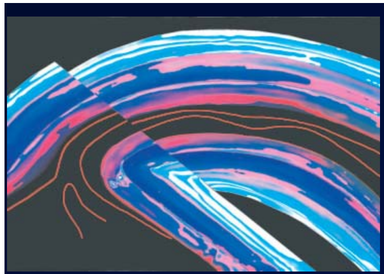

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"The Dead Sea Rift as a natural laboratory
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The ESI 2007 scale and a global catalogue of earthquake environmental effects

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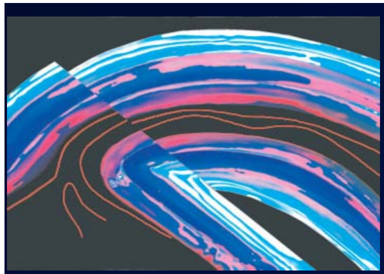
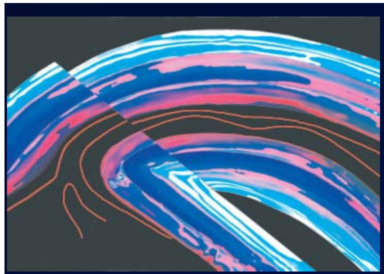
“The Dead Sea Rift as a natural laboratory
for earthquake behavior: prehistorical, historical



Outline

1. Definition of earthquake intensity
2. Earthquake ground effects, dynamic source parameters and maximum magnitude determination – quality of data and resolution; Assam 1897, Muzaffarabad 2005
3. Structure of the ESI 2007 scale: keeping phenomena of the physical environment in line with the damage indicators
4. New Madrid 1811, Anchorage 1964,
5. Paleoseismic intensity: Kashiwazaki-Kariwa and Monte Netto
6. Future directions: a global catalogue



1. INTENSITY: ORIGIN AND DEFINITIONS

Well before the introduction, in 1935 by Charles Richter, of the notion of "magnitude" based on measurements made on instrumentally-recorded motion, certain erudite seismologists (in the persons of Mercalli, Cancani, and Sieberg, among others), in the early years of the last century, devised the notion of the "intensity" of an earthquake at a given location, in the absence of any seismometer (e.g., Mercalli, 1897; Omori, 1900; Cancani, 1904; Sieberg, 1930; Wood and Neumann, 1931).

Basic structure of 12 degrees scales

MCS Scale
Mercalli – Cancani – Sieberg
(1930)
Mostly used in S Europe

A. Empirical scale, rating of earthquake effects are based on a rather subjective assessment, or expert judgement

B. Damage saturates at intensity X in most cases

C. Invaluable information, cannot be replaced by instrumental records

A) I. People do not feel any Earth movement.

II. A few people might notice movement if they are at rest and/or on the upper floors of tall buildings.

III. Many people indoors feel movement. Hanging objects swing back and forth. People outdoors might not realize that an earthquake is occurring.

IV. Most people indoors feel movement. Hanging objects swing. Dishes, windows, and doors rattle. The earthquake feels like a heavy truck hitting the walls. A few people outdoors may feel movement. Parked cars rock.

V. Almost everyone feels movement. Sleeping people are awakened. Doors swing open or close. Dishes are broken. Pictures on the wall move. Small objects move or are turned over. Trees might shake. Liquids might spill out of open containers.

VI. Everyone feels movement. People have trouble walking. Objects fall from shelves. Pictures fall off walls. Furniture moves. Plaster in walls might crack. Trees and bushes shake. Damage is slight in poorly built buildings. No structural damage.

VII. People have difficulty standing. Drivers feel their cars shaking. Some furniture breaks. Loose bricks fall from buildings. Damage is slight to moderate in well-built buildings; considerable in poorly built buildings.

B) VIII. Drivers have trouble steering. Houses that are not bolted down might shift on their foundations. Tall structures such as towers and chimneys might twist and fall. Well-built buildings suffer slight damage. Poorly built structures suffer severe damage. Tree branches break. Hillsides might crack if the ground is wet. Water levels in wells might change.

IX. Well-built buildings suffer considerable damage. Houses that are not bolted down move off their foundations. Some underground pipes are broken. The ground cracks. Reservoirs suffer serious damage.

X. Most buildings and their foundations are destroyed. Some bridges are destroyed. Dams are seriously damaged. Large landslides occur. Water is thrown on the banks of canals, rivers, lakes. The ground cracks in large areas. Railroad tracks are bent slightly.

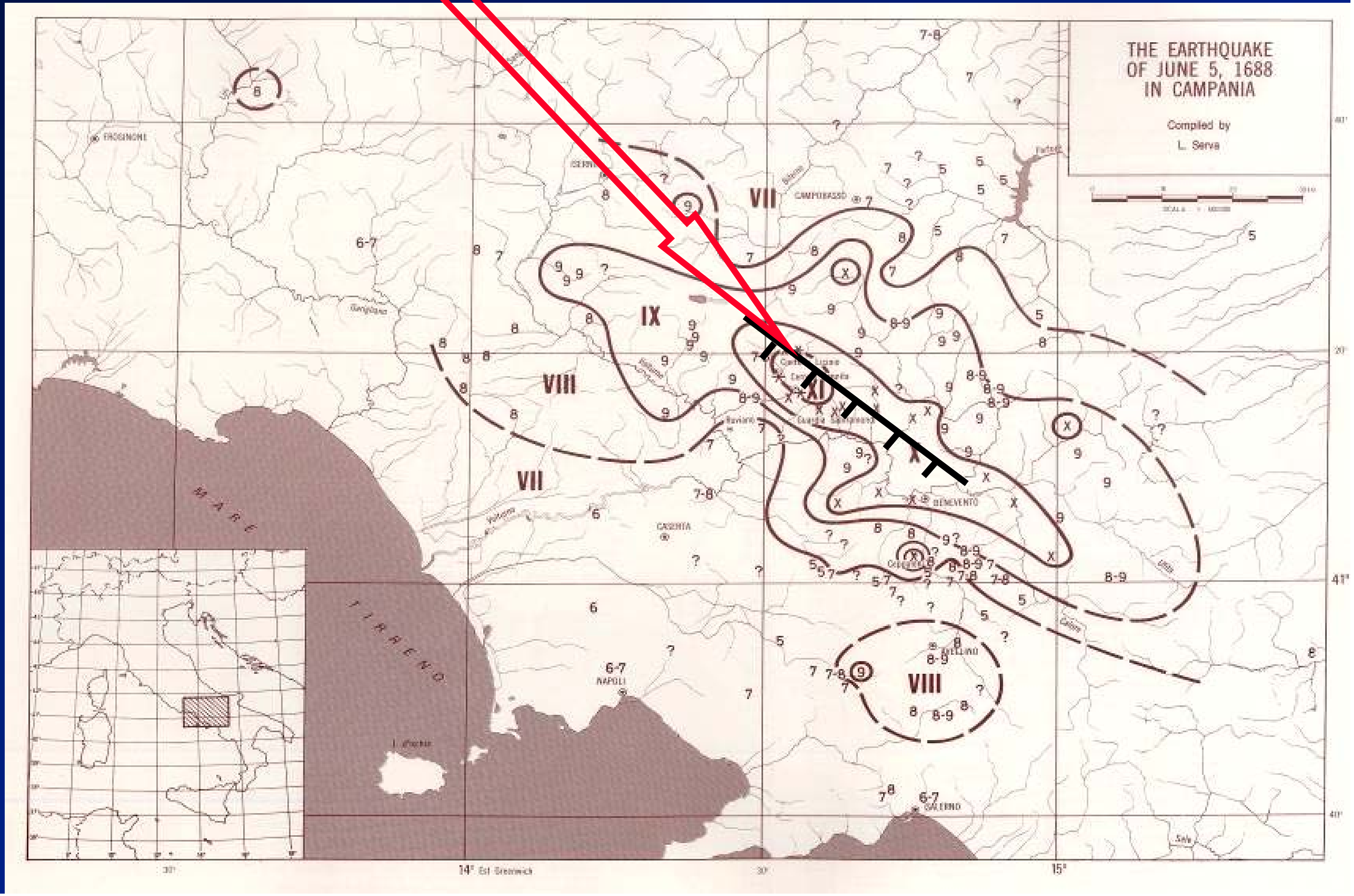
XI. Most buildings collapse. Some bridges are destroyed. Large cracks appear in the ground. Underground pipelines are destroyed. Railroad tracks are badly bent.

XII. Almost everything is destroyed. Objects are thrown into the air. The ground moves in waves or ripples. Large amounts of rock may move.

Modified Mercalli scale, simplified

Epicentral intensity Io = XI

C) Isoseismal map of the June 5, 1688, Sannio earthquake (Serva, 1985) MCS scale



Intensity concept (Ruben Tatevossian, 2007)

1) What we measure: effect itself or causa of effect via effect?

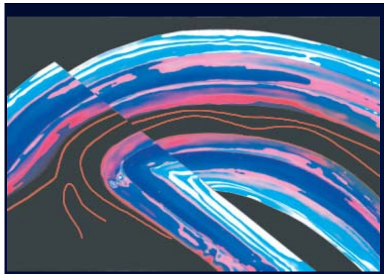
2) What reflects intensity? Is it an ill-defined analogue of PGA, or it reflects a phenomenon, which depends in a complex way on PGA, PGV, residual slip.

3) What is the subject of hazard assessment? (choice of site + seismic loading).

Intensity concept

Further refinements of the macroseismic scales brought EMS98. It is a perfect tool to measure vibrational part of ground shaking but the basic concept was broken.

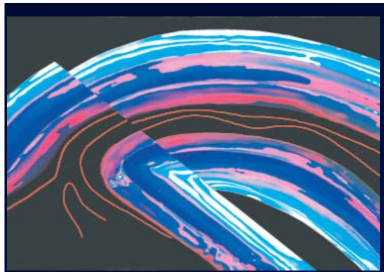
Intensity reflects a phenomenon depending in a complex way on PGA, PGV, and residual slip.
Excluding environmental effects violates this concept. But they should be treated in such a way, that intensity scale category will not be reduced to a ranking scale.
Such research helps promote our understanding of the earthquake history of a region, and estimate future hazards



Mercalli, Omori, Sieberg and the formal definition of intensity

❖ INTENSITY is a parameter intended to quantify the effects of the earthquake at a site based on both “shaking effects” and “primary tectonic effects”; particular value for historical and pre-historical earthquakes

❖ The effects on humans are the most important indicators of intensity up to the V degree for the “Mercalli”-derived, 12 degrees scales. The assessment of intensity in the range VI to IX is based mostly on effects on man-made structures (damage), in the range X to XII on effects on the natural environment (ground effects or environmental earthquake effects, EEE). Also in the Omori scale, the highest degrees are defined based on geological effects.



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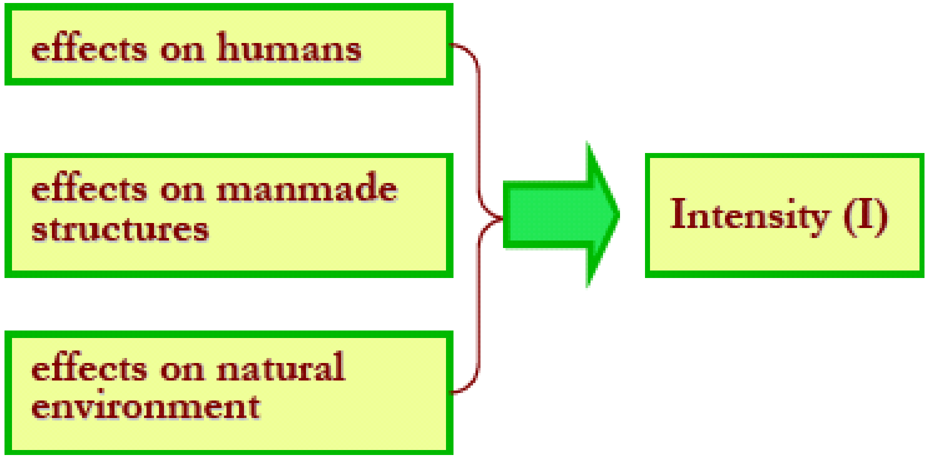
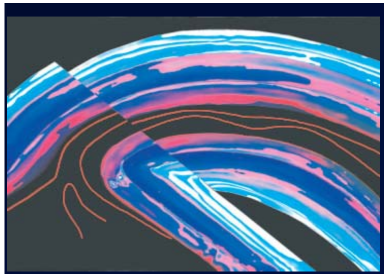


Fig. 1 - According to the original definition of intensity in the twelve degrees scales, i.e., the Mercalli-Cancani-Sieberg Scale (MCS), the Modified Mercalli scale (MM-31 and MM-56) and the Medvedev-Sponheuer-Karnik scale (MSK-64), the assessment of intensity degrees has to be based on humans, manmade structures and natural environment.
- *Secondo la definizione originale di intensità nelle scale a dodici gradi, quali la scala Mercalli-Cancani-Sieberg (MCS), la scala Mercalli Modificata (MM-31 e MM - 56) e la scala Medvedev-Sponheuer-Karnik (MSK 64), la valutazione del grado di intensità deve essere basata sugli effetti sull'uomo, sulle strutture antropiche e sull'ambiente naturale.*



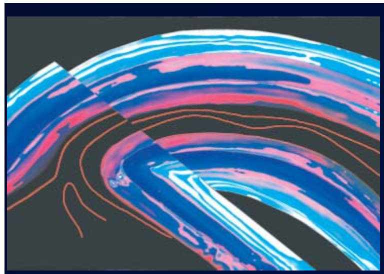
2. ESI SCALE: A BETTER LINK TO DYNAMIC SOURCE PARAMETERS AND MMAX DETERMINATION, A BETTER TOOL FOR SITING

Intensity is a measure of the earthquake based on human perceptions, damage (buildings/man made structures), and the impact on the natural environment, which is the cumulative, final EFFECT from

- the SOURCE
    - VIBRATIONS generated during slip
    - FINITE DEFORMATIONS
- the PROPAGATION of seismic waves
- the local SITE CONDITIONS

The definition of intensity IN THE NEAR FIELD OF STRONG EARTHQUAKES is essentially based on the study of natural effects, since indicators based on human perception and damage HAVE BEEN DESIGNED by the Authors to saturate ("damage total"…) at intensity higher than IX in the MCS, MM1931, MM1958, and MSK scales

If we do not use environmental effects, as in the case of the EMS scale, the original concept of intensity is broken, and intensity X, XI and XII become practically useless.



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12 june 1897, M8+ Assam earthquake
Revised by Ambraseys and Bilham (2003)

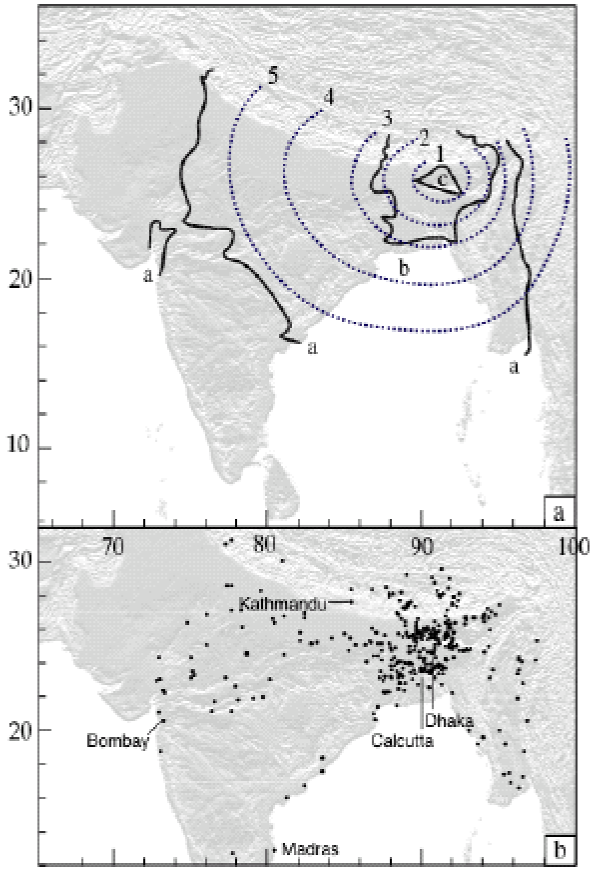


Fig. 1a. Location map for the 1897 Assam earthquake showing isoseismal approximations assigned by Oldham (1899) as dashed incomplete ellipses. Bold lines enclose Oldham's (a) felt area, (b) "area of extensive damage" and (c) "the probable limits of the epicentre", beneath and north of the Shillong Plateau. Fig.1b. Locations of observational data (dots) used to evaluate MSK intensities.

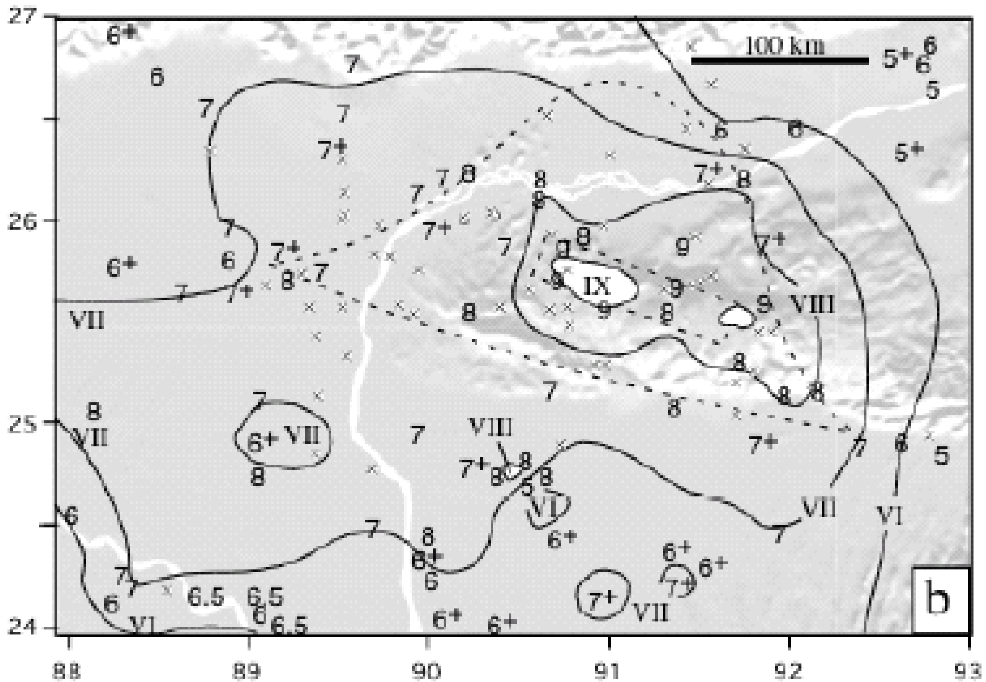
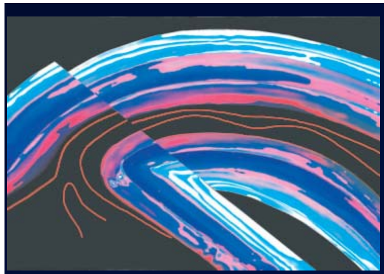


Fig. 2a. Epicentral location map showing Oldham's (1899) epicentral area centered on the Shillong Plateau, and dashed rectangle indicating the inferred 1897 subsurface rupture. Fig. 2b Same area with evaluated MSK intensities, rejected observational data (x), and isoseismal contours evaluated using kriging methods described in the text.



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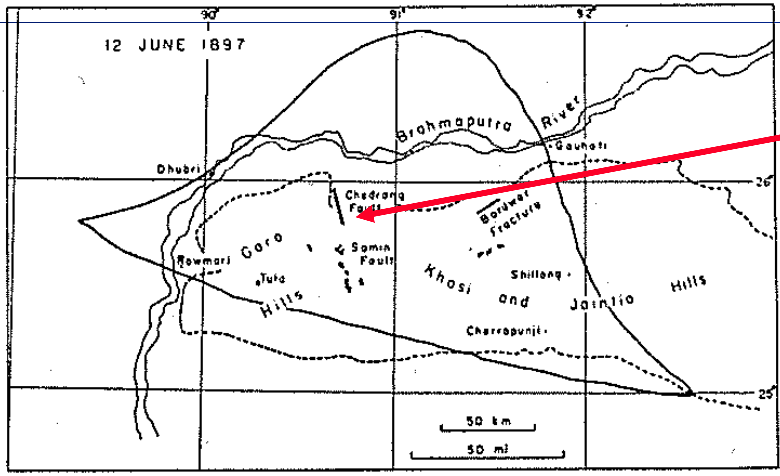
Isoseismals and Magnitude

Figure 5-1 shows Oldham's three most important isoseismals, which bound the area of perceptible shaking, the region of significant damage to masonry, and the meizoseismal area. The inset shows the first two corresponding isoseismals for the California earthquake of 1906; on that occasion effects comparable with those in the meizoseismal area of 1897 were observed only close to the San Andreas fault. The greatest linear extent of the 1906 isoseismals is nearly the same as in 1897, but the area included is much narrower. The magnitude of the 1906 earthquake was 8¼. Seismographs which registered the 1897 earthquake were not of modern type; it is difficult to use their records for deter-

FIGURE 5-2 *Indian earthquake, 1897. Meizoseismal area. [Oldham.] Solid outline, region of violent shaking; dashed outline, hill area.*



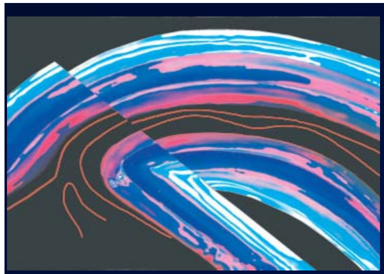
Richter, Elementary Seismology, p. 49, quoting Oldham, 1899

Chedrang Fault,
ca. **24 Km**,
up to **10 m**
of vertical
displacement
in the bedrock

TAB. 1 - *Ranges of surface faulting parameters (primary effects) and typical extents of total area (secondary effects) for each intensity degree.*
- Valori di riferimento per ciascun grado di intensità relativo ai parametri di fagliazione superficiale (effetti primari) e all'area totale degli effetti secondari.

I_0 Intensity	PRIMARY EFFECTS		SECONDARY EFFECTS
	SURFACE RUPTURE LENGTH	MAX SURFACE DISPLACEMENT / DEFORMATION	TOTAL AREA
IV	-	-	-
V	-	-	-
VI		-	-
VII	(*)	(*)	10 km²
VIII	Several hundreds meters	Centimetric	100 km²
IX	1- 10 km	5 - 40 cm	1000 km²
X	10 - 60 km	40 - 300 cm	5000 km²
XI	60 – 150 km	300 – 700 cm	10000 km²
XII	> 150 km	> 700 cm	> 50000 km²

(*) Limited surface fault ruptures, tens to hundreds meters long with centimetric offset may occur essentially associated to very shallow earthquakes in volcanic areas.



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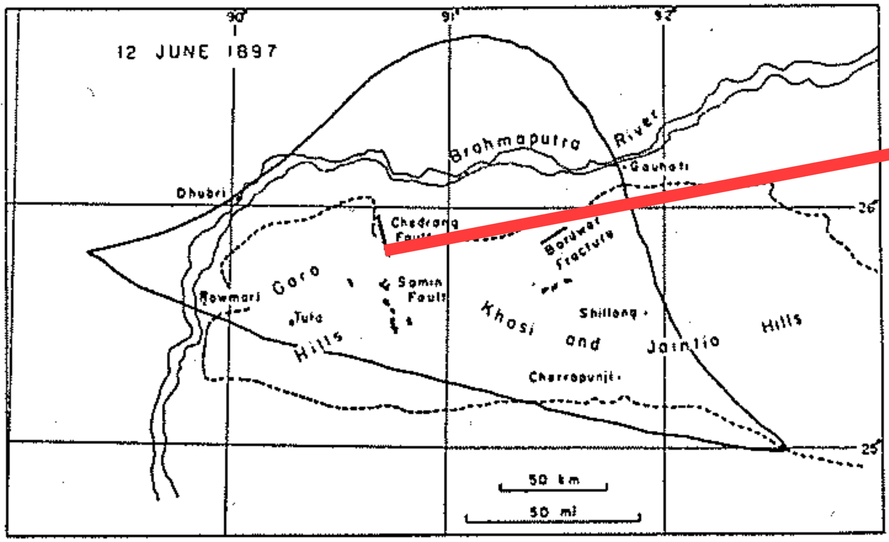

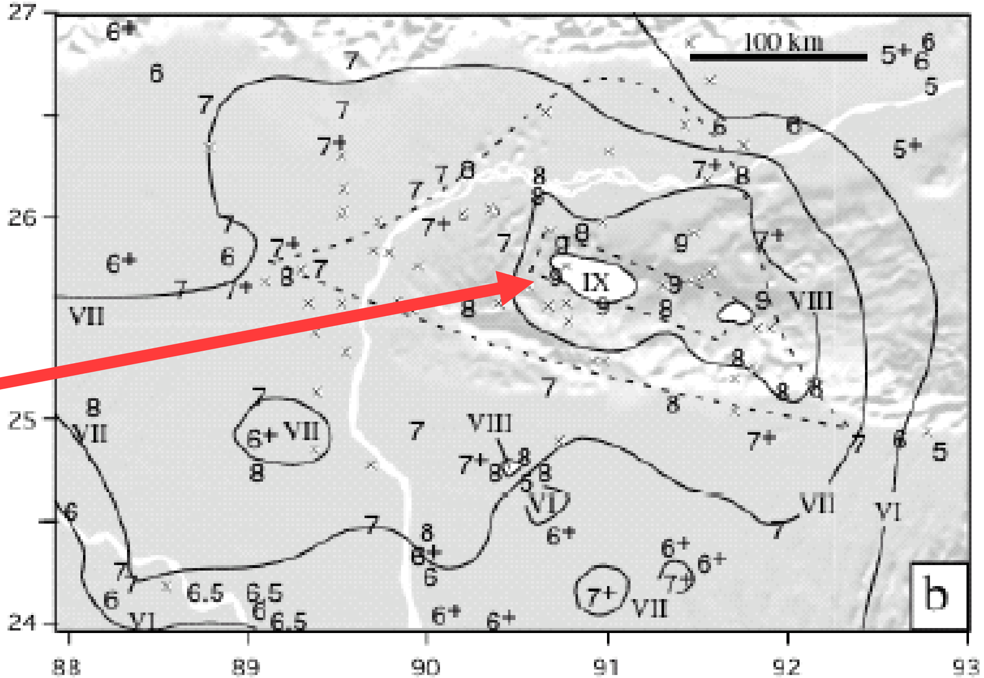

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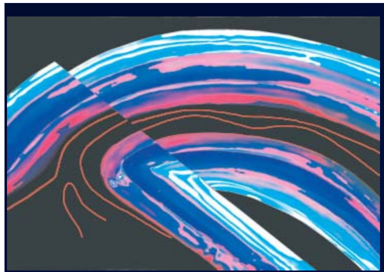
✓**ESI 2007 intensity XII**



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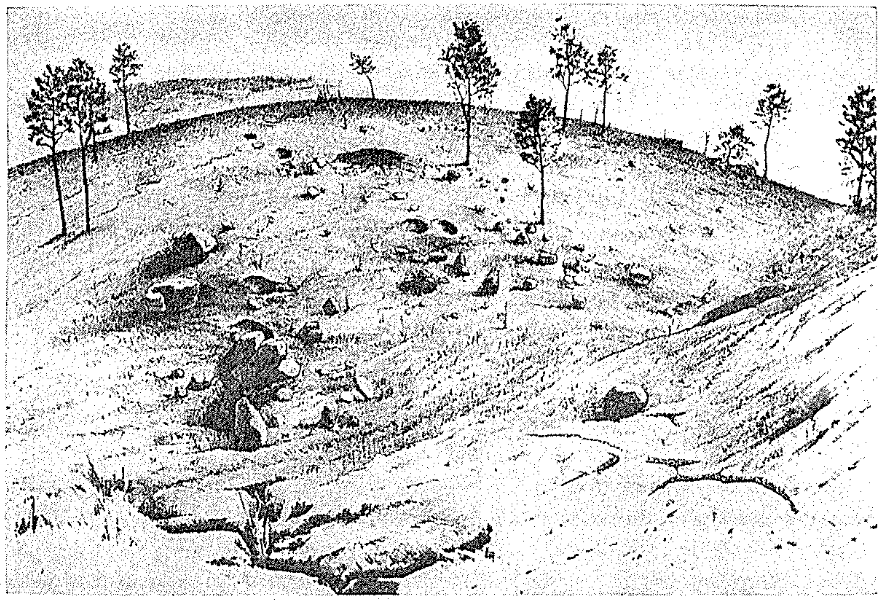


FIGURE 5-4 *Indian earthquake, 1897. Dislodged boulders. [Oldham.]*

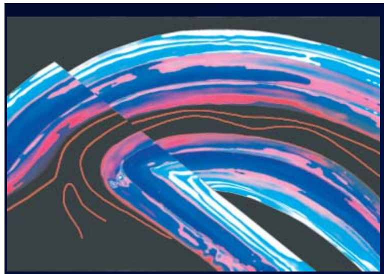
his result fully and with circumstantial care. Not merely did eyewitnesses report seeing pebbles bouncing on the ground "like peas on a drumhead," but numerous instances were observed, photographed, and figured in detail, of posts shot out of their holes and of boulders lifted out of the ground without cutting the edges of their former seats (Fig. 5-4). This high acceleration is consistent with evidence in the granitic rock of the Assam hills, of widespread surface distortion, and of complex fracturing best characterized as shattering. The few features Oldham was able to find in a limited time in difficult jungle country can be no more than a representative fraction of those formed.

Faults and Fractures

Two true faults were found. The Chedrang fault was the greater, extending over 12 miles with throws up to 35 feet, in crystalline rock. It followed the general line of a stream, which suggests an old line of weakness. However, the winding course of the stream took it back and forth across the fault. Result: a series of waterfalls alternating with pools, as the stream dropped down over the fault scarp or flowed against it. Ponding was also observed along the stream where the former grade had reversed; and in the jungle, out of line with the Chedrang and Samin faults, similar pools indicated extensive warping.

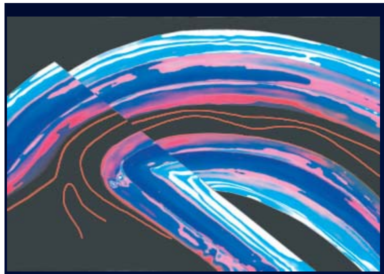
There was other evidence that the surface had been distorted. Oldham's

✓ESI 2007 intensity XII



MM scale, 1931; intensity XII

Damage total - practically all works of construction damaged greatly or destroyed.
Disturbances in ground great and varied,
numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc. numerous and extensive. Wrenched loose, tore off, large rock masses. **Fault slips in firm rock, with notable horizontal and vertical offset displacements.** Water channels, surface and underground, disturbed and modified
greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. **Threw objects upward into the air.**

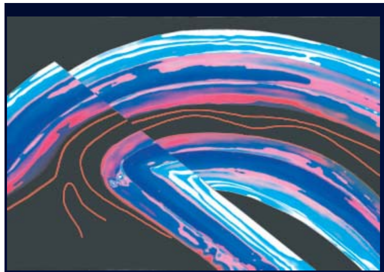


MSK scale, 1964; intensity XII

(a) Practically all structures above and below ground are greatly damaged or destroyed

(c) The surface of the ground is radically changed. Considerable ground cracks with extensive vertical and horizontal movements are observed. Fall of rock and slumping of river banks over wide areas; lakes are dammed; waterfalls appear; and river are deflected.

The intensity of the earthquake requires to be investigated in a special way.



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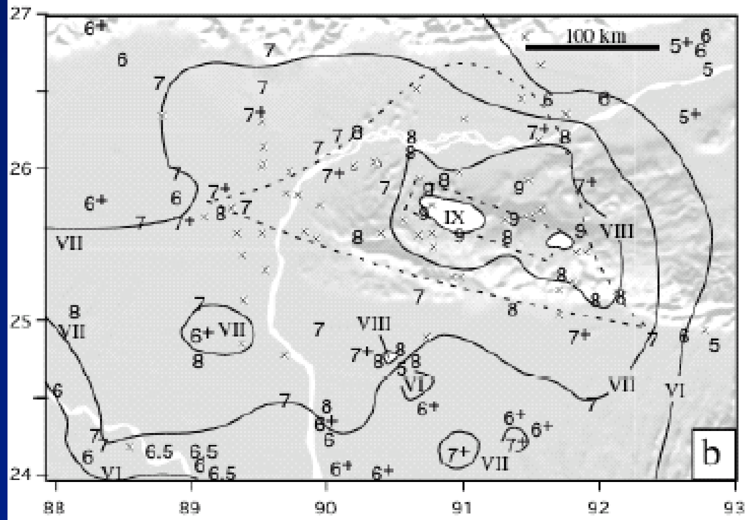
This cannot be called intensity. This is something else. Intensity, as formally defined by Mercalli, Cancani, Sieberg, Richter, and the other Authors in their original macroseismic scales, must include the comprehensive assessment of earthquake effects based on human perception, damage, and phenomena in the natural environment.



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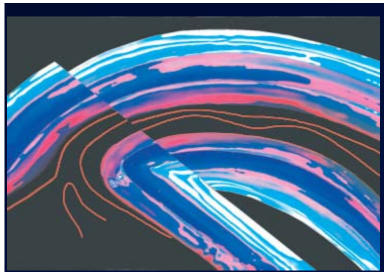
As seismologists, geologists and engineers, we all need this information about intensity, in particular in the near field of the strong earthquakes (fault directivity, fault geometry, dynamic source parameters) .

✓ “Maximum intensity in any destructive earthquake in a rural area in the Eastern Mediterranean, Middle East and the Indian subcontinent appears to be effectively the same. That is, it "saturates" at intensity VII-VIII MSK when all adobe, rubble-stone- masonry, and *pukka* houses are destroyed or damaged beyond repair. Any town or village would thus appear equally, but no more, devastated at so-called higher intensities.
The vulnerability of kuccha, timber-framed and lath constructions is low, but intensity scales are not designed for these types of construction, so their degree of damage cannot be used easily as a qualitative description to assess intensity. Also the fact that only one of these types of construction is predominantly available for observation makes it difficult to assess epicentral intensity greater than VII-VIII MSK
Intensities higher than VII-VIII MSK can only be assessed from the behaviour of modern buildings for which intensity scales have been calibrated. Such structures did not exist in 1897. For these reasons any attempt to estimate epicentral intensity for the Assam earthquake would be highly subjective, and, in our estimation, unjustified.”

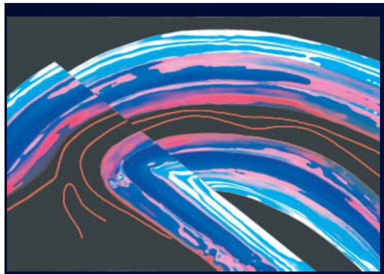
Ambraseys and Bilham, 2003



ESI 2007 scale

Better link to dynamic source parameters and maximum magnitude determination

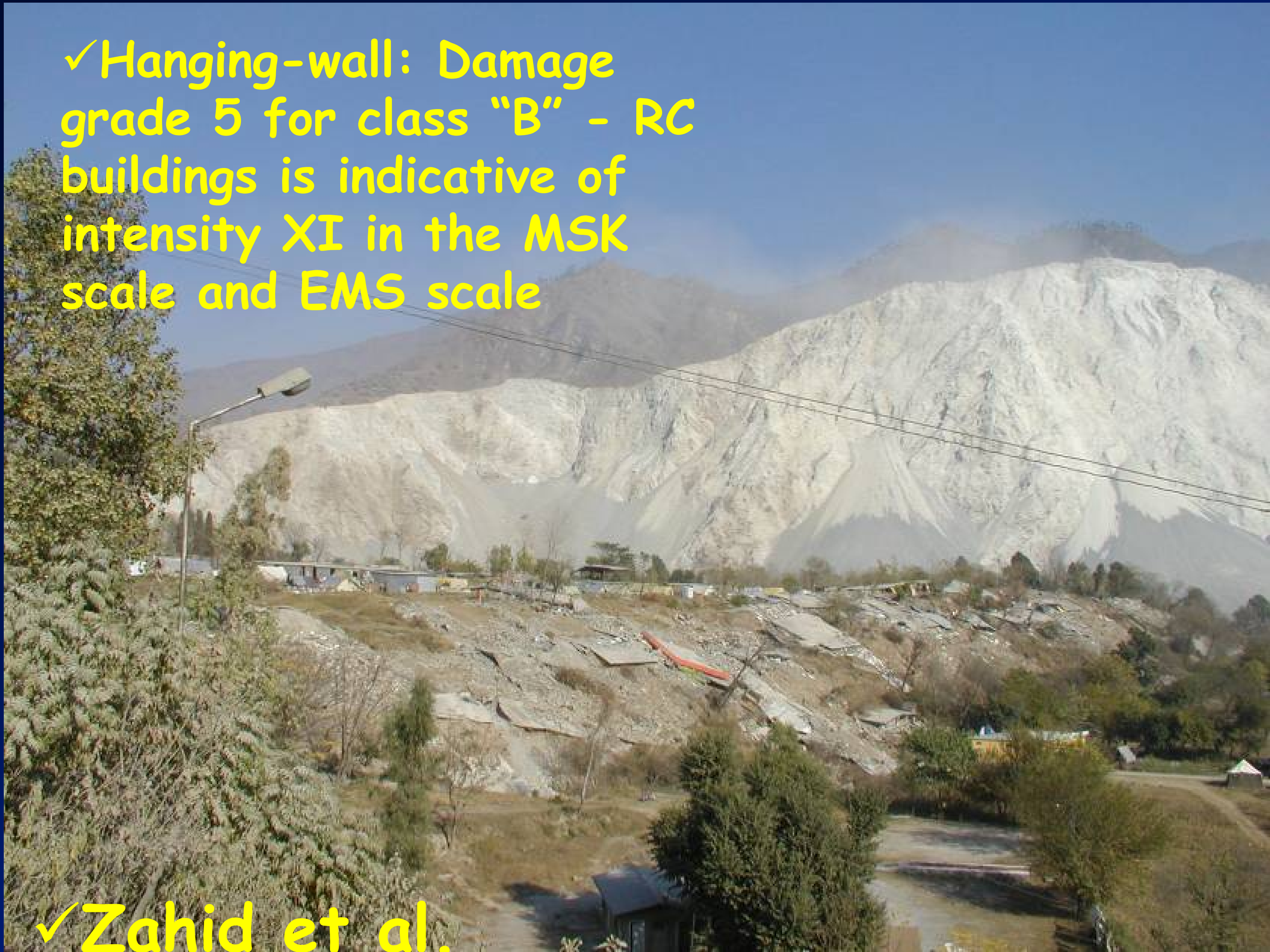
Tool for the identification of most severe ground effects at each site



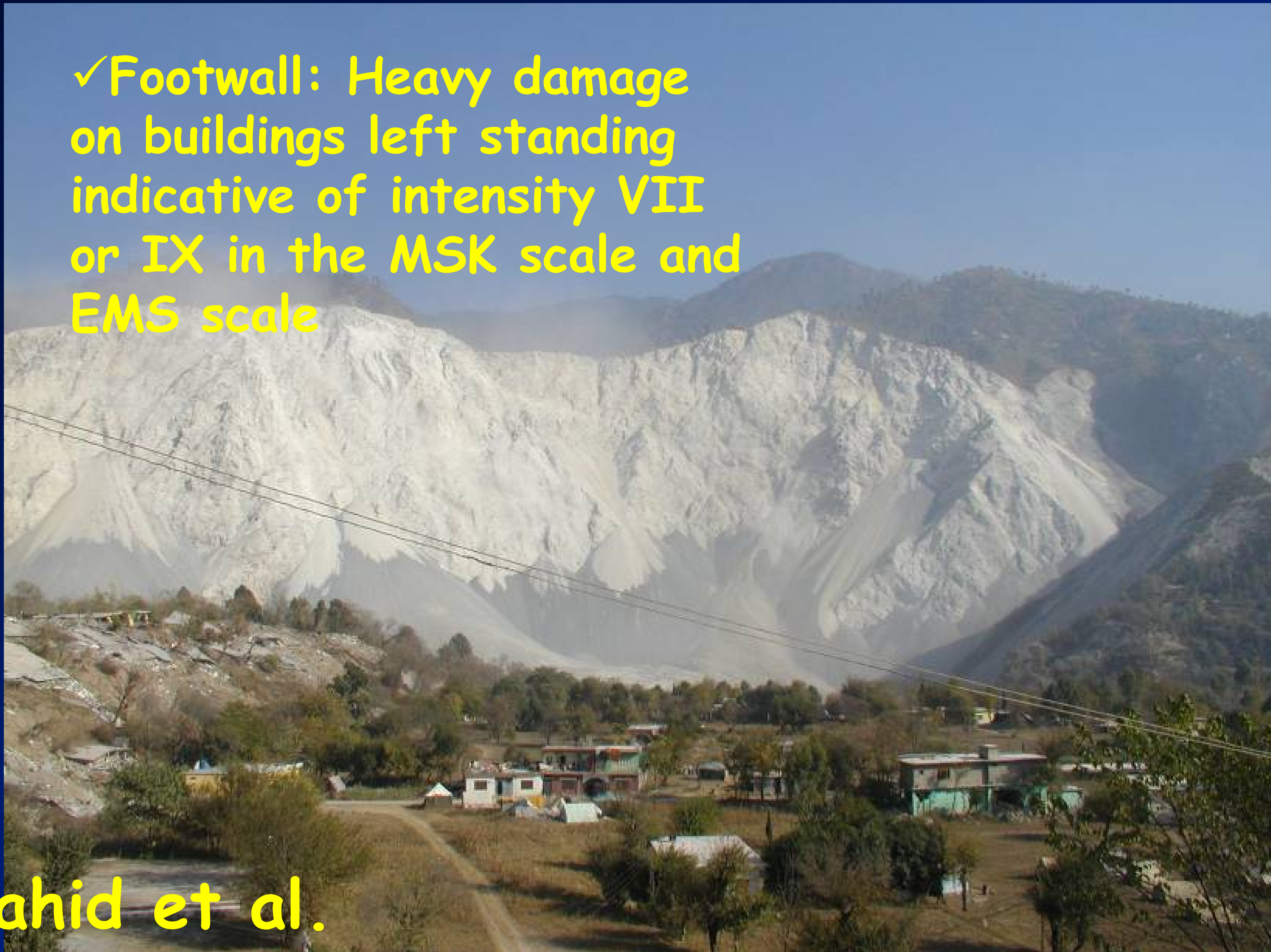
ESI 2007 scale → **Consistent intensity assessment for pre-historical, historical and instrumental events; quality of the data and resolution**

Left-lateral (5 m; ESI2007 = XI) and vertical (0.7 m) faulting associated to the 16 July 1990 Luzon (Philippines) earthquake (Ms 7.8) (Yomogida and Nakata, 1994). Photo courtesy of T. Nakata.

✓Hanging-wall: Damage grade 5 for class “B” - RC buildings is indicative of intensity XI in the MSK scale and EMS scale

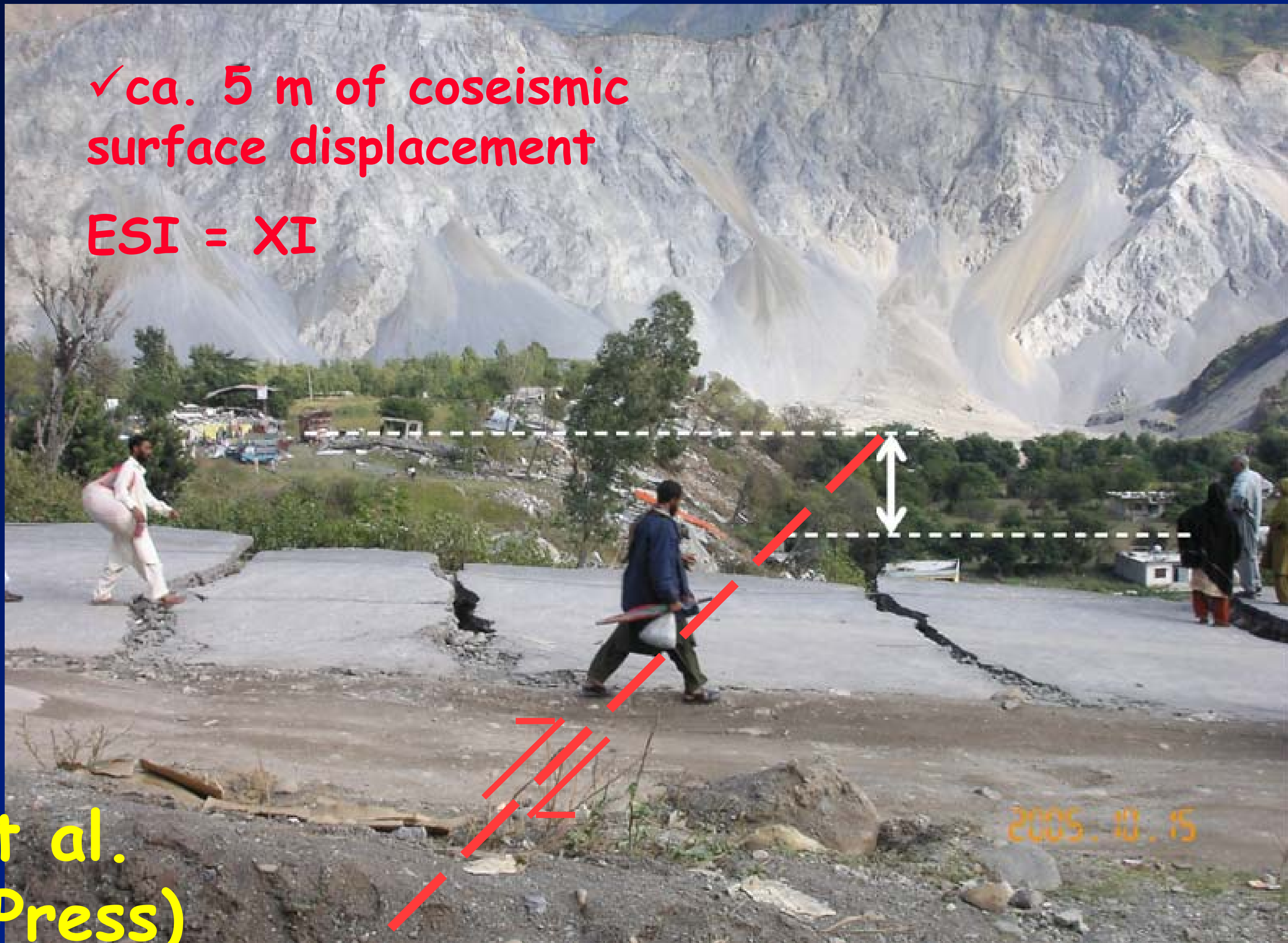


✓Zahid et al. 2009 (in Press)



✓Footwall: Heavy damage on buildings left standing indicative of intensity VII or IX in the MSK scale and EMS scale

✓Zahid et al. 2009 (in Press)



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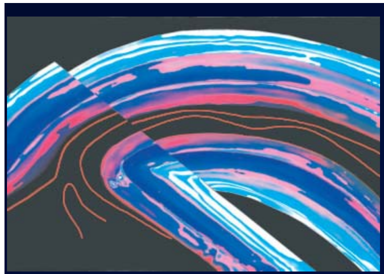

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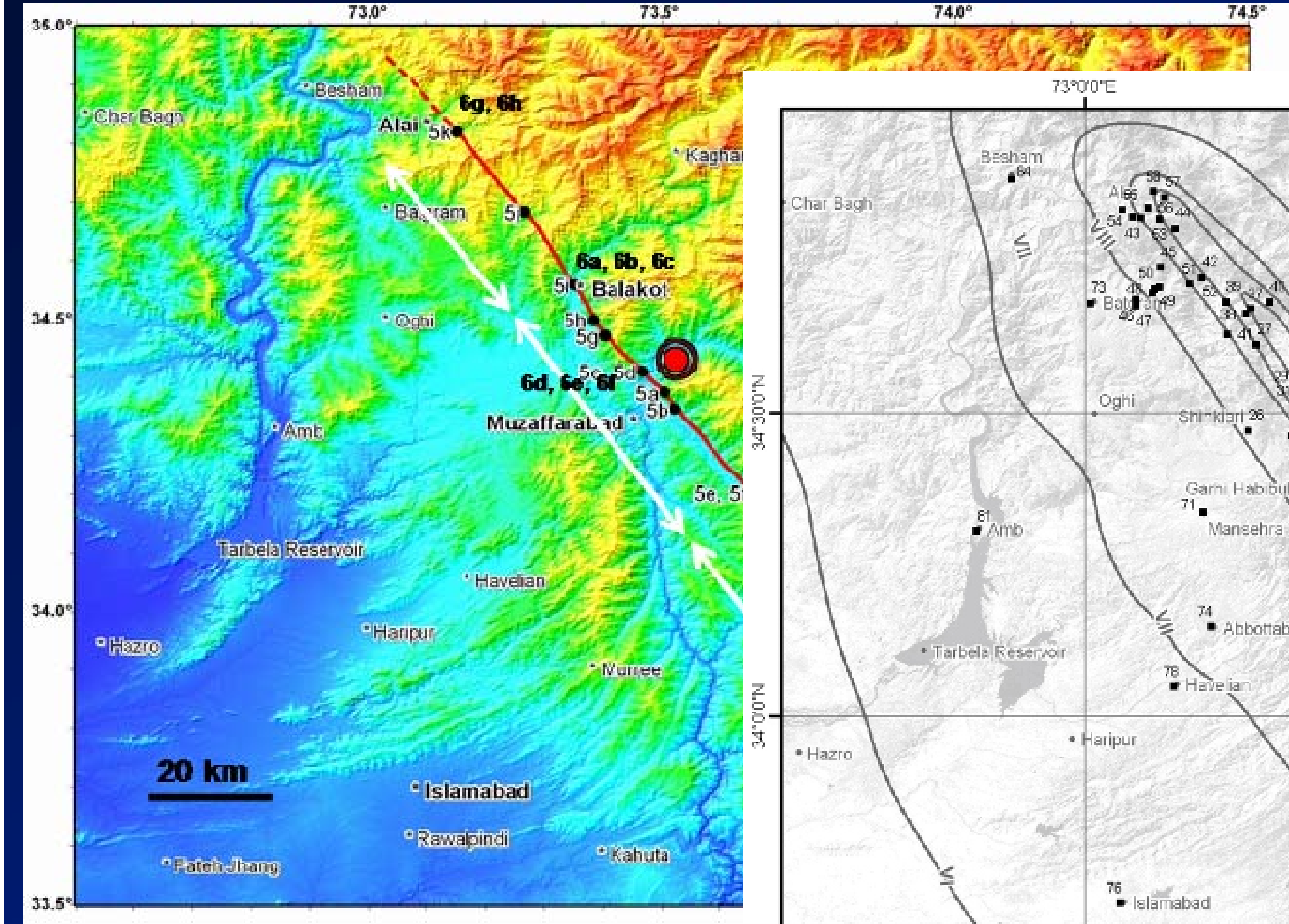
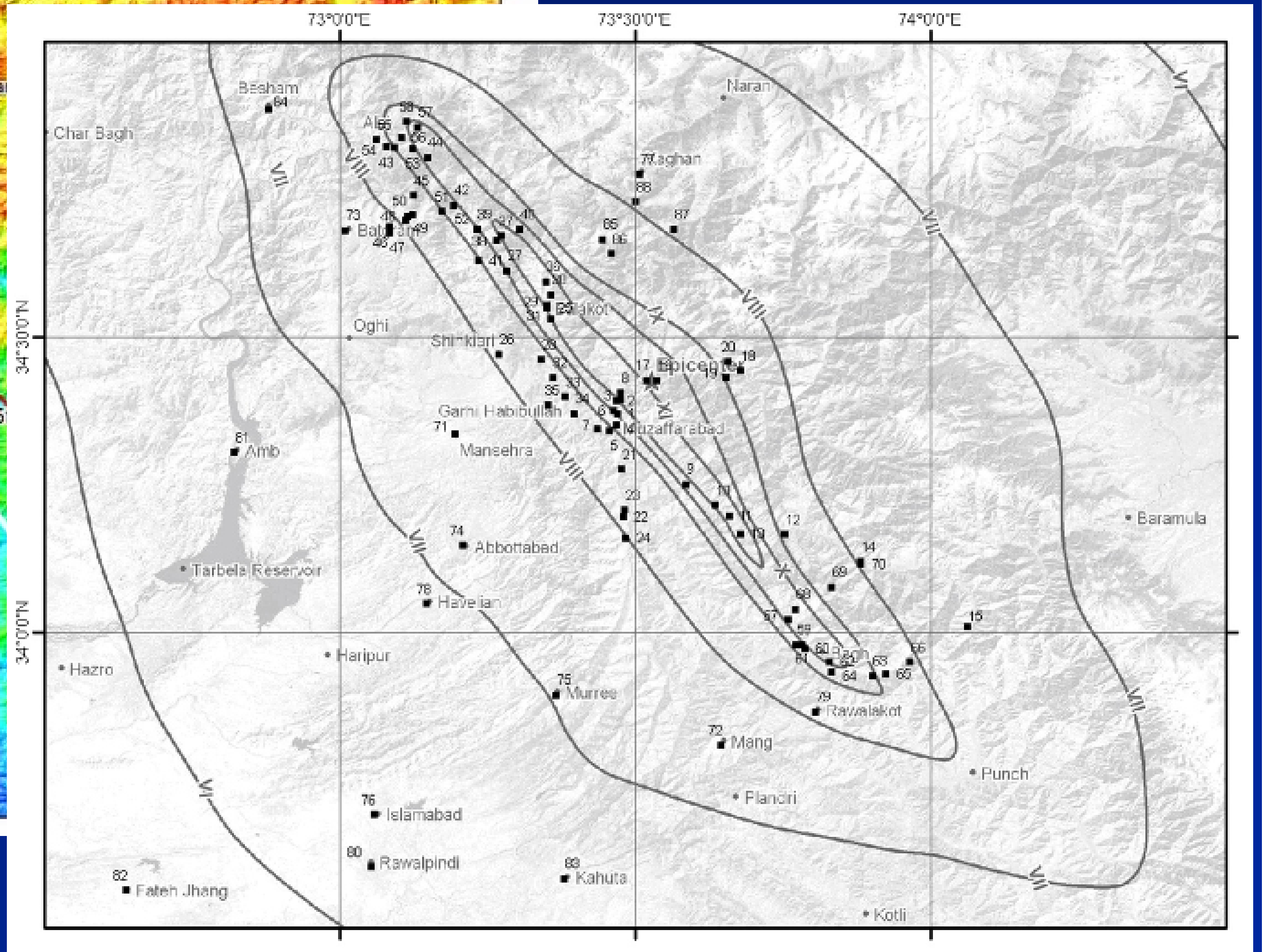


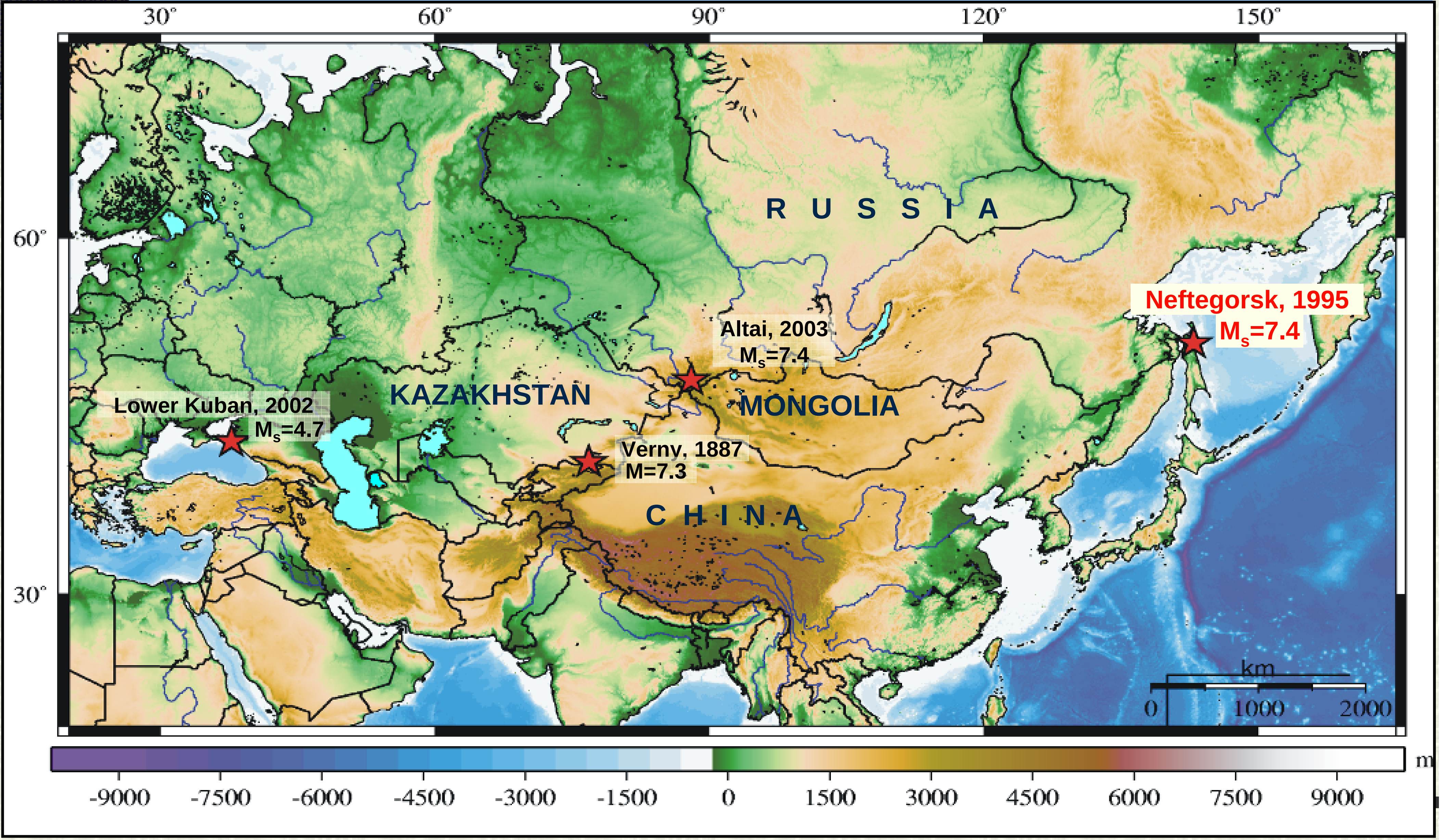


Ruben Tatevossian (2007) Earthquake intensity: concept and applications

Data of the Epicentral Seismological Expedition of the Institute of Physics of the Earth, RAS

Case studies

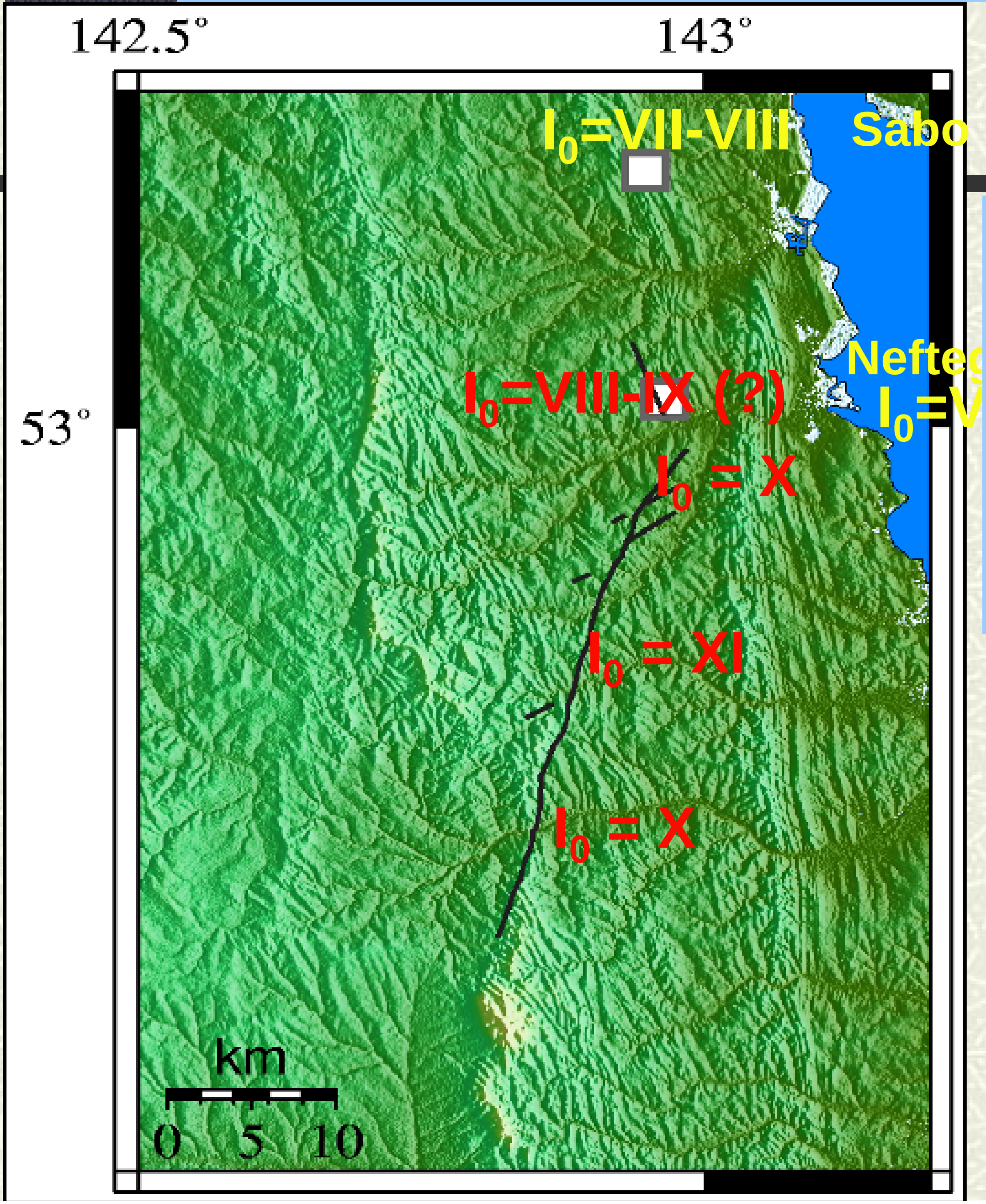
Application of the ESI 2007 scale to recent earthquake: part 2



Case studies

Application of the ESI 2007 scale to recent earthquake: part 2

EEE and Macroseisimic intensities

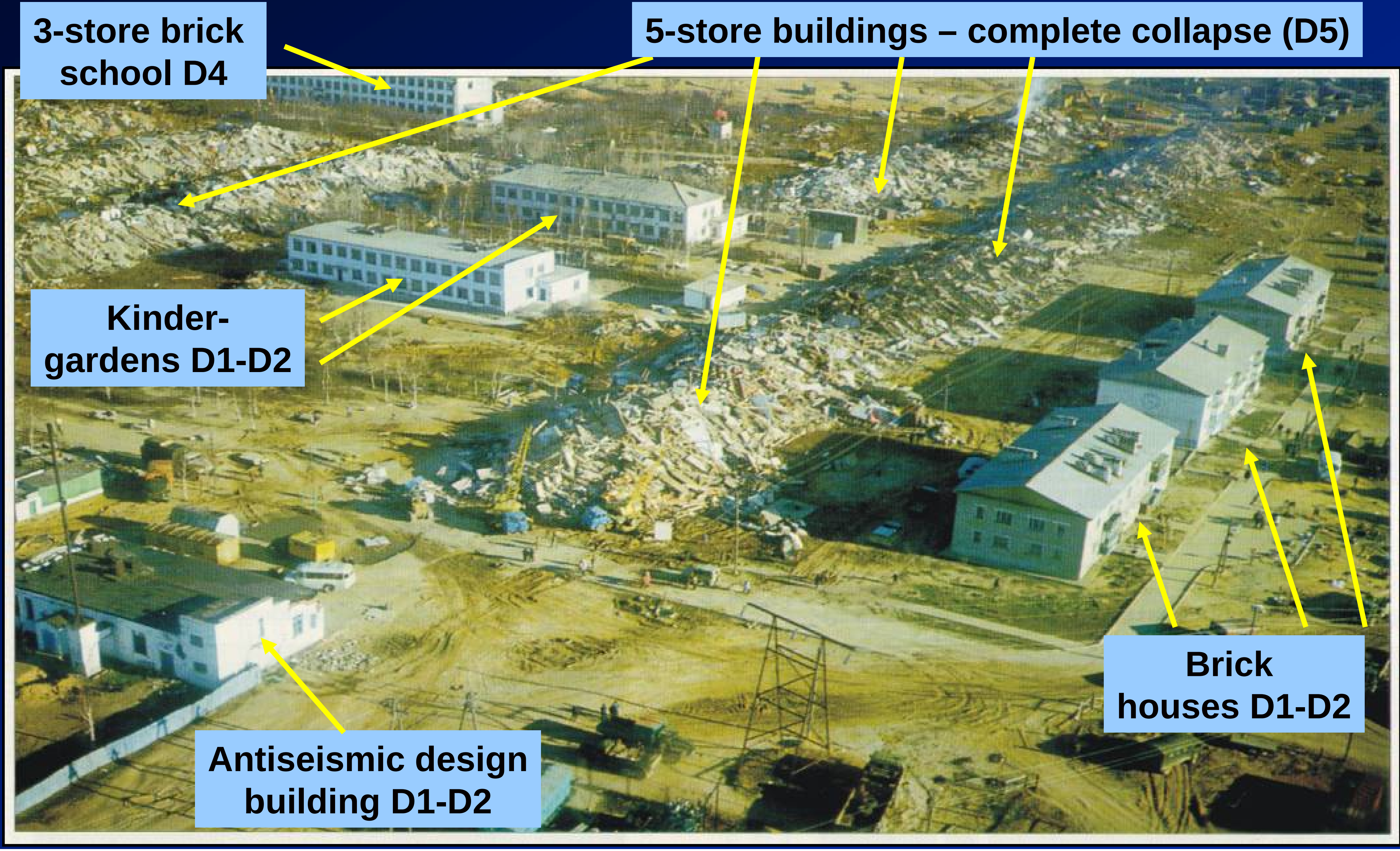


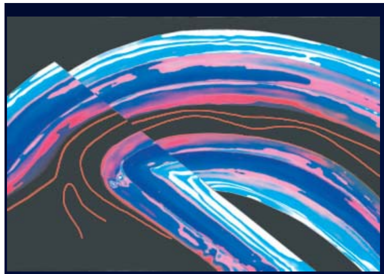
1995 Neftegorsk eq.
M_s=7.4
Sakhalin Island

Large discrepancy in intensity assessments for Neftegorsk, depending on how to evaluate vulnerability of buildings.

Building type	I
Complete collapse of 17 5-store buildings (type A or A1)	IX - X
Damage degree 3-4 to buildings of type B (5 buildings)	VIII
Damage degree 1 to type C7 (4 buildings)	VII

Vulnerability – Damage – Intensity





✓UNCERTAINTY and CONSISTENCY

✓ Yes, the use of ground effects in the Intensity scales is controversial

✓ Yes, there are examples of surface faulting with very low level of shaking – Nakata, 1990 Luzon Fault

✓ This is expected, intensity often shows large variations - 2005 Muzaffarabad example at Nizar Camp

✓ Surface faulting is always associated with high shaking along the fault rupture

✓ After 40 years of paleoseismological study we know this for sure; Mercalli, Richter, Omori they had no similar information

3. STRUCTURE OF THE ESI 2007 SCALE

Like any other diagnostic effects used in the scales, environmental ones must be constantly updated, in order to keep the physical phenomena (such as surface faulting, landsliding, and hydrological changes) in line with the damage indicators.

Definition of intensity degrees

Definizione dei gradi di intensità

From I to III: There are no environmental effects that can be used as diagnostic.

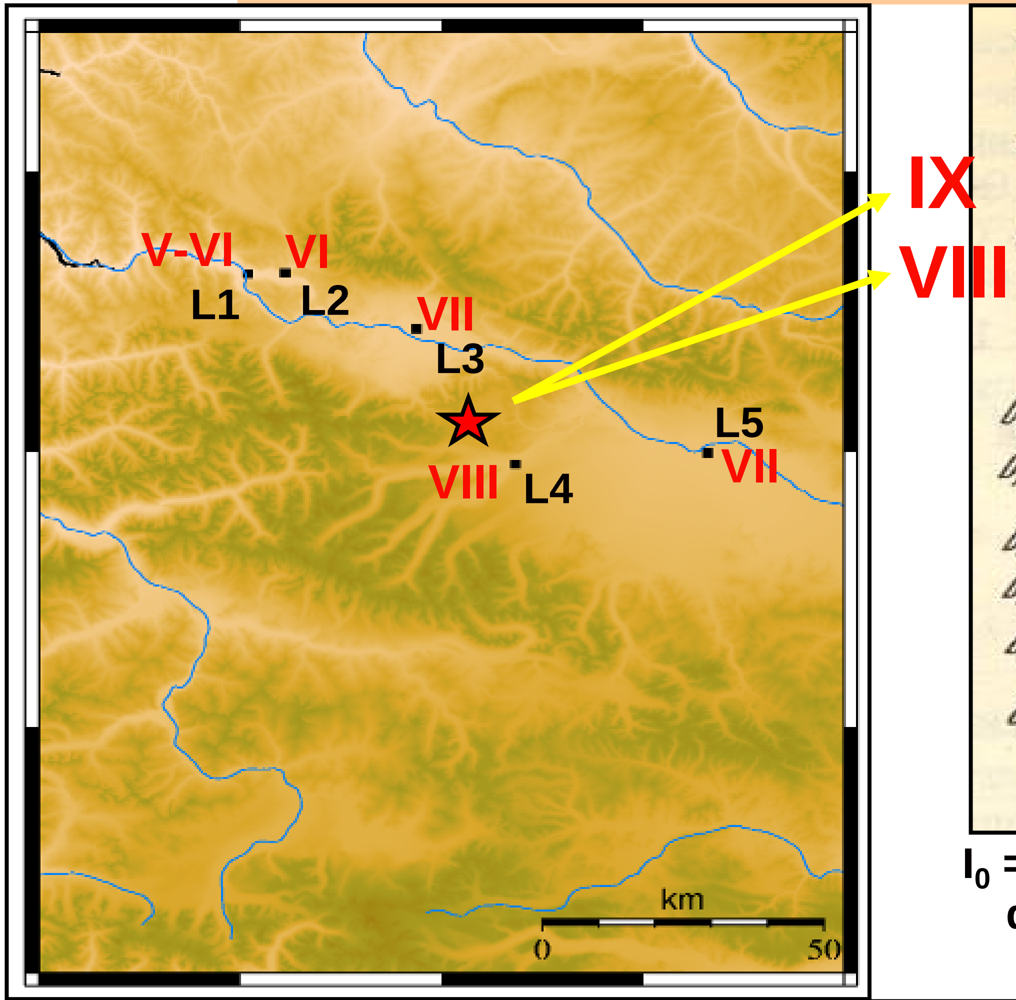
IV - LARGELY OBSERVED - First unequivocal effects in the environment

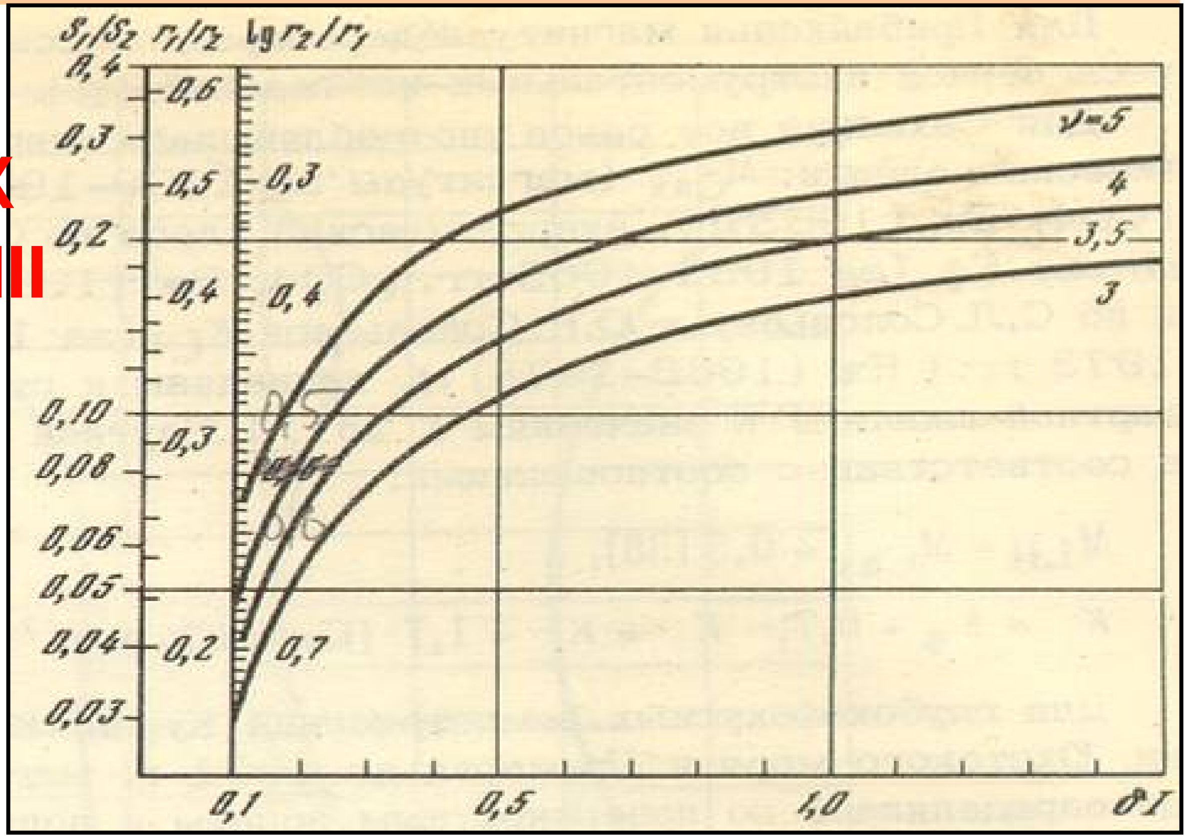
Primary effects are absent.

Secondary effects:

a) Rare small variations of the water level in wells and/or of the flow-rate of springs are locally recorded, as well as extremely rare small variations of chemical-physical properties of water and turbidity in springs and wells, especially within large karstic spring systems, which appear to be most prone to this phenomenon.
b) In closed basins (lakes, even seas) seiches with height not exceeding a few centimeters may develop, commonly observed only by tidal gauges, exceptionally even by naked eye, typically in the far field of strong earthquakes. Anomalous waves are perceived by all people on small boats, few people on larger boats, most people on the coast. Water in swimming pools swings and may sometimes overflows.
c) Hair-thin cracks (millimeter-wide) might be occasionally seen where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon.
d) Exceptionally, rocks may fall and small landslide may be (re)activated, along slopes where the equilibrium is already near the limit state, e.g. steep slopes and cuts, with loose and generally saturated soil.
e) Tree limbs shake feebly.

Macroseismic Epicenter and I_0

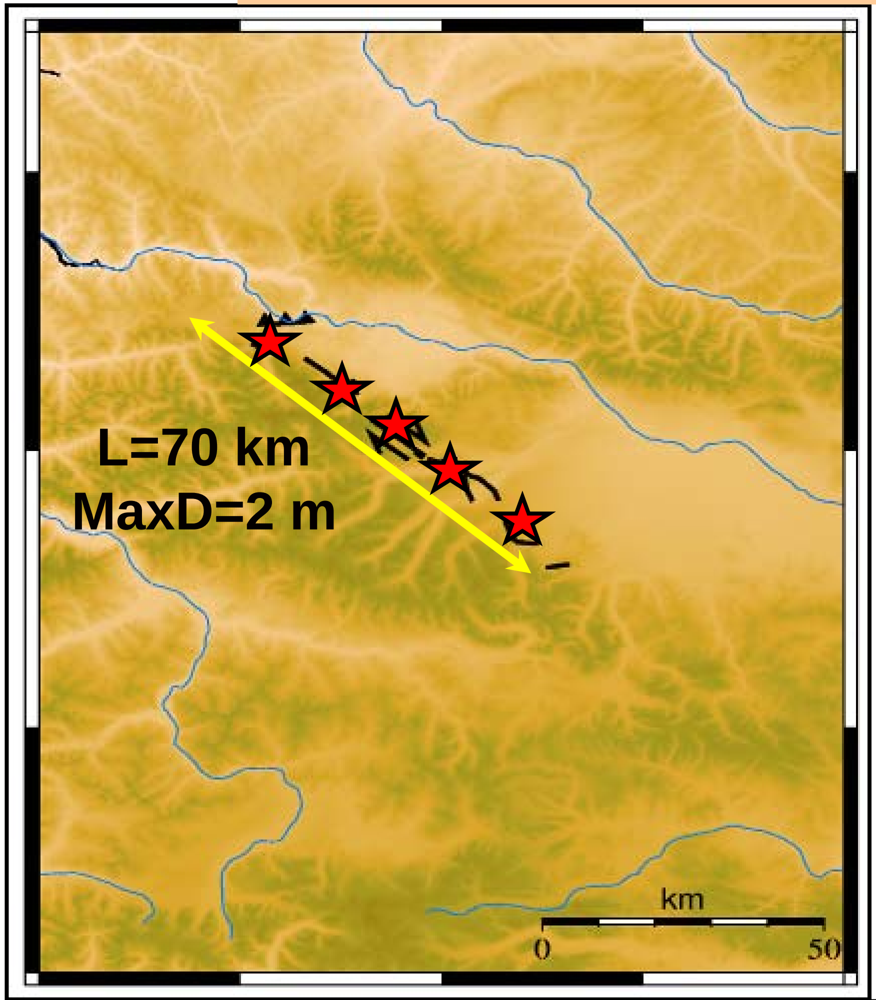




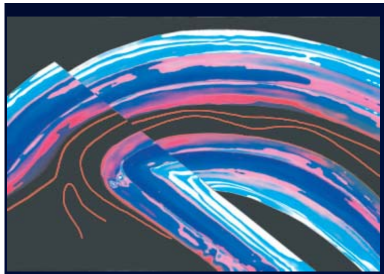
$I_0 = I_1 + \delta I$, where I_1 is radius of the first isoseismal, and δI depends on ratio of first to second isoseismal sizes (scaled for different attenuations ν).

Epicenter is a point – like any other locality on the map. To assess I_0 we do extrapolation (using nomograms or by expert judgment) from distribution of observed intensities in the localities.

ESI 2007 Epicenter and I_0



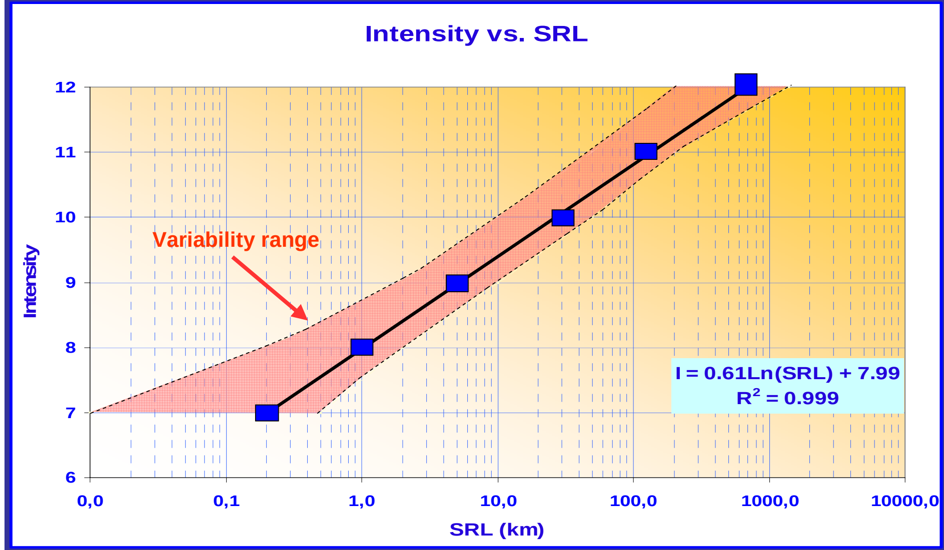
Epicentral intensity is an earthquake characteristic parameter. It is evaluated based on surface rupture (length or max offset). When the source does not expose on the surface – based on total area of secondary effects.

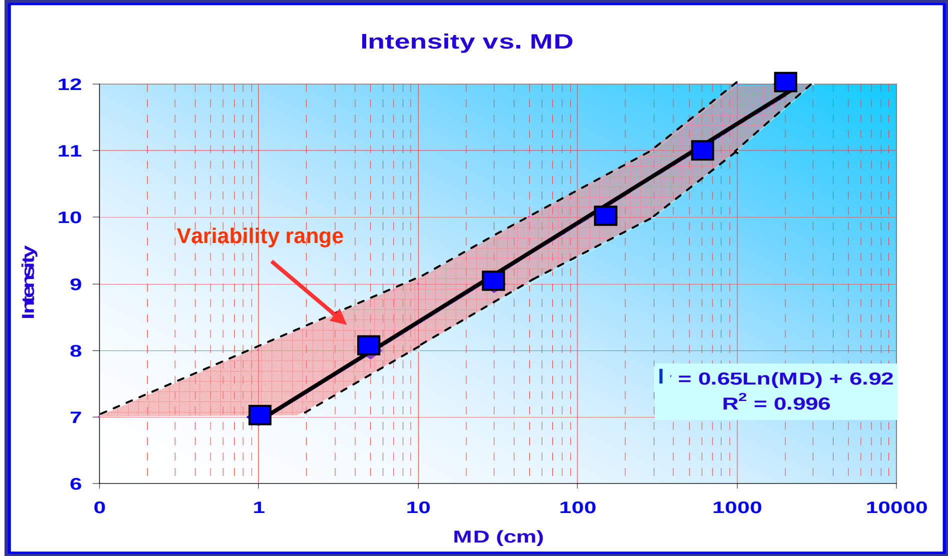


TAB. 1 - *Ranges of surface faulting parameters (primary effects) and typical extents of total area (secondary effects) for each intensity degree.*
- Valori di riferimento per ciascun grado di intensità relativo ai parametri di fagliazione superficiale (effetti primari) e all'area totale degli effetti secondari.

I_0 Intensity	PRIMARY EFFECTS		SECONDARY EFFECTS
	SURFACE RUPTURE LENGTH	MAX SURFACE DISPLACEMENT / DEFORMATION	TOTAL AREA
IV	-	-	-
V	-	-	-
VI		-	-
VII	(*)	(*)	10 km²
VIII	Several hundreds meters	Centimetric	100 km²
IX	1- 10 km	5 - 40 cm	1000 km²
X	10 - 60 km	40 - 300 cm	5000 km²
XI	60 – 150 km	300 –700 cm	10000 km²
XII	> 150 km	> 700 cm	> 50000 km²

(*) Limited surface fault ruptures, tens to hundreds meters long with centimetric offset may occur essentially associated to very shallow earthquakes in volcanic areas.



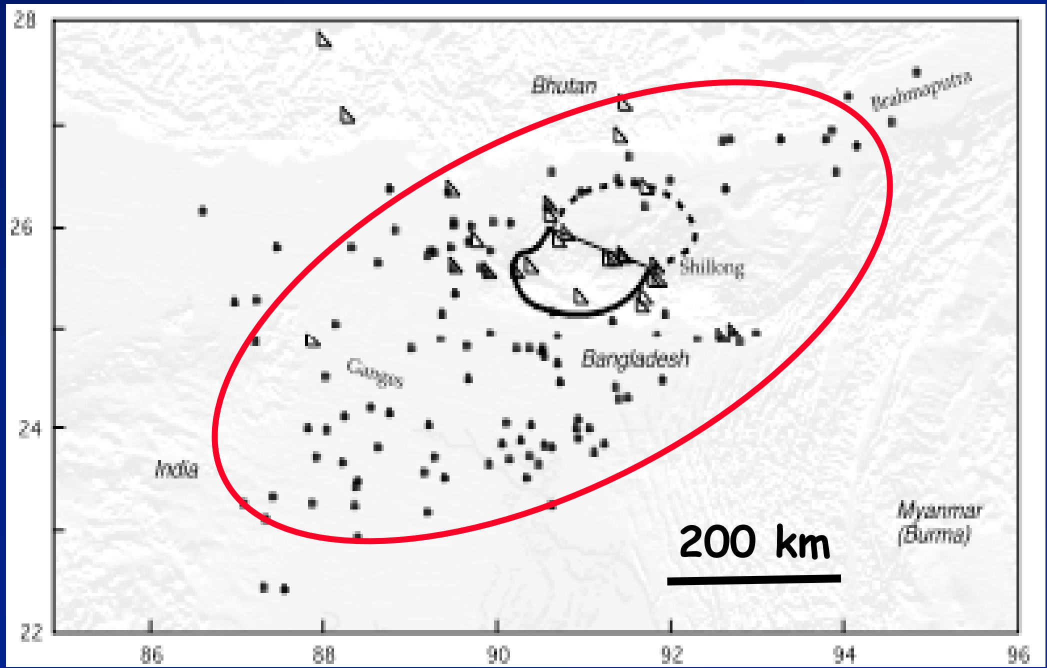


ESI 2007	SRL range	MD range	SRL plot (km)	MD plot (cm)
VII	generally absent or negligible, might be hundreds of meters for very shallow events	generally absent or negligible, centimetric for very shallow events	0,2	1
VIII	generally absent might be up to several hundred meters	up to a few cm, typically less or even absent	1	5
IX	up to a few km	in the order of several cm	5	30
X	few tens of km	from tens of cm up to a few meters	30	150
XI	from several tens up to more than 100 km	several meters	120	600
XII	> few hundreds of km	up to 24 m (largest known displacement)	700	2000

Comerci et al., 2007

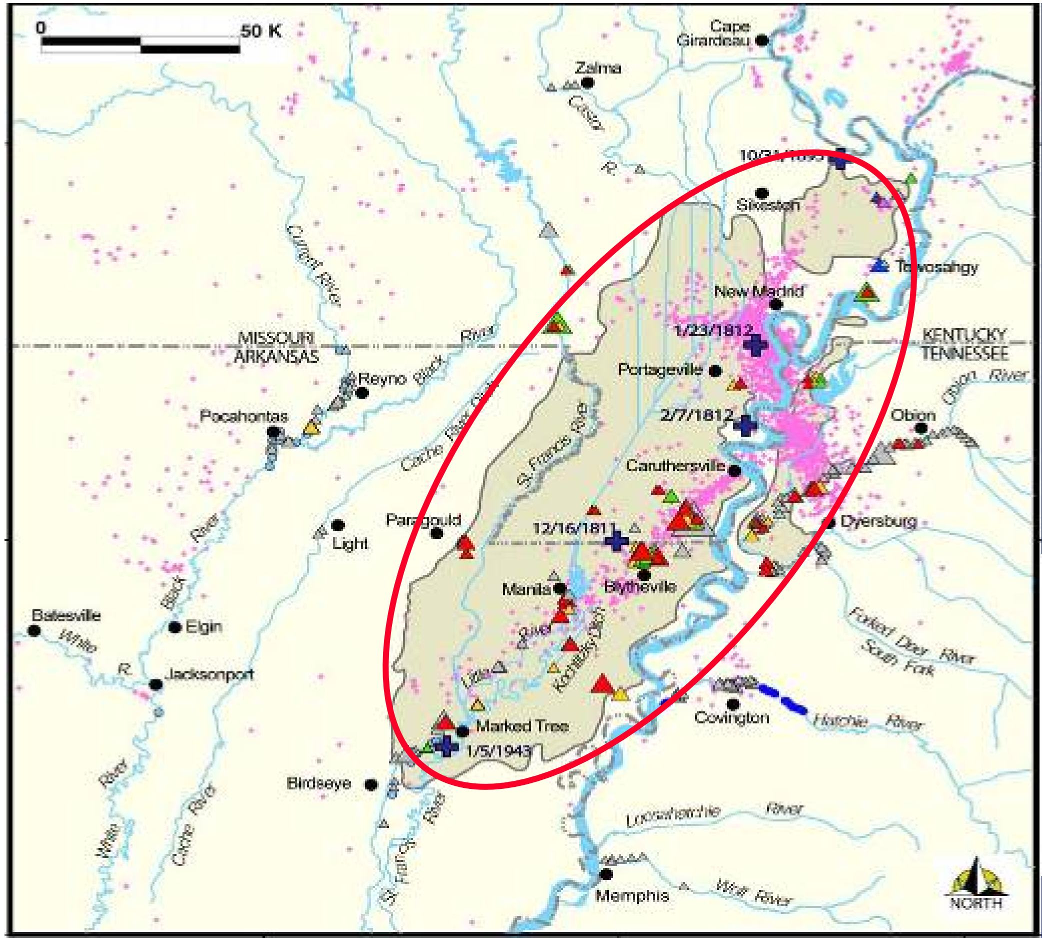
4. Total area of liquefaction: Assam, New Madrid and Anchorage

Liquefaction sites (#) and landslide locations (triangles) reported for the 12 june 1897, M8+ Assam earthquake mainshock (as revised by Ambraseys and Bilham (2003)

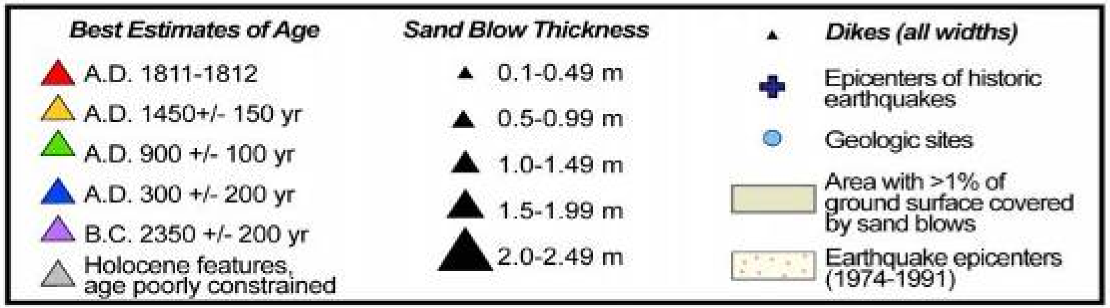


TOTAL AREA OF LIQUEFACTION ca. 250.000 KM^2

ESI = XII



Environmental effects during the New Madrid 1811-1812, M7.5-8?, seismic sequence - Tuttle and Schweig (2003) NEHRP Report



TOTAL AREA OF LIQUEFACTION ca. 20.000 KM^2

ESI = XI

Geologic effects of earthquake of 27 March 1964

(a XII on the ESI 2007 scale)

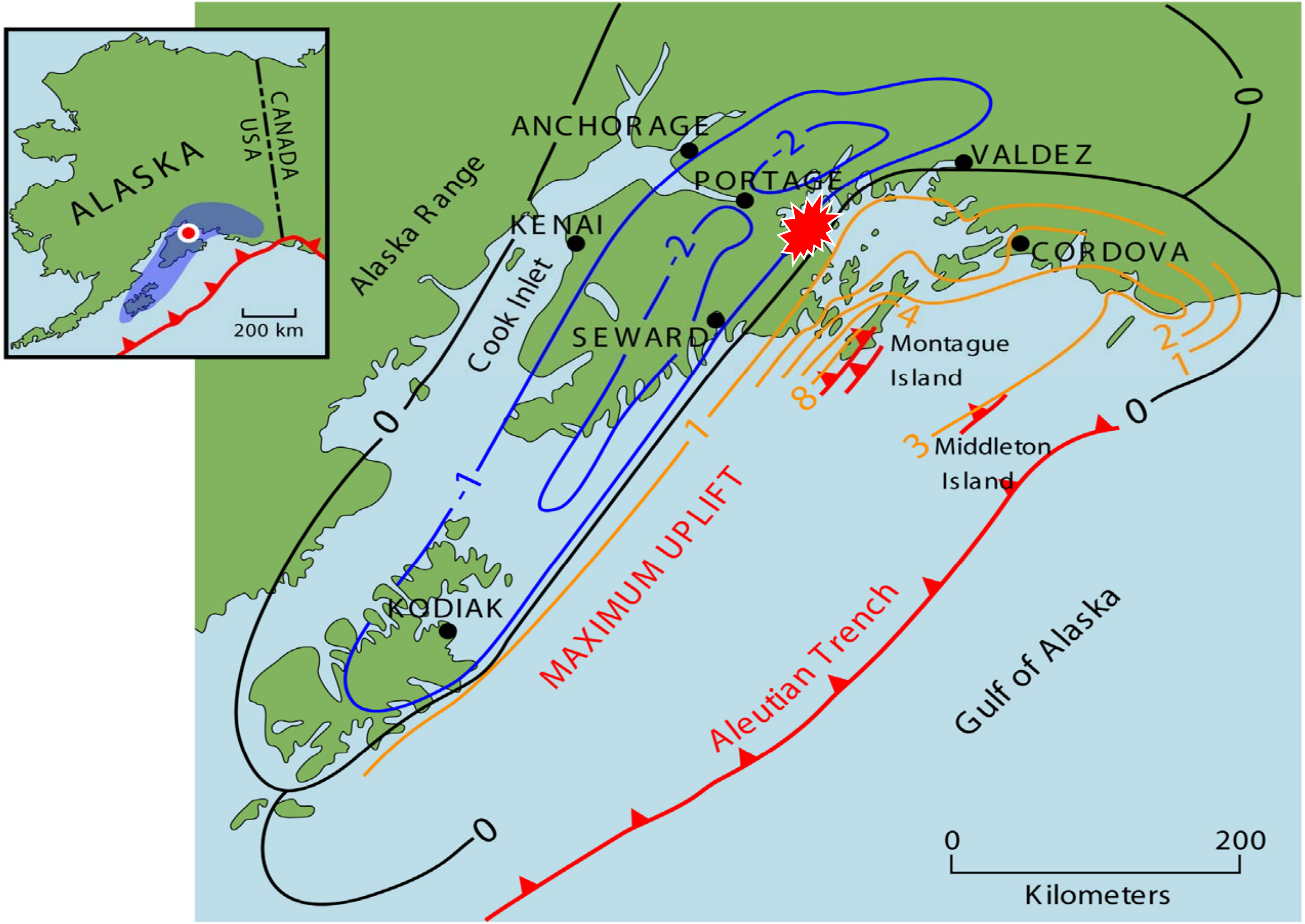
- regional coastal uplift – area of 60,000 km^2 uplifted 1-2 m; along fault 850 km long
- regional coastal subsidence – area of 110,000 km^2 subsided up to 3 m
- surface faulting and localized uplift – max 3-9 m
- liquefaction and lateral spreading – >800,000 km^2
- landsliding – 250,000 km^2
- local tsunamis – landslide-induced max 52 m high

USGS

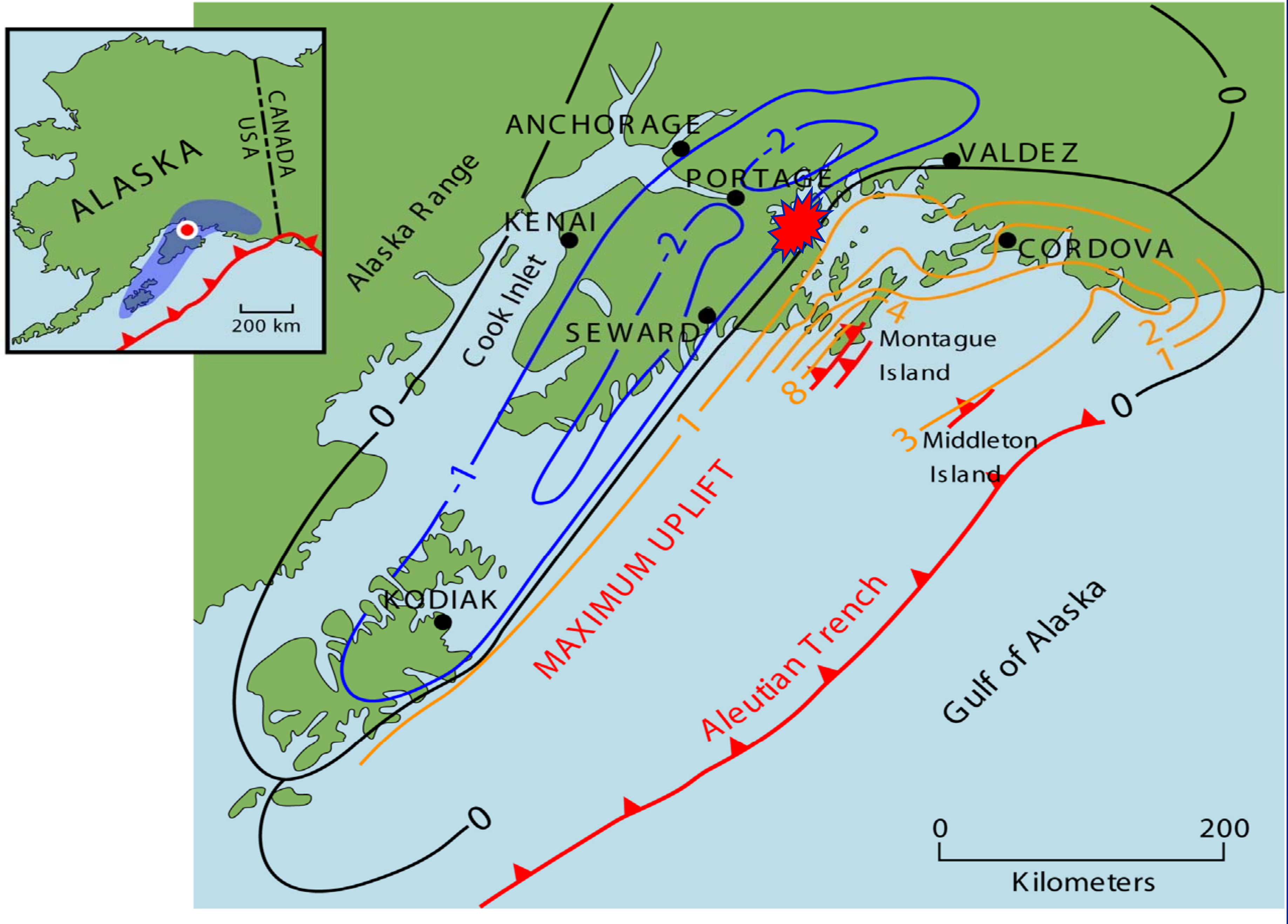
Earthquakes accompanied by tsunamis:
Their paleoseismic records and application to the INQUA intensity scale

Alan Nelson
U.S. Geological Survey
Golden, Colorado

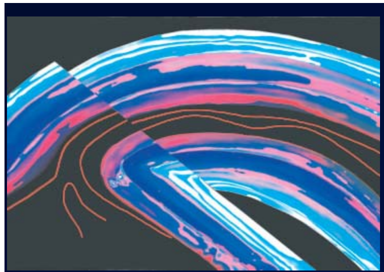
USGS



USGS Alaska, M9, Earthquake of 27 March 1964



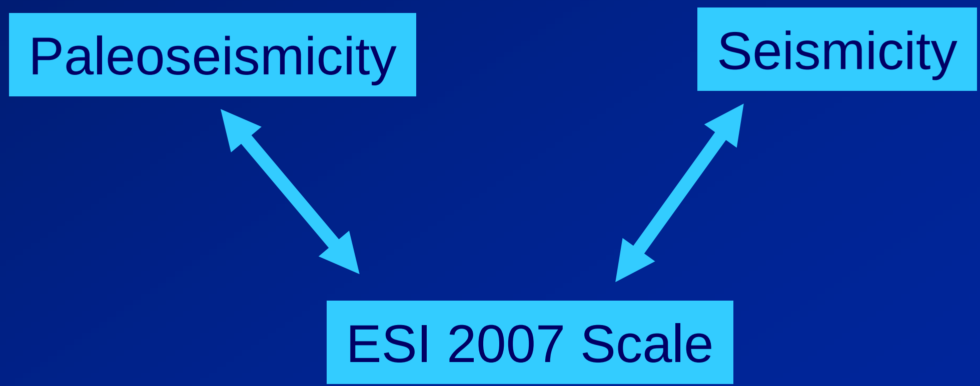
Alaska, M9, Earthquake of 27 March 1964



5. PALEOSEISMIC INTENSITY

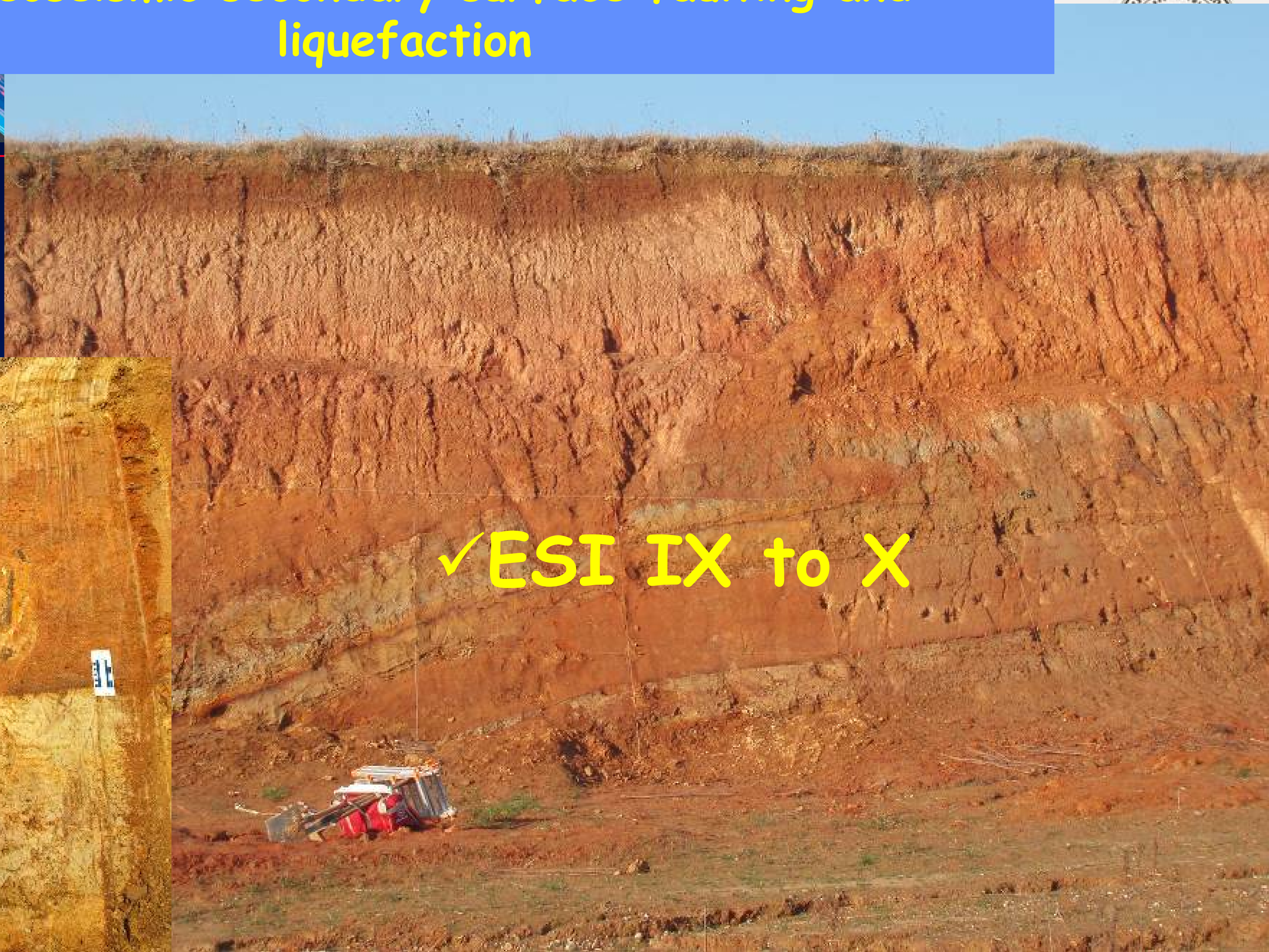
Paleo-perspective of earthquakes

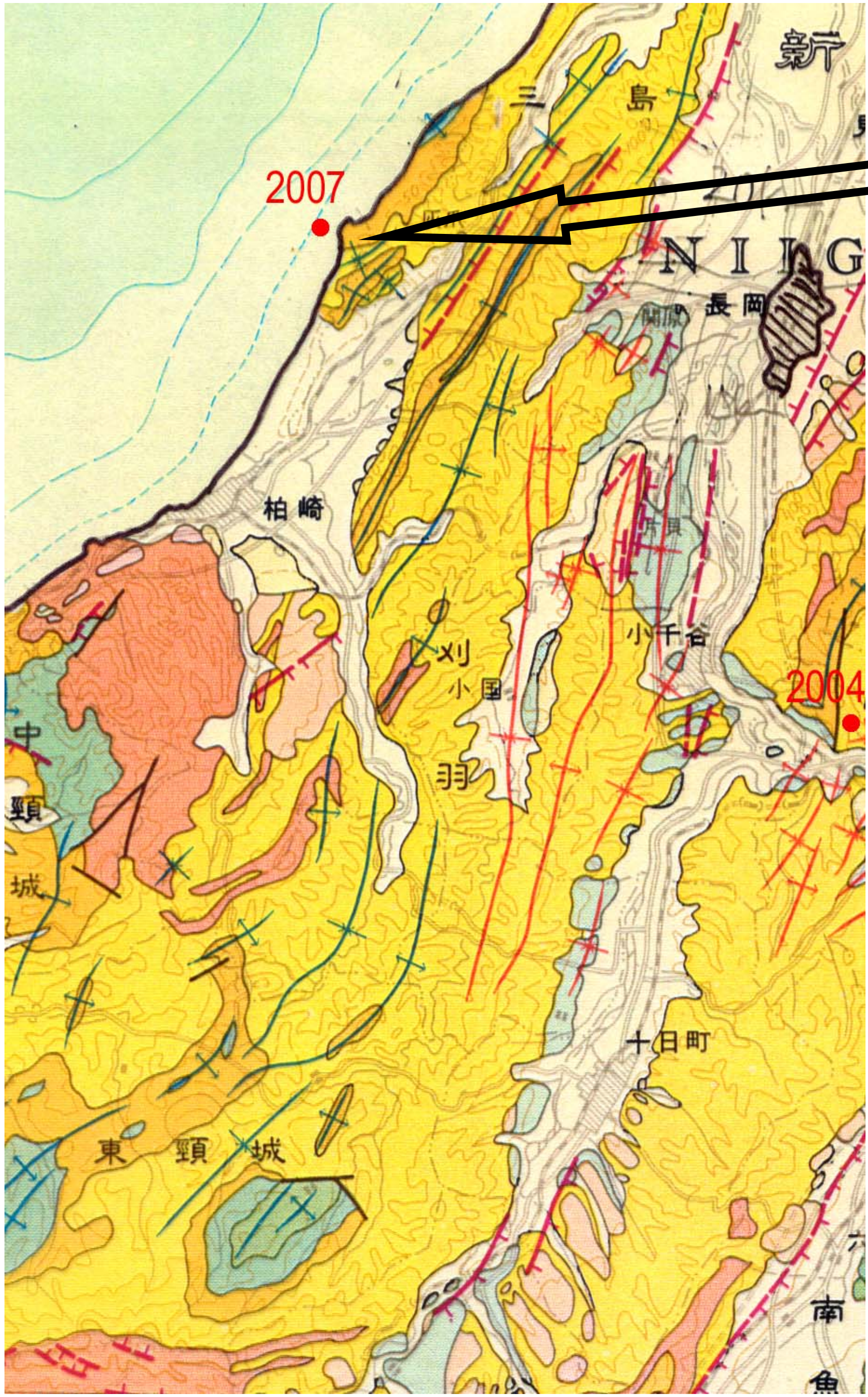
In this perspective, the study of EEE aims at linking seismological and paleoseismological records




✓Growing fault propagation fold, “blind” structure
✓Monte Netto site, Brescia, N Italy (Livio et al. 2009)

✓Paleoseismic secondary surface faulting and liquefaction





✓Kashiwakaki-Kariwa NPP site

6. Chuetsu-Oki Earthquake of 2007.July, 16, Magnitude,6.8

1964

2004

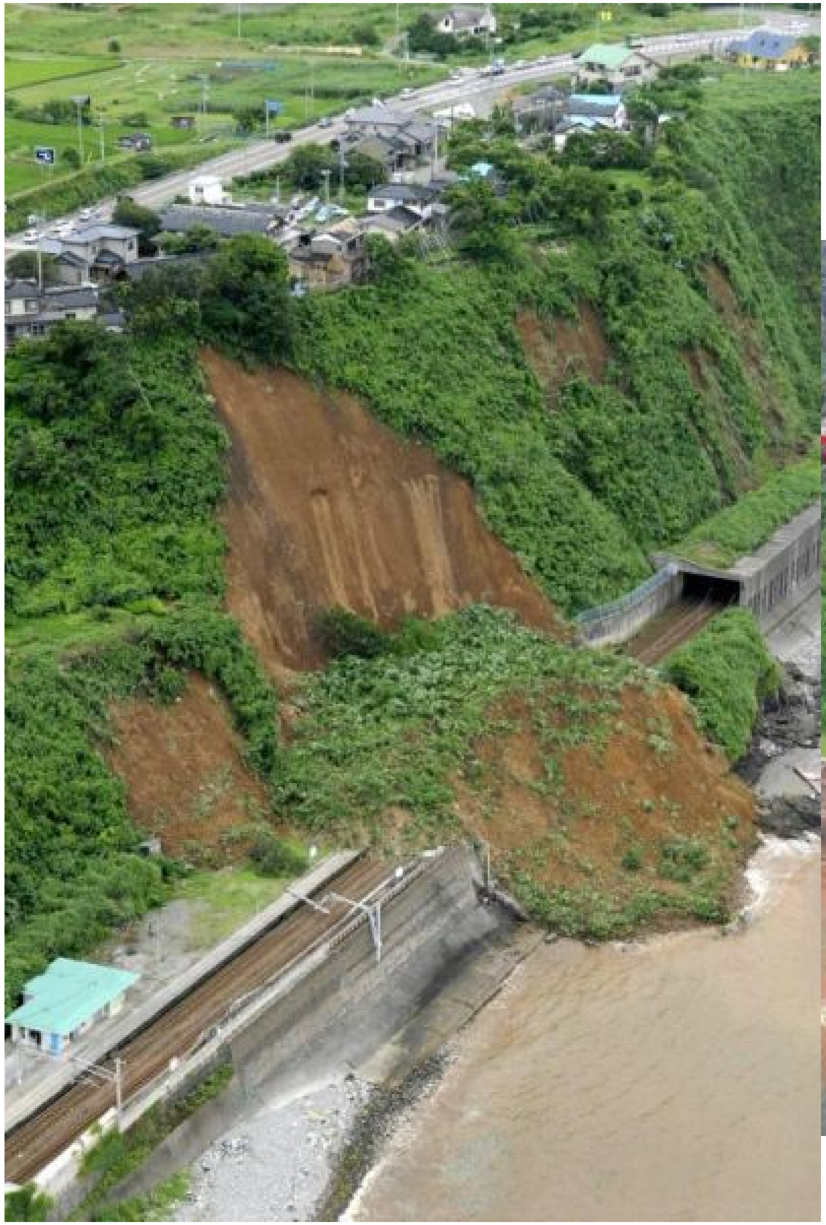
2007

Yoko Ota and Takashi Azuma

Coseismic coastal uplift

Surface cracks

Landlsides



« Previous Back to Search Results Page Next »

Vehicles drive on a damaged road leading to the Tokyo Electric Power Co.'s Kashiwazaki-Kariwa nuclear power plant (R-background) in Kariwa village, Kashiwazaki, 18 July 2007. Authorities in Japan on 17 July were investigating a second nuclear scare following a deadly earthquake, as relief workers struggled to feed and shelter thousands of shaken survivors. About 100 sealed barrels filled with contaminated clothes and gloves tipped over at the massive Kashiwazaki-Kariwa nuclear power plant in the 16 July 6.8-magnitude quake, which killed nine people and injured more than 1,000 more. AFP PHOTO/KAZUHIRO NOGI (Photo credit should read KAZUHIRO NOGI/AFP/Getty Images)

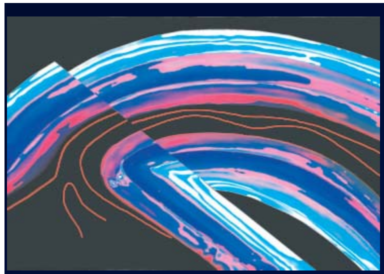
Current Picture

« Previous Back to Search Results Page Next »

Kashiwazaki Kariwa nuclear plant in Kashiwazaki, Niigata Prefecture (State) is seen from helicopter Tuesday, July 17, 2007. The power plant suffered burst pipes, water leaks and radioactive waste spillage when it was hit by Monday's earthquake, the plant's operator announced Tuesday. (AP Photo/Kyodo News) ** JAPAN OUT NO SALES MANDATORY CREDIT **

Environmental effects, ESI 2007 scale, and SITING OF CRITICAL FACILITIES

Identification of maximum ground effect at the site = paleoseismic intensity



Conclusion

and Future Perspectives….

You are invited to the Business Meeting of the INQUA Focus Group on Paleoseismology and Active Tectonics later this week