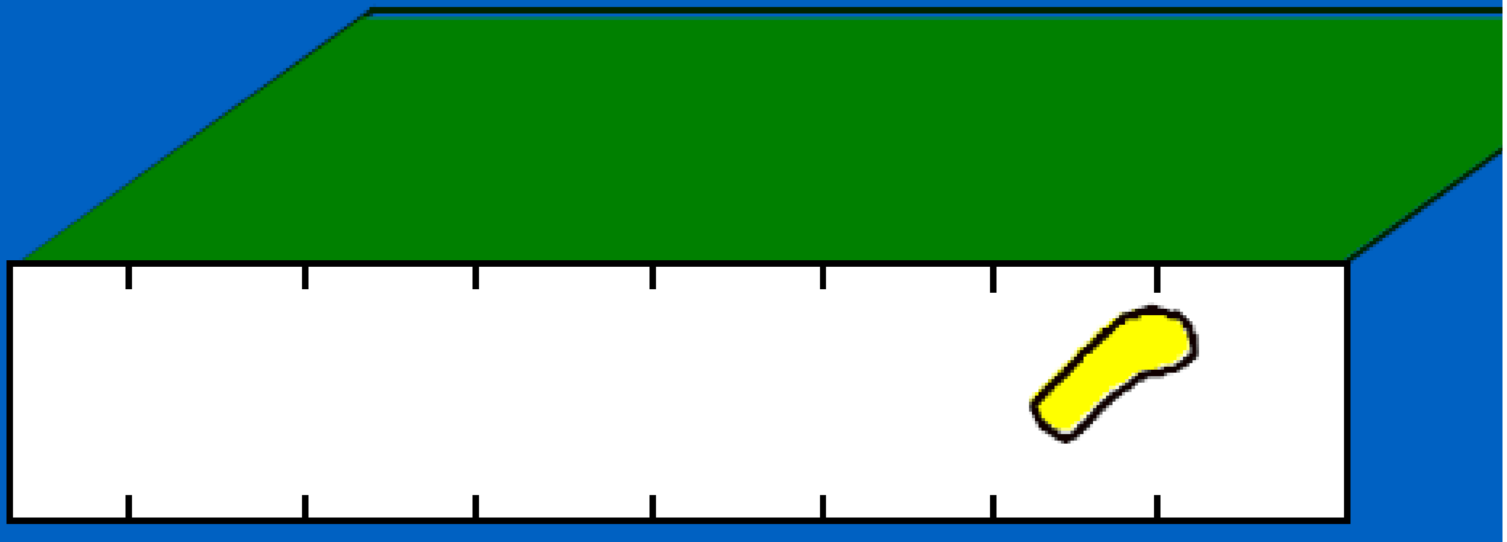
Depth
Into the
earth

100 km (60 miles)

Distance along the fault plane

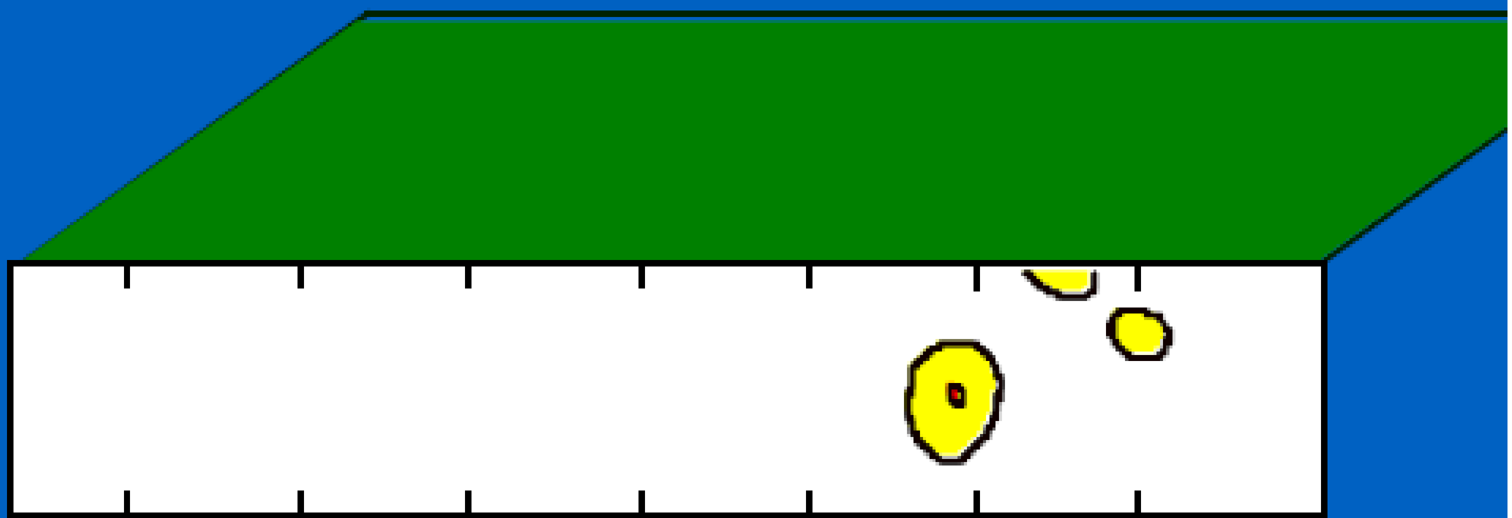
Slip on an earthquake fault

Second 2.0



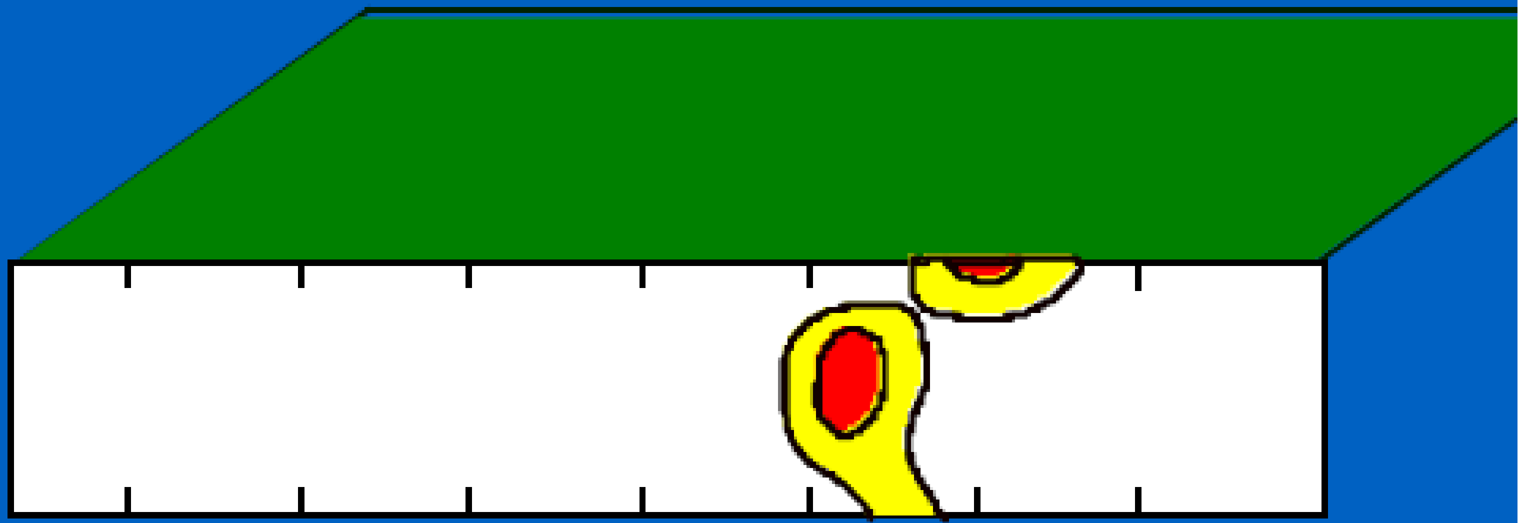
Slip on an earthquake fault

Second 4.0



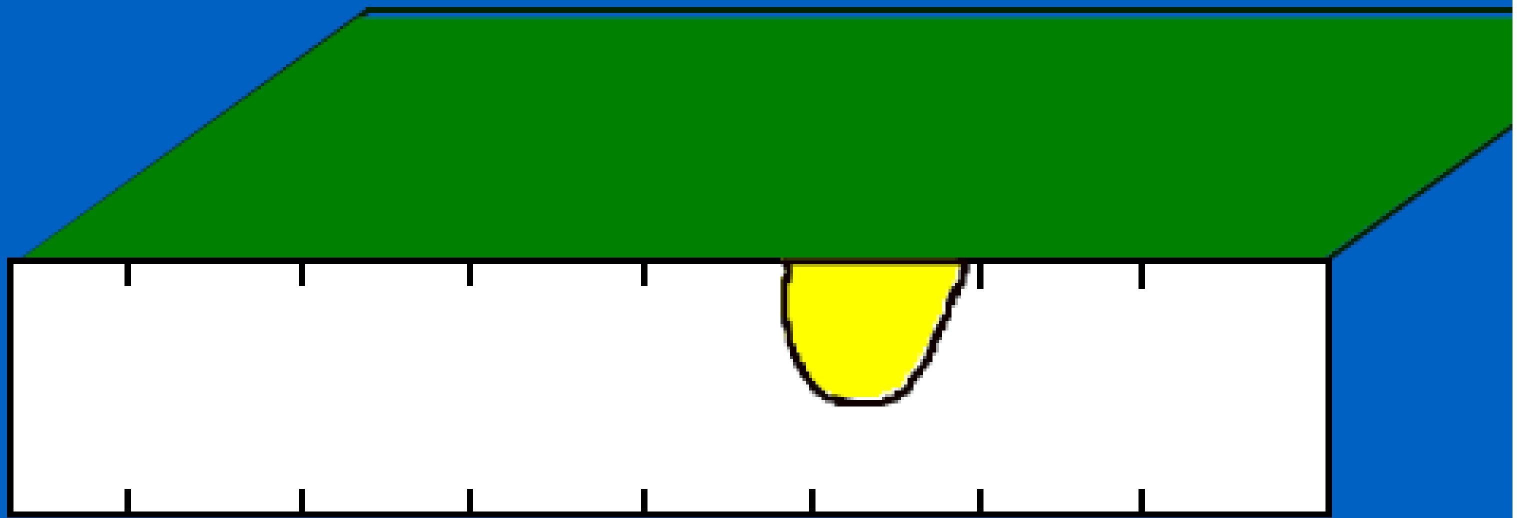
Slip on an earthquake fault

Second 6.0



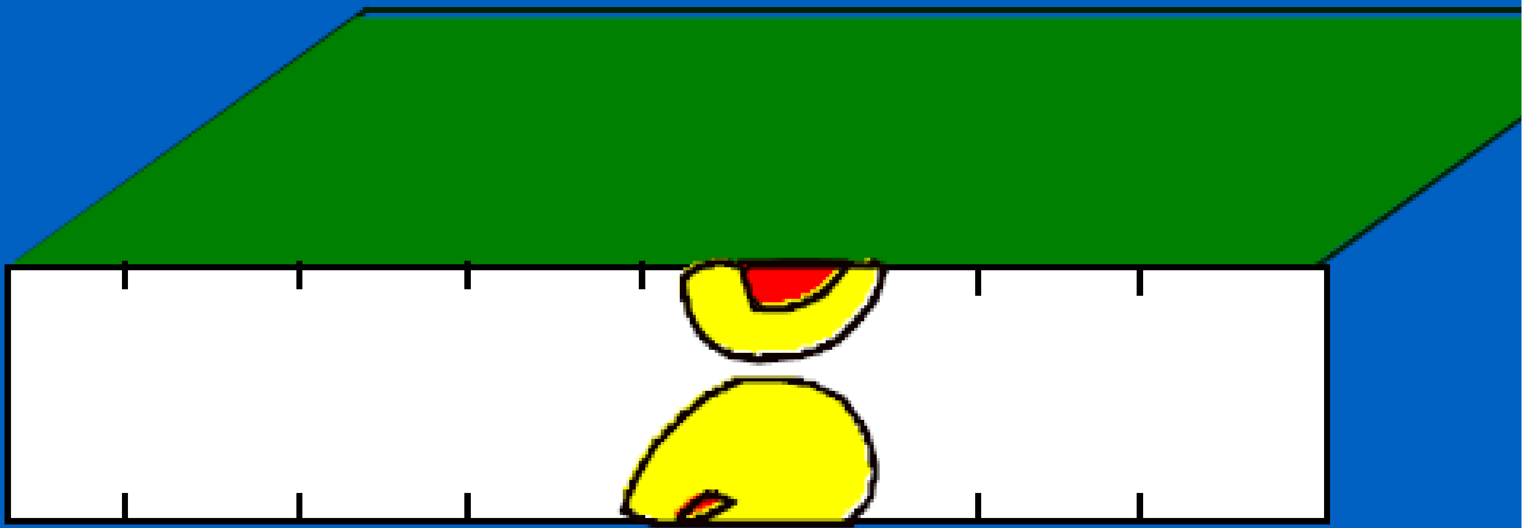
Slip on an earthquake fault

Second 8.0



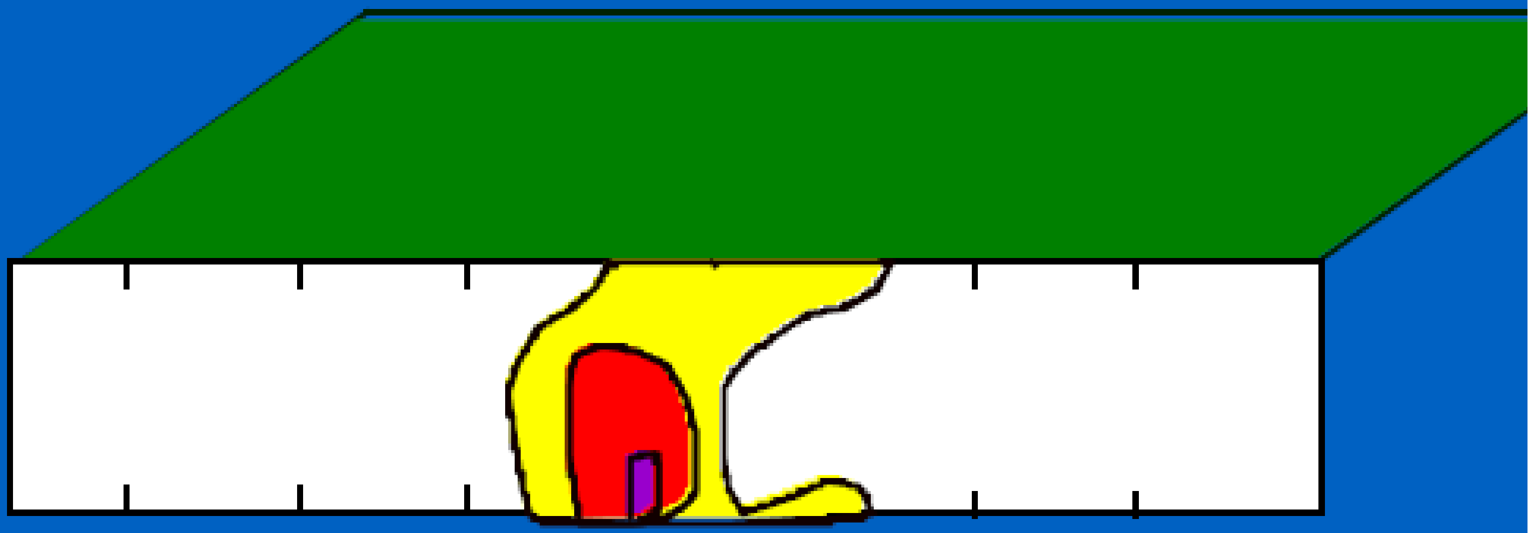
Slip on an earthquake fault

Second 10.0



Slip on an earthquake fault

Second 12.0

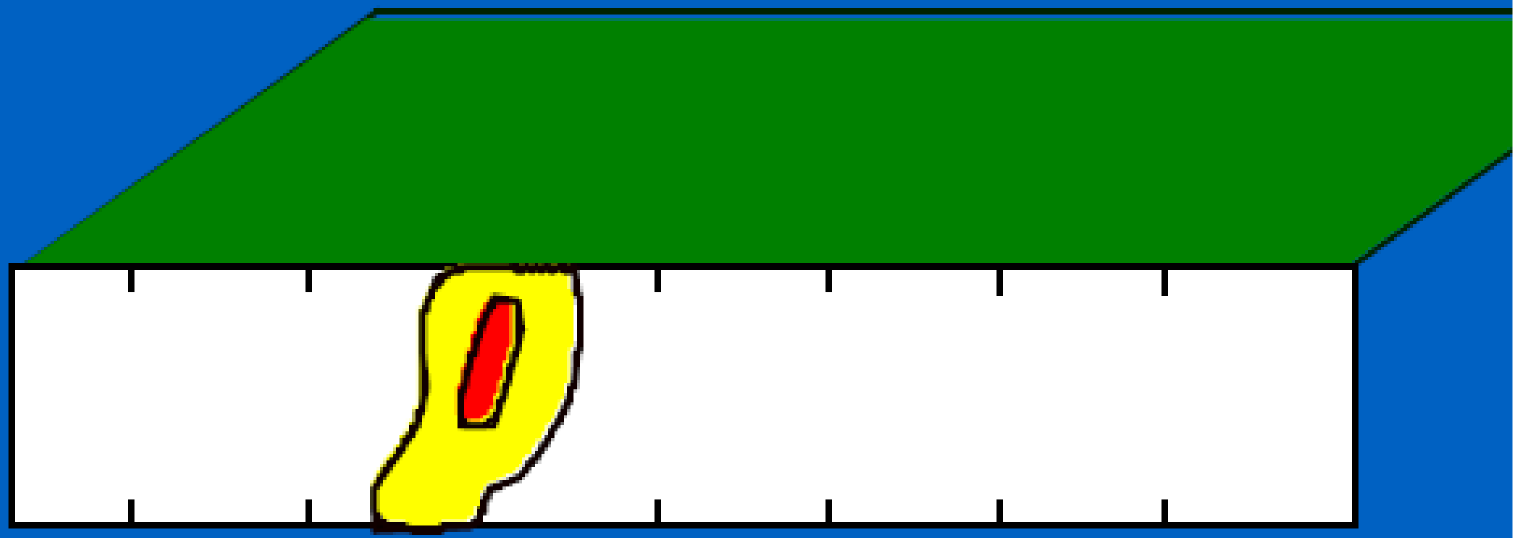


Slip on an earthquake fault

Second 14.0

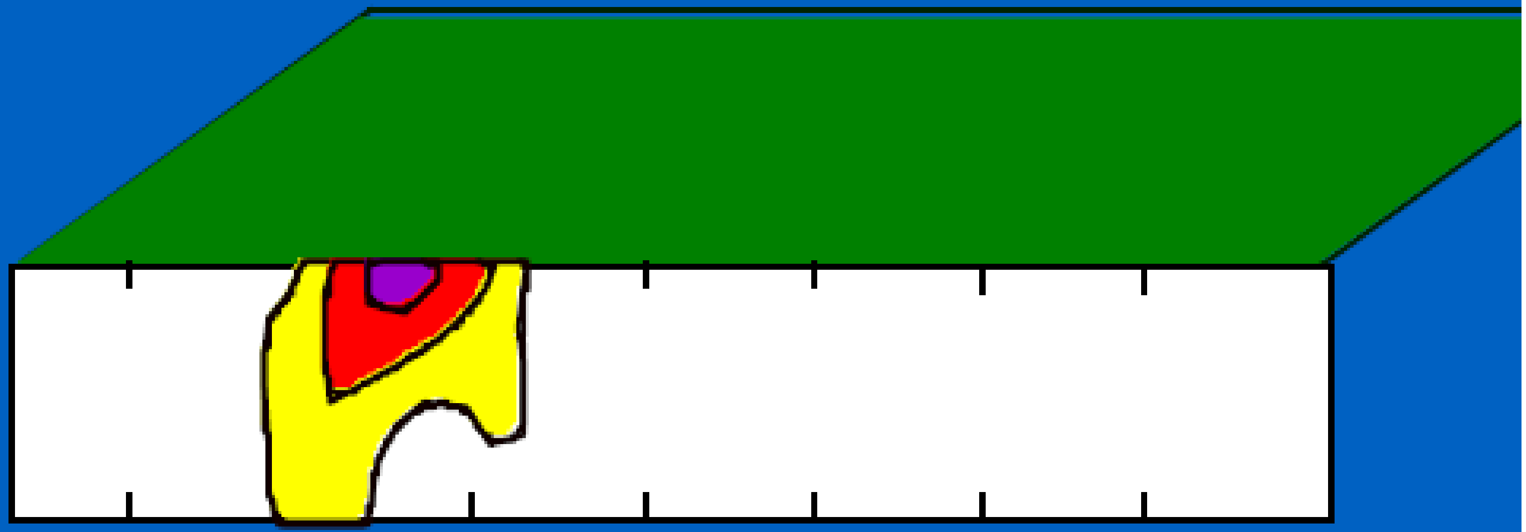
Slip on an earthquake fault

Second 16.0



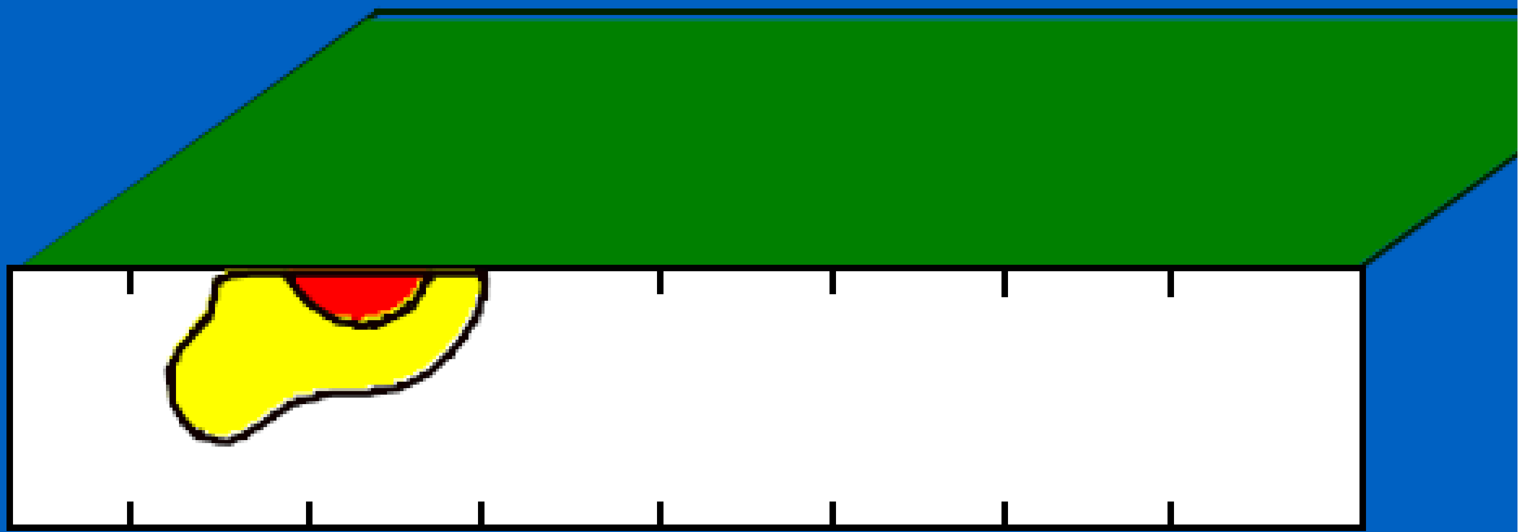
Slip on an earthquake fault

Second 18.0



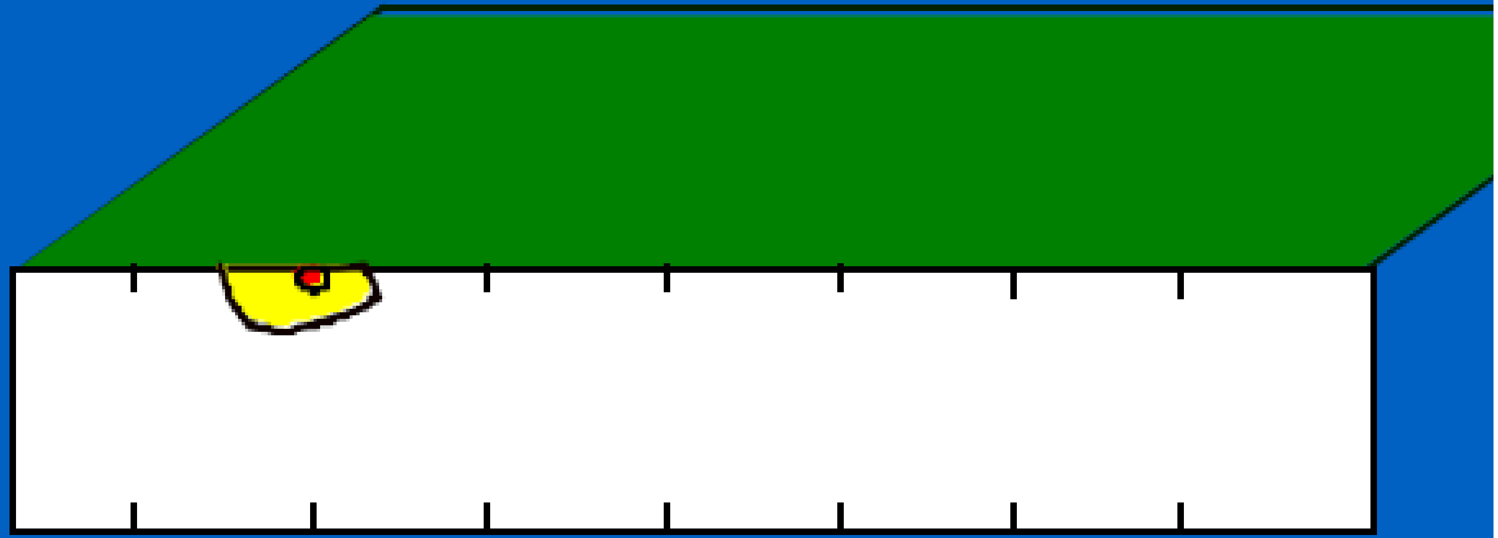
Slip on an earthquake fault

Second 20.0



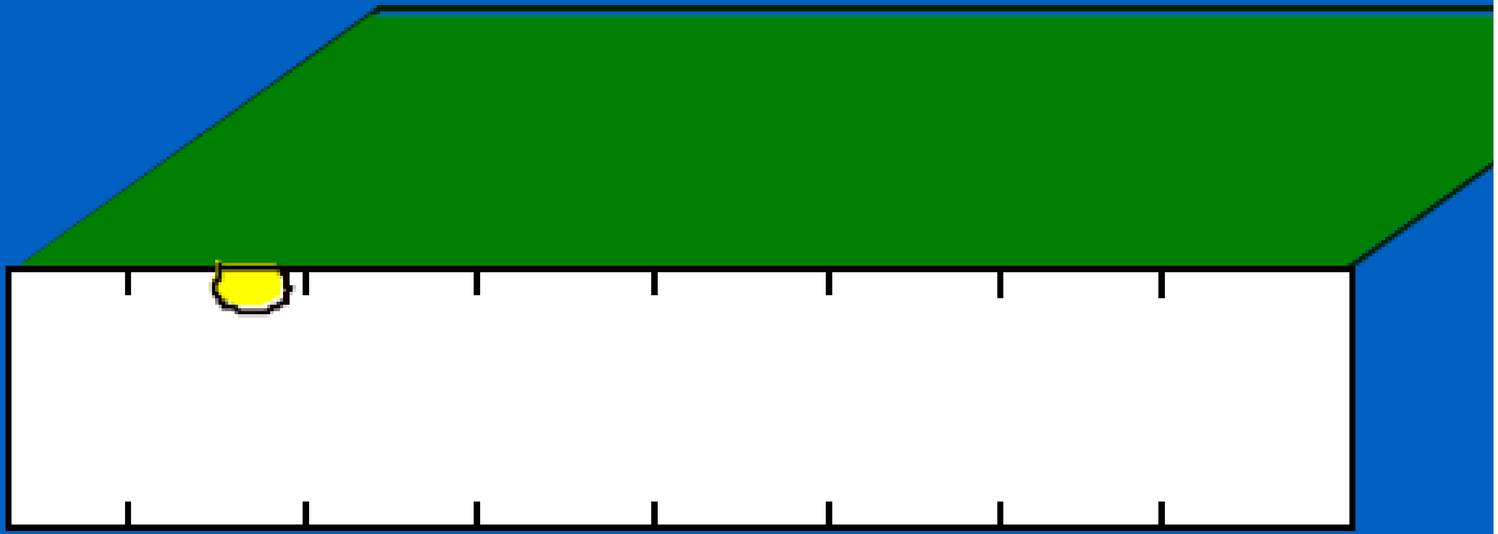
Slip on an earthquake fault

Second 22.0



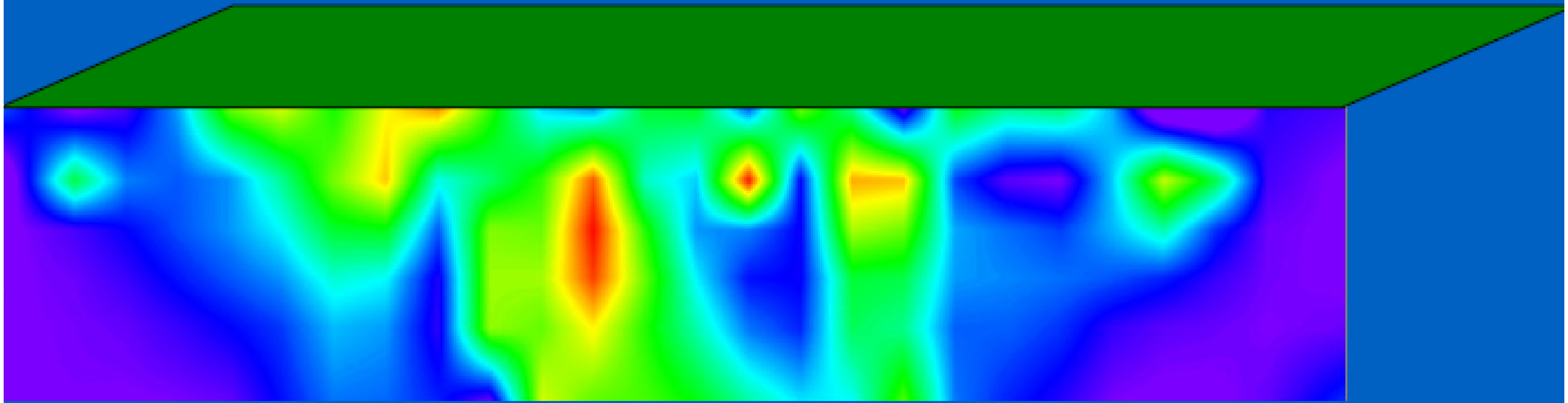
Slip on an earthquake fault

Second 24.0

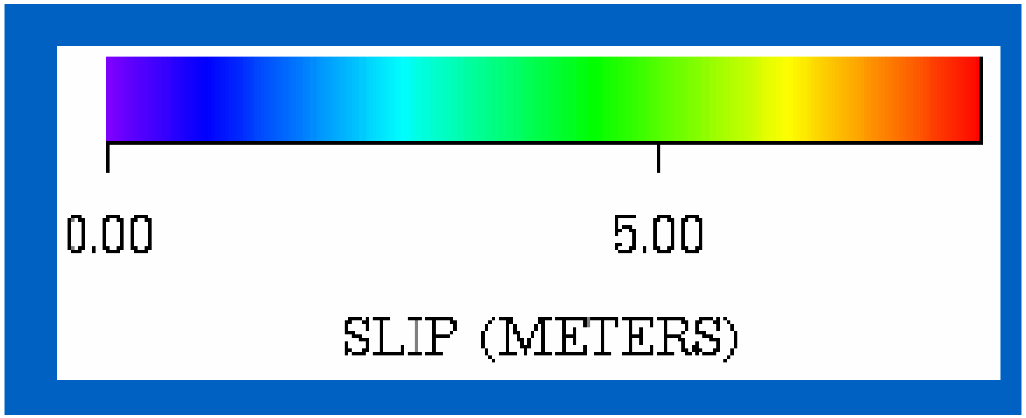


Rupture on a Fault

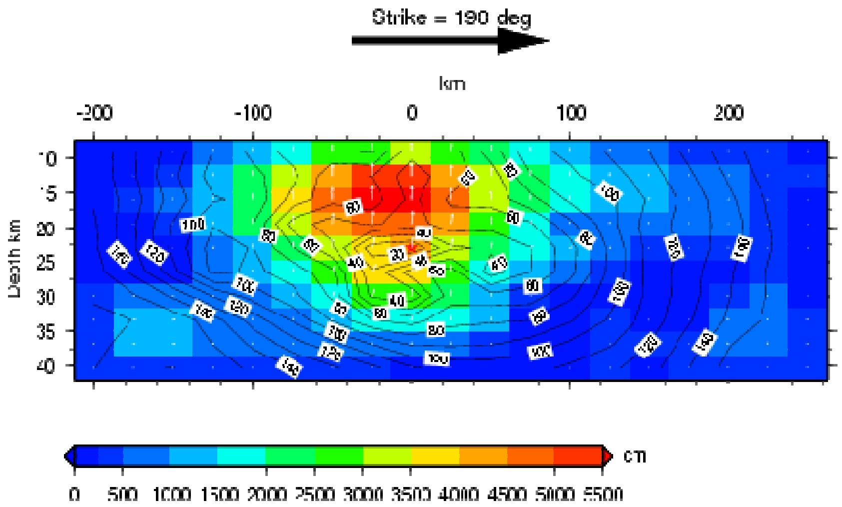
Total Slip in the M7.3 Landers Earthquake

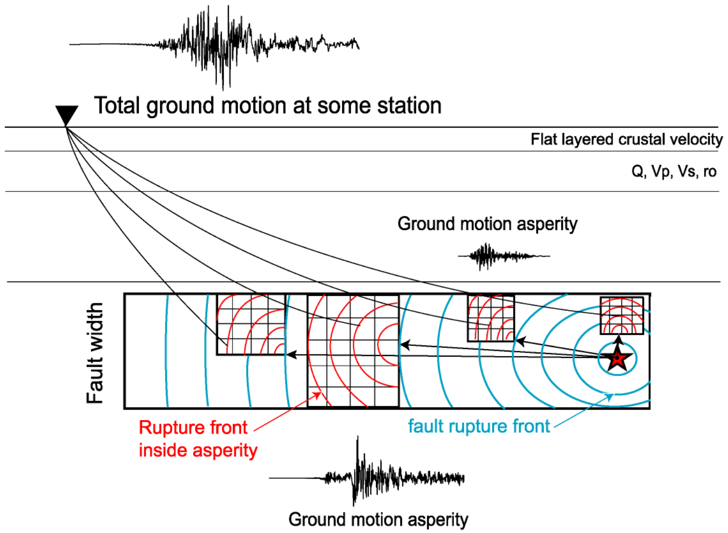


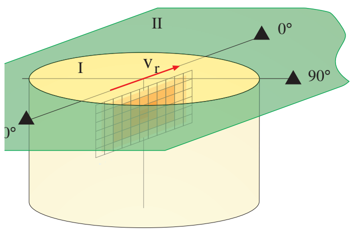
Oct. 1999,
Mw 7.1

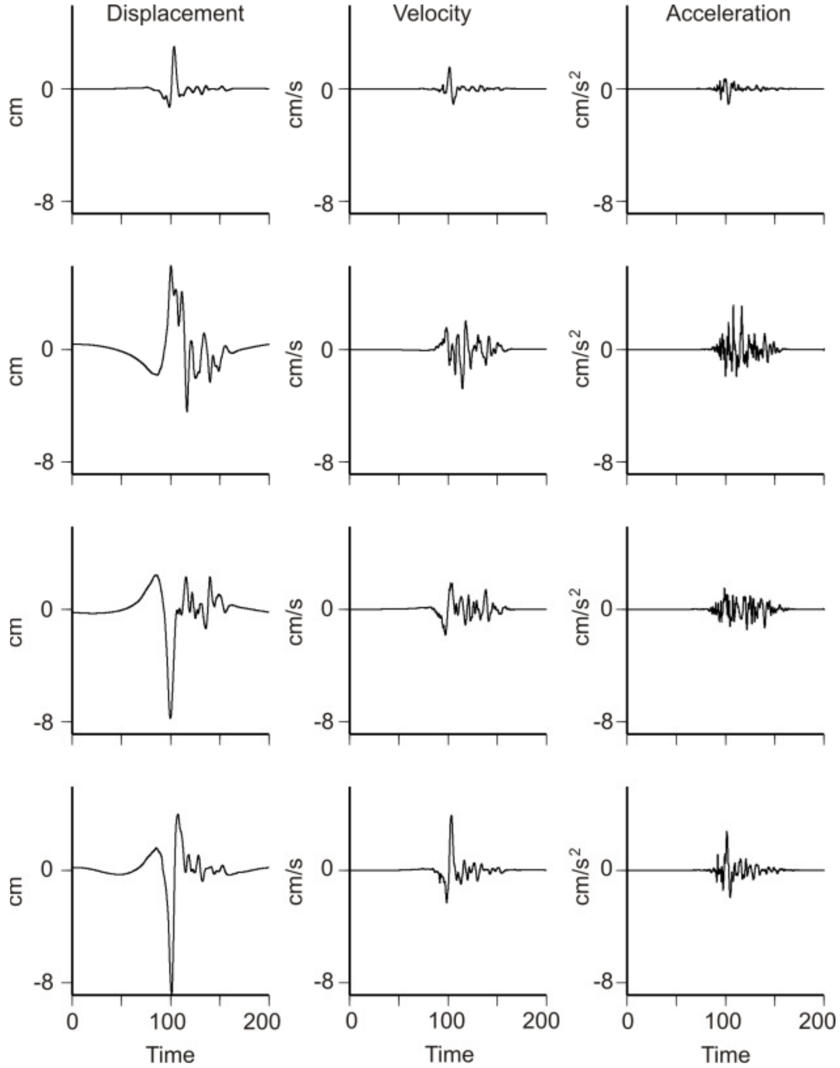


Computation of Ground Motion due to a given Fault Slip



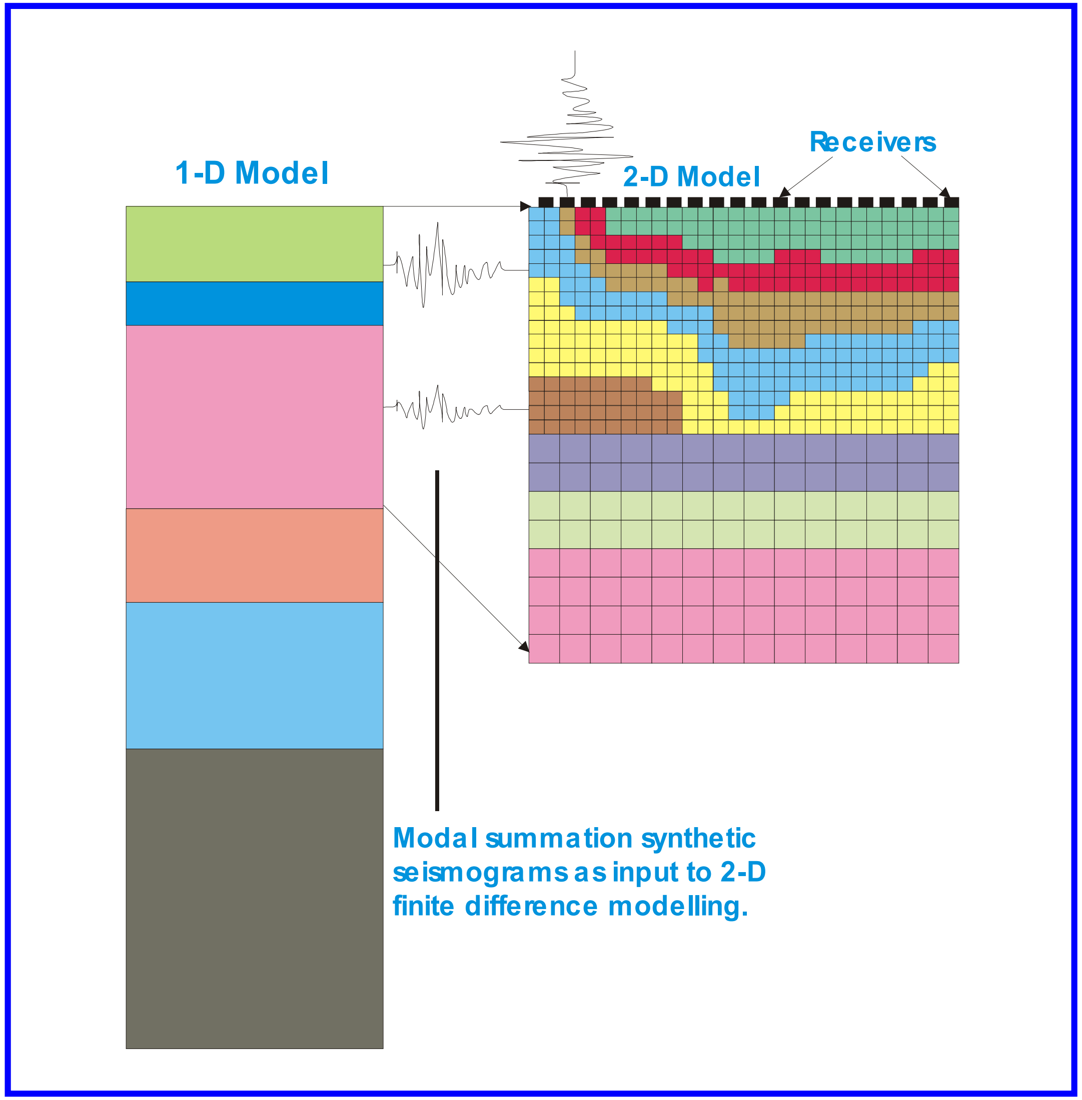


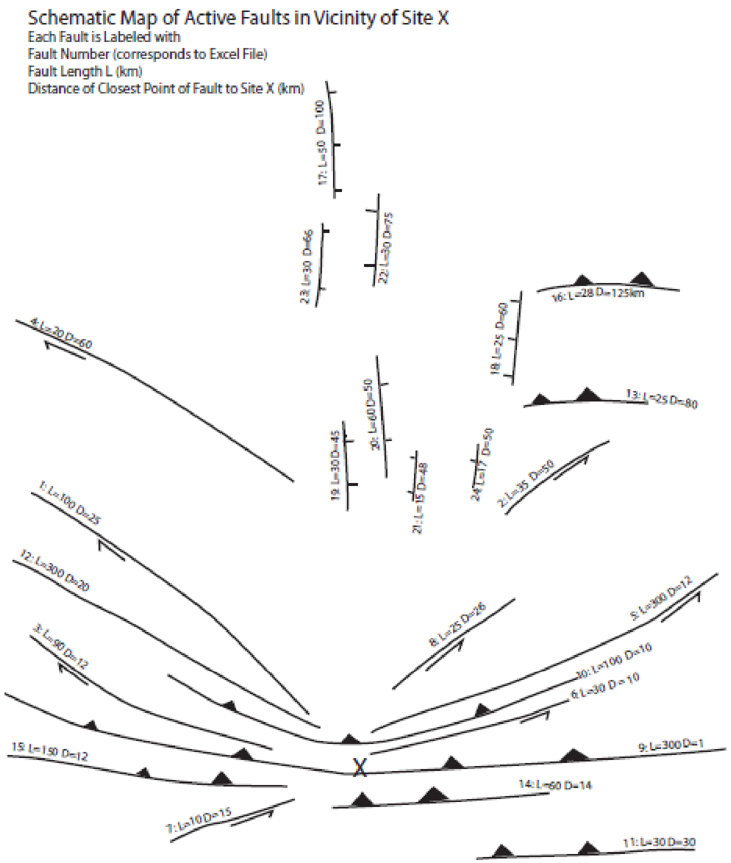




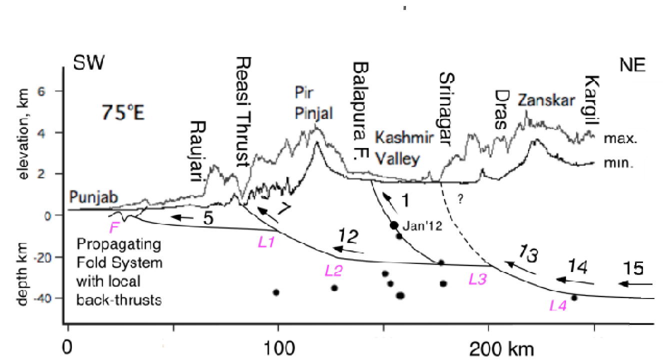
Ground Motion at a Bedrock site underneath due to an Earthquake Rupture is calculated by vectorial addition of the Finite Rupture response contributed by each cell as the rupture front runs along the fault.

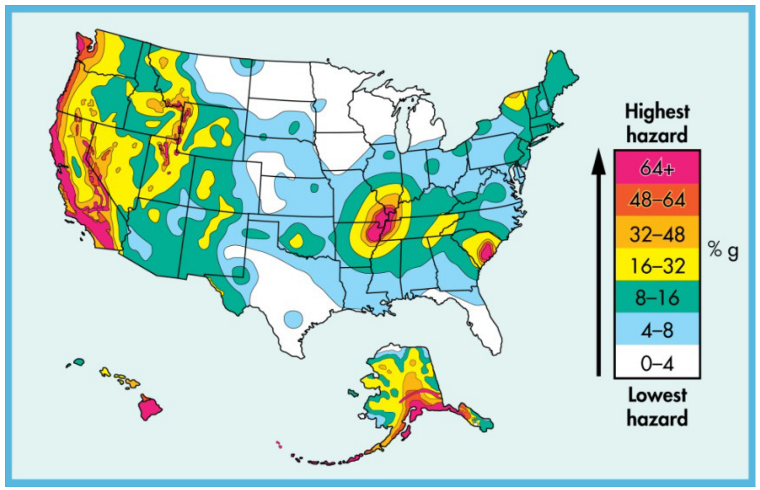
Finally, the Effect of Site Conditions such as Loose sediments which amplify Ground Motion, is Accounted for by Applying Known Physical Laws



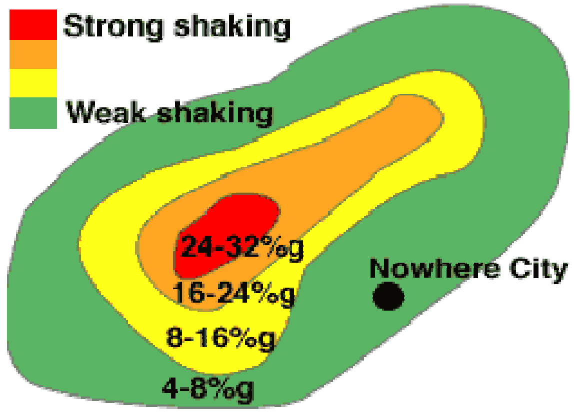


Ground Motion at various sites in the region, calculated for each fault and their anticipated faulting scenarios, are then fused in a Bayesian framework to obtain the final estimate and its variaance





A Quantitative Hazard Map
for the region to form the
Basic Canvass for Designing
its Hazard Mitigation Plans,
could be outsourced
by the Government from a
Credible Agency within or
outside the country
To be delivered within a year



After Hazard Maps, What?

1. Set the State Planning Board to construct Land Use Maps to Delineate Planning Options for Roads/ Housing colonies and Commons. Initiate necessary Legislative & Management Actions to Realize the Plans

2. Obtain Earthquake safe Designs from Professional/Scientific Agencies for New as well as Retrofitting Existing Structures for various typologies of dwellings, Public buildings and Business Centres

3 Ask Engineering Colleges in the State to Design summer projects for their students to study private and Public buildings in Allocated areas of the state, and Assess their vulnerabilities on the scale of 0-1 to withstand the Quantified Accelerations for the area, and

a) Cause all public Government departments to retrofit their buildings and Infrastructure according to specified Engineering designs
b) Disseminate User friendly Graphic Designs for State wide Retrofitting work through Participatory Initiatives local Communities.