Seismic Vulnerability Assessment of State Capitals: Focus NE India

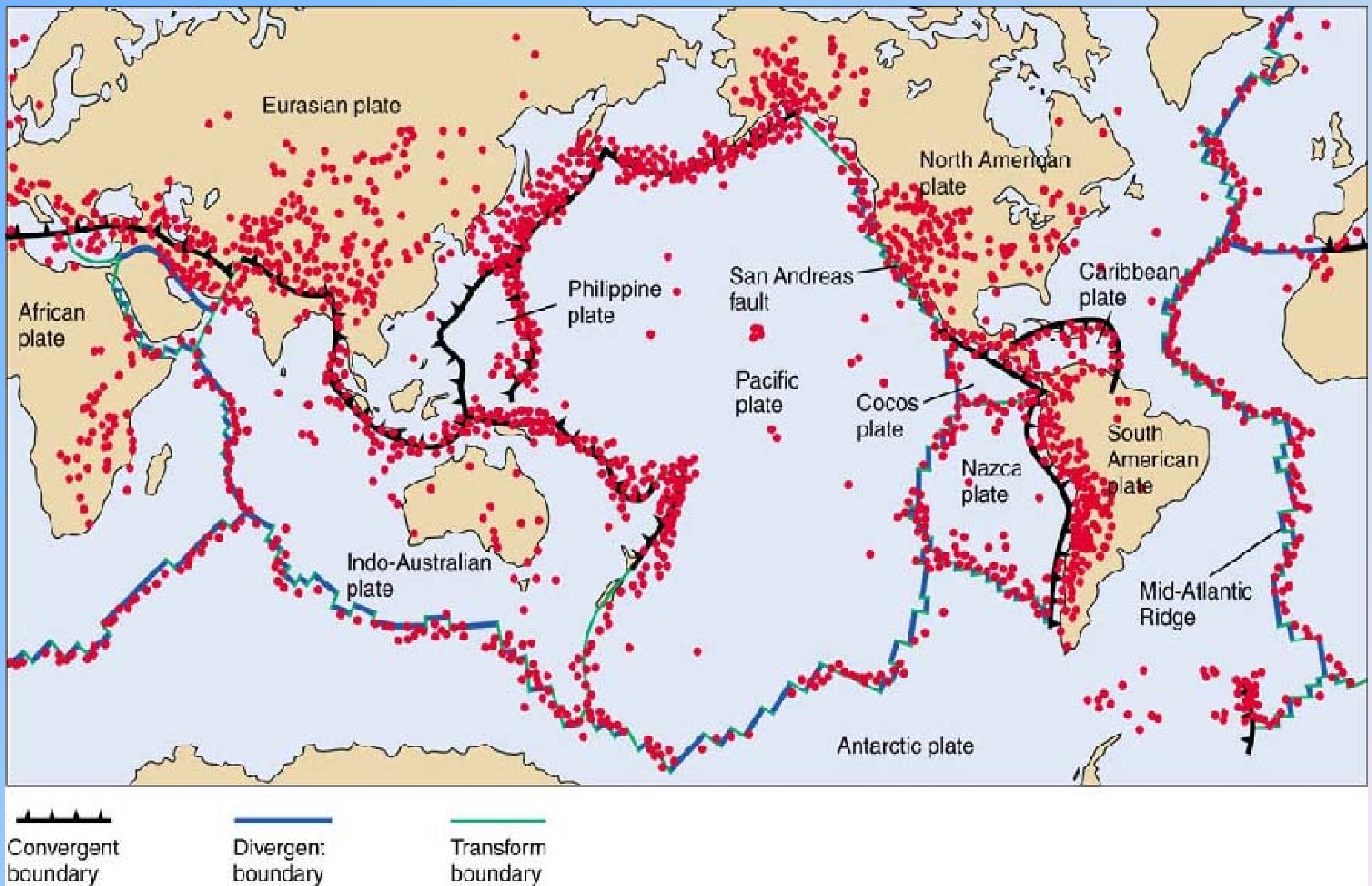
M K Phukan
Scientist,
Geoscience & Technology Division,
CSIR – NEIST, Jorhat

Where Do Earthquakes Occur and How Often?

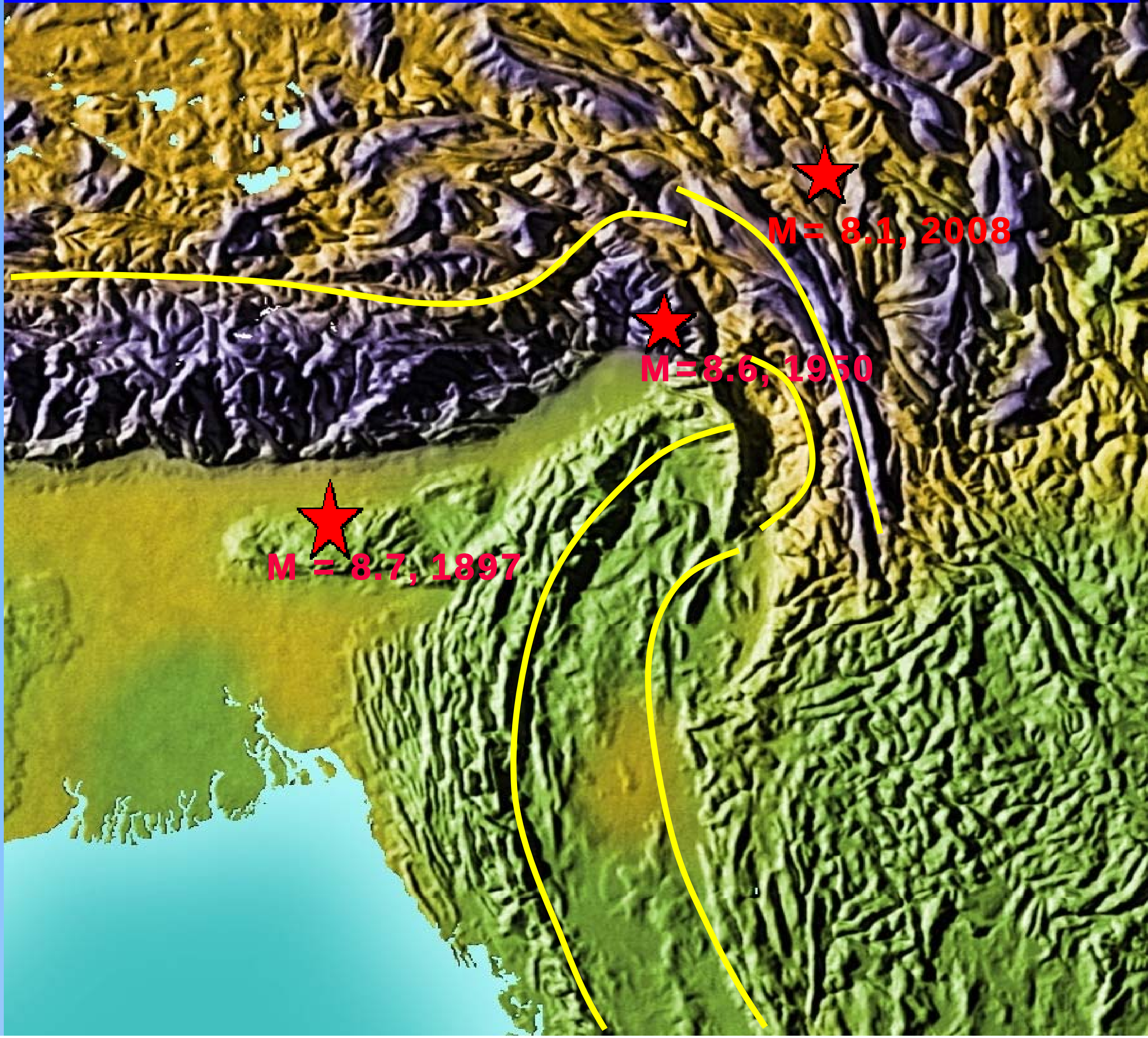
~ 80% of all earthquakes occur in the circum-Pacific belt
most of these result from convergent margin activity

~ 15% occur in the Mediterranean-Asiatic belt
5% occur in the interiors of plates and on spreading ridges

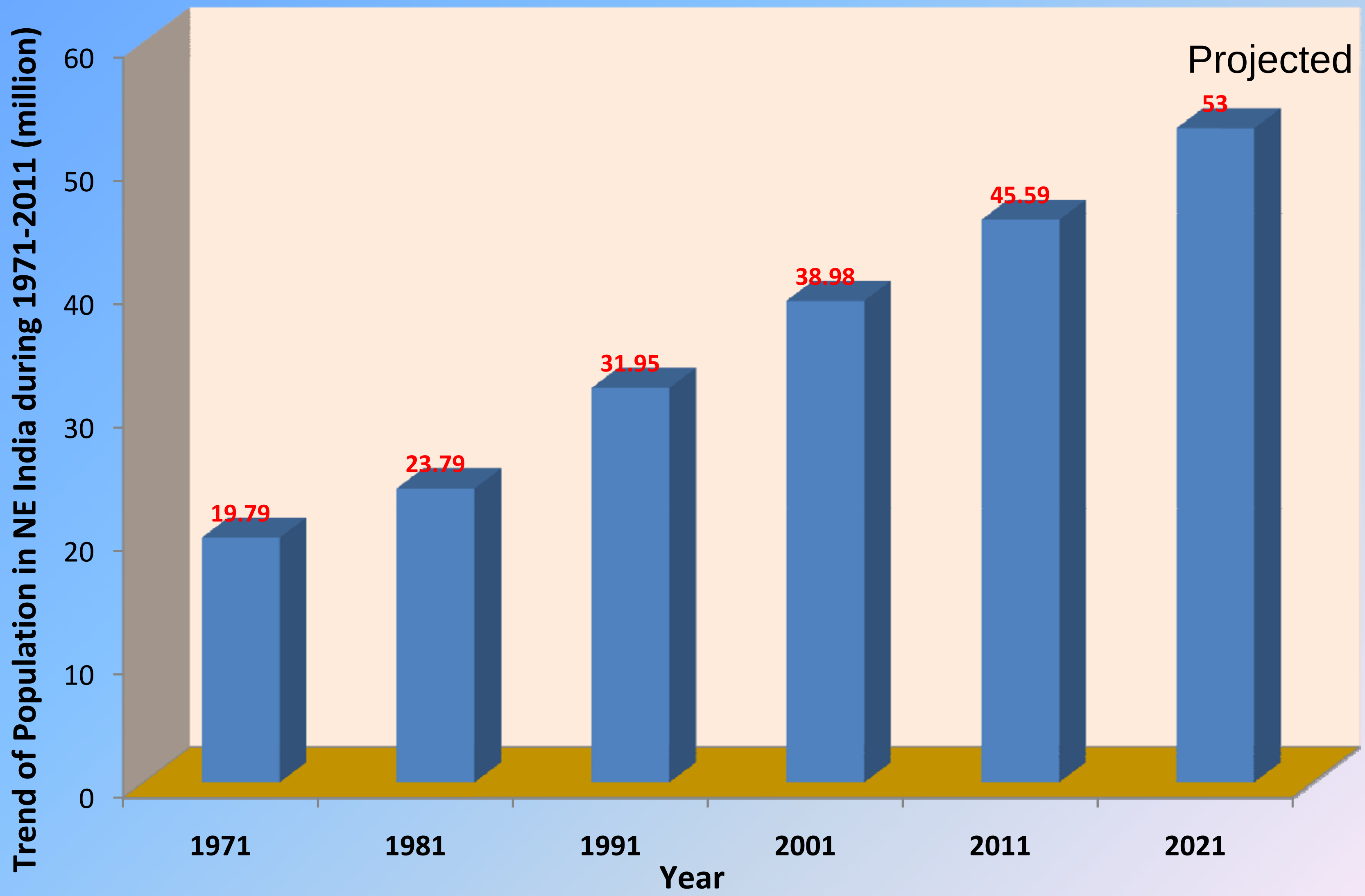
~ Nearly 150,000 felt earthquakes are recorded each year



Maximum (Probabilistic) Earthquake

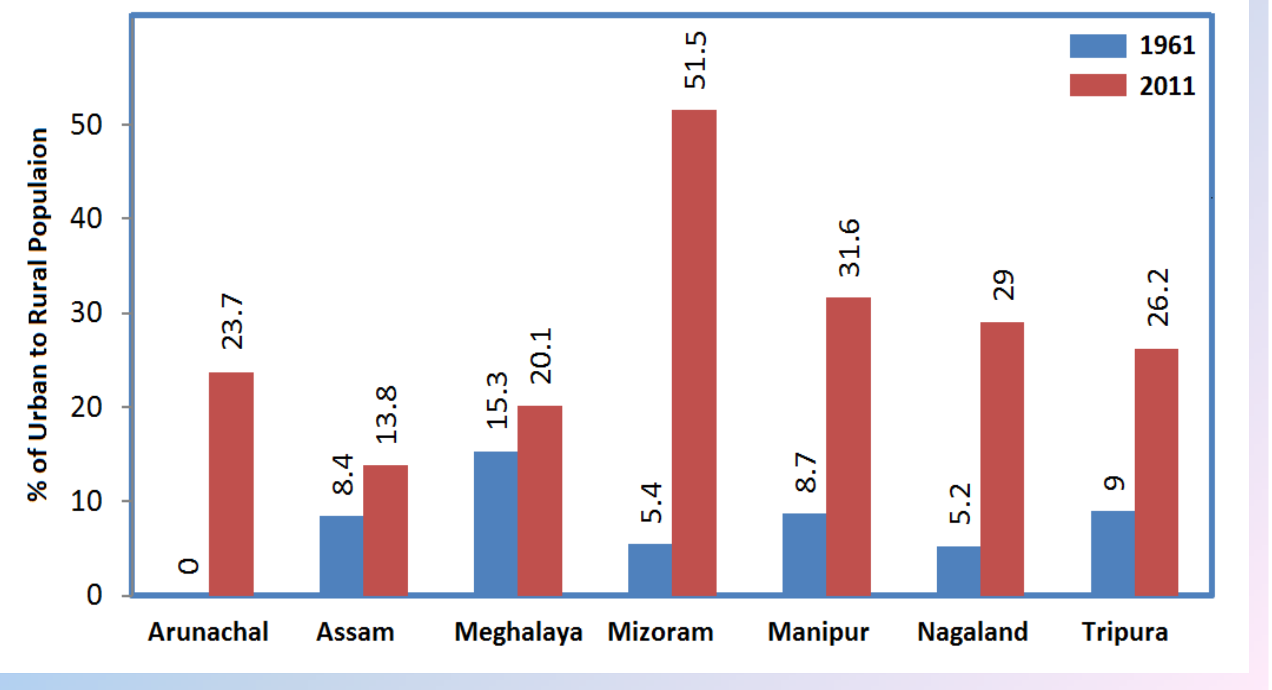


Population Trend in NE India (Census data)



Percentage of urban to rural population

State	1961	1971	1981	1991	2011
Arunachal	0	3.7	6.6	12.2	23.7
Assam	8.4	8.9	10.3	11.1	13.8
Meghalaya	15.3	14.6	18.1	18.7	20.1
Mizoram	5.4	11.4	24.7	46.2	51.5
Manipur	8.7	13.2	26.4	27.7	31.6
Nagaland	5.2	10	15.5	17.3	29
Tripura	9	10.4	11	15.3	26.2
Sikkim	-	-	-	-	42.9



EARTHQUAKE RISK:

Probability of damage and losses due to earthquake

- EARTHQUAKE RISK COMPRISES 3 BASIC FACTORS:

    1. **Hazard:** Probability of ground motion

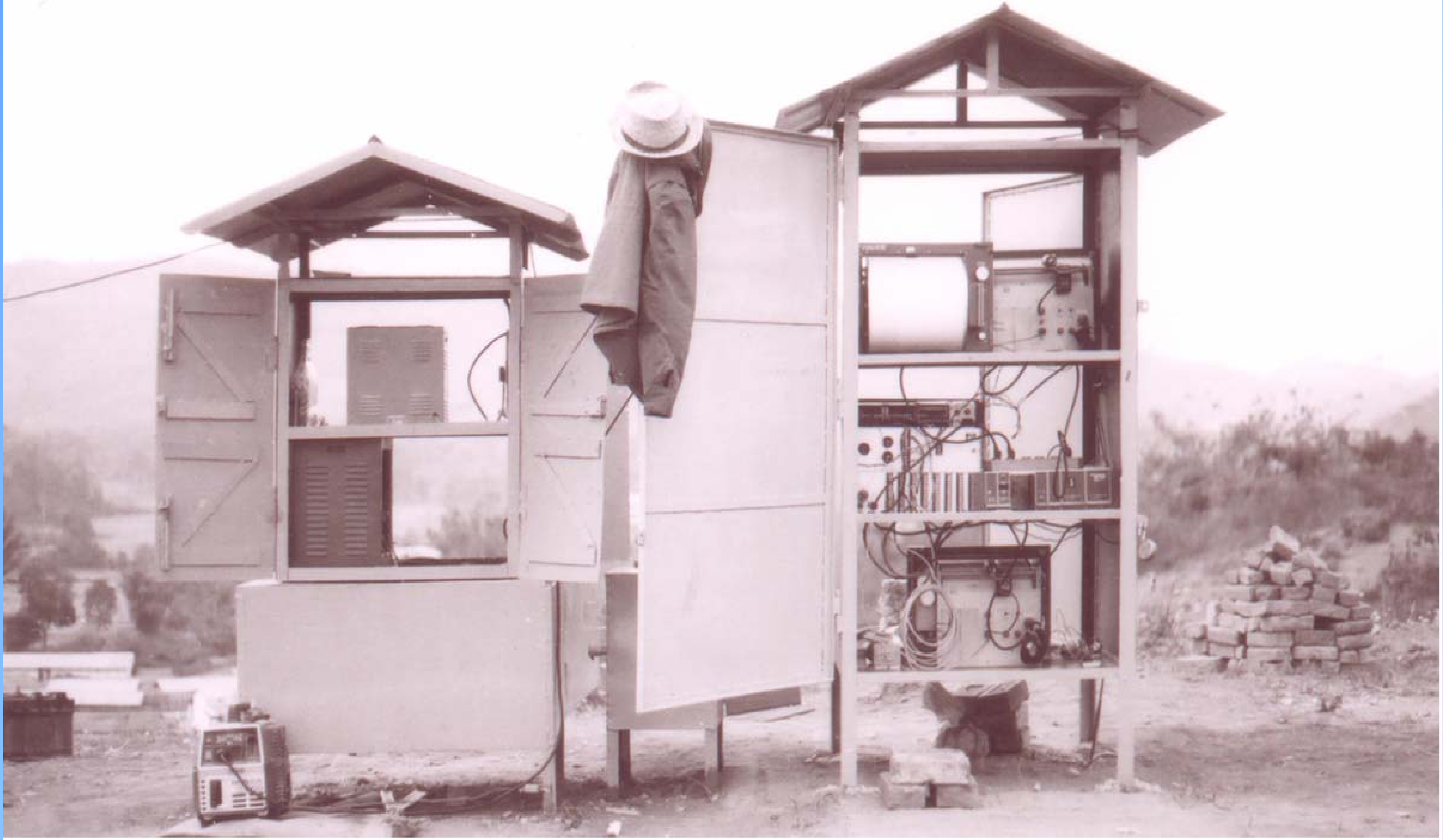
    2. **Site Condition:** Ground motion amplification due to site effects (soil type, topography)

    3. **Vulnerability:** Effects on structures (building type and age, population density, landuse, time of event)

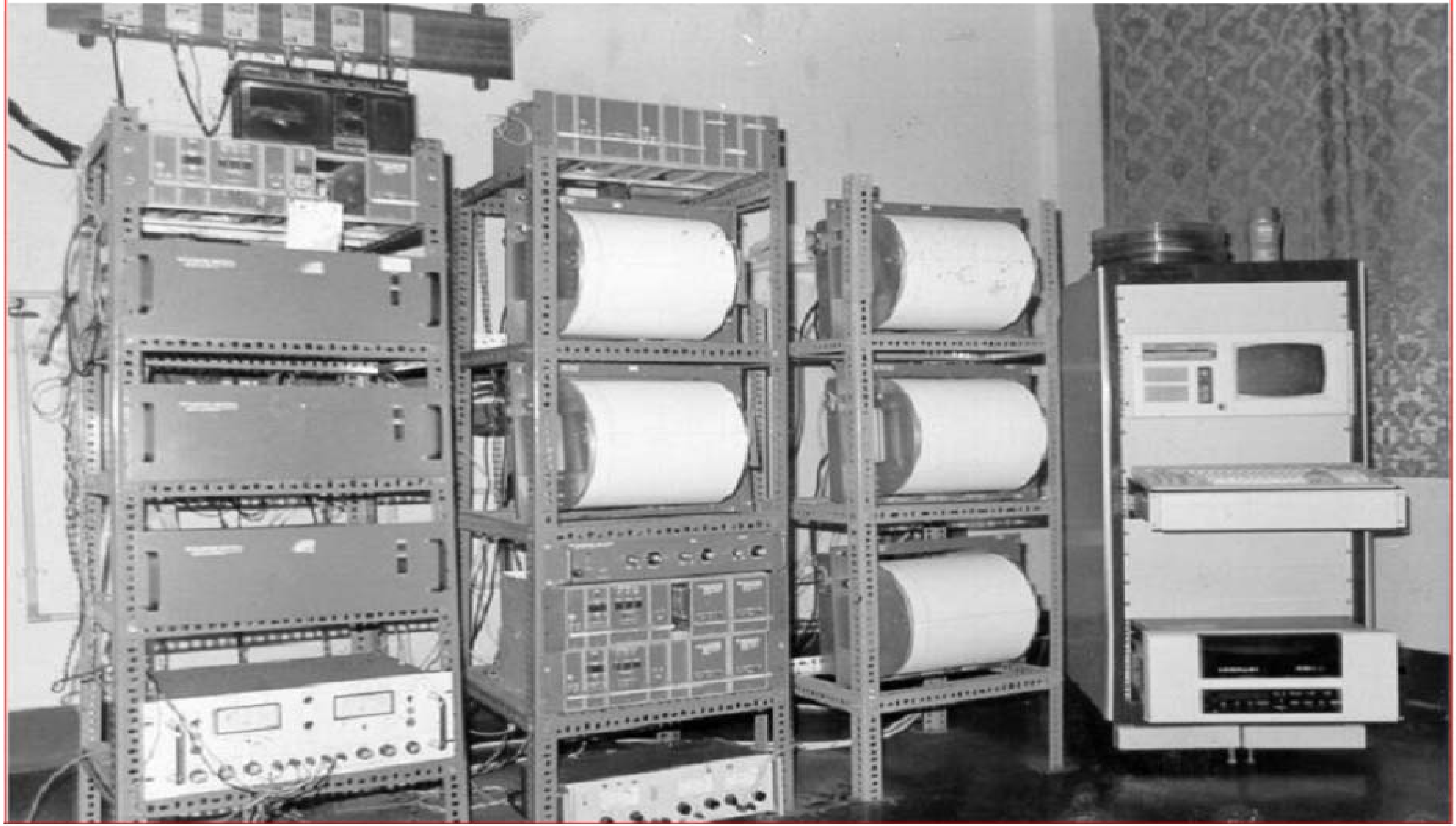
Seismic Hazard

- **There are significant challenges in seismic Hazard Assessment:**
  - **Identification of active faults**
  - **Maximum credible earthquake and return period**
  - **Instrumental and historical earthquake data is very limited as compared to earth history**
  - **Knowledge on local shallow sub-surface**
- **Detail scientific input on these parameters require long-term observation and reliable data**

Seismic Stations run by RRL (NEIST) Jorhat
(1978 - 1990)

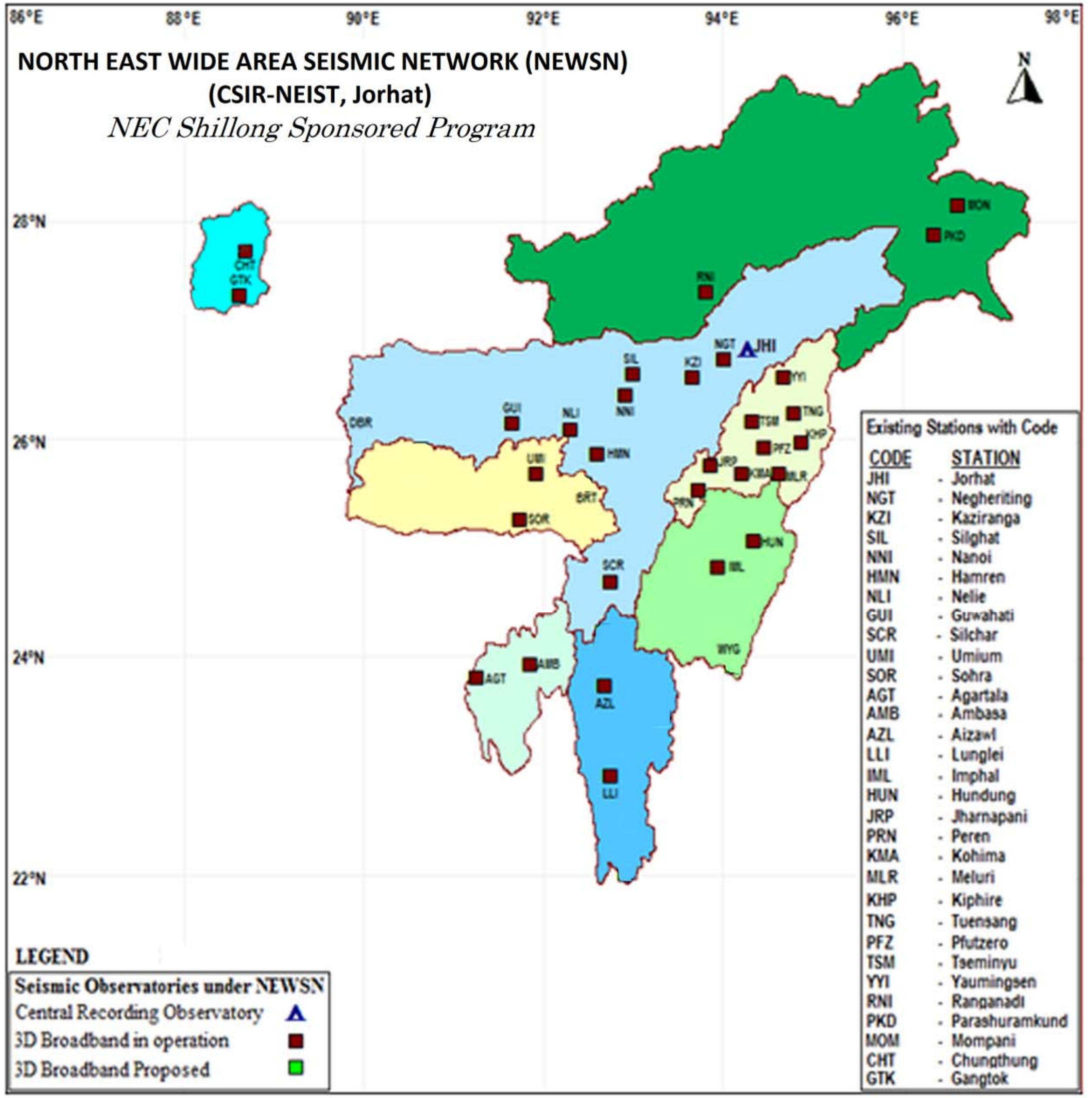


Central Recording Station
RRL (J) Seismic Telemetry Network (1990 - 1997)

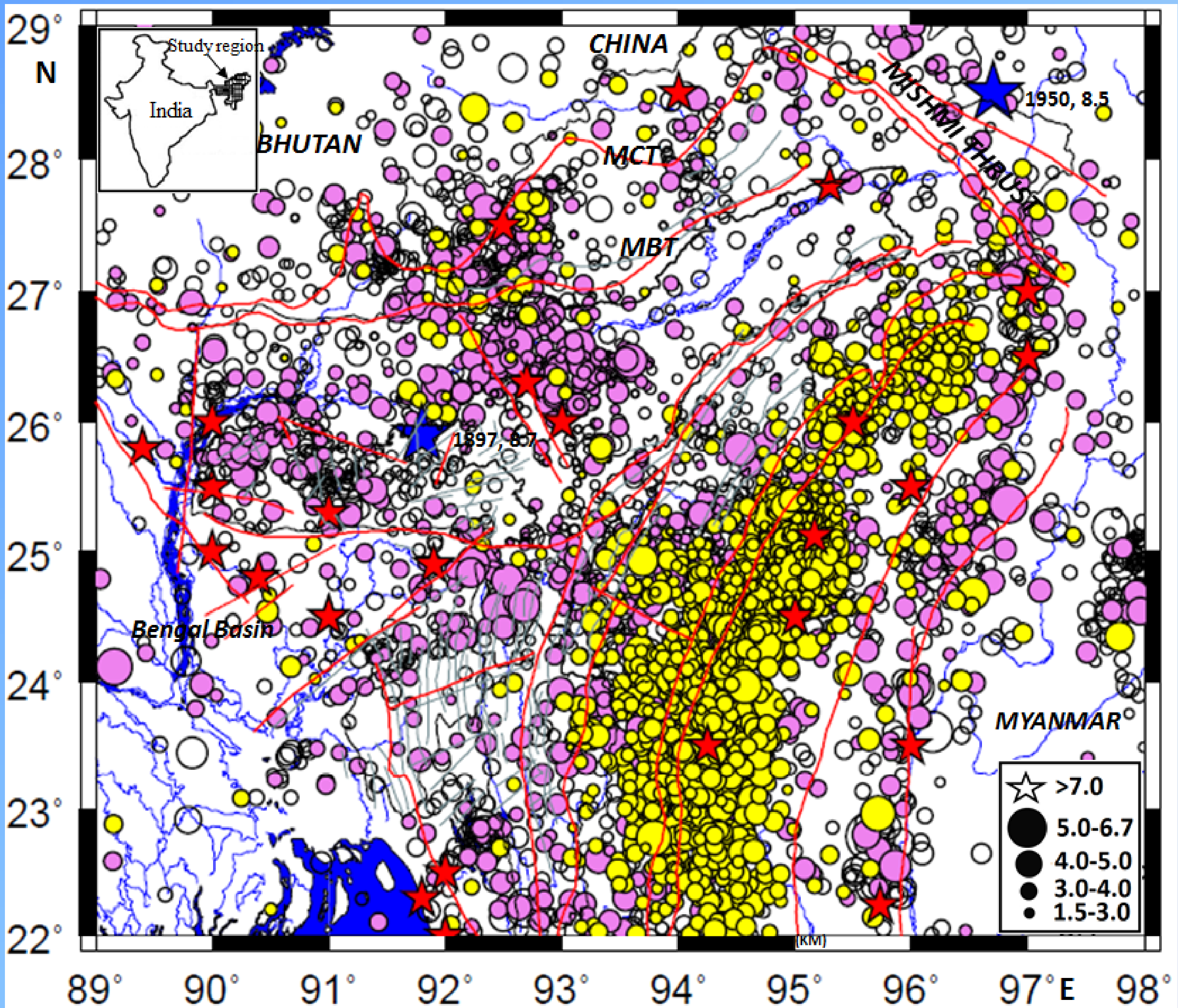


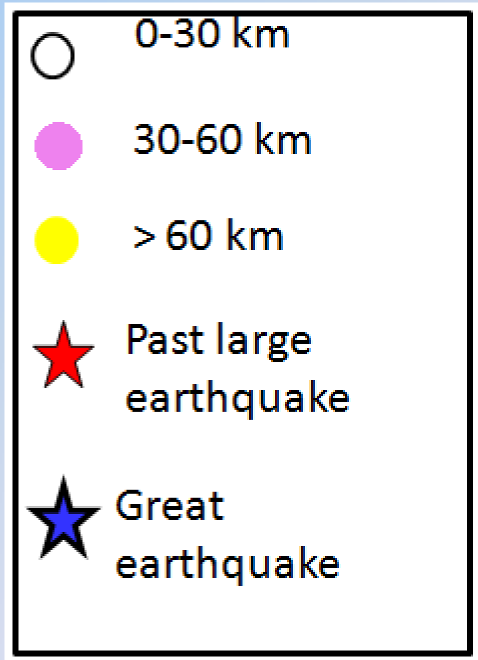
Installed during 1990 the 5(five) station Telemetry Network was discontinued after 1997 due to frequent breakdown of components, non-availability of spares and problem in line of Sight (UHF FM Radio transmission)

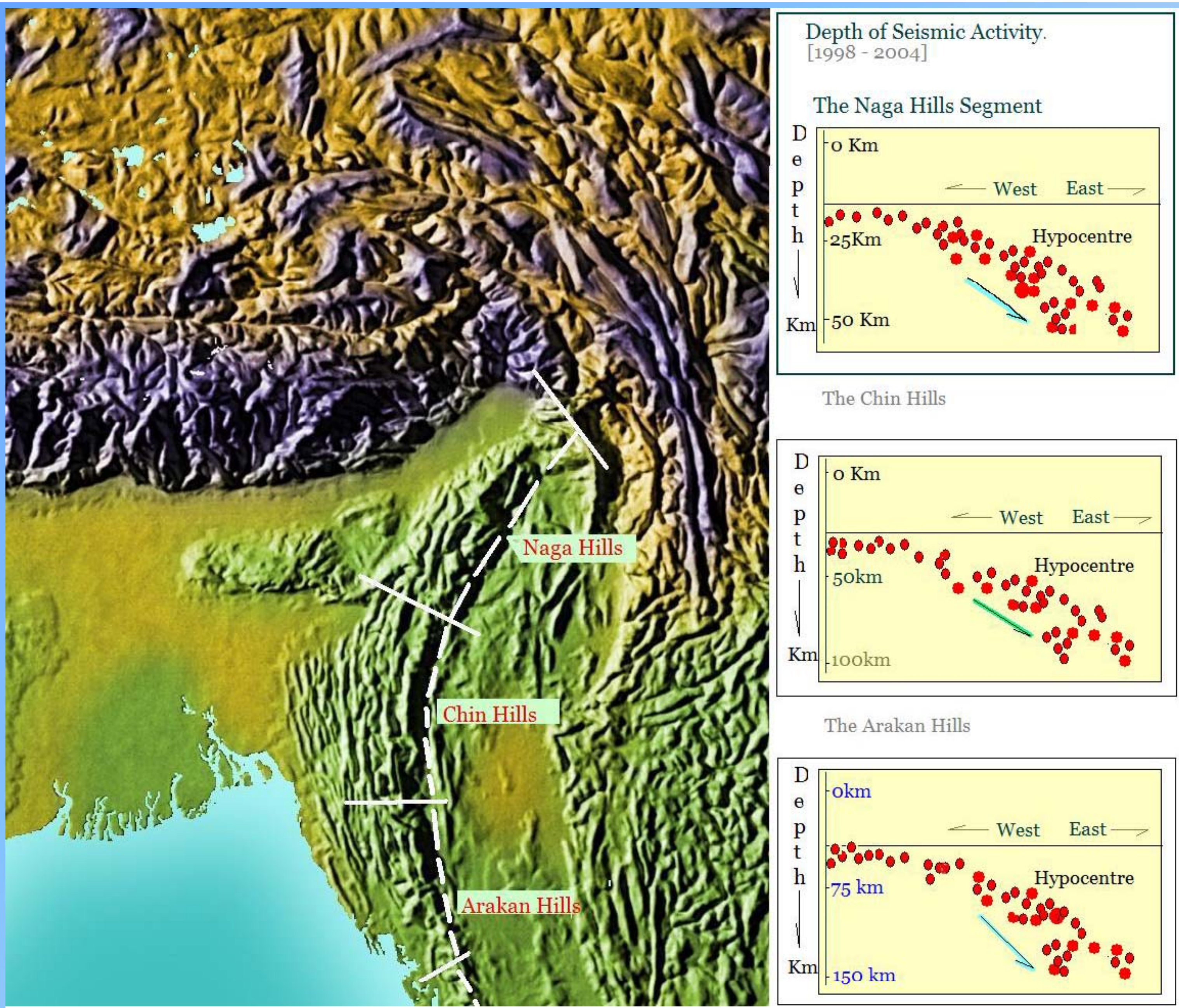
North East Wide Area Seismic Network (NEWSN)



Seismicity of the NE India & adjoining region

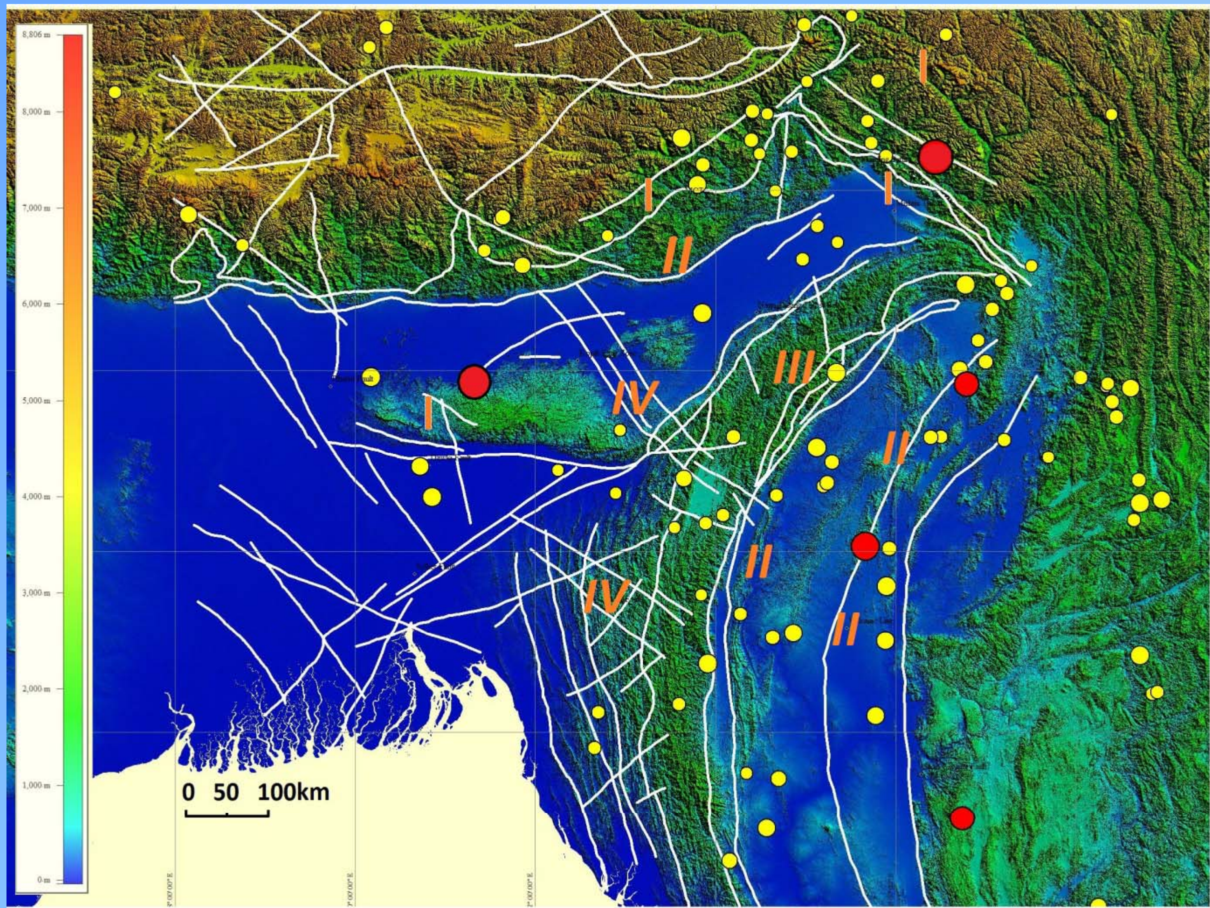






Earthquake depth variation in the Indo-Burma region

TECTONIC MAP OF NE INDIA & ADJOINING REGION



MAJOR FAULT SYSTEM IN NE INDIA & MAXIMUM CREDIBLE EARTHQUAKE

I. Tsungpo Suture Zone, Shillong Plateau & Lohit Himalaya (Mc > 8.5)
II. Himalayan Thrusts & Transverse faults, Indo-Burman Source (Mc > 7.5)
III. Tizu-Zumki Thrust in Nagaland extending upto Mizoram (Mc > 6.5)
IV. Other Localized Fault System (Mc > 6.0)

Maximum Credible Earthquake: Time-independent largest magnitude earthquake that appears capable of occurring in a fault system or seismic source zone.

SEISMIC ACTIVITY IN NE INDIA

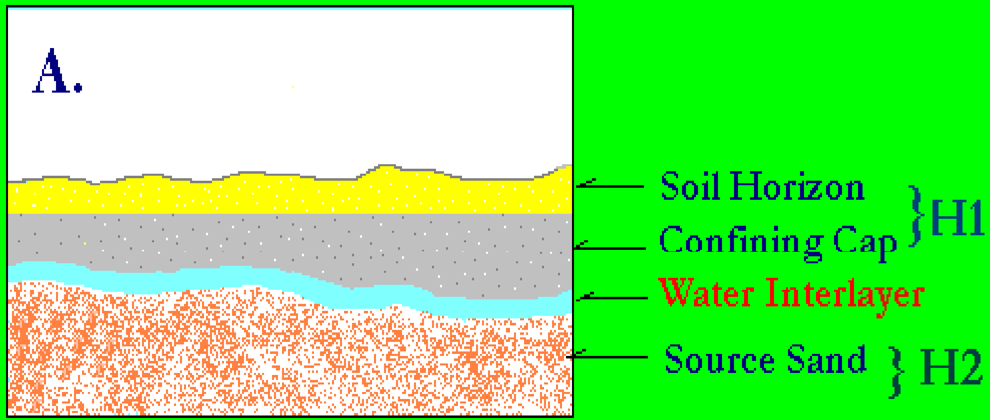
Region	Activity	Behavior	Hazard type
1. **Shillong Plateau** Continental Crust	**High**	**Shallow-Upper Crustal** Felt shocks ~ 20% Max mag=8.7	**Seismic shaking,** ground rupture, Landslide
2. **Kopili-Mikir Block** Continental Crust	**High**	**Crustal** Felt shocks ~10% Max mag=7.3	do
3. **Arunachal Himalaya** Meta Sediments	**Moderate**	**Shallow Crustal** Felt shocks~15% Max mag=8.6	do
4. **Indo-Burman Belt** Folded Belt	**do**	**Shallow Crustal (Naga Hills)** **Intermediate (Chin - Arakan)** Felt shocks ~ 5%, Max mag=7.0	**do**
5. **Assam Valley** Alluvium	**Free from seismic activity,** No valid record of past earthquakes		**Liquefaction &** Ground failure

Co-seismic Deformation
Ground rupture & Faulting

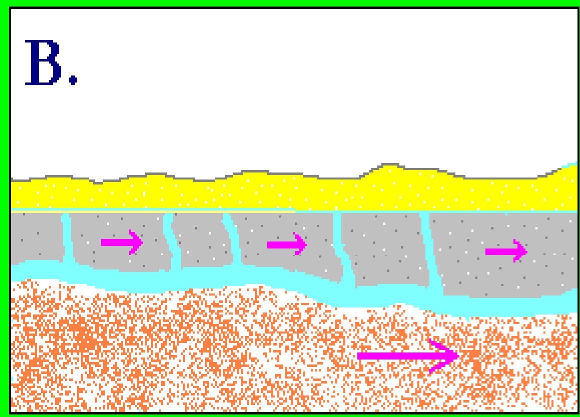
- **Co-seismic Deformation**

  Ground failure & Liquefaction

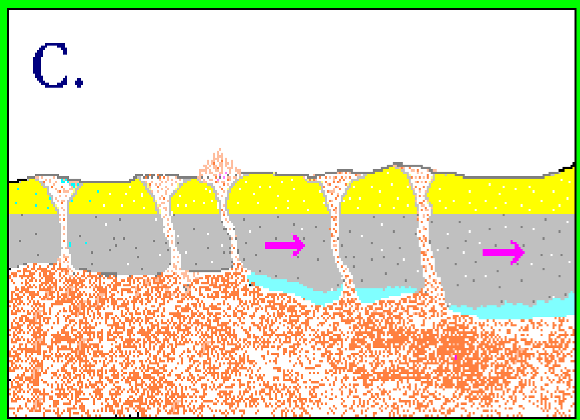
Seismically induced Liquefaction (SIL)



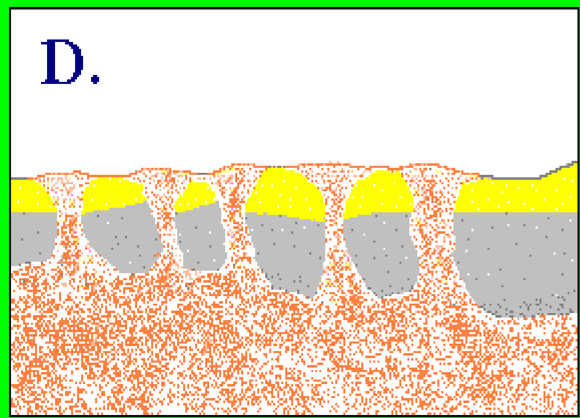
A. Development of Water Interlayer due to cyclic shear strain and increase in pore pressure.



B. Lateral Flowage Phase - with the liquefaction of underlying sand and water Interlayer, friction at contact between H1 & H2 & Cap layer moves



C. Confining Cap Rupture Phase - Cap layer begins to break apart and fractures are filled with liquefied sand



D. Sand Extrusion Phase - venting out of sands and Pore pressure is reduced, lateral spreading ceases.

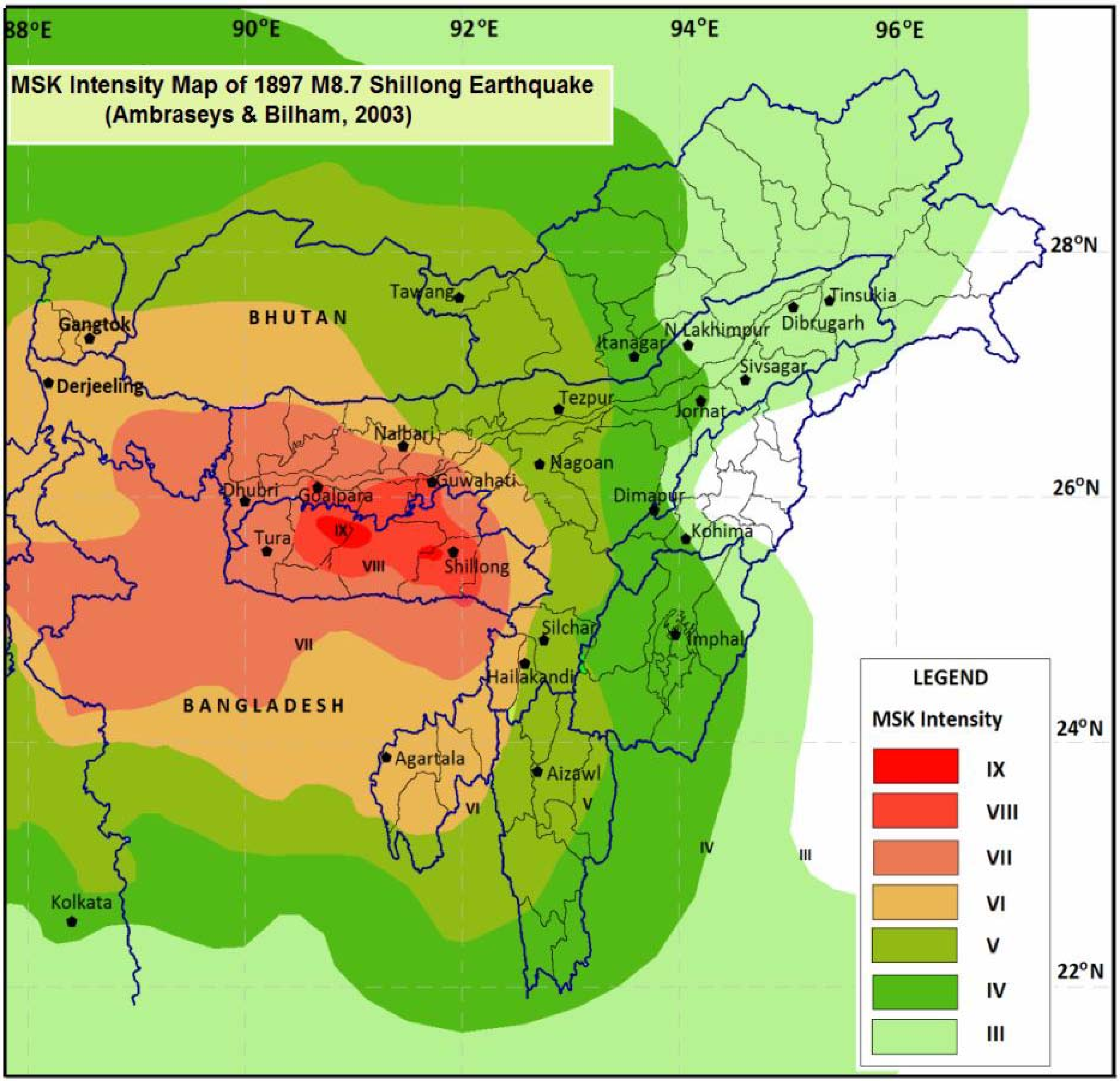
Present Day Scenario of 1897 M8.7 Great Assam Earthquake

R D Oldham (1899) used the term isoseist to denote the intensity contour of 1897 earthquake. His Isoseist I corresponds to following description:

- **Isoseist – I** corresponds approximately to Rossi-Forel (1883) Intensity - X has a radius of 160 km in which serious damage occurred to buildings. **Within this highest intensity zone Oldham defines the epicentral tract that includes the Shillong Plateau, defined in the south by the towns of Rangpur, Tura, Cherrapunji and Silchar, and in the north by Dhubri, Bongaigaon, Guwahati and Shillong, an area which extends to the north across the Brahmaputra river valley towards the hills of Assam and Bhutan.** In places within this epicentral tract Oldham observed the PGA to exceeded 1.0g.

Panoramic view of Shillong before 1897 earthquake

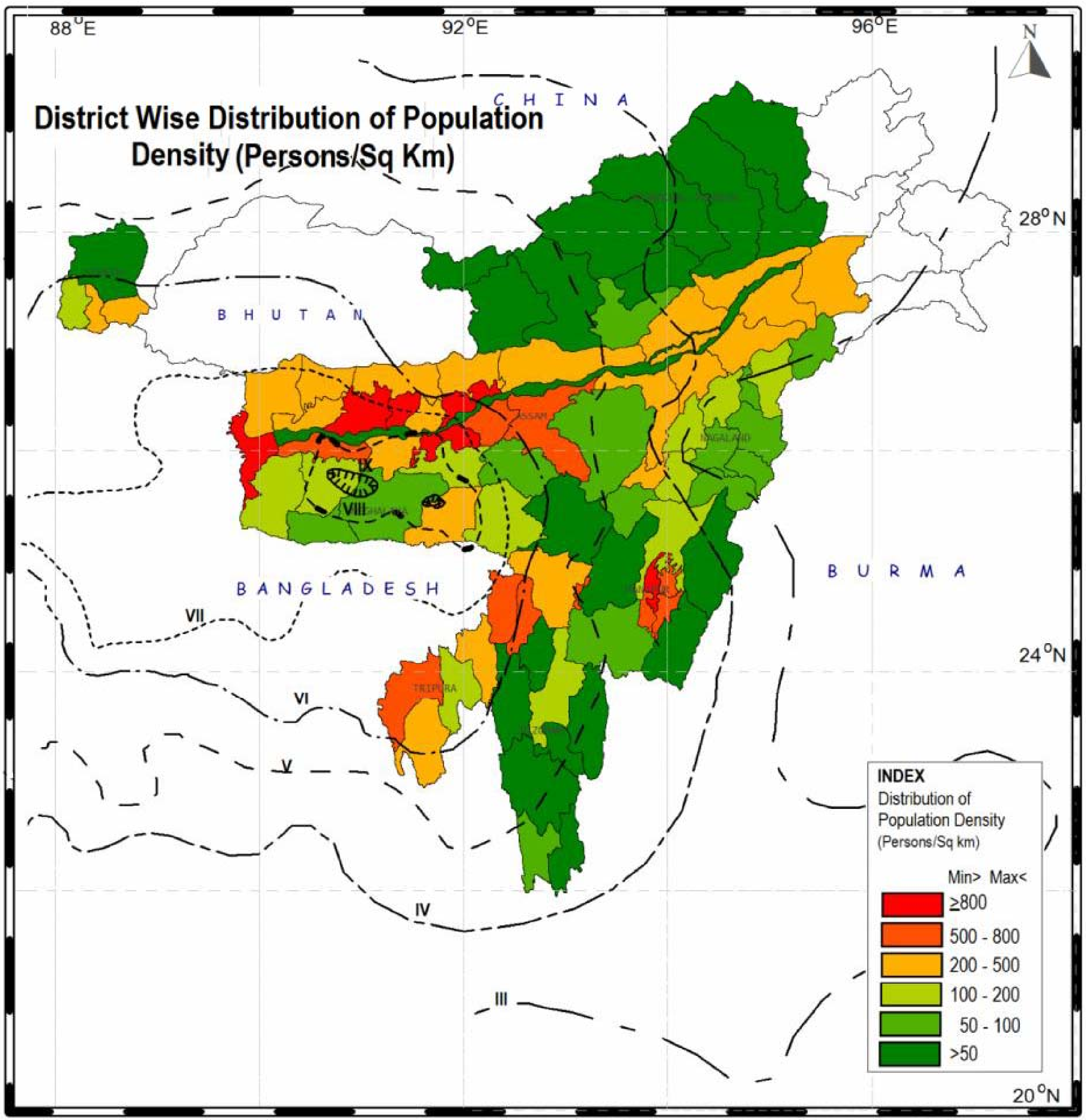
Present-day panoramic view of Shillong city

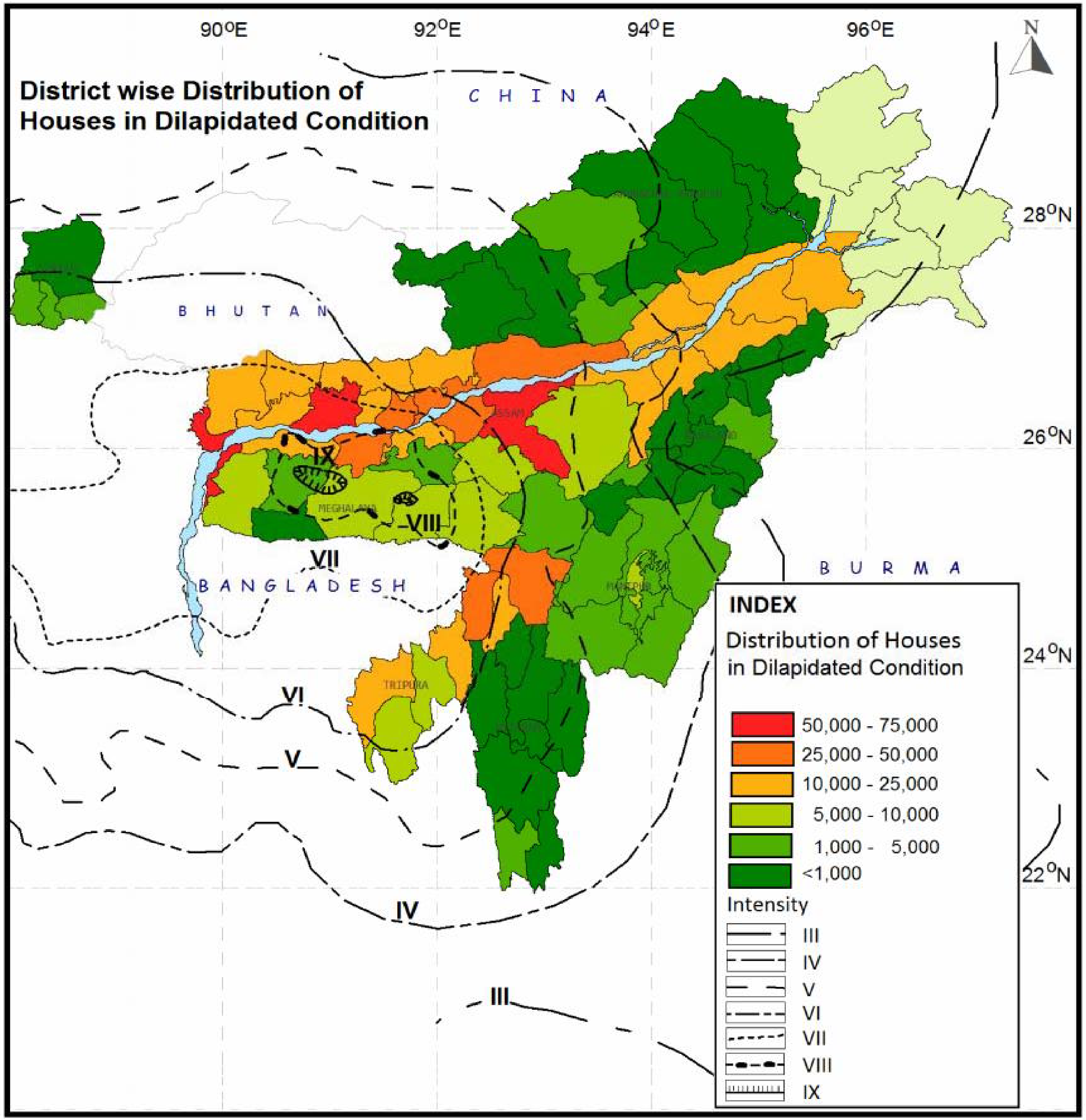


MSK Intensity Map of 1897 M8.7 Shillong Earthquake
(Ambraseys & Bilham, 2003)
88°E
90°E
92°E
94°E
96°E
28°N
26°N
24°N
22°N
BHUTAN
BANGLADESH
Gangtok
Derjeeling
Tawang
Itanagar
N Lakhimpur
Dibrugarh
Tinsukia
Sivsagar
Jorhat
Tezpur
Nalbari
Nagoan
Guwahati
Dhubri
Goalpara
Dimapur
Kohima
Tura
Shillong
Silchar
Imphal
Hailakandi
Agartala
Aizawl
Kolkata
IX
VIII
VII
VI
V
IV
III
LEGEND
MSK Intensity
IX
VIII
VII
VI
V
IV
III

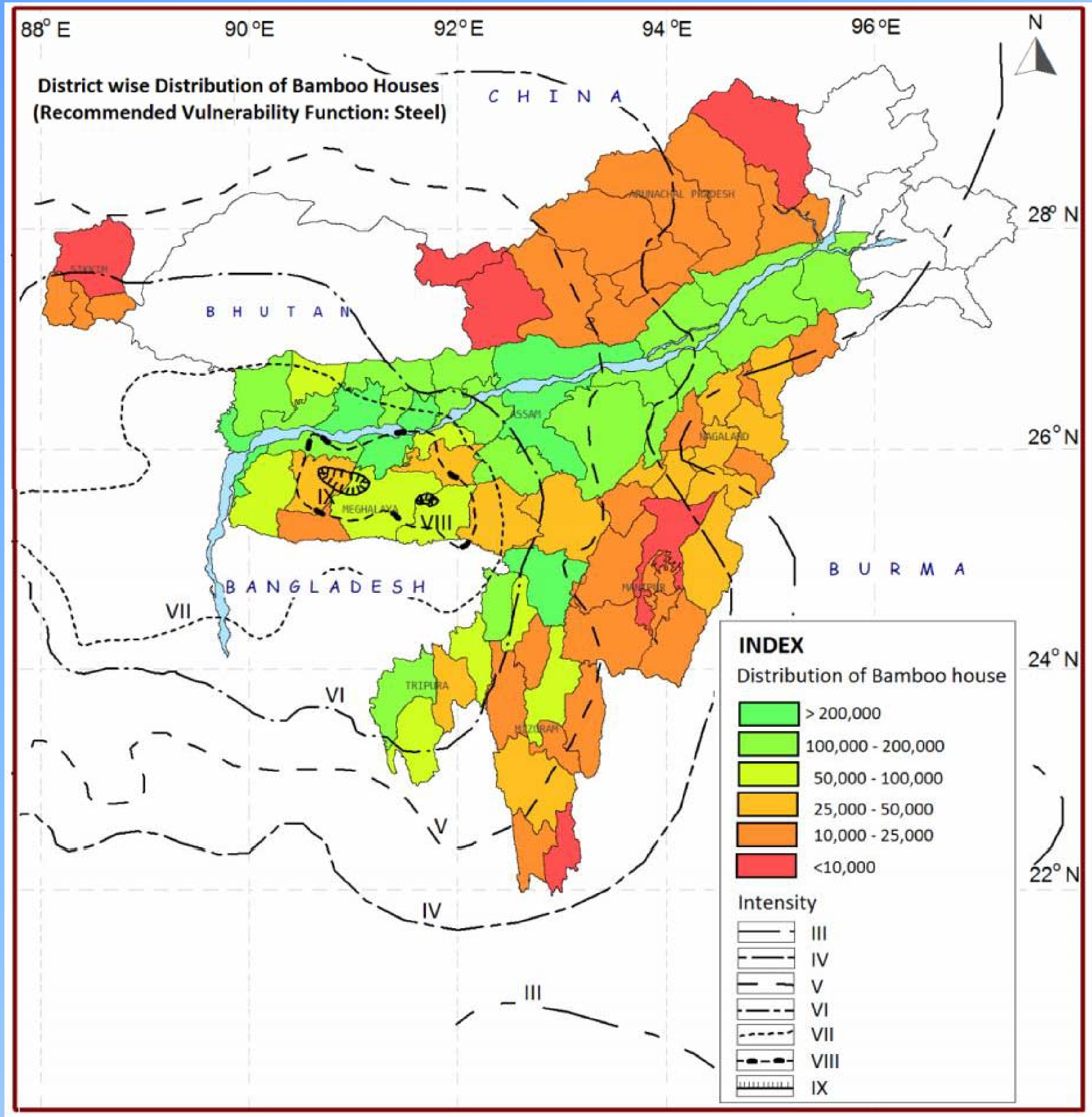
MSK-64 earthquake intensity scale adopted in India (IS:1893-2002)

Intensity Grade	Description
I	Not noticeable
II	Scarcely noticeable
III	Weak, partially observed only
IV	Largely observed
V	Awakening
VI	Frightening
VII	Damage of buildings
VIII	Destruction of buildings
IX	General damage of buildings
X	General destruction of buildings
XI	Destruction
XII	Landscape changes


District Wise Distribution of Population Density (Persons/Sq Km)
88°E
92°E
96°E
N
28°N
24°N
20°N
C H I N A
B H U T A N
B A N G L A D E S H
B U R M A
IX
VIII
VII
VI
V
IV
III
INDEX
Distribution of Population Density
(Persons/Sq km)
Min> Max<
≥800
500 - 800
200 - 500
100 - 200
50 - 100
>50



District wise Distribution of Houses in Dilapidated Condition
90°E
92°E
94°E
96°E
28°N
26°N
24°N
22°N
N
CHINA
BHUTAN
BURMA
BANGLADESH
IX
VIII
VII
VI
V
IV
III
INDEX
Distribution of Houses in Dilapidated Condition
50,000 - 75,000
25,000 - 50,000
10,000 - 25,000
5,000 - 10,000
1,000 - 5,000
<1,000
Intensity
III
IV
V
VI
VII
VIII
IX



88° E
90 °E
92° E
94 °E
96 °E
N
District wise Distribution of Bamboo Houses
(Recommended Vulnerability Function: Steel)
C H I N A
B H U T A N
B A N G L A D E S H
B U R M A
28° N
26° N
24° N
22° N
ARUNACHAL PRADESH
ASSAM
NAGALAND
MEGHALAYA
MANIPUR
TRIPURA
MIZORAM
SIKKIM
VII
VI
V
IV
III
VIII
IX
INDEX
Distribution of Bamboo house
> 200,000
100,000 - 200,000
50,000 - 100,000
25,000 - 50,000
10,000 - 25,000
<10,000
Intensity
III
IV
V
VI
VII
VIII
IX

Classification of houses of NE India with respect to construction material.

(Type of structures with level of structural damage when exposed to MSK intensity VI-X)

Construction Material	House Class Symbol	Description	Recommended Vulnerability Class	Intensity wise Structural damage(SD) VI	VII	VIII	IX	X
CONCRETE	CWCR	Reinforced Concrete wall & roof	RCC	0.42	0.63	0.81	0.94	1.0
	CWBR	Concrete wall & burnt brick roof with cement mortar	RCC	0.42	0.63	0.81	0.94	1.0
	LWCR	Concrete structure with bamboo /wood/GI sheet/ walls and concrete roof	RCC	0.42	0.63	0.81	0.94	1.0
	CWLR	Concrete wall & roofs of GI/ metal sheet/ thatch/Bamboo/ other light materials	RCC	0.42	0.63	0.81	0.94	1.0
	BWCR	Burnt brick wall with mortar & Concrete roof with concrete post/tie column & beam	RCC	0.42	0.63	0.81	0.94	1.0
	SWCR	Stone wall with cement mortar and concrete structure with Concrete roof	RCC	0.42	0.63	0.81	0.94	1.0
	CWSR	Concrete wall & Stone/Tiles roof	RCC	0.42	0.63	0.81	0.94	1.0

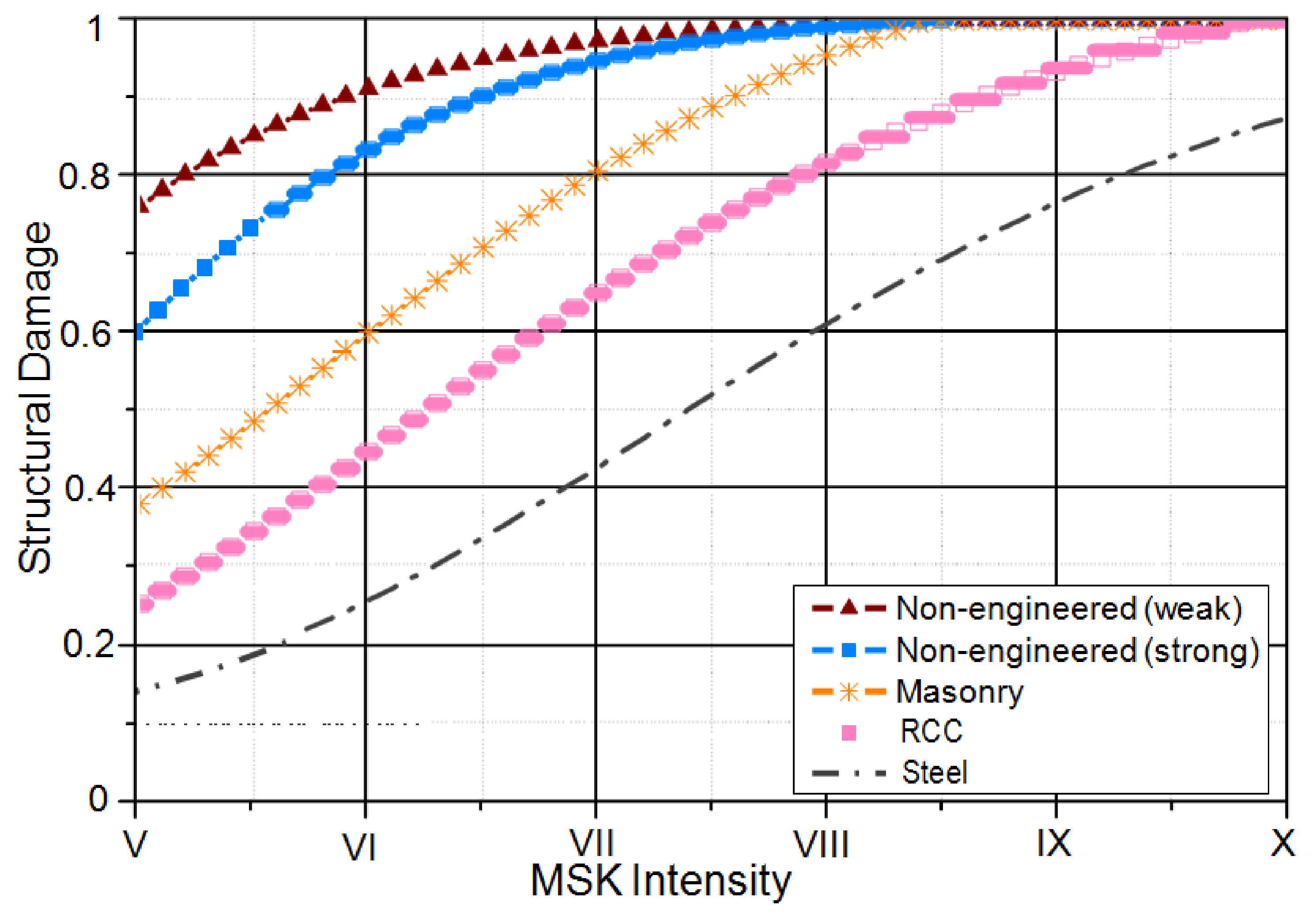
Classification of houses of NE India with respect to construction material, type of structure with level of structural damage at MSK intensity VI-X.

Construction Material	House Class Symbol	Description	Recommended Vulnerability Class	Intensity wise Structural damage(SD) VI	VII	VIII	IX	X
MASONRY	BWBR	Burnt brick masonry wall with cement mortar & Burnt brick roof with	Masonry	0.60	0.80	0.94	1.0	1.0
	BWSR	Burnt brick masonry wall with cement mortar and roof of stone slab/tiles	Masonry	0.60	0.80	0.94	1.0	1.0
	BWLR	Burnt brick masonry wall with lime/cement mortar and grass/ thatch/bamboo/ GI/other light roof	Masonry	0.60	0.80	0.94	1.0	1.0
	SWBR	Stone wall with cement/ lime mortar and masonry structure with Burnt brick roof	Masonry	0.60	0.80	0.94	1.0	1.0
Non-Engg. (Strong)	LWBR	bamboo/GI sheet/wood walls with Burnt brick roof	Non Engineered (Strong)	0.83	0.95	0.98	1.0	1.0

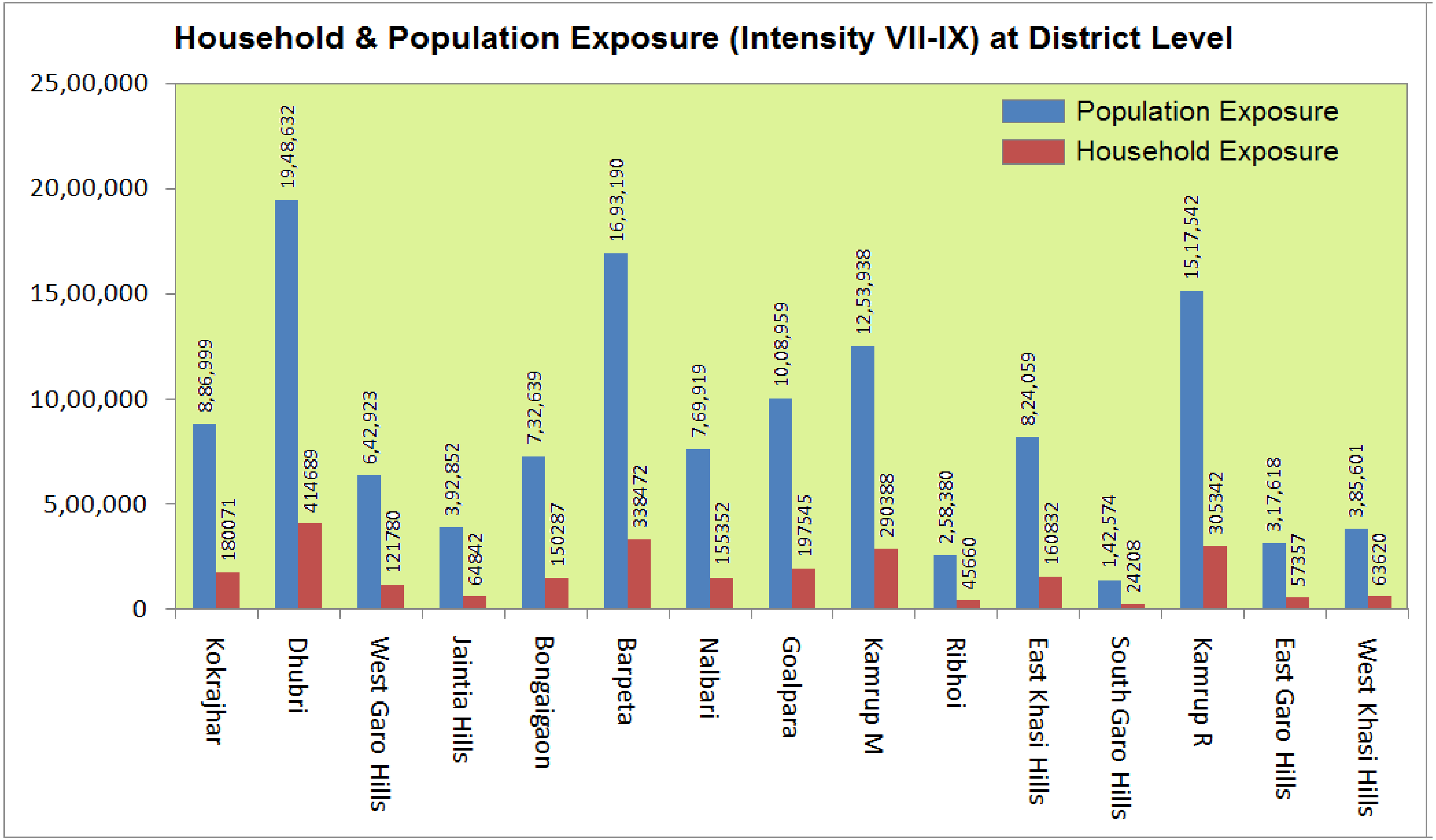
Classification of houses of NE India with respect to construction material, type of structure with level of structural damage at MSK intensity VI-X.

Construction Material	House Class Symbol	Description	Recommended Vulnerability Class	Intensity wise Structural damage(SD) VI	VII	VIII	IX	X
NON ENGINEERED (WEAK)	SWSR	Stone wall without mortar /mud mortar and stone slab/handmade tiles roof	Non Engineered (weak)	0.90	0.98	1.0	1.0	1.0
	SWLR	Stone wall without mortar /mud mortar and roof of grass/thatch/ bamboo/ temporary roof material	Non Engineered (weak)	0.90	0.98	1.0	1.0	1.0
	LWSR	Wood/Bamboo/GI sheet walls with Stone slab/tiles roof	Non Engineered (weak)	0.90	0.98	1.0	1.0	1.0
BAMBOO/ GRASS/ THATCH/ GI, etc.	, LWLR	Bamboo/wood/Grass/Thatch/metal sheet walls with bamboo/wood frame and Grass/thatch/plastic /metal/GI sheet roof	Steel	0.25	0.42	0.60	0.76	0.87

Vulnerability functions for various building typologies



Ref: Seismic vulnerability Assessment Project Group of IIT Bombay, IIT Guwahati, IIT Kharagpur, IIT Madras & IIT Roorkee. Submitted to NDMA, SEP 13 2013


Household & Population Exposure (Intensity VII-IX) at District Level
Population Exposure
Household Exposure
25,00,000
20,00,000
15,00,000
10,00,000
5,00,000
0
8,86,999
180071
19,48,632
414689
6,42,923
121780
3,92,852
64842
7,32,639
150287
16,93,190
338472
7,69,919
155352
10,08,959
197545
12,53,938
290388
2,58,380
45660
8,24,059
160832
1,42,574
24208
15,17,542
305342
3,17,618
57357
3,85,601
63620
Kokrajhar
Dhubri
West Garo Hills
Jaintia Hills
Bongaigaon
Barpeta
Nalbari
Goalpara
Kamrup M
Ribhoi
East Khasi Hills
South Garo Hills
Kamrup R
East Garo Hills
West Khasi Hills

Direct Consequences

- Nearly 35,000 people living in about 6000 houses of **East Garo Hills, and West Khasi Hills,** Meghalaya may be rendered homeless due to house collapse and face the most serious consequences.

- More than 1.5 lakh people living in about 35,000 houses falling within the Intensity Zone VIII-VII (MSK) in **East Khasi Hills, South Garo Hills, Ribhoi (Meghalaya); and Kamrup Rural, Kamrup (metro) and Goalpara (Assam)** may face serious injury and traumatize. May have to abandon house and property due to complete or partial collapse of the dwellings.

- **The roads, bridges, transportation, communication network and such others/within the isoseismal MSK (VIII-IX) will be seriously damaged rendering the infrastructure unusable and paralyzing normal road communication to standstill to several weeks.**
- **Away from the epicentral tract (250 - 300km) the long waves traveling along/across Brahmaputra alluvial plains and Barak valley will cause significant damage to the tall and weak structures due to seismic site amplification.**
- **The shaking effect of M 8.7 will be highly visible in the form of ground rupture, secondary fault displacement, liquefaction and landslides covering a large distance.**

- **Almost in all hill districts experiencing MSK VII -IX will be seriously affected by landslide and rock fall causing blockade to road communication, relief & rescue and slow down all other mitigation activities.**

- **Extensive liquefaction, ground rupture and differential settlement of the runways and buildings may distort the entire Guwahati airport. The approach to Shillong airport may be blocked by heavy landslide.**

Way forward

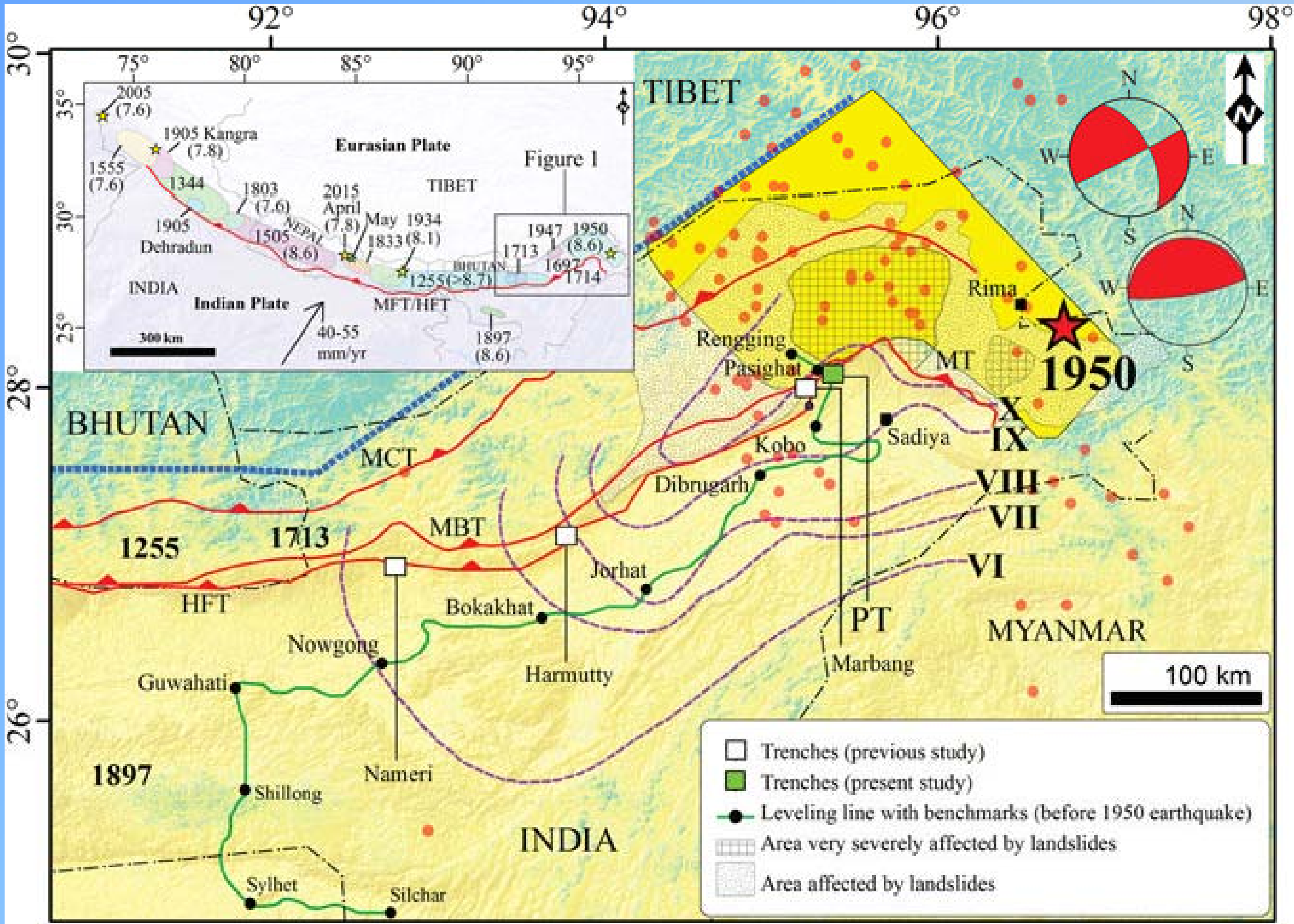
- States to plan state-of-art Emergency Operation Centre (EOC) with fail-safe communication system with redundancy.
- Web based Decision Support System (DSS) should be in place
- DM plans to be regularly updated with resource/ inventories mapping
- A well-equipped SDRF should be in place for each state.
- RVS of critical lifeline buildings to be undertaken.

- **Building Codes be put in public domain and brought into practice.**
- **Mock Drills to be regularly organized by State and Districts with procedures in place.**
- **Greater community participation has to be ensured; more initiatives needed to promote awareness among school children and the community.**
- **Augmentation of medical resources and medical teams required with capacity to function outdoors.**
- **Fire & Emergency Services to be equipped with basic DM equipment**
- **Training, exposure and exercises needed by Police and Civil Defense.**

www.ndma.gov.in/images/pdf/PR-M8.7-Shillong.pdf (Full Report)

https://ndma.gov.in/images/pdf/IA-M8.7-Shillong.pdf (Impact Assessment)

Intensity Isoseismal map of Assam 1950 Earthquake



(Rao et al. 2017, Primary surface rupture of the 1950 Tibet-Assam great earthquake along the eastern Himalayan front, India, ***Nature,*** 7: 5433 | DOI:10.1038/s41598-017-05644-y***)***

Seismic Microzonation of N E State Capitals

Seismic Zoning

Seismic zoning consists of subdividing a national territory into several seismic zones indicating progressive levels of expected seismic intensity or peak ground acceleration for different return periods based on historic and predicted intensity of ground motion.

SEISMIC ZONING MAP OF INDIA

Zone II

Zone III

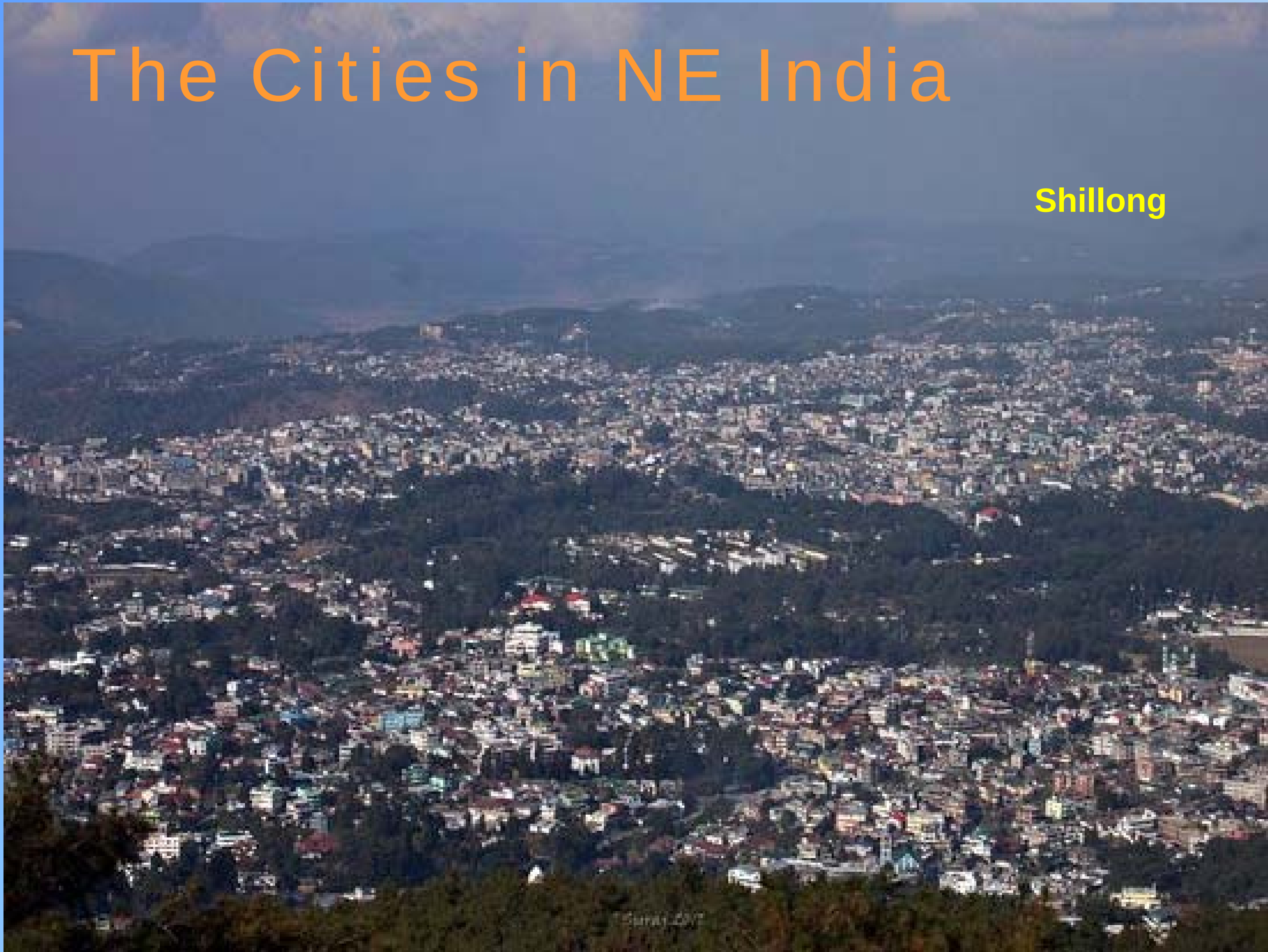
Zone IV

Zone V

Traditional dwelling pattern of NE India

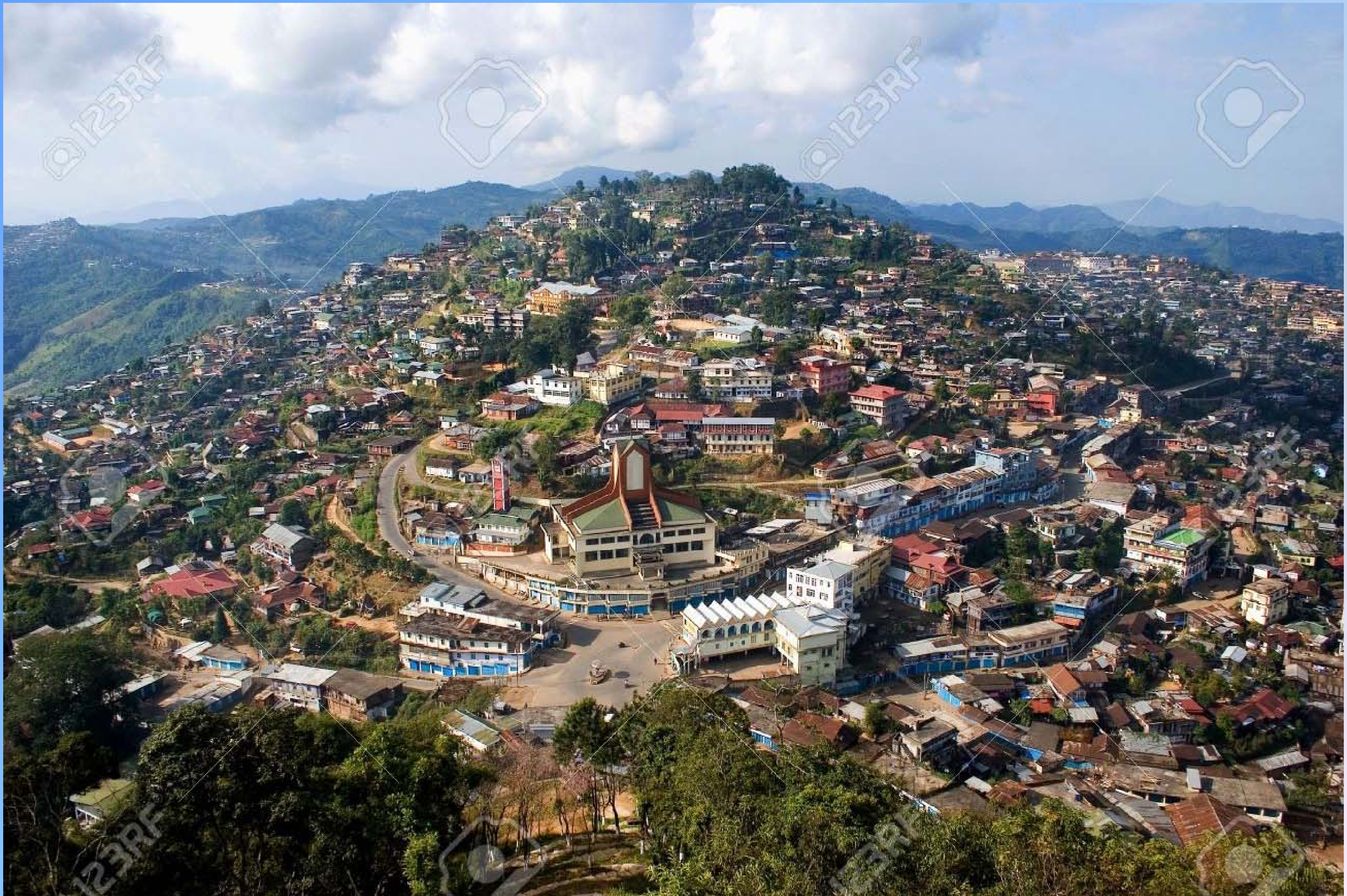
Recent dwelling pattern in NE India

The Cities in NE India

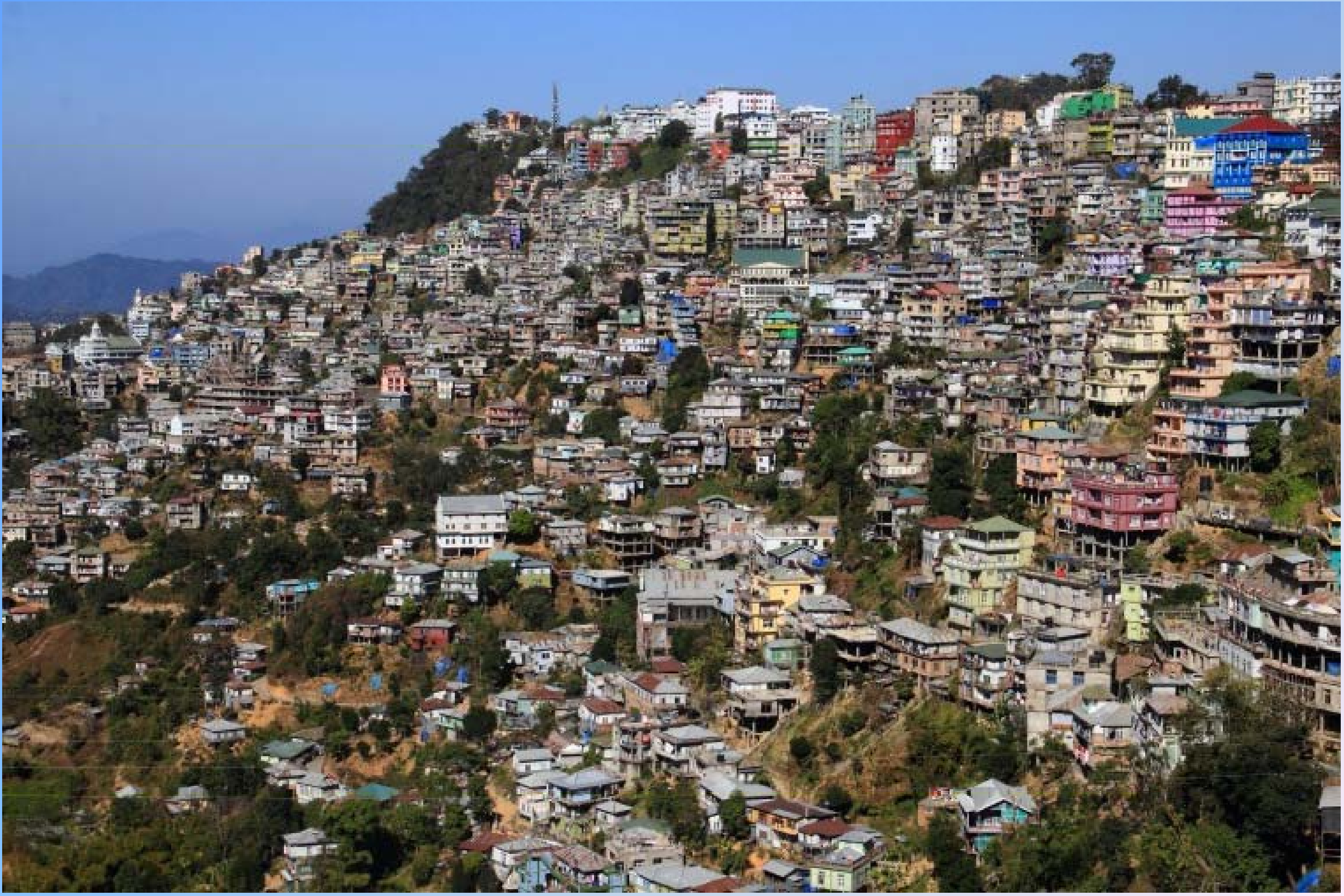


Gangtok

Kohima

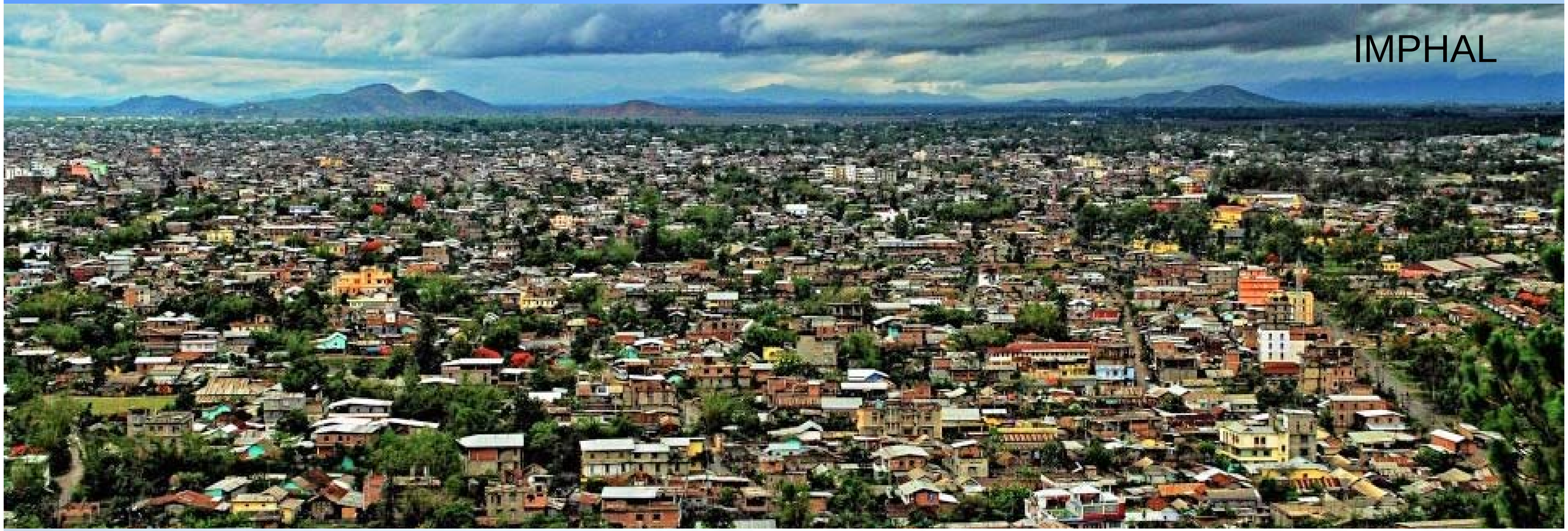


AIZAWL




ITANAGAR

GUWAHATI



IMPHAL

AGARTALA

Seismic Microzonation

- **Seismic microzonation is defined as the process of subdividing a potential seismic or earthquake prone area into zones with respect to some geological and geophysical characteristics of the sites. Such geological and geophysical characteristics are ground shaking, liquefaction susceptibility, landslide and rock-fall hazard, earthquake related flooding and others.**
- **Seismic microzoning provides detailed information on earthquake hazard on a much larger scale.**
- **It recognizes the fact that spectral acceleration values for sites within a seismic zone vary in tune with the location specific geological conditions.**
- **It therefore consists of mapping in detail all possible earthquake and earthquake-induced hazards.**
- **Seismic Microzonation include delineation of zones that are homogenous in seismological and geological characteristics**

SEISMIC SITE CHARACTERIZATION

- **Geology and geomorphology**
- **Soil condition/ mechanical & geometrical characters of sub-surface**
- **Ground water level/Permeability**
- **H/V spectral ratio to estimate amplification characteristics and predominant frequency**
- **Multi Channel Analysis of Surface Wave (MASW)**
- **Geographical distribution of site classes based on Vs^{30}**

Site Class Definitions as per International Building Code (IBC, 2009)

Site Classification	Description	Average Properties in Top 30m		
		Shear wave velocity (m/s)	SPT N (blows/300mm)	Undrained Shear Strength s_u (kPa)
A	Hard Rock	>1500	NA	NA
B	Rock	750-1500	NA	NA
C	Very dense soil and Soft rock	360-750	>50	>100
D	Stiff soil	180-360	15-50	50-100
E	Soft Soil	<180	<15	<50
		Plus any profile with more than 3m of soil having the following characteristics: Plasticity Index, PI >20% Moisture content, w ≥ 40% Undrained Shear strength, Su <25kPa		
F	Any profile containing soils with one or more of the following characteristics Soil vulnerable to potential collapse under seismic loading e.g. liquefiable soils, quick and highly sensitive clay, collapsible weakly cemented soils. Peats and/or highly organic clays (H>8m of peat and/or highly organic clay) Very high plasticity clays (H>8m with PI>75%) Very thick soft/medium stiff clays (H>36m)			





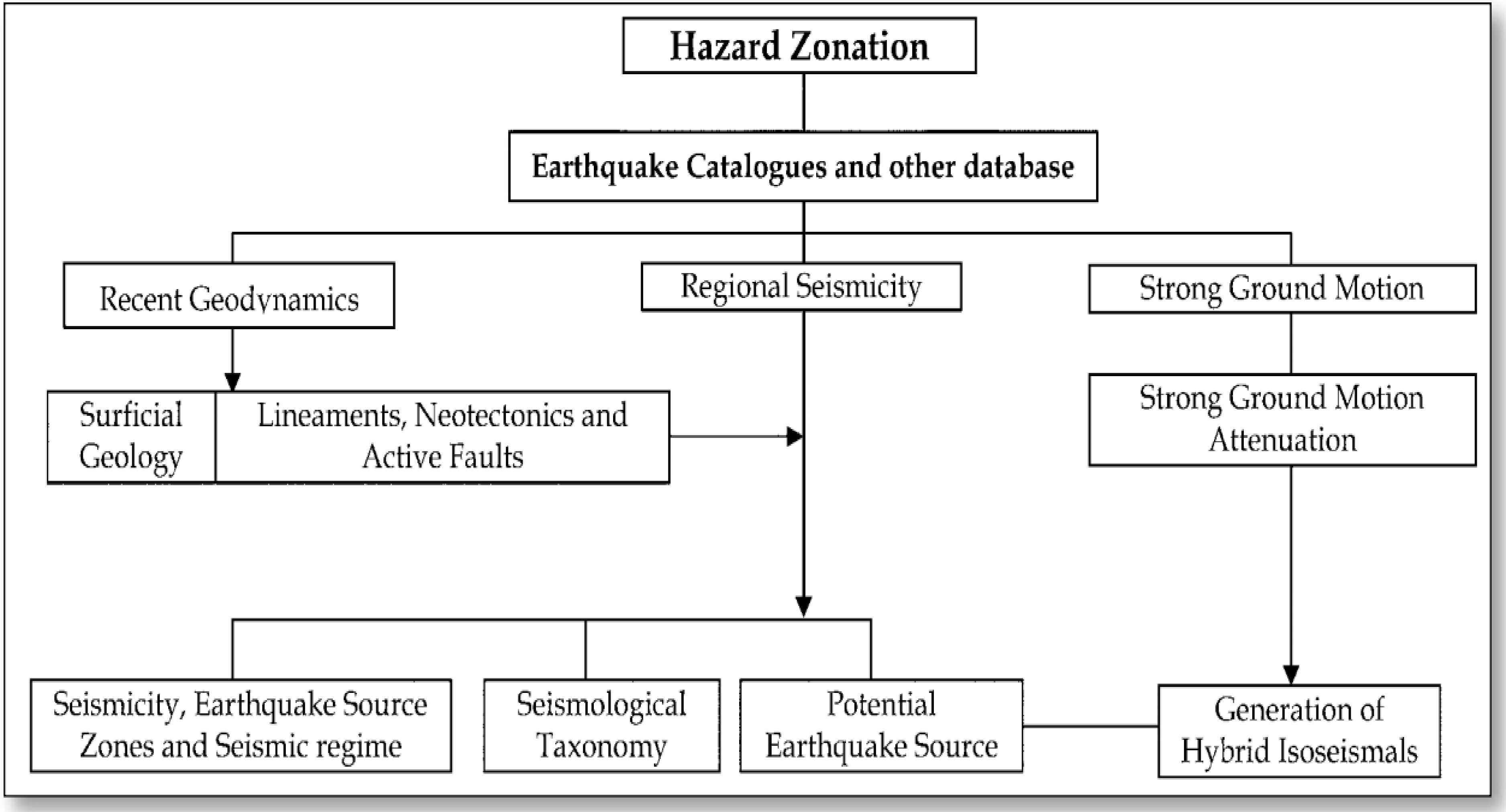
FEB 5 2005


12 DEC 2007

Use of input data depending on the scale of mapping, i.e., the level of zonation (ISSRM, 1999).

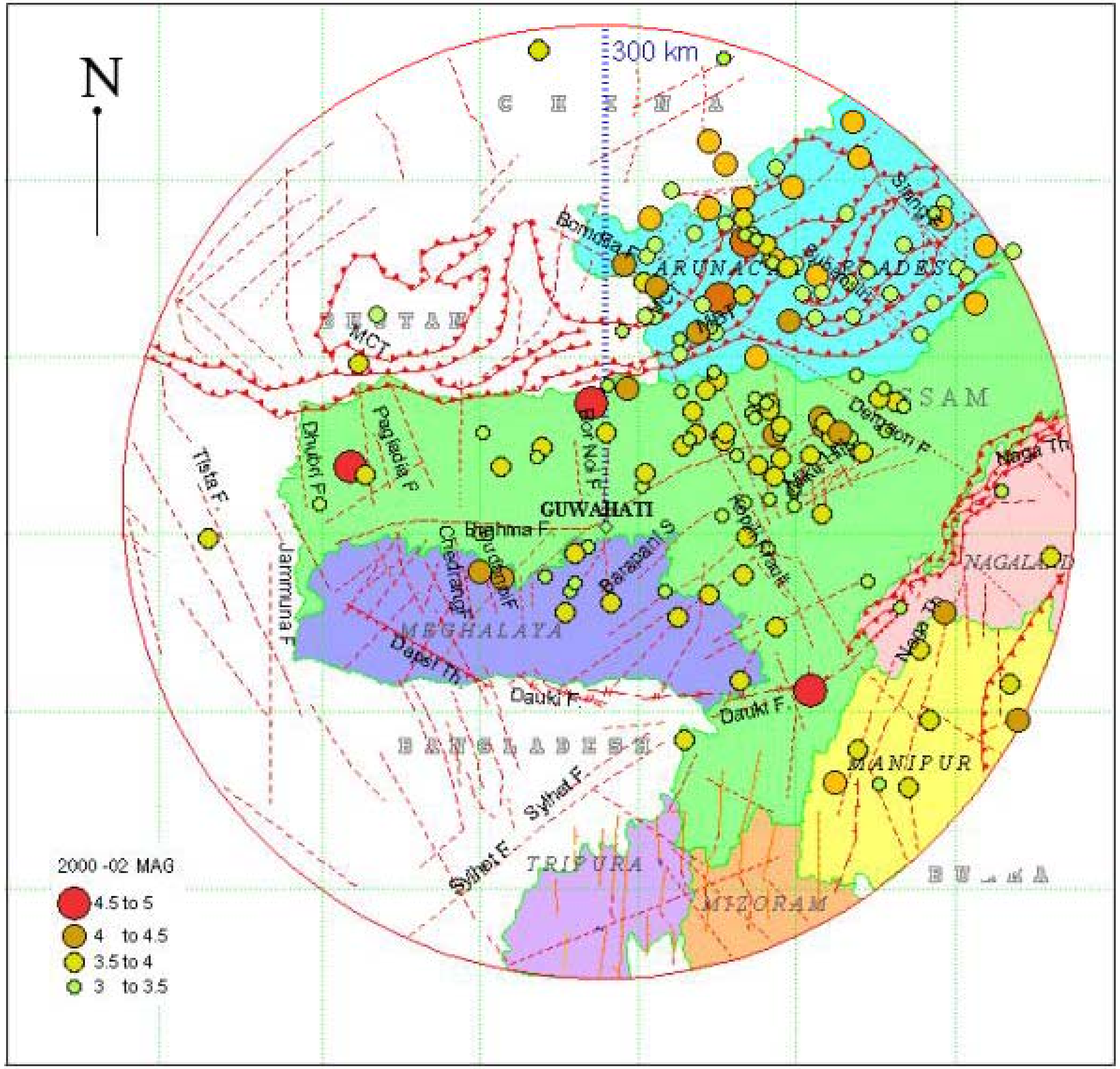
	Grade I	Grade II	Grade III
Ground motions	• historical earthquakes and existing information • geological maps • interviews with local residents	• microtremor • simplified geotechnical studies	• geotechnical investigations • ground response analysis
Slope instability	• historical earthquakes and existing information • geological and geomorphologic maps	• air photos and remote sensing • field studies • vegetation and precipitation data	• geotechnical investigations • analysis
Liquefaction	• historical earthquakes and existing information • geological and geomorphologic maps	• air photos and remote sensing • field studies • interviews with local residents	• geotechnical investigations • analysis
Scale of mapping	1:1000000–1:50000	1:100000–1:10000	1:25000–1:5000

ISSRM: International Symposium on Society and Resource Management



Hazard Zonation
Earthquake Catalogues and other database
Recent Geodynamics
Regional Seismicity
Strong Ground Motion
Surficial Geology
Lineaments, Neotectonics and Active Faults
Strong Ground Motion Attenuation
Seismicity, Earthquake Source Zones and Seismic regime
Seismological Taxonomy
Potential Earthquake Source
Generation of Hybrid Isoseismals

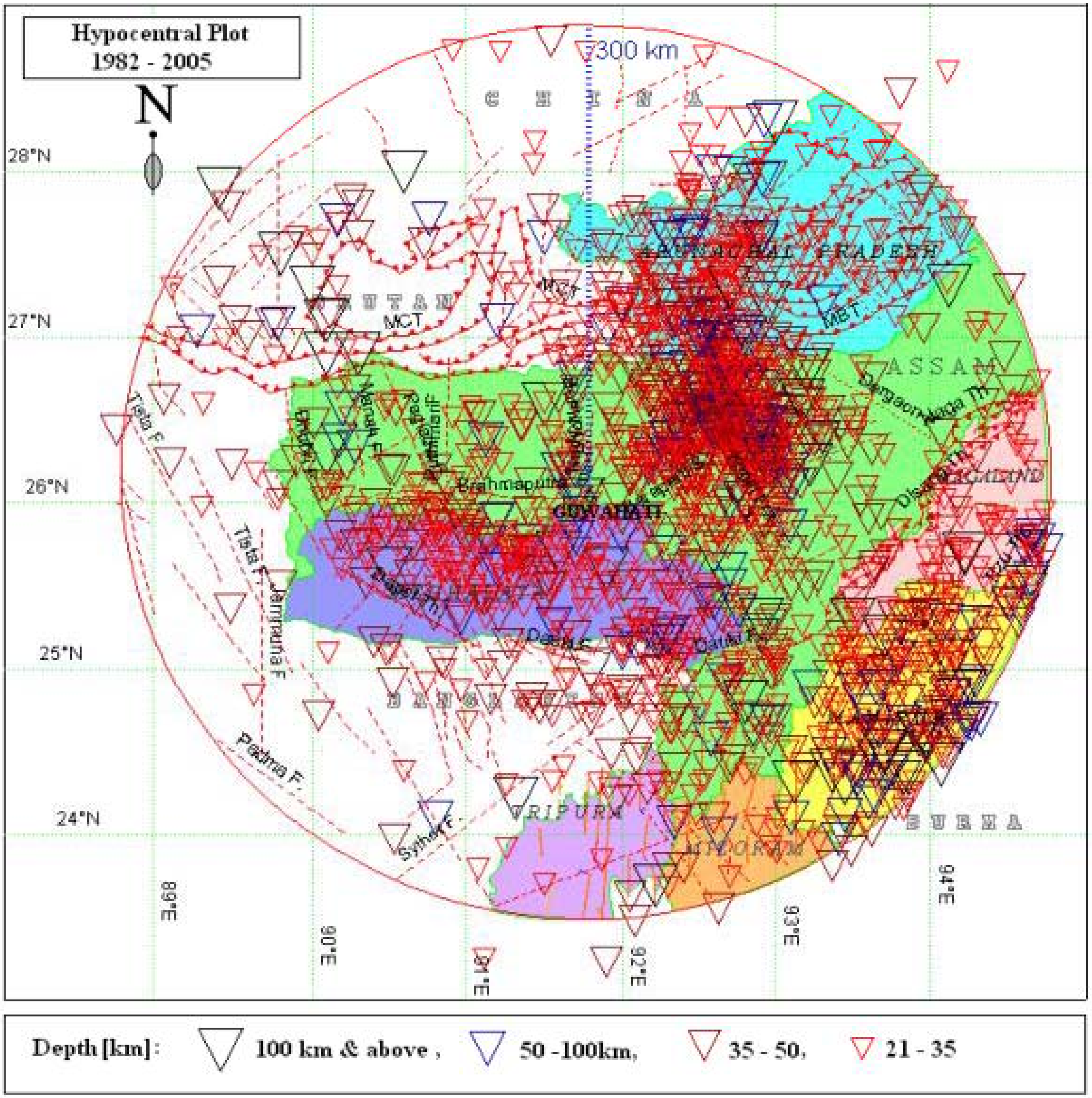
Seismic Activity along major Tectonic Lineaments
[300 km radius of greater Guwahati]
Year 2000 -2002



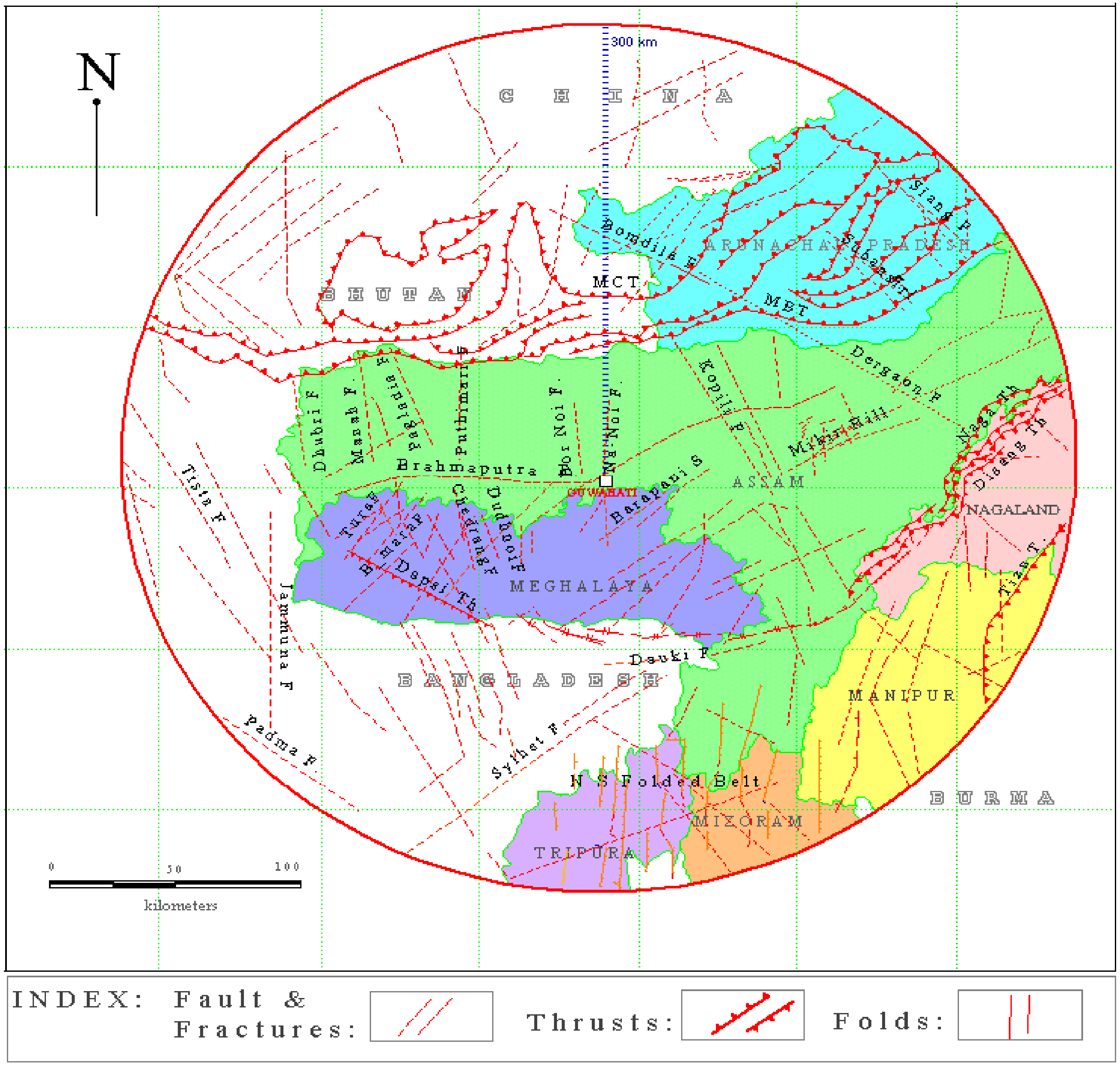
Seismic Activity along major Tectonic lineaments

Hypocentral distribution, 300km radius of greater Guwahati

Year 1982 – 2005



Major Lineaments within 300km radius of greater Guwahati



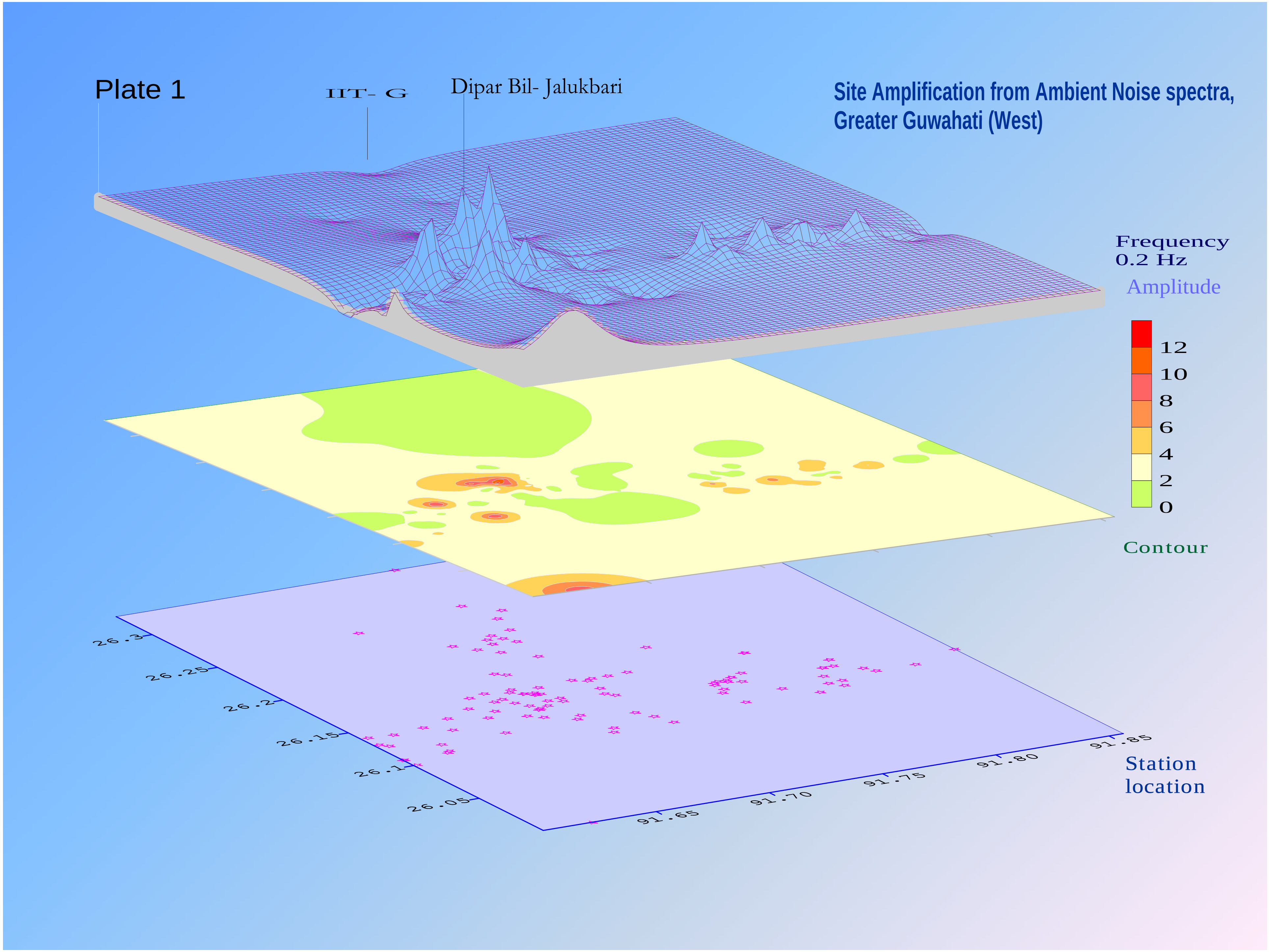


Plate 1
IIT- G
Dipar Bil- Jalukbari
Site Amplification from Ambient Noise spectra, Greater Guwahati (West)
Frequency 0.2 Hz
Amplitude
12
10
8
6
4
2
0
Contour
26.3
26.25
26.2
26.15
26.1
26.05
91.65
91.70
91.75
91.80
91.85
Station location

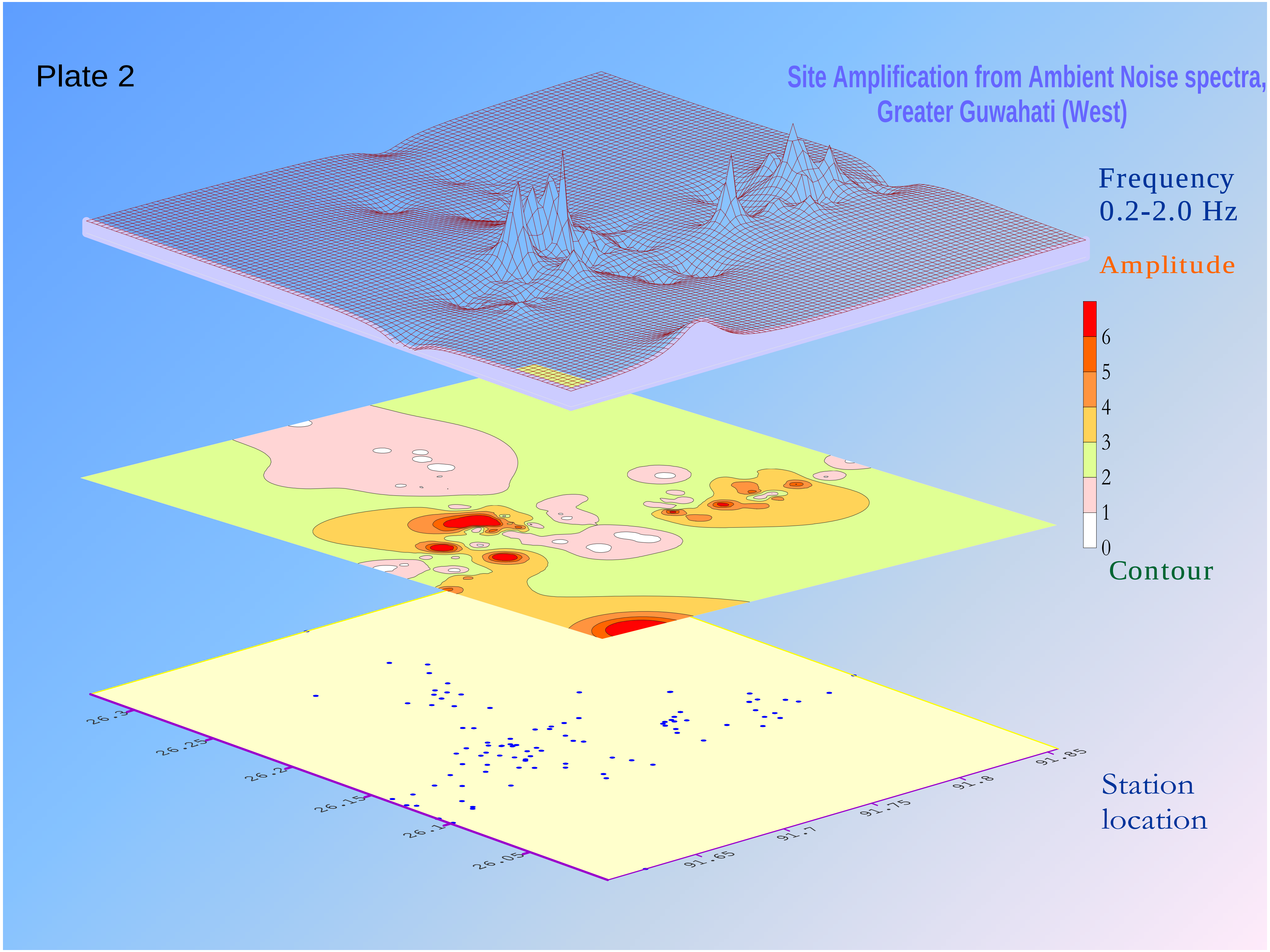


Plate 2
Site Amplification from Ambient Noise spectra,
Greater Guwahati (West)
Frequency
0.2-2.0 Hz
Amplitude
6
5
4
3
2
1
0
Contour
Station
location
26.3
26.25
26.2
26.15
26.1
26.05
91.65
91.7
91.75
91.8
91.85

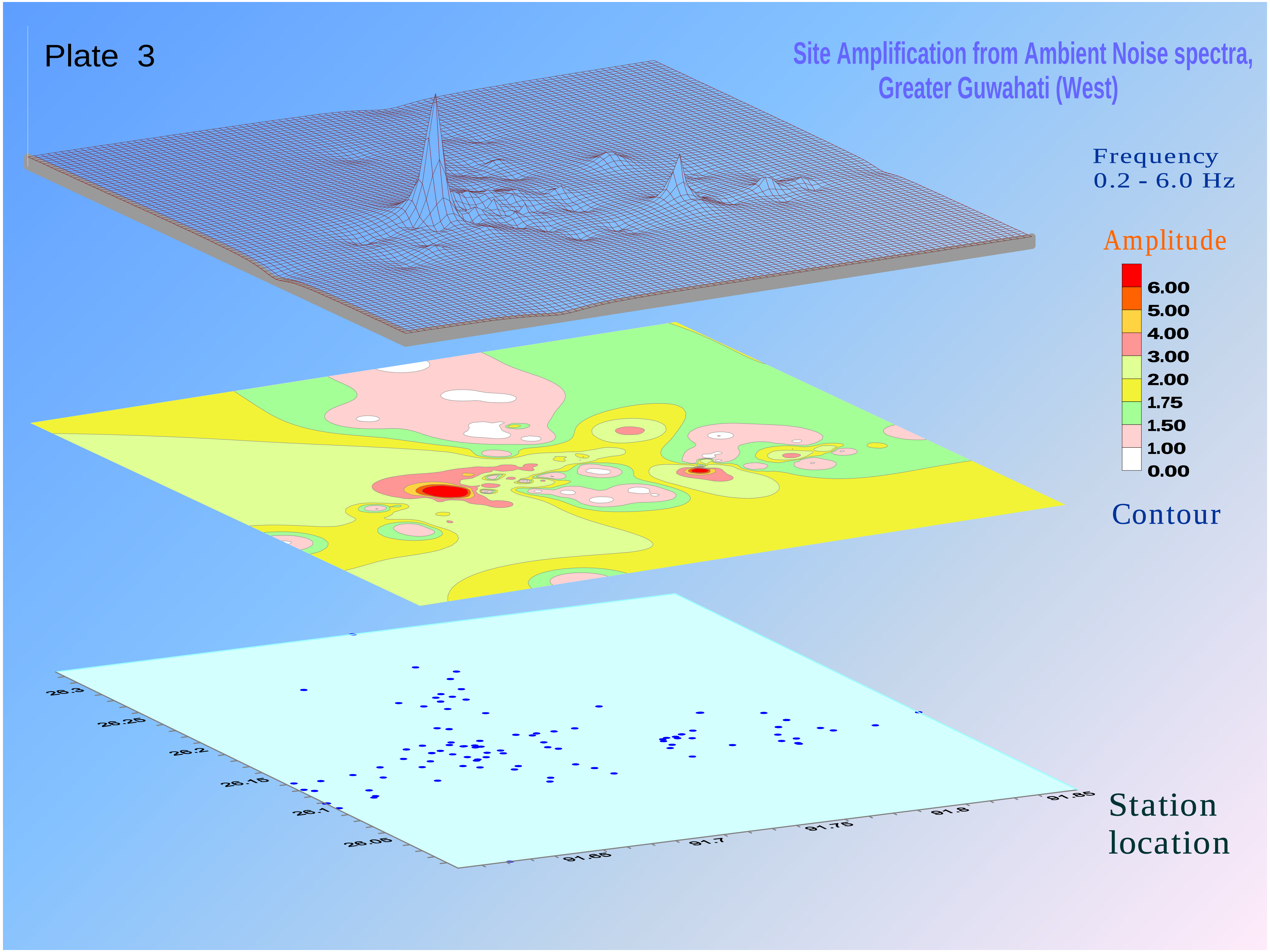
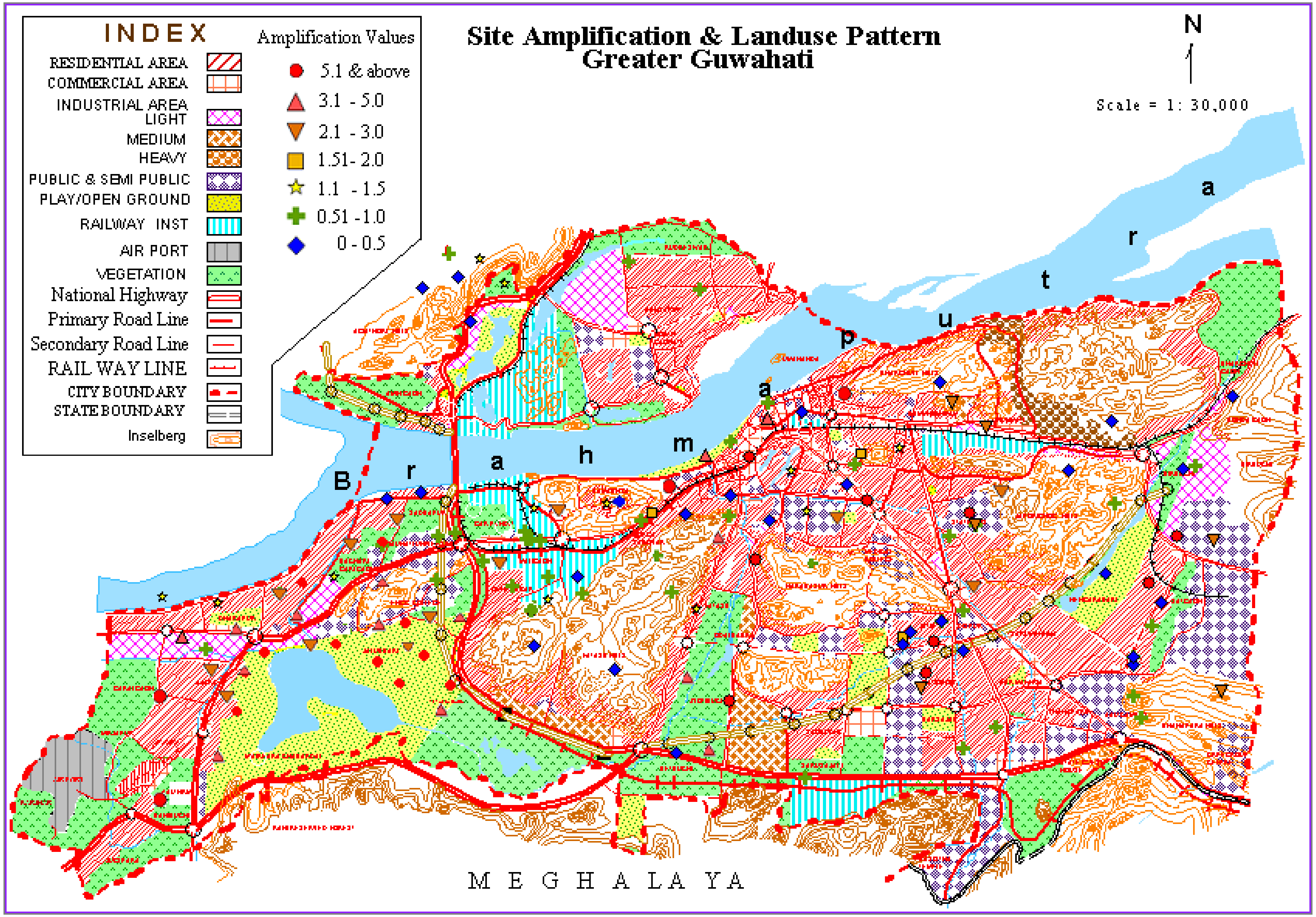


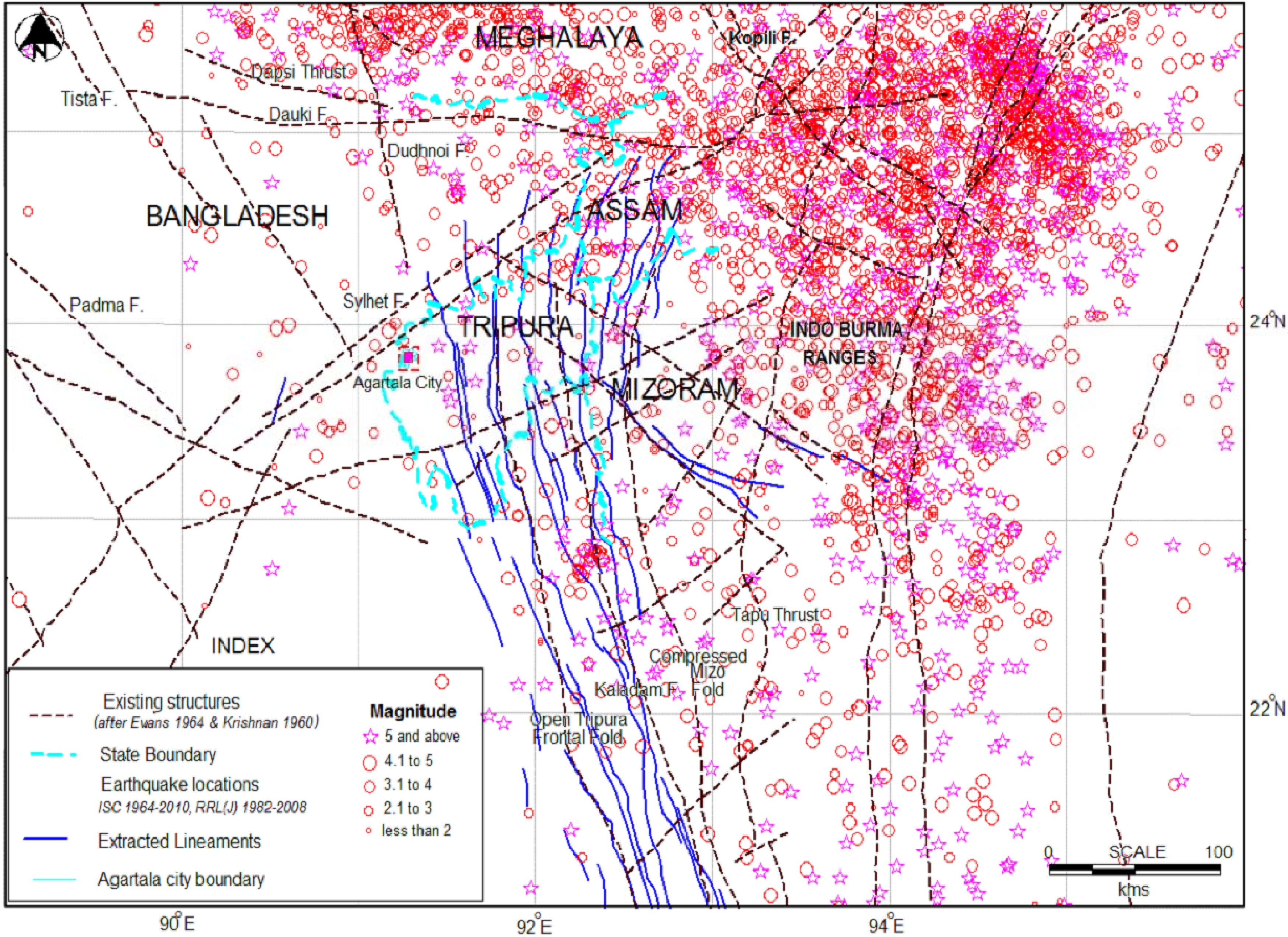
Plate 3
Site Amplification from Ambient Noise spectra,
Greater Guwahati (West)
Frequency
0.2 - 6.0 Hz
Amplitude
6.00
5.00
4.00
3.00
2.00
1.75
1.50
1.00
0.00
Contour
Station
location
26.3
26.25
26.2
26.15
26.1
26.05
91.65
91.7
91.75
91.8
91.85

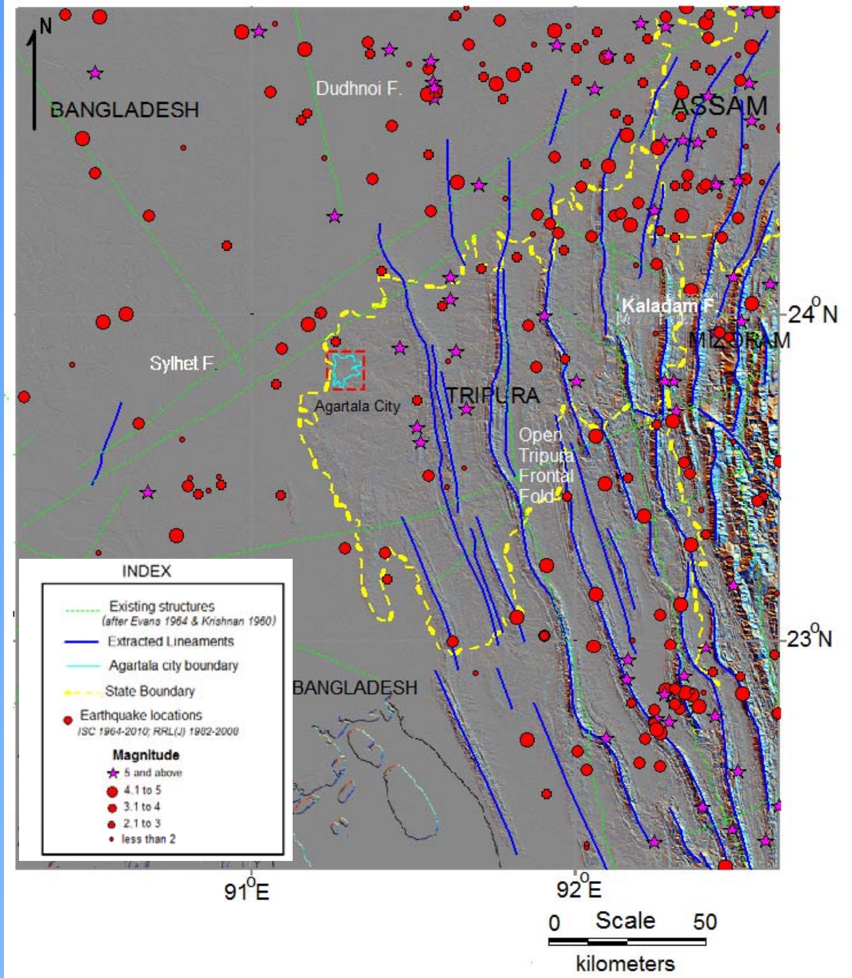


Site Amplification & Landuse Pattern
Greater Guwahati
N
Scale = 1: 30,000
INDEX
RESIDENTIAL AREA
COMMERCIAL AREA
INDUSTRIAL AREA
LIGHT
MEDIUM
HEAVY
PUBLIC & SEMI PUBLIC
PLAY/OPEN GROUND
RAILWAY INST
AIR PORT
VEGETATION
National Highway
Primary Road Line
Secondary Road Line
RAIL WAY LINE
CITY BOUNDARY
STATE BOUNDARY
Inselberg
Amplification Values
5.1 & above
3.1 - 5.0
2.1 - 3.0
1.51- 2.0
1.1 - 1.5
0.51 - 1.0
0 - 0.5
B r a h m a p u t r a
M E G H A L A YA

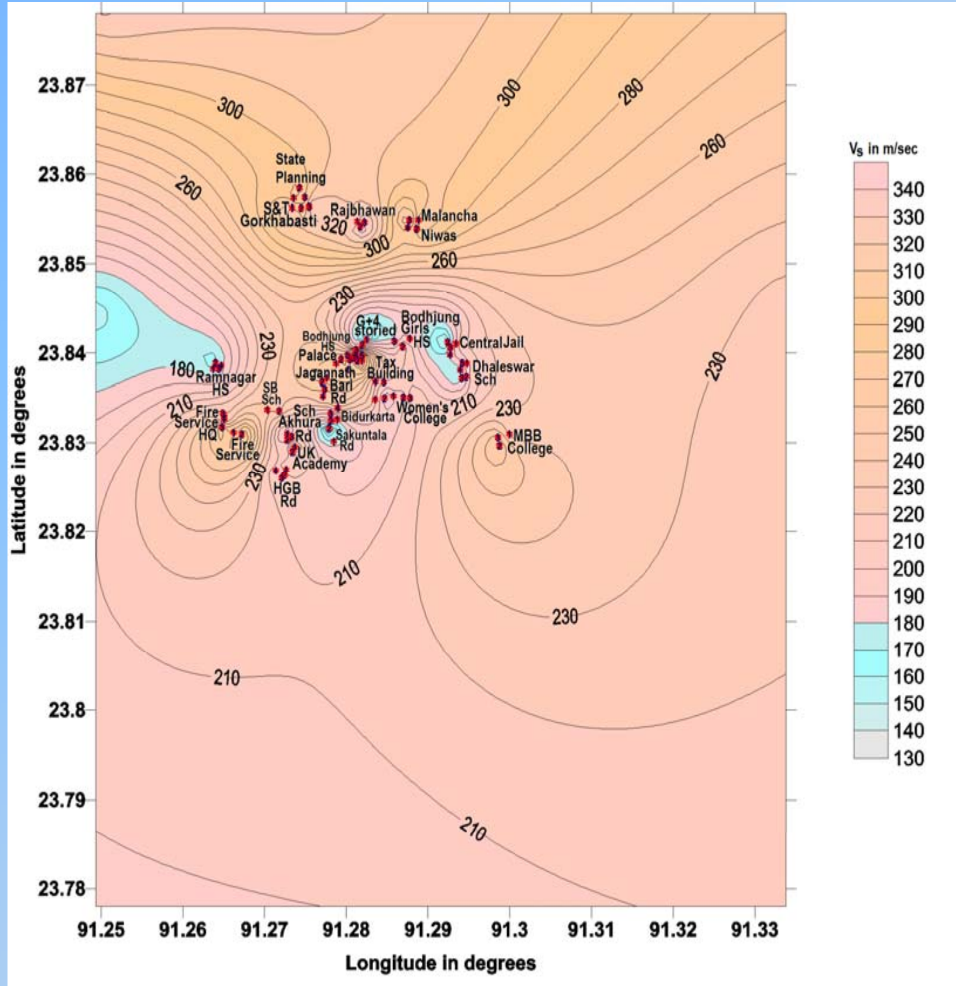
Seismicity in and around Agartala, Tripura

JHI LOCAL SEISMIC NETWORK 1982-2010



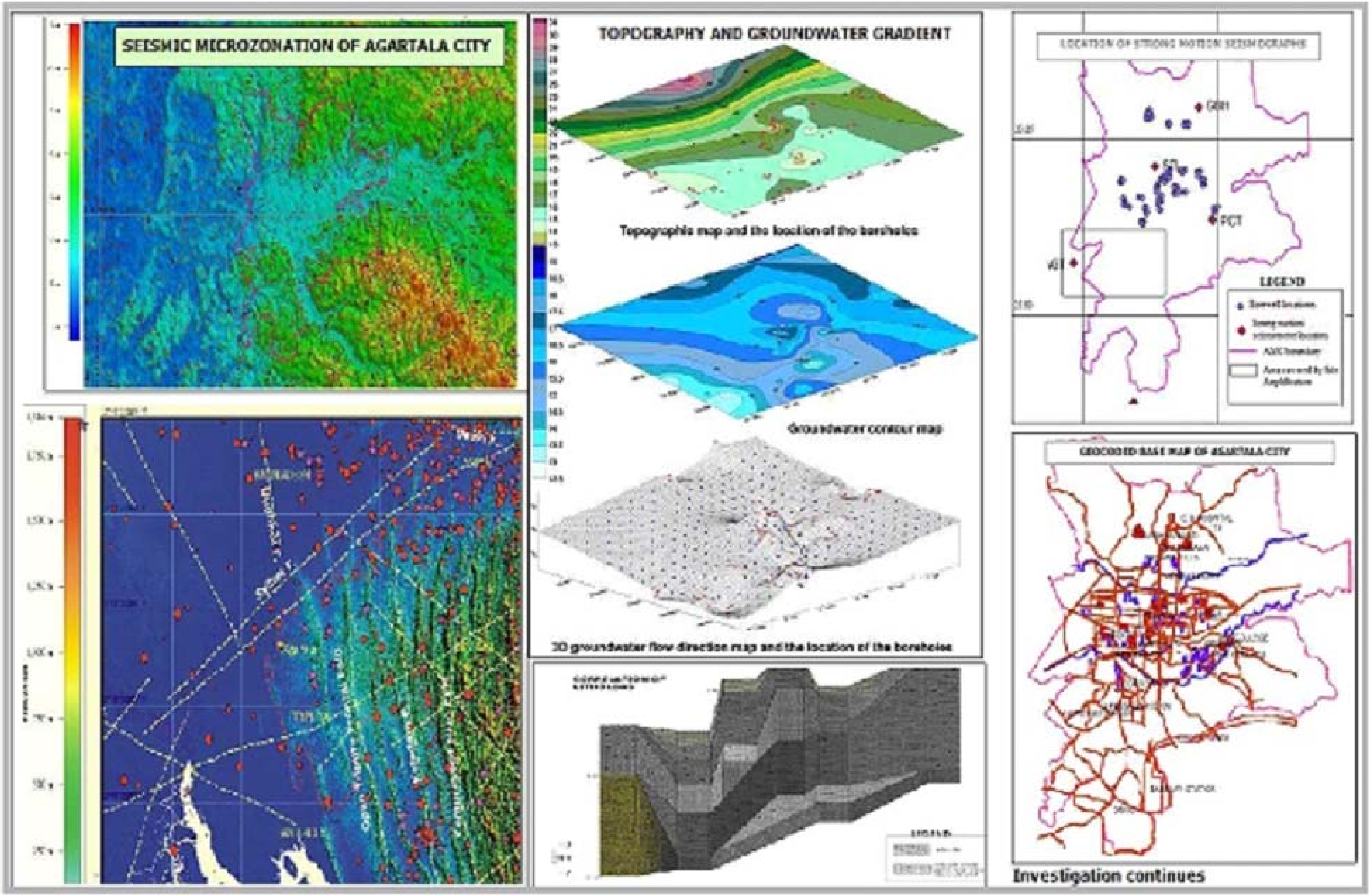


Identification of Lineaments

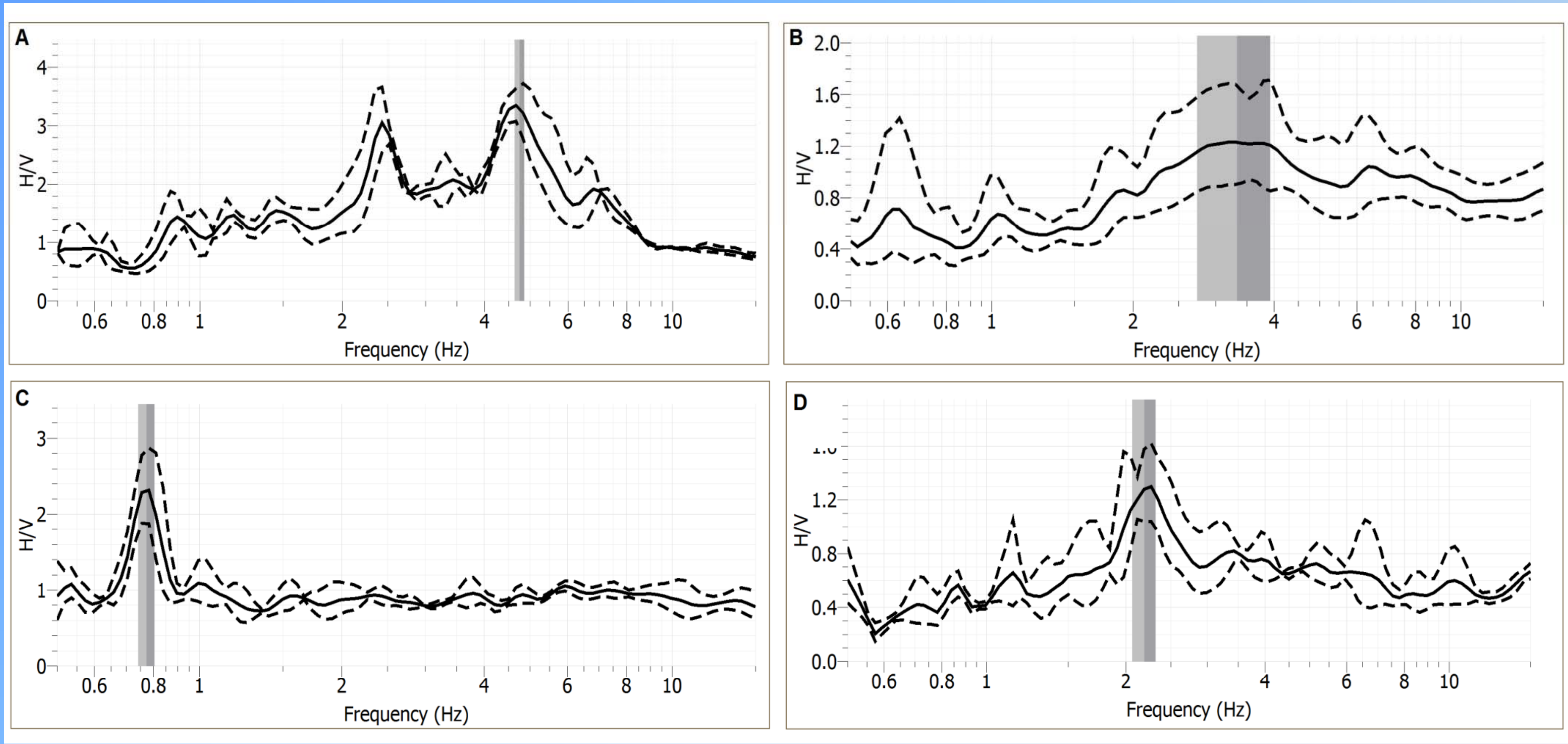


Shear wave velocity map using empirical relation by Imai and Tonouchi (1982). Shear wave velocity corresponds to Soil type 'D' & 'E' (site classification of NEHRP, Romero & Rix, 2001). Most of the city area is composed of stiff soil (Vs 180-340m/s); some small patches of soft clay (Vs 130-180m/s) localised in the central and western parts are observed

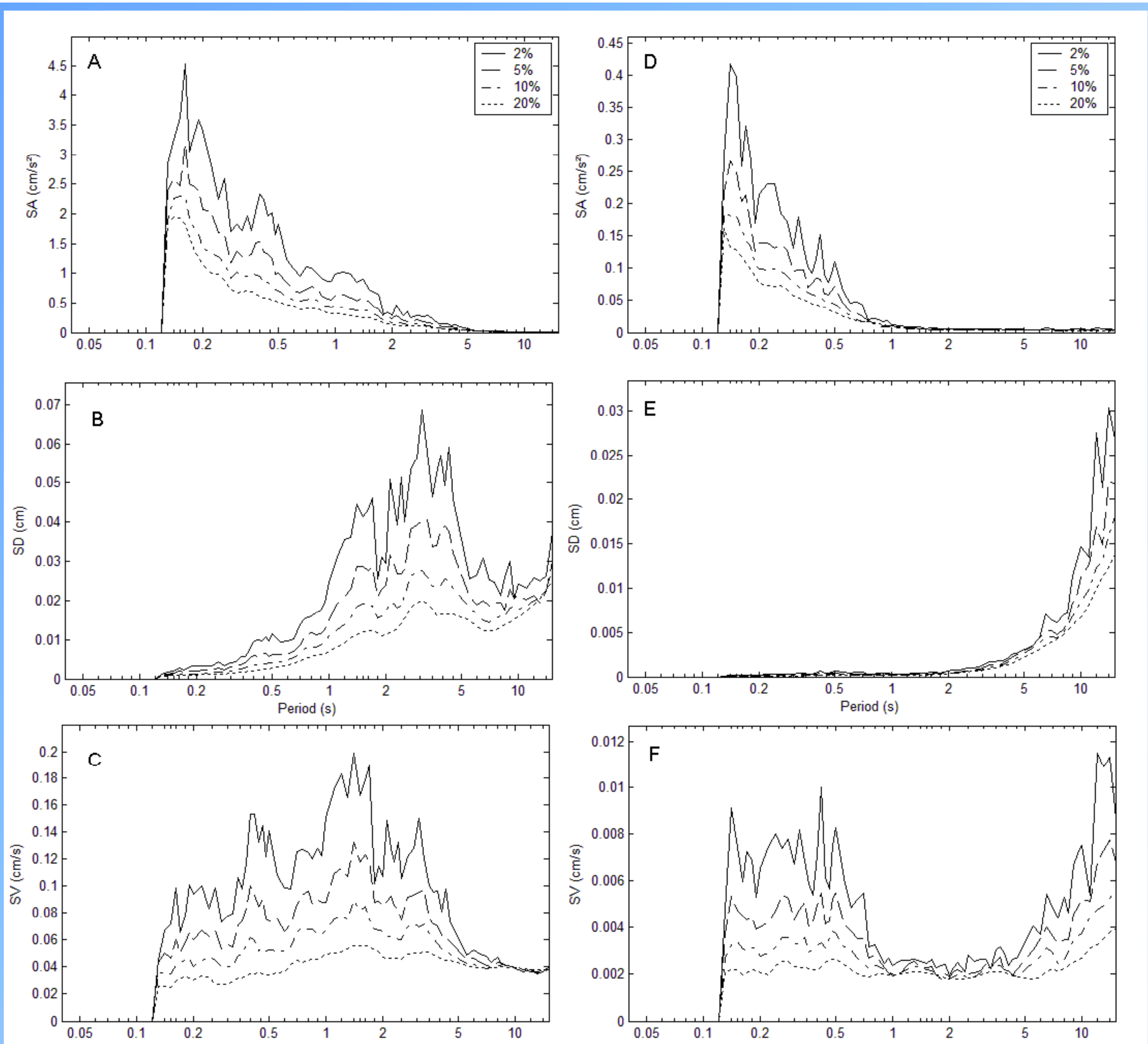
Seismic Site Amplification Study of Agartala City



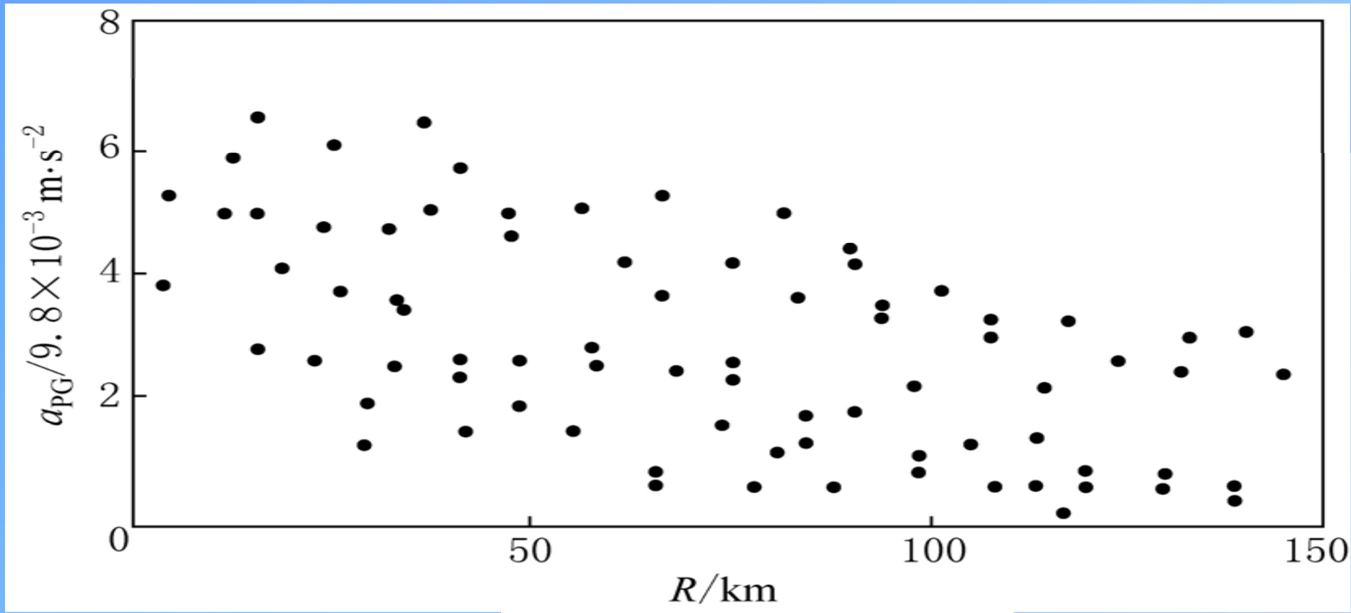
Investigation continues



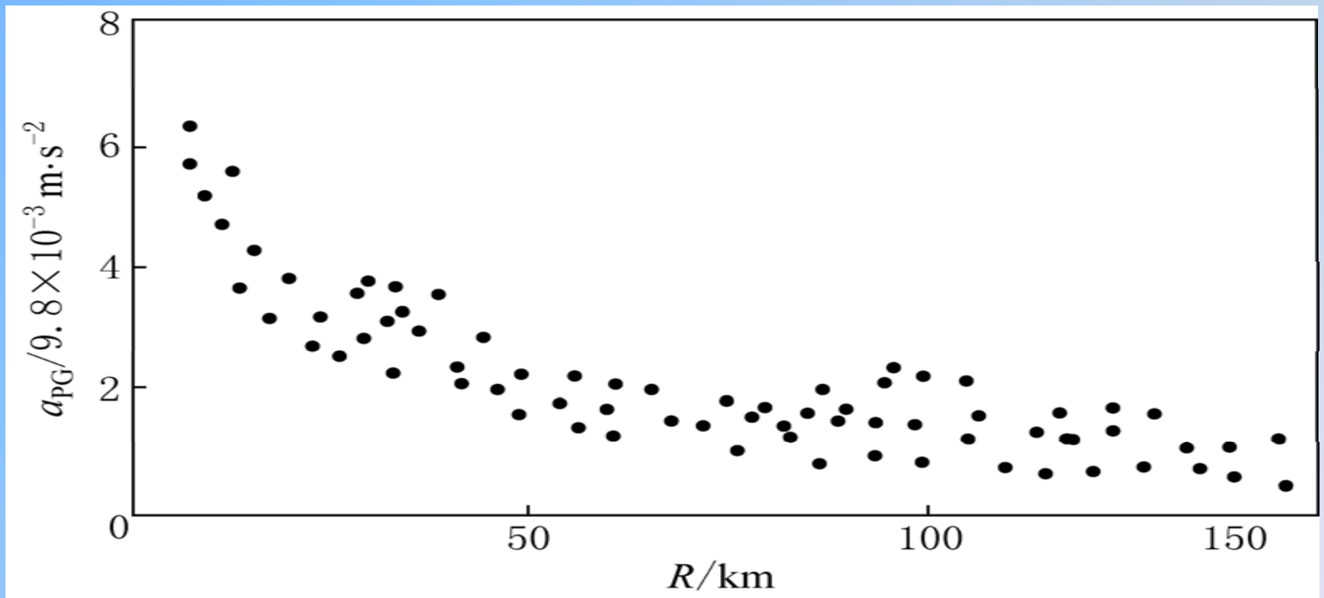
Examples of average H/V spectra (solid lines) with $\pm 1\sigma$ (dashed lines). Spectra representative of – A) stiff silty clayey soil, B) hard silty soil, C) soft sandy soil, D) sandy soil.



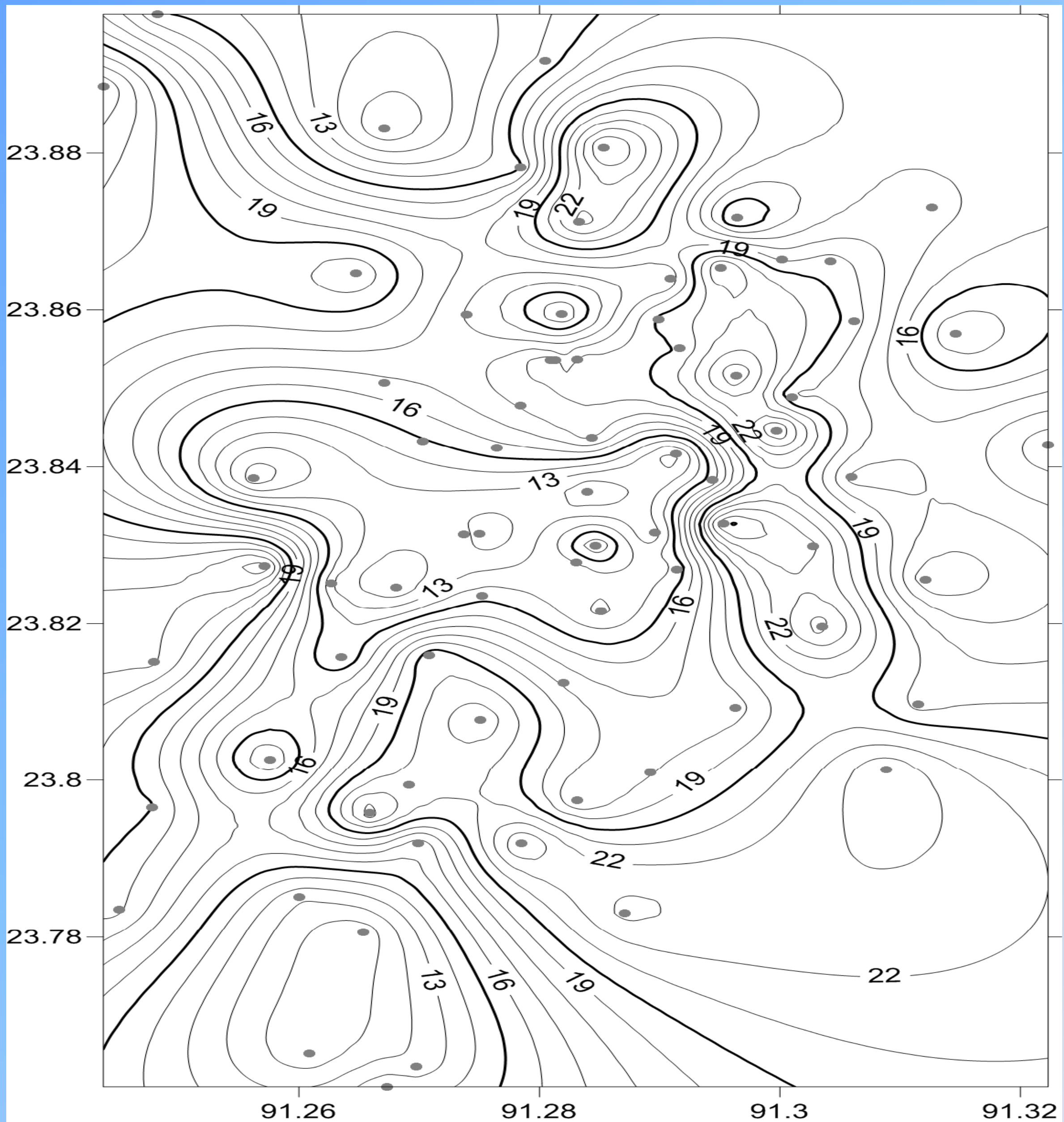
Response spectra showing acceleration (A&D), displacement (B&E) and velocity (C&F) at 2%, 5%, 10% and 20% damping for two events. A, B & C shows acceleration, displacement and velocity response spectra respectively for a M5.8 event and D, E & F shows acceleration, displacement and velocity response spectra respectively for a M3.6 events. Both the events originated at Indo-Burma border area.



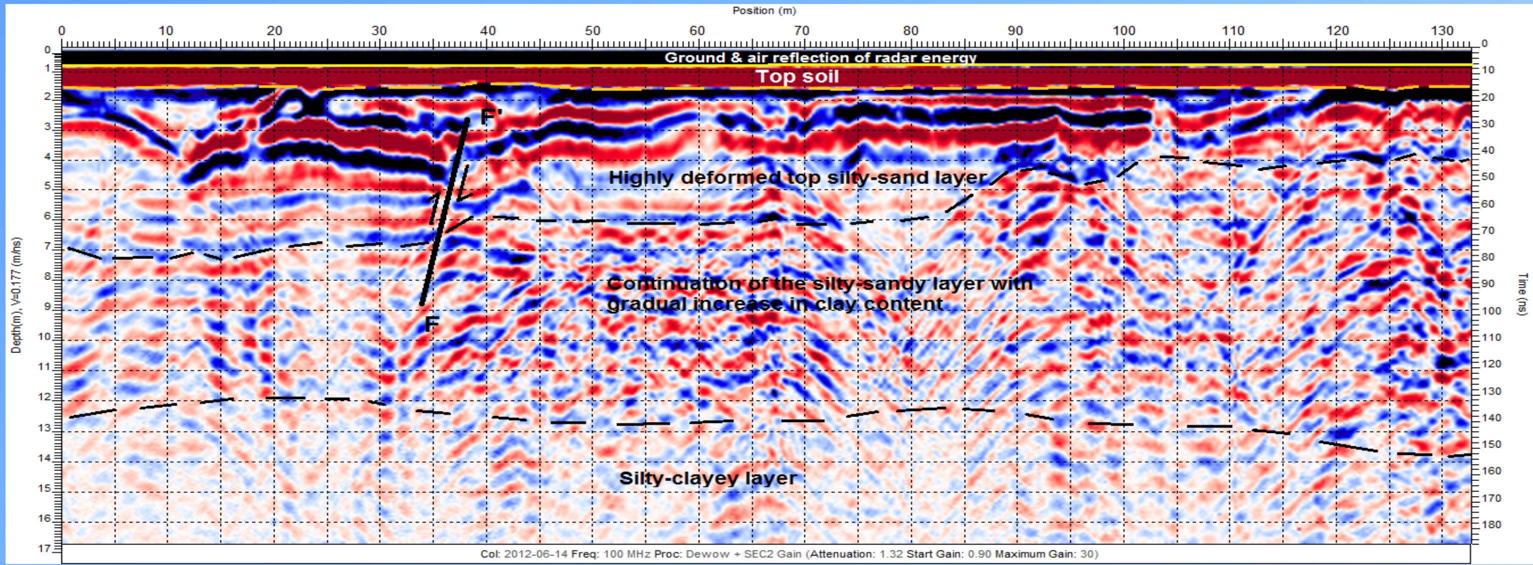
Observed PGA

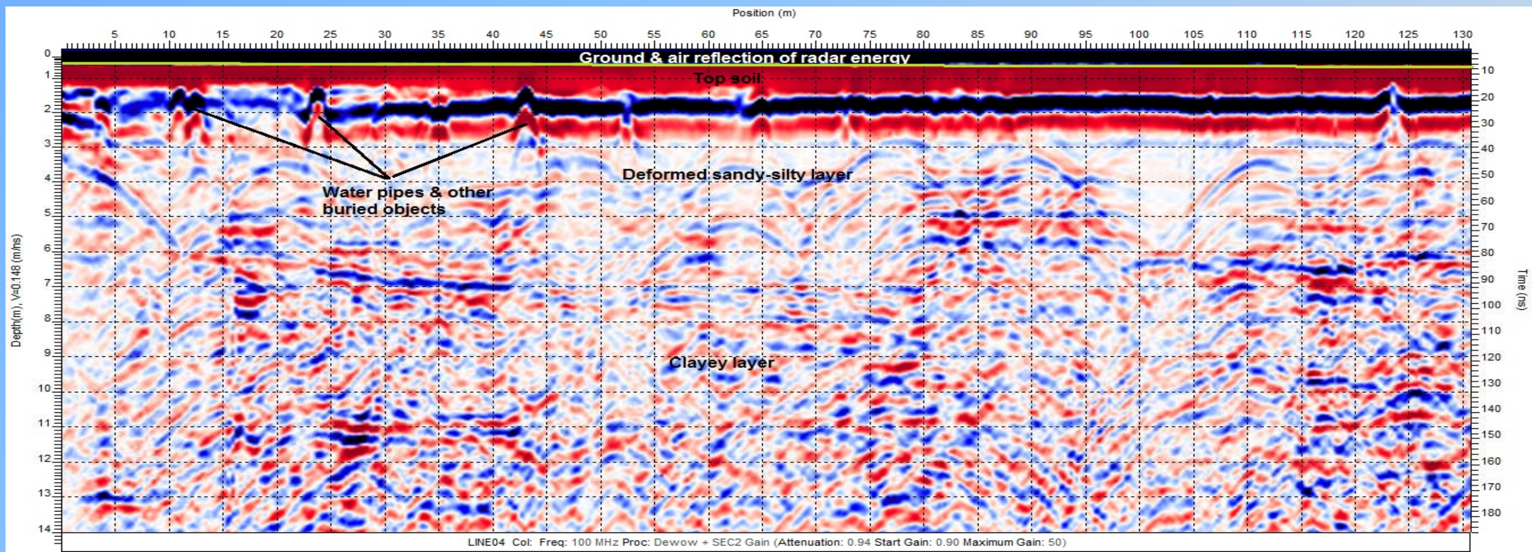


Estimated PGA vs Epicentral Distance



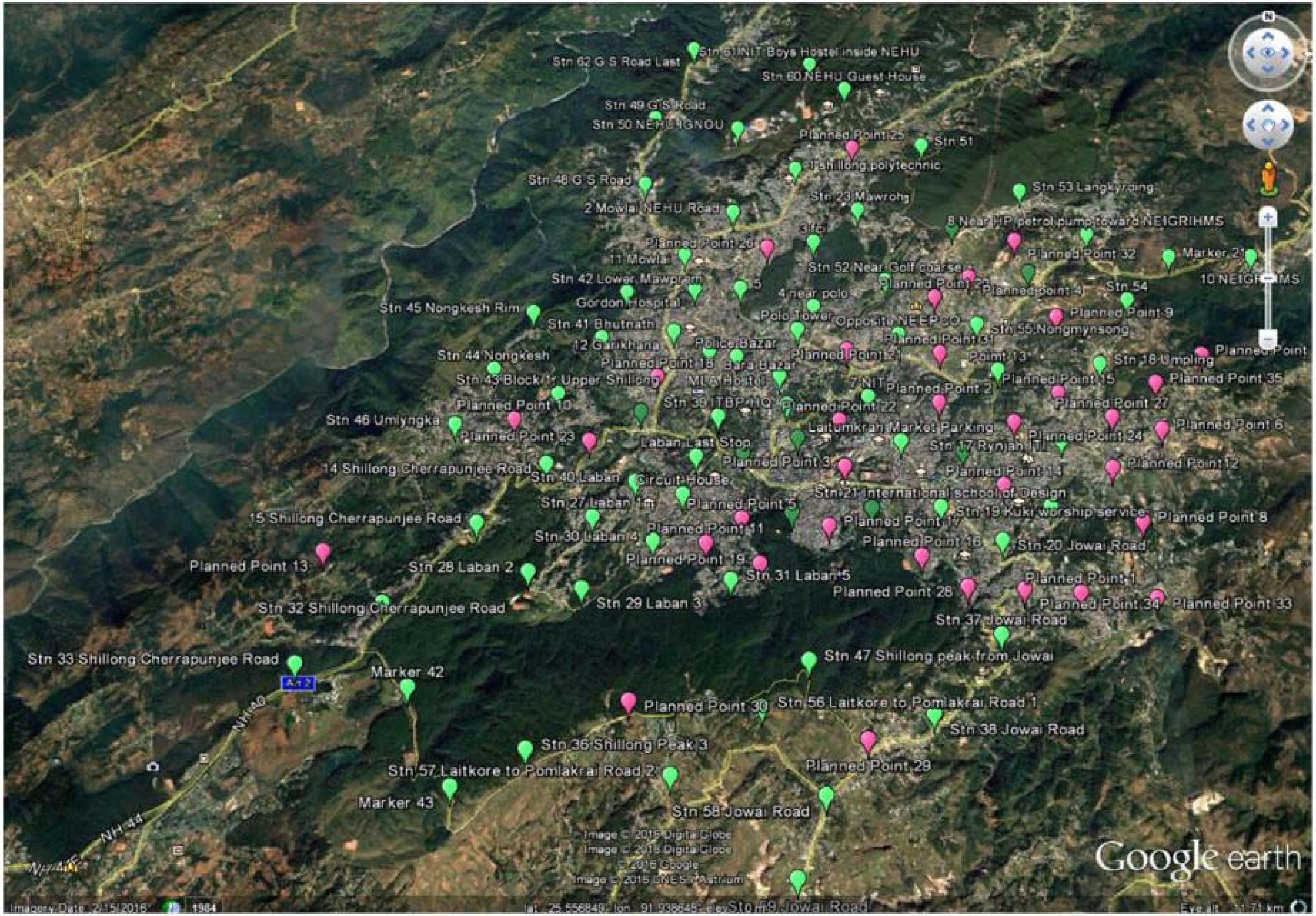
Soil thickness contour map of the area. The grey circles show the locations of ambient noise survey points.



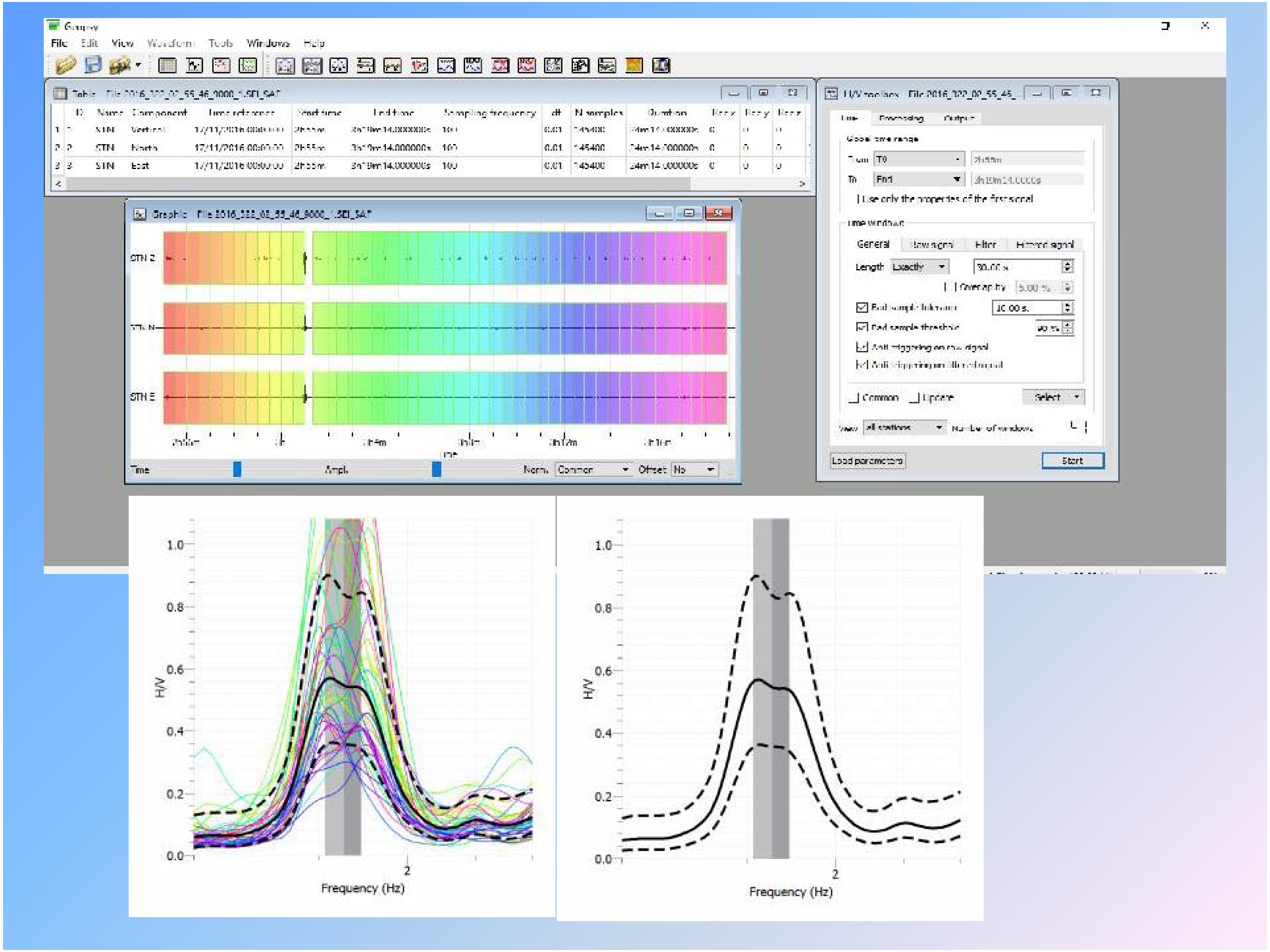


GPR section showing three distinct layers. Recent deformation in the form of faults and minor foldings can be easily visible. Hyperbolas are indicative of water pipes and other buried objects. Frequent lateral variation of lithology is very distinct in the GPR section.

SEISMIC SITE AMPLIFICATION OF GREATER SHILLONG CITY



Seismic Ambient Noise Survey covering Shillong city and neighbouring areas



File Edit View Waveform Tools Windows Help
STN Z
STN E
Time
Ampl.
Norm. Common
Offset No
General
Length Exactly
Load parameters
Start
H/V
1.0
0.8
0.6
0.4
0.2
0.0
2
Frequency (Hz)
H/V
1.0
0.8
0.6
0.4
0.2
0.0
2
Frequency (Hz)

Work done so far:

Acquisition, processing and analysis of seismic ambient noise data from 130 sites covering greater Shillong city

Estimation of amplification factor of all the sites with corresponding predominant frequencies

Acquired Ground Penetrating Radar (GPR)
data, processed and comparison with geological & geotechnical data

Acquired Very Low Frequency (VLF) data to compare with geological information

Integration of all the data to prepare comprehensive site amplification & predominant frequency map


TILTING DUE TO SOIL LIQUEFACTION
3 2 '01

Bhuj Earthquake 2001

Collapse of a water tank near Manfara

The Jubilee Hospital, Bhuj

Damage to Railway Bridge

GK Gen Hospital, Bhuj

Sikkim Earthquake 2011

Damaged Water Supply Pipleline

Damaged school building

Extensive damage to buildings supporting the mobile communication towers and dish antennae

2015 NEPAL Earthquake

THANK YOU