インドネシア南スマトラ地震

(地震の概要と地盤，構造物の被害)

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南スマトラ地震調査団長

土木学会　地震工学委員会　地震被害研究小委員会

(東海大学　海洋建設工学科)

土木学会　　日本建築学会

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Ömer AYDAN

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Andalas University

Ismail FEBRIN

Abdul HAKAM

Mas MERA

KOGAMI (Tsunami Alert Community-NPO)

Patra Rina DEWI

調査期間とルート

LOCATION・位置

調査期間：10月4日ー10月9日

地震の主な特徴

9月12日　6:10PM (11:10UTC)　M8.4 (陸に遠い・ベンクル州)

9月13日　6:49AM (23:49UTC)　M7.9 (陸に近い・西スマトラ州)

9月13日　10:35AM (03:35UTC)　M7.1 (北Pagai島に近い)

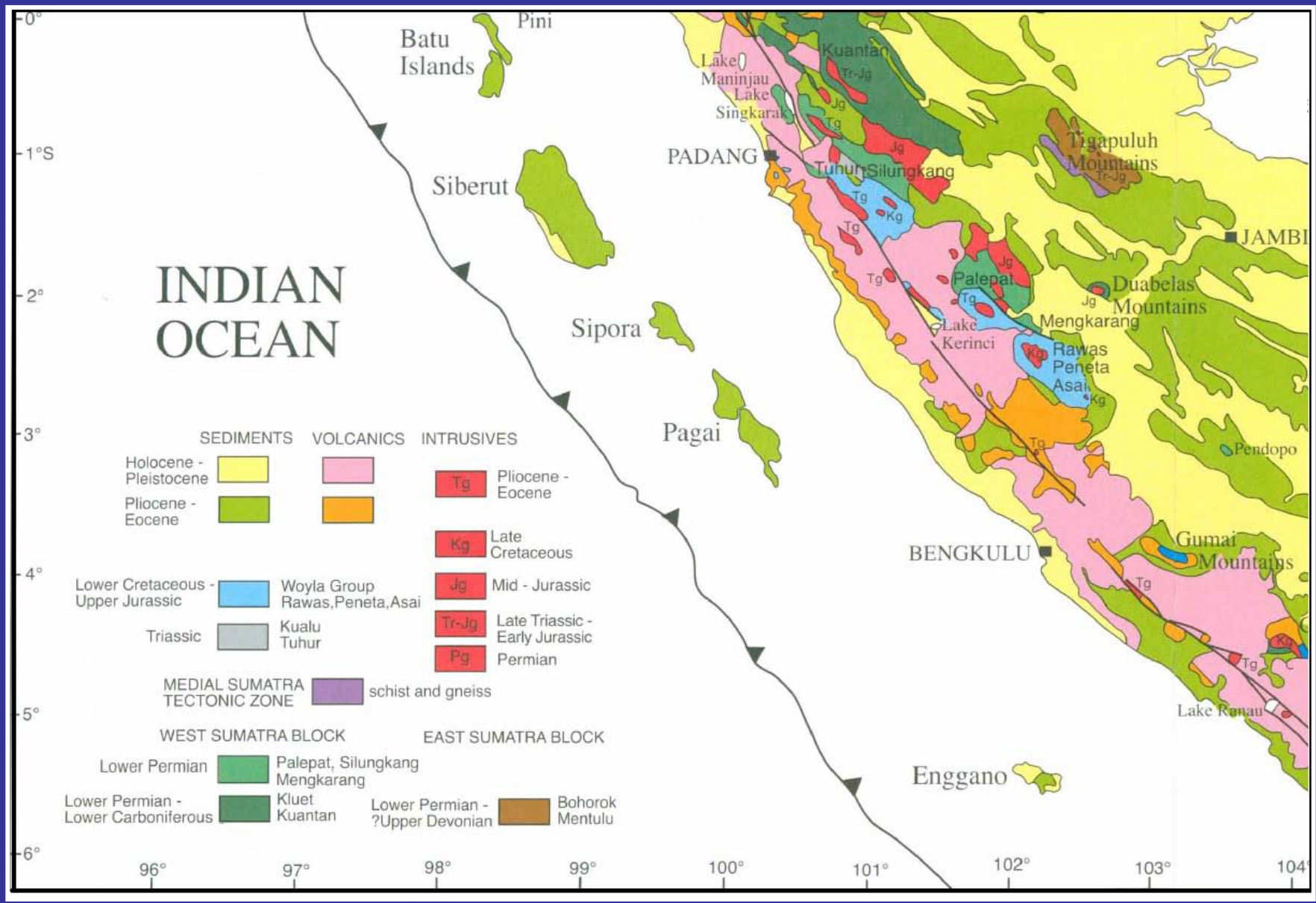
地域	*死者*	重怪我人	軽怪我人
Bengkulu	15	12	26
West Sumatra	10	29	25
Total	25	41	51

Bengkulu-建築物:　7,360崩壊；16,810 重損傷；35,041軽損傷

West Sumatra-建築物:　32,600損傷

Jambi-建築物:　8 重損傷；63軽損傷

GEOLOGY – 地質


INDIAN OCEAN
Batu Islands
Pini
Siberut
Sipora
Pagai
Enggano
PADANG
JAMBI
BENGKULU
Lake Maninjau
Lake Singkarak
Kuantan
Tuhur
Silungkang
Palepat
Mengkarang
Lake Kerinci
Rawas
Peneta
Asai
Tigapuluh Mountains
Duabelas Mountains
Gumai Mountains
Pendopo
Lake Ranau
SEDIMENTS
VOLCANICS
INTRUSIVES
Holocene - Pleistocene
Pliocene - Eocene
Tg Pliocene - Eocene
Kg Late Cretaceous
Lower Cretaceous - Upper Jurassic
Woyla Group Rawas,Peneta,Asai
Jg Mid - Jurassic
Triassic
Kualu Tuhur
Tr-Jg Late Triassic - Early Jurassic
Pg Permian
MEDIAL SUMATRA TECTONIC ZONE
schist and gneiss
WEST SUMATRA BLOCK
EAST SUMATRA BLOCK
Lower Permian
Palepat, Silungkang Mengkarang
Lower Permian - Lower Carboniferous
Kluet Kuantan
Lower Permian - ?Upper Devonian
Bohorok Mentulu
0°
1°S
2°
3°
4°
5°
6°
96°
97°
98°
99°
100°
101°
102°
103°
104°

Geology in the vicinity of Ketaun Shore

NE

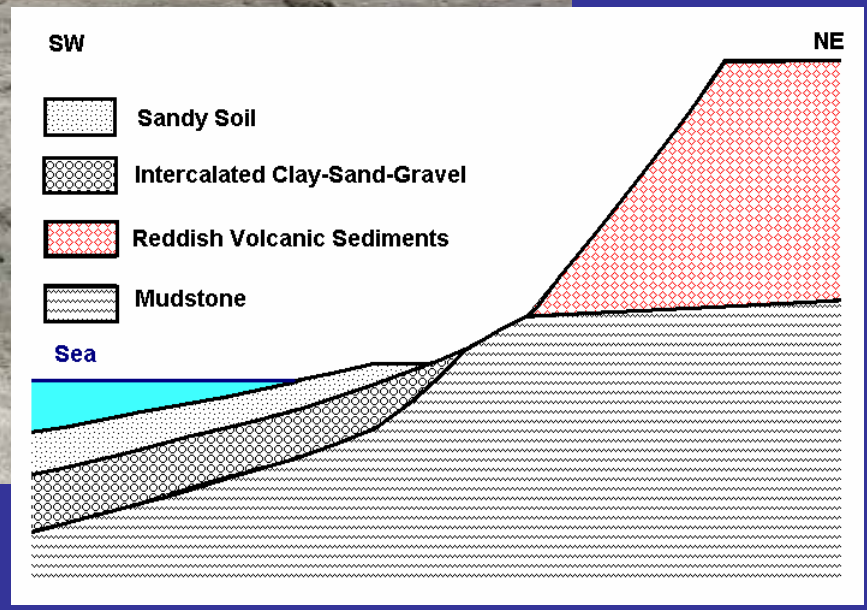
Redish Volcanic Sediments

Mudstone

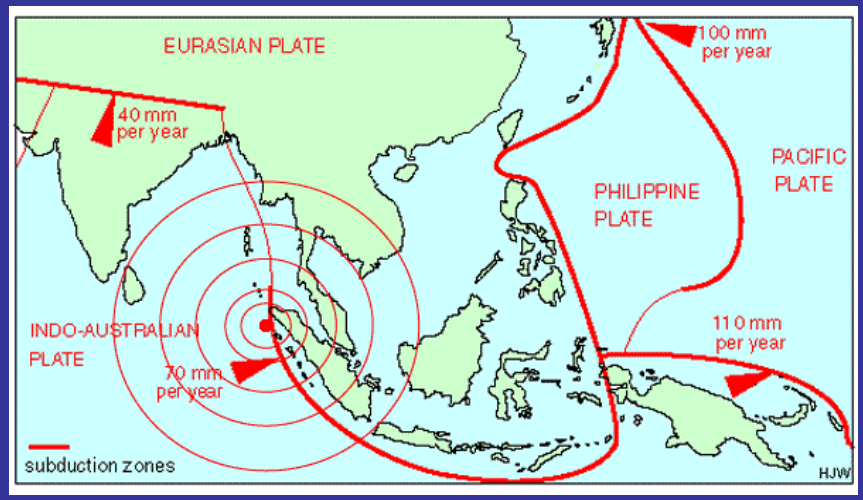
Clay-Gravel-Sandy Zone

Sandy Coastal Soil

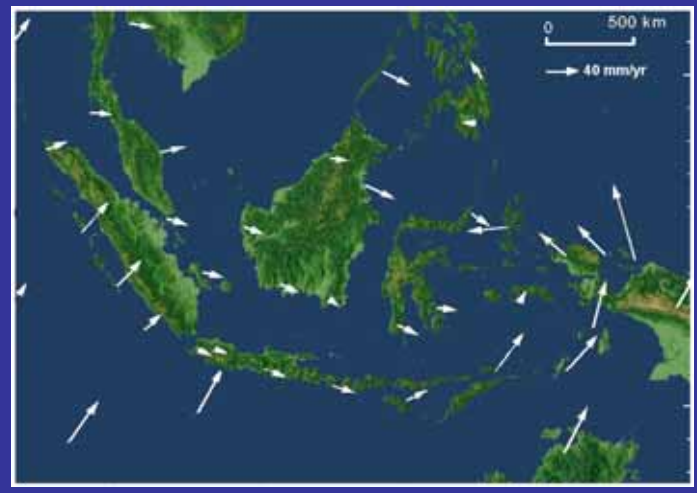
SW



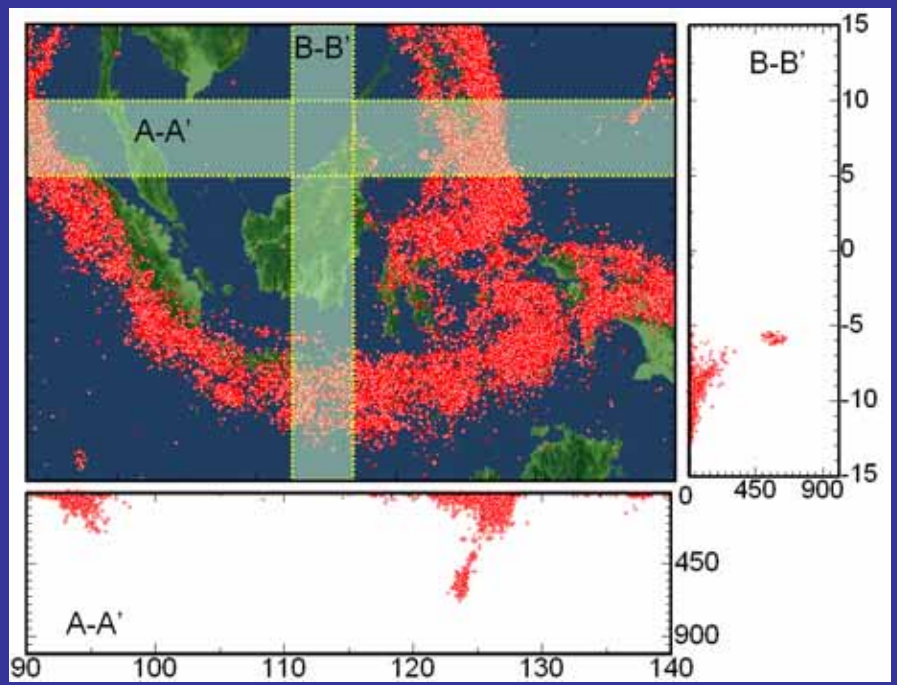
TECTONICS・テクトニクス

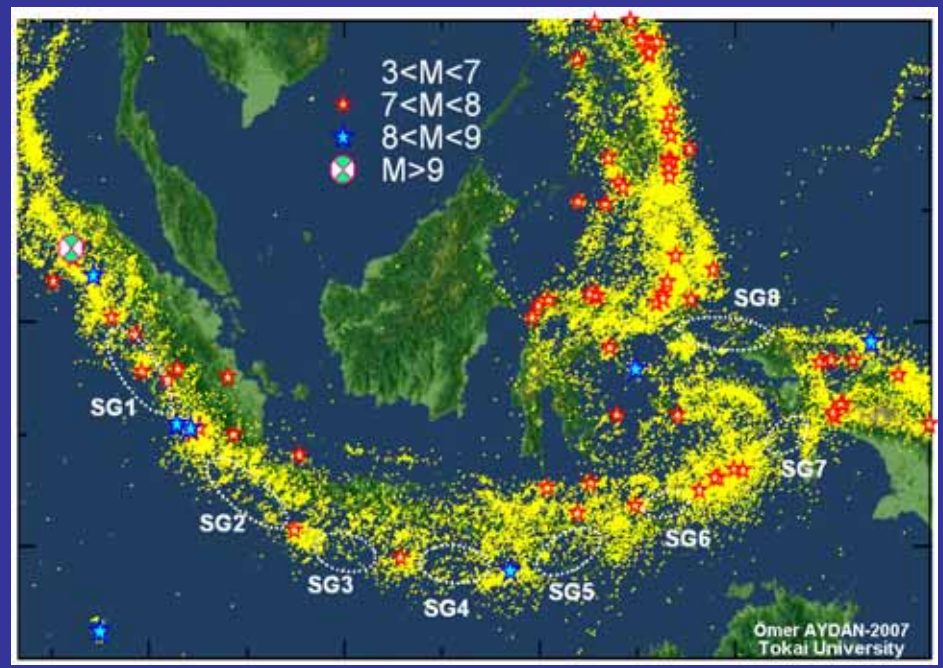


Plates　ー　プレート



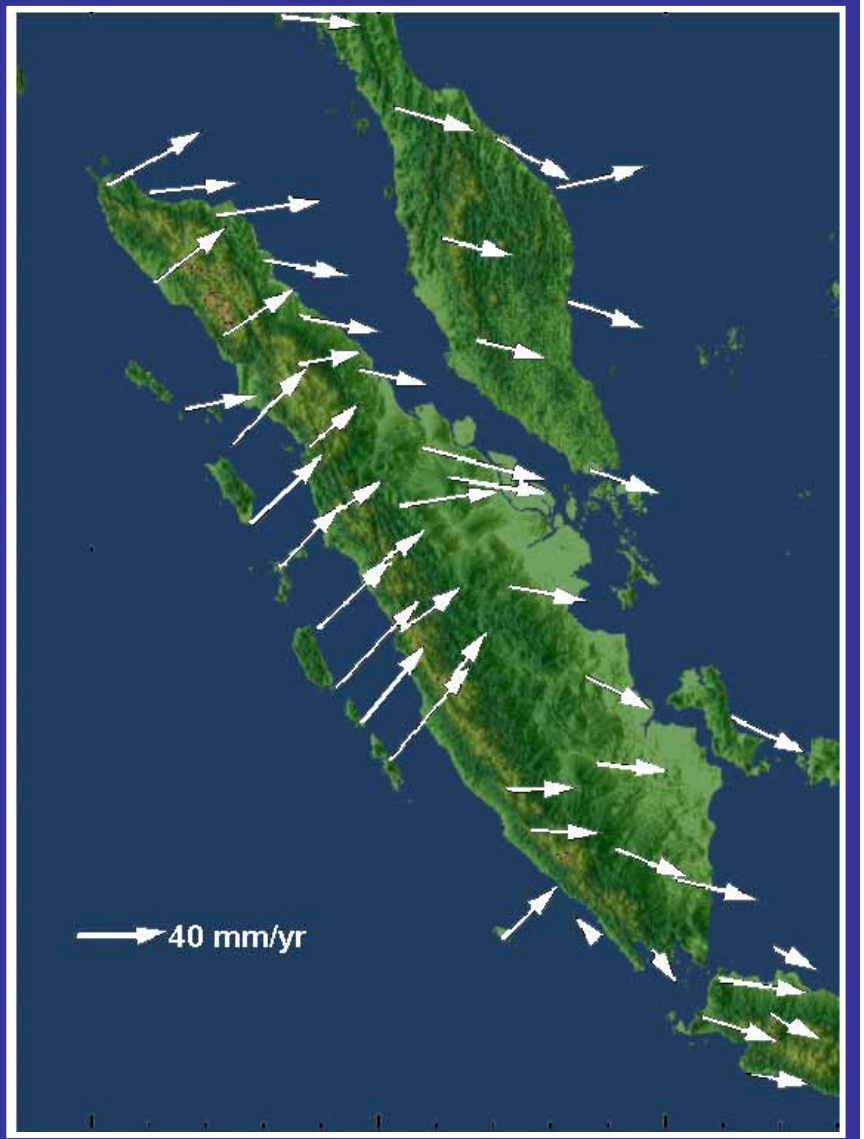
地殻の変形



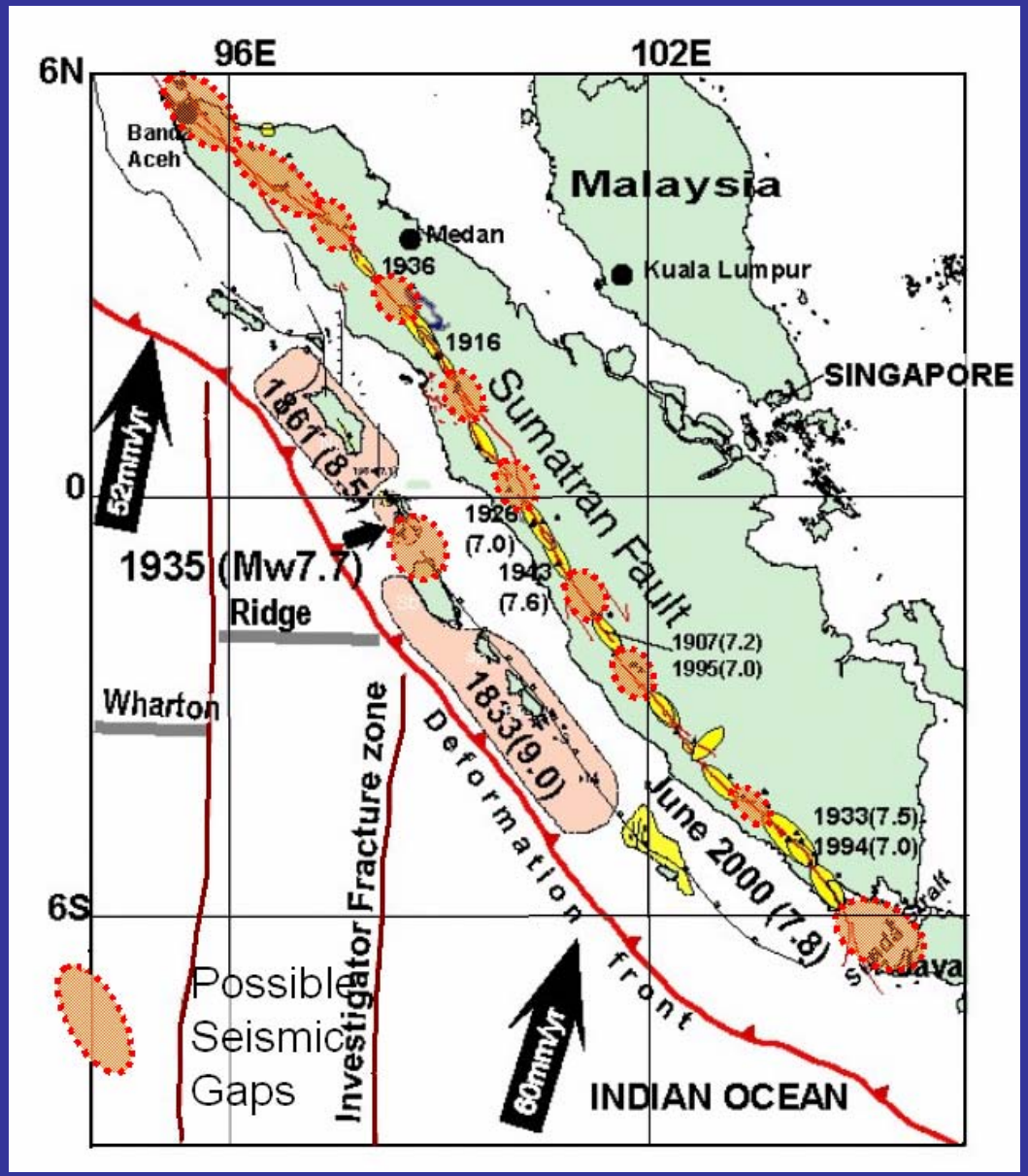


Seismic Gaps – 空白域

スマトラ周辺

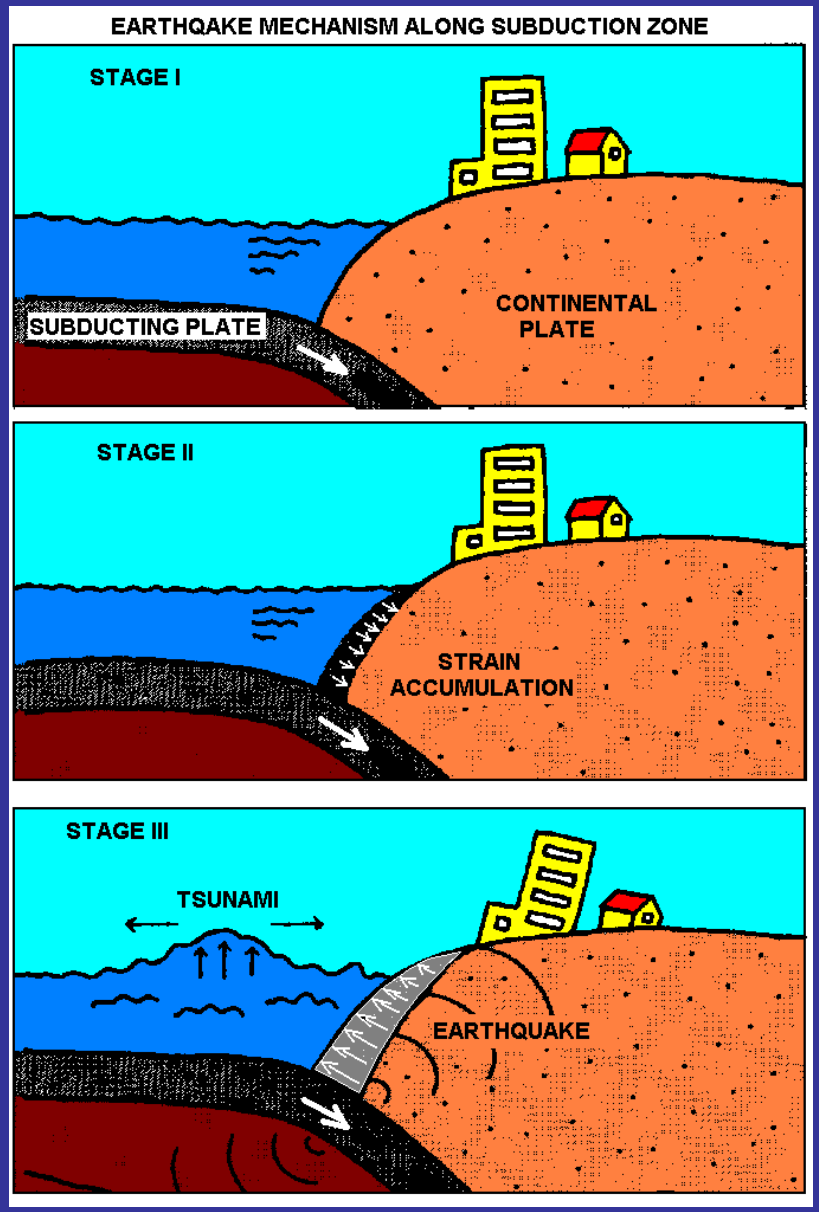


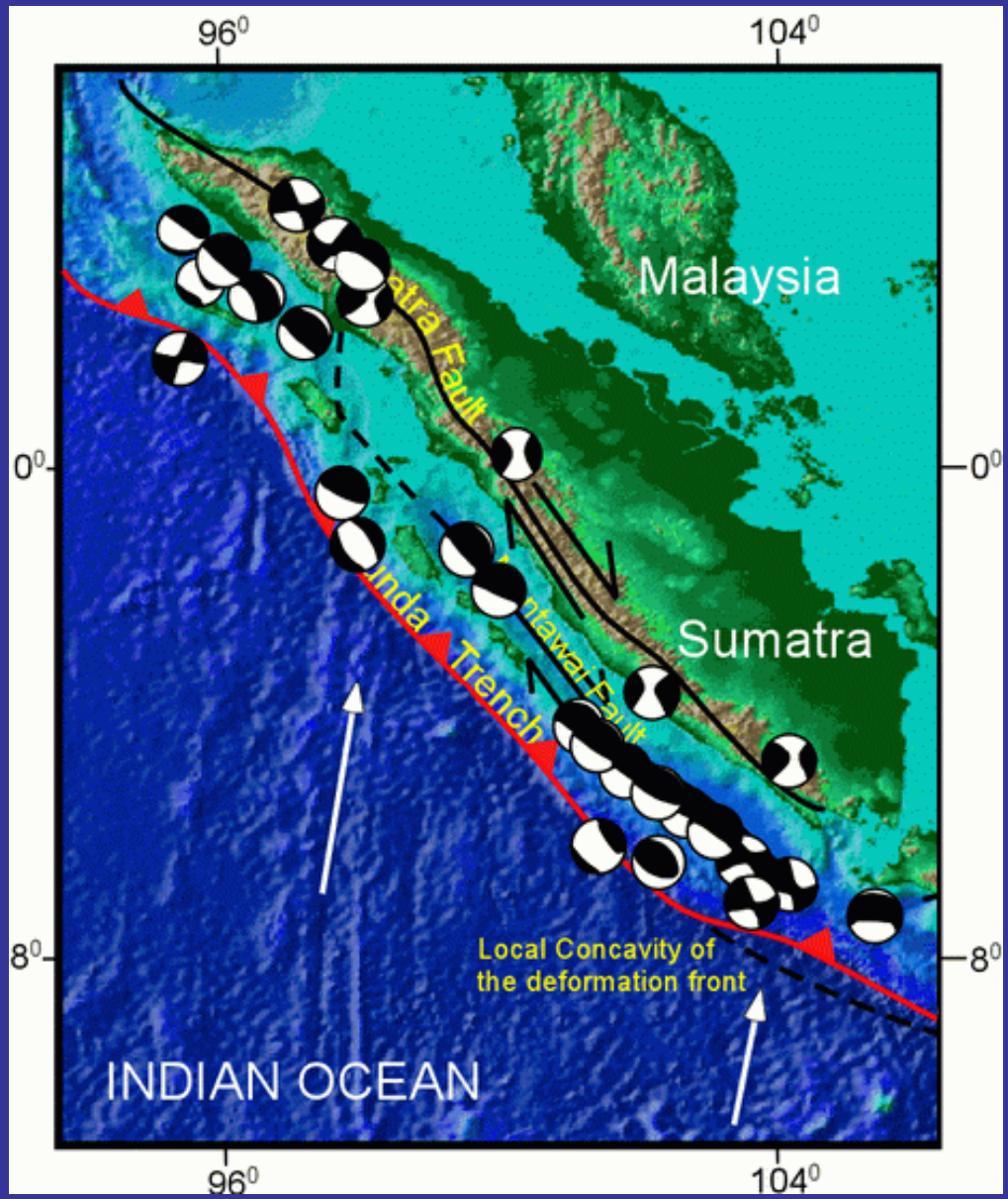
地殻運動



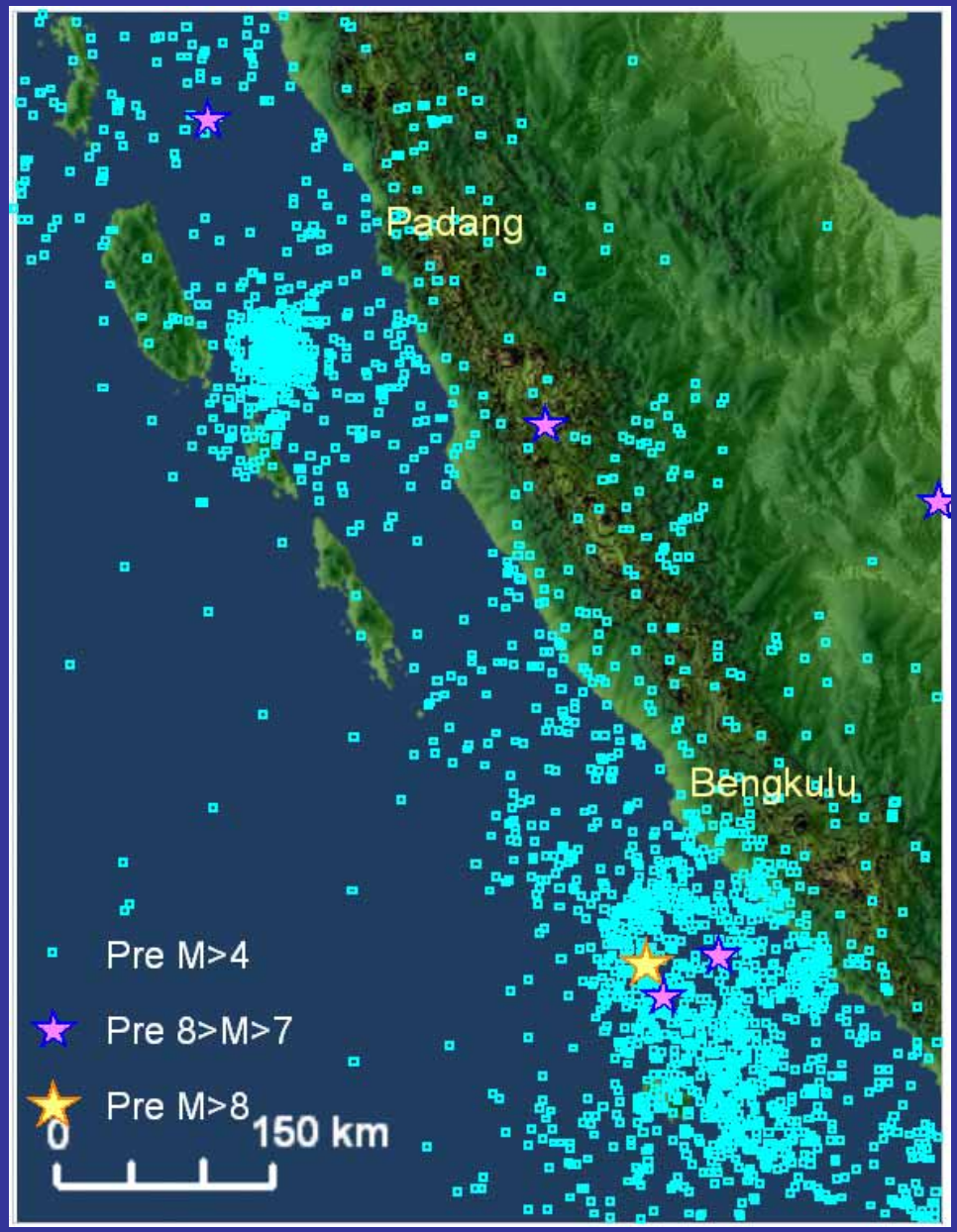
Seismic Gaps – 空白域

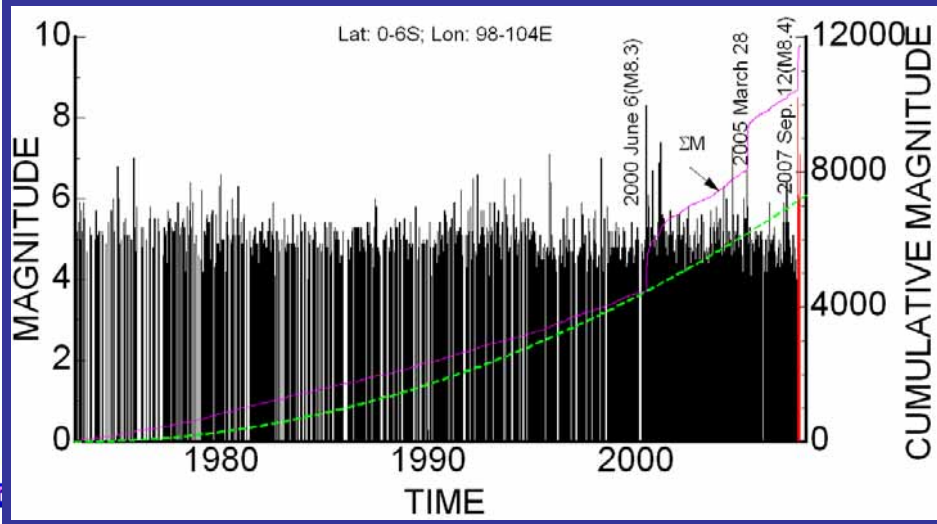
地震の発生機構

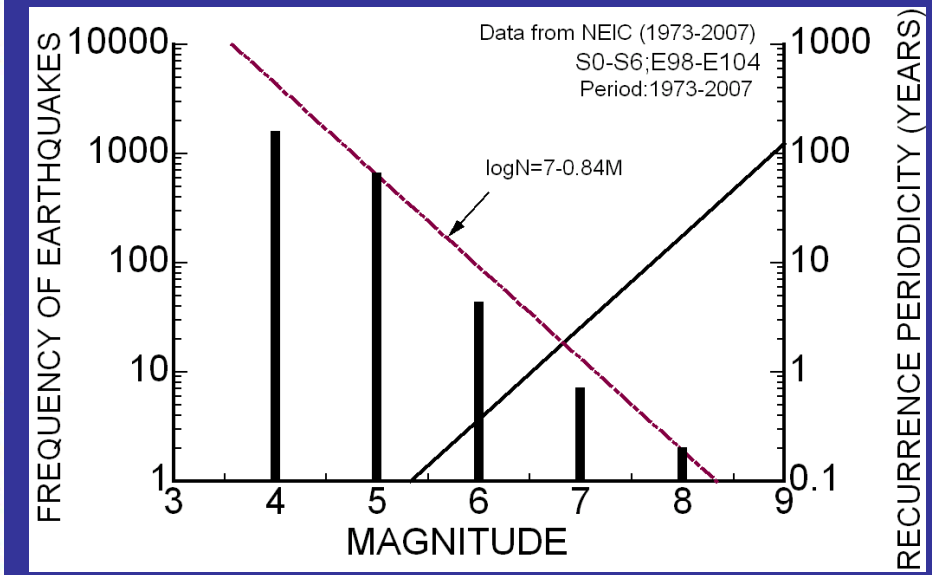

EARTHQAKE MECHANISM ALONG SUBDUCTION ZONE
STAGE I
SUBDUCTING PLATE
CONTINENTAL PLATE
STAGE II
STRAIN ACCUMULATION
STAGE III
TSUNAMI
EARTHQUAKE


96⁰
104⁰
0⁰
8⁰
Malaysia
Sumatra
Trench
Local Concavity of the deformation front
INDIAN OCEAN

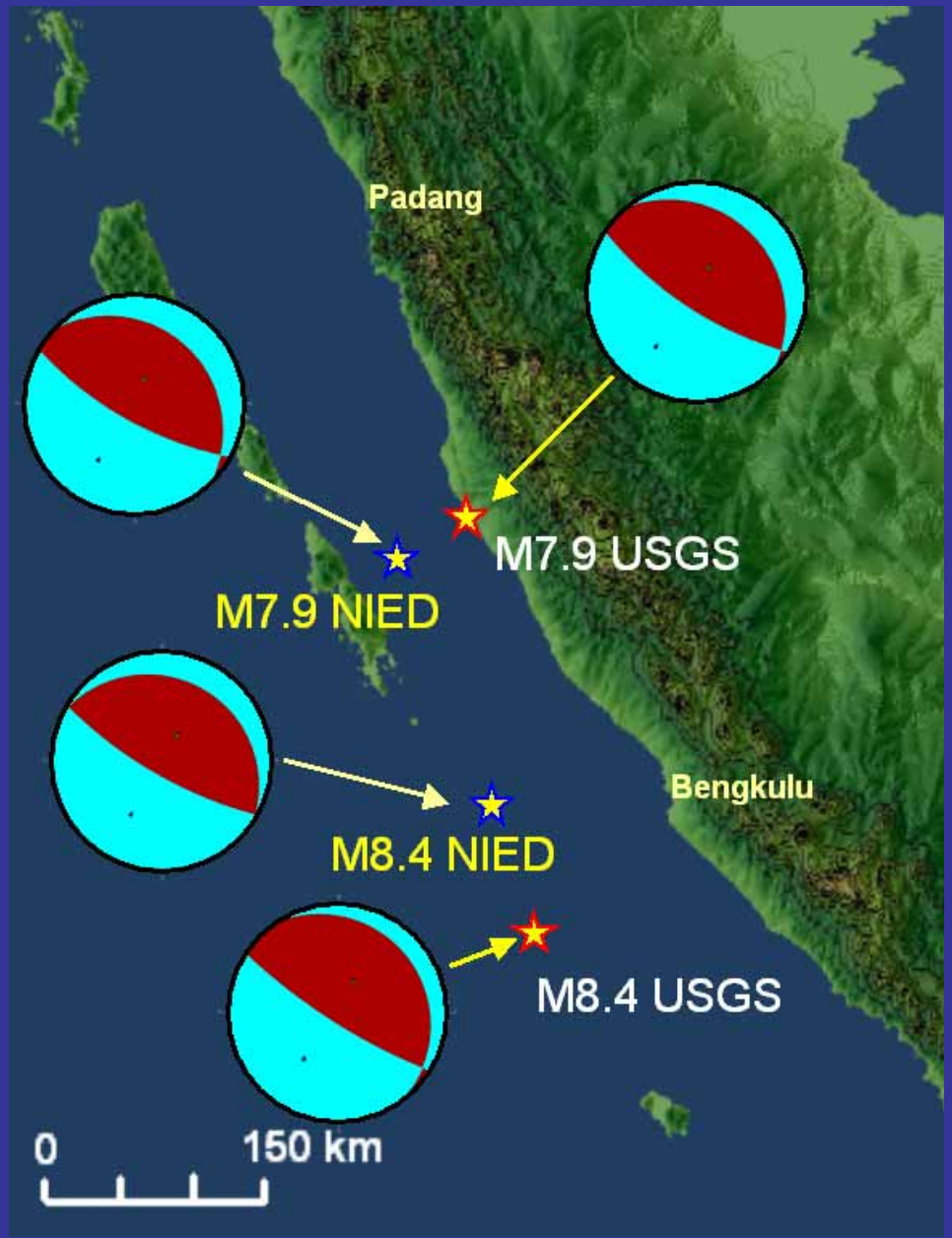
南スマトラ地震の前の地震活動

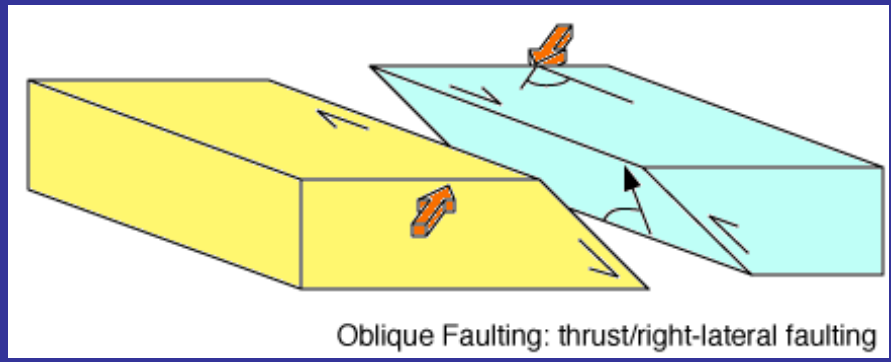






FAULTING MECHANISM・地震発生機構





Low angle thrust faulting

低角度の逆断層

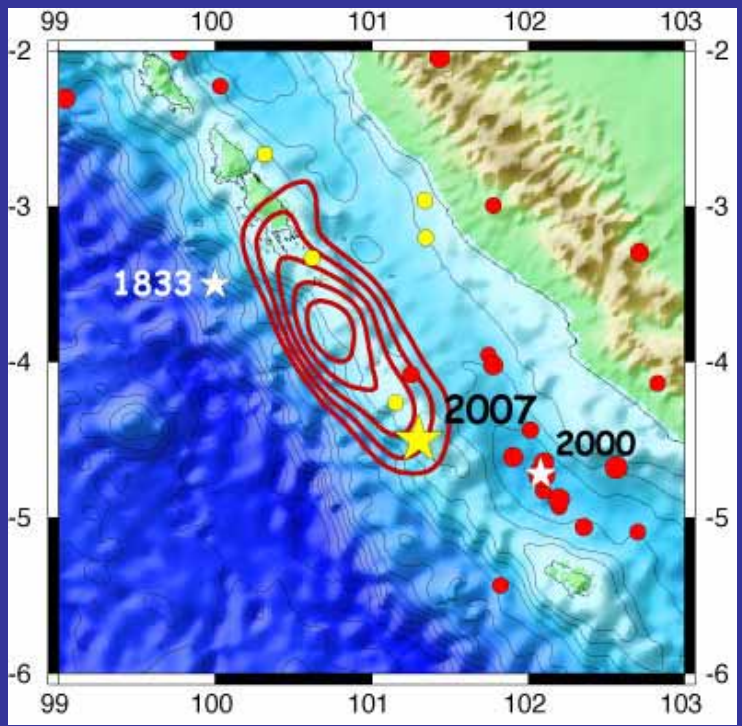
M8.4はプレート境界地震

M7.9はプレート内地震(？)

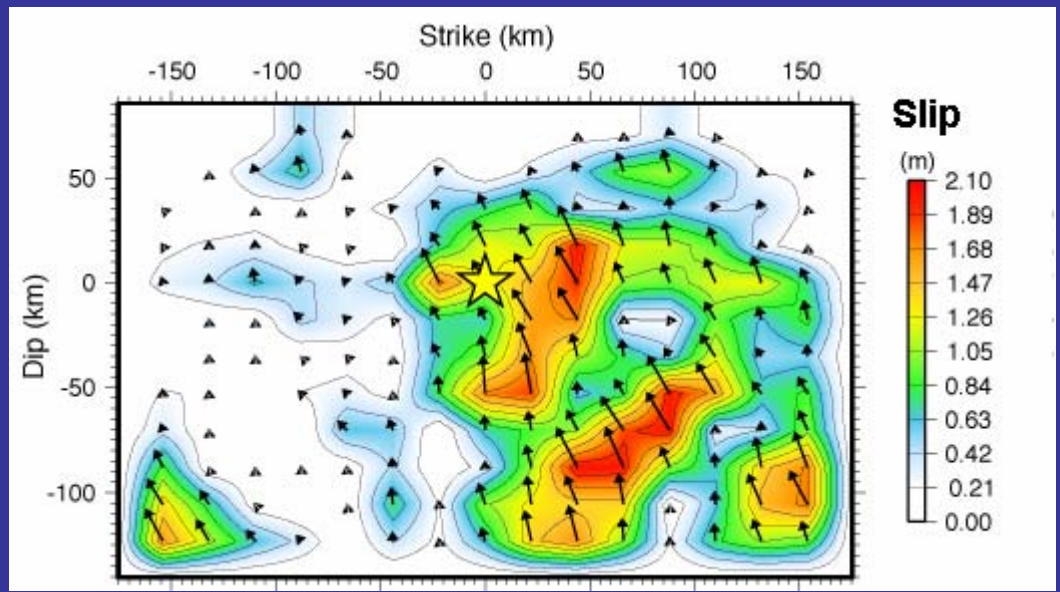
RUPTURE PROPAGATION
破壊伝達過程

400km long; 160km wide; uplift 1m

断層長が400km、巾が160km、上下変位約1m



Yamanaka, 2007



Yagi, 2007

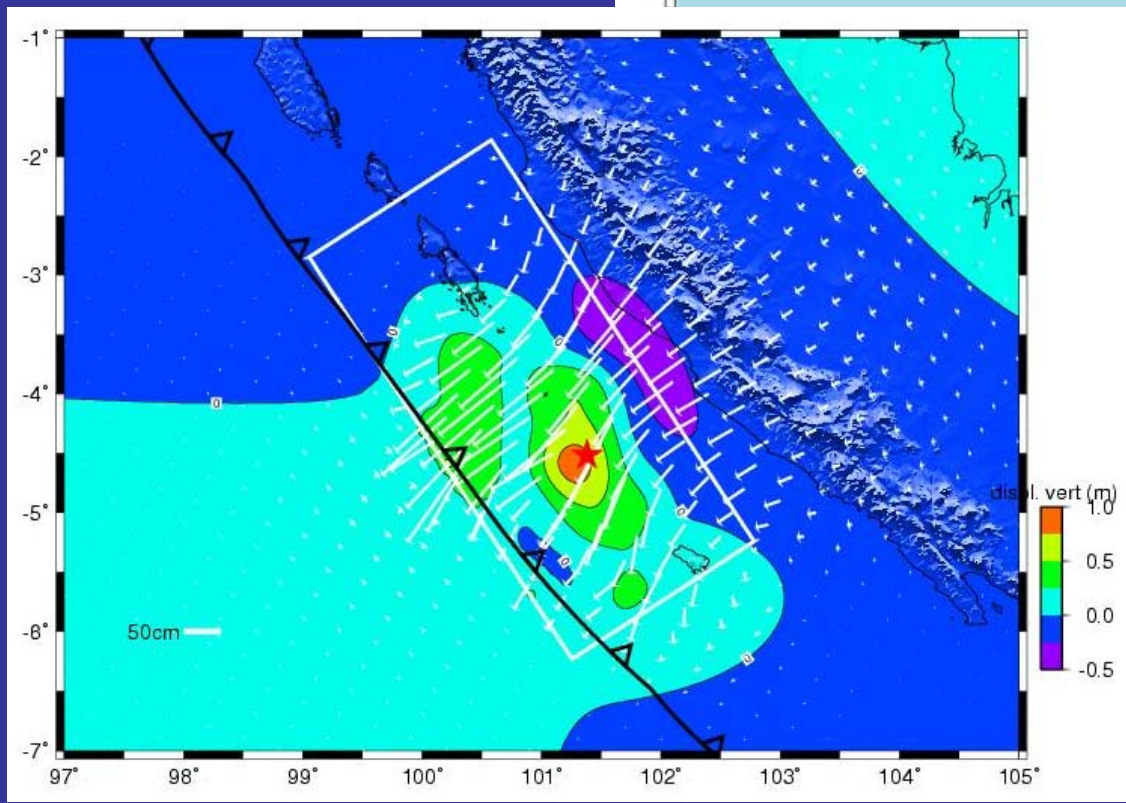
Institute	Mw	DEP (km)	Earthquake Fault			T_d sec	Vr (km/s)	Slip (m)
			strike/dip/rake	Length (km)	Width (km)			
Yagi	8.2	25.0	327/18/112	350	225	115	2.5	2.1
Yamanaka	8.4	30.0	327/15/109	300	100	90		15
Chen Ji			323/12/	560	160			4.5

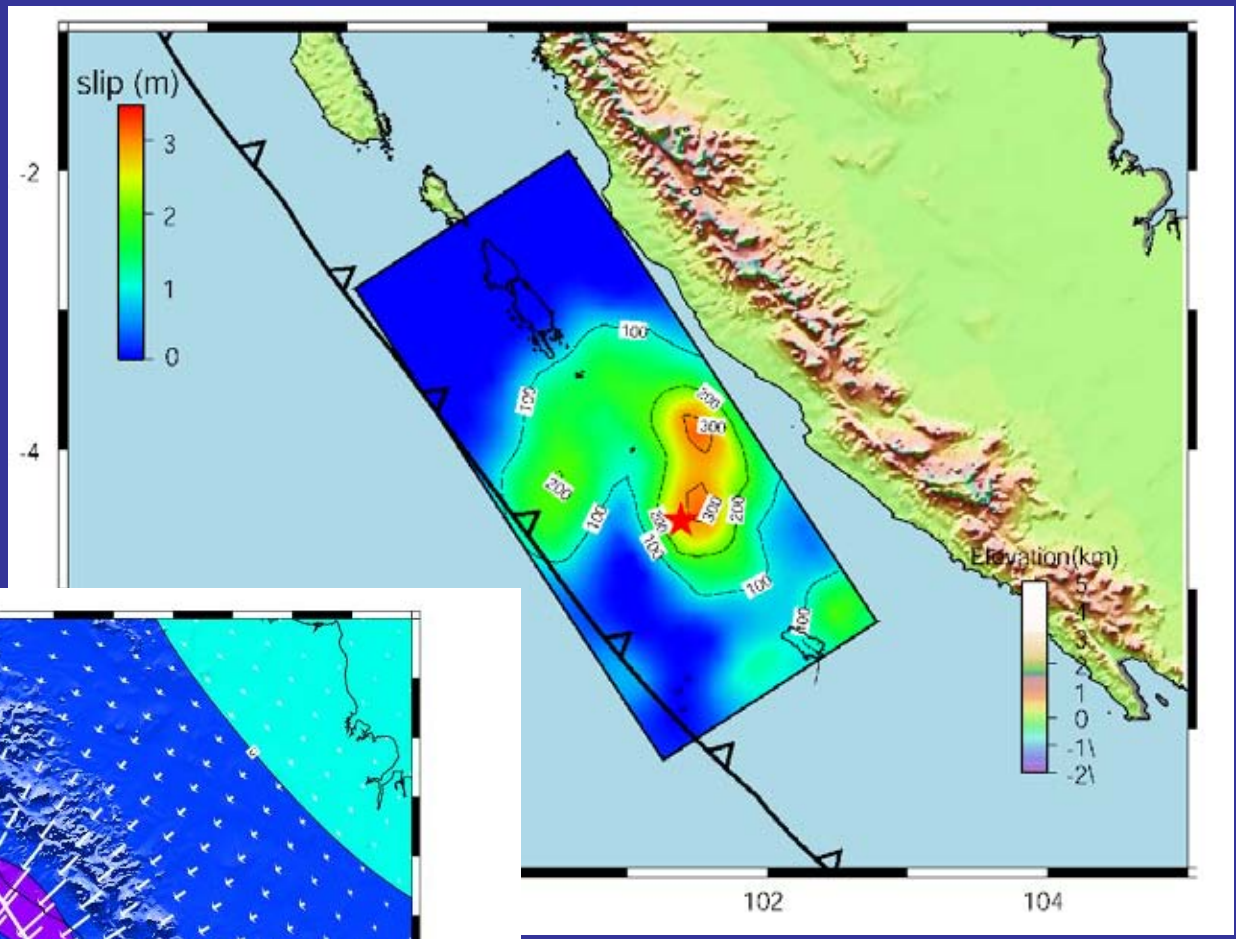
M8.4

CalTec

Konca 2007

断層上の鉛直変位





断層上のすべり

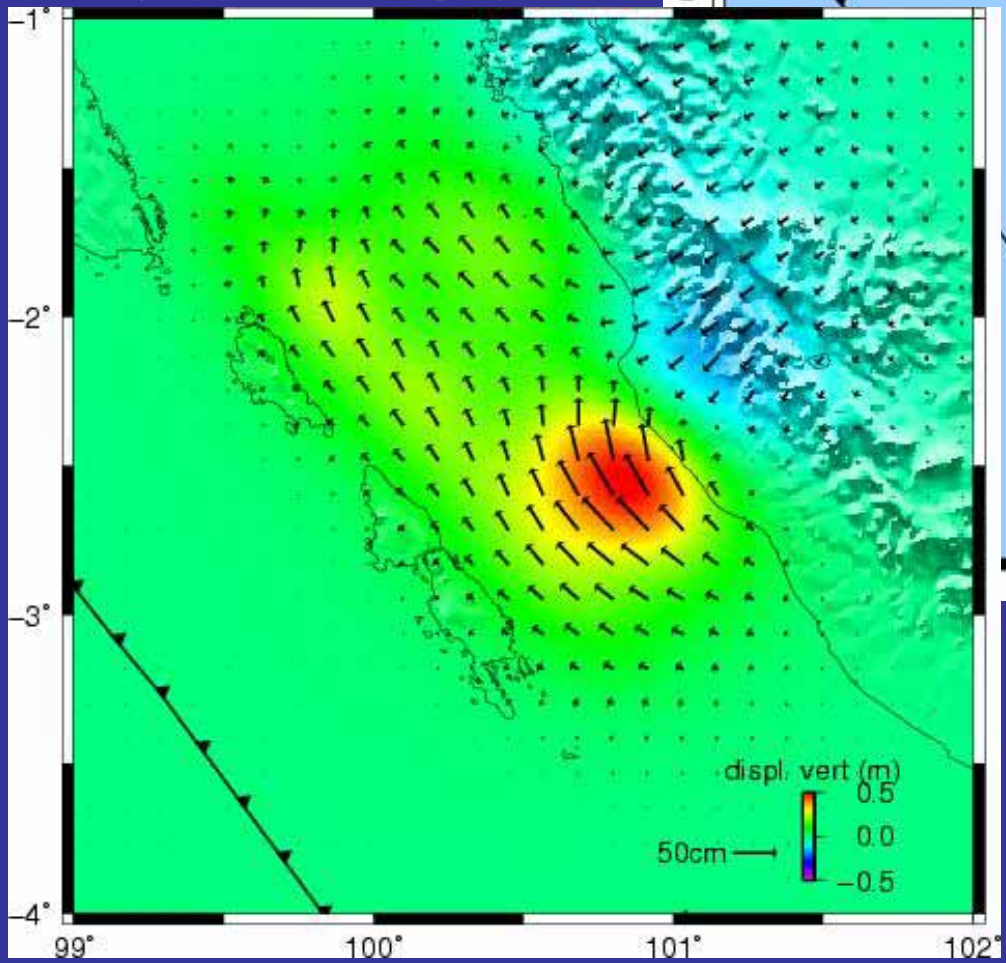
Dmax=4m

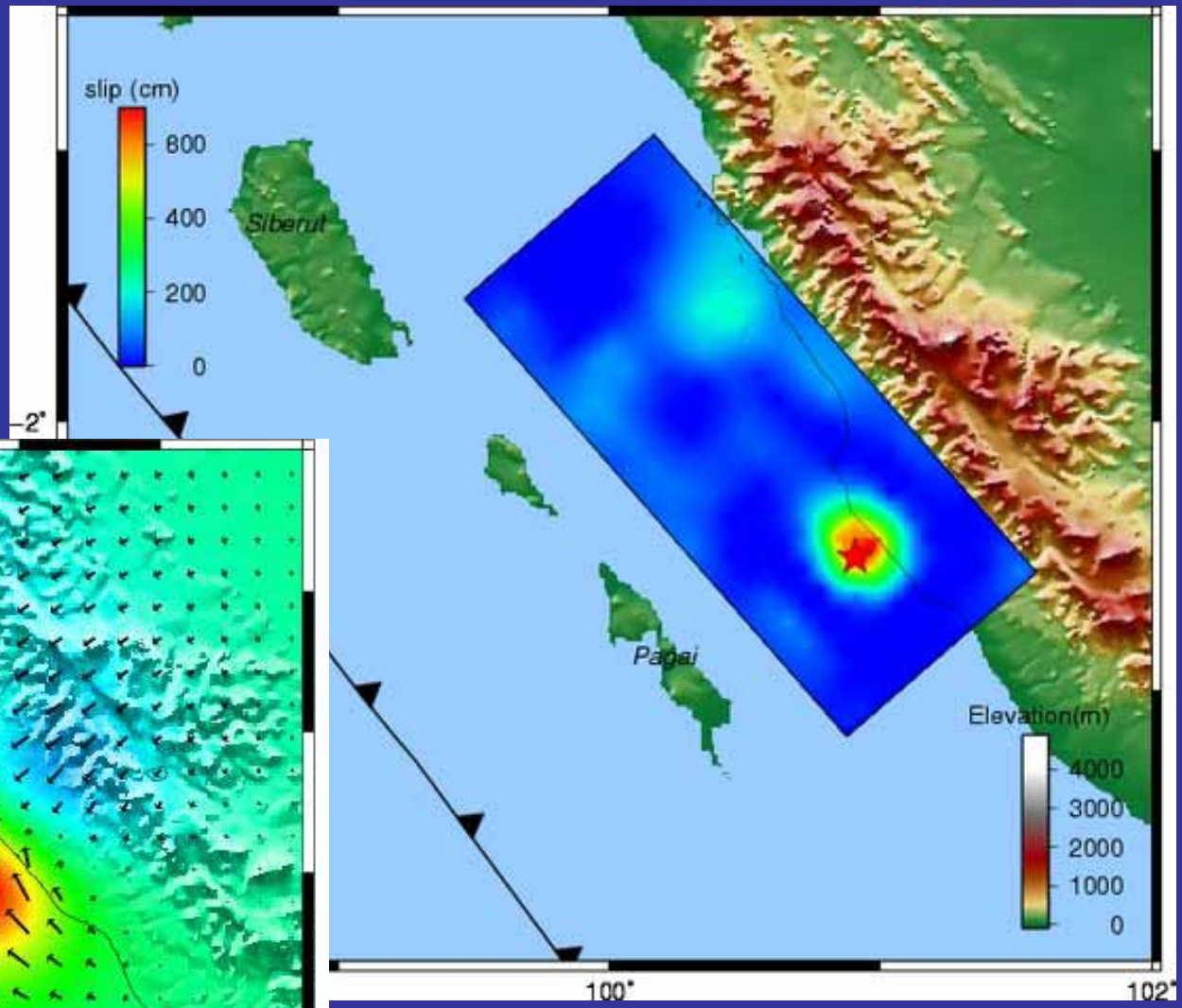
M7.9

CalTec

Konca 2007

断層上の鉛直変位



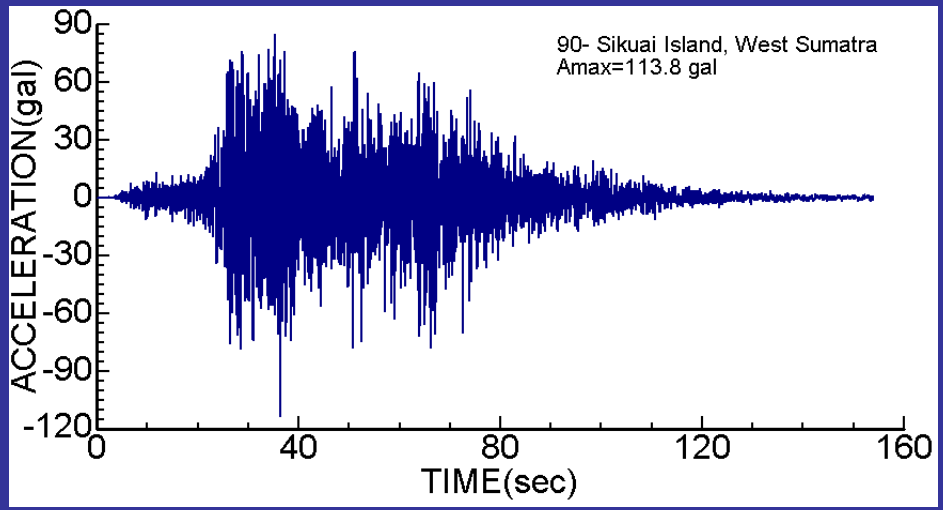


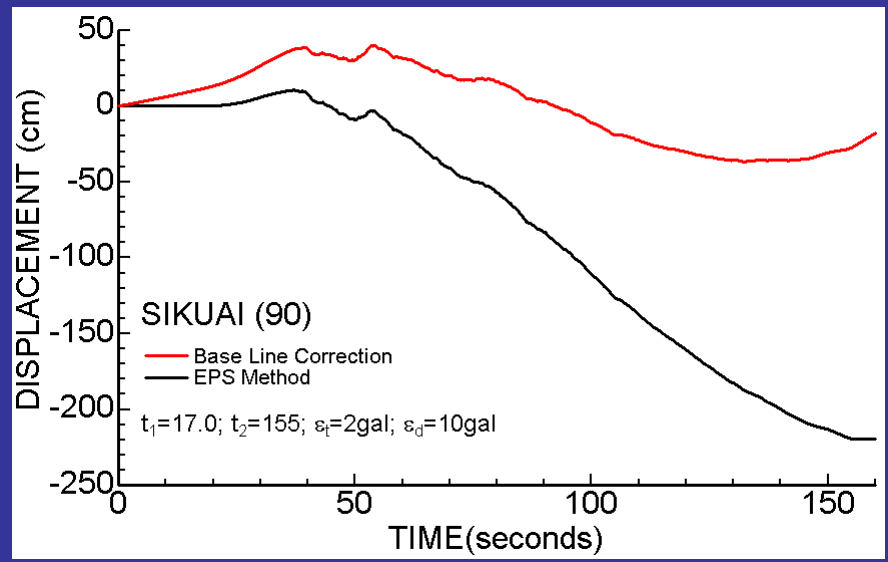
断層上のすべり

Vr=2.2km/s

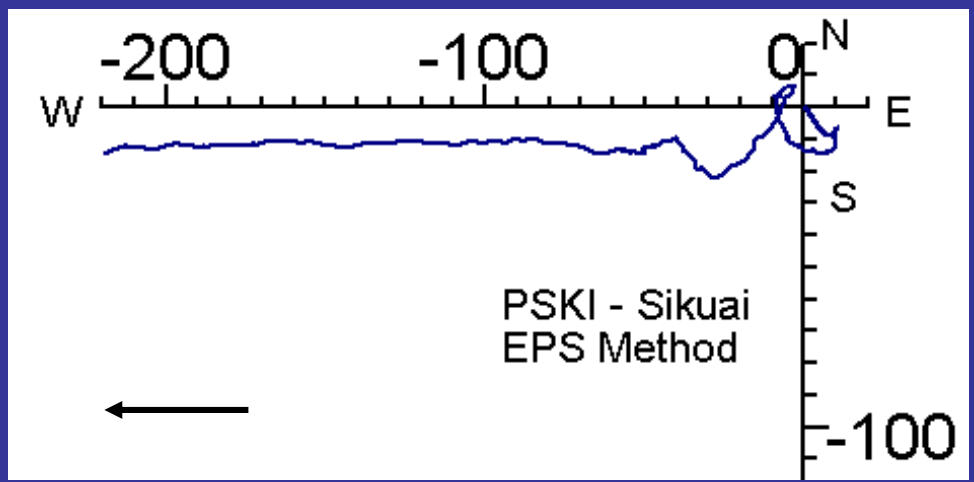
Dmax=8m

Sikuai強震観測点における地表面の永久変形

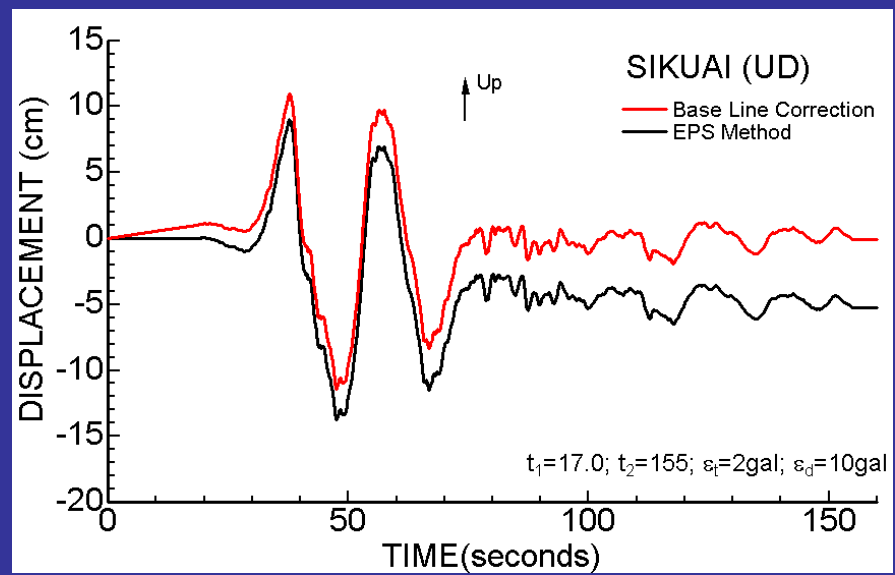




東西方向の変位応答

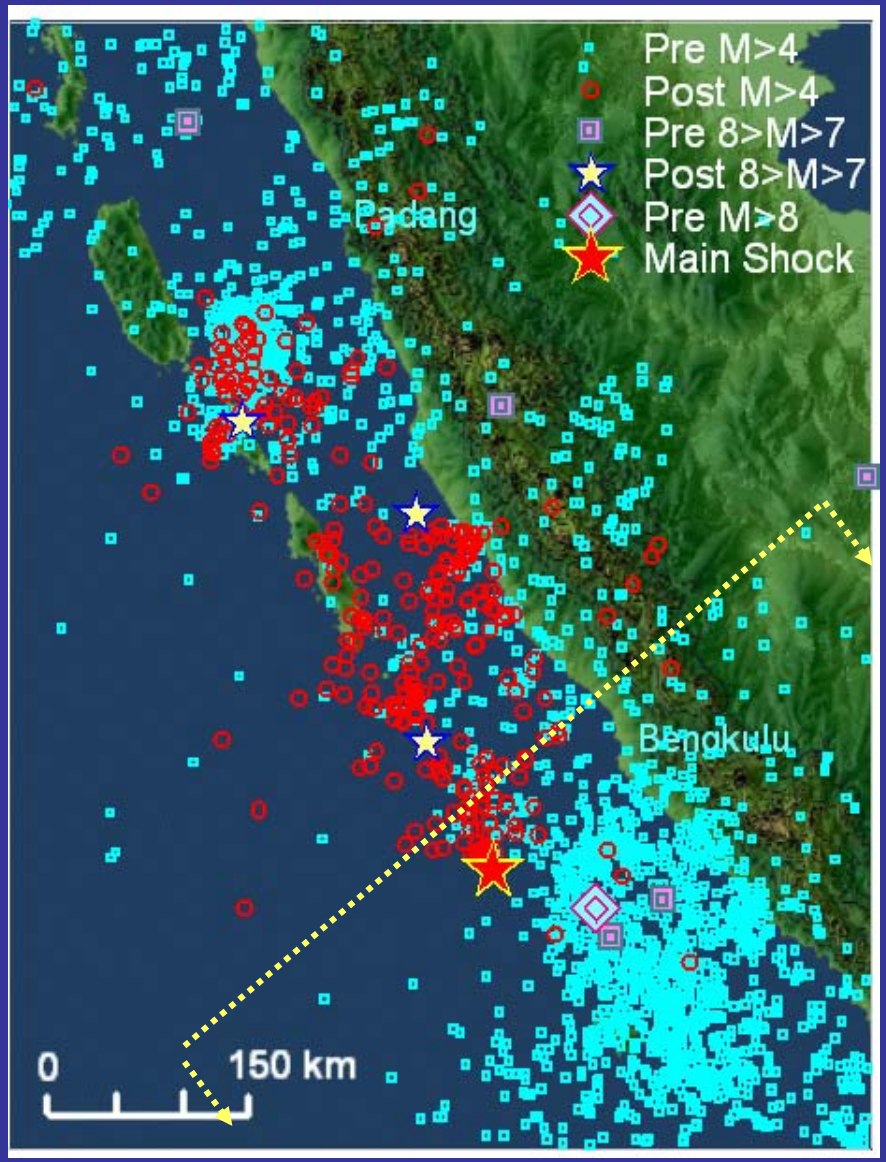


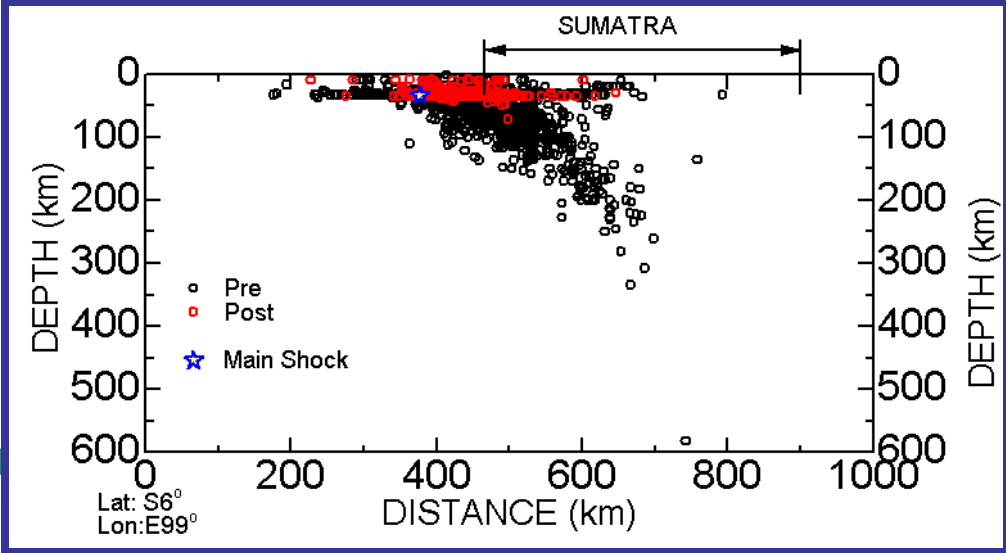
EPS法（太田・アイダン、2007）

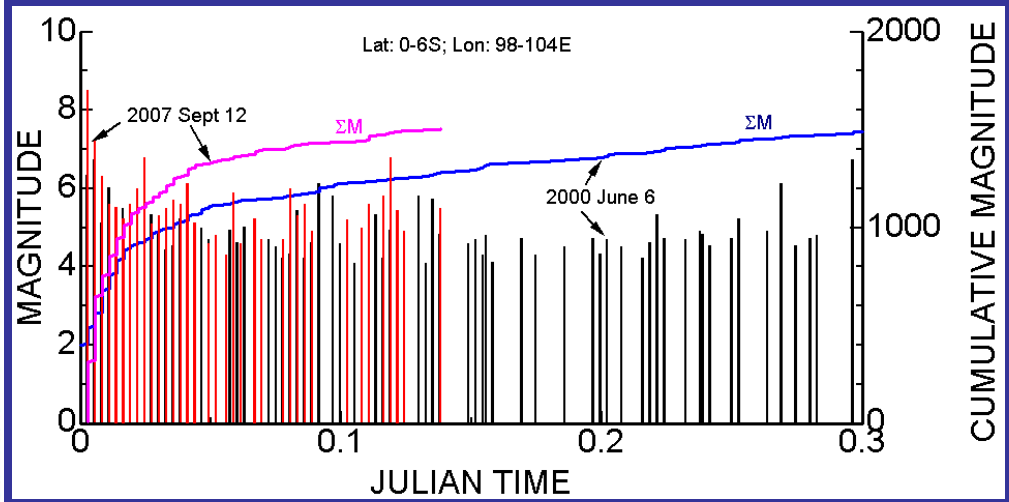


上下方向の変位応答

余震活動


Pre M>4
Post M>4
Pre 8>M>7
Post 8>M>7
Pre M>8
Main Shock
Padang
Bengkulu
0
150 km


SUMATRA
DEPTH (km)
0
100
200
300
400
500
600
Pre
Post
Main Shock
Lat: S6°
Lon:E99°
0
200
400
600
800
1000
DISTANCE (km)


Lat: 0-6S; Lon: 98-104E
2007 Sept 12
ΣM
ΣM
2000 June 6
MAGNITUDE
CUMULATIVE MAGNITUDE
0
2
4
6
8
10
0
1000
2000
0
0.1
0.2
0.3
JULIAN TIME

GROUND MOTIONS - 地震動

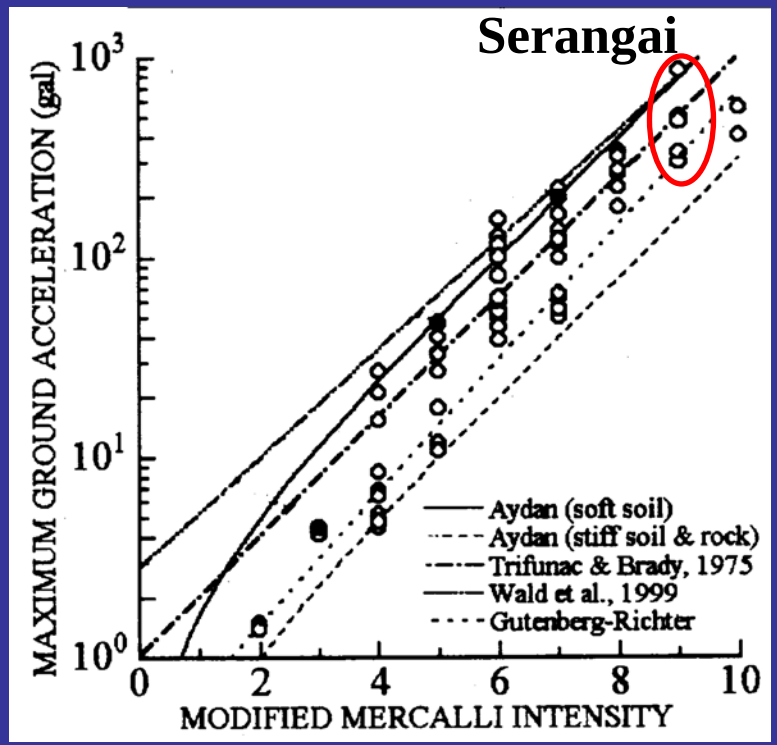
Ground Acceleration

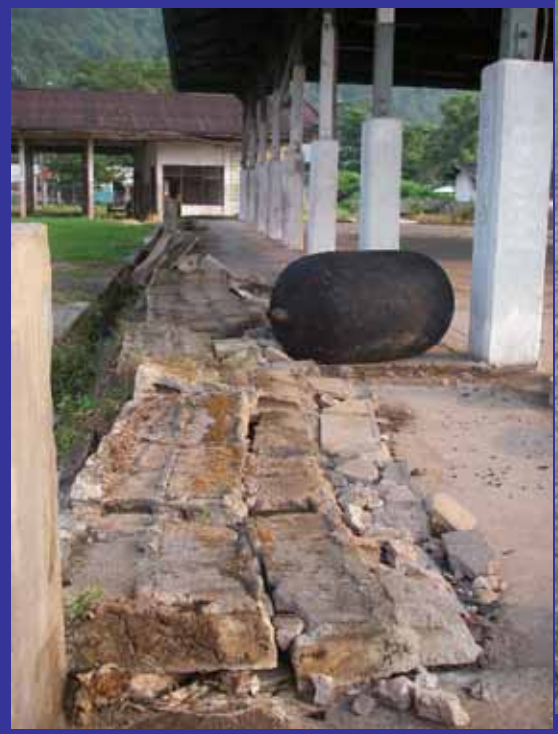
(加速度)： 300-600gal

震度：6弱； MMI:IX

Serangai

Ketaun



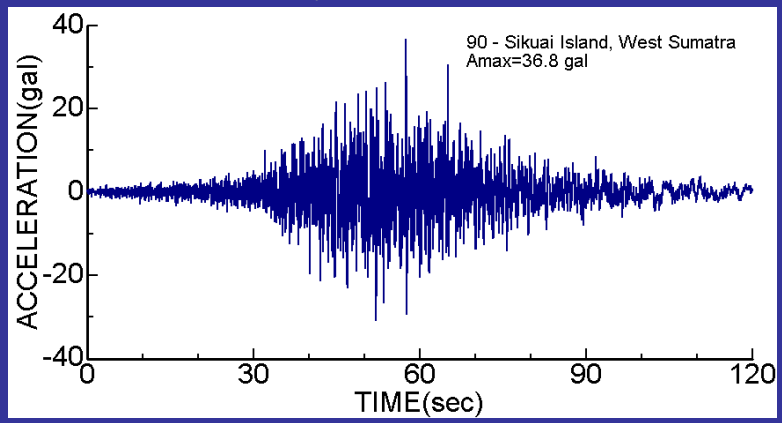


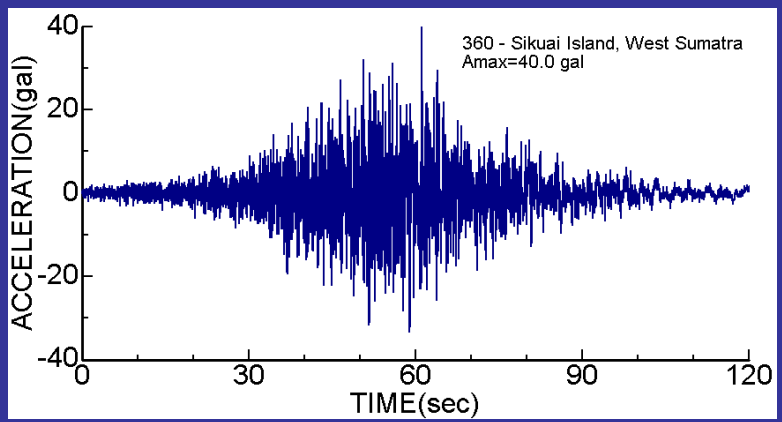
Bungus

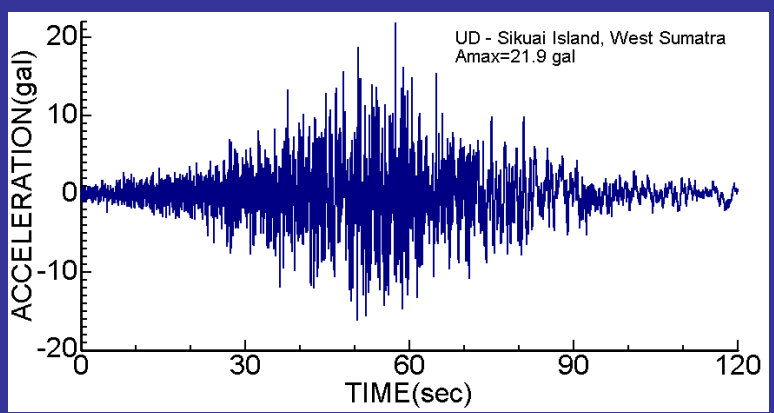
Basar Bantal

USGS - Sikuai 強震観測点

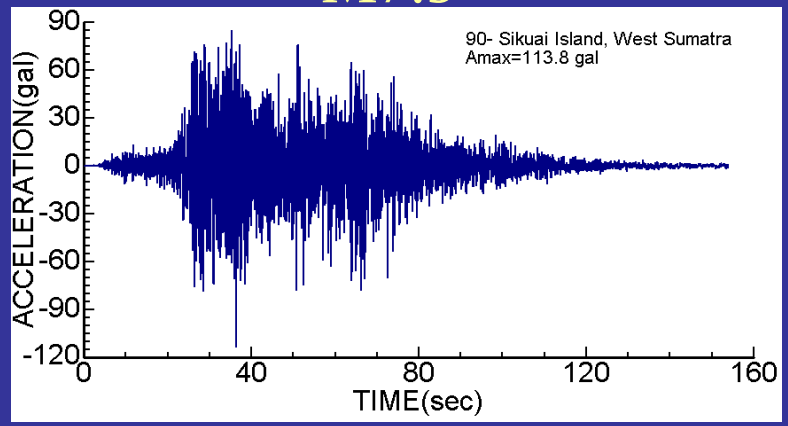
M8.4

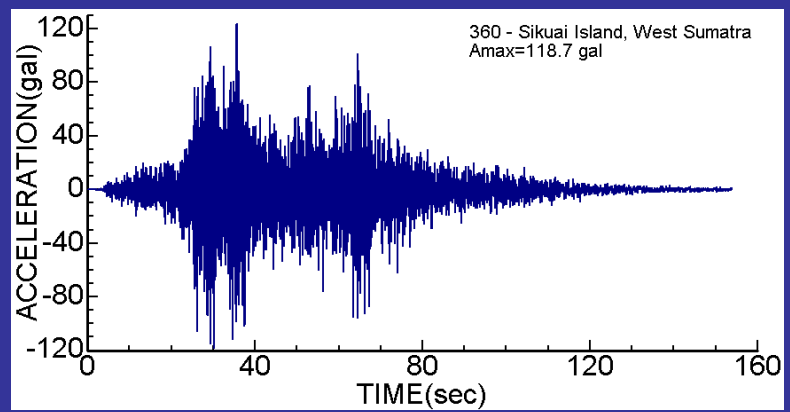


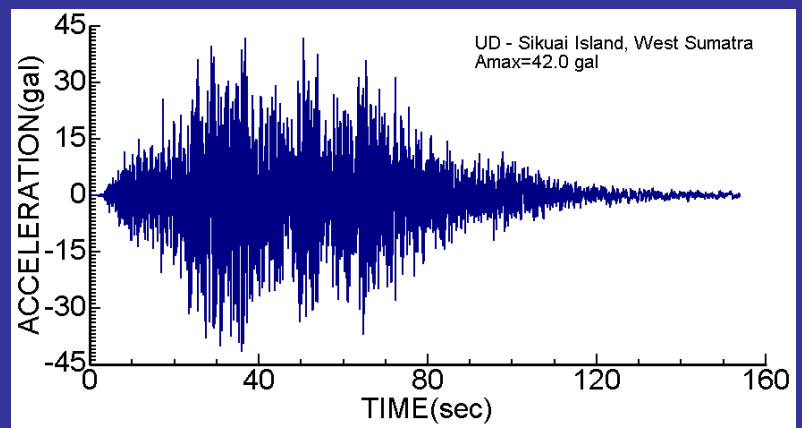




M7.9

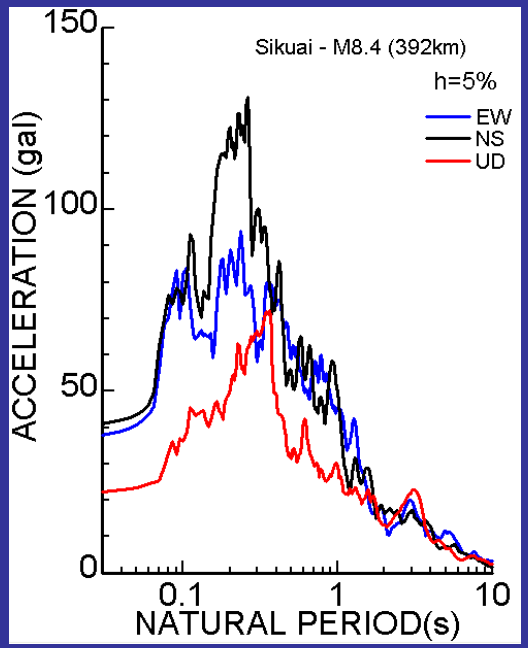


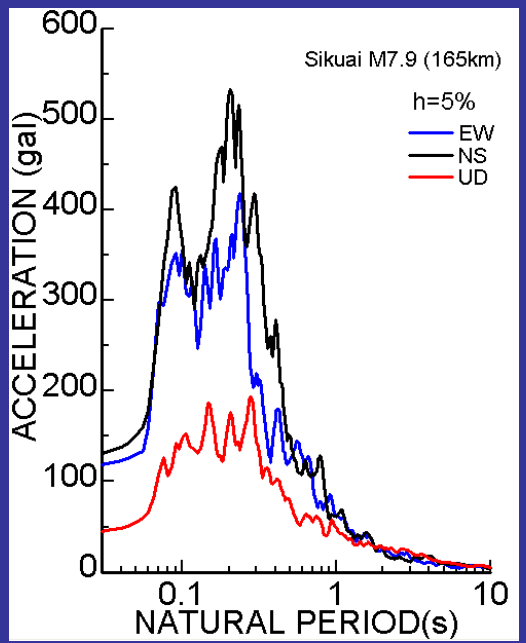


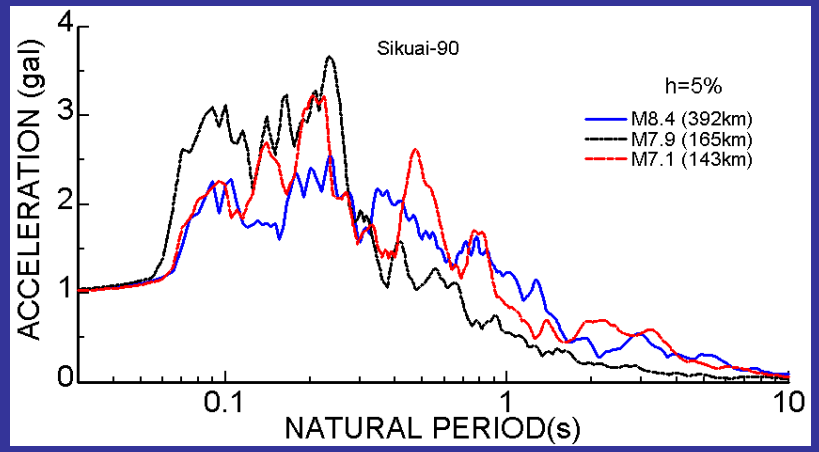


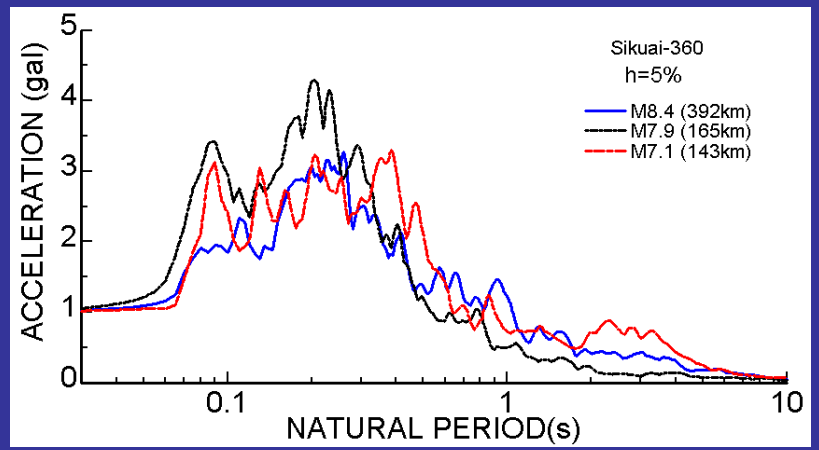
パダン市近くのSikuai島で初めて強震記録が取得された。

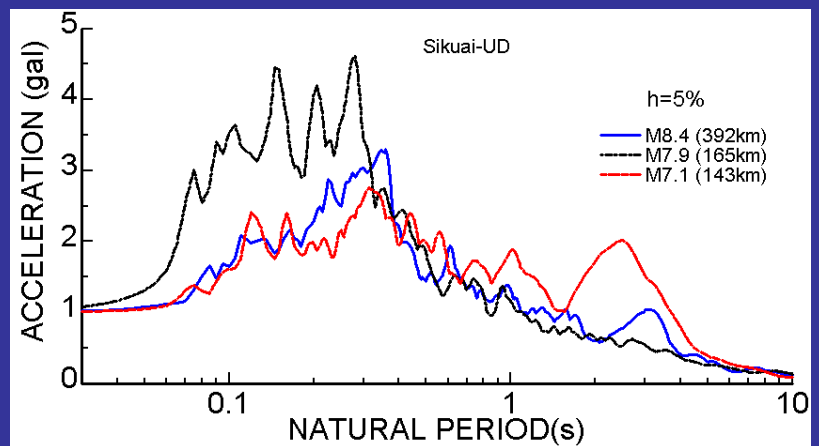
Sikuai強震観測点における加速度応答スペクトル





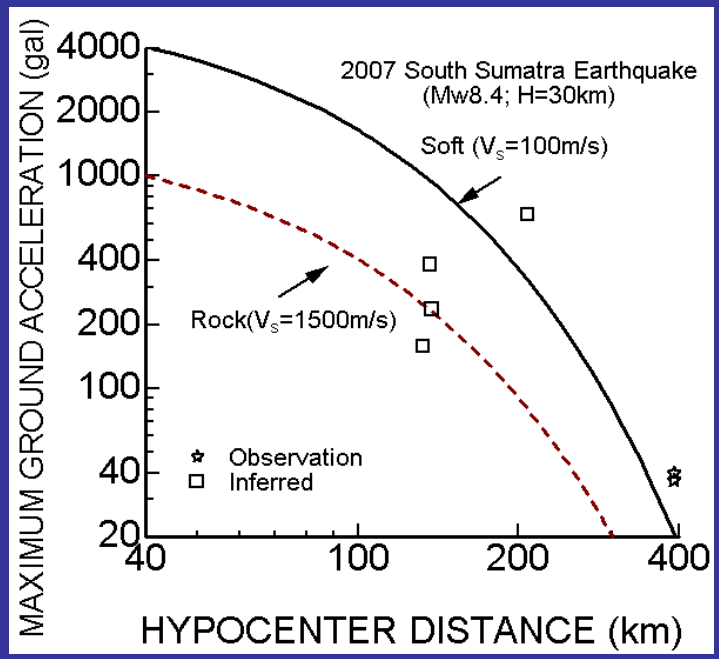


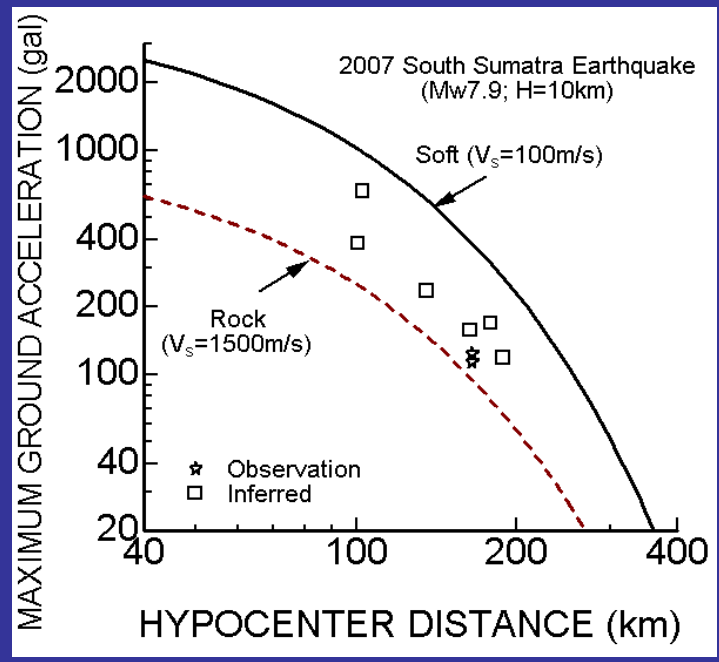


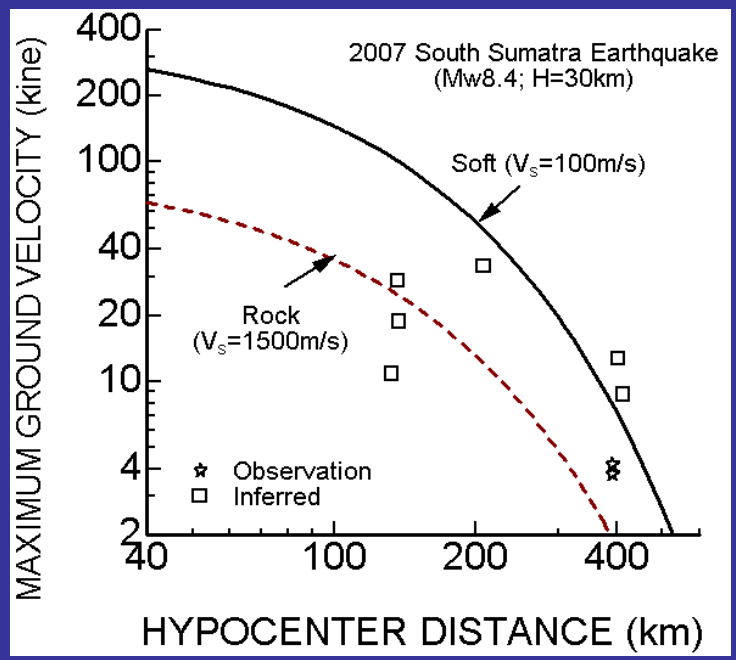


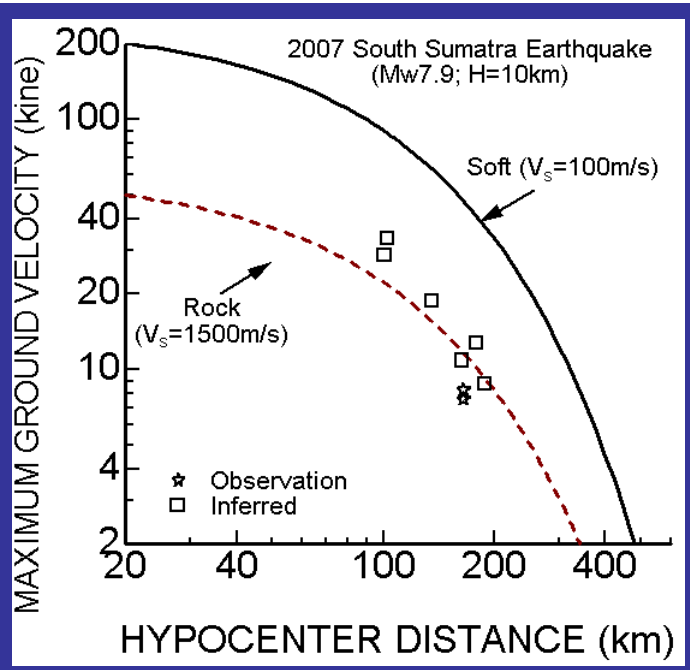
M8.4

M7.9


2007 South Sumatra Earthquake
(Mw8.4; H=30km)
Soft (V_S=100m/s)
Rock(V_S=1500m/s)
Observation
Inferred
MAXIMUM GROUND ACCELERATION (gal)
HYPOCENTER DISTANCE (km)


2007 South Sumatra Earthquake
(Mw7.9; H=10km)
Soft (V_S=100m/s)
Rock
(V_S=1500m/s)
Observation
Inferred
MAXIMUM GROUND ACCELERATION (gal)
HYPOCENTER DISTANCE (km)


2007 South Sumatra Earthquake
(Mw8.4; H=30km)
Soft (V_S=100m/s)
Rock
(V_S=1500m/s)
Observation
Inferred
MAXIMUM GROUND VELOCITY (kine)
HYPOCENTER DISTANCE (km)


2007 South Sumatra Earthquake
(Mw7.9; H=10km)
Soft (V_S=100m/s)
Rock
(V_S=1500m/s)
Observation
Inferred
MAXIMUM GROUND VELOCITY (kine)
HYPOCENTER DISTANCE (km)

推定最大加速度分布

USGS震央

NIED震央

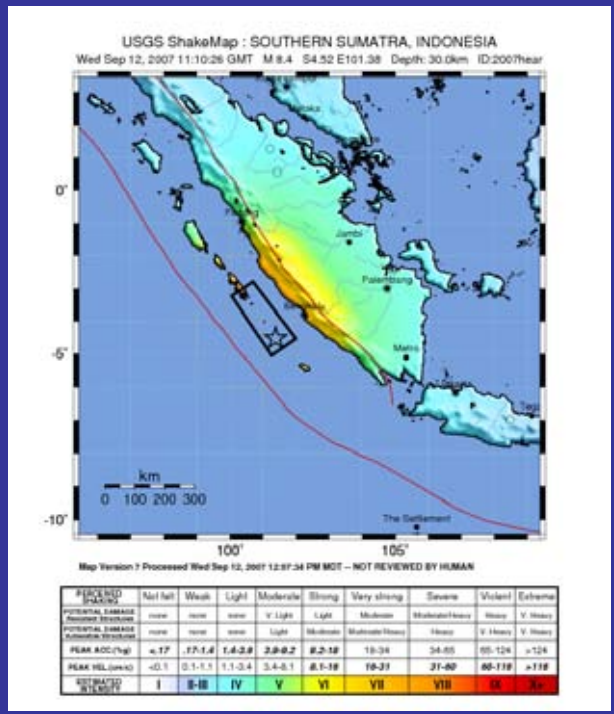
USGS

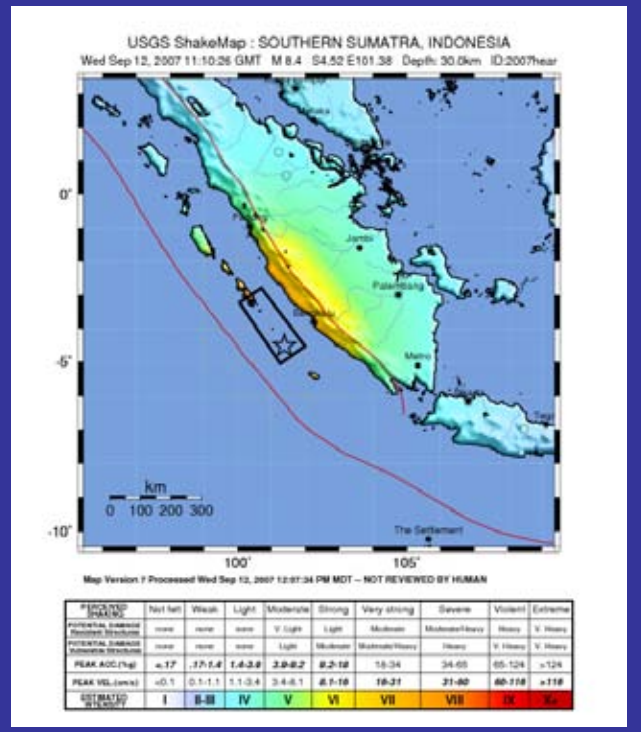
M8.4

M7.9

最大加速度

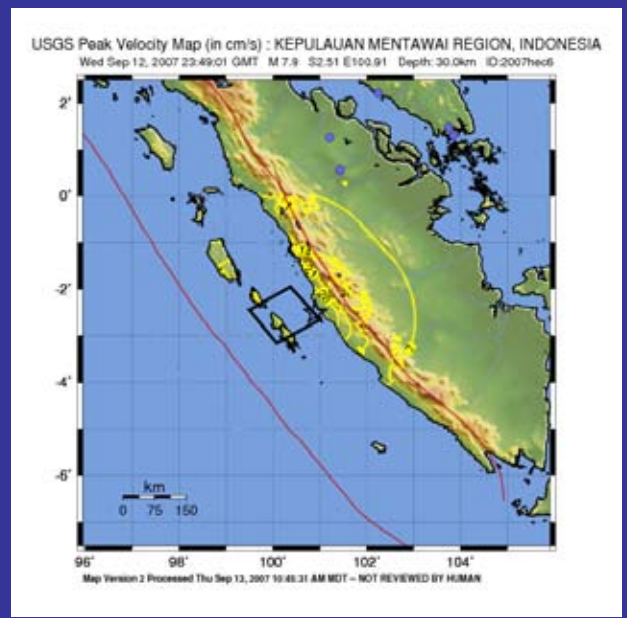
(Amax:0.18-0.34g)





最大速度

(Vmax:16-31cm/s)



DAMAGE DUE TO GROUND SHAKING & GROUND FAILURE
地震動および地盤破壊による被害

M8.4の地震の震源より約400km離れているパダン市で3階以上のRC建築物は大きな被害を受け，一階がショールームとして利用されている2つの建物が崩壊した。

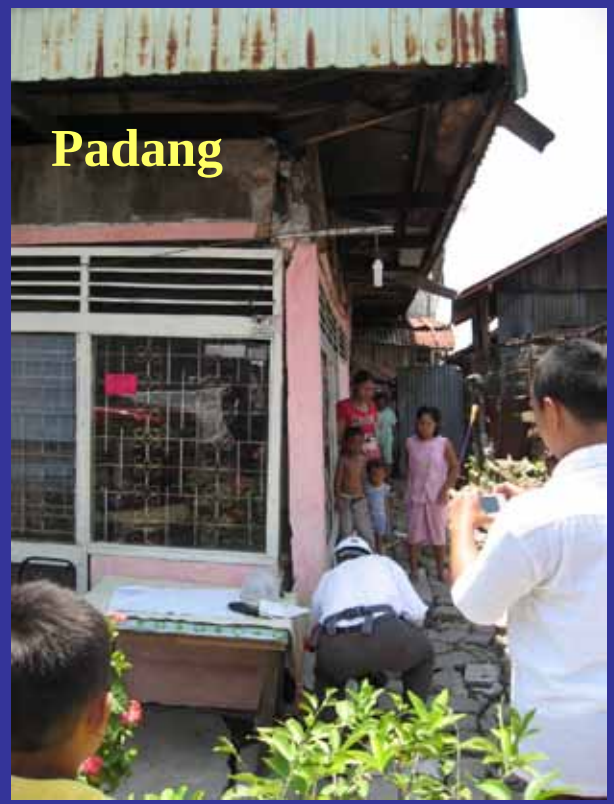
モッスク　－　MOSQUES

semi-reinforced concrete structures

Beam &Column cross sections: (15x15 to 20x20cm)

4-6 smooth steel bars;diameter: 8-12mm.

Masonry Buildings-レンガ積みの家屋



大変貧弱で耐震補強が必要

RC BUILDINGS : PANCAKE MODE

鉄筋コンクリート建物

Soft Floor

Poor Ground Conditions

Poor construction quality & workmanship

弱階問題

軟弱の地盤

施工不良

Repair-修理

木造家屋

地震に強いが地盤の破壊と津波によって被害を受けやすい

BRIDGES・橋

Liquefaction
Lateral
Spreading

液状化
側方流動

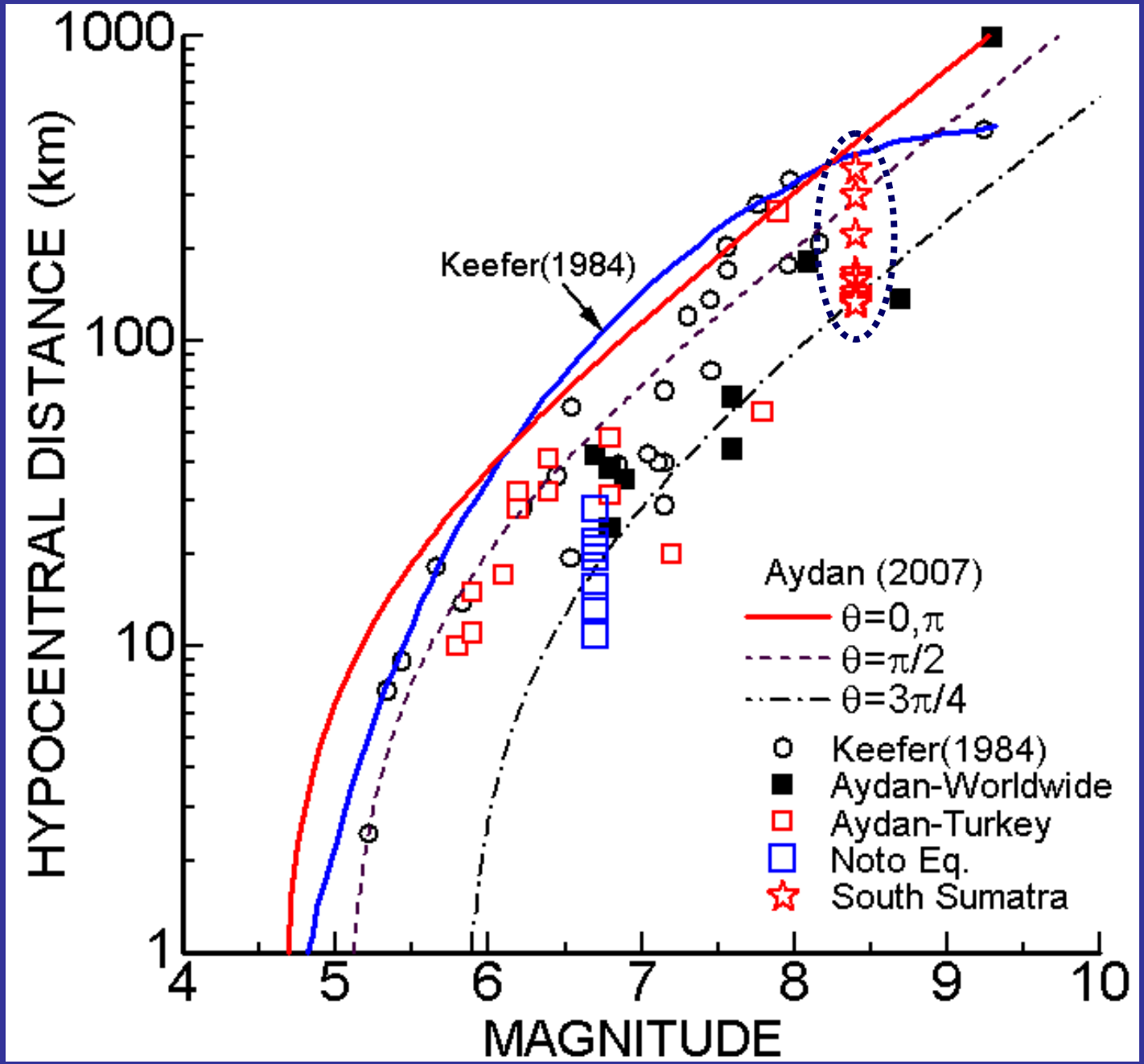
Pasir Gantingにおける地盤の液状化によるアーチ橋の被害

Seblatにおける地盤の液状化および地震動によるトラス橋の被害


BEBAN MAX 8 TON
Masuk Satu Persatu

SLOPES・斜面

山岳地域で火山性風化岩盤斜面の破壊が見られた。大半の斜面崩壊は平面すべりあるいは円形すべりであった。


HYPOCENTRAL DISTANCE (km)
1000
100
10
1
4
5
6
7
8
9
10
MAGNITUDE
Keefer(1984)
Aydan (2007)
θ=0,π
θ=π/2
θ=3π/4
Keefer(1984)
Aydan-Worldwide
Aydan-Turkey
Noto Eq.
South Sumatra

ROAD FAILURES・道路被害

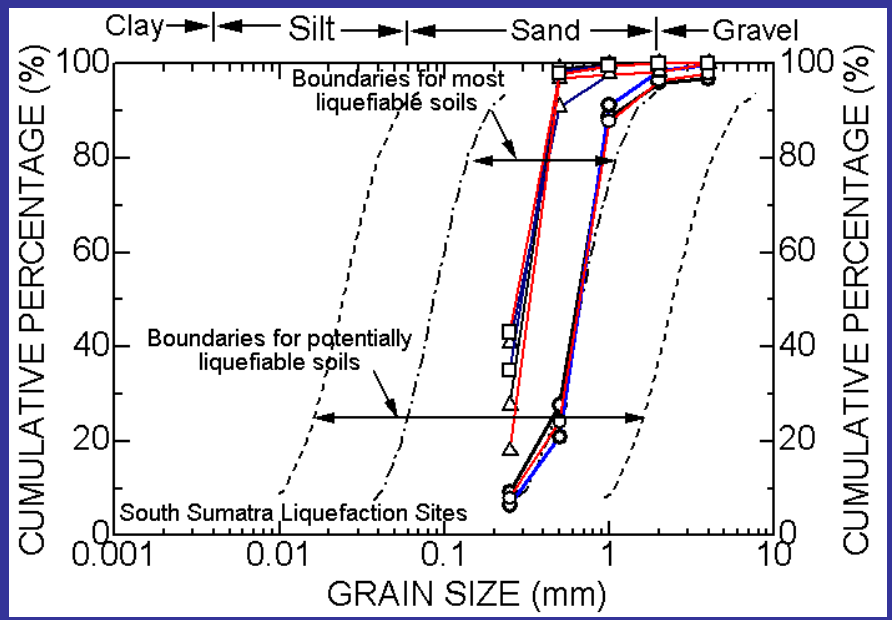
道路の盛土被害は多く見られたが、交通に与える影響は軽微であった。

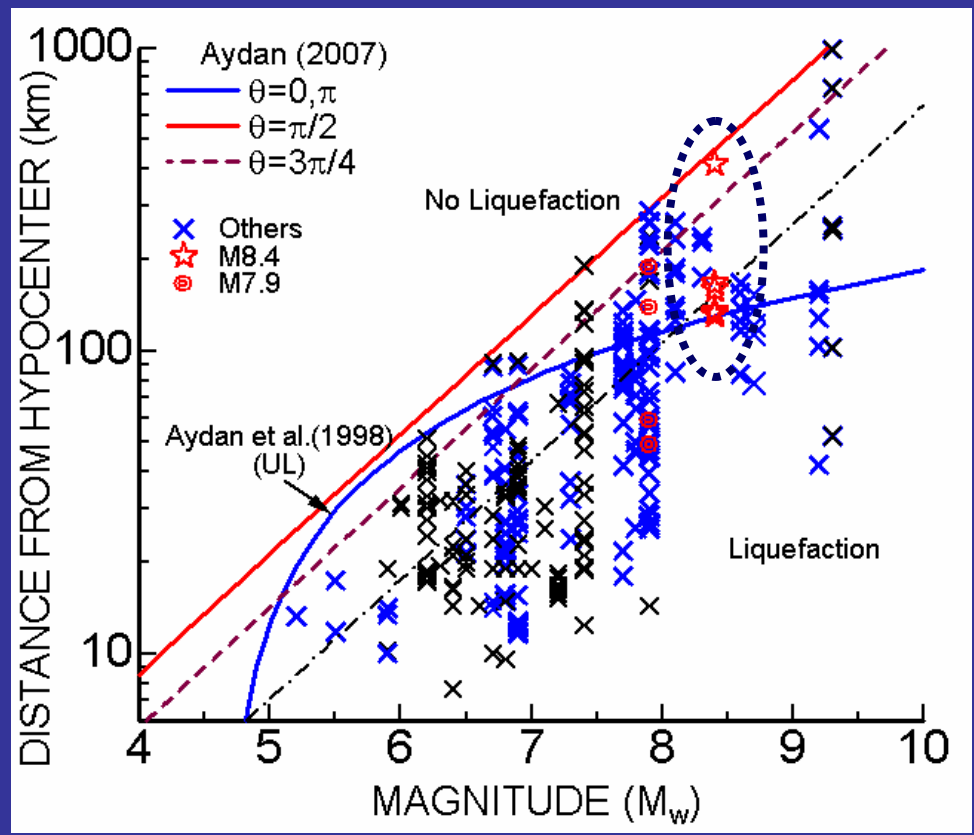
Bengkulu Airport　ー　ベンクル空港

地盤の液状化 LIQUEFACTION

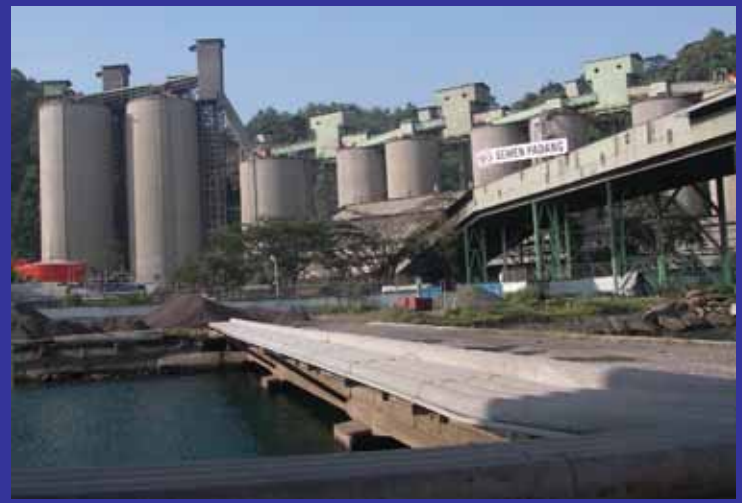
海岸および河川周辺地域で液状化現象が発生した。

Soil Sample Location	Dry Unit Weight (kN/m^3)	Porosity (%)	Mean Grain Size D50 (mm)	Friction Angle (°)
Pasir Ganting	14.6	38-4	0.28-0.33	32-35
Basar Bantal	14.7	42.6	0.27-0.33	34-36
Seblat	14.7	36.7	0.63-0.66	32-34





DAMAGE TO PORTS・港の被害



被害は軽微であった。

地震や津波で産業施設に大きな被害が発生しなかった。被害があった施設でも被害が軽微であった。

Sigunturmuda

Teluk Bayur

Teluk Bayur

ライフライン

今回の地震で，ライフライン被害は軽微である．**Ketaun** の一部と電柱が倒れた地域以外で電気は当日復旧した.

Bungus

Bengkulu

ELECTRIC POLES・Telecommunication Towers 電柱・塔


Serangai


Seblat


Bengkulu

CONCLUSIONS一結論

Some of conclusions drawn from this earthquake may be summarized as follows:

- In a very recent study by (Aydan 2007b) on crustal deformation and straining of Sumatra Island using the GPS deformation rates, it is pointed out that there are three high stress rate concentration regions along the Sumatra Fault and seismic gap between the 2005 Nias and 2007 South Sumatra rupture zones.

- As happened in many earthquakes in Indonesia, there is also no strong motion record for this earthquake except the one at Sikuai strong motion station, which is very close to Padang City. Indonesia lacks the strong motion network. It is strongly recommended to establish it as soon as possible. The estimations maximum ground acceleration and velocity at the epicenter for a ground with shear wave velocity of 300m/s are greater than 400 gal and 40 kine, respectively. These results are quite similar to the estimations from collapsed or displaced simple structures as well as to those estimations by the USGS.

➢When masonry buildings are constructed with bricks without reinforced concrete slab and columns, they were fragile against ground shaking observed in this earthquake. However, constructions utilizing reinforced concrete slabs and columns with the integration of masonry walls within the load bearing system performed better and they prevented the total collapse of the buildings in-spite of some structural damage.

➢The causes of damage to RC buildings can be re-stated for this earthquake as follows:

- ✓Soil liquefaction and lack of the soil bearing capacity
- ✓Large ground settlement of embankments
- ✓Fragile structural walls and lack of lateral stiffness,
- ✓Poor concrete quality and workmanship,
- ✓Plastic hinge development at the beam-column joints,
- ✓Lack of shear reinforcement and confinement,
- ✓Soft story,
- ✓Pounding and torsion and

- Transportation facilities performed relatively better than other structures. However, there were some obstructions due to slope and embankment failures and settlement of bridge abutments..

- Extensive slope failures observed along roadways between Ketaun and Lais. Extensive liquefaction observed along the sea shores and major rivers. The bridges performed well inspite of ground liquefaction in the vicinity of theri foundations and abutments. There is no doubt that it will be desirable to carry out detailed geotechnical investigations for determining the properties of ground conditions and evaluate the performance of bridges and roadways.

- Major industrial and port facilities in West Sumatra and Bengkulu provinces did not suffer any major damage by this earthquake.

RECOMMENDATIONS･提言

現在2007年と2005年の地震破壊領域の間に，西スマトラ州沖で大きな空白域が存在している。予想される地震のマグニチュードは8.7から8.8であり，パダン市を直撃し，大きな津波がパダン市を襲う可能性が高い。

1)構造物の耐震補強

2)津波に対する警告システムの導入および鉛直避難対策

3）計測システムを強化

Measures against Ground Shaking

Measures against Tsunami

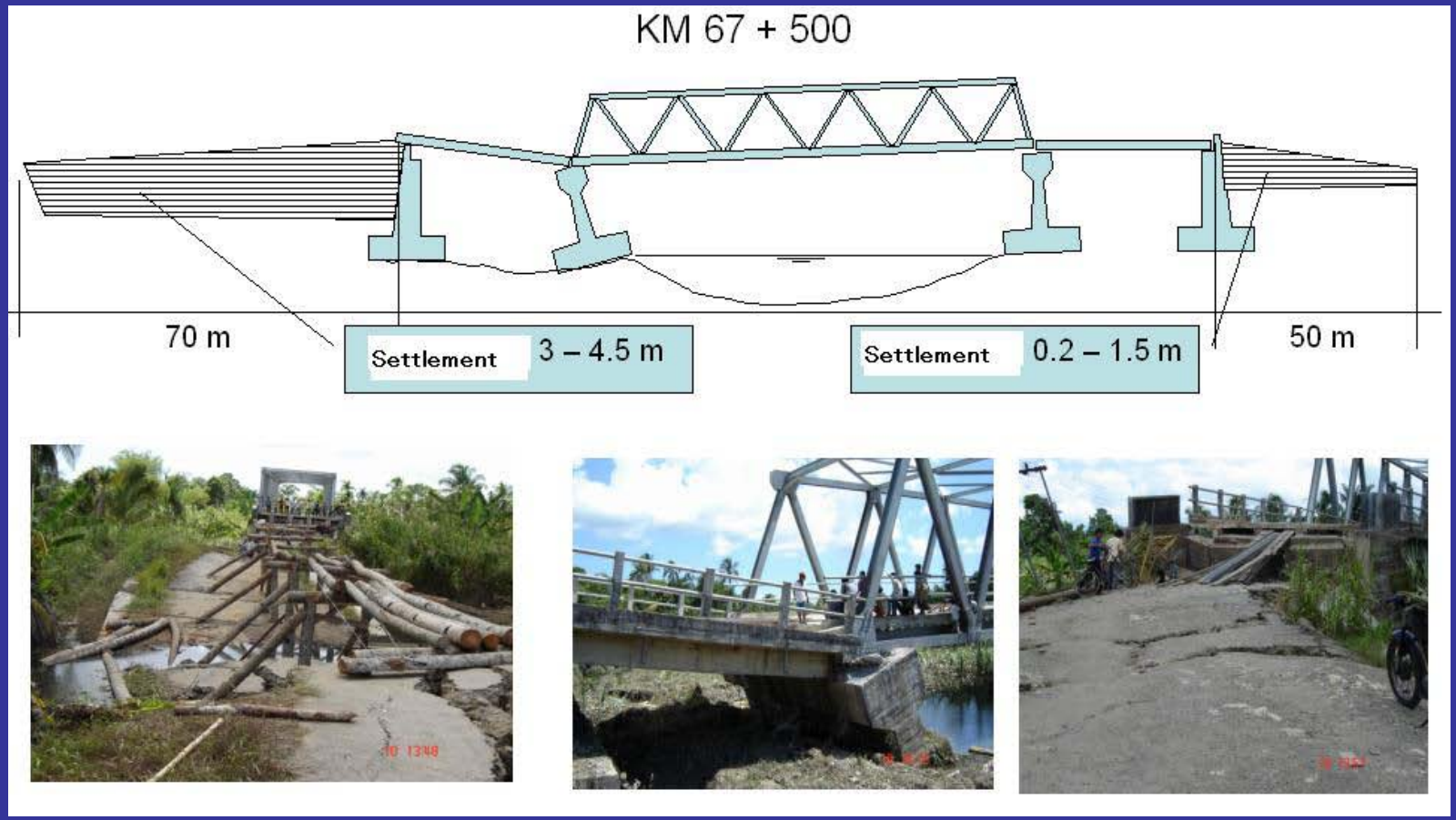
Monitoring

Measures against Ground Shaking 一地震動に対する対策

The existing buildings must be retrofitted against strong ground shaking and they should be equipped with terraces and stairs for the vertical evacuation in tsunami-vulnerable areas

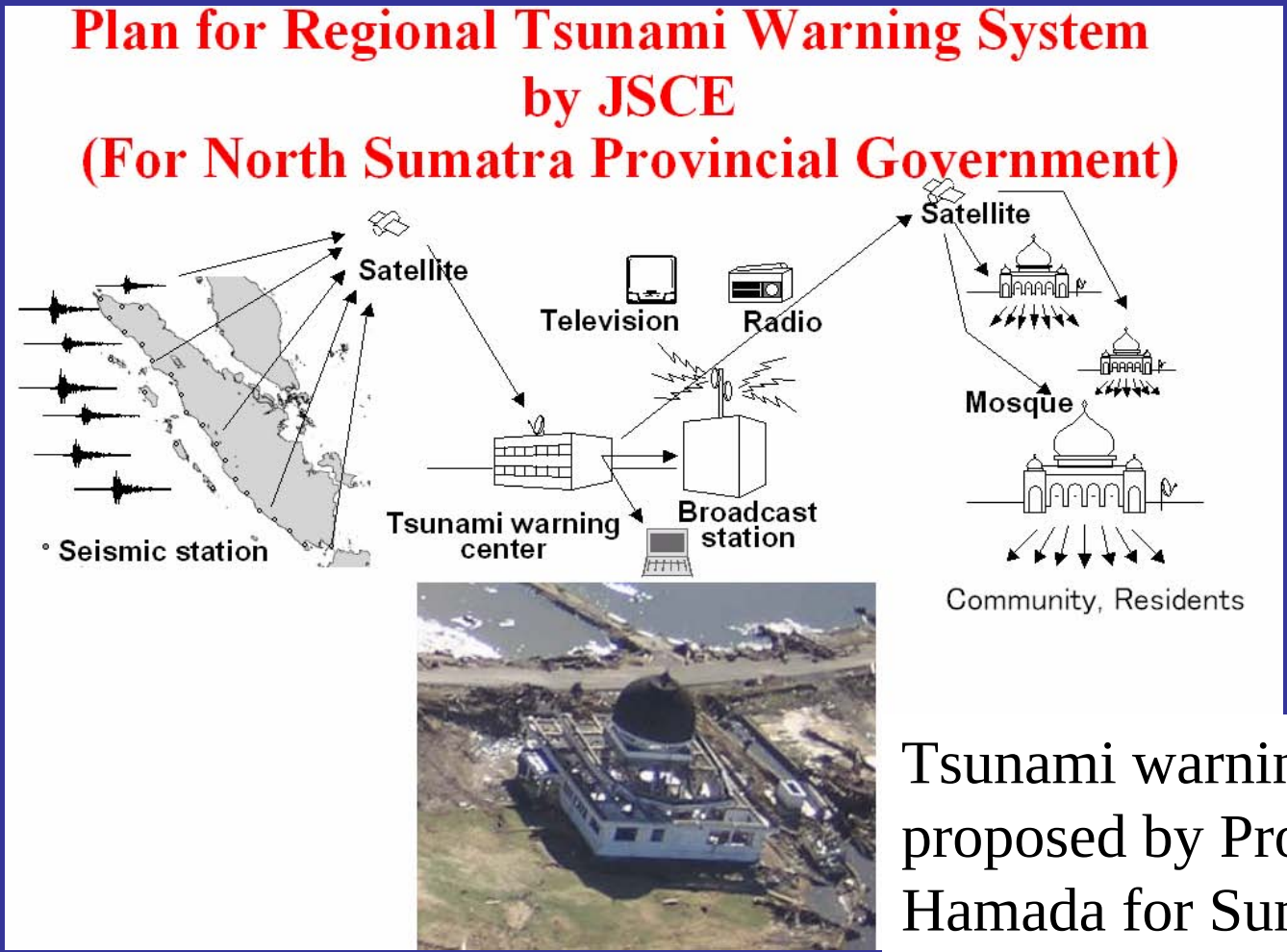
既設建物は耐震補強が必要であり、津波災害に関して鉛直避難機能を持たせるように外付け階段とテラスを備えるべきである

It is urgent to check the vulnerability of ground in relation to the foundations of superstructures and infrastructures.



既設土木構造物とその基礎地盤の耐震診断が必要である。

Recommendations for measures against Tsunami



Tsunami warning system proposed by Prof. M. Hamada for Sumatra

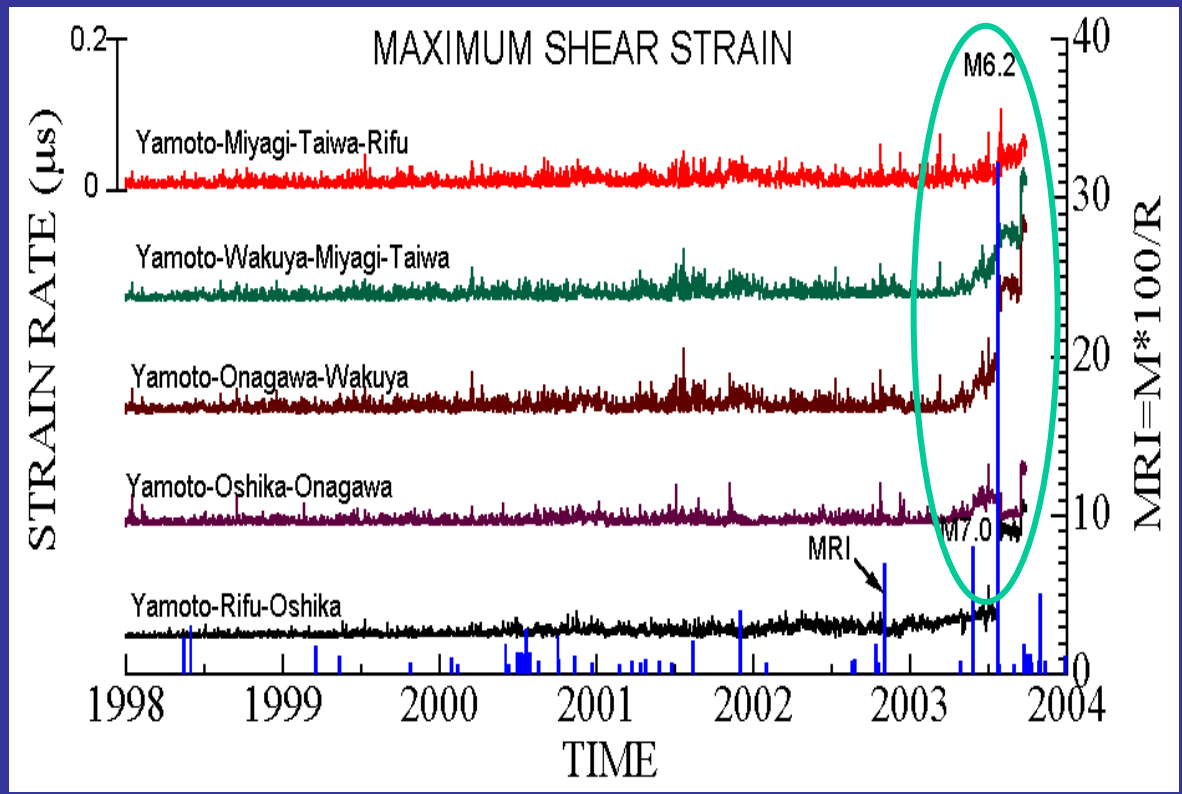
Japanese Tsunami Warning System（日本津波警告システムの導入）

Vertical Evacuation (Retrofitted RC Buildings with Terraces on top)

Education of people – KOGAMI （鉛直避難および教育）

Monitoring－計測

- Strong Motion Network （強震計ネットワークの強化）
- Real-time GPS Network （リアルタイムGPS計測と解釈システム）
- The physical and chemical variations at hot springs（他の項目の計測）



2003 Miyagi Hokubu earthquake (from Aydan, 2004)

TERIMA KASIH