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# Earthquake Environmental Effect for seismic hazard assessment: the ESI intensity scale and the EEE Catalogue

## *Gli effetti dei terremoti sull'ambiente per la valutazione della pericolosità sismica: la scala di intensità ESI e il Catalogo EEE*

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# PREFAZIONE

Negli ultimi venti anni, l'interesse della comunità scientifica verso gli effetti geologici e ambientali indotti dai terremoti è stato sempre maggiore, soprattutto nell'ambito dell'INQUA - *International Union for Quaternary Research*.

Nel 2007 è stata prodotta la scala di intensità ESI 2007 (*Environmental Seismic Intensity scale*), una scala di intensità sismica basata esclusivamente sugli effetti sull'ambiente, derivante da un processo di revisione durato otto anni cui hanno collaborato numerosi geologi, sismologi e ingegneri coordinati dal Servizio Geologico d'Italia (oggi ISPRA). La scala ESI 2007 integra le scale di intensità tradizionali, consentendo di definire l'intensità sismica sulla base di tutti gli effetti a disposizione.

Nel 2011 è stato invece realizzato l'EEE *Catalogue*, un'infrastruttura realizzata da ISPRA per la raccolta dei dati relativi agli effetti geologici dei terremoti recenti, storici e paleo avvenuti in varie parti del mondo. La catalogazione e la classificazione degli effetti geologici consente di confrontare in maniera *standard* gli eventi sismici del passato e di individuare le aree maggiormente vulnerabili a causa di effetti di sito.

Alcuni forti terremoti avvenuti negli ultimi anni hanno purtroppo evidenziato il ruolo primario degli effetti geologici nello scenario di danneggiamento, confermando che la pericolosità sismica non può essere valutata esclusivamente sullo scuotimento sismico ma deve invece tenere conto anche delle conoscenze sugli effetti cosismici sull'ambiente.

Questo volume, oltre a fare il punto sullo stato delle conoscenze in materia, intende promuovere l'uso dell'ESI 2007 *intensity scale*, che viene riportata tradotta in dieci lingue, e dell'EEE *Catalogue*, quale strumento utile anche in sede di pianificazione territoriale, specie in aree ad elevata pericolosità sismica.

# *PREFACE*

*In the last twenty years, the interest of scientific community towards Earthquake Environmental Effects (EEEs) has progressively increased especially in the frame of INQUA - International Union for Quaternary Research.*

*In 2007 the ESI 2007 (Environmental Seismic Intensity scale) was published, a new intensity scale based only on EEEs resulting by a revision process taking about 8 years, and promoted by several geologists, seismologists and engineers coordinated by* Servizio Geologico d'Italia *(now ISPRA). The ESI 2007 scale integrates traditional intensity scales, and allow to define seismic intensity based on the entire scenario of effects.*

*In 2011 the EEE Catalogue was launched, a web infrastructure realized by ISPRA for data collection of EEEs induced by recent, historical and paleoearthquakes at global level. Cataloguing and classifying EEEs has allowed to compare past seismic events and to identify the most vulnerable areas in term of site effect.*

*Some strong earthquakes occurred in the last years have unfortunately pointed out the primary role played by geological effects in the scenario of damages, confirming that seismic hazard cannot be evaluated only based on vibratory ground motion but also on the knowledge about EEEs.*

*This volume provides the state of knowledge about these topics, with the aim to promote the use of the ESI 2007 intensity scale, that has been translated into ten languages, and the EEE Catalogue, as an helpful tool also for land planning, especially in high seismic hazard areas.*

Claudio CAMPOBASSO

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fig. 1

# 1. - Earthquake Environmental Effects, intensity and seismic hazard assessment: the lesson of some recent large earthquakes

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The dreadful scenarios of effects caused by the recent catastrophic seismic events in very different parts of the world (from Eastern Asia to Chile and Haiti) are renewing the longlasting global debate among seismologists, geologists and engineers about the best practices and tools to achieve the most complete and reliable seismic hazard assessment. In this note we focus on three recent events that have clearly demonstrated once more that the vibratory ground motion, although a serious source of direct damage, it is by no means the only parametr that should be considered, being most damages caused by the coseismic geological effects, either directly linked to the earthquake source or provoked by the ground shaking ("Earthquake Environmental Effects", EEE). Surface faulting, regional uplift and subsidence, tsunamis, liquefaction, ground resonance, landslides, ground failure, are indeed controlled or induced by the local geological setting.

The 2011 March 11, Mw 8.9 Tohoku earthquake occurred in the Pacific Ocean near the coast of northeastern Japan, where the Pacific Plate plunges under the Asian Plate. The interface is marked by a deep trench and a megathrust. A displacement (reverse slip) of the sea bottom along a distance in excess of 500 km, reaching maximum values of ca. 20 m, produced a very large tsunami (with values of run up reaching 38 m, and 14 m at the Fukushima NPP's site) which affected a wide stretch of coast, penetrating 5 km inland in the Sendai coastal plain. Probably, the impact of this tsunami has been even larger than that caused by the Sumatra earthquake in 2004, due to the much higher degree of urbanization in NE Japan. Most of the damage in terms of dead toll (more than 20,000 people) and destruction was in fact caused by the subsequent tsunami. Conversely, limited damage was induced by the vibratory ground motion itself.

The size of the 2011 tsunami was fairly larger than that of the largest tsunamis recorded in the affected area (Myagi and Fukushima prefectures) in the last century (max wave height not more than 5 m). Nevertheless, looking just a little backwards in time, tsunamis comparable in size to the 2011 event did affect the same areas, the latest one in 869 A.D. (Jogan tsunami), as well documented by means of geological and paleoseismic/paleotsunami studies (Minoura, 1995; Sugawara *et alii*, 2012; HERP, 2009), while historical documentation about these events is quite scarce (fig. 1.1). Unfortunately,

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tsunami hazard assessment was based only on the most recent record. Consequently, mitigation measures for the protection of people, buildings and infrastructures (including NPPs) were undersized and therefore unable to prevent the inundation of such a large sector of NE Japan coastal area. Other effects, landslides, liquefaction and ground subsidence, have certainly given a contribution of damage, but information about them has been obscured so far by the overwhelming devastation of the tsunami.

The February 22, 2011, Mw 6.3 Christchurch, New Zealand earthquake was basically an aftershock of the September 4 2010, Mw 7.0 event, part of a seismic sequence which includes also the June 13 2011, Mw 6.3, event. Nevertheless, despite the main shock did not cause victims or relevant damages, the February 22, 2011,


Fig. 1.1. - Above: the devastating tsunami occurred on March 11$^{th}$ , 2011 along the Eastern coast of Japan. Below: tsunami deposits in the Sendai coastal plain related to the AD 869 Jogan tsunami event (Okumura, 2011).
*- Sopra: lo tsunami devastante che l'11 Marzo 2011 ha colpito la costa orientale del Giappone. Sotto: tsunamiti nella piana costiera di Sendai, associata allo tsunami Jogan avvenuto nell'869 (Okumura, 2011).*

event caused the death of at least 75 people and destroyed hundreds of houses in Christchurch. This scenario of damages was mainly linked to local effects of site amplification, which depend largely on the stratigraphic characteristics (geological history) of the ground over which the town is built; as well, the same recent sediments are particularly susceptible to liquefaction. As a consequence, also houses designed in agreement with the local seismic building codes have collapsed all the same, due to liquefaction within the foundation soils.

The 2008 May 12, Mw 7.9 Wenchuan, China, earthquake (dead toll of more than 70,000 people) was caused by the reactivation of an already known thrust located in the northwestern Sichuan Province, which produced more than 200 km of surface faulting. The scenario of secondary effects was characterized by very large landslides and rock falls (volumes in the order of $10^5$ – $10^6$ cubic meters), widespread liquefaction, ground failures, anomalous waves in lakes, among others. At the local scale, the distribution of damage has been strictly linked to the occurrence of the abovementioned environmental effects, that have become dominant especially in the epicentral area. Based only on environmental effects (ESI scale) intensities up to XII have been estimated, while the widespread poor quality of the buildings has not allowed traditional damage-based intensity assessments higher than X (Lekkas *et alii*, 2010).

These events **confirm once again the relevance of earthquake environmental effects as a major source of hazard, in addition to vibratory ground motion.** Moreover, it has been clearly demonstrated that the implementation of geologically documented past earthquakes in the existing seismic catalogues is crucial for the improvement of the seismic and tsunami hazard knowledge, as well as for a more rational urban development and location of critical engineering facilities. Indeed, at present, developed countries have robust seismological surveys which provide finest information on instrumental seismicity, but differentially-documented information on historical events. In fact, seismic hazard analyses are still typically only based on recent and historical pre-instrumental records following deterministic or probabilistic approaches for relatively short time-windows. The geological analysis of hazardous areas or faults from a paleoseismological perspective, will help to refine the data on historical events, and in many zones to (a) enlarge the list of catalogued events, (b) identify hazardous active faults and (c) recognize the more realistic role of secondary environmental effects in high-rank potential damage levels.

Furthermore the lesson offered by these recent events makes evident the need of re-evaluating the significance of macroseismic intensity as an empirical measurement of earthquake size. As a matter of fact, intensity is a parameter able to describe a complete earthquake scenario, based on direct field observations. Unfortunately, since the ‘70s the research has focused mostly on instrumental seismological parameters and intensity, although still vital in historical seismology, has been gradually reduced to a representation of damage distribution, or to a mere proxy of acceleration. In the last decade instead, thanks to the recent development of paleoseismology and other innovative geological investigations, it has re-emerged the core significance of the intensity parameter as it was in the early developments of seismology, more than one century ago. At that time, the effects on the natural environment were correctly seen as the most direct manifestations of the earthquake, a geological phenomenon itself. Consequently, they were used as highly diagnostic elements in the intensity scales, especially crucial in assessing the highest degrees of intensity, when structural damage saturates, loosing its informative capability.

Today, detailed documentation is available for a very large number of environmental effects induced by recent, historical and paleo-earthquakes. Such data, now being stored in a specific database (http://www.eeecatalog.sinanet.apat.it/terremoti/index.php), have allowed to develop the ESI 2007 scale (Michetti *et alii*, 2007), that integrates and completes the traditional macroseismic intensity scales, allowing to assess the intensity parameter also where buildings are absent or damage-based diagnostics saturates.

Developing on this background, this volume aims at promoting:

- the use of the ESI 2007 intensity scale, which has been translated in ten languages (English, Italian, Spanish, French, German, Japanese, Russian, Greek, Dutch and Korean) for a more systematic application;
- the implementation of the EEE Catalogue, a standard data collection of the characteristics of Earthquake Environmental Effects at global level conducted in the frame of the INQUA TERPRO #0418 Project, with the aim to promote the use of EEE data for seismic hazard purposes.

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fig. 1

# 2. - The ESI 2007 intensity scale in ten languages

With the aim to support a worldwide use of the ESI 2007 intensity scale, in this chapter is reported the description of ESI intensity scale in ten languages (English, Italian, Spanish, French, German, Japanese, Russian, Greek, Dutch, Korean).

The description of ESI intensity degress is preceded by i) an introductive framework focused on the added value provided by the ESI 2007 intensity scale, ii) the description of ESI structure and EEE classification, and iii) some methodological explanation.

In fig. 2.1, is reported a graphic representation of the ESI 2007 intensity degrees (after SILVA *et alii*, 2008 and REICHERTER *et alii*, 2009), for primary and secondary effects. The evaluation of epicentral intensity ($I_0$) can be done only based on primary effects and on the total area affected by secondary effects (last column on the right).

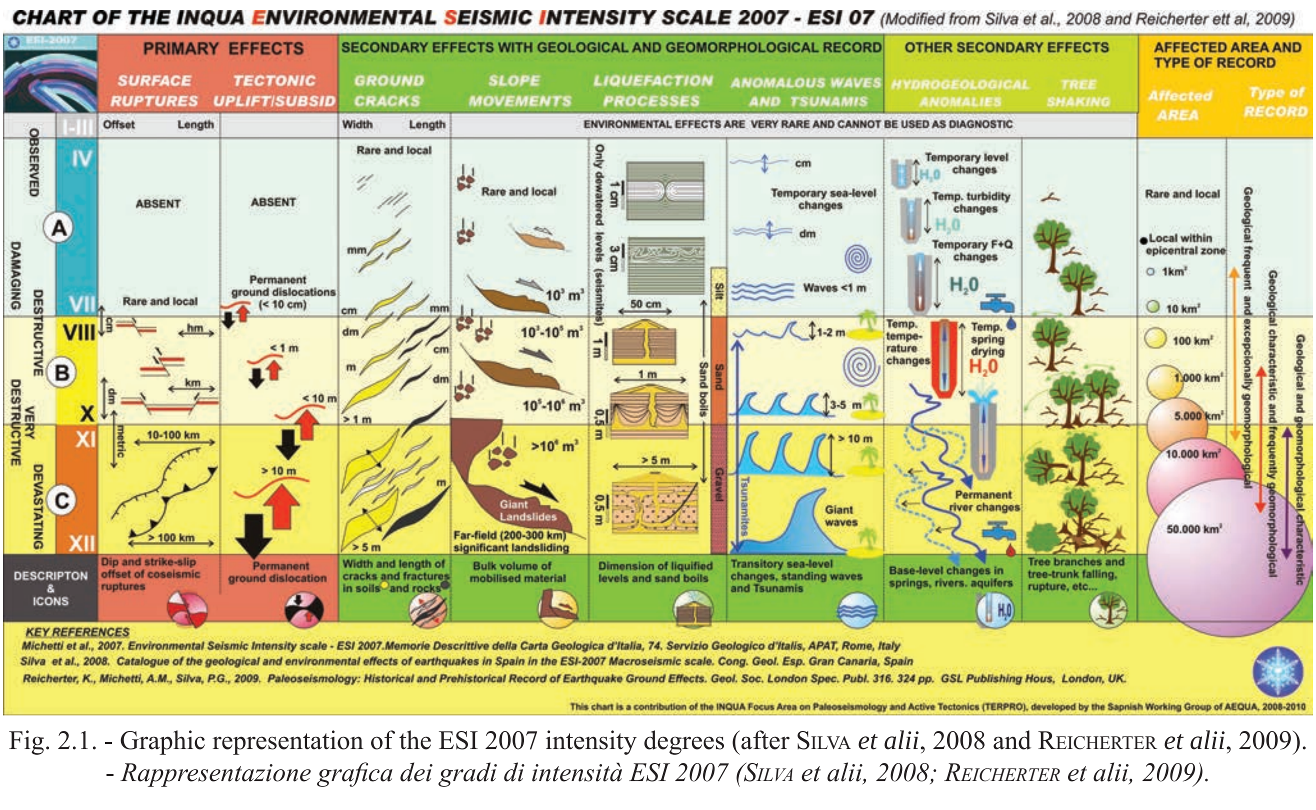


Fig. 2.1. - Graphic representation of the ESI 2007 intensity degrees (after SILVA *et alii*, 2008 and REICHERTER *et alii*, 2009).
- *Rappresentazione grafica dei gradi di intensità ESI 2007 (SILVA et alii, 2008; REICHERTER et alii, 2009).*

*Mem. Descr. Carta Geol. D'It.*
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tab. 1

# 2.1. - Environmental Seismic Intensity scale - ESI 2007 (English)

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## *Introduction*

Earthquake intensity is based on a classification of effects caused by the seismic event on man, on man-made structures (buildings and infrastructures) and on natural environment (environmental or geological effects). This intensity provides a measure of earthquake severity taking into account the effects in the whole range of frequencies of vibratory motion as well as static deformations.

All the intensity scales (Rossi-Forel, Mercalli, MCS, MSK, Mercalli Modified) consider the effects on natural environment as diagnostic elements for the evaluation of the intensity degree. Instead, some modern scales (e.g., Espinosa *et alii*, 1976a; 1976b; Grunthal, 1998) consider only the effects on man and man-made structures, and strongly reduce the diagnostic relevance of environmental effects, based on the assumption that these effects are too variable and aleatory. Nevertheless, recent studies (e.g. Dengler & McPherson, 1993; Serva, 1994, Dowrick, 1996; Esposito *et alii*, 1997; Hancox *et alii*, 2002; Michetti *et alii*, 2004) have provided clear evidences that the characteristics of geological and environmental effects, that are nowadays widely retrievable from historical and paleoseismological sources, are an essential information for the assessment of earthquake size and in particular of intensity.

With this aim, it was built the ESI 2007 intensity scale (Michetti *et alii*, 2007) based only on environmental effects. Its use, alone or integrated with the other traditional scales affords a better picture of the earthquake scenario, because only environmental effects allow suitable comparison of the earthquake intensity both:

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• *in time*: effects on the natural environment are comparable for a time-window (recent, historic and palaeo seismic events) much larger than the period of instrumental record (last century), and
• *in different geographic areas*: environmental effects do not depend on peculiar socio-economic conditions or different building practices.
• Thus, the new scale aims at integrating traditional seismic scales:
• for earthquake intensity degree larger or equal to X, when damage-based assessments are extremely difficult, while environmental effects are still diagnostic;
• in sparsely populated areas, where the effects on man-made structures are lacking and therefore intensity assessments have to be based on the environmental effects, which are the only available diagnostic elements.

• The definition of intensity degrees is the result of a revision conducted by an International Working Group formed by geologists, seismologists and engineers focused on the effects caused by a large number of earthquakes at global level. The ESI 2007 has been ratified by INQUA (International Union for Quaternary Research) at the XVII INQUA Congress (Cairns, Australia) in 2007.

## *Description*

The ESI 2007 intensity scale is structured in twelve degrees. The title of each degree reflects the corresponding force of the earthquake and the role of environmental effects. In the description, the characteristics and size of primary effects associated to each degree are reported firstly. Then, secondary effects are described in terms of total area of distribution for the assessment of epicentral Intensity grouped in several categories, ordered by the initial degree of occurrence. Text in Italic has been used to highlight descriptions regarded as diagnostic by itself for a given degree.

***Primary effects*** are directly linked to the earthquake energy and in particular to the surface expression of the seismogenic source. The size of primary effects is typically expressed in terms of two parameters: i) Total Surface Rupture Length (SRL) and ii) Maximum Displacement (MD). Their occurrence is commonly associated to a minimum intensity value (VIII), except in case of very shallow earthquakes in volcanic areas. Amount of tectonic surface deformation (uplift, subsidence) is also taken into account.

***Secondary effects*** are any phenomena induced by the ground shaking and are classified into eight main categories.

***a)*** ***Hydrological anomalies***: in this category are reported changes in water discharge of springs, and rivers as well as changes in the chemical-physical properties of surface and groundwater (e.g. temperature, turbidity). These effects are diagnostic from IV to X degree.

***b)*** ***Anomalous waves/tsunamis:*** In this category are included: seiches in closed basins, outpouring of water from pools and basins, and tsunami waves. In the case of tsunamis, more than the size of the tsunami wave itself, the effects on the shores (especially run-up, beach erosion, change of coastal morphology), without neglecting those on humans and manmade structures, are taken as diagnostic of the suffered intensity. Effects may already occur at intensity IV, but are more diagnostic from IX to XII.

***c)*** ***Ground cracks:*** ground cracks are described in terms of length (from cm to some hundreds of meters), width (from mm to m), areal density. Ground cracks show up from intensity IV and saturate (i.e. their size does not increase) at intensity X .

***d)*** ***Slope movements:*** this category comprehends all the typologies of landslides, including rockfalls, slides and earth flows.

*e)* ***Trees shaking***: These effects are diagnostic from IV to X degree The definition of intensity degrees basically follows these provided by Dengler and McPherson (1993).

*f)* ***Liquefactions:*** in this category are included sand volcanoes, water and sand fountains, some types of laterl spreading, ground compaction and subsidence. Their size is diagnostic for intensity degree from V to X.

*g)* ***Dust clouds***: may be observed in arid/dry areas, starting from VIII degree.

*h)* ***Jumping stones:*** the maximum size of jumping stones is diagnostic for intensity assessment. These effects may be observed from minimum intensity IX up to XII. Such evidences show that ground acceleration larger than gravity may locally occur starting from intensity IX. Environmental effects may be observed and characterized from intensity IV. Some types of environmental effects (hydrological anomalies) may be observed even in lower degrees, but cannot be characterized to be considered diagnostic elements. Accuracy of evaluation increases towards the highest degrees, in particular in the range of occurrence of primary effects (typically from intensity VIII), with resolution up to intensity XII. From intensity X, effects on man and man-made structures saturate (i.e. buildings are often completely destroyed) and therefore it is not possible to distinguish between different intensity degrees. In this range, environmental effects are dominant and therefore are the most powerful tool for intensity evaluation.

## *How to use the ESI 2007 intensity scale*

The use of the ESI intensity scale a san independent tool for intensity assessment is recommended when only environmental effects are diagnostic because effects on man and man-made structures are too scarce or saturate. When these latter are also available, it is possible to estimate two independent intensity assessment. In general, the final intensity will be equal to the higher value between both the assessments. Obviously, in this case an expert judgment will be essential.

Epicentral intensity ($I_0$) indicates the intensity of the shaking in correspondence to the epicenter. Surface faulting parameters and the total areal distribution of secondary effects (landslides and/or liquefactions) are to independent tools for assessing $I_0$ on the basis of environmental effects, starting from intensity VII (tab. 2.1).

Specific care has to be paid when surface faulting parameters are at the boundaries between two different degrees. In this case, it should be selected the intensity value more consistent with characteristics and areal distribution of secondary effects. Moreover, in the evaluation of the total area, it is recommended to not including isolated effects occurred in the far field. This evaluation also requie an expert judgment.

Local intensity is basically evaluated through the description of secondary effects occurred in different “Sites” included in a specific Locality. This type of intensity has to be comparable with the corresponding traditional local intensity based on damages. Please note that a “Locality” can be referred to an inhabitated area (a village, a town) but also to natural areas without human settlements. When only primary effects are present, it is also possible to use the local expression of surface faulting, in terms of maximum displacement.

Tab. 2.1 - *Ranges of surface faulting parameters (primary effects) and typical extents of total area (secondary effects) for each intensity degree.*

| $I_0$ | PRIMARY EFFECTS | | SECONDARY EFFECTS |
|---|---|---|---|
| | SURFACE RUPTURE LENGTH | MAX SURFACE DISPLACEMENT / DEFORMATION | TOTAL AREA |
| **IV** | - | - | - |
| **V** | - | - | - |
| **VI** | | - | - |
| **VII** | (*) | (*) | 10 $km^2$ |
| **VIII** | Several hundreds meters | Centimetric | 100 $km^2$ |
| **IX** | 1- 10 km | 5 - 40 cm | 1000 $km^2$ |
| **X** | 10 - 60 km | 40 - 300 cm | 5000 $km^2$ |
| **XI** | 60 – 150 km | 300 –700 cm | 10000 $km^2$ |
| **XII** | > 150 km | > 700 cm | > 50000 $km^2$ |

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

## *Definition of intensity degrees*

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

### IV - Largely observed / First unequivocal effects in the environment

<u>Primary effects</u> are absent.

<u>Secondary effects</u>

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

c) larger boats, most people on the coast. Water in swimming pools swings and may sometimes overflows.

d) 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.

e) 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.

f) Tree limbs shake feebly.

## V - Strong / Marginal effects in the environment

Primary effects are absent.

Secondary effects

a) Rare variations of the water level in wells and/or of the flow-rate of springs are locally recorded, as well as small variations of chemical-physical properties of water and turbidity in lakes, springs and wells.

b) In closed basins (lakes, even seas) seiches with height of decimeters may develop, sometimes noted also by naked eye, typically in the far field of strong earthquakes. Anomalous waves up to several tens of cm high are perceived by all people on boats and on the coast. Water in swimming pools overflows.

c) Thin cracks (millimeter-wide and several cms up to one meter long) are locally seen where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon.

d) Rare small rockfalls, rotational landslides and slump earth flows may take place, along often but not necessarily steep slopes where equilibrium is near the limit state, mainly loose deposits and saturated soil. Underwater landslides may be triggered, which can induce small anomalous waves in coastal areas of sea and lakes.

e) Tree limbs and bushes shake slightly, very rare cases of fallen dead limbs and ripe fruit.

f) Extremely rare cases are reported of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (highly susceptible, recent, alluvial and coastal deposits, near-surface water table).

## VI - Slightly damaging / Modest effects in the environment

Primary effects are absent.

Secondary effects:

a) Significant variations of the water level in wells and/or of the flow-rate of springs are locally recorded, as well as small variations of chemical-physical properties of water and turbidity in lakes, springs and wells.

b) Anomalous waves up to many tens of cm high flood very limited areas nearshore. Water in swimming pools and small ponds and basins overflows.

c) *Occasionally, millimeter-centimeter wide and up to several meters long fractures are observed in loose alluvial deposits and/or saturated soils; along steep slopes or riverbanks they can be 1-2 cm wide. A few minor cracks develop in paved (either asphalt or stone) roads.*

d) Rockfalls and landslides with volume reaching ca. $10^3$ $m^3$ can take place, especially where equilibrium is near the limit state, e.g. steep slopes and cuts, with loose saturated soil, or highly weathered / fractured rocks. Underwater landslides can be triggered, occasionally provoking small anomalous waves in coastal areas of sea and lakes, commonly seen by intrumental records.

e) *Trees and bushes shake moderately to strongly; a very few tree tops and unstable-dead limbs may break and fall, also depending on species, fruit load and state of health.*

f) *Rare cases are reported of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (highly susceptible, recent, alluvial and coastal deposits, near surface water table).*

## VII - Damaging / Appreciable effects in the environment

Primary effects observed very rarely, and almost exclusively in volcanic areas. Limited surface fault ruptures, tens to hundreds of meters long and with centimetric offset, may occur, essentially associated to very shallow earthquakes.

Secondary effects: The total affected area is in the order of 10 $km^2$.

a) Significant temporary variations of the water level in wells and/or of the flow-rate of springs are locally recorded.

Seldom, small springs may temporarily run dry or appear. Weak variations of chemical-physical properties of water and turbidity in lakes, springs and wells are locally observed.

b) Anomalous waves even higher than a meter may flood limited nearshore areas and damage or wash away objects of variable size. Water overflows from small basins and watercourses.

c) *Fractures up to 5-10 cm wide and up to hundred metres long are observed, commonly in loose alluvial deposits and/or saturated soils; rarely in dry sand, sand-clay, and clay soil fractures, up to 1 cm wide. Centimeter-wide cracks are common in paved (asphalt or stone) roads.*

d) Scattered landslides occur in prone areas, where equilibrium is unstable (steep slopes of loose / saturated soils), while modest rock falls are common on steep gorges, cliffs). Their size is sometimes significant ($10^3$ - $10^5$ $m^3$); in dry sand, sand-clay, and clay soil, the volumes are usually up to 100 $m^3$. Ruptures, slides and falls may affect riverbanks and artificial embankments and excavations (e.g., road cuts, quarries) in loose sediment or weathered / fractured rock. Significant underwater landslides can be triggered, provoking anomalous waves in coastal areas of sea and lakes, directly felt by people on boats and ports.

e) Trees and bushes shake vigorously; especially in densely forested areas, many limbs and tops break and fall.

f) *Rare cases are reported of liquefaction, with sand boils up to 50 cm in diameter, in areas most prone to this phenomenon (highly susceptible, recent, alluvial and coastal deposits, near surface water table).*

## VIII - Heavily damaging / Extensive effects in the environment

Primary effects: observed rarely.

*Ground ruptures (surface faulting) may develop, up to several hundred meters long, with offsets not exceeding a few cm, particularly for very shallow focus earthquakes such as those common in volcanic areas. Tectonic subsidence or uplift of the ground surface with maximum values on the order of a few centimeters may occur.*

Secondary effects: The total affected area is in the order of 100 $km^2$.

a) Springs may change, generally temporarily, their flow-rate and/or elevation of outcrop. Some small springs may even run dry. Variations in water level are observed in wells. Weak variations of chemical-physical properties of water, most commonly temperature, may be observed in springs and/or wells. Water turbidity may appear in closed basins, rivers, wells and springs. Gas emissions, often sulphureous, are locally observed.

b) Anomalous waves up to 1-2 meters high flood nearshore areas and may damage or wash away objects of variable size. Erosion and dumping of waste is observed along the beaches, where some bushes and even small weak-rooted trees can be eradicated and drifted away. Water violently overflows from small basins and watercourses.

c) *Fractures up to 50 cm wide are and up to hundreds metres long commonly observed in loose alluvial deposits and/or saturated soils; in rare cases fractures up to 1 cm can be observed in competent dry rocks. Decimetric cracks common in paved (asphalt or stone) roads, as well as small pressure undulations.*

d) Small to moderate ($10^3$ - $10^5$ $m^3$) landslides widespread in prone areas; rarely they can occur also on gentle slopes; where equilibrium is unstable (steep slopes of loose / saturated soils; rock falls on steep gorges, coastal cliffs) their size is sometimes large ($10^5$ - $10^6$ $m^3$). Landslides can occasionally dam narrow valleys causing temporary or even permanent lakes. Ruptures, slides and falls affect riverbanks and artificial embankments and excavations (e.g., road cuts, quarries) in loose sediment or weathered / fractured rock. Frequent occurrence of landslides under the sea level in coastal areas.

e) *Trees shake vigorously; branches may break and fall, even uprooted trees, especially along steep slopes.*

f) *Liquefaction may be frequent in the epicentral area, depending on local conditions; sand boils up to ca. 1 m in diameter; apparent water fountains in still waters; localised lateral spreading and settlements (subsidence up to ca. 30 cm), with fissuring parallel to waterfront areas (river banks, lakes, canals, seashores).*

g) *In dry areas, dust clouds may rise from the ground in the epicentral area.*

h) Stones and even small boulders and tree trunks may be thrown in the air, leaving typical imprints in soft soil.

## IX - Destructive / Effects in the environment are a widespread source of considerable hazard and become important for intensity assessment

Primary effects: observed commonly.

Ground ruptures (surface faulting) develop, up to a few km long, with offsets generally in the order of several cm. Tectonic subsidence or uplift of the ground surface with maximum values in the order of a few decimeters may occur.

Secondary effects: *The total affected area is in the order of 1000 km$^2$.*

a) *Springs can change, generally temporarily, their flow-rate and/or location to a considerable extent. Some modest springs may even run dry. Temporary variations of water level are commonly observed in wells. Water temperature often changes in springs and/or wells. Variations of chemical-physical properties of water, most commonly temperature, are observed in springs and/or wells. Water turbidity is common in closed basins, rivers, wells and springs. Gas emissions, often sulphureous, are observed, and bushes and grass near emission zones may burn.*

b) *Meters high waves develop in still and running waters. In flood plains water streams may even change their course, also because of land subsidence. Small basins may appear or be emptied. Depending on shape of sea bottom and coastline, dangerous tsunamis may reach the shores with runups of up to several meters flooding wide areas. Widespread erosion and dumping of waste is observed along the beaches, where bushes and trees can be eradicated and drifted away.*

c) *Fractures up to 100 cm wide and up to hundreds metres long are commonly observed in loose alluvial deposits and/or saturated soils; in competent rocks they can reach up to 10 cm. Significant cracks common in paved (asphalt or stone) roads, as well as small pressure undulations.*

d) *Landsliding widespread in prone areas, also on gentle slopes; where equilibrium is unstable (steep slopes of loose / saturated soils; rock falls on steep gorges, coastal cliffs) their size is frequently large ($10^5$ m$^3$), sometimes very large ($10^6$ m$^3$). Landslides can dam narrow valleys causing temporary or even permanent lakes. Riverbanks, artificial embankments and excavations (e.g., road cuts, quarries) frequently collapse. Frequent large landslides under the sea level in coastal areas.*

e) Trees shake vigorously; branches and thin tree trunks frequently break and fall. Some trees might be uprooted and fall, especially along steep slopes.

f) *Liquefaction and water upsurge are frequent; sand boils up to 3 m in diameter; apparent water fountains in still waters; frequent lateral spreading and settlements (subsidence of more than ca. 30 cm), with fissuring parallel to waterfront areas (river banks, lakes, canals, seashores).*

g) In dry areas, dust clouds commonly rise from the ground.

h) *Small boulders and tree trunks may be thrown in the air and move away from their site for meters, also depending on slope angle and roundness, leaving typical imprints in soft soil.*

## X - Very destructive / Effects on the environment become a leading source of hazard and are critical for intensity assessment

Primary effects become leading.

*Surface faulting can extend for few tens of km, with offsets from tens of cm up to a few meters. Gravity grabens and elongated depressions develop; for very shallow focus earthquakes in volcanic areas rupture lengths might be much lower. Tectonic subsidence or uplift of the ground surface with maximum values in the order of few meters may occur.*

Secondary effects. *The total affected area is in the order of 5000 km$^2$.*

a) Many springs significantly change their flow-rate and/or elevation of outcrop. Some springs may run temporarily or even permanently dry. Temporary variations of water level are commonly observed in wells. Even strong variations of chemical-physical properties of water, most commonly temperature, are observed in springs and/or wells. Often water becomes very muddy in even large basins, rivers, wells and springs. Gas emissions, often sulphureous, are observed, and bushes and grass near emission zones may burn.

b) *Meters high waves develop in even big lakes and rivers, which overflow from their beds. In flood plains rivers may change their course, temporary or even permanently, also because of widespread land subsidence. Basins may appear or be emptied. Depending on shape of sea bottom and coastline, tsunamis may reach the shores with runups exceeding 5 m flooding flat areas for thousands of meters inland. Small boulders can be dragged for many meters. Widespread deep erosion is observed along the shores, with noteworthy changes of the coastline profile. Trees nearshore are eradicated and drifted away.*

c) *Open ground cracks up to more than 1 m wide and up to hundred metres long are frequent, mainly in loose alluvial deposits and/or saturated soils; in competent rocks opening reach several decimeters. Wide cracks develop in paved (asphalt or stone) roads, as well as pressure undulations.*

d) *Large landslides and rock-falls (> $10^5$ - $10^6$ $m^3$) are frequent, practically regardless to equilibrium state of the slopes, causing temporary or permanent barrier lakes. River banks, artificial embankments, and sides of excavations typically collapse. Levees and earth dams may even incur serious damage. Frequent large landslides under the sea level in coastal areas.*

e) *Trees shake vigorously; many branches and tree trunks break and fall. Some trees might be uprooted and fall.*

f) *Liquefaction, with water upsurge and soil compaction, may change the aspect of wide zones; sand volcanoes even more than 6 m in diameter; vertical subsidence even > 1m; large and long fissures due to lateral spreading are common.*

g) In dry areas, dust clouds may rise from the ground.

f) *Boulders (diameter in excess of 2-3 meters) can be thrown in the air and move away from their site for hundreds of meters down even gentle slopes, leaving typical imprints in soil.*

## XI - Devastating / Effects on the environment become decisive for intensity assessment, due to saturation of structural damage

Primary effects are dominant

*Surface faulting extends from several tens of km up to more than one hundred km, accompanied by offsets reaching several meters. Gravity graben, elongated depressions and pressure ridges develop. Drainage lines can be seriously offset. Tectonic subsidence or uplift of the ground surface with maximum values in the order of numerous meters may occur.*

Secondary effects. *The total affected area is in the order of 10.000 $km^2$.*

a) Many springs significantly change their flow-rate and/or elevation of outcrop. Many springs may run temporarily or even permanently dry. Temporary or permanent variations of water level are generally observed in wells. Even strong variations of chemical-physical properties of water, most commonly temperature, are observed in springs and/or wells. Often water becomes very muddy in even large basins, rivers, wells and springs. Gas emissions, often sulphureous, are observed, and bushes and grass near emission zones may burn.

b) *Large waves develop in big lakes and rivers, which overflow from their beds. In flood plains rivers can change their course, temporary or even permanently, also because of widespread land subsidence and landsliding. Basins may appear or be emptied. Depending on shape of sea bottom and coastline, tsunamis may reach the shores with runups reaching 15 meters and more devastating flat areas for kilometers inland. Even meter-sized boulders can be dragged for long distances. Widespread deep erosion is observed along the shores, with noteworthy changes of the coastal morphology. Trees nearshore are eradicated and drifted away.*

c) Open ground cracks up to several meters wide are very frequent, mainly in loose alluvial deposits and/or saturated soils. In competent rocks they can reach 1 m. Very wide cracks develop in paved (asphalt or stone) roads, as well as large pressure undulations.

d) *Large landslides and rock-falls (> $10^5$ - $10^6$ $m^3$) are frequent, practically regardless to equilibrium state of the slopes, causing many temporary or permanent barrier lakes. River banks, artificial embankments, and sides of excavations typically collapse. Levees and earth dams incur serious damage. Significant landslides can occur at 200 – 300 km distance from the epicenter. Frequent large landslides under the sea level in coastal areas.*

e) *Trees shake vigorously; many branches and tree trunks break and fall. Many trees are uprooted and fall.*

f) *Liquefaction changes the aspect of extensive zones of lowland, determining vertical subsidence possibly exceeding several meters, numerous large sand volcanoes, and severe lateral spreading features.*

g) In dry areas dust clouds arise from the ground.

f) *Big boulders (diameter of several meters) can be thrown in the air and move away from their site for long distances down even gentle slopes., leaving typical imprints in soil.*

## XII - Completely devastating / Effects in the environment are the only tool for intensity assessment

Primary effects are dominant.

Surface faulting is at least few hundreds of km long, accompanied by offsets reaching several tens of meters. Gravity graben, elongated depressions and pressure ridges develop. Drainage lines can be seriously offset. Landscape and geomorphological changes induced by primary effects can attain extraordinary extent and size (typical examples are the uplift or subsidence of coastlines by several meters, appearance or disappearance from sight of significant landscape elements, rivers changing course, origination of waterfalls, formation or disappearance of lakes).

Secondary effects *The total affected area is in the order of 50.000 km$^2$ and more.*

a) Many springs significantly change their flow-rate and/or elevation of outcrop. Temporary or permanent variations of water level are generally observed in wells. Many springs and wells may run temporarily or even permanently dry. Strong variations of chemical-physical properties of water, most commonly temperature, are observed in springs and/or wells. Water becomes very muddy in even large basins, rivers, wells and springs. Gas emissions, often sulphureous, are observed, and bushes and grass near emission zones may burn.

b) *Giant waves develop in lakes and rivers, which overflow from their beds. In flood plains rivers change their course and even their flow direction, temporary or even permanently, also because of widespread land subsidence and landsliding. Large basins may appear or be emptied. Depending on shape of sea bottom and coastline, tsunamis may reach the shores with runups of several tens of meters devastating flat areas for many kilometers inland. Big boulders can be dragged for long distances. Widespread deep erosion is observed along the shores, with outstanding changes of the coastal morphology. Many trees are eradicated and drifted away. All boats are tore from their moorings and swept away or carried onshore even for long distances. All people outdoor are swept away.*

c) Ground open cracks are very frequent, up to one meter or more wide in the bedrock, up to more than 10 m wide in loose alluvial deposits and/or saturated soils. These may extend up to several kilometers in length.

d) *Large landslides and rock-falls (> $10^5$ - $10^6$ m$^3$) are frequent, practically regardless to equilibrium state of the slopes, causing many temporary or permanent barrier lakes. River banks, artificial embankments, and sides of excavations typically collapse. Levees and earth dams incur serious damage. Significant landslides can occur at more than 200 – 300 km distance from the epicenter. Frequent very large landslides under the sea level in coastal areas.*

e) Trees shake vigorously; many branches and tree trunks break and fall. Many trees are uprooted and fall.

f) *Liquefaction occurs over large areas and changes the morphology of extensive flat zones, determining vertical subsidence exceeding several meters, widespread large sand volcanoes, and extensive severe lateral spreading features.*

g) In dry areas dust clouds arise from the ground.

h) Also very big boulders can be thrown in the air and move for long distances even down very gentle slopes, leaving typical imprints in soil.

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 21 - 30
tab. 1

# 2.2. - La scala di intensità sismica ESI 2007 (Italian)

TRADUZIONE A CURA DI: GUERRIERI L. (1), ESPOSITO E. (2), PORFIDO S. (2), MICHETTI A.M. (3) & VITTORI E. (1)

## *Introduzione*

L'intensità di un terremoto si definisce in base alla classificazione degli effetti prodotti dal sisma sull'uomo, sulle costruzioni (edifici e infrastrutture) e sull'ambiente naturale (effetti geologici e ambientali). L'intensità così determinata consente di misurare la severità dell'evento sismico tenendo conto sia degli effetti nell'intero intervallo di frequenze del moto vibratorio sia delle deformazioni statiche.

Tutte le scale d'intensità (Rossi-Forel, Mercalli, MCS, MSK, Mercalli Modificata) considerano gli effetti sull'ambiente naturale quali elementi diagnostici utili per la valutazione del grado di intensità. Alcune scale moderne (e.g., ESPINOSA *et alii*, 1976a; 1976b; GRUNTHAL, 1998) considerano invece fondamentalmente gli effetti sull'uomo e sul costruito, riducendo notevolmente il significato diagnostico degli effetti sull'ambiente, tutto ciò sulla base dell'assunzione che essi sono molto più variabili degli altri effetti e quindi potenzialmete aleatori. Studi recenti (es. DENGLER & MCPHERSON, 1993; SERVA, 1994, DOWRICK, 1996; ESPOSITO *et alii*, 1997; HANCOX *et alii*, 2002; MICHETTI *et alii*, 2004, PORFIDO *et alii*, 2007) hanno invece fornito chiare evidenze che gli effetti geologici ed ambientali, dei quali oggi si dispone di un database storico e, soprattutto, paleosismologico, estremamente ricco, sono in grado di fornire informazioni fondamentali per la stima delle dimensioni del terremoto ed in particolare dell'intensità.

Con questo obiettivo è stata realizzata la scala di intensità ESI 2007 (MICHETTI *et alii*, 2007) che si basa esclusivamente sugli effetti geologici e ambientali. Il suo utilizzo, da solo o insieme ad altre scale macrosismiche "tradizionali", fornisce il quadro più completo degli effetti del terremoti, in quanto solamente gli effetti ambientali sono confrontabili:

- *nel tempo*: infatti la finestra temporale dei terremoti recenti, storici e paleo sismici è assai più grande del periodo strumentale (ultimo secolo), e
- *in diverse aree geografiche*: gli effetti ambientali non dipendono da specifiche condizioni socio-economiche o da diverse pratiche costruttive.

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Pertanto lo scopo è quello di integrare le scale d'intensità sismica tradizionali, ovvero:

- per i terremoti con intensità maggiori o uguali al X grado, in quanto spesso la stima del danneggiamento sul costruito risulta estremamente difficoltosa, mentre gli effetti geologici e ambientali continuano ad essere presenti e diagnostici;
- in aree scarsamente abitate o deserte, dove gli effetti sulle strutture antropiche sono assenti o comunque radi e la valutazione dell'intensità del terremoto deve necessariamente basarsi sugli effetti sull'ambiente, unici elementi disponibili.

La definizione dei gradi di intensità è frutto di una revisione critica dei dati di un elevato numero di terremoti avvenuti in tutto il mondo da parte di un gruppo di lavoro internazionale composto da geologi, sismologi ed ingegneri. La ESI 2007 è stata ratificata dall'INQUA (*International Union for Quaternary Research*) durante il XVII INQUA Congress tenutosi a Cairns (Australia) nel 2007.

## *Descrizione*

La scala ESI 2007 è strutturata in dodici gradi. Il titolo di ciascun grado riflette la severità del terremoto ed il ruolo degli effetti sull'ambiente. Nella descrizione sono riportate in primo luogo le caratteristiche degli effetti primari ossia la fagliazione superficiale e le altre deformazioni di origine tettonica. Quindi gli effetti secondari sono descritti in termini di area totale di occorrenza (per la valutazione dell'intensità epicentrale), raggruppate nelle diverse categorie e ordinate in senso crescente a seconda del grado in cui essi iniziano a manifestarsi. Il testo in *corsivo* evidenzia le descrizioni ritenute maggiormente diagnostiche per il dato grado di intensità.

Gli ***effetti primari*** direttamente legati all'energia del terremoto e in particolare, alla manifestazione in superficie della faglia sismogenetica, sono espressi in termini di due parametri fondamentali: la lunghezza totale della rottura in superficie (SRL *total surface rupture length*), e la massima dislocazione ad essa associata (MD *maximum displacement)*. Si osservano generalmente al di sopra di una certa soglia di magnitudo e si manifestano in genere a partire dall'VIII grado ESI, salvo in alcune zone vulcaniche dove eventi sismici molto superficiali possono dare luogo ad effetti primari già al VII grado. Rientrano negli effetti primari anche le deformazioni della superficie topografica di natura tettonica (*uplift,* sollevamento e *subsidence*, subsidenza).

Gli ***effetti secondari***, indotti dallo scuotimento sismico, sono classificati in otto categorie principali**:**

a) ***Anomalie idrologiche***: in questa categoria sono comprese le variazioni di portata delle sorgenti e dei corsi d'acqua e le modificazioni delle proprietà chimico-fisiche delle acque superficiali e sotterranee (es. temperatura, torbidità). Sono diagnostici a partire dal IV fino al X grado.

b) ***Onde anomale/tsunami:*** questa categoria comprende tutte le onde anomale dalle piccole onde di sessa in specchi lacustri, fino alle onde anomale legate a maremoti. Le altezze variano da pochi centimetri ad alcune decine di metri. Si rilevano a partire dal IV fino al XII grado.

c) ***Fratture al suolo:*** le fratture nel terreno sono descritte in termini di lunghezza (da centimetrica fino a qualche centinaio di metri), di ampiezza (da millimetrica a metrica), e di densità areale. Sono diagnostiche a partire dal IV fino al X grado.

d) ***Movimenti di versante****:* in questa classe sono comprese tutte le tipologie di fenomeni franosi, dai crolli agli scivolamenti, agli scoscendimenti, fino alle colate in terra. A parità di condizioni predisponenti (pendenza, litologia), sono considerati elementi utili per la valutazione dell'intensità il volume e l'area totale in frana. Sono diagnostici a partire dal IV fino al X grado.

e) ***Scuotimenti degli alberi***: sono diagnostici a partire dal IV fino al XI grado. La definizione del grado di intensità segue quella proposta da DENGLER & MCPHERSON (1993).

f) ***Liquefazioni***: sono compresi tutti gli effetti imputabili al fenomeno della liquefazione, ovvero i vulcanelli di sabbia, le fontane di acqua e sabbia, alcune tipologie di espandimento laterale, di compattazione e di subsidenza. Le dimensioni dei fenomeni concorrono a stabilire il grado di intensità. Sono diagnostici a partire dal V fino al X grado.

g) ***Nuvole di polvere***, sono osservabili nelle zone generalmente aride/secche, a partire dall'VIII grado.

h) ***Massi saltanti****,* le dimensioni massime dei massi che dal terreno vengono scagliati verso l'alto e l'impronta lasciata sul suolo sono fattori diagnostici ai fini dell'attribuzione del grado di intensità. Sono osservabili a partire dal IX grado fino al XII. Queste evidenze mostrano che accelerazioni del suolo superiori a quella di gravità si possono produrre a partire dal IX grado.

Gli effetti ambientali sono pertanto osservabili e di facile identificazione a partire dal IV grado. Dal I al III grado, gli effetti ambientali, pur osservabili in alcune tipologie (soprattutto nel campo delle variazioni idrologiche), non sono attualmente così ben caratterizzati da poter essere considerati diagnostici. L'accuratezza della valutazione aumenta verso i gradi più alti della scala, in particolare nell'intervallo di occorrenza degli effetti primari, che tipicamente iniziano a manifestarsi dall'VIII grado con risoluzione crescente fino al XII grado. A partire dal X grado gli effetti sull'uomo e sulle strutture giungono a saturazione, ossia gli edifici sono completamente distrutti e pertanto non consentono di distinguere i diversi gradi di intensità. Gli effetti sull'ambiente divengono allora dominanti in questo range di intensità, rappresentando di fatto lo strumento più efficace per la valutazione dell'intensità.

### *Come si utilizza la scala ESI 2007*

L'utilizzo della ESI 2007 come uno strumento indipendente di valutazione viene raccomandato solamente quando solo gli effetti ambientali sono diagnostici perché gli effetti sull'uomo o sul costruito sono assenti o troppo scarsi (es. in aree scarsamente abitate o deserte) o perché giungono a saturazione. Ovviamente, quando gli effetti ambientali non sono disponibili l'intensità viene valutata solo con le scale macrosismiche tradizionali basate sugli effetti sull'uomo e sul costruito.

Quando sono disponibili sia effetti sull'uomo e sul costruito, che sull'ambiente è possibile stimare due valori di intensità in maniera indipendente. In generale, il valore finale di intensità è il maggiore tra le due stime. Naturalmente, anche in questo caso è essenziale l'esperienza del rilevatore (corretto giudizio professionale).

L'intensità epicentrale ($I_0$), ovvero l'intensità dello scuotimento all'epicentro, indica quale intensità si sarebbe registrata se ci fosse stato un centro abitato in corrispondenza dell'epicentro. I parametri di fagliazione superficiale e l'area totale di distribuzione degli effetti secondari (frane e/o liquefazioni) sono due strumenti indipendenti per valutare $I_0$ sulla base degli effetti ambientali, a partire dal grado di intensità VII in su (tab. 2.1).

Particolare attenzione è richiesta quando i parametri di fagliazione superficiale sono al limite tra due gradi. In questo caso è raccomandabile scegliere il grado di intensità più consistente con le caratteristiche e la distribuzione degli effetti secondari.

Inoltre, nella valutazione dell'area totale, è raccomandato di non considerare gli effetti isolati che si verificano occasionalmente in zone a notevole distanza dall'epicentro. Tale valutazione richiede evidentemente un giudizio professionale *ad hoc*.

Tab. 2.1 - Per ciascun grado di intensità sono riportati gli intervalli tipici dei parametri di fagliazione superficiale (effetti primari) e la tipica area di estensione totale degli effetti secondari.

| $I_0$ | EFFETTI PRIMARI | | EFFETTI SECONDARI |
|---|---|---|---|
| | LUNGHEZZA DELLA ROTTURA IN SUPERFICIE | MASSIMO RIGETTO SUPERFICIALE | AREA TOTALE |
| **IV** | - | - | - |
| **V** | - | - | - |
| **VI** | - | - | - |
| **VII** | (*) | (*) | 10 km$^2$ |
| **VIII** | Diverse centinaia di metri | Qualche cm | 100 km$^2$ |
| **IX** | 1- 10 km | 5 - 40 cm | 1000 km$^2$ |
| **X** | 10 - 60 km | 40 - 300 cm | 5000 km$^2$ |
| **XI** | 60 – 150 km | 300 –700 cm | 10000 km$^2$ |
| **XII** | > 150 km | > 700 cm | > 50000 km$^2$ |

(*) Rotture superficiali dovute a fagliazione limitata, da dieci a centinaia di metri con rigetti centimetrici si possono verificare in aree vulcaniche, associate essenzialmente a terremoti assai superficiali.

L'intensità locale viene essenzialmente stimata attraverso la descrizione degli effetti secondari avvenuti in diversi "Siti" compresi tutti in una determinata Località. Questo tipo di intensità deve esser confrontabile con quella corrispondente ricavabile da un'analisi macrosismica tradizionale. In ogni caso "Località" può riferirsi sia a località effettivamente abitate (un paese, una città), sia ad aree naturali prive di insediamenti antropici. Infine, quando sono disponibili solo effetti primari, è possibile utilizzare l'espressione della fagliazione superficiale locale, tenendo conto del massimo rigetto osservato.

## *Definizione dei Gradi di Intensità*

**Da I a III -** Non ci sono effetti sull'ambiente che possono essere usati come diagnostici per la valutazione del grado di intensità

### IV - AMPIAMENTE AVVERTITO / Primi inequivocabili effetti sull'ambiente

<u>Gli effetti primari sono assenti</u>.

<u>Effetti secondari</u>

a) In rari casi si osservano modeste variazioni locali del livello idrico nei pozzi e/o della portata delle sorgenti, nonché assai rare e modeste variazioni delle proprietà chimico-fisiche delle acque e della torbidità nelle sorgenti e nei pozzi, con particolare riferimento alle sorgenti dei sistemi carsici, che risultano più soggette a questi fenomeni.

b) In bacini chiusi (laghi, talvolta anche mari), si possono produrre sesse di altezza non superiore ad alcuni centrimetri, registrabili unicamente dai mareografi e solo eccezionalmente ad occhio nudo. Tipicamente si verificano nell'area di *far field* di forti terremoti. Onde anomale sono avvertite da tutti coloro che si trovano su piccole imbarcazioni, solamente da alcuni che si trovano su battelli di maggiori dimensioni, e dalla maggior parte di chi si trova sulla riva. L'acqua nelle piscine oscilla e in alcuni casi fuoriesce.

c) Fratture molto sottili (ampiezza millimetrica) possono occasionalmente prodursi laddove la litologia (cfr. depositi alluvionali sciolti, terreni saturi) e/o la morfologia (versanti o creste) sono particolarmente favorevoli a questo fenomeno.

d) Eccezionalmente possono verificarsi crolli e (ri) attivarsi piccoli movimenti franosi, lungo versanti che si trovano in condizioni di equilibrio limite (versanti molto ripidi, tagli stradali in terreni sciolti e generalmente saturi).

e) I rami degli alberi si scuotono debolmente.

## V - Forte / Effetti ambientali marginali

Gli effetti primari sono assenti.

Effetti secondari

a) Raramente si registrano variazioni locali del livello idrico nei pozzi e/o di portata delle sorgenti nonché modeste variazioni delle proprietà chimico-fisiche delle acque, della torbidità in laghi, sorgenti e pozzi.

b) Nei bacini chiusi (laghi, talvolta anche mari), si possono produrre sesse di altezza decimetrica, talvolta visibili ad occhio nudo: tipicamente si verificano nell'area di *far field* di forti terremoti. Onde anomale di altezza anche pari a diverse decine di centimetri sono percepite da tutti coloro che si trovano in barca o sulla riva. L'acqua nelle piscine tracima.

c) Fratture sottili (ampiezza millimetrica e lunghezza centimetrica fino ad un metro) si producono laddove la litologia (cfr. depositi alluvionali sciolti, terreni saturi) e/o la morfologia (versanti e creste) sono particolarmente favorevoli a questo fenomeno.

d) Raramente si possono verificare piccoli crolli, scorrimenti rotazionali e colate di terra, su versanti in condizioni di equilibrio limite, spesso ma non necessariamente molto ripidi, su terreni generalmente sciolti e saturi. Possono attivarsi frane sottomarine in grado di indurre piccole onde anomale sulle coste di mari e laghi.

e) I rami degli alberi e i cespugli si scuotono leggermente e, molto raramente, cadono rami secchi e frutti maturi.

f) Si osservano assai rari casi di liquefazione (vulcanelli di sabbia – *sand boils*) di piccole dimensioni e nelle aree maggiormente favorevoli a questo fenomeno (depositi recenti, alluvionali e costieri, altamente suscettibili, con falda prossima al piano campagna).

## VI - LIEVEMENTE DANNOSO / Effetti ambientali modesti

Gli effetti primari sono assenti.

Effetti secondari

a) Variazioni significative del livello idrico nei pozzi e/o della portata delle sorgenti si registrano localmente, nonché modifiche delle proprietà chimico-fisiche dell'acqua e della torbidità in laghi, sorgenti e pozzi.

b) Onde anomale alte fino a diverse decine di centimetri possono allagare un'area molto limitata prossima alla linea di costa. L'acqua fuoriesce dalle piscine e da piccoli stagni e specchi d'acqua.

b) *Occasionalmente, si osservano fratture di ampiezza millimetrico-centimetrica e di lunghezza anche di parecchi metri in depositi alluvionali sciolti e/o in terreni saturi; lungo versanti ripidi o argini di corsi d'acqua possono essere ampie 1-2 cm. Fratture minori si formano nella pavimentazione stradale (sia in asfalto che in pietra).*

c) Possono verificarsi crolli e fenomeni franosi con volumi fino all'ordine di grandezza dei 1000 $m^3$, specialmente in condizioni di equilibrio limite (cfr. versanti ripidi e tagli, terreni sciolti saturi o rocce profondamente alterate e/o fratturate). Frane sottomarine si possono occasionalmente attivare causando piccole onde anomale nelle zone costiere di mari e laghi, di solito registrate strumentalmente.

d) *Alberi e cespugli oscillano da moderatamente a fortemente; a seconda della specie, del carico di frutti e dello stato di salute della pianta, poche cime di alberi e rami instabili o secchi possono rompersi e cadere.*

e) *Rari casi di liquefazione (sand boil), di piccole dimensioni, sono riportati nelle aree maggiormente favorevoli a questo fenomeno (depositi recenti, alluvionali e costieri, altamente suscettibili, con falda prossima al piano campagna).*

## VII - DANNOSO / Significativi effetti sull'ambiente

Effetti primari: si osservano assai raramente, e quasi esclusivamente in aree vulcaniche. Limitata fagliazione superficiale, da decine a centinaia di metri di lunghezza e rigetti centimetrici, può prodursi, associata fondamentalmente a terremoti molto superficiali.

Effetti secondari: l'area totale interessata da effetti secondari è nell'ordine dei 10 $km^2$.

a) Si registrano localmente significative variazioni temporanee del livello idrico nei pozzi e/o della portata delle sorgenti. Di rado, piccole sorgenti possono temporaneamente essicarsi o ne possono affiorare di nuove. Localmente si osservano modeste variazioni delle proprietà chimico-fisiche delle acque e della torbidità in laghi, sorgenti e pozzi.

b) Onde anomale alte anche più di un metro possono allagare le zone prossime alla linea di riva e danneggiare o rimuovere oggetti di varie dimensioni. L'acqua fuoriesce da piccoli bacini e corsi d'acqua.

c) *Fratture ampie fino a 5-10 cm e di lunghezza superiore al centinaio di metri si osservano comunemente nei depositi alluvionali sciolti e/o nei terreni saturi; raramente si producono fratture di ampiezza fino ad un cm in terreni sabbiosi asciutti, sabbioso-argillosi ed argillosi. Fratture di ampiezza centimetrica sono comuni nella pavimentazione stradale (asfalto o pietra).*

d) Diffusi fenomeni franosi si verificano nelle zone in equilibrio instabile (versanti ripidi di terreni sciolti / saturi), mentre crolli di modesta entità sono comuni sulle pareti di gole e scogliere. La loro dimensione è talvolta significativa ($10^3$ - $10^5$ $m^3$); in terreni sabbiosi asciutti, sabbioso-argillosi ed argillosi i volumi sono generalmente inferiori a 100 $m^3$. Rotture, scivolamenti e crolli possono interessare gli argini dei corsi d'acqua, e gli scavi artificiali (cfr. tagli stradali, cave) in sedimenti sciolti o in rocce alterate / fratturate. Si possono innescare frane sottomarine di una certa entità che determinano onde anomale nelle zone costiere di mari e laghi, percepite direttamente dalla gente sulle barche e nei porti.

e) Alberi e cespugli oscillano vigorosamente; specialmente nelle zone a bosco fitto molti rami e cime degli alberi si spezzano e cadono.

f) *Rari casi di liquefazione sono documentati, con vulcanelli di sabbia (sand boils) che possono raggiungere i 50 cm di diametro, nelle zone maggiormente favorevoli a questo fenomeno (depositi recenti, alluvionali e costieri, altamente suscettibili, con falda prossima al piano campagna).*

## VIII - ASSAI DANNOSO / Estesi effetti sull'ambiente

Effetti primari: si osservano raramente.

*Si possono produrre rotture del terreno (fagliazione superficiale) fino a diverse centinaia di metri, con rigetti fino a pochi centimetri, soprattutto per terremoti il cui ipocentro è molto superficiale quali quelli che comunemente interessano le aree vulcaniche. Si possono anche verificare abbassamenti o sollevamenti tettonici della superficie topografica, con valori massimi dell'ordine di pochi centimetri.*

Effetti secondari: L'area totale interessata è dell'ordine di 100 $km^2$.

a) Variazioni generalmente temporanee della portate e/o della quota di emergenza possono interessare le sorgenti. Alcune di esse possono anche essiccarsi. Oscillazioni del livello idrico sono misurate nei pozzi. Modeste variazioni delle proprietà chimico-fisiche delle acque, soprattutto della temperatura, si possono osservare nelle sorgenti e/o nei pozzi. La torbidità dell'acqua può risultare evidente in specchi d'acqua chiusi, corsi d'acqua, pozzi e sorgenti. Emissioni di gas, spesso sulfuree, sono riscontrate localmente.

b) Onde anomale di altezza superiore a 1-2 metri allagano le zone prossime alla linea di riva e sono in grado di danneggiare o rimuovere oggetti di varie dimensioni. Si osserva sulle spiagge la rimozione e rideposizione di rifiuti, alcuni cespugli e persino piccoli alberi debolmente radicati possono venire sradicati e rimossi. L'acqua tracima con forza da piccoli bacini e corsi d'acqua.

c) *Fratture di ampiezza fino a 50 cm e lunghezza anche di centinaia di metri si producono in depositi alluvionali sciolti e/o in terreni saturi; in rari casi è possibile osservare fratture fino a 1 cm in rocce asciutte competenti. Fratture decimetriche sono comuni nella pavimentazione stradale (asfalto e pietra), come anche piccole onde di pressione (pressure undulations).*

d) Fenomeni franosi di dimensioni da piccole a modeste ($10^3$ - $10^5$ $m^3$) sono ampiamente diffusi nelle zone più favorevoli al loro innesco; raramente, possono verificarsi anche su versanti poco pendenti; in condizioni di equilibrio instabile (versanti ripidi di terreni sciolti / saturi; crolli su pareti di gole e scogliere) la loro dimensione è talvolta superiore ($10^5$ - $10^6$ $m^3$). Tali fenomeni franosi possono occasionalmente sbarrare le valli strette, determinando la formazione temporanea, o persino permanente, di un lago. Rotture, scivolamenti e crolli interessano gli argini dei corsi d'acqua e gli sbancamenti artificiali (cfr. tagli stradali, cave) in sedimenti sciolti o o in rocce alterate / fratturate. Nelle zone costiere sono frequenti le frane sottomarine.

e) *Gli alberi oscillano vigorosamente; i rami si possono rompere e cadere e persino gli alberi sradicarsi, specialmente su versanti assai pendenti.*

f) Nell'area epicentrale, in funzione delle condizioni locali, i fenomeni di liquefazione possono risultare frequenti; i vulcanelli di sabbia possono arrivare anche ad 1 metro di diametro; fontane d'acqua appaiono in acque calme; si osservano localizzate espansioni laterali (*lateral spreading*) ed abbassamenti (subsidenza pari anche a 30 cm), con fenditure parallele alle rive di corsi e specchi d'acqua (es., argini fluviali, laghi, canali, linee di costa).

g) *In area epicentrale si può osservare il sollevamento di nuvole di polvere dal terreno in condizioni particolarmente secche.*

h) Pietre e anche piccoli blocchi e tronchi possono essere scagliati in aria, lasciando tipiche impronte nel terreno soffice.

## IX - DISTRUTTIVO / Gli effetti sull'ambiente costituiscono una diffusa causa di elevata pericolosità e divengono importanti per la valutazione dell'intensità

Effetti primari: comunemente osservati.

Si producono rotture nel terreno (fagliazione superficiale) di lunghezza fino a pochi km, con rigetti generalmente nell'ordine di diversi cm. Si possono verificare abbassamenti o sollevamenti della superficie topografica di natura tettonica fino al massimo a pochi decimetri.

Effetti secondari*: L'area totale interessata è nell'ordine di 1000 km*$^2$*.*

a) *La portata e/o l'ubicazione delle sorgenti possono variare, generalmente temporaneamente, anche in maniera considerevole. Alcune sorgenti possono anche essicarsi. Si osservano comunemente anche oscillazioni temporanee del livello idrico nei pozzi, nonché frequenti variazioni delle proprietà chimico-fisiche dell'acqua, soprattutto la temperatura, nelle sorgenti e/o nei pozzi. L'acqua torbida è un fenomeno comune nei bacini chiusi, nei corsi d'acqua, nei pozzi e nelle sorgenti. Si registrano emissioni di gas, in genere sulfurei; i cespugli e l'erba vicino alle zone di emissione possono prendere fuoco.*

b) *Onde di altezza di alcuni metri si sviluppano nelle acque di scorrimento superficiale (corsi d'acqua) nonché in acque tranquille. Nelle piane alluvionali i corsi d'acqua possono anche modificare il proprio tracciato, anche a causa della subsidenza del terreno. Piccoli specchi d'acqua possono formarsi o sparire. A seconda della morfologia del fondale e della linea di costa, pericolosi tsunami possono raggiungere le coste con runup fino a parecchi metri, inondando aree estese.*
*Sulle spiagge si osserva la rimozione e rideposizione dei rifiuti; alberi e cespugli possono essere sradicati e spazzati via.*

c) *Fratture ampie fino a 100 cm e lunghe diverse centinaia di metri si osservano comunemente nei depositi alluvionali sciolti e/o nei terreni saturi; in rocce competenti l'ampiezza delle fratture arriva fino a 10 cm. La pavimentazione stradale (asfalto o pietra) è frequentemente interessata da rilevanti fratture e da onde di pressione (pressure undulations).*

d) *Fenomeni franosi sono diffusi nelle zone più favorevoli, anche su versanti poco pendenti; in condizioni di equilibrio instabile (versanti ripidi di terreni sciolti /saturi; crolli su pareti di gole e scogliere) sono spesso di dimensioni grandi (*$10^5$ $m^3$*), talvolta molto grandi (*$10^6$ $m^3$*). Le frane possono sbarrare le valli strette favorendo la formazione di laghi temporanei (o talvolta permanenti). Gli argini fluviali e le pareti di scavi artificiali (cfr. tagli stradali, cave) spesso collassano. Nelle zone costiere sono frequenti le frane sottomarine.*

e) Gli alberi oscillano molto forte; è frequente che i rami e i tronchi meno spessi si rompano e cadano. Alcuni alberi possono sradicarsi e cadere, specialmente sui versanti ripidi.

f) *Sono frequenti le liquefazioni e le fuoriuscite di acqua in pressione (water upsurge); vulcanelli di sabbia possono raggiungere i 3 metri di diametro; fontane d'acqua possono manifestarsi in acque calme; sono frequenti anche le espansioni laterali (lateral spreading) e i fenomeni di subsidenza (anche oltre i 30 cm), con fenditure parallele alle rive di corsi e specchi d'acqua (es., argini fluviali, laghi, canali, linee di costa).*

g) In condizioni particolarmente secche è comune osservare il sollevamento di nuvole di polvere dal terreno.

h) *Piccoli blocchi e tronchi possono essere scagliati in aria e spostati anche di alcuni metri, a seconda dell'acclività e rugosità del versante, lasciando tipiche impronte su terreno soffice.*

## X - MOLTO DISTRUTTIVO / Gli effetti sull'ambiente rappresentano una causa sostanziale di pericolosità e divengono basilari per la valutazione dell'intensità.

Effetti primari diventano dominanti.

La fagliazione superficiale si sviluppa per alcune decine di km con rigetti da decine di cm fino a pochi metri. Si producono gravity graben e depressioni allungate; per terremoti molto superficiali in aree vulcaniche la lunghezza complessiva della rottura può essere assai minore. Possono verificarsi sollevamenti e abbassamenti della superficie topografica di natura tettonica dell'ordine di alcuni metri.

Effetti secondari. *L'area totale interessata è dell'ordine di 5000 km²*.

a) Si osservano variazioni di portata consistenti di molte sorgenti e/o della loro quota di affioramento. Alcune di esse possono sgorgare o essiccarsi in via temporanea o talvolta in maniera definitiva. Si osservano temporanee oscillazioni del livello idrico nei pozzi. Variazioni delle proprietà chimico-fisiche delle acque di sorgenti e/o pozzi, soprattutto della temperatura, possono essere consistenti. Spesso l'acqua diviene molto fangosa anche in bacini più grandi, nonché in fiumi, pozzi e sorgenti. Si registrano emissioni gassose, generalmente sulfuree, e nelle aree ad esse limitrofe i cespugli e l'erba prendono talvolta fuoco.

b) *Onde di altezza metrica si formano in laghi e fiumi anche di ampie dimensioni, che esondano dagli alvei. Nelle piane alluvionali i fiumi possono modificare il loro tracciato temporaneamente o talvolta in via definitiva, anche a causa della diffusa subsidenza del terreno. Specchi d'acqua possono formarsi o scomparire. A seconda della morfologia del fondale e della linea di costa, gli tsunami possono raggiungere le coste con runup superiore a 5 metri, inondando estesamente aree pianeggianti fino ad alcune migliaia di metri nell'entroterra. Blocchi di piccole dimensioni possono essere trasportati per diversi metri. Lungo le coste si osservano diffusamente fenomeni di intensa erosione che modificano notevolmente il profilo della linea di costa. Gli alberi sulla riva sono sradicati e trascinati via.*

c) *Sono frequenti le fratture beanti fino ad oltre un metro e lunghe alcune centinaia di metri, soprattutto nei terreni alluvionali sciolti e/o nei terreni saturi; in rocce competenti l'apertura delle fratture può raggiungere diversi decimetri. La pavimentazione stradale (asfalto o pietra) è interessata da ampie fratture, nonché da onde di pressione (pressure undulations).*

d) *Sono frequenti fenomeni franosi e crolli di grandi dimensioni (>* $10^5$ - $10^6$ $m^3$*), indipendentemente dallo stato di equilibrio dei versanti, che favoriscono la formazione di laghi di sbarramento temporanei o permanenti. Gli argini fluviali e le pareti di scavo tipicamente collassano. Argini e dighe in terra possono risultare gravemente danneggiati. Nelle aree costiere sono frequenti le frane sottomarine.*

e) *Gli alberi oscillano vigorosamente; molti rami e tronchi d'albero si spezzano e cadono. Alcuni alberi possono sradicarsi e cadono.*

f) *I fenomeni di liquefazione, unitamente ai fenomeni di compattazione del terreno e di fuoriuscite di acqua in pressione (water upsurge), possono modificare l'aspetto di vaste zone; i vulcani di sabbia possono superare i 6 metri di diametro; la subsidenza verticale può superare il metro; sono comuni grandi e lunghe fenditure dovute ai fenomeni di espansione laterale (lateral spreading).*

g) In condizioni particolarmente secche è comune osservare il sollevamento di nuvole di polvere dal terreno.

h) *Blocchi di diametro anche superiore a 2-3- metri possono venire scagliati in aria e trascinati per centinaia di metri anche su versanti poco pendenti, lasciando tipiche impronte sul terreno.*

## XI - DEVASTANTE / Gli effetti sull'ambiente divengono decisivi per la valutazione dell'intensità poiché i danni alle strutture giungono a saturazione

Gli effetti primari sono dominanti

La fagliazione superficiale si estende per molte decine fino ad oltre un centinaio di km, con rigetti che possono raggiungere parecchi metri. Si formano depressioni allungate, gravity graben e pressure ridges. Le linee di drenaggio possono venire significativamente dislocate. Si possono verificare abbassamenti o sollevamenti della superficie topografica di natura tettonica con valori massimi di diversi metri.

Effetti secondari: *l'area totale interessata è nell'ordine di 10.000 km$^2$.*

a) Si osservano variazioni di portata consistenti di molte sorgenti e/o della loro quota di affioramento. Molte di esse possono sgorgare o essiccarsi in via temporanea o talvolta in maniera definitiva. Si osservano temporanee oscillazioni del livello idrico nei pozzi. Si osservano consistenti variazioni delle proprietà chimico-fisiche delle acque di sorgenti e/o pozzi, soprattutto della temperatura. Spesso l'acqua diviene molto fangosa anche in bacini molto grandi, nonché in fiumi, pozzi e sorgenti. Si registrano emissioni gassose, generalmente sulfuree, e nelle aree ad esse limitrofe i cespugli e l'erba prendono talvolta fuoco.

b) Notevoli *onde si formano in grandi laghi e nei corsi d'acqua, i quali esondano dal loro alveo. Nelle piane alluvionali i fiumi possono modificare il loro tracciato, in via temporanea ma anche permanente, anche a causa dei diffusi fenomeni franosi e di subsidenza del terreno. Specchi d'acqua possono formarsi o scomparire. A seconda della morfologia del fondale e della linea di costa, gli tsunami possono raggiungere le coste con runup fino a 15 metri e più, inondando estesamente aree pianeggianti per km nell'entroterra. Blocchi di dimensioni anche metriche possono venire trasportati per lunghe distanze. Lungo le coste si osservano diffusamente fenomeni di intensa erosione che modificano notevolmente la morfologia costiera. Gli alberi sulla riva sono sradicati e trascinati via.*

c) Fratture di ampiezza anche di diversi metri sono assai comuni, soprattutto nei depositi alluvionali e/o nei terreni saturi. Nelle rocce competenti esse raggiungono il metro di larghezza. La pavimentazione stradale (asfalto o pietra) è interessata da fratture molto ampie e da onde di pressione (*pressure undulations*).

d) *Sono frequenti grandi fenomeni franosi e crolli (> $10^5$ - $10^6$ m$^3$), indipendentemente dallo stato di equilibrio dei versanti, che favoriscono la formazione di laghi di sbarramento temporanei o permanenti. Gli argini fluviali, gli sbancamenti artificiali e le pareti di scavo tipicamente collassano. Argini e dighe in terra possono risultare gravemente danneggiate. Frane significative possono verificarsi a distanza anche di 200 – 300 km dall'epicentro. Nelle zone costiere sono frequenti ampie frane sottomarine.*

e) *Gli alberi oscillano vigorosamente; molti rami e tronchi si spezzano e cadono. Molti alberi vengono sradicati e cadono.*

f) *I fenomeni di liquefazione modificano l'aspetto di estese aree di pianura, causando abbassamenti verticali anche superiori a diversi metri, parecchi vulcani di sabbia e considerevoli fenomeni di espansione laterale.*

g) In condizioni particolarmente secche è comune osservare il sollevamento di nuvole di polvere dal terreno.

h) *Grossi blocchi (diametro anche di parecchi metri) possono essere scagliati in aria e trascinati via per lunghe distanze anche su versanti poco pendenti, lasciando tipiche impronte nel terreno.*

## XII - TOTALMENTE DEVASTANTE / Gli effetti sull'ambiente sono l'unico strumento per valutare l'intensità

Effetti primari: sono dominanti.

La fagliazione superficiale si estende per centinaia di km, con rigetti che possono raggiungere decine di metri. Si formano depressioni allungate, gravity graben e pressure ridges. Le linee di drenaggio possono venire significativamente dislocate. Le trasformazioni geomorfologiche e del paesaggio indotte dagli effetti primari possono risultare eccezionalmente intense ed estese (tipici esempi sono il sollevamento o l'abbassamento di parecchi metri delle linee di costa, la formazione o la scomparsa dalla vista di elementi significativi del paesaggio, variazioni del tracciato di corsi d'acqua, sviluppo di cascate, formazione o scomparsa di laghi).

Effetti secondari: *L'area totale interessata è nell'ordine di 50000 km$^2$ o superiore.*

a) Si osservano variazioni di portata consistenti di molte sorgenti e/o della loro quota di affioramento. Temporanee oscillazioni del livello idrico nei pozzi. Molte sorgenti possono sgorgare o essiccarsi in via temporanea o talvolta in maniera definitiva. Si osservano consistenti variazioni delle proprietà chimico-fisiche delle acque di sorgenti e/o pozzi, soprattutto della temperatura. l'acqua diviene molto fangosa anche in bacini molto grandi, nonché in fiumi, pozzi e sorgenti. Si registrano emissioni gassose, generalmente sulfuree, e nelle aree ad esse limitrofe i cespugli e l'erba prendono talvolta fuoco.

b) *Onde gigantesche si formano in grandi laghi e fiumi, che esondano dal proprio alveo. Nelle piane alluvionali i fiumi possono modificare il loro tracciato e persino la direzione del deflusso in via temporanea o anche permanente, anche* *a causa dei diffusi fenomeni franosi e di subsidenza del terreno. Estesi specchi d'acqua possono formarsi o sparire. A seconda della morfologia del fondale e della linea di costa, gli tsunami possono raggiungere le coste con runups fino a diverse decine di metri, recando devastazione nelle aree pianeggianti per vari km nell'entroterra. Grossi blocchi possono venire trasportati per lunghe distanze. Lungo le coste si osservano diffusi fenomeni di intensa erosione con notevolissimi sconvolgimenti della morfologia costiera. Molti alberi sulla riva sono sradicati e trascinati via. Tutte le barche sono strappate ai loro ormeggi e spazzate via o trasportate sulla terraferma anche per lunghe distanze. Tutte le persone all'esterno vengono travolte.*

c) Fratture nel terreno sono molto frequenti, beanti anche più di un metro nel bedrock, fino anche a 10 metri in depositi alluvionali sciolti e/o in terreni saturi. Si estendono per diversi chilometri in lunghezza.

d) *Grandi fenomeni franosi e crolli (> $10^5$ - $10^6$ $m^3$) sono frequenti, indipendentemente dallo stato di equilibrio dei versanti, che favoriscono la formazione di laghi di sbarramento temporanei o permanenti. Gli argini fluviali, gli sbancamenti artificiali e le pareti di scavo tipicamente collassano. Argini e dighe in terra risultano gravemente danneggiate. Frane significative possono verificarsi ad oltre 200-300 km dall'epicentro. Nelle zone costiere sono frequenti notevoli frane sottomarine.*

e) Gli alberi oscillano vigorosamente; molti rami e tronchi si spezzano e cadono. Molti alberi vengono sradicati e cadono.

f) *Le liquefazioni si verificano in aree assai estese e vanno a modificare la morfologia di vaste zone pianeggianti, determinando abbassamenti verticali anche superiori a parecchi metri. Sono diffusi vulcani di sabbia di grandi dimensioni ed estesi e considerevoli fenomeni di espansione laterale (lateral spreading).*

g) In condizioni particolarmente secche è comune osservare il sollevamento di nuvole di polvere dal terreno.

h) Blocchi anche molto grandi possono essere scagliati in aria e trascinati via per lunghe distanze anche su versanti poco pendenti, lasciando tipiche impronte nel terreno.

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 31 - 42
figg. 1, tab. 1

# 2.3. - Escala medio-ambiental de intensidad sismica ESI 2007 (Spanish)

TRADUCCIÓN: SILVA P. G. (1), PEREZ LÓPEZ R. (2), RODRÍGUEZ PASCUA M.A. (2)

## *Introducción*

La intensidad sísmica se basa en la clasificación de los efectos causados por los terremotos sobre las personas, construcciones humanas (edificaciones e infraestructuras) y en el medio natural (efectos ambientales o geológicos). Este parámetro de tamaño sísmico proporciona una estimación de la severidad de la sacudida sísmica teniendo en cuenta los efectos producidos por el rango completo de frecuencias del movimiento ondulatorio así como de las deformaciones estáticas que se produzcan.

Todas las escalas de intensidades (Rossi-Forel, Mercalli, MCS, MSK, Mercalli Modificada) consideran los efectos sobre la naturaleza como elementos diagnósticos a la hora de evaluar la intensidad sísmica. No obstante, algunas escalas modernas (e.g., ESPINOSA *et alii*, 1976a; 1976b; GRUNTHAL, 1998) tan solo consideran los efectos sobre las personas y sobre las construcciones en la evaluación de intensidades, reduciendo drásticamente la relevancia diagnóstica de los efectos sobre la naturaleza aduciendo que tales efectos presentan una gran variabilidad y aleatoriedad siendo difíciles de cuantificar. A pesar de ello, estudios recientes (e.g. DENGLER & MCPHERSON, 1993; SERVA, 1994, DOWRICK, 1996; ESPOSITO *et alii*, 1997; HANCOX *et alii*, 2002; MICHETTI *et alii*, 2004) aportan claras evidencias de que las características de los efectos ambientales o geológicos de los terremotos, son en la actualidad ampliamente clasificables a partir de fuentes históricas y análisis paleosismológicos, los cuales aportan una información esencial para la evaluación del tamaño de los terremotos y en particular de su intensidad.

Con este propósito se ha desarrollado la Escala de Intensidad ESI 2007 (MICHETTI *et alii*, 2007), la cual se encuentra basada exclusivamente en los efectos ambientales de los terremotos. Su uso, en solitario o integrada con otras escalas tradicionales, ofrece una mejor imagen de los escenarios sísmicos acontecidos ya que solo los efectos ambientales de los terremotos permiten la comparación aceptable de la severidad del movimiento del terreno en diferentes escalas temporales y zonas geográficas:

- *tiempo*: los efectos sobre la naturaleza pueden ser comparados para ventanas temporales (eventos sísmicos recientes, históricos y paleosísmos) mucho más amplia que los periodos registrados por la sismicidad instrumental (último siglo).
- *diferentes áreas geográficas:* los efectos ambientales no dependen de las diferentes

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condiciones socio-económicas de una zona, ni de las diferentes prácticas de construcción, ni del grado de urbanización de las zonas afectadas.

Así, esta nueva escala puede integrarse con las escalas sísmicas tradicionales:

- para intensidades sísmicas de grado superior o igual a X, en las que la evaluación de la intensidad basada en los daños llega a saturarse siendo difícil de estimar, mientras que los efectos ambientales todavía son diagnósticos.
- En áreas escasamente pobladas, donde los efectos sobre las construcciones pueden no existir y por tanto la única manera viable de establecer la intensidad son los efectos ambientales, que son los únicos efectos diagnósticos disponibles.

La definición de los grados de intensidad es el resulta do de una revisión de los efectos ambientales causada por un gran número de grandes terremotos a nivel mundial, llevada a cabo por un Grupo de Trabajo Internacional integrado por geólogos, sismólogos e ingenieros. La escala ESI 2007 fue ratificada por INQUA (International Union for Quaternary Research) durante el XVII INQUA Congress (Cairns, Australia) en el año 2007.

## *Descripción*

La escala de intensidades ESI 2007 se encuentra estructurada en doce grados de intensidad. El título de cada grado de intensidad refleja la fuerza correspondiente del terremoto y el papel de los efectos sobre la naturaleza. En su descripción, se indica para cada grado en primer lugar las características y dimensiones de los efectos primarios. Seguidamente, los efectos secundarios son descritos en función del área total afectada y su distribución espacial para la determinación de la intensidad epicentral. Estos se encuentran agrupados en diferentes categorías ordenados por la secuencia de ocurrencia inicial. Los textos en *Cursiva* se han usado para resaltar aquellas descripciones que se consideran diagnósticas por si mismas para un grado de intensidad dado.

***Los Efectos Primarios*** se encuentran directamente relacionados con la energía sísmica liberada y en particular con la expresión en superficie de la fuente sismogenética. Las dimensiones o escala de los efectos primarios se expresan en términos de dos diferentes parámetros: i) La longitud de ruptura total (SRL); y ii) Desplazamiento máximo (MD). Su presencia se encuentra normalmente asociada a un valor de intensidad minima (VIII), excepto en el caso de terremotos muy superficiales en zonas volcánicas. La cantidad de deformación superficial (elevación o subsidencia tectónica) también es considerada en la escala.

***Los Efectos Secundarios*** constituyen cualquier fenómeno natural inducido por la sacudida sísmica y se clasifican en ocho grandes categorías:

a) ***Anomalías Hidrológicas.*** Esta categoría incluye cambios en el caudal de fuentes, manantiales y cursos de agua, así como cambios en las propiedades físico-químicas de aguas superficiales y subterráneas (e.g. temperatura, turbidez, etc.). Estos efectos son diagnósticos para intensidades comprendidas entre IV y X.

b) ***Oleaje anómalo y tsunamis.*** En esta categoría se incluyen: seiches en cuencas cerradas, desbordamientos de agua de estanques, lagos y presas, así como tsunamis. En el caso de los tsunamis, más que el tamaño propiamente dicho de la ola, se consideran sus efectos sobre el litoral (especialmente el runup, erosión litoral y cambios en la morfología de la línea de costa), sin olvidarse de aquellos efectos sobre las personas, edificaciones y estructuras que son tomados como diagnósticos de la intensidad sufrida. Los efectos catalogados pueden ocurrir a partir de intensidad IV, pero son más diagnósticos para intensidades IX a XII.

c) ***Agrietamientos y fisuración del terreno.*** Los agrietamientos del terreno se describen en términos de su longitud (desde cm hasta algunos cientos de metros), anchura (desde mm a m) y densidad espacial. Son observables a partir de intensidad IV, pero se saturan (su tamaño no se incrementa) a partir de intensidad X.

d) ***Movimientos de ladera:*** Esta categoría incluye todas las tipologías de procesos gravitacionales, incluyendo, caídas de rocas, deslizamientos y flujos de tierra. En aquellos casos en que el contexto litológico y geomorfológico es similar, los parámetros diagnósticos lo constituyen el volumen movilizado y el área total afectada. Estos efectos comienzan a ser patentes a partir de intensidad IV y se saturan (su tamaño no incrementa) a partir de intensidad X.

e) ***Agitamiento de Árboles y Vegetación***: Estos efectos son diagnósticos para intensidades de IV a X. These effects are diagnostic from IV to X degree La definición de los grados de intensidad basicamente se ajusta a la propuesta por Dengler & McPherson (1993).

f) ***Licuefacción del terreno:*** Esta categoría incluye volcanes de arena, ejecciones de agua, barro y arena, algunos tipos de expansión lateral, compactación y subsidencia del terreno. Sus dimensiones son diagnósticas para intensidades comprendidas entre los grados V y X. n this category are included sand volcanoes, water and sand fountains, some types of laterl spreading, ground compaction and subsidence. Their size is diagnostic for intensity degree from V to X.

g) ***Nubes de Polvo***: pueden desarrollarse a partir de intensidad VIII, típicamente en zonas áridas/secas.

h) ***Desplazamiento de cantos y rocas:*** Estos efectos se observan a partir de intensidad IX. Las dimensiones de las rocas y bloques movilizados son consideradas como elementos diagnósticos para la asignación de intensidades. Estas evidencias indican que la aceleración del terreno es mayor que la de la gravedad y puede localmente ocurrir a partir de intensidad IX hasta XII.

Los efectos ambientales de los terremotos pueden observarse y catalogarse a paratir de intensidad IV (fig. 2.2). Algunos tipos de efectos (anomalías hidrológicas) pueden incluso observarse en grados inferiores, pero no pueden considerarse como elementos diagnósticos. La precisión en la evaluación de intensidades aumenta hacia los grados más fuertes y, en particular en el rango de intensidades a partir de las cuales los efectos primarios comienzan a ser patentes (típicamente a partir de intensidad VIII) hasta intensidad XII- A partir de intensidad X comúnmente los efectos sobre las personas y construcciones se saturan (i.e. los edificios se encuentran generalmente completamente destruidos) y es virtualmente imposible diferenciar entre grados de intensidad. Es eneste rango de intensidades donde los efectos ambientales son los dominantes, constituyendo la herramienta más valiosa (a veces la única) para la evaluación de intensidades.

## *Como usar la Escala de Intensidades ESI 2007*

El uso de la escala ESI como una herramienta independiente para la evaluación de intensidades se recomienda únicamente cuando los efectos ambientales son diagnósticos debido a que los efectos sobre las personas o construcciones estén ausentes, sean muy escasos o se encuentren saturados. Cuando estos dos últimos tipos de efectos estén también disponibles será posible llevar a cabo dos estimaciones independientes de la intensidad. En general, la intensidad final que se obtenga tiene que ser igual al valor más alto obtenido mediante las dos evaluaciones. Obviamente, en este caso la participación de expertos es esencial.

La intensidad Epicentral ($I_0$) queda definida como la intensidad de la sacudida sísmica en el epicentro del terremoto. Los parámetros de las rupturas de falla así como el área total afectada por efectos secundarios (licuefacción y/o deslizamientos), son dos criterios independientes que pueden

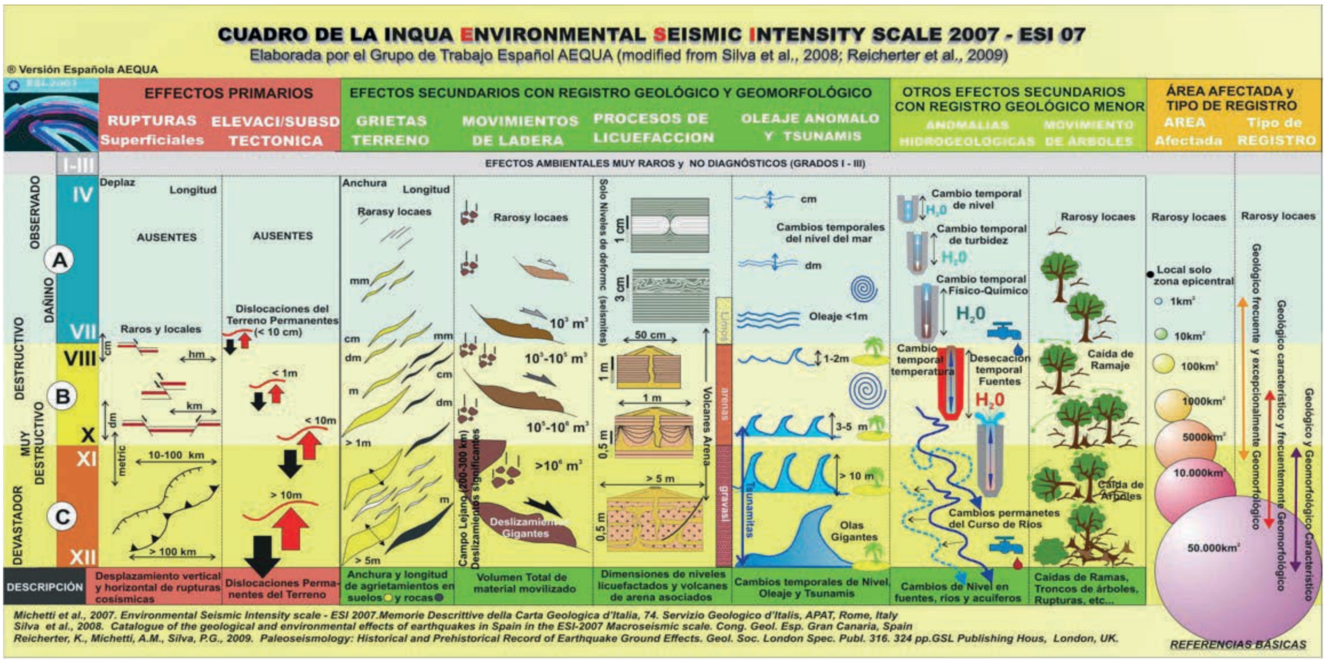


Fig. 2.2. - Esquema gráfico de los diferentes efectos geológicos y ambientales cosísmicos considerados en la Escala Macrosísmica ESI-2007. Se indica el tipo de registro geológico y/o geomorfológico más normal en cada uno de los grupos de categorías de intensidades. Figura Actualizada de la original según la versión en inglés publicada en REICHERTER *et alii*, 2009.

utilizarse para la evaluación de $I_0$ a partir de intensidad VII (tab. 2.1).

Hay que prestar especial atención cuando las dimensiones de las rupturas superficiales se encuentran próximas a los límites establecidos para dos grados de intensidades consecutivos. En estos casos se recomienda utilizar las características y distribución espacial de los efectos secundarios como criterio diagnóstico principal con el fin de evitar evaluaciones subjetivas. En cualquier caso, en la evaluación del área total afectada se recomienda no incluir efectos aislados ocurridos en campo lejano.

Tab. 2.1 - *Rango de los parámetros de rupturas de falla (efectos primarios) y extensión areal típica del registro de los efectos secundrios para cada uno de los grados de intensidad ESI-2007*

| | LONGITUD DE LA RUPTURA DE FALLAS | MÁXIMO DESPLAZAMIENTO O DEFORMACIÓN | AREA TOTAL AFECTADA |
|---|---|---|---|
| **IV** | - | - | - |
| **V** | - | - | - |
| **VI** | | - | - |
| **VII** | (*) | (*) | 10 km2 |
| **VIII** | Cientos de metros | Centimetrico | 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 |

(*) Rupturas de falla de decenas a algunas centenas de metros de longitud y desplazamiento centimétrico, pueden desarrollarse asociadas a terremotos muy superficiales, generalmente ocurridos en zonas volcánicamente activas.

La intensidad Local puede evaluarse esencialmente a partir de la descripción de los efectos secundarios ocurridos en diferentes “sitios” una localidad determinada. Este tipo de intensidad tiene que ser comparable con la determinada a partir de las escalas tradicionales basadas en daños. Hay que tener en cuenta que el concepto de "Localidad" puede tanto referirse a una zona habitada (pueblo, ciudad) como a un paraje natural sin asentamientos humanos. Cuando únicamente se encuentren disponibles efectos primarios, puede utilizarse para esta evaluación la expresión local de la ruptura de falla, en términos de máximo desplazamiento.

## *Definiciones de los grados de intensidad*

### I a III - EFECTOS NO PERCEPTIBLES EN EL AMBIENTE que puedan ser usados como diagnósticos

### IV - AMPLIAMENTE OBSERVADO: Primeros efectos inequívocos sobre el Ambiente

***Efectos primarios:*** ausentes.

***Efectos secundarios:***

a) En raras ocasiones suceden pequeñas variaciones locales del nivel de agua en pozos y/o en el caudal de manantiales y fuentes. En muy raras ocasiones ocurren pequeñas variaciones de las propiedades físicas - químicas del agua y de la turbidez del agua en los lagos, manantiales, fuentes y pozos, especialmente dentro de grandes acuíferos kársticos que son los más propensos a este fenómeno.

b) En cuencas cerradas (lagos e incluso mares) se pueden formar pequeños seiches centimétricos que comúnmente solo son detectados por los mareógrafos, aunque excepcionalmente pueden ser vistos. Característicos en el campo lejano de fuertes terremotos. Oleaje anómalo es percibido por todo el mundo en pequeñas embarcaciones, por algunas personas en barcos y por la mayoría en la costa. El gua de piscinas y enstanques se agita y algunas veces puede desbordarse.

c) Ocasionalmente, muy pocos casos de grietas muy finas (mm) en zonas donde la litología (ej. depósitos aluviales poco compactados, suelos saturados) y/o morfología (laderas escarpadas o cimas de colinas) son más propensos a este fenómeno.

d) Excepcionalmente pueden ocurrir caídas de rocas, y pequeños deslizamientos existentes pueden reactivarse. Fundamentalmente en laderas donde el equilibrio es ya muy inestable (ej. laderas o cuestas, escarpadas y cortadas, desarrolladas sobre suelos saturados o material coluvial poco compactado, así como en cortes y taludes artificiales de caminos, carreteras, ferrocarriles y canteras o areneros a cielo abierto).

e) Las ramas de los árboles pueden verse sacudidas.

### V - FUERTE: Efectos marginales sobre el Ambiente

*(Los efectos naturales afectan marginalmente al terreno y solo en ocasiones excepcionales dejan evidencia en el registro geológico -procesos de liquefacción-y en ningún caso afectan al registro geomorfológico permanente del paisaje afectado).*

***Efectos primarios*** ausentes.

***Efectos secundarios:***

a) En raras ocasiones ocurren variaciones apreciables en el nivel de agua en pozos y/o caudal en manantiales y fuentes, así como pequeñas variaciones en las propiedades físico-químicas y turbidez del agua de lagos, manantiales, fuentes y pozos.

b) En cuencas cerradas (lagos e incluso mares) se pueden formar pequeños seiches decimétricos que comúnmente pueden ser observados. Característicos en el campo lejano de fuertes terremotos. Oleaje anómalo de pocas decenas de centímetros es percibido por todo el mundo en todo tipo de embarcaciones y en la costa. Piscinas y estanques comúnmente se desbordan.

c) Localmente se desarrollan finas grietas de anchura milimétrica, y longitud decimétrica a métrica, en zonas donde la litología (ej. depósitos aluviales poco compactados, suelos saturados) y/o morfología (laderas o escarpes de colinas) son más propensos a este fenómeno.

d) En raras ocasiones ocurren caídas de rocas, deslizamientos rotacionales y flujos de tierras, a pequeña escala (muy locales), especialmente a lo largo de pendientes donde el equilibrio es inestable (ej. laderas o cuestas escarpadas sobre materiales sedimentarios poco compactados o suelos saturados, así como en cortes y taludes artificiales de caminos, carreteras, ferrocarriles y canteras o areneros a cielo abierto).Ocasionalmente se pueden generar pequeños deslizamientos submarinos que dan lugar a oleajes anómalos transitorios en zonas litorales.

e) Las ramas de los árboles y arbustos se sacuden ligeramente y en muy raros casos pueden caer ramas muertas o frutos.

f) Extremadamente raros casos de licuefacción (volcanes de arena) de pequeño tamaño (cm) en áreas propensas a este tipo de fenómeno (llanuras costeras y fondos aluviales recientes arenosos con nivel freático muy somero).

## VI - LIGERAMENTE DAÑINO: Efectos moderados sobre el Ambiente

*(Los efectos naturales pueden dejar alguna traza significativa en el terreno, pero por lo general con un grado de supervivencia en el paisaje muy corto, de semanas o pocos meses. El registro geológico de procesos de liquefacción y deslizamientos comienza a ser significativo).*

***Efectos primarios*** ausentes.

***Efectos secundarios:***

a) Registro común de variaciones significativas en el nivel de agua en pozos y/o caudal en manantiales y fuentes, así como pequeñas variaciones en las propiedades físico-químicas y turbidez del agua de lagos, manantiales, fuentes y pozos.

b) Oleaje anómalo de varias decenas de centímetros producen inundaciones limitadas en zonas de costa y ribera. Piscinas, estanques y pequeñas lagunas comúnmente se desbordan.

c) *Ocasionalmente se observan* **fracturas** *de anchura mili a centimétrica y longitud métrica en depósitos aluviales poco compactados y/o suelos saturados. Especialmente a lo largo de pendientes escarpadas y márgenes (orillas) de ríos, donde pueden alcanzar de 1 a 2 cm de anchura. Algunas agrietamientos milimétricos pueden desarrollarse en carreteras pavimentadas (asfaltos / empedrados).*

d) Ocasionalmente pueden ocurrir caídas de rocas y deslizamientos de hasta ca. 103 m3, especialmente donde el equilibrio es inestable y existen fuertes pendientes. (ej. Laderas o cuestas escarpadas sobre materiales sedimentarios poco compactados, suelos saturados, o rocas fracturadas / meteorizadas). Ocasionalmente pueden suceder eventos de deslizamientos submarinos o subacuáticos en zonas costeras y lagos generando oleaje anómalo que por lo general solo es detectado por registros instrumentales.

e) Las ramas de árboles y arbustos son sacudidas visiblemente. Algunas pocas ramas inestables y copas de árboles pueden romperse y caer, dependiendo de la especie y del estado de madurez de los frutos.

f) *En raras ocasiones pueden ocurrir casos de licuefacción (volcanes de arena), pequeños en tamaño (cm), en areas propensas a este tipo de fenómeno como llanuras costeras y fondos aluviales recientes con nivel freático muy somero.*

## VII - DAÑINO: Efectos apreciables sobre el Ambiente

*(Los efectos naturales pueden dejar trazas significativas en el terreno, pero por lo general con un grado de supervivencia en el registro geomorfológico muy corto, de meses o pocos años, muy excepcionalmente permanentes. El registro geológico de procesos de liquefacción, deslizamientos comienza a ser bastante significativo en áreas propicias)*

***Efectos primarios***: Muy raramente observados, casi exclusivamente en zonas volcánicas.

*Pueden generarse* ***rupturas superficiales de falla limitadas****, con longitud de decenas a centenares de metros y desplazamiento (offset) centimétrico, esencialmente asociadasa* **terremotos tectó-volcánicos** *muy superficiales.*

***Efectos secundarios:*** El área afectada es generalmente inferior o del orden de 10 km$^2$.

a) Localmente se registran variaciones significativas en el nivel de agua en pozos y/o caudal de manantiales y fuentes. Raramente, pequeños manantiales o fuentes pueden temporalmente secarse, y/o aparecer otros nuevos. Comúnmente se producen variaciones apreciables en las propiedades físico-químicas y turbidez del agua de lagos, manantiales, fuentes y pozos.

b) Olas anómalas, incluso de más de un metro de altura producen inundaciones limitadas en zonas de costa y ribera, dañando y arrastrando objetos de distintas dimensiones. Se producen desbordamientos en lagunas, estanques e incluso ríos. ESI-2007. Pág. 6

c) *Fracturas de hasta 5 - 10 centímetros de ancho y centenares de metros de longitud son comúnmente observadas endepósitos aluviales poco compactados y/o suelos saturados. Raramente también se observan fracturas de hasta 1 centímetro de ancho en materiales arenosos secos y suelos arcillosos. Son comunes las grietas centimétricas en caminos pavimentados (asfalto o empedrados).*

d) Comúnmente ocurren deslizamientos aislados y dispersos en áreas especialmente propensas donde el equilibrio es inestable (ej. laderas o cuestas de alta pendiente sobre materiales sedimentarios poco compactados, suelos saturados o rocas fracturadas /meteorizadas). Caída de rocas apreciable en desfiladeros y gargantas escarpadas o acantilados costeros. Su tamaño es a veces considerable (103 – 105 m3). En materiales arenosos secos, areno-arcillosos y suelos arcillosos los volúmenes son normalmente hasta 100 m3. Rupturas, derrumbes y caídas (rocas) pueden afectar las orillas de los ríos y terraplenes o taludes artificiales (ej. cortes de caminos, canteras, etc.) desarrollados en materiales sedimentarios poco compactados o rocas fracturadas/meteorizadas. Se pueden generar deslizamientos submarinos o subacuáticos significativos que provocan oleajes anómalos en zonas costeras de mares y lagos observados por la mayoría de las personas en embarcaciones y puertos.

e) *En zonas boscosas los árboles y arbustos son sacudidos vigorosamente. Muchas ramas y copas de árboles rompen y caen.*

f) *Raros casos de licuefacción (volcanes de arena) de hasta 50 cm de diámetro pueden desarrollarse en áreas propensas a este tipo de fenómeno como (llanuras costeras y fondos aluviales recientes con nivel freático muy somero.*

g) *En zonas secas o semiáridas, pueden levantarse nubes de polvo en el área epicentral.*

h) Piedras e incluso pequeños cantos y troncos de árboles pueden ser arrojados al aire dejando huellas de caída en suelos blandos.

## VIII - MUY DAÑINO: Efectos considerables sobre el Ambiente

*(Los efectos naturales dejan trazas significativas y en algunas ocasiones permanentes en el terreno. El registro geomorfológico comienza a ser algo significativo y el registro geológico de rupturas de falla –excepcionalmente- procesos de liquefacción y deslizamientos ya toma un cuerpo notable)***.**

***Efectos primarios***: *Raramente observados.*

*Las rupturas de falla pueden alcanzar hasta varios centenares de metros de longitud, con desplazamientos (offset) de pocos centímetros (< 5 cm), particularmente durante terremotos muy superficiales, como ocurre en eventos tectó-volcánicos. Subsidencia o elevación tectónica de la superficie del terreno puede presentar valores máximos de orden centimétrico.*

***Efectos secundarios:*** El área afectada es generalmente inferior o del orden de 100 $km^2$.

a) Los manantiales y fuentes pueden cambiar, generalmente de forma temporal, tanto su caudal y/o posición altimétrica (sobrepresión). Algunas manantiales y fuentes pequeñas pueden incluso secarse. Las variaciones en el nivel del agua en los pozos son comunes y significativas. Las propiedades físico-químicas y, más comúnmente la temperatura, cambia en manantiales y/o pozos. El agua de lagos, ríos y manantiales frecuentemente puede volverse turbia, incluso ligeramente fangosa. Localmente se pueden producir emisiones de gases normalmente sulfurosos.

b) Olas anómalas de entre 1-2 m de altura producen inundaciones en zonas de costa y ribera, dañando y arrastrando objetos de distintas dimensiones. Se producen desbordamientos violentos en lagunas, estanques y ríos. Erosión y acumulación de restos flotantes en las playas, donde los arbustos e incluso árboles débilmente enraizados pueden ser arrancados y arrastrados hacia el interior.

c) *Fracturas de hasta 50 centímetros de anchura y centenares de metros de longitud son comúnmente observadas en* depósitos aluviales poco compactados y/o suelos saturados*. En raros casos pueden desarrollarse fracturas de hasta 1 cm de anchura en rocas competentes o firmes. Son comunes grietas decimétricas y pequeñas ondulaciones de presión en caminos y zonas pavimentadas (asfalto o empedrados).*

d) Deslizamientos pequeños a moderados ($10^3$ – $10^5$ $m^3$) pueden ocurrir extensamente en áreas propensas. Raramente pueden también ocurrir en laderas de poca pendiente donde el equilibrio es inestable (ej. pendientes o laderas sobre materiales sedimentarios poco compactados, suelos saturados o rocas fracturadas / meteorizadas). Caída de rocas en desfiladeros escarpados y acantilados costeros. Su tamaño es a veces grande ($10^5$ - $10^6$ $m^3$). Algunos deslizamientos pueden ocasionalmente obturar valles estrechos causando lagos temporales e incluso permanentes. Rupturas, derrumbes y caídas (rocas) pueden afectar las márgenes (orillas) de los ríos, los terraplenes y taludes artificiales (p.ej. cortes de caminos, canteras, etc.) desarrollados en materiales sedimentarios poco compactados o rocas fracturadas/meteorizadas. Es común la generación de deslizamientos submarinos en zonas costeras. ESI-2007. Pág. 7

e) *Los árboles se sacuden fuertemente. Muchas ramas se rompen y caen. Más raramente, troncos en equilibrio pueden desenraizarse y caer, especialmente en laderas con fuerte pendiente.*

f) *Los Procesos de Licuefacción pueden ser frecuentes en el área epicentral, dependiendo de las condiciones locales. Los efectos más característicos son volcanes de arenas de hasta ca. 1 m de diámetro; chorros de agua (Water fountains) pueden ser visibles en aguas tranquilas de lagos someros (lagoones, salinas, zonas pantanosas); extensiones laterales y asentamientos locales (subsidencia hasta aprox. 30 cm) con agrietamientos paralelos a los cuerpos de agua (márgenes deríos, lagos, canales y líneas de costa).*

g) *En zonas secas o semiáridas, pueden levantarse nubes de polvo en el área epicentral.*

h) Piedras e incluso pequeños cantos y troncos de árboles pueden ser arrojados al aire dejando huellas de caída en suelos blandos.

## IX - DESTRUCTIVO: Los efectos en el ambiente son generalizados, constituyendo una fuente de peligrosidad considerable, y empiezan a ser importantes para la determinación de la intensidad.

*(Los efectos naturales dejan trazas considerables y permanentes en el terreno. El registro geomorfológico de este tipo de eventos comienza a ser un dato muy significativo, mientras que en el registro geológico, rupturas de falla, procesos de liquefacción, deslizamiento y excepcionalmente tsunamis es una pauta común)***.**

***Efectos primarios***: *Comúnmente observados.*

*Las rupturas de falla pueden alcanzar una longitud de unos pocos kilómetros, con desplazamientos (offset) de algunas decenas de centímetros (10 – 20 cm). Subsidencia o elevación tectónica de la superficie del terreno con valores máximos de orden decímetro.*

***Efectos secundarios:*** El área afectada es generalmente inferior o del orden de 1000 $km^2$.

a) *Los manantiales y fuentes pueden cambiar, generalmente de forma temporal, tanto su caudal y/o posición altimétrica (sobrepresión). Algunas manantiales y fuentes pueden incluso secarse. Las variaciones en el nivel del agua en los pozos son comunes y significativas. Las propiedades físico-químicas y, más comúnmente la temperatura, cambia en manantiales y/o pozos. El agua de lagos, ríos y manantiales frecuentemente puede volverse muy turbia, incluso ligeramente fangosa. Localmente se pueden producir emisiones de gases normalmente sulfurosos y, ocasionalmente tanto la hierba como los arbustos alrededor de estos puntos de emisión pueden arder.*

b) Se producen **Olas anómalas** de **varios metros** de altura en cuerpos de agua y cursos fluviales. En zonas de llanura de inundación los cauces de agua pueden incluso variar sus cursos, fundamentalmente ocasionado por procesos de subsidencia. Pueden aparecer y/o desaparecer pequeñas lagunas. Dependiendo de la topografía de la línea de costa y el fondo marino, pueden producirse **tsunamis peligrosos de algunos metros de runup** provocando la inundación de zonas extensas a lo largo del litoral. Erosión generalizada de las zonas de playa, donde los arbustos e incluso árboles pueden ser arrancados y arrastrados hacia el interior.

c) *Fracturas de hasta 100 centímetros de anchura y centenares de metros de longitud son comúnmente observadas en* depósitos aluviales poco compactados y/o suelos saturados*. En rocas competentes o firmes pueden desarrollarse fracturas de hasta 10 cm de anchura. En caminos y zonas pavimentadas (asfalto o empedrados) es común el desarrollo de grinta decimétricas significativas, así como pequeñas ondulaciones de presión.*

d) *Deslizamientos extensos y frecuentes en áreas propensas, incluso en laderas de poca pendiente en condiciones de equilibrio inestable* (ej. pendientes o laderas escarpadas sobre materiales sedimentarios poco compactados, suelos saturados o rocas fracturadas / meteorizadas). Caída de rocas en desfiladeros escarpados y acantilados costeros. Su tamaño es frecuentemente grande (**$10^5$ $m^3$**) y *a veces muy grande* (**$10^6 m^3$**). Algunos deslizamientos pueden ocasionalmente obturar valles estrechos, causando lagos temporales e incluso permanentes. Las orillas de los ríos, así como terraplenes y taludes artificiales (ej. cortes de caminos, canteras, etc.) frecuentemente colapsan. Son frecuentes grandes deslizamientos submarinos o subacuáticos en zonas costeras y lagos.

e) Los árboles se sacuden vigorosamente. Las ramas y troncos de árboles de pequeño diámetro, frecuentemente se rompen y caen. Algunos árboles situados en laderas de fuerte pendiente pueden ser desenraizados y colapsar.

f) *Los Procesos de Licuefacción y eyección de agua son frecuente. Los efectos más típicos son: Volcanes de arena de hasta 3 m de diámetro; chorros de agua (Water fountains) pueden ser visibles en aguas tranquilas de lagos someros (lagoones, salinas, zonas pantanosas); extensiones laterales y asentamientos locales (subsidencia hasta ca. 30 cm), con agrietamientos paralelos a los cuerpos de agua (márgenes de ríos, lagos, canales y líneas de costa).*

g) En zonas secas o semiáridas, pueden levantarse nubes de polvo en el área epicentral.

h) *Pequeños cantos y troncos de árboles pueden ser arrojados al aire desplazándose varios metros (dependiendo de la pendiente del terreno) dejando huellas de caída en suelos blandos.*

## X - MUY DESTRUCTIVO: Los Efectos Ambientales se convierten en una de las fuentes de peligrosidad dominantes y son esenciales para la evaluación de la intensidad.

*(Los efectos Ambientales son dominantessobre otro tipo de criterios en la evaluación de los daños, son relevantes en el registro geomorfológico y fundamentales en el geológico, incluyendo el registro de tsunamis).*

***Efectos primarios***: *Comienzan a ser importantes.*

*Las rupturas de falla se convierten en un fenómeno característico. Pueden alcanzar una longitud de decenas de kilómetros, con desplazamientos (offset) decimétricos hasta unos pocos metros (ca. 1 - 2 m). Desarrollo de micrograbens y depresiones tectónicas alargadas en terremotos con hipocentros muy superficiales. En el caso de eventos tectó-volcánicos la longitud de lasrupturas puede ser muy inferior. Puede ocurrir subsidencia o elevación tectónica del terreno con valores máximos de unos pocos metros.*

***Efectos secundarios:*** *El área afectada es generalmente inferior o del orden de 5000 km$^2$.*

a) Los manantiales y fuentes cambian significativamente tanto su caudal como su posición altimétrica (sobrepresión). Algunas manantiales y fuentes pueden secarse incluso permanentemente. Las variaciones en el nivel del agua en los pozos son comunes y significativas. Las propiedades físico-químicas de manantiales y/o pozos y, más comúnmente la temperatura en fuentes termales, sufren fuertes variaciones. El agua de manantiales, ríos e incluso grandes lagos a menudo se vuelve muy fangosa. Las emisiones de gases, normalmente sulfurosos, son comúnmente observadas. La hierba y los arbustos en el entorno de estos puntos de emisión pueden arder.

b) *Se producen **Olas anómalas** de **varios metros** de altura incluso en grandes lagos y ríos. En zonas de llanura de inundación los cauces de agua pueden sufrir significativos cambios de curso temporales e incluso permanentes, debido a la generalización de procesos de subsidencia. Pueden aparecer y/o desaparecer lagunas de entidad. Dependiendo de la topografía de la línea de costa y el fondo marino, pueden producirse **tsunamis de hasta 5 m de runup** provocando la inundación generalizada de zonas costeras bajas de hasta miles de metros de penetración tierra adentro. Pequeños bloques pueden ser arrastrados hacia el interior. Erosión significativa generalizada de las zonas costeras bajas que producen significativos cambios la geometría de la línea de costa. La mayoría de la vegetación litoral (arbustos y árboles) es mayoritariamente arrasada y arrastrada hacia el interior.*

c) *Son frecuentes grandes grietas en el terreno con aberturas de hasta más de 1 m de anchura, principalmente en depósitos aluviales poco compactados y/o suelos saturados. En rocas competentes pueden alcanzar varios decímetros de anchura. Se desarrollan grietas anchas en caminos pavimentados (asfalto o empedrados), acompañadas por significativas ondulaciones de presión. En suelos enlosados y bordillos de aceras pueden desarrollarse estructuras de tipo pop-up de altura centimétrica y de extensión métrica a decamétrica.*

d) *Grandes deslizamientos y caídas de rocas (> $10^5$ - $10^6$ m$^3$) son frecuentes, prácticamente con independencia del estado del equilibrio y pendiente de las laderas, causando lagos de obturación temporales o permanentes. Las márgenes de los ríos, terraplenes, taludes y excavaciones artificiales típicamente colapsan. Levees, terraplenes y represas de tierra pueden incluso sufrir serios daños*

e) *Los árboles se sacuden fuertemente. Muchas ramas y troncos de árboles se rompen y caen. Algunos árboles pueden ser desenraizados y colapsar incluso en laderas de poca pendiente.*

f) *Los Procesos de Licuefacción, eyección de agua y compactación del suelo pueden cambiar el aspecto de extensas zonas, aplanando la topografía de llanuras costeras y llanuras de inundación fluviales y aluviales; volcanes de arenas de hasta aproximadamente 6 m de diámetro. Los procesos de subsidencia > 1m produciendo grandes y largas grietas debido a extensiones laterales son comunes a lo largo de márgenes de ríos, lagos, y canales. Grandes deslizamientos submarinos o subacuáticos son frecuentes en zonas costeras y lagos.*

g) En zonas secas o semiáridas, pueden levantarse nubes de polvo en el área epicentral.

h) *Cantos y bloques (de hasta 2-3 metros de diámetro) pueden ser arrojados al aire desplazándose centenares de metros incluso en zonas de suave pendiente, dejando trazas y huellas de caída en suelos blandos.*

## XI - DEVASTADOR: Los Efectos Ambientales se hacen totalmente esenciales para evaluar la intensidad debido a la saturación de los daños estructurales en edificaciones

*(Los efectos Ambientales llegan a ser esenciales para evaluaciones de Intensidad dada la casi total saturación de otro tipo de criterios para estimar los niveles de daños)*

***Efectos primarios***: *Dominantes.*

*Las* ***rupturas de falla primarias*** *pueden extenderse desde varias decenas de kilómetros hasta unos 100 km, acompañadas por desplazamientos de varios metros (> 2m). Es patente el desarrollo de fosas tectónicas, depresiones alargadas y lomas de presión. Las líneas de drenaje pueden desplazarse ostensiblemente.Puede ocurrir subsidencia o elevación tectónica del terreno con valores de muchos metros.*

***Efectos secundarios:*** *El área afectada es generalmente inferior o del orden de 10.000 km2.*

a) Los manantiales y fuentes cambian significativamente tanto su caudal como su posición altimétrica (sobrepresión). Algun manantiales y fuentes pueden secarse incluso permanentemente. Las variaciones en el nivel del agua en los pozos son comunes y significativas. Las propiedades físico-químicas de manantiales y/o pozos y, más comúnmente la temperatura en fuentes termales, sufren fuertes variaciones. El agua de manantiales, ríos e incluso grandes lagos a menudo se vuelve muy fangosa. Las emisiones de gases, normalmente sulfurosos, son comúnmente observadas. La hierba y los arbustos en el entorno de estos puntos de emisión pueden arder.

b) *Se producen* ***Olas anómalas*** *de* ***varios metros*** *de altura incluso en grandes lagos y ríos. En zonas de llanura de inundació los cauces de agua pueden sufrir significativos cambios de curso temporales e incluso permanentes, debido a la generalización de procesos de subsidencia y desplomes de los márgenes. Pueden aparecer y/o desaparecer lagunas de entidad. Dependiendo de la topografía de la línea de costa y el fondo marino, pueden producirse* ***tsunamis de hasta 15 m de runup*** *provocando la inundación y devastación de vastas zonas costeras bajas con penetraciones kilométricas tierra adentro. Incluso bloques de diámetro métrico pueden ser arrastrados hacia el interior a lo largo de grandes distancias. Erosión importante generalizada de las zonas costeras bajas que producen cambios muy notorios en la geometría de la línea de costa. La vegetación litoral (arbustos y árboles) es arrasada y arrastrada hacia el interior.*

c) Son muy frecuentes grandes grietas en el terreno con aberturas de varios metros de anchura, principalmente en depósitos aluviales poco compactados y/o suelos saturados. En rocas competentes pueden alcanzar hasta 1 m de anchura. Grietas muy anchas se desarrollan en caminos pavimentados (asfalto o empedrados), acompañadas por grandes ondulaciones de presión. En suelos enlosados y bordillos de aceras pueden desarrollarse estructuras de tipo pop-up de altura centimétrica y de extensión métrica a decamétrica.

d) Grandes deslizamientos y caídas de rocas (> 105 - 106 m3) son frecuentes, independientemente del estado de equilibrio y pendiente de las laderas, causando lagos de obturación temporales o permanentes. Las márgenes (orillas) de los ríos, terraplenes, taludes y excavaciones artificiales típicamente colapsan. Terraplenes y represas de tierra pueden incluso incurrir en serios daños. Deslizamientos considerables pueden tener lugar hasta 200-300 kilómetros de distancia epicentral. Grandes deslizamientos submarinos o subacuáticos son frecuentes en zonas costeras y lagos.

e) *Los árboles se sacuden violentamente. Muchas ramas se rompen y caen. Incluso árboles enteros pueden desenraizarse del terreno y caer peligrosamente.*

f) Los Procesos de Licuefacción cambian el aspecto de extensas zonas, aplanando la topografía de llanuras costeras y llanuras de inundación fluviales y aluviales, acompañadas por procesos de subsidencia generalizados que pueden exceder varios metros. Los volcanes de arena de gran tamaño son numerosos; grandes y largas grietas debido a extensiones laterales afectan severamente a las márgenes de ríos, lagos y canales.

g) En áreas secas, se levantan grandes nubes de polvo.

h) *Grandes bloques, incluso de varios metros de diámetro pueden ser arrojados al aire desplazándose cientos de metros, incluso en laderas de poca pendiente, dejando impresiones o huellas características en suelos blandos o poco consolidados.*

## XII - COMPLETAMENTE DEVASTADOR: Efectos Ambientales son el único criterio para determinar la intensidad

*(Los efectos Ambientales son ahora la única herramienta disponible para evaluar la intensidad, los demás criterios para estimar el nivel de daños se encuentran saturados por el colapso generalizado de todo tipo de construcciones)*

***Efectos primarios***: *Dominantes.*

*Las rupturas de falla se extienden como mínimo varios centenares de kilómetro, acompañadas por desplazamientos de hasta decenas demetros. Es patente el desarrollo de grandes fosas tectónicas, depresiones alargadas y lomas de presión. Las líneas de drenaje pueden desplazarse ostensiblemente. Los cambios en el paisaje y en la geomorfología inducidos por estas rupturas primarias pueden alcanzar tamaños y extensiones extraordinarios (ejemplos típicos son la elevación y/o subsidencia de líneas costa de hasta varios metros, la aparición o desaparición de la vista de elementos paisajísticos significativos, los ríos cambian de curso, formación de cascadas, y formación o desaparición de lagos).*

***Efectos secundarios:*** *El área afectada es generalmente inferior o del orden de 50.000 km2.*

a) Los manantiales y fuentes cambian significativamente tanto su caudal como su posición altimétrica (sobrepresión). Algunas manantiales y fuentes pueden secarse incluso permanentemente. Las variaciones en el nivel del agua en los pozos son comunes y significativas. Las propiedades físico-químicas de manantiales y/o pozos y, más comúnmente la temperatura en fuentes termales, sufren fuertes variaciones. El agua de manantiales, ríos e incluso grandes lagos a menudo se vuelve muy fangosa. Las emisiones de gases, normalmente sulfurosos, son comúnmente observadas. La hierba y los arbustos en el entorno de estos puntos de emisión pueden arder.

b) *Desarrollo de* ***Olas gigantes en*** *lagos y ríos que causan importantes inundaciones en las zonas de ribera. En zonas de llanura de inundación los cauces de agua pueden sufrir significativos cambios de curso permanentes, e incluso invertirse el sentido de la corriente, debido a la generalización de procesos de subsidencia y desplomes de los márgenes. Pueden aparecer y/o desaparecer lagos de extensión significativa. Dependiendo de la topografía de la línea de costa y el fondo marino, pueden producirse* ***tsunamis de varias decenas de metros de runup*** *provocando la inundación y devastación de vastas zonas costeras bajas con penetraciones de varios kilómetros tierra adentro. Grandes bloques pueden ser arrastrados hacia el interior a lo largo de grandes distancias. Erosión devastadora y generalizada de las zonas costeras bajas que producen cambios muy notorios en la geometría de la línea de costa. La vegetación litoral (arbustos y árboles) es arrasada y arrastrada hacia el interior.*

c) Grandes grietas en el terreno con aberturas de varios metros de anchura son muy frecuentes, de hasta más de 1 metro en el sustrato rocoso competente, y de hasta más de 10 metros en depósitos aluviales poco compactados y/o suelos saturados, donde pueden extenderse a lo largo de varios kilómetros de longitud. En suelos enlosados y bordillos de aceras pueden desarrollarse estructuras de tipo pop-up de altura centimétrica y de extensión métrica a decamétrica.

d) Grandes deslizamientos y caídas de rocas (> 105 - 106 m3) son frecuentes, independientemente del estado de equilibrio y pendiente de las laderas, causando muchos lagos de obturación temporales o permanentes. Las márgenes (orillas) de los ríos, terraplenes, taludes y excavaciones artificiales típicamente colapsan. Terraplenes y represas de tierra pueden incluso incurrir en serios daños. Deslizamientos considerables pueden tener lugar en hasta 200-300 kilómetros de distancia epicentral. Grandes deslizamientos submarinos o subacuáticos son frecuentes en zonas costeras y lagos.

e) Los árboles se sacuden violentamente. Muchas ramas se rompen y caen. Incluso árboles enteros pueden desenraizarse del terreno y caer peligrosamente.

f) Los Procesos de Licuefacción cambian el aspecto de extensas zonas, aplanando la topografía de llanuras costeras y llanuras de inundación fluviales y aluviales, acompañadas por procesos de subsidencia generalizados que pueden exceder varios metros. Los volcanes de arena de gran tamaño son muy numerosos; grandes y largas grietas debido a extensiones laterales afectan severamente a las márgenes de ríos, lagos y canales.

g) En áreas secas, se levantan grandes nubes de polvo.

h) *Bloques de grandes dimensiones pueden ser arrojados al aire desplazándose cientos de metros, incluso en laderas de poca pendiente, dejando impresiones o huellas características en suelos blandos o poco consolidados.*

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 43 - 52
tab. 1

# 2.4. - L'échelle d'Intensité Sismique Environmentale - ESI 2007 (French)

TRANSLATED: BAIZE S. (1)

## *Introduction*

L'intensité du tremblement de terre est estimée à partir des effets causés par le séisme sur l'homme, sur les structures (bâtiments et infrastructures) et sur l'environnement naturel (effets environnementaux ou géologiques). Cette intensité est une mesure de la gravité du tremblement de terre, intégrant les effets sur toute la gamme des fréquences du mouvement vibratoire ainsi que les déformations statiques.

Plusieurs échelles d'intensité (par exemple Rossi - Forel, Mercalli, MCS, MSK, Mercalli Modifiée) considèrent les effets sur l'environnement naturel comme des éléments de diagnostic pour l'évaluation du degré d'intensité.

En revanche, certaines échelles plus modernes (par exemple ESPINOSA *et alii*, 1976a; 1976b; GRÜNTHAL, 1998) ne considèrent que les effets sur l'homme et sur les structures artificielles et anthropiques, et réduisent fortement la pertinence du diagnostic des effets environnementaux, sur la base de l'hypothèse que ces effets sont trop variables et aléatoires. Néanmoins, des études récentes (par exemple DENGLER & MCPHERSON, 1993; SERVA, 1994; DOWRICK, 1996; ESPOSITO *et alii*, 1997; HANCOX *et alii*, 2002 ; MICHETTI *et alii*, 2004) ont clairement fourni la preuve que les effets géologiques des tremblements de terre, qui sont aujourd'hui largement accessibles à partir de sources historiques et de la paléosismologie, sont une information essentielle pour l'évaluation de la « taille » des séismes, et en particulier de l'intensité.

Dans le but de formaliser ces constats, l'échelle ESI 2007 a été construite uniquement à partir des effets sur l'environnement (MICHETTI *et alii*, 2007). Son utilisation, seule ou combinée à d'autres échelles traditionnelles, donne une meilleure image du scénario du tremblement de terre, car seuls les effets environnementaux permettent une comparaison appropriée de l'intensité, à la fois:

- Dans le temps: les effets sur l'environnement naturel sont comparables sur une fenêtre de temps beaucoup plus grande (couvrant les événements sismiques récents, historiques et préhistoriques) que la période d'enregistrement instrumental (siècle dernier);
- Dans des zones géographiques différentes: les effets environnementaux ne dépendent pas des conditions socio- économiques ou de différentes pratiques de construction.

(1) Institut de Radioprotection et de Sûreté Nucléaire, BP 17, 92262 Fontenay-aux-Roses, France

Ainsi, la nouvelle échelle vise à compléter les échelles macrosismiques traditionnelles:

• Pour les degrés d'intensité supérieurs ou égal à X, lorsque les évaluations sur la base des dommages aux structures anthropiques sont extrêmement difficiles, les effets sur l'environnement sont encore pertinents pour établir un diagnostic;

• Dans les zones peu peuplées, où les effets sur les structures artificielles font défaut, l'évaluation de l'intensité doit être fondée sur les effets environnementaux qui sont les seuls éléments de diagnostic disponibles.

La définition des degrés d'intensité est le résultat d'un inventaire effectué par un Groupe de Travail International formé de géologues, de sismologues et d'ingénieurs qui se sont penchés sur les effets causés par un grand nombre de séismes à travers le monde. L'échelle ESI 2007 a été ratifiée par l'INQUA (Union Internationale pour l'étude du Quaternaire) en 2007, lors du XVII$^{ème}$ Congrès INQUA à Cairns, en Australie.

## *Description*

L'échelle d'intensité ESI 2007 est structurée en douze degrés. L'intitulé de chaque degré reflète la sévérité du tremblement de terre et de ses effets sur l'environnement. Dans la description qui suit, les caractéristiques et la dimension des effets primaires associés à chaque degré sont tout d'abord présentés. Ensuite, les effets secondaires sont décrits en termes de surface totale de distribution pour l'évaluation de l'intensité épicentrale. Ces effets sont regroupés en plusieurs catégories et sont classés par ordre d'apparition.

Le texte en *italique* a été utilisé pour mettre en évidence les descriptions considérées comme diagnostiques d'un degré donné.

Les ***effets primaires*** sont directement liés à l'énergie du tremblement de terre et notamment à l'expression en surface de la source sismogénique. La taille des effets primaires est généralement exprimée par deux paramètres : i) La longueur totale de la rupture de faille en surface et ii) le déplacement maximal. Leur occurrence est le plus souvent associée à une valeur d'intensité minimum de VIII, sauf en cas de séismes très peu profonds dans les zones volcaniques. L'ampleur de la déformation tectonique en surface par soulèvement ou subsidence est également prise en compte.

Les ***effets secondaires*** sont les phénomènes induits par la secousse et sont classés en huit catégories principales.

a) Les ***anomalies hydrologiques*** : Dans cette catégorie, sont présentés les changements de débit des sources et des rivières, ainsi que les changements des propriétés physico-chimiques des eaux de surface et des eaux souterraines (par exemple température, turbidité). Ces effets sont diagnostiques des degrés d'intensité IV à X.

b) Les ***vagues anormales et tsunamis*** : Dans cette catégorie, sont inclus les seiches dans les bassins fermés, les débordements de l'eau des piscines et des bassins, et les vagues de tsunami. Dans le cas des tsunamis, plus que la taille de la vague elle-même, ce sont les effets sur les rives (surtout run-up, érosion des plages, changement de la morphologie du littoral) qui sont considérés comme diagnostiques de l'intensité subie, sans pour autant négliger celles sur les populations et les structures artificielles. Des effets peuvent se produire dès l'intensité IV, mais sont plus diagnostiques des degrés de IX à XII.

c) Les ***fissures et fractures*** dans les sols : Elles sont décrites par leur longueur (de quelques centimètres à quelques centaines de mètres), leur largeur (du millimètre au mètre), leur densité en surface. Les fissures apparaissent dès l'intensité IV et elles saturent (leur taille n'augmente plus) à partir de l'intensité X.

d) Les ***mouvements de pente*** : Cette catégorie inclut toutes les typologies de glissements de terrain, y compris les chutes de pierres, les glissements et les coulées de boue. A contexte lithologique et morphologique (relief) similaire, les paramètres de diagnostic sont le volume et la superficie totale. Ils se présentent dès l'intensité IV et saturent (leur taille n'augmente plus) à partir de l'intensité X.

e) Le ***tremblement des arbres***: Ces effets sont diagnostiques du degré IV au degré X. La définition des degrés d'intensité suit essentiellement celle fournie par Dengler et McPherson (1993).

f) Les ***liquéfactions***: Dans cette catégorie, sont inclus les volcans de sable, les fontaines de sable et d'eau, certains types d'étalements latéraux, le compactage du sol et la subsidence. Leur taille est diagnostique pour les degrés d'intensité de V à X.

g) Les ***nuages de poussière*** : On peut les observer dans les zones arides et désertiques, à partir du degré d'intensité VIII.

h) Les ***sauts de pierres*** : La taille maximale des pierres en question est diagnostique pour l'évaluation de l'intensité. Ces effets peuvent être observés entre les degrés d'intensité IX et XII. Ces phénomènes montrent que l'accélération du sol est supérieure à la gravitation, ce qui peut se produire localement à partir de l'intensité IX.

Les effets sur l'environnement peuvent être observés et caractérisés à partir de l'intensité IV. Certains types d'effets (ex. anomalies hydrologiques) peuvent cependant être observés à des degrés inférieurs, mais ils ne peuvent alors pas être considérés comme des éléments diagnostiques. La précision de l'évaluation est améliorée vers les hauts degrés de l'échelle, en particulier dans la gamme où surviennent les effets primaires à partir de l'intensité VIII jusqu'à l'intensité XII. A partir de l'intensité X, les effets sur l'homme et les structures artificielles saturent (i.e. les bâtiments sont souvent déjà complètement détruits) et il n'est donc pas possible de faire la distinction entre les différents degrés d'intensité. Dans cette gamme, les effets environnementaux sont dominants et ils constituent donc l'outil le plus puissant pour l'évaluation de l'intensité.

## *Comment utiliser l'échelle d'intensité ESI 2007 ?*

Il est recommandé d'utiliser l'échelle d'intensité ESI comme un outil indépendant lorsque seuls les effets sur l'environnement sont diagnostiques, notamment lorsque les effets sur l'homme et les structures artificielles sont trop rares ou saturent. Lorsque ceux-ci sont également disponibles, il est possible d'estimer l'intensité selon les deux approches indépendantes. En général, l'intensité finale retenue sera la valeur la plus élevée des deux. Évidemment, dans ce cas, un jugement d'expert sera essentiel.

L'intensité épicentrale ($I_0$) est la valeur d'intensité de la secousse à l'épicentre. Les paramètres de la rupture de faille en surface et l'extension totale des effets secondaires (glissements de terrain et/ou liquéfactions) sont des outils indépendants pour évaluer $I_0$ sur la base des effets sur l'environnement, à partir de l'intensité VII (tab. 2.1).

Une attention particulière doit être portée lorsque les paramètres de la faille de surface sont à la frontière entre deux degrés différents. Dans ce cas, il doit être choisi la valeur d'intensité la plus cohérente avec les caractéristiques et la distribution spatiale des effets secondaires. En outre, dans l'évaluation de la surface totale des effets, il est recommandé de ne pas inclure les effets isolés qui ont pu avoir lieu en champ lointain. Cette évaluation requiert également un avis d'expert.

Tab. 2.1 - *Gamme de valeur des paramètres de failles de surface (effets primaires) et extension superficielle typique des effets secondaires pour chaque degré d'intensité.*

| $I_0$ | EFFETS PRIMAIRES | | EFFETS SECONDAIRES |
|---|---|---|---|
| | LONGUEUR DE RUPTURE DE SURFACE | DÉPLACEMENT MAXIMAL DE SURFACE / DÉFORMATION | AIRE TOTALE |
| **IV** | - | - | - |
| **V** | - | - | - |
| **VI** | - | - | - |
| **VII** | (*) | (*) | 10 $km^2$ |
| **VIII** | Plusieurs centaines de mètres | Centimétrique | 100 $km^2$ |
| **IX** | 1- 10 km | 5 - 40 cm | 1000 $km^2$ |
| **X** | 10 - 60 km | 40 - 300 cm | 5000 $km^2$ |
| **XI** | 60 – 150 km | 300 –700 cm | 10000 $km^2$ |
| **XII** | > 150 km | > 700 cm | > 50000 $km^2$ |

(*) Ruptures de failles limitées en extension à la surface, de quelques dizaines à centaines de mètres de long, avec des déplacements de surface centimétriques essentiellement associés aux séismes superficiels des zones volcaniques.

L'intensité locale est essentiellement évaluée par la description des effets secondaires survenus en différents «sites» inclus dans une localité spécifique. Ce type d'intensité doit être comparable à l'intensité localement estimée à partir des dommages. Il faut noter que le terme "localité" peut se référer à une zone habitée (un village, une ville), mais aussi à un espace naturel sans installation anthropique. Lorsque les effets primaires sont présents seuls, il est également possible d'utiliser la dimension locale des ruptures de faille de surface, en termes de déplacement maximal.

## *Définition des degrés d'intensité*

**Degrés I à III –** Il n'y a pas d'effets environnementaux qui puissent être considérés comme diagnostiques.

### Degré IV – Largement observé / Les premiers effets sur l'environnement sont sans equivoque

<u>Les effets primaires</u> sont absents.

<u>Les effets secondaires</u>

a) De rares petites variations du niveau d'eau dans les puits et/ou de débit des sources sont enregistrées localement, ainsi que de très rares petites variations des propriétés physico-chimiques de l'eau et de la turbidité dans les sources et les puits, en particulier dans les grands systèmes de sources karstiques, qui semblent être les plus sensibles à ce phénomène.

b) Dans les bassins fermés (lacs, mers), des seiches d'une hauteur inférieure à quelques centimètres peuvent se développer, couramment observées par les marégraphes, exceptionnellement à l'œil nu, et généralement à grande distance des forts séismes. Des vagues anormales sont perçues par toutes les personnes sur de petits bateaux, une minorité de gens sur de plus grands bateaux, ou par la plupart des gens sur la côte. Les eaux des piscines oscillent et peuvent parfois déborder.

c) Des fissures étroites (largeur millimétrique) peuvent être observées où la lithologie (par exemple les dépôts alluviaux meubles, les sols saturés) et/ou la morphologie (pentes ou des crêtes) sont les plus favorables à ce phénomène.

d) Exceptionnellement, des chutes de pierre, petits glissements de terrain peuvent être réactivés, le long des pentes fortes où l'équilibre est déjà près de l'état limite, par exemple sur des pentes fortes avec des sols meubles et généralement saturés.

e) Les branches des arbres sont faiblement secouées.

## Degré V – Fort / Les effets sur l'environnement sont marginaux

Les effets primaires sont absents.

Les effets secondaires

a) Les rares variations du niveau d'eau dans les puits et/ou de débit des sources sont enregistrées localement, ainsi que de petites variations des propriétés physico-chimiques de l'eau et de la turbidité dans les lacs, les sources et les puits.

b) Dans les bassins fermés (lacs, mers), des seiches de hauteur décimétrique peuvent se développer, parfois même observées à l'œil nu, généralement loin de forts séismes. Les vagues anormales, atteignant jusqu'à plusieurs dizaines de cm de hauteur, sont perçues par toutes les personnes sur les bateaux et sur la côte. L'eau dans les piscines déborde.

c) D'étroites fissures (de quelques millimètres à centimètres de large et jusqu'à un mètre de long) sont localement observées où la lithologie (par exemple, les dépôts alluviaux meubles, les sols saturés) et/ou la morphologie (pentes ou crêtes) sont les plus favorables.

d) De rares petites chutes de pierres, des glissements de terrain rotationnels et des coulées de boue peuvent avoir lieu, le long de pentes raides (mais pas seulement) où l'équilibre est proche de l'état limite, essentiellement au sein de dépôts meubles et sols saturés. Des glissements de terrain sous-aquatiques peuvent être déclenchés, ce qui peut induire de petites vagues anormales dans les zones côtières de mer et de lacs.

e) Les branches des arbres et de buissons sont légèrement secouées ; de très rares cas de branches mortes et de fruits mûrs tombés.

f) Les cas rapportés de liquéfaction sont extrêmement rares (volcans de sable), quoiqu'il en soit de petites tailles et dans les zones les favorables (dépôts alluviaux et côtiers récents, très sensibles à ce phénomène, proches de la nappe phréatique).

## Degré VI – Légèrement dommageable / Les effets sur l'environnement sont modestes

Les effets primaires sont absents.

Les effets secondaires:

a) Des variations importantes du niveau de l'eau dans les puits et/ou de débit de sources sont enregistrées localement, ainsi que de petites variations des propriétés physico-chimiques de l'eau et de la turbidité dans les lacs, sources et puits.

b) Des vagues anormales de hauteur allant jusqu'à plusieurs dizaines de cm inondent des zones littorales très limitées. L'eau des piscines, des petits étangs et des bassins débordent.

c) *A l'occasion, des fractures de largeur millimétrique à centimétrique et de longueur pluri-métrique sont observées dans les dépôts alluviaux meubles et/ou les sols saturés ; le long des pentes raides ou des berges, ces fractures peuvent être larges de 1-2 cm. Quelques petites fissures se développent sur les routes pavées (qu'elles soient d'asphalte ou de pierre).*

d) Des chutes de pierres et glissements de terrain dont les volumes atteignent environ $10^3$ $m^3$ peuvent avoir lieu, en particulier lorsque l'équilibre est proche de l'état limite, par exemple sur des pentes ou des incisions raides avec un sol saturé meuble, ou aux dépens de roches fortement altérées/fracturées. Des glissements de terrain sous-aquatiques peuvent être déclenchés, provoquant de petites vagues anormales dans les zones côtières des mers et des lacs, fréquemment observées par les enregistrements instrumentaux.

e) *Les arbres et les buissons sont modérément à fortement secoués ; un faible nombre de cimes d'arbres et de branches instables mortes peuvent se briser et tomber, dépendant des espèces, de la quantité de fruits et de l'état de santé de l'arbre.*

f) *De rares cas de liquéfaction sont rapportés (volcans de sable), de petites tailles et dans les zones les plus favorables (dépôts alluviaux et côtiers récents, très sensibles à ce phénomène, à proximité de la nappe phréatique).*

## Degré VII – Dommageable / Effets sensibles sur l’environnement

Des effets primaires sont très rarement observés, presque exclusivement dans les régions volcaniques. Des ruptures de surface limitées à quelques dizaines à centaines de mètres de long, avec des rejets centimétriques, peuvent se produire, surtout associées à des séismes très superficiels.

Effets secondaires : La surface totale de l’aire affectée est de l’ordre de la dizaine de 10 $km^2$.

a) D’importantes variations temporaires du niveau d’eau dans les puits et/ou du débit des sources sont localement enregistrées. Plus rarement, de petites sources peuvent temporairement s’assécher ou apparaître. De faibles variations des propriétés physico-chimiques de l’eau et de la turbidité dans les lacs, puits ou sources sont localement observées.

b) Des vagues anomaliques parfois plus haute que le mètre peuvent inonder des zones côtières limitées et endommager ou déplacer des objets de tailles variables. L’eau déborde des petits bassins et des cours d’eau.

c) *Des fractures jusqu’à 5-10 cm de large et jusqu’à une centaine de mètres de long sont observées, généralement dans des dépôts alluviaux meubles et/ou des sols saturés ; plus rarement, les fractures se développent dans des sols sableux secs, des sols argilo-sableux ou argileux, jusqu’à 1 cm de large. Des fissures de largeur centimétrique sont communes sur les routes pavées (qu’elles soient en pierre ou en asphalte).*

d) Des glissements de terrain épars ont lieu dans les zones sujettes à ce phénomène, là où l’équilibre est instable (pentes raides dans des sols meubles/saturés), tandis que de modestes chutes de pierre sont communes dans les gorges et le long des falaises. Leur taille peut être importante ($10^3$ - $10^5$ $m^3$), jusqu’à 100 $m^3$ usuellement dans les sols secs sableux, sablo-argileux ou argileux. Des fractures, glissements et écroulements peuvent affecter les berges de rivière, les digues et excavations artificielles (e.g. bords de routes, carrières) dans les sédiments meubles ou les roches altérées/fracturées. D’importants glissements sous-aquatiques peuvent être déclenchés, provoquant des vagues anomaliques dans les zones côtières des mers ou lacs, directement senties par les personnes sur les bateaux ou dans les ports.

e) Les arbres et buissons sont secoués vigoureusement, particulièrement dans les forêts denses, et de nombreuses branches et cimes d’arbres rompent et tombent.

f) *De rares cas de liquéfaction sont rapportés, avec des volcans de sable jusqu’à 50 cm de diamètre, dans les zones les plus sujettes à ce phénomène (dépôts hautement susceptibles, d’origine alluviale ou côtière, d’âge récent et proches de la nappe phréatique).*

## Degré VIII – Fortement dommageable / Vastes effets sur l’environnement

Des effets primaires sont rarement observés.

*Des ruptures de failles en surface peuvent se développer, jusqu’à plusieurs centaines de mètres de longueur, avec des rejets ne dépassant pas quelques centimètres, particulièrement pour les séismes à foyers très superficiels comme ceux communs dans les régions volcaniques. Une subsidence ou un soulèvement tectonique de la surface du sol peut se produire, avec des valeurs maximales de l’ordre de quelques centimètres.*

Effets secondaires : La surface totale affectée est de l’ordre de 100 $km^2$.

a) Les sources peuvent changer, généralement temporairement, de débit et/ou d’altitude d’affleurement. Quelques petites sources peuvent même s’assécher. Des variations du niveau d’eau sont observées dans les puits. De faibles variations des propriétés physico-chimiques des eaux, le plus souvent la température, peuvent être observées dans les sources et/ou les puits. La turbidité de l’eau peut apparaître dans les bassins clos, les rivières, les puits ou les sources. Des émissions de gaz, souvent sulfureux, sont localement observées.

b) Des vagues anomaliques jusqu’à 1-2 mètres de hauteur inondent les zones côtières et peuvent endommager ou déplacer des objets de taille variable. L’érosion et le dépôt de déchets sont observés le long des plages, où des buissons ou même des arbres faiblement enracinés peuvent être arrachés et emportés à la dérive. L’eau déborde violemment des petits bassins et des cours d’eau.

c) *Des fractures jusqu’à 50 cm de large et plusieurs centaines de mètres de long sont observées généralement dans des dépôts meubles alluviaux et/ou sols saturés ; dans de rares cas, des fractures atteignant jusqu’à 1 cm de large peuvent être observées dans les roches sèches et compétentes. Des fissures décimétriques sont communes sur les routes pavées (qu’elles soient en asphalte ou en pierre), tout comme de petites ondulations de pression.*

d) Des glissements de terrain de taille petite à modérée ($10^3$ - $10^5$ $m^3$) sont largement répandus dans les zones propices ; ils se produisent rarement le long des pentes faibles ; là où l'équilibre est instable (pentes raides dans des sols meubles/saturés ; gorges abruptes ; falaises côtières), leur taille est parfois grande ($10^5$ - $10^6$ $m^3$). Les glissements de terrain peuvent occasionnellement barrer d'étroites vallées, créant des lacs temporaires ou même permanents. Des ruptures, glissements et écroulements affectent les berges des rivières, les digues et les excavations artificielles (e.g. bords de routes, carrières) dans des sédiments meubles ou des roches altérées/fracturées. Les glissements de terrain sont fréquents sous le niveau de la mer en zone côtière.

e) *Les arbres sont vigoureusement secoués ; les branches peuvent casser et tomber ; certains arbres peuvent être déracinés, le long des pentes raides.*

f) *La liquéfaction peut être fréquente en zone épicentrale, en fonction des conditions locales ; des volcans de sable jusqu'à environ 1 m de diamètre apparaissent ; des fontaines d'eau apparaissent dans les eaux calmes, de même que des étalements latéraux et des tassements (subsidence jusqu'à environ 30 cm), avec fissuration parallèle à la ligne de rivage (berges de rivière, de lacs, de canaux, littoral marin).*

g) *Dans les zones arides, des nuages de poussière peuvent s'élever du sol en zone épicentrale.*

h) Des pierres et même des petits blocs, ainsi que des troncs d'arbre peuvent être projetés en l'air, laissant des empreintes typiques dans les sols mous.

## Degré IX – Destructif / Les effets dans l'environnement sont une source de danger considérable et deviennent importants pour l'évaluation de l'intensité

Les effets primaires sont couramment observés.

Les ruptures de faille en surface se développent, jusqu'à quelques km de long, avec des rejets généralement de l'ordre de plusieurs cm. La subsidence ou le soulèvement tectonique de la surface du sol peuvent survenir, avec des valeurs maximales de l'ordre de quelques décimètres.

Effets secondaires : *L'aire totale affectée est de l'ordre de 1000 km².*

a) *Les sources peuvent changer, généralement temporairement mais de façon considérable, de débit et/ou de position. Quelques sources de taille modeste peuvent même s'assécher. Des variations temporaires du niveau d'eau sont couramment observées dans les puits. La température de l'eau change fréquemment dans les puits et/ou les sources. La turbidité de l'eau apparaît aussi communément dans les bassins clos, les rivières, les puits et les sources. Des émissions de gaz, souvent sulfureux, sont observées, et les herbes et buissons au voisinage de ces émissions peuvent brûler.*

b) *les rivières peuvent changer de cours, à cause d'affaissements du sol. De petits bassins peuvent apparaître ou peuvent se vider. En fonction de la bathymétrie et de la forme du trait de côte, de dangereuses vagues de tsunami peuvent atteindre le littoral avec des runups jusqu'à plusieurs mètres, inondant de larges surfaces. Une érosion et un déversement de déchêts se produisent de manière généralisée le long des plages, où buissons et arbres peuvent être arrachés et emportés à la dérive.*

c) *Des fractures jusqu'à 1 m de largeur et plusieurs centaines de mètres de long sont généralement observées dans les dépôts alluviaux meubles et/ou les sols saturés ; dans les roches compétentes, elles peuvent atteindre jusqu'à 10 cm de large. D'importantes fissures sont communes sur les routes pavées (asphaltées ou en pierre), tout comme de petites ondulations de pression.*

d) *Les glissements de terrain sont très développés dans les zones favorables, également le long des pentes faibles ; là où l'équilibre est instable (pentes raides dans des sols meubles/saturés ; gorges abruptes ; falaises côtières), leur taille est fréquemment grande ($10^5$ $m^3$), parfois très grande ($10^6$ $m^3$). Les glissements de terrain peuvent barrer d'étroites vallées, provoquant la formation de lacs temporaires ou même permanents. Les berges, digues et excavations artificielles (e.g., bords de route, carrières) s'effondrent fréquemment. Les grands glissements sont fréquents sous le niveau de la mer des zones côtières.*

e) Les arbres sont secoués vigoureusement ; branches et minces troncs d'arbre rompent et tombent fréquemment. Quelques arbres pourraient être déracinés et tomber, particulièrement le long des pentes raides.

f) *La liquéfaction et l'expulsion d'eau souterraine sont fréquentes ; les volcans de sable atteignent jusqu'à 3 m de diamètre; des fontaines d'eau apparaissent dans les eaux calmes, de même que de fréquents étalements latéraux et tassements* *(subsidence de plus d'environ 30 cm), avec fissuration parallèle à la ligne de rivage (berges de rivière, de lacs, de canaux, littoral marin).*

g) Dans les zones arides, des nuages de poussière s'élèvent communément du sol.

h) *Des petits blocs et des troncs d'arbre peuvent être projetés en l'air et déplacés de quelques mètres, en fonction de la pente locale et de leur arrondi, laissant des empreintes typiques dans les sols mous.*

## Degré X – Très destructif / Les effets sur l'environnement deviennent une source prépondérante de danger et sont critiques pour l'évaluation de l'intensité

Effets primaires : ils deviennent prépondérants.

*Les ruptures de failles en surface peuvent s'étendre sur des dizaines de km, avec des rejets de quelques dizaines de cm à quelques mètres. Des fossés et des dépressions allongées se développent. Pour les séismes très superficiels en zone volcanique, les longueurs de rupture peuvent être beaucoup plus faibles. Une subsidence ou un soulèvement tectonique de la surface du sol peut se produire, avec des valeurs maximales de l'ordre de quelques mètres.*

Effets secondaires: *L'aire totale affectée est de l'ordre de 5000 km²*

a) De nombreuses sources changent significativement de débit et/ou d'altitude d'affleurement. Quelques sources peuvent s'assécher, parfois de manière permanente. Des variations temporaires du niveau d'eau sont couramment observées dans les puits. Des variations parfois fortes des propriétés physico-chimiques des eaux, le plus souvent la température, sont observées dans les puits et/ou les sources. Les eaux deviennent fréquemment boueuses même dans les grands bassins, rivières, puits et sources. Des émissions de gaz, souvent sulfureux, sont observées, et les herbes et buissons au voisinage de ces émissions peuvent brûler.

b) *Des vagues de hauteur métrique se développent, y compris dans les grands lacs et rivières, qui débordent de leurs lits. Dans les plaines d'inondation, les rivières peuvent changer de cours, temporairement ou même définitivement, en raison de la subsidence généralisée de la surface. Des bassins peuvent apparaître ou disparaître. En fonction de la bathymétrie et de la forme du trait de côte, des vagues de tsunami peuvent atteindre le littoral avec des runups dépassant 5 mètres, inondant de larges surfaces planes, jusqu'à plusieurs km vers l'intérieur des terres. Des petits blocs peuvent être traînés sur plusieurs mètres. Une érosion profonde et généralisée est observée le long du littoral, avec des changements notables du profil littoral. Les arbres côtiers sont arrachés et emportés à la dérive.*

c) *Des fractures ouvertes jusqu'à plus de 1 m en largeur et jusqu'à une centaine de mètres en longueur sont fréquentes, principalement dans les dépôts alluviaux meubles et/ou les sols saturés ; dans les roches compétentes, l'ouverture atteint plusieurs dm de large. De larges fissures se développent sur les routes pavées (asphaltées ou en pierre), tout comme de petites ondulations de pression.*

d) *De grands glissements de terrain et chutes de blocs (> $10^5$ - $10^6$ m³) sont fréquents, quasiment indépendamment de l'état d'équilibre des pentes, provoquant des lacs de barrage temporaires ou permanents. Les berges, digues artificielles et bords de carrière s'effondrent. Les grands glissements sont fréquents sous le niveau de la mer des zones côtières.*

e) *Les arbres sont secoués vigoureusement ; beaucoup de branches et troncs d'arbre rompent et tombent. Des arbres pourraient être déracinés et tomber.*

f) *La liquéfaction, avec expulsion d'eau et compaction des sols, peuvent changer le paysage de larges zones géographiques; des volcans de sable parfois plus larges que 6 m de diamètre sont communs, ainsi que de la subsidence supérieure à 1 m, de larges et longues fissures dues à des étalements latéraux.*

g) Dans les zones arides, des nuages de poussière s'élèvent du sol.

h) *Des blocs (diamètre au-delà de 2-3 mètres) peuvent être projetés en l'air et déplacés de centaines de mètres, même sur des pentes faibles, laissant des empreintes typiques dans les sols.*

## Degré XI – Dévastateur / Les effets sur l'environnement deviennent décisifs pour l'évaluation de l'intensité, du fait de la saturation des dommages aux structures

Effets primaires : ils sont dominants.

*Les ruptures de failles en surface s'étendent de plusieurs dizaines à plus d'une centaine de km, accompagnées de rejets atteignant plusieurs mètres. Des fossés, dépressions allongées et des rides de pression se développent. Les axes de drainage peuvent être sérieusement déplacés. Subsidence ou soulèvement tectonique de la surface du sol peuvent se produire, avec des valeurs maximales de l'ordre de nombreux mètres.*

Effets secondaires. *L'aire totale affectée est de l'ordre de 10 000 km$^2$.*

a) De nombreuses sources changent significativement de débit et/ou d'altitude d'affleurement. Beaucoup de sources peuvent s'assécher, parfois de manière permanente. Des variations temporaires ou permanente du niveau d'eau sont généralement observées dans les puits. Des variations parfois fortes des propriétés physico-chimiques des eaux, le plus souvent la température, sont observées dans les puits et/ou les sources. Les eaux deviennent souvent boueuses même dans les grands bassins, rivières, puits et sources. Des émissions de gaz, souvent sulfureux, sont observées, et les herbes et buissons au voisinage de ces émissions peuvent brûler.

b) *De grandes vagues se développent dans les grands lacs et rivières, qui débordent de leurs lits. Dans les plaines d'inondation, les rivières peuvent changer de cours, temporairement et même définitivement, en raison de la subsidence généralisée de la surface et des glissements de terrain. Des bassins peuvent apparaître ou disparaître. En fonction de la bathymétrie et de la forme du trait de côte, des vagues de tsunami peuvent atteindre le littoral avec des runups jusqu'à 15 mètres ou plus, dévastant de larges surfaces planes sur des kilomètres vers l'intérieur des terres. Des blocs métriques peuvent être traînés sur de longues distances. Une érosion profonde et généralisée est observée le long du littoral, avec des changements notables de la morphologie côtière. Les arbres côtiers sont arrachés et emportés à la dérive.*

c) Des fissures ouvertes jusqu'à plusieurs mètres de largeur sont très fréquentes, principalement dans les dépôts alluviaux meubles et/ou les sols saturés. Dans les roches compétentes, elles peuvent atteindre 1 mètre de large. De très larges fissures se développent sur les routes pavées (asphaltées ou en pierre), tout comme de grandes ondulations de pression.

d) *De grands glissements de terrain et chutes de blocs (> $10^5$ - $10^6$ m$^3$) sont fréquents, quasiment indépendamment de l'état d'équilibre des pentes, provoquant de nombreux lacs de barrage temporaires ou permanents. Les berges des rivières, les digues et bords d'excavations artificielles s'effondrent. Les levées et barrages de terre sont exposés à de sérieux dommages. D'importants glissements de terrain peuvent se produire à des distances de 200 à 300 km de l'épicentre. Les grands glissements sont fréquents sous le niveau de la mer des zones côtières.*

e) *Les arbres sont secoués vigoureusement ; beaucoup de branches et troncs d'arbre cassent et tombent. Beaucoup d'arbres sont déracinés et tombent.*

f) *La liquéfaction change l'aspect de vastes zones basses, causant une subsidence verticale qui peut dépasser plusieurs mètres, de nombreux et grands volcans de sable, ainsi que de sévères figures d'étalement latéral.*

g) Dans les zones arides, des nuages de poussière s'élèvent du sol.

h) *De gros blocs (diamètre de plusieurs mètres) peuvent être projetés en l'air et déplacés sur de grandes distances, même sur des pentes faibles, laissant des empreintes typiques dans les sols.*

## Degré XII – Entièrement dévastatateur / Les effets sur l'environnement sont le seul moyen pour évaluer l'intensité

Effets primaires: ils sont dominants.

La rupture de faille en surface est au moins de plusieurs centaines de km, accompagnées de rejets atteignant plusieurs dizaines de mètres. Des fossés, dépressions allongées et des rides de pression se développent. Les axes de drainage peuvent être sérieusement déplacés. Le paysage et les changements géomorphologiques induits par les effets primaires peuvent être considérables en extension et en amplitude (typiquement, par exemple : soulèvement ou subsidence de plusieurs mètres de la ligne de rivage, apparition ou disparition d'éléments du paysage, changements de cours des rivières, création de cascades, formation ou disparition de lacs).

Effets secondaires *L'aire totale affectée est de l'ordre de 50.000 km² ou plus.*

a) De nombreuses sources changent significativement de débit et/ou d'altitude d'affleurement. Beaucoup de sources et de puits peuvent s'assécher, parfois de manière permanente. Des variations fortes des propriétés physico-chimiques des eaux, le plus souvent la température, sont observées dans les puits et/ou les sources. Les eaux deviennent très boueuses même dans les grands bassins, rivières, puits et sources. Des émissions de gaz, souvent sulfureux, sont observées, et les herbes et buissons au voisinage de ces émissions peuvent brûler.

b) *Des vagues géantes se développent dans les lacs et rivières, qui débordent de leurs lits. Dans les plaines d'inondation, les rivières peuvent changer de cours, et même leur direction d'écoulement, de façon temporaire ou même permanente, en raison de la subsidence généralisée de la surface et de glissements de terrain. De grands bassins peuvent apparaître ou disparaître. En fonction de la bathymétrie et de la forme du trait de côte, des vagues de tsunami peuvent atteindre le littoral avec des runups de plusieurs dizaines de mètres, dévastant de larges surfaces planes sur de nombreux kilomètres vers l'intérieur des terres. De gros blocs peuvent être traînés sur de longues distances. Une érosion profonde et généralisée est observée le long du littoral, avec des changements remarquables de la morphologie côtière. Beaucoup d'arbres côtiers sont arrachés et emportés à la dérive. Tous les bateaux sont arrachés de leur amarrage et emportés au large ou charriés sur terre sur de longues distances. Toutes les personnes sont emportées.*

c) Les fissures ouvertes sont très fréquentes et larges jusqu'à un mètre ou plus dans le rocher, et jusqu'à 10 mètres dans les sédiments meubles et/ou les sols saturés. Elles peuvent s'étendre sur plusieurs km de long.

d) *De grands glissements de terrain et chutes de blocs (> $10^5$ - $10^6$ m³) sont fréquents, quasiment indépendamment de l'état d'équilibre des pentes, provoquant de nombreux lacs de barrage temporaires ou permanents. Les berges de rivières, digues artificielles et bordures d'excavations s'effondrent. Les levées et barrages de terre s'exposent à de sérieux dommages. D'importants glissements de terrain peuvent se produire à des distances de 200 à 300 km de l'épicentre. Les grands glissements sont fréquents sous le niveau de la mer des zones côtières.*

e) Les arbres sont secoués vigoureusement ; beaucoup de branches et troncs d'arbre cassent et tombent. Beaucoup d'arbres sont déracinés et tombent.

f) *La liquéfaction se produit sur de larges zones et change la morphologie de vastes zones plates, causant une subsidence verticale dépassant plusieurs mètres, de grands volcans de sable généralisés, ainsi que de sévères étalement latéraux sur de larges étendues.*

g) Dans les zones arides, des nuages de poussière s'élèvent du sol.

h) De très gros blocs peuvent être projetés en l'air et déplacés sur de grandes distances, même sur des pentes faibles, laissant des empreintes typiques dans les sols.

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 53 - 62
tab. 1

# 2.5. ESI 2007 Intensitätsskala (German)

TRANSLATED: GRÜTZNER C. (1), REICHERTER K. (1)

## *Einführung*

Die Intensität von Erdbeben wird anhand der Auswirkungen bestimmt, die ein seismisches Ereignis auf den Menschen, auf Gebäude und Infrastruktur sowie auf die natürliche Umgebung hat. Diese Intensität ist ein Maß der Zerstörungskraft eines Bebens und berücksichtigt neben den durch die seismischen Erschütterungen hervorgerufenen Effekten in allen Frequenzbereichen auch solche Erscheinungen, die durch statische Deformationen hervorgerufen werden.

Alle Intensitätsskalen (Rossi-Forel, Mercalli, MCS, MSK, Mercalli Modified) nutzen die Analyse von Umwelteffekten als diagnostische Elemente zur Bestimmung des Intensitätsgrades. Für einige modernere Skalen werden jedoch nur die Effekte auf den Menschen und auf Gebäude und Infrastruktur berücksichtigt (z.B. ESPINOSA *et alii*, 1976a; 1976b; GRUNTHAL, 1998). Hierbei wird die diagnostische Relevanz der Umwelteffekte vernachlässigt, weil man davon ausgeht, dass diese zu variabel und unsicher sind, um eine verlässliche Intensitätsbestimmung zu erlauben. In neuen Studien (z.B. DENGLER & MCPHERSON, 1993; SERVA, 1994; DOWRICK, 1996; ESPOSITO et alii, 1997; HANCOX *et alii*, 2002; MICHETTI *et alii*, 2004) konnte hingegen gezeigt werden, dass die Umwelteffekte von solchen Erdbeben, die in historischen Berichten vermerkt sind oder durch paläoseismologische Untersuchungen dokumentiert wurden, essentielle Informationen zur Abschätzung der Stärke eines Erdbebens beinhalten und insbesondere eine Intensitätsbestimmung erlauben.

Um diese Informationen zu nutzen, wurde 2007 die ESI Intensitätsskala entwickelt (MICHETTI *et alii*, 2007). Die Intensitätsbestimmung erfolgt ausschließlich anhand von Umwelteffekten, die durch ein Erdbeben hervorgerufen wurden. Mit Hilfe dieser Skala (auch in Kombination mit den klassischen Intensitätsskalen) können die verschiedenen Auswirkungen in ihrer Gesamtheit besser erfasst werden. Die Konzentration auf Umwelteffekte erlaubt einen besseren Vergleich von Erdbebenintensitäten in zweierlei Hinsicht:

- zeitlich: Effekte auf die Umwelt sind für sehr lange Zeiträume vergleichbar (aktuelle Erdbeben, historische Ereignisse, Paläo-Erdbeben), während der instrumentellen Seismologie nur Aufzeichnungen über die letzten 100 - 120 Jahre zur Verfügung stehen;

- räumlich: Erdbeben können weltweit verglichen werden, unabhängig von den örtlichen Bauweisen oder sozio-ökonomischen Voraussetzungen.

Daher zielt die neue Intensitätsskala auch

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darauf ab, traditionelle Skalen zu ergänzen:

• ab Erdbebenintensitäten von X wird die Intensitätsbestimmung anhand von Gebäudeschäden nahezu unmöglich, während Umwelteffekte noch immer aussagekräftig sind;

• in dünn besiedelten Gegenden können oftmals nicht ausreichend viele Gebäudeschäden analysiert werden, um eine verlässliche Intensitätsbestimmung durchzuführen - hier können einzig Umwelteffekte Aufschluss über die Stärke eines Bebens geben.

Die Intensitätsgrade der ESI Skala wurden durch eine internationale Arbeitsgruppe von Geologen, Seismologen und Ingenieuren definiert, indem die Effekte einer Vielzahl unterschiedlicher Erdbeben weltweit klassifiziert wurden. Auf dem XVII INQUA Congress 2007 (Cairns, Australien) erfolgte die Ratifizierung der ESI Skala durch die INQUA (International Union for Quaternary Research).

## *Beschreibung*

Die ESI Skala hat zwölf Grade. Der Name jeden Grades beschreibt kurz die dazugehörige Stärke eines Erdbebens und die Umwelteffekte. In der Beschreibung werden zunächst die charakteristischen Haupteffekte und deren Stärke dem jeweiligen Grad zugeordnet. Darauf folgen Angaben zur räumlichen Verbreitung der Nebeneffekte zur Bestimmung der Epizentralintensität. Diese werden in Kategorien unterteilt und nach der Häufigkeit ihres Auftretens gruppiert. Kursiver Text markiert solche Effekte, die als charakterisitsch für ihren Grad angesehen werden.

***Haupteffekte*** *hängen direkt von der Energie eines Erdbebens ab und werden insbesondere durch die* Oberflächenerscheinung der seismogenen Störung bestimmt. Die Größe der Haupteffekte wird typischerweise durch zwei Parameter angegeben: i) Länge der Oberflächenruptur und ii) maximaler Versatz an der Störung. Das Auftreten dieser beiden ist üblicherweise ab einer Intensität von VIII zu erwarten; nur in vulkanisch aktiven Gebieten können auch sehr oberflächennahe, schwächere Beben Oberflächenrupturen und sichtbaren Versatz erzeugen. Des Weiteren wird die Ausdehnung von tektonischer Oberflächendeformation (Hebung und Senkung) für die Intensitätsabschätzung berücksichtigt.

***Nebeneffekte*** sind alle Erscheinungen, die durch die Bodenerschütterung verursacht werden. Es werden acht Kategorien unterschieden:

a) *Hydrologische Anomalien*: In diese Kategorie fallen Veränderungen der Schüttmenge von Quellen und Flüssen sowie Änderungen der chemisch-physikalischen Eigenschaften von Grund- und Oberflächenwasser (z.B. Temperatur, Trübung). Diese Effekte gelten als diagnostisch für Intensitäten von IV bis X.

b) *Anomale Wellen/Tsunamis:* Diese Kategorie umfasst: Seichen (stehende Wellen) in geschlossenen Becken, das Auslaufen von Wasser aus Teichen und Becken sowie Tsunamiwellen. Im Falle von Tsunamis werden die Effekte der Wellen an der Küste zur Intensitätsabschätzung herangezogen, weniger die Höhe der Tsunamiwellen selbst. Charakteristisch sind vor allem die maximale Auflaufhöhe, Stranderosion und Änderungen der Küstenmorphologie. Derartige Effekte könne bereits ab Intensität IV auftreten, sind aber vor allem für Intensitäten von IX - XII diagnostisch.

c) *Bodenrisse:* Es werden die Längen der Risse (von Zentimetern bis zu einigen hundert Metern), die Breite (Millimeter bis Meter) und die Dichte des Auftretens bestimmt. Bodenrisse können ab Intensität IV auftreten; ab Intensität X ist keine Zunahme in Größe und Häufigkeit mehr zu erwarten.

d) *Massenbewegungen:* In dieser Kategorie werden alle Typen von Erdrutschen, Felsstürzen, Bodenfließen und Muren eingeordnet. Sofern Morphologie und Lithologie verschiedener Gebiete vergleichbar sind, werden Volumen und Fläche des Auftretens als charakteristische Größen angenommen. Massenbewegungen können ab Intensität IV auftreten; ab Intensität X ist keine Zunahme in Größe und Häufigkeit mehr zu erwarten.

e) *Wackelnde Bäume*: Diese Effekte sind für Intensitäten von IV - X diagnostisch. Die Definition der Intensitätsgrade orientiert sich an den Vorgaben von Dengler und McPherson (1993).

f) *Bodenverflüssigung:* Diese Kategorie umfasst Sandvulkane, Wasser- und Sandfontänen, einige Arten von seitlicher Ausbreitung von Bodenmaterial, Setzungen und Sackungen. Ihre Größe ist diagnostisch für Intensitäten von V bis X.

g) *Staubwolken*: Diese können in trockenen/ariden Gebieten ab Intensität VIII beobachtet werden.

h) *Springende Steine*: Die maximale Größe der springenden Steine ist hierbei das diagnostische Kriterium. Springende Steine können bei Intensitäten IX - XII beobachtet werden. Dieser Effekt bezeugt, dass die Bodenbeschleunigung während des Bebens größer als die Erdbeschleunigung war. Dieses Phänomen kann lokal ab Intensität IX auftreten.

Umwelteffekte können ab Intensitäten von IV beobachtet und kategorisiert werden. Einige Effekte wie hydrologische Anomalien können unter Umständen auch schon bei geringeren Intensitäten auftreten, eignen sich dann jedoch nicht als diagnostische Kriterien. Die Genauigkeit der Abschätzung steigt grundsätzlich mit höheren Graden an, insbesondere dann, wenn Haupteffekte beobachtet werden können. Dies ist typischerweise ab Intensität VIII der Fall. Ab Intensitäten von X sind die Folgen eines Erdbebens auf Gebäude und Infrastruktur kaum oder gar nicht mehr zu unterscheiden und können verschiedenen Graden nicht oder nur selten zugeordnet werden, da die meisten Gebäude völlig zerstört werden. Insbesondere in diesem Bereich stellt die ESI Skala die einzige Möglichkeit dar, sinnvoll Intensitäten anzugeben.

## *Zur Benutzung der ESI 2007 Intensitätsskala*

Die Verwendung der ESI 2007 Intensitätsskala als unabhängige Methode zur Intensitätsbestimmung ist immer dann ratsam, wenn nur Umwelteffekte zur Abschätzung der Erdbebenstärke geeignet sind. Dies kann der Fall sein, wenn die Auswirkungen auf Infrastruktur und Gebäude zu selten beobachtet werden können oder wenn diese so stark beschädigt sind, dass eine Unterscheidung der Grade nicht mehr möglich ist. Falls die Intensität auch traditionell anhand von Gebäudeschäden bestimmt werden kann, können zwei unabhängige Intensitätsabschätzungen vorgenommen werden. Generell wird dann der höhere der beiden ermittelten Grade als Intensität angegeben. Offensichtlich ist hierbei die Beurteilung durch Experten unabdingbar.

Die Epizentralintensität ($I_0$) bezeichnet die Intensität der Erschütterungen bezogen auf das Epizentrum. Die Parameter der Oberflächenrupturen und die räumliche Verteilung von Nebeneffekten (z.B. Erdrutsche oder Bodenverflüssigung) dienen als unabhängige Methoden zur Bestimmung von $I_0$ auf der Basis von Umwelteffekten, meist ab Intensität VII (tab. 2.1).

Besondere Vorsicht ist geboten, wenn Haupteffekte (z.B. Oberflächenrupturen) gerade auf einen Wert zwischen zwei Intensitätsgraden hindeuten. In diesem Fall sollte derjenige Grad angenommen werden, der durch die Nebeneffekte am besten bestätigt wird. Außerdem wird empfohlen, keine räumlich isoliert beobachteten, weit vom Epizentrum entfernten Nebeneffekte in die Berechnung der betroffenen Gesamtfläche einzubeziehen. Für die Auswertung solcher Beobachtungen sollte ein Experte zu Rate gezogen werden.

Tab. 2.1 - *Wertebereiche der oberflächlich sichtbaren Störungseffekte (Haupteffekte) und typische Gesamtflächen der Nebeneffekte für jeden Intensitätsgrad.*

| $I_0$ | HAUPTEFFEKTE | | NEBENEFFEKTE |
|---|---|---|---|
| | Länge der Oberflächenruptur | Maximaler Oberflächenversatz/ Deformation | Gesamtfläche |
| **IV** | - | - | - |
| **V** | - | - | - |
| **VI** | - | - | - |
| **VII** | (*) | (*) | 10 $km^2$ |
| **VIII** | Einige hundert Meter | einige Zentimeter | 100 $km^2$ |
| **IX** | 1- 10 km | 5 - 40 cm | 1000 $km^2$ |
| **X** | 10 - 60 km | 40 - 300 cm | 5000 $km^2$ |
| **XI** | 60 – 150 km | 300 –700 cm | 10000 $km^2$ |
| **XII** | > 150 km | > 700 cm | > 50000 $km^2$ |

(*) Sehr kurze Oberflächenrupturen (einige Zehnermeter bis wenige hundert Meter) können in vulkanisch aktiven Gebieten bei oberflächennahen Beben auftreten.

Lokale Intensitäten warden hauptsächlich anhand der Beschreibung von Nebeneffekten an bestimmtem Lokalitäten abgeschätzt. Diese Intensitätsgrade sind vergleichbar mit denen, die durch die traditionellen Intensitätsskalen aufgrund von Gebäudeschäden ermittelt wurden. Es muss darauf hingewiesen werden, dass der Begriff „Lokalität“ sowohl eine bewohnte Ortschaft als auch einen Naturraum ohne menschliche Siedlungen bezeichnen kann. Sollten nur Haupteffekte dokumentiert worden sein, ist es auch möglich, die lokalen Auswirkungen der oberflächlich sichtbaren Störungseffekte zur Intensitätsbestimmung zu nutzen (maximaler Versatz).

## *Beschreibung der Intensität*

**I – III** keine Auswirkungen auf die Umwelt.

### Stufe IV

Haupteffekte fehlen. Nebeneffekte sind:

a) Kleine Veränderungen des Wasserstandes in Brunnen oder der Menge der Wasserschüttung von Quellen treten ganz vereinzelt und begrenzt auf. Sehr selten werden kleine physikalische und chemische Veränderungen oder Trübung des Wassers von Brunnen oder Quellen beobachtet, dies vor allem in Quellen aus größeren Karst-Aquiferen.

b) Entwicklung von einige Zentimeter hohen Seiches in abgeschlossenen Becken (in Seen und im Meer) – typischerweise im Fernbereich von Erdbeben –, die im Allgemeinen nur von Pegeln erfasst werden, selten auch mit bloßem Auge. Anomale Wellen werden von allen Menschen in kleinen Booten wahrgenommen, von einigen in großen Booten, von den meisten an der Küste. Schwingung und manchmal Überschwappen des Wassers in Schwimmbecken werden beobachtet.

c) Auftreten von millimeterdicken Haarrissen bei geeigneter Geländeform (Hänge, Bergkämme) oder bei bestimmter Bodenbeschaffenheit (wassergesättigter Boden, unverfestigter Schwemmboden).

d) In steilen Hängen nahe dem kritischen Winkel und bei losem oder wassergesättigtem Boden kommt es vereinzelt zu Steinschlag und kleinen Erdrutschen, manchmal infolge der Reaktivierung alter Rutschmassen.

e) Schwaches Zittern von Ästen.

## Stufe V

Haupteffekte fehlen. Nebeneffekte sind:

a) Selten und begrenzt treten kleine Veränderungen des Wasserstandes in Brunnen oder der Menge der Wasserschüttung von Quellen auf. Ebenso werden vereinzelte kleine physikalische und chemische Veränderungen oder Trübung des Wassers von Seen, Brunnen oder Quellen beobachtet.

b) Entwicklung von einige Dezimeter hohen Seiches in abgeschlossenen Becken (in Seen und im Meer) – typischerweise im Fernbereich von Erdbeben –, die manchmal auch mit bloßem Auge erfasst werden. Anormale Wellen von einigen Dezimetern Höhe werden von allen Menschen in Booten und an der Küste wahrgenommen. Überschwappen des Wassers aus Schwimmbecken tritt auf.

c) Begrenztes Auftreten von millimeterdünnen Rissen mit einer Länge von einigen Zentimetern bis zu einem Meter bei geeigneter Geländeform (Hänge, Bergkämme) oder bei bestimmter Bodenbeschaffenheit (wassergesättigter Boden, unverfestigter Schwemmboden).

d) Vereinzelt Steinschlag und Erdrutsche nicht nur in steilen Hängen nahe dem kritischen Winkel, meist bei losen Ablagerungen oder wassergesättigtem Boden. Unterseeische Rutschungen können ausgelöst werden, die möglicherweise kleine anomale Wellen an den Küsten von See und Meer erzeugen.

e) Äste und Büsche erbeben leicht, sehr selten fallen tote Äste und reife Früchte zu Boden.

f) Äußerst seltene Beobachtungen von Bodenverflüssigung („aufkochender“ Treibsand) in sehr begrenzten Bereichen, die aufgrund von hohem Grundwasserstand und geeigneter Bodenbeschaffenheit (z. B. Schwemmsand) anfällig dafür sind.

## Stufe VI

Haupteffekte fehlen. Nebeneffekte sind:

a) Räumlich begrenzt treten deutliche Veränderungen des Wasserstandes in Brunnen oder der Menge der Wasserschüttung von Quellen auf. Ebenso werden kleine physikalische und chemische Veränderungen oder Trübung des Wassers von Seen, Brunnen oder Quellen beobachtet.

b) Anomale Wellen von mehreren Dezimetern Höhe überfluten sehr begrenzte Bereiche des Ufers. Überschwappen des Wassers aus Schwimmbecken, kleinen Tümpeln und Teichen.

c) Bei geeigneter Bodenbeschaffenheit (wassergesättigter Boden, unverfestigter Schwemmboden) gelegentliches Auftreten von millimeter- bis zentimeterbreiten Rissen mit einer Länge von bis zu einigen Metern, die an steilen Hängen oder Flussufern 1–2 cm offen stehen können. Einige kleine Risse entstehen in asphaltierten oder gepflasterten Straßen.

d) Steinschlag und Erdrutsche mit einem Volumen von bis zu 1.000 $m^3$ vor allem an steilen Hängen und Geländeeinschnitten nahe dem kritischen Winkel, meist bei losen wassergesättigten Ablagerungen oder stark verwittertem und brüchigem Fels. Unterseeische Rutschungen können ausgelöst werden, die hin und wieder kleine, vor allem von Messinstrumenten verzeichnete, anomale Wellen an den Küsten von See und Meer erzeugen.

e) Äste und Büsche erbeben gemäßigt bis stark; in Abhängigkeit von der Baumart, dem Gesundheitszustand und der Fruchtlast brechen einige wenige Baumkronen und instabile tote Äste und fallen zu Boden.

f) Seltene Beobachtungen von Bodenverflüssigung („aufkochender“ Treibsand) in sehr begrenzten Bereichen, die aufgrund von hohem Grundwasserstand und geeigneter Bodenbeschaffenheit (z. B. Schwemmsand) anfällig dafür sind.

## Stufe VII

Haupteffekte werden sehr selten beobachtet, hauptsächlich in vulkanischen Gebieten. Vor allem sehr oberflächennahe Beben erzeugen begrenzte Oberflächenrupturen von einigen hundert Metern Länge und mit wenigen Zentimetern Versatz.

Nebeneffekte betreffen eine Fläche in der Größenordnung von 10 $km^2$.

a) Räumlich begrenzt treten vorübergehend deutliche Veränderungen des Wasserstandes in Brunnen oder der Menge der Wasserschüttung von Quellen auf. Selten kommt es vorübergehend zum Versiegen oder Entstehen von kleinen Quellen. Ebenso werden örtlich kleine physikalische und chemische Veränderungen oder Trübung des Wassers von Seen, Brunnen oder Quellen beobachtet.

b) Anomale Wellen von mehr als einem Meter Höhe überfluten begrenzte Bereiche des Ufers und beschädigen Objekte verschiedener Größe oder spülen sie fort. Überschwappen des Wassers aus kleinen Becken und Wasserläufen tritt auf.

c) Bei geeigneter Bodenbeschaffenheit (wassergesättigter Boden, unverfestigter Schwemmboden) können 5 bis 10 Zentimeter breite Rissen mit einer Länge von bis zu hundert Metern auftreten. In trockenem Sand, sandigem Schluff und in Ton werden seltene Risse bis zu einer Breite von 1 Zentimeter beobachtet. Zentimeterbreite Risse entstehen in asphaltierten oder gepflasterten Straßen.

d) Verstreutes Auftreten von Erdrutschen, in einigen Fällen mit einem Volumen von bis zu 10.000 $m^3$ vor allem an steilen Hängen und Geländeeinschnitten nahe dem kritischen Winkel, meist bei losen oder wassergesättigten Ablagerungen. Steinschlag ereignet sich vor allem in steilen Schluchten und an Klippen. Bei trockenem Boden aus Sand, sandigem Schluff oder Ton erreichen die Massenbewegungen ein Volumen von bis zu 100 $m^3$. Bedeutende unterseeische Rutschungen können ausgelöst werden, die anomale Wellen an den Küsten von See und Meer erzeugen, welche von Personen in Booten und Häfen bemerkt werden.

e) Bäume und Büsche erbeben stark, vor allem in dicht bestandenen Wäldern brechen viele Baumkronen und instabile tote Äste und fallen zu Boden.

f) Seltene Beobachtungen von Bodenverflüssigung („aufkochender“ Treibsand bis zu 50 cm im Durchmesser) in sehr begrenzten Bereichen, die aufgrund von hohem Grundwasserstand und geeigneter Bodenbeschaffenheit (z. B. Schwemmsand) anfällig dafür sind.

## Stufe VIII

Haupteffekte werden selten beobachtet. Vor allem sehr oberflächennahe Beben, wie sie häufig in vulkanischen Gebieten vorkommen, erzeugen begrenzte Oberflächenrupturen von einigen hundert Metern Länge und mit wenigen Zentimetern Versatz. Darüber hinaus kann tektonische Hebung oder Senkung der Erdoberfläche über einige Zentimeter vorkommen.

Nebeneffekte betreffen eine Fläche in der Größenordnung von 100 $km^2$.

a) Die Wasserschüttung oder die Austrittshöhe von Quellen ändert sich, meist vorübergehend. Manchmal kommt es vorübergehend zum Versiegen oder Entstehen von kleinen Quellen. Beobachtet werden Veränderungen des Wasserstandes in Brunnen. Kleine physikalische und chemische Veränderungen des Wassers sind nachweisbar, meist Änderungen der Temperatur. Eine Trübung des Wassers lässt sich in abgeschlossenen Seen, in Flüssen, Brunnen oder Quellen beobachten. An manchen Stellen tritt Gas aus, meist schwefelhaltig.

b) Anomale Wellen von ein bis zwei Meter Höhe überfluten ufernahe Bereiche und beschädigen Objekte verschiedener Größe oder spülen sie fort. Erosion und Ablagerung von Treibgut kommt entlang der Küsten vor. Unterspülung und Verdriften einiger Büsche und kleiner, schlecht verwurzelter Bäume wird beobachtet. Heftiges Überschwappen des Wassers aus kleinen Becken und Wasserläufen ist möglich.

c) Bei geeigneter Bodenbeschaffenheit (wassergesättigter Boden, unverfestigter Schwemmboden) häufiges Auftreten von bis zu 50 Zentimeter breiten Rissen mit einer Länge von bis zu hundert Metern. In seltenen Fällen werden Risse von bis zu 1 Zentimeter Breite in hartem Felsgestein beobachtet. Dezimeterbreite Risse und kleine Druckwellungen der Oberfläche entstehen in asphaltierten oder gepflasterten Straßen.

d) Auftreten von kleinen und mittleren Erdrutschen mit einem Volumen von 1.000 bis 100.000 $m^3$ in geeigneten Gebieten, selten auch an flachen Hängen. In Ablagerungen nahe dem kritischen Winkel, etwa an steilen Hängen bei losen oder wassergesättigten Ablagerungen sowie Steinschlagmassen in Schluchten und an Steilküsten können Erdrutsche ein großes Ausmaß erreichen (100.000 bis 1.000.000 $m^3$). Erdrutsche können schmale Täler versperren und so zur Entstehung eines vorübergehenden oder bleibenden Stausees führen. Brüche, Rutschungen und Steinschläge betreffen

Flussufer, künstliche Böschungen und Abgrabungen wie Straßeneinschnitte und Steinbrüche in Lockersedimenten und verwittertem Gestein. Häufig werden unterseeische Rutschungen ausgelöst.

e) Bäume werden stark geschüttelt, Äste brechen und fallen zu Boden, vor allem an steilen Hängen werden manche Bäume entwurzelt.

f) Bodenverflüssigung kann im Bereich des Epizentrums bei geeigneten Bodenverhältnissen häufig sein, hier treten vor allem „aufkochender“ Treibsand bis zu einem Meter Durchmesser auf sowie scheinbare Fontänen in stillem Wasser, seitliche Ausbreitung von Bodenmaterial und Setzungen bis zu 30 cm. Parallel zu den Ufern von Flüssen, Seen, Kanälen und zur Meeresküste bilden sich Spalten.

g) In trockenen Gebieten können im Bereich des Epizentrums Staubwolken aufsteigen.

h) Steine und sogar kleine Felsen sowie gefallene Baumstämme können in die Luft geworfen werden, ihr Wiederauftreffen hinterlässt typische Spuren in weichem Boden.

## Stufe IX

Haupteffekte wie Oberflächenrupturen von einigen Kilometern Länge und mit einigen Zentimetern Versatz werden häufig beobachtet. Darüber hinaus kann tektonische Hebung oder Senkung der Erdoberfläche über einige Dezimeter vorkommen.

Nebeneffekte betreffen eine Fläche in der Größenordnung von 1.000 km$^2$.

a) Die Wasserschüttung oder der Ort von Quellen ändert sich deutlich, meist vorübergehend. Manchmal kommt es zum Versiegen mittelgroßer Quellen. Häufig sind vorübergehende Veränderungen des Wasserstandes in Brunnen. Kleine physikalische und chemische Veränderungen des Wassers von Brunnen oder Quellen sind nachweisbar, meist Änderungen der Temperatur. Eine Trübung des Wassers lässt sich in abgeschlossenen Seen, in Flüssen, Brunnen oder Quellen beobachten. An manchen Stellen tritt Gas aus, meist schwefelhaltig. Stellenweise kommt es zur Entzündung des Gases und die Vegetation nahe der Austrittsstelle kann verbrennen.

b) Entstehung von mehrere Meter hohen Wellen in Still- und Fließgewässern, Verlagerung von Wasserläufen in Überschwemmungsebenen durch Bodensenkungen, Erscheinen und Verschwinden kleiner Wasserbecken. Je nach unterseeischem oder untermeerischem Geländerelief können Tsunamis von mehreren Metern Höhe entstehen, die weite Gebiete überschwemmen und eine Gefahr für Mensch und Tier darstellen. Erosion und Ablagerung von Treibgut kommt entlang der gesamten Küste vor. Unterspülung und Verdriften von Büschen und Bäumen wird beobachtet.

c) Bei geeigneter Bodenbeschaffenheit (wassergesättigter Boden, unverfestigter Schwemmboden) treten bis zu 100 Zentimeter breite Rissen mit einer Länge von bis zu mehreren hundert Metern auf. Risse von bis zu 10 Zentimeter Breite werden in hartem Felsgestein beobachtet. Breite Risse und kleine Druckwellungen der Oberfläche entstehen in asphaltierten oder gepflasterten Straßen.

d) Erdrutsche sind häufig, auch an flachen Hängen. In Ablagerungen nahe dem kritischen Winkel, etwa an steilen Hängen bei losen oder wassergesättigten Ablagerungen sowie Steinschlagmassen in Schluchten und an Steilküsten können Erdrutsche ein großes bis sehr großes Ausmaß erreichen (100.000 bis 1.000.000 m$^3$). Erdrutsche können schmale Täler versperren und so zur Entstehung eines vorübergehenden oder bleibenden Stausees führen. Brüche, Rutschungen und Steinschläge betreffen Flussufer, künstliche Böschungen und Abgrabungen wie Straßeneinschnitte und Steinbrüche in Lockersedimenten und verwittertem Gestein. Häufig werden unterseeische Rutschungen in Küstennähe ausgelöst.

e) Bäume werden heftig geschüttelt, Äste und dünne Baumstämme brechen häufig und fallen zu Boden, vor allem an steilen Hängen werden manche Bäume entwurzelt.

f) Bodenverflüssigung und das Aufwallen von Wasser sind häufig, hier treten vor allem „aufkochender“ Treibsand bis zu drei Metern Durchmesser auf sowie scheinbare Fontänen in stillem Wasser, häufig seitliche Ausbreitung von Bodenmaterial und Setzungen von mehr als 30 cm. Parallel zu den Ufern von Flüssen, Seen, Kanälen und zur Meeresküste bilden sich Spalten.

g) In trockenen Gebieten können Staubwolken aufsteigen.

h) Kleine Felsen und gefallene Baumstämme können in die Luft geworfen werden und wandern je nach ihrer Form und der Geländeneigung mehrere Meter, ihr Wiederauftreffen hinterlässt typische Spuren in weichem Boden.

## Stufe X

Haupteffekte übertreffen die Nebeneffekte. Oberflächenrupturen von einigen Zehnerkilometern Länge und mit einigen Zentimetern bis einigen Metern Versatz werden häufig beobachtet, in vulkanischen Gebieten kann die Länge der Brüche bei sehr flachgründigen Erdbeben wesentlich größer sein. Einbruchgräben und längliche Senken entwickeln sich. Darüber hinaus kann tektonische Hebung oder Senkung der Erdoberfläche über einige Meter vorkommen.

Nebeneffekte betreffen eine Fläche in der Größenordnung von 5.000 km$^2$.

a) Die Wasserschüttung oder die Austrittshöhe vieler Quellen ändert sich deutlich. Manchmal kommt es zum vorübergehenden oder vollständigen Versiegen mancher Quellen. Häufig sind vorübergehende Veränderungen des Wasserstandes in Brunnen. Teilweise starke physikalische und chemische Veränderungen des Wassers von Brunnen oder Quellen sind nachweisbar, meist Änderungen der Temperatur. Eine Verschlammung des Wassers lässt sich sogar in großen Seen sowie in Flüssen, Brunnen oder Quellen beobachten. An manchen Stellen tritt Gas aus, meist schwefelhaltig. Stellenweise kommt es zur Entzündung des Gases und die Vegetation nahe der Austrittsstelle kann verbrennen.

b) Entstehung von mehrere Meter hohen Wellen sogar in großen Still- und Fließgewässern, die deren Bett verlassen können. Zeitweilige oder bleibende Verlagerung von Wasserläufen in Überschwemmungsebenen durch Bodensenkungen sind möglich, auch das Erscheinen und Verschwinden von Wasserbecken. Je nach unterseeischem oder untermeerischem Geländerelief und der Ausbildung der Küste entstehen Tsunamis von mehr als 5 Metern Höhe, die mehrere Kilometer ins Land eindringen und kleine Felsbrocken über viele Meter mitschleifen können. Tiefreichende Erosion kommt entlang der gesamten Küste vor. Die Küstenlinie kann deutlich verändert werden. Unterspülung und Verdriften von ufernahen Bäumen warden beobachtet.

c) Bei geeigneter Bodenbeschaffenheit (wassergesättigter Boden, unverfestigter Schwemmboden) treten mehr als 1 Meter offen stehende Risse mit einer Länge von bis zu mehreren hundert Metern häufig auf. Risse von mehreren Dezimetern Breite werden in hartem Felsgestein beobachtet. Breite Risse und Druckwellungen der Oberfläche entstehen in asphaltierten oder gepflasterten Straßen.

d) Große Erdrutsche (größer als 100.000 bis 1.000.000 m$^3$)sind häufig, ungeachtet des Gleichgewichtszustandes von Berghängen. Die Erdrutsche können schmale Täler versperren und so zur Entstehung eines vorübergehenden oder bleibenden Stausees führen. Flussufer, künstliche Böschungen und die Wände künstlicher Abgrabungen wie Straßeneinschnitte und Steinbrüche brechen zusammen. Straßen- und Erddämme können schwer beschädigt werden. Häufig werden unterseeische Rutschungen in Küstennähe ausgelöst.

e) Bäume werden heftig geschüttelt, viele Äste und Baumstämme brechen und fallen zu Boden, manche Bäume werden entwurzelt.

f) Bodenverflüssigung im Verbund mit Aufwallen von Wasser und Bodenverdichtung verändern das Aussehen weiter Zonen, hier treten vor allem Sandvulkane mit bis zu sechs Metern Durchmesser auf. Setzungen erreichen eine Höhe von mehr als einem Meter. Breite und lange Spalten aufgrund der seitlichen Ausbreitung von Bodenmaterial sind häufig.

g) In trockenen Gebieten steigen meistens Staubwolken auf.

h) Felsen mit mehr als 2 bis 3 m Durchmesser können in die Luft geworfen werden und auch bei geringer Geländeneigung hunderte Meter über den Boden wandern. Dabei entstehen typische Spuren in weichem Boden.

## Stufe XI

Haupteffekte überwiegen. Oberflächenrupturen von einigen Zehnerkilometern bis über hundert Kilometer Länge und mit einigen Metern Versatz treten auf. Einbruchgräben, Pressungsrücken und längliche Senken entwickeln sich, Entwässerungsmuster können stark verändert werden. Darüber hinaus kann tektonische Hebung oder Senkung der Erdoberfläche über viele Meter vorkommen.

Nebeneffekte betreffen eine Fläche in der Größenordnung von 10.000 km$^2$.

a) Die Wasserschüttung oder die Austrittshöhe vieler Quellen ändert sich deutlich. Häufig kommt es zum vorübergehenden oder vollständigen Versiegen von Quellen. Häufig sind vorübergehende Veränderungen des Wasserstandes in Brunnen. Teilweise sind starke physikalische und chemische Veränderungen des Wassers von Brunnen oder Quellen nachweisbar, meist Änderungen der Temperatur. Eine starke Verschlammung des Wassers lässt sich sogar in großen Seen sowie in Flüssen, Brunnen oder Quellen beobachten. An manchen Stellen tritt Gas aus, oft schwefelhaltig. Stellenweise kommt es zur Entzündung des Gases und die Vegetation nahe der Austrittsstelle kann verbrennen.

b) Entstehung von mehrere Meter hohen Wellen in großen Still- und Fließgewässern, die deren Bett verlassen können. Zeitweilige oder bleibende Verlagerung von Wasserläufen in Überschwemmungsebenen durch Bodensenkungen; Erscheinen und Verschwinden von Wasserbecken. Je nach unterseeischem oder untermeerischem Geländerelief und der Ausbildung der Küste entstehen Tsunamis von mehr als 15 Metern Höhe, die mehrere Kilometer ins Land eindringen und metergroße Felsbrocken über große Entfernung transportieren können. Tiefreichende Erosion kommt entlang der gesamten Küste vor, die Küstenlinie kann deutlich verändert werden. Unterspülung und Verdriften von ufernahen Bäumen sind häufig.

c) Bei geeigneter Bodenbeschaffenheit (wassergesättigter Boden, unverfestigter Schwemmboden) wird häufiges Auftreten von mehrere Meter offen stehenden Rissen beobachtet. Risse von bis zu einem Meter Breite werden in hartem Felsgestein beobachtet. Sehr breite Risse und starke Druckwellungen der Oberfläche entstehen in asphaltierten oder gepflasterten Straßen.

d) Große Erdrutsche und Felsstürze (größer als 100.000 bis 1.000.000 $m^3$) sind häufig, ungeachtet des Gleichgewichtszustandes von Berghängen, und ereignen sich in geringerem Maße noch in 200 bis 300 Kilometer vom Epizentrum. Die Erdrutsche versperren häufig schmale Täler und tragen so zur Entstehung eines vorübergehenden oder bleibenden Stausees bei. Flussufer, künstliche Böschungen und die Wände künstlicher Abgrabungen wie Straßeneinschnitte und Steinbrüche brechen zusammen. Straßen- und Erddämme können schwer beschädigt werden. Häufig werden große unterseeische Rutschungen in Küstennähe ausgelöst.

e) Bäume werden heftig geschüttelt, viele Äste und Baumstämme brechen und fallen zu Boden, manche Bäume werden entwurzelt.

f) Bodenverflüssigung verändert das Aussehen ausgedehnter Zonen, hier treten vor allem viele große Sandvulkane auf. Setzungen erreichen eine Höhe von mehreren Metern. Starke seitliche Ausbreitung von Bodenmaterial ist häufig.

g) In trockenen Gebieten steigen Staubwolken auf.

h) Felsen mit mehreren Metern Durchmesser können in die Luft geworfen werden und auch bei geringer Geländeneigung hunderte Meter über den Boden wandern. Dabei entstehen typische Spuren in weichem Boden.

## Stufe XII

Haupteffekte überwiegen. Oberflächenrupturen mit mindestens einigen hundert Kilometern Länge und mit einigen Zehnermetern Versatz treten auf. Einbruchgräben, Pressungsrücken und längliche Senken entwickeln sich, Entwässerungsmuster können stark verändert werden. Veränderungen der Landschaft und Oberflächenformen durch die Hauptwirkungen können außerordentlich ausgedehnt und groß sein. Beispiele solcher Veränderungen sind Veränderungen der Küstenhöhe von mehreren Metern, Erscheinung oder Verschwinden bedeutender Landschaftselemente oder von Seen, Änderung von Flussläufen, Entstehung von Wasserfällen.

Nebenwirkungen betreffen eine Fläche in der Größenordnung von 50.000 $km^2$ und mehr.

a) Die Wasserschüttung oder die Austrittshöhe vieler Quellen ändert sich deutlich. Häufig kommt es zum vorübergehenden oder vollständigen Versiegen von Quellen. Häufig sind vorübergehende Veränderungen des Wasserstandes in Brunnen. Starke physikalische und chemische Veränderungen des Wassers von Brunnen oder Quellen sind nachweisbar, meist Änderungen der Temperatur. Eine starke Verschlammung des Wassers lässt sich sogar in großen Seen sowie in Flüssen, Brunnen oder Quellen beobachten. An manchen Stellen tritt Gas aus, oft schwefelhaltig. Stellenweise kommt es zur Entzündung des Gases und die Vegetation nahe der Austrittsstelle kann verbrennen.

b) Entstehung von gigantischen Wellen in großen Still- und Fließgewässern, die deren Bett verlassen. Zeitweilige oder bleibende Verlagerung von Wasserläufen oder sogar der Fließrichtung in Überschwemmungsebenen durch Bodensenkungen und Erdrutsche; Erscheinen und Verschwinden von großen Wasserbecken. Je nach unterseeischem oder untermeerischem Geländerelief und der Ausbildung der Küste entstehen Tsunamis von mehreren Zehnermetern Höhe, die mehrere Kilometer ins Land eindringen und große Felsbrocken über große Entfernung transportieren können.

Tiefreichende Erosion kommt entlang der gesamten Küste vor, die Küstenlinie kann vollkommen verändert werden. Häufig Unterspülung und Verdriften von ufernahen Bäumen. Alle Boote werden aus ihrer Verankerung gerissen und weggeschwemmt oder über teilweise große Strecken landeinwärts getragen. Alle Personen, die sich in Reichweite befinden, werden weggespült.

c) Mehr als zehn Meter offen stehende und mehrere Kilometer lange Risse in wassergesättigtem Boden oder unverfestigtem Schwemmboden, Risse von mehr als einem Meter Breite werden in hartem Felsgestein beobachtet.

d) Große Erdrutsche und Felsstürze (größer als 100.000 bis 1.000.000 $m^3$) sind häufig, ungeachtet des Gleichgewichtszustandes von Berghängen, und ereignen sich auch in 200 bis 300 Kilometer vom Epizentrum in bedeutender Größe. Die Erdrutsche versperren häufig schmale Täler und tragen so zur Entstehung eines vorübergehenden oder bleibenden Stausees bei. Flussufer, künstliche Böschungen und die Wände künstlicher Abgrabungen wie Straßeneinschnitte und Steinbrüche brechen zusammen. Straßen- und Erddämme können schwer beschädigt werden. Häufig werden sehr große unterseeische Rutschungen in Küstennähe ausgelöst.

e) Bäume werden heftig geschüttelt, viele Äste und Baumstämme brechen und fallen zu Boden, manche Bäume werden entwurzelt.

f) Bodenverflüssigung verändert das Aussehen ausgedehnter Zonen, hier treten vor allem viele große Sandvulkane auf. Setzungen erreichen eine Höhe von mehreren Metern. Sehr starke seitliche Ausbreitung von Bodenmaterial ist häufig.

g) In trockenen Gebieten steigen Staubwolken auf.

h) Auch sehr große Felsen können in die Luft geworfen werden und auch bei geringer Geländeneigung hunderte Meter über den Boden wandern. Dabei entstehen typische Spuren in weichem Boden

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 63 - 74
tab. 1

# 2.6. - ESIの2007年の震度 (Japanese)

TRANSLATED: AZUMA T. (1), OTA Y. (2)

序

地震の震度階は，人や構造物（建物およびその内部構造），または自然現象（環境ないしは地質）に及ぼす地震の影響を階級区分したものである．この震度階は，あらゆる静力学的な変形および振動周期帯を考含んだ地震の強度を知る手法を提供する.

あらゆる震度階（たとえば，Rossi — Forel, メルカリ， MCS, MSK,
改正メルカリ）は，自然現象の変化を震度を判断する特徴的な要素としている．一方，自然現象の多様性や偶発性を敬遠し，人や構造物に与える影響のみを考慮した震度階も提案されている（たとえば Espinosa et al.,1976a;1076b；Grunthal,
1998．しかし，最近になって，歴史記録または古地震学的な資料に基づく自然環境の変化の特徴が震度の評価に重要であることが提案されている（たとえば Dengler & McPherson, 1993; Serva, 1994, Dowrick, 1996; ESPOSITO *et alii*, 1997; HANCOX *et alii*, 2002; Michetti et al., 2004).

この目的のために，自然現象のみに基づいたESI2007震度階が作成された
(MICHETTI *et alii*, 2007).
この震度階は，単独でも使えるし，従来からの震度階と併用することによって地震シナリオのよりよき理解をもたらすことができる．なぜならば自然現象のみが時間的にも空間的にも震度を適切に比較できるからである.
時間的；自然現象は機器で記録されている時代（20世紀）よりはるかに長い異なる時間尺度（最近の地震，歴史および古地震から求められ
るもの）で比較できる，
空間的；環境要素は特別な社会，経済的条件とか，建物の条件とは無関係であ.

したがって，この新しい震度階は従来の地震震度階と併用されることを意図している：
震度Xまたはそれ以上の地震は，被害に基づく評価が著しく困難であるが，自然現象は明確である.
人口希薄な地域で人間の構造物はないところでも自然現象に基づいて震度を評価できる．このような場所では自然現象が唯一の特徴的な要素である.

震度階の定義は，地質学者，地震学者．工学者などからなる国際ワーキンググループにより，世界的規模で多数の地震による自然現象を考慮して討議された結果である.
ESL2007は，2007 年の第17回国際第四紀学連合（オーストラリア，ケアンで開催）で改訂されたものである.

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(1) National Institute of Advanced Industrial Science and Technology, Tokyo, Japan.
(2) Emeritous of Yokohama National University, Japan.

記載

ESI2007震度階では地震の強さを12階級に区分している．各階級につけられた見出しは，地震の強さと自然環境との関係を示している，まず，各階級に対応する本質的な現象の特徴と規模を示す．二次的な現象は，震央での震度を評価するために，いくつかの範疇に区分された自然現象の分布の広がりについて記載されたものである．文章のうちの斜体で書かれている部分は，その階級の特徴的な記載を強調するために用いられている．

本質的現象は，地震エネルギー，とくに震源域の地表表現と直接に関連する．本質的な現象の規模は以下の二つの数値，i)　地表地震断層の全長（ SRL）およびii)
最大変位量（MD）により表現される：
これらの出現は，火山地域のごく浅い地震の場合を除いて通常最少で震度はVIIIに対応する．地殻変動による地表変形量（隆起，沈降）もまた考慮に入れる．

二次的現象は地地震によってもたらされる現象でおもに以下の８種類に分類される．

a)　水の変化；この範疇には泉や川への水の流出の変化，および地表または地下水の化学的物理的な性質の変化（たとえば温度やにごりの状態）がある．これらは階級IV~Xに特徴的である．

b)　異常な波/津波：この範疇には以下のものが含まれる：閉じられた水域でのセイシュ（静振），池や湖からの水の流出，および津波．津波の場合には，津波の大きさよりも，津波が海岸に与える影響（とくに狙上高，海岸侵食，海岸地形の変化）を，人や構造物への影響とともにみることが重要である．この現象は，震度IVからみられるが，IXからXIIでよりはっきりと表れる．

c)　地表の割れ目：地表の割れ目は長さ（数cm程度から数百m程度），幅（数mmから数m程度）および地表での密度などによって区分される．地表の割れ目は震度IVから現れ，Xで最大である（大きさは増えない）．

d)　斜面移動：この中には
落石，滑落，斜面移動などのあらゆるタイプの地すべりや崩壊が含まれる．地質や地形が同様ならば，土砂量や全体の面積によって区分される．震度IV
から現れ，Xで最大となる（数は増えない）

e)　木の振動：震度IVからXで現れる．この震度階の定義はおもに Dengler and McPherson (1993)による．

f)　液状化現象：泥火山，水や砂の噴出，側方流動，地盤の収縮や沈降が含まれる．これらは一般に震度VからXにみられる

g)　粉塵：乾燥地域で震度VIII 以上でみられる．

ｈ）飛び石：移動した石の最大の大きさは震度の評価にとって重要である．これらは震度IXVで現れ，XIIで最大となる．このような現象は地面の加速度が重力より大きくなる際に局地的に発生する．

自然環境に対する地震の影響は震度IV以上の場合に観察される．ある種の現象 (水文異常) はこれより小さい震度でも現れるが，特長的な要素としてとりあげられるものではない．震度が大きいものほど評価の精度は高くなる．とくに，本質的現象が出現する範囲（通常は震度VIII以上）において顕著である．震度X以上については，人や構造物への影響は

飽和してしまい（たとえば建物はほとんどが全壊），異なる震度階の間での比較が困難となる．一方，この範囲において地震による自然現象は顕著であり，震度評価に対して効果を発揮することができる．

ESI 2007震度階の活用法
ESI 2007
震度階は，人や人口構造物に対する地震の影響が過小であったり，過大であったりして，震度階の判断に自然現象しか用いることができないときに，独自に使うことを勧める．両方の震度階を利用できるときにはそれぞれを独立させて震度を評価することができる．一般に最終的な震度は，両方の評価結果のより高い方が用いられる．この場合には専門家の判断が必要であることは明らかである．

震央震度（Io）は，震央における地震動の強さを示す．自然現象に基づく震度VII以上でのIoの推定方法としては，地表地震断層による評価値と，二次的現象（地すべりまたは液状化など）の発生範囲を利用する方法がある（表１）．地表地震断層の値が震度区分の境界に近い場合には特別な配慮が必要である．この場合には，二次的現象の特徴や分布面積と照らしあわせて震度階を決定する．さらに全域の評価にあたっては，遠地で孤立して発生した現象を含めないことを勧める．この評価についても専門家の判断が重要である．

| **Io** | 本質的現象 | | 二次的現象 |
|---|---|---|---|
| | 地表地震断層の長さ | 最大地表変位 | 総面積 |
| | | | |
| **IV** | **-** | **-** | **-** |
| **V** | **-** | **-** | **-** |
| **VI** | **-** | **-** | **-** |
| **VII** | **(*)** | **(*)** | **10 km$^2$** |
| **VIII** | 数百m | 数 **cm** | **100 km$^2$** |
| **IX** | **1-10 km** | **5-40 cm** | **1000 km$^2$** |
| **X** | **10-60 km** | **40-300 cm** | **5000 km$^2$** |
| **XI** | **60-150 km** | **300-700 cm** | **10000 km$^2$** |
| **XII** | **>150** | **>700 cm** | **>50000 km$^2$** |

**(*)**
長さ**10**～**100m**程度，数**cm**程度の変位量の局地的な地表地震断層が火山地域のごく浅い地震で発生することがある.

表１．震度階ごとの地表地震断層（本質的現象）と現象発生範囲（二次的現象）

翻訳；太田陽子・吾妻　崇

**震度階の定義**

I〜III　自然現象は明瞭には現れない.

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IV: 主に観測のみ　最初の環境への明瞭な影響

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＜本質的現象＞
なし

＜二次的現象＞

a) 井戸の水位や泉の湧水量にわずかな変化が稀にみられる．カルストの大規模な湧水系では，非常にわずかな水質の化学成分の変化や混濁が生じる.

b) 閉鎖系の水域で波高数cmに満たないセイシュが発生し，通常は潮位計で観測される程度で，非常に稀に肉眼でも認識できる．小さなボートに乗っていれば異常な波に気づくが，大きな船に乗っていたり，岸にいる場合には気づかない.

c) 軟弱な沖積堆積物や含水率が高い土壌といった地質条件あるいは斜面や尾根の頂部といった地形条件においては，幅数 mm の亀裂が地表に生じることがある.

d) 均衡状態が限界に近い急斜面に沿って，落石や小規模なランドスライドが稀に発生する

e) 木々が少し揺れる.

V: 強い揺れ　環境へのわずかな影響

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＜本質的現象＞
なし

＜二次的現象＞

a) 井戸の水位や泉の湧水量に変化が稀にみられる．湖，泉，井戸で，わずかな水質の化学成分の変化や混濁が生じる.

b) 閉鎖系の水域で波高数十cmのセイシュが発生し，肉眼でも認識できる．船に乗っていても，岸にいても異常な波に気づく．プールでは波で水があふれ.

c) 軟弱な沖積堆積物や含水率が高い土壌といった地質条件あるいは斜面や尾根の頂部といった地形条件においては，幅数mm〜数cm，長さ1 m以下の亀裂が地表に生じる.

d) 小規模な落石や回転性のランドスライドや表層すべりが急傾斜地に限らず発生する. 水面下のランドスライドによって、小規模ではあるが異常な波が海岸や湖岸で発生する.

e) 木の枝や茂みがわずかに揺れ，稀に枯れた枝や熟した実が落ちる.

f) 年代の新しい沖積層や海成層が堆積し，地下水位が高い地域で，ごく稀に小規模な液状化現象（噴砂）が生じる.

VI: わずかな被害　　　中程度の自然現象

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＜本質的現象＞
なし

＜二次的現象＞

a) 井戸の水位や泉の湧水量に顕著な変化がみられる．湖，泉，井戸で，わずかな水質の化学成分の変化や混濁が生じる.

b) 波高数十cmの異常な波が発生し，岸近くに限られた地域に浸水する．池やプールでは波で水があふれる

c) *軟弱な沖積堆積物や含水率が高い土壌といった地質条件においては，幅数mm〜数cm, 長さ数 mの亀裂が地表に生じる．急斜面や河畔では亀裂の幅が1〜2cmに達する．舗装道路にもわずかに亀裂が生じる.*

d) 急斜面や切り割りなど均衡状態が限界に近い場所で含水率が高い土壌や風化が進んだ岩盤地域を中心に，$10^3$ ㎥規模に達する落石やランドスライドが発生する．水面下のランドスライドによって、小規模ではあるが異常な波が海岸や湖岸で発生する

e) 木や茂みがかなり揺れ，ごく一部で木の梢や枯れた枝が落ち，種類によっては健全な実が落下する.

f) 年代の新しい沖積層や海成層が堆積し，地下水位が高い地域で，稀に小規模な液状化現象（噴砂）が生じる.

## VII: 被害発生　感知できる程度の自然現象

＜本質的現象＞
極めて稀であり，火山地域に限られる．長さが数十〜数百m，ずれ量が数cmの地表地震断層が，震源のごく浅い地震で生じる．

＜二次的現象＞　現象発生の総面積は $10\ km^2$ 規模

a) 井戸の水位や泉の湧水量に一時的に顕著な変化がみられる．めったにはないが，小規模な泉が一時的に湧き出たり，消失したりする．湖，泉，井戸で，わずかな水質の化学成分の変化や混濁が生じる．

b) 沿岸では波高1m以上の異常な波が発生し，岸近くに限られた地域に浸水して様々な大きさのものが流される．水路や池などでは波で水があふれる．

c) *幅5-10 cm, 長さ数百m以下の地表亀裂が，軟弱な沖積層や含水率の高い土壌では共通して，乾燥した年度やや砂，土壌では稀にみられる．舗装道路に幅数cmの亀裂が入る．*

d) 不安定な場所（急斜面や含水率の高い土壌）でランドスライドが散在的に発生し、その規模は乾燥した砂や土壌では$10^3$−$10^5$㎥である。堤防や採石場等で、亀裂や滑落、崩落が発生する．顕著な水面下のランドスライドによって異常な波が発生し，海岸や船上でも認識される．

e) 木々が激しく揺れ，森林では木の梢や枝が多く落ちる．

f) 年代の新しい沖積層や海成層が堆積し，地下水位が高い地域で，稀に直径50cm以下の噴砂等の液状化現象が生じる．

## VIII: 著しい被害　広域的な自然現象

＜本質的現象＞
稀に観察される．

*長さが数百m以下，ずれ量が数 cm 以下の地表地震断層が，震源が浅い地震で生じる．数 cm 規模の隆起・沈降が生じる．*

＜二次的現象＞　現象発生の総面積は $100\ km^2$ 規模

a) 泉の湧水量が変化するが，通常は一時的である．小規模な池が干上がる．井戸の地下水位変化が観察される．井戸や泉で水温異常などのわずかな変化が観察される．閉鎖系の池や河川，井戸や泉で水が混濁する．硫黄を含むガスが発生する．

b) 沿岸で波高1〜2mの異常な波が発生し，様々な大きさのものが流される．海岸では浸食

と漂着がみられ，根が弱い小さな木は根こそぎ運ばれる．水路や池では激しい波で水があふれる．

c) *軟弱な沖積堆積物や含水率の高い土壌などで幅50cm以下、長さ数百m以下の地表亀裂が発生する．乾燥した岩盤に幅1cm以下の亀裂が稀に観察される．舗装道路に幅数十cmの亀裂や圧縮による小規模な起伏が生ずる．*

d) 小〜中規模（$10^3-10^5$
$m^3$) の落石やランドスライドが広域に発生し，緩斜面で発生することもある．不安定な場所や峡谷や海食崖では$10^5$〜$10^6$
$m^3$) 規模に達する．小河川がせき止められ，一時的に湖が形成される．堤防や採石場等で、亀裂や滑落、崩落が発生する．顕著な水面下のランドスライドが発生する．

e) *木々が激しく揺れる．急な斜面では木の根が抜ける．*

f) *震央域では直径1m以下の噴砂等の液状化現象が生じる．水中でも水の噴出が起こる．河畔や湖，水路，海岸などの水域周辺に沿って，側方流動や30cm以下の地盤沈下がみられる．*

g) *乾燥地域では，震央周辺で粉塵雲が発生することがある．*

h) 砂や小礫，倒木等が宙に浮き上がり，柔らかい土壌の上に跡を残す．

IX: 破壊的

自然現象が被害の特徴的な原因として広域に認められ，震度の評価にとって重要になる．

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＜本質的現象＞
広い地域で観察される．

長さ数km以下，ずれ量数cm程度の地表地震断層が発生する．地殻変動による数十cm規模の隆起・沈降が生じる．

＜二次的現象＞　　現象発生の総面積は1,000 $km^2$規模

a) *泉の湧水量が変化するが，通常は一時的である．中規模な池が干上がる．井戸の地下水位変化が観察される．井戸や泉で水温異常などのわずかな変化が観察される．閉鎖系の池や河川，井戸や泉で水が混濁する．硫黄を含むガスが発生し，周辺の草木が燃えることがある．*

b) *波高数mの波が静水域や流水域で発生する．氾濫原では河川の流路変更が生じる．海底地形や海岸の形状によっては波高数mの津波が発生し，広範囲に浸水する．海岸では浸食と漂着がみられ，根が弱い小さな木は根こそぎ運ばれる．*

c) *軟弱な沖積堆積物や含水率の高い土壌などで幅100
cm以下、長さ数百m以下の地表亀裂が発生する．乾燥した岩盤に幅10
cmに達する亀裂が観察される．舗装道路に顕著な亀裂や圧縮による変形が生ずる．*

d) *落石やランドスライドが広域に発生し，緩斜面で発生することもある．不安定な場所や峡谷や海食崖では，その規模は多くが$10^5 m^3$であるが$10^6 m^3$規模に達するものもある．小河川がせき止められ，一時的に湖が形成される．堤防や採石場等で、亀裂や滑落、崩落が発生する．顕著な水面下のランドスライドが頻繁に発生する.*

e) *木々が激しく揺れる．枝や細い幹が折れたり，倒れたりすることが頻繁にみられる．急な斜面では木の根が抜ける.*

f) *液状化現象や水の噴出が多く見られる．噴砂の直径は 3m 以下に達する。沿岸域では側方流動や 30 cm を超える地盤沈下が多くみられる.*

g) 乾燥地域では，震央周辺で粉塵雲が発生する.

h) *小礫や倒木が宙に飛び上がり，斜面状態などによっては数m移動する．柔らかい土壌の上に跡を残す.*

X: 非常に破壊的
自然現象が被害の主要な要因となり，震度の評価にとって決定的とな.

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＜本質的現象＞
主要な現象となってくる.
長さ数十km 以下，ずれ量数十cm～数m 程度の地表地震断層が発生する．重力性の地溝や引長性の陥没が形成される．火山地域の震源がごく浅い地震で，地表破断がより長くなる．数m規模の隆起・沈降が生じることがある

＜二次的現象＞　現象発生の総面積は 5,000 $km^2$ 規模

a) 多くの泉の湧水量が変化する．複数の池が干上がる．井戸で一時的な水位変化が広く観察される．井戸や泉で水温異常などの顕著な変化が観察される．閉鎖系の池や河川，井戸や泉で水が混濁する．硫黄を含むガスが発生し，周辺の草木が燃えることがある.

b) *波高数 m の波が大きな湖や河川で発生し，水があふれる．氾濫原では，広域に生じた地盤の沈降によって河川の流路が一時的あるいは恒久的に変更する．海底地形や海岸の形状によっては波高 5 mを超える津波が発生し，平地では海岸線から数千mまで浸水する．小さめの巨礫が数 m 運ばれる．海岸では広域で大きく浸食を受け，海岸線の様子が変化する.*

c) *軟弱な沖積堆積物や含水率の高い土壌などで幅 100 cm以上，長さ数百m以上の地表亀裂が発生する．乾燥した岩盤に幅数十cm に達する亀裂が発生する．舗装道路に幅広い亀裂や圧縮による変形が生ずる.*

d) *大規模な（$10^5$–$10^6$ $m^3$以上）落石やランドスライドが，斜面の安定性とは関係なく頻繁に発生する．河川がせき止められ，一時的あるいは恒久的な湖が形成される．堤防や採石場等で、亀裂や滑落、崩落が発生する．自然堤防や天然ダムが深刻な損傷を受ける．大規模な水面下のランドスライドが頻繁に発生する．*

e) *木々が激しく揺れる．枝や細い幹が折れたり，倒れたりすることが頻繁にみられる．木の根が抜けて倒れることもある．*

f) *噴砂や圧密沈下などの液状化現象が多く見られる．直径6 m以上の噴砂丘が形成される．1 mを超える地盤沈下が発生する．大規模で広い範囲にわたる側方流動が発生する．*

g) 乾燥地域では，震央周辺で粉塵雲が発生する．

h) *直径2-3mの礫が宙に飛び上がる．緩斜面上でも数百m下方へ移動し，土壌の上に跡を残すことがある．*

XI: 壊滅的

構造物被害が飽和状態になるため，自然現象が震度評価にとってより決定的となる

＜本質的現象＞

現象が卓越する．

長さ数十～100 km以上，ずれ量数mの地表地震断層が発生する．重力性の地溝や引長性の陥没が形成される．水系が著しくずれる．数m規模の隆起・沈降が生じる

＜二次的現象＞　　現象発生の総面積は10,000 $km^2$規模

a) 多くの泉の湧水量が変化する．多くの泉が一時的あるいは恒久的に干上がる．井戸で一時的あるいは恒久的な水位変化が広く観察される．井戸や泉で水温異常などの顕著な変化が観察される．池や河川，井戸や泉で水が泥質になる．硫黄を含むガスが発生し，周辺の草木が燃えることがある．

b) *大きな波が大きな湖や河川で発生し，水があふれる．氾濫原では，広域に生じた地盤の沈降やランドスライドによって河川の流路が一時的あるいは恒久的に変更される．海底地形や海岸の形状によっては波高15 mに達する津波が発生し，平地では海岸線から数kmまで浸水する．1 m以上の巨礫が長い距離を引きずられる．海岸では広域で大きく浸食を受け，海岸線の様子が変化する．海岸付近の木は引き抜かれて，流失する．*

c) *主に軟弱な沖積堆積物や含水率の高い土壌などで，幅1 m以上の地表亀裂が非常に頻繁に発生する．堅固な岩盤に幅数1*

*mに達する亀裂が発生する．舗装道路に幅広い亀裂や圧縮による大規模な変形が生ずる.*

d) 大規模な（$10^5$–$10^6$
$m^3$ 以上）落石やランドスライドが，斜面の安定性とは関係なく頻繁に発生する．河川がせき止められ，一時的あるいは恒久的な湖が形成される．堤防や採石場等で、亀裂や滑落、崩落が発生する．自然堤防や天然ダムが深刻な損傷を受ける．顕著なランドスライドが震央から200〜300 km
離れた場所でも発生する．水面下で大規模なランドスライドが頻繁に発生する.

e) *木々が激しく揺れる．枝や細い幹が折れたり，倒れたりすることが頻繁にみられる．多くの木の根が抜けて倒れる.*

f) 液状化現象により低地の大部分は大きく変化し、数 m を超える地盤沈下が広域でみられる．大規模な噴砂丘や著しい側方流動が多数みられる.

g) 乾燥地域では，粉塵雲が地表から舞い上がる.

h) *直径数 m の礫が宙に飛び上がり，緩斜面上でもはるか下方へ移動し，土壌の上に跡を残すことがある.*

XII: 完全な壊滅状態　　自然現象が震度評価の唯一の指標となる

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＜本質的現象＞
卓越する.

長さ100 km以上、ずれ量10
m以上の地表地震断層が発生する．重力性の地溝や引長性の陥没が形成される．水系が著しくずれる．本質的な影響によって，隆起や沈降で河川が消失したり，滝ができたり，湖が形成・消失するなど，地形が様変わりする.

＜二次的現象＞　　現象発生の総面積は 50,000 $km^2$ 規模

a) 多くの泉の湧水量が変化する．多くの泉が一時的あるいは恒久的に干上がる．井戸で一時的あるいは恒久的な水位変化が広く観察される．井戸や泉で水温異常などの顕著な変化が観察される．池や河川，井戸や泉で水が泥質になる．硫黄を含むガスが発生し，周辺の草木が燃えることがある.

b) *巨大な波が大きな湖や河川で発生し，水があふれる．氾濫原では，広域に生じた地盤の沈降やランドスライドによって河川の流路が一時的あるいは恒久的に変更する．海底地形や海岸の形状によっては波高数十*
*mに達する津波が発生し，平地では海岸線から数kmまで浸水する．大きな巨礫が長い距離を引きずられる．海岸では広域で大きく浸食を受け，海岸線の様子が変化する．海*

*岸付近の木は引き抜かれて，流失する．船はすべて繋がれたところから離され，流失したり，はるか内陸へ打ち上げられる．屋外にいる人は皆流される．*

c) 幅1 m以上の地表亀裂が非常に頻繁に発生する．堅固な岩盤に幅数1 mに達する亀裂が基盤上に発生する．軟弱な沖積堆積物や含水率の高い土壌などでは10 m以上に及ぶ．これらの長さは数kmになることもある．

d) 大規模な（$10^5$–$10^6$ $m^3$ 以上）落石やランドスライドが，斜面の安定性とは関係なく頻繁に発生する．河川がせき止められ，一時的あるいは恒久的な湖が形成される．堤防や採石場等で、亀裂や滑落、崩落が発生する．自然堤防や天然ダムが深刻な損傷を受ける．顕著なランドスライドが震央から200～300 km以上離れた場所でも発生する．水面下で非常に大規模なランドスライドが頻繁に発生する．

e) *木々が激しく揺れる．枝や細い幹が折れたり，倒れたりすることが頻繁にみられる．多くの木の根が抜けて倒れる．*

f) 液状化現象が広い範囲で発生し，低地の大部分で地形を大きく変化させる．数mを超える地盤沈下が広域でみられる．大規模な噴砂丘や著しい側方流動が多数みられる．

g) 乾燥地域では，粉塵雲が地表から舞い上がる．

h) *直径数mの礫が宙に飛び上がる．非常に緩い勾配の緩斜面上でも礫がはるか下方へ移動し，土壌の上に跡を残すことがある．*

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 75 - 84
tab. 1

# 2.7. - Шкала сейсмической интенсивности на основании природных эффектов - ESI 2007 (Russian)

TATEVOSSIAN R. (1)

## *Введение*

Интенсивность землетрясений основана на классификации эффектов сейсмического события по ощущениям людей, реакции искусственных сооружений (здания и инфраструктура) и в природной среде (природные или геологические эффекты). Определенная таким образом интенсивность дает представление о силе землетрясения в широком диапазоне частот от вибраций до статических деформаций.

Все шкалы интенсивности (Росси-Фореля, Меркалли, MCS, MSK, модифицированная Меркалли) рассматривали эффекты в природной среде в качестве диагностического признака для оценки балльности. В отличие от этого некоторые современные шкалы (например, Espinosa *et alii*, 1976a; 1976b; Grunthal, 1998) учитывают только реакцию людей и зданий и сооружений., существенно снижая диагностическое значение природных эффектов, исходя из того, что они слишком неустойчивы и случайны. Между тем недавние исследования (например, Dengler & McPherson, 1993; Serva, 1994, Dowrick, 1996; Esposito *et alii*, 1997; Hancox *et alii*, 2002; Michetti *et alii*, 2004) продемонстрировали убедительные свидетельства того, что характерные признаки природных эффектов, которые могут быть сегодня получены из исторических источников и палеосейсмологических исследований, несут существенную информацию для оценки величины землетрясения и в частности интенсивности.

С этой целью была создана шкала интенсивности ESI2007 (Michetti *et alii*, 2007) основанная исключительно на эффектах в природной среде. Ее использование, отдельно либо совместно с другими традиционными шкалами, нацелено на более полное описание сценария землетрясения, поскольку только природные эффекты позволяют сравнение интенсивности:

• во времени: эффекты в природной среде сравнимы для гораздо более длительного временного окна (современные, исторические и палео землетрясения), чем период инструментальной регистрации (последнее столетие) и

• в различных географических областях: природные эффекты не зависят от социальных и экономических условий либо от различия в строительных технологиях.

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• Новая шкала нацелена на дополнение традиционных сейсмических шкал:

• для интенсивности равной или превышающей X баллов, когда оценки основанные на повреждении зданий и сооружений практически невозможны, тогда как природные эффекты все еще могут использоваться для диагностики;

• в малонаселенных областях, где эффекты на зданиях и сооружениях отсутствуют и потому оценка интенсивности может основываться только на природных эффектах, которые в этом случае являются единственным диагностическим элементом.

Шкала является результатом работы международной рабочей группы, сформированной из геологов, сейсмологов и инженеров, нацеленных на анализ природных эффектов большого числа землетрясений по всему миру. Шкала ESI2007 была принята INQUA (Международный союз по четвертичной геологии) на своем XVII конгрессе в Каирне, Австралия в 2007 г.

## Описание

Шкала интенсивности ESI2007 двенадцатибалльная. Название балла соответствует силе землетрясения и роли природных эффектов. В описании балла вначале указываются параметры первичных природных эффектов. Затем описываются вторичные эффекты, начиная с общей площади их распространения, что используется для оценки эпицентральной интенсивности. Эффекты сгруппированы по категориям в порядке их распространенности. Текст, выделенный курсивом, указывает на основные диагностические признаки для данного балла.

**Первичные эффекты** прямо связаны с энергией землетрясения и с выходом на поверхность очага землетрясения. Величина первичных эффектов обычно выражается двумя параметрами: 1) общая длина разрывов (SRL) и 2) максимальное смещение (MD). Как правило их появление связано с интенсивностью как минимум VIII баллов, за исключением приповерхностных землетрясений в вулканических областях. Учитывается также величина тектонических деформаций (поднятия и опускания).

**Вторичные эффекты** – это любые явления, вызванные сотрясениями грунта. Они сгруппированы в восемь основных категорий.

***a)*** ***Гидрологические аномалии***: в эту категорию включены сообщения об изменении дебита источников и рек, а также изменения химических и физических свойств поверхностных и грунтовых вод (например, температура, мутность). Эти эффекты являются диагностическими от IV до X баллов.

***b)*** ***Аномальные волны/цунами***: в эту категорию включены сейши в закрытых бассейнах, выплескивание воды из бассейнов и волны цунами. В случае цунами, диагностическое значение даже больше, чем сама высота волны, имеют эффекты на берегах (особенно высота заплеска, эрозия берега, изменение морфологии берега). Нельзя также игнорировать воздействие цунами на здания и сооружения. Эффект может наблюдаться уже при IV баллах, но является диагностическим от IX до XII баллов.

***c)*** ***Трещины в грунте***: описываются в терминах длины (от см до нескольких сотен метров), ширины (от мм до м), площадной плотности. Трещины в грунте появляются при IV баллах и насыщаются (т.е. их размеры перестают расти) при интенсивности X баллов.

***d)*** ***Склоновые движения***: включает все типологии оползней, включая камнепады и грязевые потоки. В одинаковых литологических и морфологических условиях диагностическим параметром является объем т общая площадь. Они возникают при IV баллах и насыщаются (т.е. их размеры перестают расти) при интенсивности X баллов.

***e)*** ***Качание деревьев***: является диагностическим от IV до X баллов. Определения балла по этому признаку основываются на предложениях Dengler, McPherson (1993).

***f)*** ***Разжижения***: в эту категорию включены песчаные вулканы, фонтанирование песка и воды, некоторые типы оседания и обрушение грунта. Их величина является диагностической в интервале от V до X баллов.

*g)* ***Пыльные облака***: могут наблюдаться в засушливых/пустынных областях начиная с VIII баллов.

*h)* ***Подбрасывание камней***: максимальная величина подброшенных камней является диагностической для оценки интенсивности. Это явление наблюдается как минимум при IX баллах и вплоть до XII баллов. Свидетельствует в пользу того, что локально сила тяжести может быть превышена начиная с IX баллов.

Природные эффекты могут наблюдаться начиная с интенсивности IV балла. Некоторые категории природных эффектов (гидрологические аномалии) могут наблюдаться и при меньшей интенсивности,

но они не могут служить диагностическими элементами. Точность оценок возрастает для высших баллов, в частности, когда начинают появляться первичные эффекты (обычно от VIII баллов) – они остаются диагностическими вплоть до XII баллов. Начиная с X балов эффекты на зданиях и сооружениях насыщаются (т.е. здания часто полностью разрушены) и потому нет возможности на их основании различать балльность. В этом диапазоне природные эффекты доминируют и потому являются наиболее действенным средством оценки интенсивности.

## *Как пользоваться шкалой ESI2007*

Использование шкалы интенсивности ESI2007 как самостоятельного средства оценки интенсивности рекомендуется лишь в случае, когда, из-за насыщения реакции людей и эффектов на зданиях и сооружениях либо их отсутствия, природные эффекты являются единственными диагностическими признаками. Если же эффекты на зданиях и сооружениях также доступны, тогда становится возможным оценить интенсивность двумя независимыми способами. Обычно, заключительная оценка равна большей из этих двух. Но, разумеется, в такой ситуации окончательное решение является экспертным.

Эпицентральная интенсивность ($I_0$) обозначает интенсивность, относящуюся к эпицентру. Размеры выхода очага на поверхность и общая площадь распространения вторичных эффектов (оползни и/или разжижения) являются двумя независимыми параметрами для оценки $I_0$ начиная с интенсивности VII баллов (таблица 2.1).

Особую осторожность следует соблюдать, когда параметры выхода очага на поверхность находятся вблизи пограничного значения между двумя соседними баллами. В таком случае следует выбрать то значение балла, которое наилучшим образом согласуется с общей площадью проявления вторичных эффектов. Определяя общую площадь вторичных эффектов не следует включать в оценку отдельно отстоящие изолированные эффекты в дальней зоне. Эта оценка основывается на экспертном заключении.

Локальная интенсивность в основном определяется по описаниям вторичных эффектов на «площадках», которые принадлежат данному «пункту». Оцененная таким образом интенсивность должна соответствовать оценкам локальной интенсивности с использованием традиционных шкал, использующих для диагностики повреждения. Следует обратить внимание на

то, что «пункт» может относится как к населенному пункту (деревня или город), так и к природному объекту, на котором отсутствуют жилища. Когда единственная доступная информация представлена первичными эффектами, локальная интенсивность может быть определена на основании максимального смещения.

Табл. 2.1 - *Интервалы параметров поверхностных разрывов (первичные эффекты) и типичные величины площади (вторичные эффекты) для соответствующих баллов интенсивности.*

| $I_0$ | ПЕРВИЧНЫЕ ЭФФЕКТЫ | | ВТОРИЧНЫЕ ЭФФЕКТЫ |
|---|---|---|---|
| | ДЛИНА ПОВЕРХНОСТНЫХ РАЗРЫВОВ | MAX СМЕЩЕНИЕ / ДЕФОРМАЦИЯ | ОБЩАЯ ПЛОЩАДЬ |
| **IV** | - | - | - |
| **V** | - | - | - |
| **VI** | - | - | - |
| **VII** | (*) | (*) | 10 км$^2$ |
| **VIII** | сотни метров | сантиметровые | 100 км$^2$ |
| **IX** | 1 - 10 км | 5 - 40 см | 1000 км$^2$ |
| **X** | 10 - 60 км | 40 - 300 см | 5000 км$^2$ |
| **XI** | 60 – 150 км | 300 –700 см | 10000 км$^2$ |
| **XII** | > 150 км | > 700 cm | > 50000 км$^2$ |

(*) Ограниченные поверхностные разрывы в десятки и сотни метров длиной с сантиметровыми смещениями по ним могут возникать в случае приповерхностных очагов землетрясений в вулканических областях.

## Определения градаций шкалы

От I до III баллов: природных эффектов, пригодных для оценки интенсивности, нет.

### IV – ШИРОКО НАБЛЮДАЕМОЕ – появляются первые явные природные эффекты

*Первичные эффекты* отсутствуют

Вторичные эффекты:

a) Редко локально отмечаются небольшие вариации уровня воды в колодцах и/или дебита источников, а также крайне редко – небольшие вариации физико-химических свойств воды и помутнение источников, особенно в крупных карстовых провинциях, которые, видимо, наиболее подвержены этому явлению.

b) В закрытых водоемах (озерах и даже морях) могут развиваться сейши высотой не более нескольких сантиметров, обычно регистрируются только мореографами, в исключительных случаях могут быть замечены визуально, обычно в дальней зоне сильных землетрясений. Аномальные волны ощущают все люди в небольших лодках, некоторые – и на больших судах, большинство – на берегу. Вода в плавательных бассейнах плещется и иногда может выплескиваться.

c) Иногда могут наблюдаются волосяные трещины (миллиметровой ширины) в местах, где литология (например, рыхлые аллювиальные отложения, влагонасыщенная почва) и/или морфология (крутые склоны или седловины) наиболее благоприятны для возникновения таких явлений.

d) В исключительных случаях могут срываться камни и (ре)активизироваться небольшие оползни вдоль склонов, которые находятся на пределе устойчивости, например, крутые склоны и разрезы с рыхлой и часто влагонасыщенной почвой.

e) Ветки деревьев слабо раскачиваются.

### V – СИЛЬНОЕ – пограничные эффекты в природе

*Первичные эффекты* отсутствуют

*Вторичные эффекты:*

a) Редко локально наблюдаются вариации уровня воды в колодцах и/или дебита источников, а также небольшие вариации физико-химических свойств воды и помутнение воды в озерах, колодцах и источниках.

b) В закрытых водоемах (озерах и даже морях) могут развиваться сейши высотой в дециметры, иногда видимые невооруженным глазом обычно в дальней зоне сильных землетрясений. Аномальные волны высотой до нескольких десятков сантиметров ощущают все люди в лодках и на берегу. Из плавательных бассейнов выплескивается вода.
c) Тонкие трещины (миллиметровой ширины и длиной от нескольких сантиметров до одного метра) наблюдаются локально в местах, где литология (например, рыхлые аллювиальные отложения, влагонасыщенные почвы) и/или морфология (склоны или седловины) наиболее благоприятны для возникновения таких явлений.
d) Редко могут возникать небольшие камнепады, оползни и грязевые потоки часто, но не обязательно, вдоль крутых склонов, равновесие которых близко к предельному, главным образом, в рыхлых отложениях и влагонасыщенной почве. Могут возникать подводные оползни, которые образуют небольшие аномальные волны в прибрежных областях морей и озер.
e) Ветви деревьев и кустарники слабо качаются, в редких случаях падают отмершие ветки и спелые фрукты.
f) В исключительно редких случаях сообщается о разжижении (песчаные воронки) небольшого размера и в областях наиболее подверженных этому явлению (рыхлые аллювиальные или прибрежные отложения, высокий уровень грунтовых вод).

## VI – С ЛЕГКИМИ ПОВРЕЖДЕНИЯМИ – умеренные природные эффекты

*Первичные эффекты* отсутствуют

*Вторичные эффекты:*
a) Локально отмечаются значительные вариации уровня воды в колодцах и/или дебита источников, а также небольшие вариации химико-физических свойств воды и помутнение ее в озерах, источниках и колодцах.
b) Аномальные волны высотой в десятки сантиметров заливают ограниченные участки близ берега. Из плавательных бассейнов, небольших прудов и бассейнов выплескивается вода.
c) *В редких случаях разрывы шириной в миллиметры – сантиметры и длиной до нескольких метров наблюдаются в рыхлых аллювиальных отложениях и/или во влагонасыщенных грунтах; вдоль крутых склонов или вдоль речного берега они достигают 1 – 2 см в ширину. Небольшое количество мелких трещинок развивается на дорогах с покрытием (асфальт или булыжник).*
d) Возникают камнепады и оползни объемом около $10^3 м^3$ особенно в местах, где состояние равновесия близко к предельному, например, на крутых склонах и разрезах с рыхлой водонасыщенной почвой или с сильно выветрелыми/трещиноватыми скальными породами. Возникают подводные оползни, иногда образуя небольшие аномальные волны в прибрежных районах морей и озер, обычно хорошо видны на инструментальных записях.
e) Деревья и кусты раскачиваются от умеренного до сильного. В редких случаях верхушки деревьев и отмершие ветки могут ломаться и падать, что зависит также от породы дерева, его состояния и нагруженности плодами.
f) *В редких случаях сообщается о разжижениях (песчаные воронки) небольшого размера в местах наиболее подверженных этому явлению (рыхлые аллювиальные или прибрежные отложения, высокий уровень грунтовых вод)*

## VII – С ПОВРЕЖДЕНИЯМИ – заметные природные эффекты

*Первичные эффекты* наблюдаются крайне редко и почти исключительно в вулканических областях. Могут возникать небольшие поверхностные разрывы длиной в десятки и сотни метров с сантиметровыми смещениями, которые связаны с очень неглубокими землетрясениями.

*Вторичные эффекты:* Общая площадь порядка 10 $км^2$.
a) *Локально отмечаются существенные временные вариации уровня воды в колодцах и/или дебита источников. Редко небольшие источники могут временно высыхать или возникать. Локально отмечаются слабые вариации химико-физических свойств воды и помутнение ее в озерах, источниках и колодцах.*
b) Аномальные волны высотой свыше метра могут заливать небольшие прибрежные участки и повреждать или смывать объекты различного размера. Вода может выплескиваться из небольших бассейнов и каналов.
c) *Наблюдаются трещины шириной 5 – 10 см и длиной до сотни метров обычно в рыхлых аллювиальных отложениях и/или влагонасыщенных грунтах, реже в сухих песках, песчано-глинистых и глинистых грунтах также возникают разрывы шириной до 1. Сантиметровые трещины обычны на дорогах с покрытием (асфальт или булыжник).*
d) Возникают отдельные оползни в местах с неустойчивым равновесием (крутые склоны из рыхлых/влагонасыщенных почв) между тем как небольшие камнепады часто возникают на крутых утесах, скалах. Их размер иногда может быть значительным ($10^3 – 10^5 м^3$); в сухих песках, в песчано-глинистых и глинистых грунтах

объем обычно достигает 100 м$^3$. Разрывы, оползни и камнепады повреждают берега рек, причалы и выемки (например, карьеры и дорожные разрезы) в рыхлых осадках или выветрелых/трещиноватых скальных породах. Могут возникать значительные подводные оползни, образующие аномальные волны в прибрежных районах морей и озер, непосредственно ощущаемые людьми в лодках и в гаванях.

e) Деревья и кусты энергично качаются; в лесных массивах многие ветви и верхушки деревьев ломаются и падают.

f) *Редко сообщается о разжижениях с образованием песчаных воронок диаметром 50 см в областях, наиболее подверженных этому явлению (свежие аллювиальные отложения, высокий уровень грунтовых вод).*

## VIII – С СИЛЬНЫМИ ПОВРЕЖДЕНИЯМИ - Обширные природные эффекты

*Первичные эффекты:* наблюдаются редко.

*Поверхностные разрывы (выход очага) могут достигать несколько сотен метров со смещениями по нему не превышающими несколько см, особенно для очень неглубоких очагов, как в вулканических областях. Тектоническое поднятие или опускание достигает максимум несколько см.*

*Вторичные эффекты:* Общая площадь порядка 100 км$^2$.

a) Меняется (обычно временно) дебит источников и/или место выхода. Некоторые небольшие источники могут даже высохнуть. Наблюдается изменение уровня воды в колодцах. Наблюдаются небольшие вариации физико-химических свойств воды (чаще всего температуры) в источниках и/или колодцах. Может наблюдаться помутнение воды в закрытых бассейнах, реках, колодцах и источниках. Локально наблюдаются эманации газа, часто с содержанием серы.

b) Аномальные волны до 1-2 м высотой заливают прибрежные районы и могут повреждать или смывать объекты различных размеров. Наблюдается подмыв берега и откладывание мусора вдоль пляжей, где кусты и даже небольшие деревья могут быть сорваны с мест и перемещены. Вода с силой выплескивается из небольших бассейнов и каналов.

c) *Обычно в рыхлых аллювиальных отложениях и/или влагонасыщенных почвах возникают трещины до 50 см шириной и сотни метров в длину; в редких случаях трещины до 1 см наблюдаются в сухом скальном грунте. Обычно возникают дециметровые трещины на дорогах с покрытием (асфальт или булыжник), а также небольшие складки сдавливания.*

d) Широко распространены многочисленные оползни от небольших до умеренных ($10^3$ – $10^5$ м$^3$); в том числе (редко) на пологих склонах; в местах неустойчивых склонов (крутые склоны рыхлые/водо-насыщенные почвы; крутые утесы и береговые скалы) их размер может достигать ($10^5$ – $10^6$ м$^3$). Оползни иногда могут запруживать узкие долины, создавая временные или даже постоянные озера. Наблюдаются трещины, оползания и отрывы на берегах рек и искусственных выемках (например, дорожные разрезы и карьеры) в рыхлых осадках или выветрелых/трещиноватых скальных породах. Часто возникают подводные оползни в прибрежных районах.

e) *Деревья энергично качаются, ломаются и падают ветви, дерево может вырываться с корнем, особенно на крутых склонах.*

f) *В зависимости от локальных условий в эпицентральной области часто могут наблюдаться разжижения; наиболее типичные эффекты: песчаные воронки до 1м в диаметре, фонтанирование воды, локализованные участки бокового сдавливания и опускания (опускание до 30 см) с образованием трещин параллельных фронту воды (речные берега, каналы, морской берег).*

g) *В сухих районах эпицентральной области могут подниматься клубы пыли.*

h) Камни и даже небольшие валуны, а также стволы деревьев могут быть подброшены вверх, оставляя типичные отпечатки в мягком грунте.

## IX – РАЗРУШИТЕЛЬНОЕ – Природные эффекты являются источником значительной опасности и становятся важными для оценки интенсивности

*Первичные эффекты:* наблюдаются повсеместно.

*Поверхностные разрывы (выход очага) могут достигать несколько километров обычно со смещениями по ним порядка нескольких см. Тектоническое поднятие или опускание достигает максимум нескольких дм.*

*Вторичные эффекты:* Общая площадь порядка 1000 км$^2$.

a) *Значительно меняется (обычно временно) дебит источников и/или место выхода. Источники среднего размера могут высыхать. Обычно наблюдаются временные вариации уровня воды в колодцах. Наблюдаются вариации* *физико-химических свойств воды, чаще всего – температуры, в источниках и/или колодцах. Наблюдаются эманации газа обычно с содержанием серы, кусты и трава в зоне эманации могут сгорать.*

b) *Образуются метровые волны в стоячей и текущей воде. В пойменных долинах речные потоки могут менять русло, в том числе из-за тектонического опускания. Небольшие бассейны могут высыхать. В зависимости от рельефа дна и береговой линии цунами может достигать прибрежной полосы с высотой заплеска в несколько метров, заливая обширные участки. Широко распространены подмыв и откладывание мусора вдоль пляжей, где кусты и деревья могут быть сорваны с мест и перемещены.*

c) *Обычно в рыхлых аллювиальных отложениях и/или влагонасыщенных почвах возникают трещины до 100 см шириной и сотни метров в длину; в твердом грунте - до10 см. Значительные трещины на дорогах с покрытием (асфальт или булыжник), а также небольшие складки сдавливания.*

d) *Оползневые явления широко распространены, даже на пологих склонах; в неустойчивых местах (крутые склоны с рыхлыми / влагонасыщенными почвами, крутые скалы и береговые утесы) часто они могут достигать объема $10^5 м^3$ иногда даже $10^6$ $м^3$. Оползни могут запруживать узкие долины, образуя временные и даже постоянные озера. Часто обрушаются речные берега, искусственные набережные и выемки (дорожные разрезы и карьеры).*

e) *Деревья энергично раскачиваются, ветви и тонкие стволы часто ломаются и падают. Некоторые деревья могут вырываться с корнем и опрокидываться, в особенности на крутых склонах.*

f) *Часто возникают разжижения и выброс воды. Наиболее типичные эффекты: песчаные кратеры до 3 м в диаметре, фонтанирование стоячей воды, часты явления бокового сдавливания и опускания (опускание до 30 см), с образованием трещин параллельных фронту воды (речные берега, каналы, морской берег).*

g) В сухих районах могут подниматься клубы пыли.

h) *Небольшие валуны и стволы деревьев могут быть подброшены в воздух и сдвинуты на метры от начального положения, оставляя типичные отпечатки в мягком грунте, что также зависит от угла склона и окатанности*

## X – ОЧЕНЬ РАЗРУШИТЕЛЬНОЕ – Природные эффекты становятся ведущим источником значительной опасности и становятся важными для оценки интенсивности

*Первичные эффекты* становятся ведущими.

*Выход очага на поверхность простирается на несколько десятков км со смещениями от десятков см до нескольких метров. Возникают гравитационные грабены и протяженные депрессии; для очень неглубоких землетрясений в вулканических областях длина разрыва может быть намного меньше. Тектоническое поднятие или опускание достигает максимум несколько метров.*

*Вторичные эффекты: Общая площадь порядка 5000 $км^2$.*

a) У многих источников существенно меняется дебит и/или место выхода. Некоторые источники временно или постоянно исчезают. Обычно наблюдаются временные вариации уровня воды в колодцах. Значительные вариации химико-физических свойств воды, чаще всего температуры, в источниках и колодцах. Часто наблюдаются помутнение воды даже в больших бассейнах, реках, колодцах и источниках. Наблюдаются эманации газа обычно с содержанием серы, кусты и трава в зоне эманации могут сгорать.

*b) Возникают метровые волны даже в больших озерах и реках, которые выплескиваются из русел. В пойменных долинах реки могут менять свое течение, временно или постоянно, в том числе и из-за тектонического опускания. Могут появляться или высыхать бассейны. В зависимости от рельефа дна и береговой линии высота заплеска цунами превышает 5м, затопляя плоские участки на тысячи метров в сторону суши. Небольшие валуны могут быть сдвинуты на многие метры. Широко распространены явления глубинной эрозии вдоль берегов, что ведет к заметному изменению берегового профиля. Деревья вблизи берега вырываются с корнем и уносятся.*

c) *Часто появляются зияющие трещины шириной более 1м и длиной сотни метров главным образом в рыхлых аллювиальных отложениях и/или во влагонасыщенных почвах; в твердых породах раскрытие достигает нескольких дм. Возникают широкие трещины на дорогах с покрытием (асфальт или булыжник), а также складки сдавливания.*

d) *Почти независимо от состояния равновесия склонов часто возникают* обширные оползни и камнепады ($> 10^5$ - $10^6$ $м^3$), *образуя временные или постоянные запрудные озера. Речные берега, набережные и места выемок обычно обрушаются. Дамбы и земляные плотины могут серьезно пострадать. В береговой зоне часты крупные подводные оползни.*

e) *Деревья энергично раскачиваются, ветви и тонкие стволы часто ломаются и падают. Некоторые деревья могут вырываться с корнем и опрокидываться.*

f) *Разжижение с фонтанированием воды и обрушение грунта могут изменить вид местности; песчаные вулканы диаметром более 6м, вертикальное опускание больше 1м; обычны широкие длинные трещины, возникшие из-за бокового растяжения.*
g) В сухих районах могут подниматься клубы пыли.
h) *Даже на пологих склонах валуны (диаметром более 2-3м) могут быть подброшены в воздух и сдвинуты на сотни метров от начального положения, оставляя типичные отпечатки в грунте.*

## XI – ОПУСТОШИТЕЛЬНОЕ – Природные эффекты становятся решающими для оценки интенсивности из-за насыщения структурных повреждений

*Первичные эффекты* доминируют.

*Поверхностные разрывы простираются от десятков до более чем 100 км, сопровождаясь подвижками в несколько метров. Возникают гравитационные грабены, протяженные депрессии и валы сдавливания. Дренажные линии могут быть значительно смещены. Порядок максимальных значений тектонических опусканий или поднятий поверхности земли может достигать многих метров.*

*Вторичные эффекты: Общая площадь порядка 10000 км$^2$.*

a) Многие источники существенно меняют дебит и/или место выхода. Многие источники могут временно или постоянно высыхать. Повсеместно наблюдаются временные или постоянные вариации уровня воды в колодцах. Наблюдаются сильные изменения физико-химических свойств воды, чаще всего, температуры в источниках и/или колодцах. Вода становится очень грязной даже в больших бассейнах, реках, колодцах и источниках. Наблюдаются эманации газа обычно с содержанием серы, кусты и трава в зоне эманации могут сгорать.
b) *В крупных озерах и реках образуются большие волны, которые выплескиваются из русла. В пойменных долинах реки могут изменить русло временно или постоянно, в том числе по причине тектонического опускания или оползней. Могут образовываться или исчезать водоемы. В зависимости от рельефа дна и береговой линии волна цунами высотой может достигать 15 м, опустошая прилегающую сушу на многие километры. Даже метровые валуны могут смещаться на большие расстояния. Происходит глубинная эрозия вдоль берега со значительными изменениями морфологии берега. Деревья в прибрежной полосе вырваны с корнем и уносятся на большие расстояния.*
c) Часто возникают зияющие трещины шириной несколько метров, главным образом в рыхлых аллювиальных отложениях и/или влагонасыщенных почвах. В твердых породах они могут достигать 1м. Очень широкие трещины развиваются на дорогах с покрытием (асфальт или булыжник), а также крупные складки сдавливания.
d) Почти независимо от состояния равновесия склонов часты обширные оползни и камнепады (> $10^5$ - $10^6$ м$^3$), которые образуют временные или постоянные запрудные озера. Речные берега, набережные и места выемок обычно обрушаются. Дамбы и земляные плотины могут серьезно пострадать. Существенные оползни возникают на расстояниях в 200-300 км от эпицентра. Частыми являются крупные подводные оползни в береговой зоне.
e) *Деревья энергично раскачиваются, ветви и тонкие стволы часто ломаются и падают. Многие деревья могут вырываться с корнем и опрокидываться.*
f) Разжижение меняет облик обширных низменных территорий, приводя к вертикальному опусканию, возможно превышающему несколько метров; могут наблюдаться многочисленные крупные песчаные вулканы, сильное боковое растяжение.
g) В сухих районах могут подниматься клубы пыли.
h) *Даже на пологих склонах валуны (диаметром несколько метров) могут быть подброшены в воздух и сдвинуты на большие расстояния от начального положения, оставляя типичные отпечатки в грунте.*

## XII – ПОЛНОСТЬЮ ОПУСТОШИТЕЛЬНОЕ – Природные эффекты являются единственным средством для оценки интенсивности

*Первичные эффекты* доминируют.

*Поверхностные разрывы простираются как минимум на несколько сотен километров, сопровождаясь подвижками в несколько десятков метров. Возникают гравитационные грабены, протяженные депрессии и валы сдавливания. Дренажные линии могут быть значительно смещены. Изменения в пейзаже и геоморфологии, вызванные первичными эффектами, могут достигать исключительных* *размеров (типичны примеры поднятия или опускания береговых линий на несколько метров, появление или исчезновение из виду существенных элементов пейзажа, изменения русла рек, образование водопадов, образование и исчезновение озер).*

*Вторичные эффекты: Общая площадь порядка 50000 км$^2$ и более.*

a) Многие источники существенно меняют дебит и/или место выхода. Многие источники могут временно или постоянно высыхать. Повсеместно наблюдаются временные или постоянные вариации уровня воды в колодцах. Наблюдаются сильные изменения физико-химических свойств воды, чаще всего, температуры в источниках и/или колодцах. Вода становится очень грязной даже в больших бассейнах, реках, колодцах и источниках. Наблюдаются эманации газа обычно с содержанием серы, кусты и трава в зоне эманации могут сгореть
b) *Образуются гигантские волны в крупных озерах и реках, которые выплескиваются из русла. В пойменных долинах реки могут изменить русло временно или постоянно, в том числе по причине тектонического опускания или оползней. Могут образовываться или исчезать крупные водоемы. В зависимости от рельефа дна и береговой линии волна цунами высотой несколько десятков метров может достигать берега, опустошая прилегающую сушу на многие километры. Крупные валуны могут смещаться на большие расстояния. Происходит глубинная эрозия вдоль берега с чрезвычайными изменениями морфологии берега. Деревья в прибрежной полосе вырваны с корнем и уносятся на большие расстояния. Все катера срываются с якоря и выносятся на сушу на большом удалении. Всех людей вне помещения смывает.*
c) Возникают зияющие трещины, достигающие в ширину 1м и более в коренных породах и до 10 м в рыхлых аллювиальных отложениях и/или во влагонасыщенных почвах. Они могут простираться на несколько километров..
d) Почти независимо от состояния равновесия склонов часты обширные оползни и камнепады (> $10^5$ - $10^6$ м$^3$), которые образуют временные или постоянные запрудные озера. Речные берега, набережные и места выемок обрушаются. Дамбы и земляные плотины могут серьезно пострадать. Существенные оползни возникают на расстояниях более чем 200-300 км от эпицентра. Часты крупные подводные оползни в береговой зоне.
e) Деревья энергично раскачиваются, ветви и тонкие деревья часто ломаются и падают. Многие деревья могут вырываться с корнем и опрокидываться.
f) Разжижение меняет облик обширных низменных территорий, приводя к вертикальному опусканию, превышающему несколько метров; могут наблюдаться многочисленные крупные песчаные вулканы, сильное боковое растяжение.
g) В сухих районах могут подниматься клубы пыли.
h) *Даже на очень пологих склонах очень большие валуны могут быть подброшены в воздух и сдвинуты на большие расстояния от начального положения, оставляя типичные отпечатки в грунте.*

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 85 - 94
tab. 1

# 2.8. - Η μακροσεισμική κλίμακα έντασης ESI 2007 (Greek)

TRANSLATED: PAPATHANASSIOU G. (1), PAVLIDES S. (1)

## *Εισαγωγή*

Η εκτίμηση της μακροσεισμικής έντασης βασίζεται στην ταξινόμηση και βαθμονόμηση της επίδρασης των συνεπειών μιας σεισμικής δόνησης στον άνθρωπο, στο ανθρωπογενές περιβάλλον (κτίρια και υποδομές) και στο φυσικό περιβάλλον (περιβαλλοντικές ή γεωλογικές επιπτώσεις). Αυτή η ένταση αποτελεί μια παράμετρο περιγραφής της δριμύτητας/σφοδρότητας του σεισμού και εκτιμάται λαμβάνοντας υπόψη τις επιπτώσεις τόσο των δυναμικών όσο και των στατικών παραμορφώσεων.

Οι μακροσεισμικές κλίμακες έντασης (Rossi-Forel, Mercalli, MCS, MSK, Mercalli Modified) λαμβάνουν υπόψη τους τις συνέπειες ενός σεισμού στο φυσικό περιβάλλον ως διαγνωστικά στοιχεία για την αξιολόγηση του βαθμού της έντασης. Αντιθέτως, ορισμένες σύγχρονες κλίμακες (e.g., ESPINOSA *et alii*, 1976a; 1976b; GRUNTHAL, 1998), λαμβάνουν υπόψη τους μονάχα τις επιπτώσεις στον άνθρωπο και στο ανθρωπογενές δομημένο περιβάλλον και ελαχιστοποιούν την διαγνωστική αξία των περιβαλλοντικών επιπτώσεων, βασιζόμενες στην υπόθεση ότι αυτές οι επιπτώσεις είναι ευμετάβλητες, τυχαίες και ασταθείς. Ωστόσο, πρόσφατες μελέτες (e.g. DENGLER & MCPHERSON, 1993; SERVA, 1994, DOWRICK, 1996; ESPOSITO *et alii*, 1997; Hancox et al, 2002; MICHETTI *et alii*, 2004) έδειξαν ότι τα χαρακτηριστικά των γεωλογικών και περιβαλλοντικών επιπτώσεων, τα οποία σήμερα μπορούν να ανακτηθούν από ιστορικές και παλαιοσεισμολογικές πηγές, αποτελούν μια βασική και ουσιώδη πληροφορία για την εκτίμηση του μεγέθους της σεισμικής δόνησης και προπάντων της έντασης.

Με αυτόν τον σκοπό, δημιουργήθηκε η μαρκοσεισμική κλίμακα ESI 2007 (MICHETTI *et alii*, 2007) η οποία βασίζεται μόνο στις περιβαλλοντικές επιπτώσεις. Η χρήση της, μόνη ή σε συνδυασμό με κάποια άλλη κλίμακα δίνει μια πιο σφαιρική εικόνα του σεναρίου της σεισμικής δόνησης, διότι μονάχα οι περιβαλλοντικές επιπτώσεις επιτρέπουν την κατάλληλη σύγκριση της μακροσεισμικής έντασης τόσο:

• *στο χρόνο*: οι επιπτώσεις στο φυσικό περιβάλλον είναι συγκρίσιμες για μια χρονική περίοδο (πρόσφατη, ιστορική και παλαιοσεισμικά γεγονότα) πολύ μεγαλύτερη από την περίοδο με ενόργανες καταγραφές

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(τελευταίος αιώνας)

• *σε διαφορετικές γεωγραφικές περιοχές*: οι περιβαλλοντικές επιπτώσεις δεν επηρεάζονται από ειδικές κοινωνικο-οικονομικές συνθήκες ή διαφορετικές κατασκευαστικές πρακτικές

Γι'αυτό το λόγο, η νέα κλίμακα στοχεύει στην σταδιακή ανάμειξη των υπαρχόντων μακροσεισμικών κλιμάκων έντασης:

• Για σεισμική ένταση μεγαλύτερη ή ίση με X, όταν η εκτίμηση με βάση τις ζημιές στις κατασκευές είναι εξαιρετικά δύσκολη ενώ οι περιβαλλοντικές επιπτώσεις μπορούν να εκτιμηθούν

• Σε αραιοκατοικημένες περιοχές, όπου οι επιπτώσεις στο δομημένο περιβάλλον απουσιάζουν και έτσι η εκτίμηση της έντασης πρέπει να πραγματοποιηθεί βασιζόμενη στις περιβαλλοντικές επιπτώσεις, οι οποίες είναι οι μοναδικοί διαθέσιμοι διαγνωστικοί παράγοντες

Η περιγραφή των βαθμών της έντασης προκύπτει από την αναθεώρηση που πραγματοποιήθηκε από μια διεθνή ομάδα αποτελούμενη από γεωλόγους, σεισμολόγους και μηχανικούς που επικεντρώθηκαν στις επιπτώσεις που προκλήθηκαν από σεισμικές δονήσεις σε παγκόσμιο επίπεδο. Η ESI 2007 επικυρώθηκε από την INQUA (International Union for Quaternary Research) στο XVII συνέδριο της ένωσης που πραγματοποιήθηκε στην πόλη Cairns της Αυστραλίας το 2007.

## *Περιγραφή*

Η κλίμακα ESI 2007 είναι δομημένη σε δώδεκα βαθμούς. Στον τίτλο κάθε βαθμού έντασης εκφράζεται η δριμύτητα του σεισμού και το μέγεθος των περιβαλλοντικών επιπτώσεων. Κατά την περιγραφή, τα χαρακτηριστικά και το μέγεθος των πρωτογενών επιπτώσεων αναφέρονται στην αρχή κάθε βαθμού. Έπειτα, οι δευτερογενείς επιπτώσεις περιγράφονται σε σχέση με τη συνολική περιοχή εμφάνισης τους για την εκτίμηση της επικεντρικής έντασης, η οποία ομαδοποιείται σε διάφορες κατηγορίες, όπως ορίζεται από τον αρχικό βαθμό του γεγονότος. Το μορφοποιημένο με πλάγια γραφή κείμενο χρησιμοποιείται για να δώσει έμφαση σε περιγραφές οι οποίες μπορούν να χρησιμοποιηθούν ως αποκλειστικοί διαγνωστικοί παράγοντες για ένα συγκεκριμένο βαθμό έντασης.

***Οι πρωτογενείς επιπτώσεις*** είναι σε άμεση συνάρτηση με την ενέργεια του σεισμού και προπάντων με την επιφανειακή εκδήλωση της σεισμογόνου πηγής. Το μέγεθος των πρωτογενών επιπτώσεων τυπικά εκφράζεται με δύο παραμέτρους: i) το συνολικό μήκος του επιφανειακό ίχνους του ρήγματος (SRL, Total Surface Rupture Length) και ii) τη μέγιστη μετατόπιση (MD, Maximum Displacement). Η εμφάνισή τους συνήθως συνδέεται με μια ελάχιστη τιμή της έντασης (VIII), εκτός των περιπτώσεων επιφανειακών σεισμών σε ηφαιστειακές περιοχές. Τα ποσοτικά χαρακτηριστικά της τεκτονικής επιφανειακής παραμόρφωσης (ανύψωση, ταπείνωση; uplift, subsidence) λαμβάνονται επίσης υπόψη.

***Ως δευτερογενείς επιπτώσεις*** χαρακτηρίζονται εκείνα τα φαινόμενα που προκαλούνται από την εδαφική κίνηση και ταξινομούνται σε οκτώ κύριες κατηγορίες

α) ***Υδρογεωλογικές ανωμαλίες***: στην κατηγορία αυτή περιγράφονται μεταβολές στην παροχή των πηγών και ποταμών καθώς επίσης και μεταβολές στις φυσικο-χημικές ιδιότητες των επιφανειακών και υπόγειων υδάτων (π.χ. θερμοκρασία, θολότητα). Αυτές οι επιπτώσεις παρατηρούνται σε εντάσεις από IV έως X.

β) ***Ανωμαλίες στον κυματισμό/ Tsunamis:*** στην κατηγορία αυτή περιλαμβάνονται φαινόμενα όπως κυματισμός σε κλειστές λεκάνες, υπερχείλιση νερού σε πισίνες και λεκάνες καθώς επίσης και tsunamis. Στην τελευταία περίπτωση, τα tsunamis, ως διαγνωστικοί παράγοντες θεωρούνται κυρίως οι επιπτώσεις του κύματος στις ακτές (βάθος εισχώρησης στην ενδοχώρα, διάβρωση παραλίας, αλλαγές στην παράκτια μορφολογία) χωρίς βεβαίως να αγνοούνται η επίδραση στον άνθρωπο και στις κατασκευές.

γ) ***Εδαφικές διαρρήξεις:*** οι εδαφικές διαρρήξεις περιγράφονται με βάση το μήκος τους (από cm μέχρι εκατοντάδες μέτρα), πλάτος (από mm έως m) και πυκνότητα στο χώρο. Οι εδαφικές διαρρήξεις παρατηρούνται σε εντάσεις από IV και διατηρούνται σταθερές σε μέγεθος (κορεσμός) σε ένταση βαθμού Χ.

δ) ***Αστοχίες πρανών***: στην κατηγορία αυτή περιλαμβάνονται όλοι οι τύποι των κατολισθήσεων συμπεριλαμβανομένων των καταπτώσεων, ολισθήσεων και εδαφικών ροών. Όταν το λιθολογικό και μορφολογικό πλαίσιο είναι παρόμοιο τότε ο όγκος και το εμβαδό της περιοχής αποτελούν τις διαγνωστικές παραμέτρους. Αυτές οι επιπτώσεις παρατηρούνται σε ένταση από IV και διατηρούν το μέγεθος τους σταθερό σε ένταση βαθμού Χ.

ε) ***ταλάντωση δέντρων***: αυτές οι επιπτώσεις παρατηρούνται σε εντάσεις από IV έως Χ. Η περιγραφή των βαθμών της έντασης ουσιαστικά ακολουθεί τους δημοσιευμένους βαθμούς έντασης των Dengler και McPherson (1993).

ζ) ***φαινόμενα ρευστοποίησης***: σε αυτήν την κατηγορία περιλαμβάνονται φαινόμενα κώνων και ηφαιστείων άμμου, ανάδυση νερού και αμμώδους υλικού και ορισμένοι τύποι πλευρικής εξάπλωσης, συνίζησης και καθίζησης. Χαρακτηρίζουν εντάσεις βαθμού V έως Χ

η) ***σύννεφα σκόνης***: παρατηρούνται σε περιοχές με ξηρό κλίμα σε βαθμό έντασης μεγαλύτερο από VIII

θ) ***αναπήδηση βράχων***: το μέγιστο μέγεθος των βράχων αποτελεί διαγνωστικό παράγοντα για την εκτίμηση της έντασης και παρατηρούνται σε εντάσεις από IX μέχρι XII. Τέτοια φαινόμενα παρατηρούνται σε θέσεις όπου οι εδαφικές επιταχύνσεις είναι μεγαλύτερες της βαρύτητας.

Οι περιβαλλοντικές επιπτώσεις παρατηρούνται και χαρακτηρίζουν εντάσεις βαθμού μεγαλύτερου του IV. Μερικοί κατηγορίες περιβαλλοντικών επιπτώσεων (υδρολογικές ανωμαλίες) είναι δυνατό να παρατηρηθούν ακόμα και σε χαμηλότερους βαθμούς έντασης αλλά δεν μπορούν να χαρακτηριστούν ως διαγνωστικά στοιχεία. Η ακρίβεια στην αξιολόγηση της έντασης αυξάνει στους μεγαλύτερους βαθμούς, και συγκεκριμένα σε θέσεις παρατήρησης πρωτογενών επιπτώσεων (συνήθως σε εντάσεις μεγαλύτερες του VIII), έως και ένταση XII. Σε ένταση μεγαλύτερη του Χ, οι επιπτώσεις στο ανθρωπογενές δομημένο περιβάλλον και στους ανθρώπους δεν μπορούν να χρησιμοποιηθούν καθώς οι κατασκευές έχουν συνήθως ολοκληρωτικά καταστραφεί (κορεσμός) και για αυτό το λόγο δεν είναι δυνατή η διάκριση μεταξύ διαφορετικών βαθμών έντασης. Σε αυτήν την περίπτωση, οι περιβαλλοντικές επιπτώσεις κυριαρχούν και για αυτό αποτελούν το πιο αποτελεσματικό εργαλείο για την αξιολόγηση της έντασης.

## *Πώς να χρησιμοποιήσετε την κλίμακα ESI 2007*

Η χρησιμοποίηση της μακροσεισμικής κλίμακας ESI ως ένα ανεξάρτητο εργαλείο για την εκτίμηση της έντασης προτείνεται στις περιπτώσεις εκείνες όπου μονάχα οι περιβαλλοντικές επιπτώσεις μπορούν να χρησιμοποιηθούν διαγνωστικά καθώς οι επιπτώσεις στον άνθρωπο και στο ανθρωπογενές δομημένο περιβάλλον είναι είτε ανεπαρκείς είτε κορεσμένες. Στην περίπτωση που οι τελευταίες επιπτώσεις μπορούν να ληφθούν υπόψη και να αξιολογηθούν, τότε είναι δυνατή η εκτίμηση δύο ανεξάρτητων τιμών μακροσεισμικής έντασης. Η τελική τιμή έντασης θα ισούται με την υψηλότερη τιμή μεταξύ των δύο εκτιμήσεων. Προφανώς, σε αυτές τις περιπτώσεις, η γνώμη και η εμπειρία ενός ειδικού είναι απαραίτητη

Η επικεντρική ένταση (Ιο) δηλώνει την ένταση της δόνησης σε αντιστοιχία με το επίκεντρο. Οι παράμετροι που σχετίζονται με τα χαρακτηριστικά της επιφανειακής εκδήλωσης του σεισμογόνου ρήγματος καθώς επίσης και η συνολική έκταση της κατανομής των δευτερογενών φαινομένων (κατολισθήσεις, ρευστοποιήσεις) είναι επίσης ανεξάρτητα εργαλεία που χρησιμοποιούνται για την εκτίμηση της Ιο με βάση τα περιβαλλοντικά φαινόμενα, με αφετηρία τον βαθμό έντασης VII (Πίνακας 2.1).

Ιδιαίτερη προσοχή πρέπει να δοθεί στις περιπτώσεις εκείνες όπου τα χαρακτηριστικά της επιφανειακής εκδήλωσης του σεισμογόνου ρήγματος τοποθετούνται στο όριο μεταξύ δύο βαθμών έντασης. Σε αυτήν την περίπτωση, θα πρέπει να επιλεγεί εκείνη η τιμή της έντασης που βρίσκεται σε συμφωνία με τα χαρακτηριστικά και την έκταση εμφάνισης δευτερογενών επιπτώσεων. Επίσης, κατά την αξιολόγηση της έντασης της συνολικής περιοχής, συνιστάται να μην συμπεριλαμβάνονται απομονωμένες παρατηρήσεις φαινομένων στο μακρινό πεδίο. Σε αυτήν την διαδικασία αξιολόγησης επίσης θεωρείται ουσιώδης η γνώμη ενός ειδικού.

Η τοπική ένταση αξιολογείται κυρίως δια μέσου της περιγραφής των δευτερογενών επιπτώσεων που λαμβάνουν χώρα σε διαφορετικές «θέσεις» που βρίσκονται μέσα σε μια «τοποθεσία». Αυτή η τιμή της έντασης πρέπει να συγκριθεί με την αντίστοιχη τοπική ένταση η οποία εκτιμήθηκε με βάση τις ζημιές. Προσοχή θα πρέπει να δοθεί στον όρο «τοποθεσία» ο οποίος αναφέρεται τόσο για κατοικημένες περιοχές (πόλη, χωριό) όσο και για γεωγραφικές περιοχές χωρίς την ύπαρξη κατοικημένων εκτάσεων. Όταν σε μια θέση παρατηρούνται μονάχα πρωτογενείς επιπτώσεις τότε μπορεί να χρησιμοποιηθεί το μέγεθος της μέγιστης μετατόπισης της τοπικής επιφανειακής διάρρηξης.

Πίν. 2.1 - *Διακύμανση παραμέτρων επιφανειακής εκδήλωσης του σεισμογόνου ρήγματος (πρωτογενείς επιπτώσεις) κα μέγεθος συνολικής έκτασης (δευτερογενών επιπτώσεων) για κάθε βαθμό έντασης*

| $I_0$ | ΠΡΩΤΟΓΕΝΕΙΣ ΕΠΙΠΤΩΣΕΙΣ | | ΔΕΥΤΕΡΟΓΕΝΕΙΣ ΕΠΙΠΤΩΣΕΙΣ |
|---|---|---|---|
| | ΜΗΚΟΣ ΕΠΙΦΑΝΕΙΑΚΗΣ ΔΙΑΡΡΗΞΗΣ (SRL) | ΜΕΓ. ΕΠΙΦΑΝΕΙΑΚΗ ΜΕΤΑΤΟΠΙΣΗ (MD) | ΣΥΝΟΛΙΚΗ ΕΚΤΑΣΗ |
| **IV** | - | - | - |
| **V** | - | - | - |
| **VI** | - | - | - |
| **VII** | (*) | (*) | 10 $km^2$ |
| **VIII** | Αρκετές εκατοντάδες μέτρα | εκατοστόμετρα | 100 $km^2$ |
| **IX** | 1- 10 km | 5 - 40 cm | 1000 $km^2$ |
| **X** | 10 - 60 km | 40 - 300 cm | 5000 $km^2$ |
| **XI** | 60 – 150 km | 300 –700 cm | 10000 $km^2$ |
| **XII** | > 150 km | > 700 cm | > 50000 $km^2$ |

(*) περιορισμένες επιφανειακές διαρρήξεις, δεκάδων έως εκατοντάδων μέτρων μήκους και εκατοστών μετατόπισης (offset) μπορούν να παρατηρηθούν και ουσιαστικά να συνδεθούν με επιφανειακούς σεισμούς σε ηφαιστειακές περιοχές

## *Ορισμός της έντασης*

**Από I έως III:** Δεν προκαλούνται περιβαλλοντικές επιπτώσεις οι οποίες να μπορούν να χρησιμοποιηθούν ως διαγνωστικοί στοιχεία

### IV - Αρκετά αισθητός σεισμός / Πρώτες σαφείς επιπτώσεις στο περιβάλλον

Πρωτογενείς επιπτώσεις απουσιάζουν

Δευτερογενείς επιπτώσεις

α) Καταγράφονται μικρές μεταβολές στη στάθμη του νερού σε πηγάδια και/ή στην παροχή πηγών, καθώς επίσης και εξαιρετικά σπάνια μικρές μεταβολές των φυσικο-χημικών ιδιοτήτων του νερού και θολότητα του νερού στις πηγές και στα πηγάδια, ειδικά σε πηγές που βρίσκονται σε μεγάλα καρστικά συστήματα, τα οποία θεωρούνται ως τα πιο επιρρεπή σε τέτοια φαινόμενα.

β) Κυματισμός σε κλειστές λεκάνες (λίμνες) με ύψος μερικών εκατοστών, συνήθως παρατηρείται ως παλιρροιακό κύμα, ίσως ορατός με γυμνό μάτι, συνήθως στο μακρινό πεδίο από ισχυρούς σεισμούς. Οι ανωμαλίες στον κυματισμό γίνονται αντιληπτές από όλους τους ανθρώπους που επιβαίνουν σε μικρά πλοία, ελάχιστους σε μεγαλύτερα πλοία, σχεδόν από όλους στην ακτή. Ταλάντωση νερού σε πισίνες και ίσως παρατηρηθεί υπερχείλιση.

γ) Ρωγμές με άνοιγμα χιλιοστού ίσως περιστασιακά παρατηρηθούν σε θέσεις επιρρεπείς λόγω λιθολογίας (χαλαρές αλλουβιακές αποθέσεις, κορεσμένα εδάφη) και/ή λόγω μορφολογίας (πρανή)

δ) Κατ'εξαίρεση, καταπτώσεις βράχων και μικρές κατολισθήσεις ίσως ενεργοποιηθούν σε πρανή τα οποία βρίσκονται σε οριακή ισορροπία (ευστάθεια), π.χ. απότομα πρανή με χαλαρά και γενικά κορεσμένα εδάφη

ε) Ασθενής ταλάντωση των κλαδιών των δέντρων

### V - Ισχυρός σεισμός/ βασικές επιπτώσεις στο περιβάλλον

Πρωτογενείς επιπτώσεις απουσιάζουν

Δευτερογενείς επιπτώσεις

α) Καταγράφονται μεταβολές στη στάθμη του νερού σε πηγάδια και/ή στην παροχή πηγών, καθώς επίσης και μικρές μεταβολές των φυσικο-χημικών ιδιοτήτων του νερού και θολότητα του νερού στις λίμνες, στις πηγές και στα πηγάδια.

β) Κυματισμός στις λίμνες με ύψος εκατοστών, μερικές φορές ορατός με γυμνό μάτι, στο μακρινό πεδίο από ισχυρούς σεισμούς. Οι ανωμαλίες στον κυματισμό, με ύψος μέχρι μερικές δεκάδες εκατοστά, γίνονται αντιληπτές από όλους τους ανθρώπους που είτε επιβαίνουν σε πλοία είτε βρίσκονται στην ακτή. Υπερχείλιση νερού σε πισίνες

γ) Ρωγμές (με άνοιγμα μεγέθους χιλιοστού και αρκετών εκατοστών έως ένα μέτρο μήκος) τοπικά παρατηρούνται σε θέσεις επιρρεπείς λόγω λιθολογίας (χαλαρές αλλουβιακές αποθέσεις, κορεσμένα εδάφη) και/ή λόγω μορφολογίας (πρανή)

δ) Μικρές καταπτώσεις βράχων, κυκλικές κατολισθήσεις και εδαφικές ροές ίσως συμβούν, συχνά αλλά όχι απαραίτητα κατά μήκος απότομων πρανών τα οποία βρίσκονται σε οριακή ισορροπία, κυρίως χαλαρές αποθέσεις και κορεσμένα εδάφη. Υποθαλάσσιες κατολισθήσεις ίσως προκληθούν, οι οποίες μπορεί να επιφέρουν μικρές ανωμαλίες στον κυματισμό σε παράκτιες θέσεις θαλασσών και λιμνών.

ε) Κλαδιά δέντρων και θάμνοι ταλαντώνονται ελαφρώς ενώ σπανίως ίσως πέσουν ξερά κλαδιά και ώριμα φρούτα

ζ) Σε εξαιρετικά σπάνιες περιπτώσεις καταγράφονται εμφανίσεις ρευστοποίησης (κώνοι άμμου), μικρού μεγέθους και σε θέσεις επιρρεπείς σε ρευστοποίηση (περιοχές υψηλής επιδεκτικότητας, πρόσφατες, αλλουβιακές και παράκτιες αποθέσεις, επιφανειακός υδροφόρος ορίζοντας)

## VI - Ελαφρώς βλαπτικός / μέτριες επιπτώσεις στο περιβάλλον

Πρωτογενείς επιπτώσεις απουσιάζουν

Δευτερογενείς επιπτώσεις

α) Καταγράφονται τοπικά σημαντικές μεταβολές στη στάθμη του νερού σε πηγάδια και/ή στην παροχή πηγών, καθώς επίσης και μικρές μεταβολές των φυσικο-χημικών ιδιοτήτων του νερού και θολότητα του νερού στις λίμνες, στις πηγές και στα πηγάδια

β) Κυματισμός στις λίμνες με ύψος δεκάδων εκατοστών προκαλεί πλημμυρικά φαινόμενα σε περιορισμένες περιοχές κοντά στις ακτές. Οι ανωμαλίες στον κυματισμό, με ύψος μέχρι μερικές δεκάδες εκατοστά, γίνονται αντιληπτές από όλους τους ανθρώπους που είτε επιβαίνουν σε πλοία είτε βρίσκονται στην ακτή. Υπερχείλιση νερού σε πισίνες και μικρές λίμνες

γ) *Ρωγμές, με άνοιγμα μεγέθους χιλιοστού έως εκατοστών και μήκους αρκετών μέτρων παρατηρούνται σε χαλαρές αλλουβιακές αποθέσεις και/ή σε κορεσμένα εδάφη, κατά μήκος απότομων πρανών ή όχθες ποταμών μπορούν να φτάσουν έως 1-2 εκατοστά εύρος. Μικρά ανοίγματα σχηματίζονται σε σε δρόμους είτε ασφαλτοστρωμένους είτε λιθόστρωτους.*

δ) Καταπτώσεις βράχων και κατολισθήσεις με όγκο έως $10^3 m^3$ ίσως προκληθούν, κυρίως σε θέσεις με οριακή ισορροπία όπως απότομα πρανή με χαλαρά κορεσμένα εδάφη ή σε πολύ αποσαθρωμένους / ρωγματωμένους (κατακερματισμένους) βραχώδεις σχηματισμούς. Υποθαλάσσιες κατολισθήσεις ίσως προκληθούν, οι οποίες μπορεί να επιφέρουν μικρές ανωμαλίες στον κυματισμό σε παράκτιες θέσεις οι οποίες συνήθως καταγράφονται ενόργανα

ε) *Μέτριες έως ισχυρές ταλαντώσεις κλαδιών δέντρων και θάμνων; ίσως σπάσουν και πέσουν κορυφές δέντρων και άκρα κλαδιών, ανάλογα με τα είδη, το φορτίο των φρούτων και την ωριμότητά τους*

ζ) *Αραιές εμφανίσεις ρευστοποίησης (κώνοι άμμου), μικρού μεγέθους και σε θέσεις επιρρεπείς στη ρευστοποίηση (περιοχές υψηλής επιδεκτικότητας, πρόσφατες, αλλουβιακές και παράκτιες αποθέσεις, επιφανειακός υδροφόρος ορίζοντας)*

## VII - Βλαπτικός / αξιόλογες επιπτώσεις στο περιβάλλον

Πρωτογενείς επιπτώσεις σπανίως παρατηρούνται, σχεδόν αποκλειστικά σε ηφαιστειακές περιοχές. Περιορισμένες επιφανειακές διαρρήξεις, μήκους δεκάδων έως εκατοντάδων μέτρων με μετατοπίσεις (offset) μεγέθους εκατοστόμετρου ίσως παρατηρηθούν, ειδικά σε περιπτώσεις αρκετά επιφανειακών σεισμών

Δευτερογενείς επιπτώσεις: η συνολική έκταση της πληγείσας περιοχής είναι της τάξης των $10 km^2$

α) Καταγράφονται τοπικά σημαντικές προσωρινές μεταβολές στη στάθμη του νερού σε πηγάδια και/ή στην παροχή πηγών. Σπανίως, ίσως εμφανιστούν ή ξηραθούν μικρές πηγές. Μεταβολές των φυσικο-χημικών ιδιοτήτων του νερού και θολότητα του νερού στις λίμνες, στις πηγές και στα πηγάδια

β) Κυματισμός με ύψος μεγαλύτερο του ενός μέτρου προκαλεί πλημμυρικά φαινόμενα σε περιορισμένες παράκτιες περιοχές και προκαλεί ζημιές σε αντικείμενα ποικίλου μεγέθους. Υπερχείλιση νερού σε μικρές λεκάνες και τάφρους

γ) *Ρωγμές, με άνοιγμα έως 5-10 εκατοστών και μήκους εκατοντάδων μέτρων παρατηρούνται κυρίως σε χαλαρές αλλουβιακές αποθέσεις και/ή σε κορεσμένα εδάφη, σπανίως σε ξηρή άμμο, αργιλοαμμώδη και αργιλικά εδάφη διαρρήξεις έως 1 εκατοστό εύρος. Μικρές ρωγμές μεγέθους εκατοστόμετρου είναι συνήθεις σε δρόμους είτε ασφαλτοστρωμένους είτε λιθόστρωτους.*

δ) Διεσπαρμένες κατολισθήσεις παρατηρούνται σε επιρρεπείς περιοχές όπου επικρατούν συνθήκες μη ισορροπίας (απότομα πρανή με χαλαρά/κορεσμένα εδάφη) ενώ καταπτώσεις βράχων λαμβάνουν χώρα σε απότομα φαράγγια και πρανή. Το μέγεθός τους είναι σημαντικό ($10^3$-$10^5$ $m^3$). Σε θέσεις με ξηρή άμμο, αργιλοαμμώδη και αργιλικά εδάφη ο όγκος είναι συνήθως μεγαλύτερος από 100 $m^3$. Οι διαρρήξεις, οι ολισθήσεις και οι καταπτώσεις ίσως επηρεάσουν φυσικά πρανή ποταμών, τεχνητά αναχώματα και εκσκαφές σε χαλαρά ιζήματα ή αποσαθρωμένους / ρωγματωμένους (κατακερματισμένους) βραχώδεις σχηματισμούς. Υποθαλάσσιες κατολισθήσεις ίσως προκληθούν, επιφέροντας κύμματα σε παράκτιες θέσεις θαλασσών και λιμνών, τα οποία γίνονται άμεσα αισθητά από ανθρώπους σε πλοία και στα λιμάνια ε) Δέντρα και θάμνοι ταλαντεύονται έντονα; κυρίως σε πυκνές δασικές περιοχές, κορυφές δέντρων και άκρα κλαδιών σπάνε και πέφτουν

ζ) *Παρατηρούνται αραιές εμφανίσεις ρευστοποίησης (κώνοι άμμου), με διάμετρο έως 50 εκατοστά, σε θέσεις επιρρεπείς στη ρευστοποίηση (περιοχές υψηλής επιδεκτικότητας, πρόσφατες, αλλουβιακές και παράκτιες αποθέσεις, επιφανειακός υδροφόρος ορίζοντας)*

## VIII - Αρκετά βλαπτικός / εκτεταμένες επιπτώσεις στο περιβάλλον

Πρωτογενείς επιπτώσεις σπανίως παρατηρούνται.

Επιφανειακές διαρρήξεις του σεισμογόνου ρήγματος (surface faulting), μήκους αρκετών εκατοντάδων μέτρων με μετατοπίσεις (offset) μεγέθους εκατοστόμετρου ίσως παρατηρηθούν, ειδικά σε περιπτώσεις αρκετά επιφανειακών σεισμών. Τεκτονική ταπείνωση ή ανύψωση της επιφάνειας με μέγιστες τιμές της τάξης μερικών εκατοστών ίσως παρατηρηθούν

Δευτερογενείς επιπτώσεις: η συνολική έκταση της πληγείσας περιοχής είναι της τάξης των 100 $km^2$

α) προσωρινές συνήθως μεταβολές στο σημείο εξόδου νερού και/ή στην παροχή πηγών. ίσως ξηραθούν μικρές πηγές. Διακυμάνσεις στη στάθμη του νερού σε πηγάδια. Μεταβολές των φυσικο-χημικών ιδιοτήτων του νερού, κυρίως της θερμοκρασίας ίσως παρατηρηθούν σε πηγές και/ή πηγάδια. θολότητα του νερού στις λίμνες, στις πηγές και στα πηγάδια. Εκπομπή αερίου, συνήθως θειούχου, παρατηρείται τοπικά

β) Κυματισμός με ύψος 1-2 μέτρα προκαλεί πλημμυρικά φαινόμενα σε παράκτιες περιοχές και προκαλεί ζημιές σε ποικίλου μεγέθους αντικείμενα. Διάβρωση εκτάσεων παρατηρείται κατά μήκος των ακτών όπου θάμνοι και μικρά δέντρα με αδύναμο σύστημα ριζών ξεριζώνονται και μεταφέρονται μακριά. Υπερχείλιση με ορμή του νερού σε μικρές λεκάνες και τάφρους

γ) *Ρωγμές, με άνοιγμα έως 50 εκατοστά και μήκους εκατοντάδων μέτρων παρατηρούνται κυρίως σε χαλαρές αλλουβιακές αποθέσεις και/ή σε κορεσμένα εδάφη. Παρατηρούνται διαρρήξεις μεγέθους δεκατόμετρου σε δρόμους είτε ασφαλτοστρωμένους είτε λιθόστρωτους καθώς επίσης και μικρές* πτυχώσεις *λόγω συμπίεσης.*

δ) Εκτεταμένες μικρού έως μέσου μεγέθους ($10^3$-$10^5$ $m^3$) κατολισθήσεις παρατηρούνται σε επιρρεπείς περιοχές; σπανίως ίσως παρατηρηθούν και σε πρανή με ομαλή κλίση; όπου επικρατούν συνθήκες μη ισορροπίας (απότομα πρανή με χαλαρά/κορεσμένα εδάφη) λαμβάνουν χώρα καταπτώσεις βράχων (σε απότομα φαράγγια και παράκτια πρανή) και το μέγεθος τους κάποιες φορές είναι μεγάλο ($10^5$ - $10^6$ $m^3$). Κατολισθήσεις φράζουν στενές κοιλάδες και ίσως δημιουργήσουν προσωρινές ή μόνιμες λίμνες. Οι διαρρήξεις, οι ολισθήσεις και οι καταπτώσεις ίσως επηρεάσουν τις όχθες ποταμών, τα τεχνητά αναχώματα και τις εκσκαφές σε χαλαρά ιζήματα ή αποσαθρωμένους / ρωγματωμένους (κατακερματισμένους) βραχώδεις σχηματισμούς. Συχνές υποθαλάσσιες κατολισθήσεις σε παράκτιες θέσεις

ε) *Δέντρα ταλαντώνονται έντονα; κλαδιά ίσως σπάσουν και πέσουν, ακόμα και ξεριζωμένα δέντρα σε απότομα πρανή ίσως πέσουν*

ζ) *Παρατηρούνται πυκνές εμφανίσεις ρευστοποίησης στην επικεντρική περιοχή, ανάλογα με τις επικρατούσες συνθήκες; κώνοι άμμου με διάμετρο έως 1 μέτρο; τοπικές πλευρικές εξαπλώσεις και καθιζήσεις (έως 30cm), με εμφάνιση ρηγματώσεων παράλληλων προς το παραλιακό μέτωπο (όχθη ποταμού, λίμνες, κανάλια, ακτή)*

η) *Σε ξηρές περιοχές, σύννεφα σκόνης ίσως σηκωθούν από το έδαφος στην επικεντρική περιοχή*

θ) Ίσως παρατηρηθεί αναπήδηση μικρών ογκόλιθων και πετρών και κορμών δέντρων, από την οποία δημιουργούνται ίχνη σε μαλακό έδαφος

## IX - Καταστροφικός / Οι περιβαλλοντικές επιπτώσεις συνιστούν μια εκτεταμένη πηγή κινδύνου και αποτελούν σημαντική παράμετρο για την εκτίμηση της έντασης

Πρωτογενείς επιπτώσεις παρατηρούνται.

*Δημιουργούνται εδαφικές διαρρήξεις (surface faulting), μήκους μερικών χιλιομέτρων με μετατοπίσεις (offsets) συνήθως μεγέθους αρκετών εκατοστών. Τεκτονική ταπείνωση ή ανύψωση της εδαφικής επιφάνειας με μέγιστες τιμές της τάξης μερικών δεκάμετρων ίσως παρατηρηθούν.*

Δευτερογενείς επιπτώσεις: *η συνολική έκταση της πληγείσας περιοχής είναι της τάξης των 1000 $km^2$*

α) *Προσωρινές συνήθως μεταβολές στην παροχή των πηγών και/ή στη θέση τους σε σημαντικό βαθμό. Ίσως ξηραθούν μέσου μεγέθους πηγές. Προσωρινές διακυμάνσεις στη στάθμη του νερού σε πηγάδια είναι κοινό γνώρισμα. Μεταβολές των φυσικο-χημικών ιδιοτήτων του νερού, κυρίως της θερμοκρασίας ίσως παρατηρηθούν σε πηγές και/ή πηγάδια, θολότητα του νερού στις λίμνες, στις πηγές και στα πηγάδια. Εκπομπή αερίου, συνήθως θειούχου, παρατηρείται τοπικά και ίσως καούν θάμνοι και χόρτα σε αυτές τις θέσεις.*

β) *Κυματισμός με ύψος μερικών μέτρων τόσο σε ακίνητο όσο και σε τρεχούμενο νερό. Σε πλημμυρικές πεδιάδες ίσως τα ρέματα να αλλάξουν την ροή τους λόγω εδαφικής καθίζησης. Μικρές κοιλότητες ίσως εμφανιστούν ή αδειάσουν. Tsunamis ίσως εισχωρήσουν σε βάθος δεκάδων μέτρων στην ακτή πλημμυρίζοντας τις περιοχές αυτές. Εκτεταμένη διάβρωση περιοχών κατά μήκος της παραλίας, όπου θάμνοι και δέντρα μπορεί να ξεριζωθούν και να μεταφερθούν μακριά*

γ) *Ρωγμές, με άνοιγμα έως 100 εκατοστά και μήκους εκατοντάδων μέτρων παρατηρούνται κυρίως σε χαλαρές αλλουβιακές αποθέσεις και/ή σε κορεσμένα εδάφη. Σε βραχώδεις σχηματισμούς μέχρι 10 cm. Παρατηρούνται διαρρήξεις σημαντικού μεγέθους σε δρόμους είτε ασφαλτοστρωμένους είτε λιθόστρωτους καθώς επίσης και μικρές* πτυχώσεις *λόγω συμπίεσης.*

δ) *Εκτεταμένες κατολισθήσεις παρατηρούνται σε επιρρεπείς περιοχές και σε πρανή με ομαλή κλίση; όπου επικρατούν συνθήκες μη ισορροπίας (απότομα πρανή με χαλαρά/κορεσμένα εδάφη; καταπτώσεις βράχων λαμβάνουν χώρα σε απότομα φαράγγια και παράκτια πρανή) το μέγεθός τους συνήθως είναι μεγάλο ($10^5 m^3$) και μερικές φορές αρκετά μεγάλο ($10^6 m^3$). Κατολισθήσεις φράζουν στενές κοιλάδες και ίσως δημιουργήσουν προσωρινές ή μόνιμες λίμνες. Τα πρανή στις όχθες ποταμών, τα τεχνητά αναχώματα και οι εκσκαφές συχνά αστοχούν. Συχνές μεγάλες υποθαλάσσιες κατολισθήσεις σε παράκτιες περιοχές.*

ε) Δέντρα ταλαντώνονται έντονα; Κλαδιά και κορμοί δέντρων συχνά σπάνε και πέφτουν. Μερικά δέντρα ίσως ξεριζωθούν και πέσουν κυρίως σε απότομα πρανή

ζ) *Παρατηρούνται συχνές εμφανίσεις ρευστοποίησης και ανάδυση νερού; κώνοι άμμου με διάμετρο έως 3 μέτρα; συχνές πλευρικές εξαπλώσεις και καθιζήσεις (περισσότερο από 30cm), με εμφάνιση ρηγματώσεων παράλληλων προς το παραλιακό μέτωπο (όχθη ποταμού, λίμνες, κανάλια, ακτή)*

η) Σε ξηρές περιοχές, σύννεφα σκόνης σηκώνονται από το έδαφος

θ) *Ίσως παρατηρηθεί αναπήδηση μικρών ογκόλιθων και σπάσιμο κορμών δέντρων και μετακίνηση μερικών μέτρων από την αρχική τους θέση, και ανάλογα με την κλίση του εδάφους ίσως αφήσουν αποτυπώματα σε μαλακό έδαφος*

## X - Πολύ καταστροφικός / Οι περιβαλλοντικές επιπτώσεις συνιστούν την κύρια πηγή κινδύνου και αποτελούν κρίσιμη παράμετρο για την εκτίμηση της έντασης

Πρωτογενείς επιπτώσεις κυριαρχούν.

*Η επιφανειακή εκδήλωση του ρήγματος εκτείνεται μερικές δεκάδες χιλιομέτρων με μετατόπιση από δεκάδες εκατοστών έως μερικά μέτρα. Δημιουργούνται βυθίσματα βαρύτητας και επιμήκεις δομές συμπίεσης; σε σεισμούς μικρού εστιακού βάθους σε ηφαιστειακές περιοχές το μήκος της διάρρηξης ίσως είναι αρκετά μικρότερο. Τεκτονική καθίζηση ή ανύψωση της εδαφικής επιφάνειας με μέγιστες τιμές της τάξης μερικών μέτρων ίσως παρατηρηθούν*

Δευτερογενείς επιπτώσεις: *η συνολική έκταση της πληγείσας περιοχής είναι της τάξης των 5000 $km^2$*

α) Σημαντικές μεταβολές στην παροχή πολλών πηγών και/ή στο σημείο εξόδου του νερού. Ίσως πηγές ξηραθούν προσωρινά ή μόνιμα. Προσωρινές διακυμάνσεις στη στάθμη του νερού σε πηγάδια. Μεταβολές των φυσικο-χημικών ιδιοτήτων του νερού, κυρίως της θερμοκρασίας παρατηρούνται σε πηγές και/ή πηγάδια. Λασπωμένο νερό σε μεγάλες λεκάνες, λίμνες, πηγές και σε πηγάδια. Εκπομπή αερίου, συνήθως θειούχου, παρατηρείται και ίσως καούν θάμνοι και χόρτα σε αυτές τις θέσεις

β) *Κυματισμός με ύψος μερικών μέτρων και φαινόμενα υπερχείλισης σε μεγάλες λίμνες και ποτάμια .Σε πλημμυρικές πεδιάδες τα ρέματα ίσως να αλλάξουν την διαδρομή τους, προσωρινά ή μόνιμα, λόγω εκτεταμένης εδαφικής καθίζησης. Λεκάνες ίσως εμφανιστούν ή αδειάσουν. Tsunamis ίσως πλησιάσουν στην ακτή με ύψος έως 5 μέτρα και εισχωρήσουν σε επίπεδες περιοχές σε βάθος χιλιομέτρων, πλυμμυρίζοντας τις περιοχές αυτές. Μικροί ογκόλιθοι ίσως παρασυρθούν για πολλά μέτρα. Εκτεταμένη διάβρωση περιοχών κατά μήκος της* *παραλίας, προκαλώντας αξιοσημείωτες μεταβολές στην ακτογραμμή. δέντρα κοντά στην ακτή ξεριζώνονται και μεταφέρονται μακριά*

γ) *Εδαφικές ρωγμές, με άνοιγμα μεγαλύτερο από 1 μέτρο και μήκους εκατοντάδων μέτρων παρατηρούνται συχνά σε χαλαρές αλλουβιακές αποθέσεις και/ή σε κορεσμένα εδάφη. Σε βραχώδεις σχηματισμούς το άνοιγμα των ρωγμών φθάνει αρκετά δεκάμετρα. Παρατηρούνται διαρρήξεις σημαντικού μεγέθους σε δρόμους είτε ασφαλτοστρωμένους είτε λιθόστρωτους καθώς επίσης και μικρές* πτυχώσεις *λόγω συμπίεσης.*

δ) *μεγάλες κατολισθήσεις και καταπτώσεις βράχων (>$10^5$-$10^6$ $m^3$) παρατηρούνται συχνά ανεξάρτητα από τις συνθήκες ισορροπίας, δημιουργώντας προσωρινές ή μόνιμες φραγματογενείς λίμνες (barrier lakes). Τα πρανή στις όχθες ποταμών, τα τεχνητά αναχώματα και οι εκσκαφές αστοχούν. Συχνές μεγάλες υποθαλάσσιες κατολισθήσεις σε παράκτιες περιοχές (offset).*

ε) *Δέντρα ταλαντώνονται έντονα; Κλαδιά και κορμοί δέντρων συχνά σπάνε και πέφτουν. Μερικά δέντρα ίσως ξεριζωθούν και πέσουν*

ζ) *οι εμφανίσεις ρευστοποίησης με ανάδυση νερού και η προκαλούμενη συμπύκνωση των εδαφών ίσως αλλάξουν την μορφή περιοχών; κώνοι άμμου με διάμετρο μεγαλύτερη από 6 μέτρα; Κατακόρυφη μετατόπιση > 1 μέτρο; μεγάλες και επιμήκεις ρηγματώσεις λόγω πλευρικής εξάπλωσης είναι σύνηθες φαινόμενο.*

η) Σε ξηρές περιοχές, σύννεφα σκόνης σηκώνονται από το έδαφος

θ) *Αναπήδηση ογκόλιθων (διάμετρος 2-3 μέτρων) και μετακίνηση εκατοντάδων μέτρων από την αρχική τους θέση, ακόμα και σε πρανή με ήπια κλίση, αφήνοντας αποτυπώματα σε μαλακό έδαφος*

## XI - Ισοπεδωτικός / Οι περιβαλλοντικές επιπτώσεις αποτελούν καθοριστικό παράγοντα για την εκτίμηση της έντασης εξαιτίας του κορεσμού των κατασκευαστικών αστοχιών

Πρωτογενείς επιπτώσεις κυριαρχούν.

*Το μήκος του επιφανειακού ίχνους του σεισμογόνου ρήγματος εκτείνεται από αρκετές δεκάδες χιλιομέτρων έως και περισσότερο από εκατό km με μετατόπιση (offset) έως αρκετά μέτρα. Δημιουργούνται βυθίσματα βαρύτητας και επιμήκεις δομές συμπίεσης. Δίκτυα ύδρευσης και αποστράγγισης μπορεί να υποστούν ζημιές λόγω σημαντικών μετατοπίσεων. Τεκτονική ταπείνωση ή ανύψωση της επιφάνειας με μέγιστες τιμές της τάξης πολλών μέτρων ίσως παρατηρηθούν*

Δευτερογενείς επιπτώσεις: *η συνολική έκταση της πληγείσας περιοχής είναι της τάξης των 10.000 $km^2$*

α) Σημαντικές μεταβολές στην παροχή πολλών πηγών και/ή στο σημείο εξόδου του νερού. Ίσως αρκετές πηγές ξηραθούν προσωρινά ή μόνιμα. Προσωρινές ή μόνιμες διακυμάνσεις στη στάθμη του νερού σε πηγάδια. Μεταβολές των φυσικο-χημικών ιδιοτήτων του νερού, κυρίως της θερμοκρασίας παρατηρούνται σε πηγές και/ή πηγάδια. Παρατηρείται συχνά λασπωμένο νερό σε μεγάλες λεκάνες, λίμνες, πηγές και σε πηγάδια. Εκπομπή αερίου, συνήθως θειούχου, παρατηρείται και ίσως καούν θάμνοι και χόρτα σε αυτές τις θέσεις

β) *Μεγάλα κύματα δημιουργούνται σε μεγάλες λίμνες και ποτάμια και παρατηρούνται φαινόμενα υπερχείλισης. Σε πλημμυρικές πεδιάδες τα ρέματα ίσως να αλλάξουν την πορεία τους, προσωρινά ή μόνιμα, λόγω εκτεταμένης εδαφικής καθίζησης και φαινομένων κατολίσθησης. Λεκάνες ίσως εμφανιστούν ή αδειάσουν. Tsunamis ίσως πλησιάσουν στην ακτή με ύψος ίσως και περισσότερο από 15 μέτρα, και ισοπεδώνουν επίπεδες περιοχές σε βάθος χιλιομέτρων. Ακόμα και ογκόλιθοι ίσως παρασυρθούν για πολλά μέτρα. Εκτεταμένη διάβρωση παράκτιων περιοχών, προκαλώντας αξιοσημείωτες μεταβολές στην ακτογραμμή. Δέντρα κοντά στην ακτή ξεριζώνονται και μεταφέρονται μακριά*

γ) Εδαφικές ρωγμές, με άνοιγμα αρκετών μέτρων παρατηρούνται συχνά σε χαλαρές αλλουβιακές αποθέσεις και/ή σε κορεσμένα εδάφη. Σε βραχώδεις σχηματισμού τα άνοιγμα των ρωγμών φθάνει το ένα μέτρο (1m). Παρατηρούνται διαρρήξεις σημαντικού ανοίγματος σε δρόμους είτε ασφαλτοστρωμένους είτε λιθόστρωτους καθώς επίσης και μικρές πτυχώσεις λόγω συμπίεσης.

δ) Μεγάλες *κατολισθήσεις και καταπτώσεις βράχων (>$10^5$-$10^6$ $m^3$) παρατηρούνται συχνά ανεξάρτητα από τις συνθήκες ισορροπίας, δημιουργώντας προσωρινές ή μόνιμες φραγματογενείς λίμνες (barrier lakes). Τα πρανή στις όχθες ποταμών, τα τεχνητά αναχώματα και οι εκσκαφές αστοχούν. Αναχώματα και χωμάτινα φράγματα υφίστανται σημαντικές ζημιές. Σημαντικές κατολισθήσεις μπορεί να παρατηρηθούν σε επικεντρικές αποστάσεις 200-300 km. Συχνές μεγάλες υποθαλάσσιες κατολισθήσεις σε παράκτιες περιοχές.*

ε) *Δέντρα ταλαντώνονται έντονα; Κλαδιά και κορμοί δέντρων σπάνε και πέφτουν. ξεριζώνονται και πέφτουν*

ζ) *Φαινόμενα ρευστοποίησης αλλάζουν την μορφή εκτεταμένων πεδινών εκτάσεων, όπου παρατηρείται καθίζηση αρκετών μέτρων, πολλές εμφανίσεις ηφαιστείων άμμου και σφοδρές πλευρικές εξαπλώσεις.*

η) Σε ξηρές περιοχές, σύννεφα σκόνης σηκώνονται από το έδαφος

θ) *Αναπήδηση μεγάλων ογκόλιθων (διάμετρος αρκετών μέτρων) και μετακίνηση τους από την αρχική θέση, ακόμα και σε πρανή με ήπια κλίση, αφήνοντας αποτυπώματα σε μαλακό έδαφος*

## XII - Απόλυτα Ισοπεδωτικός / Οι περιβαλλοντικές επιπτώσεις είναι το μοναδικό εργαλείο για την εκτίμηση της έντασης

Πρωτογενείς επιπτώσεις κυριαρχούν.

*Το μήκος του επιφανειακού ίχνους του σεισμογόνου ρήγματος είναι τουλάχιστον μερικές εκατοντάδες χιλιόμετρα και το άλμα (offset) δεκάδες μέτρα. Δημιουργούνται βυθίσματα βαρύτητας και επιμήκεις δομές συμπίεσης Τοπογραφικές και η γεωμορφολογικές μεταβολές, οι οποίες προκλήθηκαν από τις πρωτογενείς επιπτώσεις, παίρνουν μεγάλες διαστάσεις τόσο σε έκταση όσο και σε μέγεθος (χαρακτηριστικό παράδειγμα είναι η ανύψωση ακτογραμμών, εμφάνιση ή εξαφάνιση από το απτικό πεδίο χαρακτηριστικών τοπογραφικών στοιχείων, αλλαγή πορείας ποταμών, δημιουργία καταρρακτών, δημιουργία ή εξαφάνιση λιμνών).*

Δευτερογενείς επιπτώσεις: *η συνολική έκταση της πληγείσας περιοχής είναι της τάξης των 50.000 $km^2$ και περισσότερο*

α) *Σημαντικές μεταβολές στην παροχή πολλών πηγών και/ή στο σημείο εξόδου του νερού. Ίσως πολλές πηγές ξηραθούν προσωρινά ή μόνιμα. Προσωρινές ή μόνιμες διακυμάνσεις στη στάθμη του νερού σε πηγάδια. Σημαντικές μεταβολές των φυσικο-χημικών ιδιοτήτων του νερού, κυρίως της θερμοκρασίας παρατηρούνται σε πηγές και/ή πηγάδια. Παρατηρείται συχνά λασπωμένο νερό σε μεγάλες λεκάνες, λίμνες, πηγές και σε πηγάδια. Εκπομπή αερίου, συνήθως θειούχου, παρατηρείται και ίσως καούν θάμνοι και χόρτα σε αυτές τις θέσεις*

β) *Γιγάντια κύματα δημιουργούνται σε λίμνες και ποτάμια και παρατηρούνται φαινόμενα υπερχείλισης. Σε πλημμυρικές πεδιάδες τα ρέματα αλλάζουν την πορεία τους ακόμα και την κατεύθυνση ροής τους, προσωρινά ή μόνιμα, λόγω εκτεταμένης εδαφικής καθίζησης και φαινομένων κατολίσθησης. Λεκάνες ίσως εμφανιστούν ή αδειάσουν. Tsunamis ίσως πλησιάσουν στην ακτή με ύψος αρκετών δεκάδων μέτρων, και ισοπεδώνουν επίπεδες περιοχές σε βάθος χιλιομέτρων. Μεγάλοι ογκόλιθοι μετακινούνται σε μεγάλες αποστάσεις. Εκτεταμένη διάβρωση των ακτών, και αξιοσημείωτες μεταβολές στην παράκτια μορφολογία. Πολλά δέντρα ξεριζώνονται και μεταφέρονται μακριά. Όλα τα αγκυροβολημένα πλοία παρασύρονται και μετακινούνται προς την ενδοχώρα σε μεγάλες αποστάσεις. Οι άνθρωποι στην ύπαιθρο δεν μπορούν να σταθούν όρθιοι*

γ) Πολλές εδαφικές ρωγμές, με άνοιγμα μεγαλύτερο του ενός μέτρου ή και περισσότερο στο υπόβαθρο, και περισσότερο από 10 m σε χαλαρές αλλουβιακές αποθέσεις και/ή σε κορεσμένα εδάφη. Το μήκος τους εκτείνεται αρκετά χιλιόμετρα

δ) *Μεγάλες κατολισθήσεις και καταπτώσεις βράχων (>$10^5$-$10^6$ $m^3$) παρατηρούνται συχνά ανεξάρτητα από τις συνθήκες ισορροπίας, δημιουργώντας προσωρινές ή μόνιμες φραγματογενείς λίμνες (barrier lakes). Τα πρανή στις όχθες ποταμών, τα τεχνητά αναχώματα και οι εκσκαφές αστοχούν. Αναχώματα και χωμάτινα φράγματα υφίστανται σημαντικές ζημιές. Σημαντικές κατολισθήσεις παρατηρούνται σε επικεντρικές αποστάσεις μεγαλύτερες των 200-300 km. Συχνές μεγάλες υποθαλάσσιες κατολισθήσεις σε παράκτιες περιοχές.*

ε) Δέντρα ταλαντώνονται έντονα; Κλαδιά και κορμοί δέντρων σπάνε και πέφτουν. Πολλά δέντρα ξεριζώνονται και πέφτουν

ζ) *Φαινόμενα ρευστοποίησης παρατηρούνται σε μεγάλες σε έκταση περιοχές και αλλάζουν την μορφολογία εκτεταμένων επίπεδων εκτάσεων, όπου παρατηρείται καθίζηση αρκετών μέτρων, εκτεταμένες εμφανίσεις μεγάλων ηφαιστείων άμμου και εκτεταμένες σφοδρές πλευρικές εξαπλώσεις.*

η) Σε ξηρές περιοχές, σύννεφα σκόνης σηκώνονται από το έδαφος

θ) Αναπήδηση πολύ μεγάλων ογκόλιθων και μετακίνηση τους από την αρχική θέση σε μεγάλες αποστάσεις, ακόμα και σε πρανή με ήπια κλίση, αφήνοντας αποτυπώματα σε μαλακό έδαφος

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 95 - 104
tab. 1

# 2.9. - Seismische intensiteitschaal op basis van omgevingseffecten - ESI 2007 (Dutch)

TRANSLATED: SINTUBIN M. (1)

## *Inleiding*

De intensiteit van een aardbeving is gebaseerd op de classificatie van effecten veroorzaakt door de aardbeving op de mens, op constructies aangelegd door de mens (gebouwen en andere infrastructuur) en op de natuurlijke omgeving (omgevingseffecten en geologische effecten). Deze intensiteit is een maat voor de zwaarte van de aardbeving waarbij rekening wordt gehouden met de effecten veroorzaakt door een breed spectrum aan trillingsfrequenties, alsook met statische vervorming.

Alle intensiteitschalen (Rossi-Forel, Mercalli, MCS, MSK, aangepaste Mercalli) beschouwen de effecten op de natuurlijke omgeving als diagnostische elementen voor de evaluatie van de intensiteit. Daarentegen, bepaalde recente schalen (bv. ESPINOSA *et alii*, 1976a; 1976b; GRUNTHAL, 1998) beschouwen enkel de effecten op de mens en door de mens aangelegde constructies, en beperken in belangrijke mate de diagnostische relevantie van omgevingseffecten omwille van de aanname dat deze effecten willekeurig en sterk variabel zijn. Niettemin, recente studies (bv. DENGLER & MCPHERSON, 1993; SERVA, 1994, DOWRICK, 1996; ESPOSITO *et alii*, 1997; HANCOX *et alii*, 2002; MICHETTI *et alii*, 2004) hebben duidelijk aangetoond dat de eigenschappen van geologische en omgevingseffecten, die terug te vinden zijn in historische, archeoseismologische en paleoseismologische bronnen, essentiële informatie opleveren voor het inschatten van de omvang van een aardbeving en in het bijzonder de lokale aardbevingsintensiteit.

Om dit doel te bereiken, is de ESI 2007 intensiteitschaal (MICHETTI *et alii*, 2007) ontworpen, enkel op basis van omgevingseffecten. Het gebruik van deze schaal, al of niet geïntegreerd met de andere, traditionele schalen, laat toe een beter beeld van het aardbevingscenario te bekomen, omdat enkel omgevingseffecten een coherente vergelijking toelaten van de aardbevingintensiteit zowel

- *in tijd*: effecten op de natuurlijke omgeving zijn vergelijkbaar in een tijdsvenster (recente, historische en paleoaardbevingen) dat veel ruimer is dan de periode van het instrumentele gegevensbestand (laatste eeuw),als
- *in verschillende geografische gebieden*: omgevingseffecten hangen niet af van specifieke socio-economische omstandigheden of van verschillende bouwpraktijken.

Dus, de nieuwe schaal heeft tot doel de traditionele aardbevingschalen te integreren

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• voor een aardbevingsintensiteit groter of gelijk aan een intensiteitgraad X, wanneer inschattingen op basis van structurele schade op door de mens aangelegde constructies heel moeilijk worden, terwijl omgevingseffecten nog steeds diagnostisch zijn;

• in dunbevolkte gebieden, wanneer effecten op door de mens aangelegde constructies ontbreken, en daardoor een inschatting van de aardbevingsintensiteit moet gebaseerd worden op omgevingseffecten, omdat deze dan de enige diagnostische elementen zijn waarover men kan beschikken.

De definitie van de intensiteitgraad is het resultaat van een revisie door een internationale werkgroep van geologen, seismologen en ingenieurs van de omgevingseffecten, die veroorzaakt zijn door een groot aantal aardbevingen die zich wereldwijd voordeden. Deze ESI 2007 intensiteitschaal is goedgekeurd door INQUA (International Union for Quaternary Research) tijdens de XVII INQUA bijeenkomst in Cairns (Australië) in 2007.

## *Beschrijving*

De ESI 2007 intensiteitschaal bestaat uit 12 intensiteitgraden. De hoofding van elke intensiteitgraad geeft enerzijds de overeenkomende kracht van de aardbeving weer, en anderzijds de betekenis van de omgevingseffecten. In de daaropvolgende beschrijving worden volgens elke graad eerst de eigenschappen en de omvang van de primaire effecten weergegeven. Vervolgens worden de secundaire effecten gegroepeerd in verschillende categorieën, geordend door de initiële graad van voorkomen. De totale oppervlakte van hun voorkomen wordt aangewend als instrument om een inschatting te kunnen maken van de intensiteit in het epicentrum ($I_0$). *Cursief* gedrukte tekst benadrukt beschrijvingen die op zichzelf als diagnostisch voor een bepaalde intensiteitgraad worden aanzien.

***Primaire effecten*** zijn rechtstreeks gekoppeld aan de aardbevingsenergie en in het bijzonder aan de oppervlakkige fenomenen gerelateerd aan de seismogene bron. De omvang van de primaire effecten wordt typisch uitgedrukt aan de hand van twee parameters: i) totale lengte van de oppervlaktescheur (*Surface Rupture Length – SRL)* en ii) de maximale verplaatsing (*Maximum Displacement – MD*). Het voorkomen van primaire effecten komt doorgaans voor vanaf de intensiteitgraad VIII, met uitzondering van zeer ondiepe aardbevingen in vulkanische gebieden. Tektonische vervorming van het aardoppervlak (opheffing, subsidentie) wordt ook in rekenschap gebracht.

***Secundaire effecten*** zijn alle mogelijke fenomenen die veroorzaakt zijn door grondtrillingen en worden ondergebracht in acht hoofdcategorieën:

a) ***Hydrologische afwijkingen***: in deze categorie worden veranderingen beschreven in het debiet van bronnen en rivieren, alsook in de fysisch-chemische eigenschappen van oppervlakte- en grondwater (bv. temperatuur, watertroebelheid). Deze effecten zijn diagnostisch voor een intensiteitgraad tussen IV en X.

b) ***Afwijkende golven / tsunamis***: deze categorie omvat: ‘seiches’ in afgesloten bekkens, overspoelen van water uit plassen en bekkens, en tsunamis. In het geval van tsunamis is het niet zozeer de omvang van de tsunami zelf, maar zijn het vooral de effecten langsheen de kusten (in het bijzonder de oploophoogte (*run-up*), kusterosie, veranderingen in kustmorfologie), zonder de effecten op de mens en door de mens aangelegde structuren te verwaarlozen, die als diagnostisch voor de intensiteit worden beschouwd. Dergelijke effecten kunnen zich al voordoen bij een intensiteitgraad IV, maar zijn meer diagnostisch voor een intensiteitgraad IX tot en met XII.

c) ***Grondscheuren***: grondscheuren worden beschreven op basis van hun lengte (van cm tot meerdere honderden meter), breedte (van mm tot m), en ruimtelijke dichtheid. Grondscheuren doen zich voor vanaf een intensiteitgraad IV. Er treedt een verzadiging – hun omvang neemt niet meer toe – op bij een intensiteitgraad X.

d) ***Hellingsprocessen***: deze categorie bevatten alle types van grondverschuivingen, waaronder ook bergstortingen, afglijdingen en puinstromen (*earth flows*). Als de lithologische en morfologische context gelijkaardig is, dan zijn volume en totale oppervlakte de diagnostische parameters. Dergelijke hellingsprocessen doen zich voor vanaf een intensiteitgraad IV en verzadigen – hun omvang neemt niet meer toe – bij een intensiteitgraad X.

e) ***Trillen van bomen***: dit effect is diagnostisch voor een intensiteitgraad tussen IV en X. De bepaling van de intensiteitgraden volgt deze van Dengler & McPherson (1993).

f) ***Liquefactie / vloeibaar wording***: in deze categorie vinden we zandvulkanen (*sand boils*), water- en zandfonteinen, sommige types van laterale spreiding, grondsamendrukking en wegzakking. Hun omvang is diagnostisch voor de intensiteitgraad tussen V en X.

g) ***Stofwolken***: deze kunnen worden geobserveerd in woestijngebieden, of in gebieden onderhevig aan droogte, beginnende van een intensiteitgraad VIII.

h) ***Springende stenen***: de maximum grootte van springende stenen is diagnostisch voor de inschatting van de intensiteit. Deze effecten worden waargenomen bij een intensiteitgraad IX tot en met XII. Dit fenomeen wijst erop dat grondversnellingen die groter zijn dan de zwaartekracht, zich lokaal kunnen voordoen vanaf een intensiteitgraad IX.

Omgevingseffecten kunnen worden waargenomen vanaf een intensiteitgraad IV. Sommige types van omgevingseffecten (hydrologische afwijkingen) kunnen zich al voordoen bij een lagere intensiteitgraad, maar kunnen dan niet echt als diagnostisch worden beschouwd. Nauwkeurigheid van beoordeling neemt toe naar hogere intensiteitgraden, in het bijzonder met betrekking tot het voorkomen van primaire effecten (typisch vanaf een intensiteitgraad VIII), met een scheidend vermogen tot en met een intensiteitgraad XII. Vanaf een intensiteitgraad X verzadigen de effecten op de mens en door de mens aangelegde constructies (gebouwen zijn doorgaans volledig verwoest), waardoor het onmogelijk wordt een onderscheid te maken tussen de verschillende intensiteitgraden. In dit bereik zijn omgevingseffecten dominant en leveren zo het meest krachtige instrument om een inschatting te maken van de aardbevingsintensiteit.

## *Hoe de ESI 2007 intensiteitschaal gebruiken?*

Het gebruik van de ESI 2007 intensiteitschaal als een onafhankelijk instrument voor de inschatting van de aardbevingsintensiteit is aangeraden wanneer enkel omgevingseffecten diagnostisch zijn en de effecten op mens en door de mens aangelegde constructies te schaars zijn of verzadigd zijn (bij hogere intensiteitgraden). Indien ook effecten op mens en door de mens aangelegde constructies beschikbaar zijn, dan is het mogelijk twee onafhankelijke inschattingen van de aardbevingsintensiteit te maken. Algemeen wordt dan de hoogste van de twee intensiteitgraden genomen als uiteindelijke intensiteitgraad voor het waarnemingspunt. Natuurlijk blijft het finale oordeel van de expert steeds essentieel bij de inschatting van de intensiteitgraad.

De intensiteit in het epicentrum ($I_0$) geeft de intensiteit van de aardbeving in de omgeving van het epicentrum. Parameters die verband houden met oppervlaktebreukwerking en de totale oppervlakte waarover secundaire effecten (bv. massabewegingen en/of liquefactie) voorkomen, zijn onafhankelijke instrumenten om de $I_0$ in te schatten op basis van de omgevingseffecten vanaf een aardbevingsgraad VII (tab. 2.1).

Bijzondere aandacht moet besteed worden als de parameters die verband houden met oppervlaktebreukwerking zich situeren op de grens tussen twee intensiteitgraden. In dat geval dient de intensiteitgraad te worden gekozen die het meest consistent is met de eigenschappen en de ruimtelijke verbreiding van de secundaire effecten. Bovendien is het aangeraden om bij het vastleggen van de totale oppervlakte waarover secundaire effecten voorkomen, geen rekening te houden met geïsoleerde effecten die zich ver weg (*far field*) voordoen. Ook hier is de evaluatie van de expert noodzakelijk.

Lokale intensiteiten worden voornamelijk ingeschat op basis van de beschrijving van de secundaire effecten die zich voordoen op verschillende 'sites' (*sites*) die deel uitmaken van een specifieke 'lokaliteit' (*locality*). Deze intensiteitgraad moet vergelijkbaar zijn met de traditionele lokale intensiteitgraad bekomen op basis van schade. Gelieve er rekening mee te houden dat een 'lokaliteit' kan verwijzen naar een bewoond gebied (bv. dorp, stad), maar ook naar een onbewoond gebied. Als enkel primaire effecten aanwezig zijn, is het ook mogelijk om de lokale uitdrukking van de oppervlaktebreukwerking – onder de vorm van de maximale verplaatsing – te gebruiken bij de inschatting van de lokale intensiteit.

Tab. 2.1 - *Bereik van parameters die verband houden met oppervlaktebreukwerking (primaire effecten) en de totale oppervlakte (secundaire effecten) voor elke intensiteitgraad.*

| $I_0$ | PRIMAIRE EFFECTEN | | SECUNDAIRE EFFECTEN |
|---|---|---|---|
| | LENGTE VAN OPPERVLAKTESCHEUR | MAXIMALE OPPERVLAKTEVERPLAATSING / VERVORMING | TOTALE OPPERVLAKTE |
| **IV** | - | - | - |
| **V** | - | - | - |
| **VI** | - | - | - |
| **VII** | (*) | (*) | 10 $km^2$ |
| **VIII** | meerdere honderden meter | centimeters | 100 $km^2$ |
| **IX** | 1- 10 km | 5 - 40 cm | 1.000 $km^2$ |
| **X** | 10 - 60 km | 40 - 300 cm | 5.000 $km^2$ |
| **XI** | 60 – 150 km | 300 –700 cm | 10.000 $km^2$ |
| **XII** | > 150 km | > 700 cm | > 50.000 $km^2$ |

(*) Beperkte opervlaktebreukwerking, tientallen tot honderden meter lengte met een centimeter verplaatsing, kunnen zich voordoen bij zeer ondiepe aardbevingen in vulkanische gebieden.

## *Omschrijving van de intensiteitgraden*

**Van I tot III**: Er zijn geen omgevingseffecten dat als diagnostisch kunnen worden gebruikt.

### IV - Algemeen waargenomen – Eerste eenduidige omgevingseffecten

<u>Primaire effecten</u> zijn afwezig.

<u>Secundaire effecten</u>

a) Zeldzame, kleine veranderingen in het waterniveau in waterputten en/of in het debiet van bronnen worden lokaal waargenomen, alsook uiterst zeldzame, kleine veranderingen in de fysisch-chemische eigenschappen van het water alsook de watertroebelheid in bronnen en waterputten, in het bijzonder in bronnen in grote karstsystemen, die gevoeliger zijn voor dit fenomeen.

b) In gesloten bekkens (meren, zelfs zeeën) kunnen 'seiches' met een hoogte van maximum enkele centimeter tot ontwikkeling komen, doorgaans enkel waargenomen door getijdenmeters, uitzonderlijk zelfs met het blote oog, typisch ver weg van zware aardbevingen (*far field*). Afwijkende golven worden waargenomen door vele mensen op kleine boten, door enkelingen op grote boten, en door het merendeel van de mensen langs de kust. Water in zwembaden beweegt en loopt soms over.

c) Uiterst dunne (mm-breed) scheurtjes kunnen uitzonderlijk waargenomen worden op plaatsen waar de lithologie (bv. losse alluviale afzettingen, verzadigde bodems) en/of de morfologie (bv. hellingen of heuvelruggen) het gevoeligst zijn voor dit fenomeen.

d) Uitzonderlijk kunnen rotsblokken vallen en kleine aardverschuivingen ge(re)activeerd worden op hellingen waar het evenwicht kritisch is (bv. steile hellingen en afgravingen met losse en doorgaans verzadigde bodems).

e) Taken aan bomen kunnen zwakjes bewegen.

## V - Zwaar – Beperkte omgevingseffecten

Primaire effecten zijn afwezig.

Secundaire effecten

a) Zeldzame veranderingen in het waterniveau in waterputten en/of in het debiet van bronnen worden lokaal waargenomen, alsook uiterst kleine veranderingen in de fysisch-chemische eigenschappen van het water alsook de watertroebelheid in meren, bronnen en waterputten.

b) In gesloten bekkens (meren, zelfs zeeën) kunnen 'seiches' met een hoogte van enkele decimeter tot ontwikkeling komen, soms ook waargenomen met het blote oog, typisch ver weg van zware aardbevingen (*far field*). Afwijkende golven, tot verschillende tientallen centimeter hoog, worden opgemerkt door iedereen op boten en langs de kust. Het water in zwembaden loopt over.

c) Dunne (mm-breed; met een lengte van enkele cm, tot zelfs een meter) scheuren kunnen lokaal waargenomen worden op plaatsen waar de lithologie (bv. losse alluviale afzettingen, verzadigde bodems) en/of de morfologie (bv. hellingen of heuvelruggen) het gevoeligst zijn voor dit fenomeen.

d) Uitzonderlijk kunnen rotsblokken vallen, rotationele aardverschuivingen en puinstromen plaatsvinden op doorgaans – maar niet noodzakelijk – steile hellingen waar het evenwicht kritisch is, voornamelijk in losse afzettingen en verzadigde bodems. Aardverschuivingen onder water kunnen worden geactiveerd, welke op zich kleine afwijkende golven in kustgebieden of langs meeroevers kunnen veroorzaken.

e) Taken aan bomen en struiken bewegen zwakjes; uitzonderlijk valt dood hout of rijp fruit uit een boom.

f) Uiterst zeldzame gevallen van liquefactie, zoals zandvulkaantjes, zijn gerapporteerd. Deze zijn klein in omvang en komen enkel voor in gebieden die uiterst gevoelig zijn voor dit fenomeen (bv. uiterst gevoelige, recente alluviale of kustnabije afzettingen, ondiepe watertafel).

## VI - Lichte schade – Bescheiden omgevingseffecten

Primaire effecten zijn afwezig.

Secundaire effecten

a) Belangrijke veranderingen in het waterniveau in waterputten en/of in het debiet van bronnen worden lokaal waargenomen, alsook kleine veranderingen in de fysisch-chemische eigenschappen van het water alsook de watertroebelheid in meren, bronnen en waterputten.

b) Afwijkende golven met een hoogte van verschillende tientallen centimeter zorgen voor beperkte overstromingen in kustgebieden of langsheen de meeroevers. Het water in zwembaden, kleine vijvers en meertjes loopt over.

c) *Occasioneel worden mm- tot cm-brede en tot enkele meter lange barsten waargenomen in losse alluviale afzettingen en/of verzadigde bodems; langsheen steile hellingen en rivieroevers kunnen deze barsten 1 à 2 cm breed zijn. Enkele kleine scheuren ontwikkelen zich in verharde (asfalt of steen) wegen.*

d) Bergstortingen en aardverschuivingen met een volume tot ongeveer ~10 $m^3$ kunnen voorkomen, vooral waar het evenwicht kritisch is, zoals bijvoorbeeld op steile hellingen en uitgravingen, met losse, verzadigde bodems, of sterk verweerde / opgebroken gesteente. Aardverschuivingen onder water kunnen worden geactiveerd, welke op zich occasioneel kleine afwijkende golven in kustgebieden of langs meeroevers kunnen veroorzaken, die instrumenteel worden opgemeten.

e) *Taken aan bomen en struiken bewegen matig tot sterk; uitzonderlijk kunnen de toppen van bomen uitscheuren; ook dood hout valt uit de bomen, natuurlijk afhankelijk van de soort, of dat ze vruchten dragen en van de gezondheidstoestand van de bomen.*

f) *Zeldzame gevallen van liquefactie, zoals zandvulkaantjes, zijn gerapporteerd. Deze zijn klein in omvang en komen enkel voor in gebieden die uiterst gevoelig zijn voor dit fenomeen (bv. uiterst gevoelige, recente alluviale of kustnabije afzettingen, ondiepe watertafel).*

## VII - Schade – Aanzienlijke omgevingseffecten

Primaire effecten worden zelden waargenomen, en zo goed als enkel in vulkanische gebieden. Beperkte oppervlaktebreuken, met een lengte van enkele tientallen tot honderden meter en met een verplaatsing van enkele centimeter, kunnen zich voordoen, vooral geassocieerd met zeer ondiepe aardbevingen.

Secundaire effecten: de totale oppervlakte van het getroffen gebied is in de grootteorde van 10 $km^2$.

a) Belangrijke tijdelijke veranderingen in het waterniveau in waterputten en/of in het debiet van bronnen worden lokaal waargenomen. Het komt occasioneel voor dat kleine bronnen tijdelijk droogvallen of ontstaan. Beperkte veranderingen in de fysisch-chemische eigenschappen van het water alsook de watertroebelheid in meren, bronnen en waterputten worden lokaal waargenomen.

b) Afwijkende golven met een hoogte tot meer dan een meter zorgen voor beperkte overstromingen in kustgebieden of langsheen de meeroevers, en kunnen schade veroorzaken of objecten van verschillende omvang wegspoelen. Het water in kleine bekkens en waterlopen loopt over de oevers / randen.

c) *Barsten met een opening die kan oplopen tot 5 à 10 cm en een lengte van meerdere honderden meter, worden waargenomen, meestal in losse alluviale afzettingen en/of verzadigde bodems; langsheen steile hellingen en rivieroevers kunnen deze barsten 1 à 2 cm breed zijn. Soms komen er barsten, tot 1 cm breed, voor in droge zand-, zand-klei- en kleibodems. Cm-brede scheuren zijn veel voorkomend in verharde (asfalt of steen) wegen.*

d) Verspreid komen er aardverschuivingen voor in gevoelige gebieden, waar het evenwicht kritisch is (bv. steile hellingen in losse, verzadigde bodems), terwijl bescheiden bergstortingen veel voorkomen in diepe ravijnen en rotswanden. Hun omvang is soms belangrijk ($10^3$ tot $10^5$ $m^3$); in droge zand-, zand-klei- en kleibodems is het volume doorgaans tot 100 $m^3$. Barsten, aardverschuivingen en afstortingen kunnen zich voordoen aan rivieroevers, kunstmatige dijken en uitgravingen (bv. weginsnijdingen, groeves), met losse, verzadigde bodems, of sterk verweerde / opgebroken gesteente. Belangrijke aardverschuivingen onder water kunnen worden geactiveerd, welke op zich afwijkende golven in kustgebieden of langs meeroevers kan veroorzaken, die ervaren worden door de mens op boten en in havens.

e) Taken aan bomen en struiken bewegen krachtig, vooral in dicht beboste gebieden; takken en boomtoppen breken af en vallen.

f) *Zeldzame gevallen van liquefactie, zoals zandvulkanen tot 50 cm in diameter, zijn gerapporteerd in gevoelige gebieden voor dit fenomeen (bv. uiterst gevoelige, recente alluviale of kustnabije afzettingen, ondiepe watertafel).*

## VIII - Zware schade – Uitgebreide omgevingseffecten

Primaire effecten worden uitzonderlijk waargenomen.

*Oppervlaktescheuren (oppervlaktebreukwerking) kunnen ontstaan, tot een lengte van meerdere honderden meter en met een verplaatsing niet groter dan enkele centimeter. Dit doet zich in het bijzonder voor bij zeer ondiepe aardbevingen, zoals deze die zich voordoen in vulkanische gebieden. Tektonische verzakking of opheffing van het aardoppervlak in de grootteorde van enkele centimeter, kan zich voordoen.*

Secundaire effecten: de totale oppervlakte van het getroffen gebied is in de grootteorde van 100 $km^2$.

a) Bronnen kunnen – doorgaans tijdelijk – veranderen in plaats en/of in debiet. Sommige kleine bronnen kunnen droogvallen.

Veranderingen in het waterniveau zijn waargenomen in waterputten. Beperkte veranderingen in de fysisch-chemische eigenschappen van het water, meestal de temperatuur, kunnen worden waargenomen in bronnen en/of waterputten. Watertroebelheid kan zich voordoen in gesloten bekkens, rivieren, bronnen en waterputten. De uitstoot van gassen, vaak zwavelhoudend, wordt lokaal geobserveerd.

b) Afwijkende golven met een hoogte tot 1 à 2 meter zorgen voor beperkte overstromingen in kustgebieden of langsheen de meeroevers, en kunnen schade veroorzaken of objecten van verschillende omvang wegspoelen. Erosie en het afzetten van puin is waargenomen langsheen stranden; struiken en ondiep gewortelde bomen kunnen worden ontworteld en worden weggespoeld. Het water in kleine bekkens en waterlopen loopt krachtig over de oevers / randen.

c) *Barsten met een opening die kan oplopen tot 50 cm en een lengte van meerdere honderden meter, komen veelvuldig voor in losse alluviale afzettingen en/of verzadigde bodems; in zeldzame gevallen komen barsten tot 1 cm breed voor in competente, droge gesteenten. Scheuren van tientallen centimeter breed zijn veel voorkomend in verharde (asfalt of steen) wegen; ook drukgolven (pressure undulations) komen voor.*

d) Kleine tot gemiddelde ($10^3$ tot $10^5$ $m^3$) aardverschuivingen zijn wijdverbreid in gevoelige gebieden, waar het evenwicht kritisch is (bv. steile hellingen in losse, verzadigde bodems); uitzonderlijk komen ze ook voor op zachte hellingen; bergstortingen komen voor in diepe ravijnen en langs klifkusten. Hun omvang is soms groter ($10^5$ tot $10^6$ $m^3$). Aardverschuivingen kunnen occasioneel nauwe valleien afdammen, en zo tijdelijk of zelfs permanent meren doen ontstaan. Barsten, aardverschuivingen en afstortingen kunnen zich voordoen aan rivieroevers, kunstmatige dijken en uitgravingen (bv. weginsnijdingen, groeves), met losse, verzadigde bodems, of sterk verweerde / opgebroken gesteente. Frequent voorkomen van aardverschuivingen onder water in kustgebieden.

e) *Bomen bewegen krachtig; takken breken af en vallen; bomen kunnen ontworteld worden, in het bijzonder op steile hellingen.*

f) *Liquefactie kan frequent voorkomen in het gebied rond het epicentrum, afhankelijk van de lokale omstandigheden; zandvulkanen tot 1 meter in diameter; schijnbare waterfonteinen in stilstaande waterpartijen; gelokaliseerde laterale spreiding en zetting (verzakking tot ongeveer 30 cm), met barstontwikkeling evenwijdig aan de waterkant (rivieroever, meeroever, kanaal, kust).*

g) *In droge gebieden kunnen in het gebied rond het epicentrum stofwolken ontstaan.*

h) Stenen en zelfs kleine rotsen, alsook boomstammen kunnen de lucht worden ingeworpen, wat resulteert in typische afdrukken in zachte bodems.

## IX - Verwoestend – Omgevingseffecten zijn een wijdverbreide bron van belangrijk risico en worden belangrijke voor het inschatten van de intensiteit

Primaire effecten worden algemeen waargenomen.

*Oppervlaktescheuren (oppervlaktebreukwerking) kunnen ontstaan, tot een lengte van enkele kilometer en met een verplaatsing in de grootteorde van enkele centimeter. Tektonische verzakking of opheffing van het aardoppervlak in de grootteorde van enkele decimeter, kan zich voordoen.*

Secundaire effecten: *de totale oppervlakte van het getroffen gebied is in de grootteorde van 1.000 $km^2$.*

a) *Bronnen kunnen – doorgaans tijdelijk – veranderen in plaats en/of in debiet, en dit in belangrijke mate. Sommige bronnen kunnen droogvallen. Tijdelijke veranderingen in het waterniveau zijn geregeld waargenomen in waterputten. De temperatuur van het water in bronnen en/of waterputten veranderen dikwijls. Veranderingen in de fysisch-chemische eigenschappen van het water, meestal de temperatuur, kunnen worden waargenomen in bronnen en/of waterputten. Watertroebelheid is veel voorkomend in gesloten bekkens, rivieren, bronnen en waterputten. De uitstoot van gassen, vaak zwavelhoudend, wordt geobserveerd. Struiken en grassen dicht bij de uitstootbron kunnen vuur vatten.*

b) *Metershoge afwijkende golven komen tot stand in stilstaand en stromend water. In de riviervlakte (flood plain) kunnen de waterlopen zelfs van loop veranderen, ook omwille van verzakkingen. Kleine bekkentjes kunnen ontstaan en vollopen of leeglopen en verdwijnen. Afhankelijk van de zeebodemmorfologie en kustmorfologie, kunnen gevaarlijke tsunamis de kust bereiken met oploophoogtes (run-up) tot enkele meter hoog die weide gebieden kunnen overstromen. Wijdverbreide erosie en het afzetten van puin is waargenomen langsheen stranden; struiken en bomen kunnen worden ontworteld en worden weggespoeld.*

c) *Barsten met een opening die kan oplopen tot 100 cm en een lengte van meerdere honderden meter, komen veelvuldig voor* *in losse alluviale afzettingen en/of verzadigde bodems; in competente gesteenten komen barsten tot 10 cm breed voor. Scheuren zijn veel voorkomend in verharde (asfalt of steen) wegen; ook drukgolven (pressure undulations) komen voor.*

d) *Aardverschuivingen zijn wijdverbreid in gevoelige gebieden, waar het evenwicht kritisch is (bv. steile hellingen in losse, verzadigde bodems); ook komen ze voor op zachte hellingen; bergstortingen komen voor in diepe ravijnen en langs klifkusten. Hun omvang is doorgaans groot ($10^5$ $m^3$), soms zeer groot ($10^6$ $m^3$). Aardverschuivingen kunnen nauwe valleien afdammen, en zo tijdelijk of zelfs permanent meren doen ontstaan. Rivieroevers, kunstmatige dijken en uitgravingen (bv. weginsnijdingen, groeves) storten in. Frequent voorkomen van aardverschuivingen onder water in kustgebieden.*

e) Bomen bewegen krachtig; takken breken af en vallen; dunne boomstammen breken af en vallen. Bomen kunnen ontworteld worden, in het bijzonder op steile hellingen.

f) *Liquefactie en wateropwellingen (water upsurge) komen frequent voor; zandvulkanen tot 3 meter in diameter; schijnbare waterfonteinen in stilstaande waterpartijen; laterale spreiding en zetting (verzakking van meer dan ongeveer 30 cm), met barstontwikkeling evenwijdig aan de waterkant (rivieroever, meeroever, kanaal, kust), komen geregeld voor.*

g) In droge gebieden komen stofwolken geregeld voor.

h) *Stenen en zelfs kleine rotsen, alsook boomstammen kunnen de lucht worden ingeworpen en verplaatst worden voor meerdere meters, afhankelijk van de helling en afgerondheid van de rotsen, wat resulteert in typische afdrukken in zachte bodems.*

## X - Heel verwoestend – Omgevingseffecten worden de eerste bron van risico en zijn cruciaal voor de inschatting van de intensiteit

Primaire effecten worden dominant.

*Oppervlaktescheuren (oppervlaktebreukwerking) kunnen ontstaan, tot een lengte van enkele tientallen kilometer en met een verplaatsing in de grootteorde van enkele tientallen centimeter tot enkele meter. Gravitaire inzakkingbekkens en langwerpige depressies kunnen ontstaan; voor zeer ondiepe aardbevingen in vulkanische gebieden zijn de lengtes van oppervlaktescheuren kleiner. Tektonische verzakking of opheffing van het aardoppervlak in de grootteorde van enkele meter, kan zich voordoen.*

Secundaire effecten: *de totale oppervlakte van het getroffen gebied is in de grootteorde van 5.000 $km^2$.*

a) Vele bronnen veranderen in belangrijke mate in plaats en/of in debiet. Sommige bronnen kunnen tijdelijk of permanent droogvallen. Tijdelijke veranderingen in het waterniveau zijn veel voorkomend in waterputten. Zelfs belangrijke veranderingen in de fysisch-chemische eigenschappen van het water, meestal de temperatuur, kunnen worden waargenomen in bronnen en/of waterputten. Dikwijls wordt het water zeer modderig, zelfs in grote bekkens, rivieren, bronnen en waterputten. De uitstoot van gassen, vaak zwavelhoudend, wordt geobserveerd. Struiken en grassen dicht bij de uitstootbron kunnen vuur vatten.

b) *Metershoge afwijkende golven komen tot stand in grote meren en rivieren, gepaard gaand met de overstroming van de oevers. In de riviervlakte (flood plain) kunnen de waterlopen zelfs van loop – tijdelijk of permanent – veranderen, ook omwille van verzakkingen. Bekkens kunnen ontstaan en vollopen of leeglopen en verdwijnen. Afhankelijk van de zeebodemmorfologie en kustmorfologie, kunnen gevaarlijke tsunamis de kust bereiken met oploophoogtes (run-up) groter dan 5 meter hoog die weide gebieden tot kilometers landinwaarts kunnen overstromen. Kleine rotsen kunnen voor meerdere meters worden meegesleurd. Wijdverbreide, diepe erosie is waargenomen langsheen de kusten, met waarneembare veranderingen in het kustlijnprofiel. Bomen langsheen de kust worden ontworteld en weggespoeld.*

c) *Barsten met een opening die kan oplopen tot meer dan 1 meter en een lengte van meerdere honderden meter, komen veelvuldig voor in losse alluviale afzettingen en/of verzadigde bodems; in competente gesteenten komen barsten van meerdere decimeter breed voor. Brede scheuren zijn veel voorkomend in verharde (asfalt of steen) wegen; ook drukgolven (pressure undulations) komen voor.*

d) *Aardverschuivingen en bergstortingen (groter dan $10^5$ $m^3$-$10^6$ $m^3$) zijn wijdverbreid onafhankelijk van de evenwichttoestand van de hellingen. Ze kunnen valleien afdammen, en zo tijdelijk of zelfs permanent meren doen ontstaan. Rivieroevers, kunstmatige dijken en uitgravingen (bv. weginsnijdingen, groeves) storten doorgaans in. Aanlegsteigers en aarden dammen kunnen belangrijke schade oplopen. Frequent voorkomen van aardverschuivingen onder water in kustgebieden.*

e) *Bomen bewegen krachtig; takken en boomstammen breken af en vallen. Bomen kunnen ontworteld worden en omvallen.*

f) *Liquefactie en wateropwellingen (water upsurge) en bodemsamendrukking kunnen het landschap sterk veranderen; zandvulkanen tot 6 meter in diameter; verticale verzakking tot meer dan 1 meter; laterale spreiding geeft aanleiding tot grote en lange barsten.*

g) In droge gebieden komen stofwolken geregeld voor.

h) *Stenen en zelfs kleine rotsen (met een diameter groter dan 2 à 3 meter), alsook boomstammen kunnen de lucht worden ingeworpen en verplaatst worden voor honderden meter, zelfs op zachte hellingen, wat resulteert in typische afdrukken in zachte bodems.*

## XI - Vernietigend – Omgevingseffecten worden beslissend bij de inschatting van de intensiteit, omwille van de verzadiging van structurele schade

Primaire effecten zijn dominant.

*Oppervlaktescheuren (oppervlaktebreukwerking) kunnen ontstaan, tot een lengte van enkele tientallen kilometer tot meer dan honderd kilometer en met een verplaatsing in de grootteorde van enkele meter. Gravitaire inzakkingbekkens, langwerpige depressies en drukruggen kunnen ontstaan. Waterscheidingen kunnen in belangrijke mate worden verplaatst. Tektonische verzakking of opheffing van het aardoppervlak in de grootteorde van enkele meter, kan zich voordoen.*

Secundaire effecten: *de totale oppervlakte van het getroffen gebied is in de grootteorde van 10.000 $km^2$.*

a) Vele bronnen veranderen in belangrijke mate in plaats en/of in debiet. Vele bronnen kunnen tijdelijk of permanent droogvallen. Tijdelijke of permanente veranderingen in het waterniveau zijn algemeen in waterputten. Zelfs belangrijke veranderingen in de fysisch-chemische eigenschappen van het water, meestal de temperatuur, kunnen worden waargenomen in bronnen en/of waterputten. Dikwijls wordt het water zeer modderig, zelfs in grote bekkens, rivieren, bronnen en waterputten. De uitstoot van gassen, vaak zwavelhoudend, wordt geobserveerd. Struiken en grassen dicht bij de uitstootbron kunnen vuur vatten.

b) *Metershoge afwijkende golven komen tot stand in grote meren en rivieren, gepaard gaand met de overstroming van de oevers. In de riviervlakte (flood plain) kunnen de waterlopen zelfs van loop – tijdelijk of permanent – veranderen, ook omwille van wijdverbreide verzakkingen en massabewegingen. Bekkens kunnen ontstaan en vollopen of leeglopen en verdwijnen. Afhankelijk van de zeebodemmorfologie en kustmorfologie, kunnen gevaarlijke tsunamis de kust bereiken met oploophoogtes (run-up) tot meer dan 15 meter hoog die in vlakke kustgebieden tot kilometers landinwaarts zeer verwoestend zijn. Zelfs metersgrote rotsen kunnen voor lange afstanden worden meegesleurd. Wijdverbreide, diepe erosie is waargenomen langsheen de kusten, met waarneembare veranderingen in het kustlijnprofiel. Bomen langsheen de kust worden ontworteld en weggespoeld.*

c) Open barsten met een opening die kan oplopen tot meerdere meters komen veelvuldig voor in losse alluviale afzettingen en/of verzadigde bodems; in competente gesteenten komen barsten tot een meter breed voor. Zeer brede scheuren zijn veel voorkomend in verharde (asfalt of steen) wegen; ook drukgolven (pressure undulations) komen voor.

d) *Grote aardverschuivingen en bergstortingen (groter dan $10^5$ $m^3$-$10^6$ $m^3$) zijn wijdverbreid onafhankelijk van de evenwichttoestand van de hellingen. Ze kunnen valleien afdammen, en zo tijdelijk of zelfs permanent meren doen ontstaan. Rivieroevers, kunstmatige dijken en uitgravingen (bv. weginsnijdingen, groeves) storten doorgaans in. Aanlegsteigers en aarden dammen kunnen belangrijke schade oplopen. Belangrijke aardverschuivingen kunnen zich voordoen op een afstand van 200 à 300 km van het epicentrum. Frequent voorkomen van aardverschuivingen onder water in kustgebieden.*

e) *Bomen bewegen krachtig; vele takken en boomstammen breken af en vallen. Vele bomen kunnen ontworteld worden en omvallen.*

f) *Liquefactie kan het landschap van laaglanden sterk veranderen, bepalend voor de verticale verzakkingen van meerdere meters; veelvuldig voorkomen van grote zandvulkanen; veelvuldig voorkomen van laterale spreiding.*

g) In droge gebieden komen stofwolken geregeld voor.

h) *Stenen en zelfs rotsen (met een diameter van meerdere meters), alsook boomstammen kunnen de lucht worden ingeworpen en verplaatst worden voor grote afstanden, zelfs op zachte hellingen, wat resulteert in typische afdrukken in zachte bodems.*

## XII - Totale vernietiging – Omgevingseffecten zijn het enige instrument voor het inschatten van de intensiteit

Primaire effecten zijn dominant.

*Oppervlaktescheuren (oppervlaktebreukwerking) zijn minstens enkele honderden kilometer lang en gaan gepaard met verplaatsingen van meerdere tientallen meter. Gravitaire inzakkingbekkens, langwerpige depressies en drukruggen kunnen ontstaan. Waterscheidingen kunnen in belangrijke mate worden verplaatst. Landschappelijke en geomorfologische veranderingen, veroorzaakt door de primaire effecten, kunnen buitengewone omvang aannemen (typische voorbeelden zijn de opheffing of verzakking van kustlijnen voor meerdere meters, verschijnen of verdwijnen van belangrijke landschapselementen, verandering van de loop van rivieren, ontstaan van watervallen, vorming of verdwijnen van meren).*

Secundaire effecten: *de totale oppervlakte van het getroffen gebied is in de grootteorde van 50.000 km$^2$ en meer.*

a) Vele bronnen veranderen in belangrijke mate in plaats en/of in debiet. Vele bronnen kunnen tijdelijk of permanent droogvallen. Tijdelijke of permanente veranderingen in het waterniveau zijn algemeen in waterputten. Belangrijke veranderingen in de fysisch-chemische eigenschappen van het water, meestal de temperatuur, kunnen worden waargenomen in bronnen en/of waterputten. Dikwijls wordt het water zeer modderig, zelfs in grote bekkens, rivieren, bronnen en waterputten. De uitstoot van gassen, vaak zwavelhoudend, wordt geobserveerd. Struiken en grassen dicht bij de uitstootbron kunnen vuur vatten.

b) *Enorme afwijkende golven komen tot stand in grote meren en rivieren, gepaard gaand met de overstroming van de oevers. In de riviervlakte (flood plain) kunnen de waterlopen zelfs van loop en van richting – tijdelijk of permanent – veranderen, ook omwille van wijdverbreide verzakkingen en massabewegingen. Grote bekkens kunnen ontstaan en vollopen of leeglopen en verdwijnen. Afhankelijk van de zeebodemmorfologie en kustmorfologie, kunnen gevaarlijke tsunamis de kust bereiken met oploophoogtes (run-up) van meerdere tientallen meter hoog die in vlakke kustgebieden tot kilometers landinwaarts zeer verwoestend zijn. Grote rotsen kunnen voor lange afstanden worden meegesleurd. Wijdverbreide, diepe erosie is waargenomen langsheen de kusten, met belangrijke veranderingen in het kustlijnprofiel. Bomen langsheen de kust worden ontworteld en weggespoeld. Alle boten zijn losgerukt van hun ligplaats aan de kade en zijn weggeslagen of over grote afstand landinwaarts meegesleurd. Alle mensen buiten worden meegesleurd.*

c) Open barsten komen veelvuldig voor, tot een meter breed of meer in het vast gesteente, tot meer dan 10 m breed in losse, alluviale sedimenten en/of verzadigde bodems. Zij hebben een lengte van meerdere kilometers.

d) *Grote aardverschuivingen en bergstortingen (groter dan $10^5$ m$^3$-$10^6$ m$^3$) zijn wijdverbreid onafhankelijk van de evenwichttoestand van de hellingen. Ze kunnen valleien afdammen, en zo tijdelijk of zelfs permanent meren doen ontstaan. Rivieroevers, kunstmatige dijken en uitgravingen (bv. weginsnijdingen, groeves) storten doorgaans in. Aanlegsteigers en aarden dammen kunnen belangrijke schade oplopen. Belangrijke aardverschuivingen kunnen zich voordoen op een afstand van 200 à 300 km van het epicentrum. Frequent voorkomen van aardverschuivingen onder water in kustgebieden.*

e) Bomen bewegen krachtig; vele takken en boomstammen breken af en vallen. Vele bomen kunnen ontworteld worden en omvallen.

f) *Liquefactie komt voor over grote oppervlakte en verandert sterk het landschap van laaglanden, bepalend voor de verticale verzakkingen van meerdere meters; veelvuldig voorkomen van grote zandvulkanen; veelvuldig voorkomen van laterale spreiding.*

g) In droge gebieden komen stofwolken geregeld voor.

h) Ook grote rotsen kunnen de lucht worden ingeworpen en verplaatst worden voor grote afstanden, zelfs op zachte hellingen, wat resulteert in typische afdrukken in zachte bodems.

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 105 - 116
tab. 1

## 2.10. 환경진도단위-ESI 2007 (한국어) (Korean)

TRANSLATED: KIM Y.-S. (1), JIN K. (1)

### *서론*

진도는 지진사건에 의해 인간, 인공구조물 (건물과 사회기반시설)과 자연환경 (환경적 또는 지질학적 영향)에 끼치는 영향의 분류에 기초한다.이 진도는 정적 변형뿐만 아니라 전 진동주파수 범위 내의 영향들을 고려하여 지진강도의 척도를 제시한다.

모든 진도단위들(Rossi-Forel, Mercalli, MCS, MSK, Mercalli Modified)은 진도분류의 산정을 위한 진단요소로서 자연환경에 미치는 영향을 고려한다.대신 일부 현대적 단위들(e.g., ESPINOSA *et alii*, 1976a; 1976b; GRUNTHAL, 1998)은 환경의 영향은 너무 다양하고 우연적이라는 가정하에, 사람과 인공구조물에 미치는 영향만을 고려하고 환경적 영향의 진단 관련성을 크게 줄였다.

그럼에도 불구하고, 최근의 연구들(e.g., DENGLER & MCPHERSON, 1993; SERVA, 1994; DOWRICK, 1996; ESPOSITO *et alii*, 1997; HANCOX *et alii*, 2002; MICHETTI *et alii*, 2004)은, 최근 역사 및 고지진학적 자료로부터 폭 넓게 찾을 수 있는 지질학적, 환경적 영향의 특성이 지진의 크기, 특히 진도를 산정하기 위한 필수적인 정보라는 명백한 증거들을 제시해왔다.

이러한 목적에서 ESI 2007 진도단위(MICHETTI *et alii*, 2007)가 환경적 영향만을 고려하여 만들어졌다. 그것만 사용하든 다른 전통적인 단위들과 결합하든 그것의 사용은, 환경적 영향은 두 가지 측면에서 진도의 적절한 비교를 허락하기 때문에 더 나은 지진 시나리오를 제공한다.

· *시간적으로*: 자연환경에의 영향은 계기지진기록(지난 세기)의 기간보다 훨씬 더 긴 시간(현재, 역사, 고지진)에 대해 비교가 가능하다. 그리고

· *다른 지역에서*: 환경영향은 특이한 사회경제적인 조건 또는 다른 건축양식 등에 좌우되지 않는다.

그러므로 이 새로운 단위는 기존 지진단위들을 통합하는데 목적이 있다:

· 진도가 10 이상일 경우, 피해에 근거한 산정은 매우 어려운 반면, 환경영향은 여전히 진단적이다;

· 인구가 적은 지역에서는, 인공구조물에 대한 영향이 빈약해서 진도산정은 환경적 영향에 기초할 수 밖에 없고, 이것이 유일한 진단요소가 된다.

진도등급의 정의는, 전 세계적인 많은 지진에 의해 발생한 효과들에 기초하여, 지질학자, 지진학자 및 공학자들로 구성된 국제작업팀(International Working Group)에 의해 검토된 결과이다.

ESI 2007은 2007년 17회 INQUA 학회(Cairns, Australia)에서 INQUA (제4기 연구 국제연합)에 의해 비준되었다.

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*기재*

ESI 2007 진도단위는 12 등급으로 구성된다.

각 등급명은 상응하는 지진력과 환경영향의 역할을 반영한다.
기재에서는, 각 등급과 관련된 일차영향들의 특성과 크기가 우선적으로 보고되었다.
그 다음에 이차영향들이, 초기 산출등급의 순서로 여러 범주로 분류되어, 진앙 진도의 평가를 위해 전체 분포면적에 의해 기술되었다.
*이탤릭체*는 주어진 등급에 대한 그 자체의 특징으로 간주되는 강조된 표현에 사용되었다.
***일차영향들은*** 지진에너지 그리고 특히 지진원의 지표현상에 직접 연관된다.
일차영향들의 크기는 전형적으로 두 변수에 의하여 표현된다: i) 총 지표파열 길이(SRL: Total Surface Rupture), 그리고 ii) 최대 변위(MD: Maximum Displacement).
그들의 산출은, 화산지대에서의 극한 천발지진 경우를 제외하면, 일반적으로 최소 진도값(VIII)과 관련된다.지체구조적 지표변형(융기, 침강)의 양도 또한 고려된다.
***이차영향들은*** 지진동에 의해 유발된 모든 현상들이며 8개의 주요 범주로 구분된다.

a) ***수문학적 이상(hydrological anomalies)***: 이 범주는 지표수와 지하수의 물리화학적 변화(e.g. 온도, 혼탁도)뿐만 아니라 샘과 강의 유량에서의 보고된 변화이다. 이 영향들은 진도 IV에서 X등급까지의 특징이다.

b) ***이례적인 파도/쓰나미(Anomalous waves/tsunamis)***: 이 범주는 닫힌 분지 내의 정진동, 연못과 분지로부터의 물의 넘침, 그리고 쓰나미파 등을 포함한다. 쓰나미의 경우, 인간과 인공구조물에 대한 영향을 무시하지 않지만, 그 자체의 크기 이외에 해변에 미치는 영향(특히 해수상승, 해변침식, 해안지형의 변화)이 심한 진도의 특성으로 고려된다. 이런 영향은 진도 IV에서 발생할 수 있지만 진도 IX부터 XII에서 더욱 특징적이다.

c) ***지표 균열(Ground cracks)***: 지표균열은 길이(cm에서 수백 m까지), 폭(mm에서 m까지), 면밀도에 의해 기술된다. 지표균열은 진도 IV에서부터 나타나고, 진도 X에서 포화된다(i.e. 그들의 크기는 증가하지 않는다).

d) ***사면 이동(Slope movements)***: 이 범주는 낙석, 사태 및 토류 등을 포함하는 산사태의 모든 유형들을 포괄한다. 암석학적 및 지형적 특성이 비슷할 때, 진단 변수는 체적과 총 면적이다. 그들은 진도 IV에서 나타나고 진도 X에서 포화된다(i.e. 그들의 크기는 증가하지 않는다).

e) ***나무 진동(Tree shaking)***: 이 영향은 진도 IV에서 X까지의 특징이다. 진도등급의 정의는 기본적으로 Dengler and McPherson (1993)에 의한 분류를 따른다.

f) ***액상화(Liquefactions)***: 이 범주는 모래분출, 물과 모래 분수, 측면 확산, 지반 압밀 및 침강 등이 포함된다. 그들의 크기는 진도 V부터 X에서 진단된다.

g) ***먼지 구름(Dust clouds)***: 먼지 구름은 건조한 지역에서 관찰되며, 진도 VIII 이상부터 시작된다.

h) ***튀는 돌(Jumping stones)***: 튀는 돌의 최대 크기는 진도 산정에 진단적이다. 이러한 영향은 진도 IX부터 XII에서 관찰된다. 그런 증거들은 진도 IX부터 지반가속도가 중력을 능가할 때 지역적으로 나타난다.

환경적 영향은 진도 IV에서부터 관찰되고 특성화된다.일부 환경적 영향(수문학적 이상)은 더 낮은 등급에서도 관찰되지만, 진단적인 요소로 고려될 만큼 특징적이지 않다.평가의 정확도는, 특히 일차영향이 발생하는(전형적으로 진도 VIII부터) 범위에서 진도 XII까지 해상도가 증가하면서, 높은 진도로 갈수록 증가한다.진도 X부터는 사람과 인공구조물에 미치는 영향이 포화되므로(즉 건물이 종종 완전히 파괴된다) 다른 진도등급들 사이의 구분이 불가능하다.이 범위에서는 환경적 영향이 우세하므로 진도평가를 위한 가장 강력한 도구가 된다.

***ESI 2007 진도단위를 어떻게 사용하는가?***

진도산정을 위한 유일한 방법으로 ESI 진도단위를 사용하는 것은 인간과 인공구조물들에 대한 영향이 너무 적거나 포화되었기 때문에 환경적인 영향만이 진단적일 때 권장된다.이러한 후자의 방법이 또한 가능할 때는, 두 가지의 독립적인 진도산정 추정이 가능하다.일반적으로 최종적인 진도는 두 가지 산정값 중 더 높은 값과 일치할 것이다.이런 경우 분명히 전문가의 판단이 필수적일 것이다.

진앙진도($I_0$)는 진앙에 해당하는 지진동 강도를 지시한다.

지표단층 변수와 이차영향들(산사태 그리고/또는 액상화)의 총 면적분포는, 진도 VII에서부터(표1) 시작하는 환경적 영향에 기초한, 진앙진도($I_0$)를 산정하기 위한 두 개의 독립적인 도구이다.지표단층 변수가 두 개의 서로 다른 진도등급 사이의 경계에 존재할 때는 특별한 주의를 기울여야 한다.이런 경우 이차영향의 특징 그리고 면적분포와 더 잘 일치하는 진도 값이 선택되어야 한다.이에 더하여, 총 면적의 평가에서는 멀리 떨어진 고립된 영향을 포함하지 않는 것이 권장된다.

이 평가 또한 전문가의 판단이 요구된다.

지역적 진도는 기본적으로 특정한 위치에 포함되는 다른 “지역들”에서 발생한 이차영향들의 기술을 통해 평가된다.이런 종류의 진도는 피해에 근거한 해당되는 전통적인 지역적 진도와 비교되어야 한다.“위치”는 사람들이 거주하는 지역(마을, 시가지)뿐만 아니라 사람들이 거주하지 않은 자연지역에 대해서도 언급될 수 있다는 것에 유념하라.

단지 일차영향들만이 나타날 때도, 이 또한 최대 변위로 지표단층작용의 지역적 현상을 사용하는 것이 가능합니다.

*표1 – 각 진도등급에 대한 지표단층 변수의 범위(일차영향)와 전체 면적의 전형적인 분포(이차영향).*

| $I_0$ | PRIMARY EFFECTS | | SECONDARY EFFECTS |
|---|---|---|---|
| | Surface Rupture Length | Max Surface Displacement / Deformation | Total Area |
| **IV** | - | - | - |
| **V** | - | - | - |
| **VI** | | - | - |
| **VII** | (*) | (*) | 10 $km^2$ |
| **VIII** | Several hundreds meters | Centimetric | 100 $km^2$ |
| **IX** | 1- 10 km | 5 - 40 cm | 1000 $km^2$ |
| **X** | 10 - 60 km | 40 - 300 cm | 5000 $km^2$ |
| **XI** | 60 – 150 km | 300 –700 cm | 10000 $km^2$ |
| **XII** | > 150 km | > 700 cm | > 50000 $km^2$ |

(*) 수십에서 수백 미터 길이와 센티미터의 변위를 갖는, 매우 제한된 지표단층 파열이, 화산지역들에서 근본적으로 매우 천부의 지진과 관련하여 발생할 수 있다.

### *진도등급의 정의*

**I – III:** 특징적으로 사용될 수 있는 환경영향은 없음.

**IV 폭 넓게 관찰됨/환경에서 첫 번째 명백한 영향**

일차영향들은 없음

이차영향들

a) 드물게 관정 수위와 샘 유속의 작은 변화가 지역적으로 기록되며, 또한 특히 이러한 현상에 가장 민감한 것으로 보이는 큰 카르스트 샘 시스템 내에서 샘과 관정의 물과 혼탁도의 물리화학적 특성에서의 극도로 작은 변화가 기록된다.

b) 닫힌 분지(호수나 바다)에서 몇 cm를 넘지 않는 높이의 정진동이 발생하고, 전형적으로 발생한 강진의 먼 곳에서 조력 측정기에서만 측정될 수 있고, 예외적으로 맨눈으로 확인이 가능하다. 이상한 파도가 큰 배에 있는 일부 사람들, 작은 배에 있는 모든 사람들과 해안가에 있는 대부분의 사람들에 의해 감지된다. 수영장에 있는 물은 흔들리거나 때때로 넘치기도 한다.

c) 암석학적으로(e.g., 느슨한 충적층, 포화된 토양) 그리고 지형학적으로(사면과 산마루) 이러한 현상이 일어나기 가장 쉬운 곳에서 머리카락 두께의 균열(mm 폭)이 가끔 보여진다.

d) 특히, 느슨하거나 포화된 토양이 있는 가파른 사면이나 절취면 등에서 평형상태가 한계치에 도달한 사면을 따라서 암석붕락과 작은 규모의 산사태가 발생하거나 재발할 수 있다.

e) 나뭇가지들이 약하게 흔들린다.

**V 강함/자연환경에서의 최저 영향**

일차영향들은 없음

이차영향들

a) 물의 물리화학적 특성의 작은 변화와 호수, 샘 그리고 관정의 혼탁도 뿐만 아니라, 관정 수위 그리고/또는 샘의 유속에서의 미미한 변화들이 지역적으로 기록된다.

b) 닫힌 분지들(호수나 바다조차)에서는 전형적으로 먼 곳에서 발생한 강진에 의해 10 cm 높이의 정진동이 발생하고 때때로 눈으로도 확인된다. 수십 cm의 높이까지의 비정상적인 파도가 해안가와 배 위에 있는 모든 사람들에 의해 감지된다. 수영장에 있는 물이 넘친다.

c) 암상(e.g., 느슨한 충적층, 포화된 토양) 그리고/또는 지형(사면과 산마루)이 이러한 현상에 가장 취약한 곳에서 얇은 두께의 균열들(mm 두께와 수십 cm에서 1 m까지의 길이)이 지역적으로 보여진다.

d) 드물게 작은 규모의 낙석, 회전성 산사태, 토석류 등이, 주로 느슨한 퇴적물과 포화된 토양에서, 평형이 한계상황 근처에 있는 일반 사면이나 가파른 사면을 따라 발생할 수 있다. 수중사태가 촉발될 수 있으며, 이는 해안지역이나 호수에서 작은 규모의 비정상적인 파도를 발생시킬 수 있다.

e) 나뭇가지와 관목들이 가볍게 흔들리거나, 아주 드물게 죽은 가지나 익은 과일들이 떨어지기도 한다.

f) 극히 드문 경우로 액상화(모래)가 작은 규모로 이러한 현상에 취약한 지역(매우 민감한, 최근의 충적 그리고 해안 퇴적물, 지표근처의 수위)에서 보고된다.

**VI 약한 피해/환경에의 보통의 영향**

일차영향들은 없음

이차영향들

a) 극히 드문 경우로 액상화(모래)가 작은 규모로 이러한 현상에 취약한 지역(매우 민감한, 최근의 충적 그리고 해안 퇴적물, 지표근처의 수위)에서 보고된다.

b) 수십 cm까지의 비정상적인 높은 파도가 연안근처의 매우 제한된 지역들에 발생한다. 수영장, 작은 연못, 분지들에서는 물이 넘친다.

c) *가끔 mm에서 cm 넓이와 수 m 길이의 단열이 느슨한 충적층 그리고/또는 포화된 토양에서 발생한다; 가파른 사면이나 강둑을 따라서는 1-2 cm의 넓이로 발달할 수 있다. 일부 작은 균열이 포장된 도로(아스팔트나 석조)에 발달한다.*

d) 특히, 예를 들어 느슨하고 포화된 토양 또는 풍화가 심하거나 균열이 발달한 암석이 있는 가파른 사면이나 절취면과 같이 평형이 한계상황인 곳에서, 약 $10^3$ $m^3$의 부피에 해당하는 낙석과 산사태가

발생한다. 수중 산사태가 발생할 수 있으며, 가끔은 해안가와 호수 주변에서 작은 비정상적인 파도가 발생하며, 보통은 계기기록들에서 보여진다.

e) *나무와 관목들이 보통에서 강하게까지 흔들린다; 종류, 과실하중, 건강상태에 따라 다르지만 일부 나무의 꼭대기 부분이나 불안정한 죽은 나뭇가지가 갈라지거나 떨어진다.*

f) *드물게 액상화(모래분출)가 작은 규모로 이러한 현상에 취약한 지역에서(높은 취약성의 최근 충적층과 해안퇴적층, 지표근처의 수위) 보고된 경우도 있다.*

**VII 피해/환경에서의 뚜렷한 영향**

일차영향들은 극히 드물게 관찰되고, 대부분 화산지역이다. 극천부 지진들에 수반되어 수십에서 수백 m 길이와 cm단위의 변위를 갖는 제한적인 지표단층 파열들이 발달한다.
이차영향들: 총 영향면적은 10 $km^2$ 정도이다.

a) 관정 수위와 샘 유속의 현저한 일시적인 변화가 지역적으로 기록된다. 가끔은 작은 샘이 일시적으로 사라지거나 생성된다. 물의 물리화학적 특성 그리고 호수, 샘 및 관정 탁도의 작은 변화가 지역적으로 관찰된다.

b) 일부 해안지역에서는 수 m 이상의 비정상적인 파도가 넘쳐 흐를 수 있고 다양한 크기의 물체들에 피해를 주거나 휩쓸어 간다. 작은 분지나 수로에서 물이 넘친다.

c) *느슨한 충적층 그리고/또는 포화된 토양에서 폭 5-10 cm와 수백 m 길이에 달하는 단열들이 관찰되며; 마른 모래, 모래-점토, 그리고 점토에서 드물게 1 cm 폭까지의 토양단열들이 발달한다. cm 두께의 균열들이 포장된 도로(아스팔트나 석조)에서 일반적으로 발달한다.*

d) 분산된 산사태가, 평형이 불안정한 곳인(느슨하고 포화된 토양의 가파른 사면들) 취약한 곳에서 발생하며, 어느 정도의 낙석들이 가파른 협곡이나 절벽에서 발생한다. 때때로 산사태의 규모는 $10^3$-$10^5$ $m^3$이며, 마른 모래, 모래-점토와 점토 토양지역에서는 보통 부피가 100 $m^3$에 이른다. 지표파열, 사태, 낙석 등이 느슨한 충적층 또는 풍화되거나 균열이 발달한 암석이 분포하는 강둑, 제방과 절취사면(e.g. 도로사면, 채석장)에 영향을 줄 수 있다. 뚜렷한 수중 산사태가 발생하며, 부두나 배에 있는 사람들이 직접 느낄 수 있는 비정상적인 파도가 해안지역이나 호수에서 발생한다.

e) 나무와 관목들이 격렬하게 흔들리며; 특히 울창한 숲에서, 많은 가지와 나무 끝이 찢어지거나 떨어진다.
f) *이러한 현상에 가장 취약한 지역들에서(지표수면 근처의 매우 민감한, 최근의 충적층과 해안퇴적층)에서 지름 50 cm에 달하는 모래분출을 갖는 액상화가 드물게 보고된다.*

**VIII 심한 피해/ 환경에서의 광역적인 영향**

일차영향들은 드물게 관찰된다.

*특히 화산지역에 일반적인 극천부 지진에서 수백m의 길이와 수 cm를 넘지 않는 지반파열(지표단층) 이 발생할 수 있다. 지표에서 최대 수 cm의 지체구조적 침하 또는 융기가 발생한다.*

<u>이차영향들</u>: 총 영향면적은 100 km$^2$ 정도 이다

a) 일반적으로 일시적으로 샘은 유속과 수위가 변한다. 일부 작은 샘들은 마른다. 관정들에서 수위의 변화가 관찰된다. 가장 일반적으로 온도와 같은 물리화학적 특성의 약한 변화가 샘과 관정들에서 관찰된다. 폐쇄된 분지, 강, 관정, 샘 등에서 혼탁성이 나타난다. 지역적으로 가스 분출, 때때로 유황가스의 분출이 관찰된다.

b) 해안지역에서 1-2 m까지의 비정상적인 파도가 넘쳐 흐를 수 있고 다양한 크기의 물체들에 피해를 주거나 휩쓸어 간다. 일부 관목과 뿌리가 얕은 작은 나무들이 뿌리가 뽑히고 떨어져 나가는 곳에서 침식과 쓰레기들의 쏟아짐이 해안을 따라 관찰된다. 물이 격렬하게 작은 분지나 수로에서부터 넘쳐난다.

c) *느슨한 충적층 그리고/또는 포화된 토양에서 50 cm까지의 넓이와 수백 m까지의 길이를 갖는 단열들이 흔히 관찰되며; 드물게 신선한 암석에서 1 cm까지의 단열들이 발견될 수 있다. 포장된 도로(아스팔트 또는 석재)에서 작은 압력 굴곡뿐만 아니라 10 cm 규모의 균열들이 일반적이다.*

d) 소규모에서 중규모($10^3$-$10^5$ m$^3$)의 산사태가 취약지역에 넓게 나타나며; 드물게 완만한 경사 사면에서도 발생할 수 있고; 평형이 불안정 상태인(느슨하고 포화된 토양의 가파른 사면, 가파른 협곡이나 해안절벽에서의 낙석) 곳에서 그 규모가 크다($10^5$-$10^6$ m$^3$). 때때로 일시적인 또는 심지어는 영구적인 호수들을 만들면서 산사태가 좁은 협곡들을 막는다. 파열, 사태와 낙석 등이 충적층 또는 풍화되거나 파쇄된 암석의 강둑, 제방 그리고 절취사면(e.g., 도로사면, 채석장)에 영향을 준다. 연안지역의 해수면 아래에서 산사태가 빈번하게 발생한다.

e) *나무들이 심하게 흔들리고; 가지들은 찢어지거나 떨어지고, 심지어는 가파른 경사에 있는 나무들은 뿌리째 뽑힌다.*

f) *국지적인 조건에 따라 진앙지 부근에서는 액상화가 빈번할 수 있고; 직경이 약 1 m에 달하는 모래가 분출하고; 잔잔한 물에서 명백한 물의 분출이 나타나고; 물가(강둑, 호수, 운하, 해안)에 평행하게 열극을 수반하는 국지적인 측면 확산과 침강(약 30 cm에 달하는 침하) 등이 발달한다.*

g) *건조한 지역에서는 진앙지의 땅으로부터 먼지 구름이 발생한다.*

h) 돌, 작은 바위 덩어리와 통나무 등이 부드러운 토양에 자국을 남기며 공중으로 날아오를 수 있다.

**IX** 파괴적임/환경에의 영향이 다양한 기원에서 발생하고 상당한 재해를 가져오며 진도를 산정하는데 중요해진다.

<u>일차영향들</u>은 흔히 관찰된다.

*수 km길이와 일반적으로 수 cm의 변위규모를 갖는 지반파열(지표단층)이 발생한다. 최대 수십 cm 규모를 갖는 지표의 지체구조적 침하 또는 융기가 발생할 것이다.*

이차영향들: 총 영향면적은 1000 $km^2$ 규모이다

a) *일반적으로 일시적으로 샘의 유속 그리고/또는 위치가 상당히 변한다. 일부 중규모의 샘이 마를 수도 있다. 관정에서 일시적인 수위의 변화가 일반적으로 관찰된다. 샘과 관정들에서 가장 일반적으로 수온의 변화와 같은 물리화학적 특성의 변화가 관찰된다. 폐쇄된 분지, 강, 관정 그리고 샘에서 탁류가 흔하다. 가스 분출, 때때로 유황가스의 분출이 관찰되며, 가스 분출지 근처의 관목과 잔디가 그을릴 수 있다.*

b) *수 m 높이의 파가 고인 물과 흐르는 물에서 발생한다. 또한, 범람원의 하천은 흐름 방향이 지반침하 때문에 변할 수 있다. 작은 분지가 생기거나 없어질 수 있다. 해저면과 해안선의 모양에 따라 위험한 쓰나미가 해안가에 수 m 높이까지 넓은 지역에 도달할 수 있다. 넓은 지역의 침식과 쓰레기 더미들이, 관목과 나무들의 뿌리가 뽑히고 떨어져 나가는 곳에서, 해안을 따라 관찰된다.*

c) *느슨한 충적층과 포화된 토양에서 100 cm의 폭과 수백 m 길이까지의 단열들이 흔히 관찰되며; 단단한 암석에서는 이들이 10 cm에 이를 수 있다. 포장된 도로(아스팔트나 석조)에서는 압력 굴곡뿐만 아니라 뚜렷한 균열들이 흔하다.*

d) *산사태가 취약지역에서 넓게 나타나고, 또한 완만한 사면에서도 나타나며; 평형이 불안정한 곳(느슨하고 포화된 토양의 가파른 사면; 가파른 협곡과 해안 절벽에서의 낙석)에서 종종 그들의 크기가 크고($10^5$ $m^3$) 때때로 대규모로($10^6$ $m^3$) 발생한다. 산사태는 일시적이거나 영구적 호수를 발달시키는 좁은 협곡을 막을 수 있다. 강둑, 제방과 인공절취면(e.g. 도로사면과 채석장) 등이 종종 붕괴된다. 해안지역의 해수면 아래에서 대규모 산사태가 종종 발생한다.*

e) 나무들이 심하게 흔들리고; 나뭇가지나 가는 나무줄기들은 흔하게 찢어지거나 떨어진다. 특히 가파른 사면들을 따라 일부 나무들이 뽑히거나 떨어진다.

f) *액상화와 물의 급증이 빈번하게 발생; 직경 3 m에 이르는 모래분출이 발생; 잔잔한 물에서 명백한 물의 분출; 빈번하게 해안가 지역(강둑, 호수, 운하, 해변)에 평행하게 열극을 수반하는 측면 확산과 침전(약 30 cm 이상의 침하)이 발생한다.*

g) 건조한 지역에서는 땅으로부터 먼지 구름이 흔하게 발생한다.

h) *작은 바위 덩어리와 통나무들이, 사면의 경사와 거칠기에 따라, 부드러운 토양에 흔적을 남기면서 수 m씩 공중으로 날아갈 것이다.*

**X 매우 파괴적임/환경에서의 효과가 재해의 주요한 기원이 되고 진도 산정에 대단히 중요하다.**

일차영향들이 두드러지게 나타난다.

*지표단층 작용이 수십 cm에서 수 m에 이르는 변위를 갖고 수십 km길이로 확대될 수 있다. 중력 지구들과 신장된 압력 함몰대가 발달하며; 화산암 지역에서는 극천부 지진에 의한 파열 길이가 더 낮아진다. 지표면에서는 최대 수 m 크기를 갖는 지체구조적인 침하 또는 융기가 발생할 것이다.*

이차영향들: 총 영향면적은 5,000 $km^2$ 규모이다.

a) 많은 샘들이 그들의 유속 그리고/또는 수위를 현저히 바꾼다. 어떤 샘들은 일시적으로 또는 영구적으로 마르기도 한다. 수위의 일시적인 변화가 관정들에서 흔하게 관찰된다. 샘과 관정들에서 더욱 강한 물의 물리화학적 변화가, 가장 일반적으로 온도변화가 관찰된다. 때때로 큰 분지, 강, 관정 그리고 샘의 물 조차도 진한 흙탕물이 된다. 때때로 유황가스 등의 가스분출이 관찰되며, 가스 분출지 근처의 관목과 잔디가 그을린다.

b) *기저로부터 넘친 수 m 높이의 파가 상당히 큰 호수나 강에서 조차도 발생한다. 넓은 지반침하 때문에 범람원 강에서는 하천의 유로가 일시적으로 또는 영구적으로 변한다. 분지들이 생기거나 없어질 수 있다. 해저면과 해안선의 모양에 따라 5 m가 넘는 쓰나미가 해안에 도달하여 수천 m의 평탄한 지역에 범람할 수 있다. 작은 바위들이 수 m씩 끌려갈 수 있다. 해안선의 모양을 주목할 만큼 바꿀 수 있는 넓고 깊은 침식이 해안을 따라 관찰된다. 해안 주변의 관목들이 뽑히거나 떨어져 나간다.*

c) *1 m 이상의 폭과 수백 m에 달하는 길이의 개방된 지반 균열이 주로 느슨한 충적층과 포화된 토양에서 주로 자주 발생하며; 단단한 암석에서는 수십 cm에 달하는 개방이 발생한다. 포장된 도로(아스팔트나 석조)에서는 압력 굴곡뿐만 아니라 넓은 균열들도 발달한다.*

d) *사면의 평행상태에 관계없이, 일시적이거나 영구적인 장벽 호수들을 만들면서, 대규모 산사태와 낙석(> $10^5$ – $10^6$ $m^3$) 이 자주 발생한다. 강둑, 제방과 인공절취면들이 전형적으로 붕괴된다. 제방과 흙댐 조차도 심한 피해를 초래한다. 해안지역의 해수면 아래에서 자주 대규모 사태가 발생한다.*

e) *나무들이 심하게 흔들리고; 많은 나뭇가지와 나무 줄기들이 찢어지고 떨어진다. 일부 나무들은 뽑히거나 떨어진다.*

f) *액상화, 물의 급증과 토양압밀이 넓은 지역에 걸쳐 변하며; 직경 6 m 이상의 모래화산이 형성된다; 1 m 이상의 수직 침하; 측면 확산에 의해 크고 긴 열극들이 일반적이다.*

g) 건조한 지역에서는 땅으로부터 먼지 구름이 상승하기도 한다.

h) *바위 덩어리(직경이 2-3 m가 넘는)가, 토양에 흔적을 남기면서, 완만한 사면에서 조차도 그들의 원래 위치로부터 수백 m까지 공기 중으로 날아가고 이동된다.*

**XI 대단히 파괴적임/구조물 피해의 포화로 환경에의 영향이 진도 산정에 결정적이다.**

일차영향들이 우세하다.

*수 m까지의 변위를 갖고 수십 km에서 수백 km 길이에 달하는 지표단층이 발달한다. 중력 지구들과 긴 함몰과 압력 능선들이 발달한다. 배수로가 심하게 변위될 수 있다. 지표에서의 지체구조적인 침하와 융기가 수 m 규모로 발달할 것이다.*

이차영향들: 총 영향면적은 10,000 $km^2$ 규모이다.

a) 많은 샘들의 유속과 수위가 현저히 변한다. 많은 샘들이 일시적으로 또는 영구적으로 마르기도 한다. 수위의 일시적이거나 영구적인 변화가 관정들에서 일반적으로 관찰된다. 샘 그리고/또는 관정들에서 훨씬 강한 물리화학적 변화, 주로 온도변화가 관찰된다. 종종 큰 분지, 강, 관정과 샘들에서 조차도 물이 매우 혼탁해진다. 때때로 유황가스 등의 가스분출이 관찰되며, 가스 분출지 근처의 관목과 잔디가 그을릴 것이다.

b) *기저로부터 넘친 큰 파가 큰 호수나 강에서 발생한다. 땅의 침하와 산사태 때문에 범람원의 강에서는 하천의 흐름 방향이 일시적으로 또는 영구적으로까지 변한다. 분지들이 생기거나 없어질 수 있다. 해저면과 해안선의 모양에 따라, 15 m에 달하는 쓰나미가 해안에 도달하여 수 km의 평탄한 내륙지역을 파괴할 수 있다. 수 m 크기의 바위 덩어리들이 먼 거리를 끌려갈 수 있다. 해안 지형이 주목할 만큼 바꿀 수 있는 넓고 깊은 침식이 해안을 따라 관찰된다. 해안 주변의 관목들이 뽑히거나 떨어져 나간다.*

c) 수 m 폭에 달하는 개방 지반 균열들이 주로 느슨한 충적층 그리고/또는 포화된 토양들에서 매우 자주 발달한다. 단단한 암석들에서는 1 m 에 이를 수 있다. 포장된 도로(아스팔트나 석조)에서는 큰 압력 굴곡뿐만 아니라 매우 넓은 균열들이 발달한다.

d) *사면의 평형상태에 관계없이 많은 일시적이거나 영구적인 장벽호수들 만들면서 대규모 산사태와 낙석*($> 10^5 - 10^6$ $m^3$) *이 자주 발생한다. 강둑, 제방과 인공절취면이 전형적으로 붕괴된다. 제방과 흙댐의 심한 피해가 초래된다. 심각한 산사태가 진앙지로부터 200 – 300 km 떨어진 지점에서도 발생할 수 있다. 해안지역의 해수면 아래에서 자주 대규모 산사태가 발생한다.*

e) *나무들이 심하게 흔들리고; 나뭇가지와 나무기둥들이 찢어지고 떨어진다. 많은 나무들이 뽑히거나 떨어진다.*

f) *액상화가 아마 수 m가 넘는 수직 침하, 많은 큰 모래화산, 그리고 심각한 측방 확산 현상을 결정하면서 저지대 넓은 지역의 양상을 바꾼다.*

g) 건조한 지역에서는 땅으로부터 먼지 구름이 상승한다.

h) *큰 바위(직경이 수 m) 가, 토양에 흔적을 남기면서, 완만한 사면에서 조차도 공기 중으로 날아오르고 원래 위치에서 먼 거리를 이동한다.*

**XII 완전히 파괴적임/환경의 영향은 진도 산정을 위한 유일한 수단이다.**

일차영향들이 우세하다.

*지표단층이 수십m 변위를 갖고 최소 수백km 길이로 발달한다. 중력 지구들과 긴 함몰대 그리고 압력 능선들이 발달한다. 배수로가 심하게 변위될 수 있다. 일차적인 영향에 의한 지세와 지형의 변화는 놀랄만한 영역과 크기로 발달할 수 있다(전형적인 예는 수 m의 해안선 융기와 침강, 뚜렷한 지세들이 나타나거나 사라짐, 강수로의 변화, 폭포의 발달, 호수의 형성과 사라짐).*

이차영향들: 총 영향면적은 50,000 $km^2$ 규모 이상이다.

a) 많은 샘들의 유속과 수위가 현저히 변한다. 관정들에서 일시적이거나 영구적인 수위의 변화가 일반적으로 관찰된다. 많은 샘과 관정들이 일시적으로 또는 영구적으로 마른다. 샘과 관정들에서의 물리화학적 변화, 주로 온도변화가, 강하게 변화하는 것이 관찰된다. 큰 분지, 강, 관정과 샘 등의 물이 매우 혼탁해진다. 종종 유황가스 등의 가스분출이 관찰되며, 가스 분출지 근처의 관목과 잔디가 그을릴 것이다.

b) *기저로부터 넘친 거대 파가 호수나 강에서 발생한다. 광범위한 지면의 침하와 산사태 때문에 범람원 강에서는 하천의 유로뿐만 아니라 유동방향이 일시적으로 또는 영구적으로 바뀐다. 큰 분지들이 생기거나 없어질 수 있다. 해저면과 해안선의 모양에 따라 수십 m 높이의 쓰나미가 해안에 도달하여 수 km의 평탄한 지역을 파괴할 수 있다. 큰 바위들이 먼 거리를 끌려갈 수 있다. 해안 지형을 뚜렷이 바꿀 수 있는 광범위하고 깊은 침식이 해안을 따라 관찰된다. 많은 관목들이 뽑히거나 떨어져 나간다. 모든 보트들이 계류장으로부터 뜯어져 나와 쓸려가거나 육지로 먼 거리까지 이동된다. 밖에 있는 모든 사람들이 쓸려간다.*

c) 1 m 또는 그 이상의 지반 개방 균열이 기반암에서 발생하고, 느슨한 충적층 그리고/또는 포화된 토양에서는 10 m 이상의 폭에 이른다. 이들은 수 km의 길이까지 연장된다.

d) *사면의 평형상태와 상관없이, 일시적이거나 영구적인 장벽 호수들을 만들면서, 대규모 산사태와 낙석(> $10^5$ – $10^6$ $m^3$) 이 자주 발생한다. 강둑, 제방과 인공절취면이 전형적으로 붕괴된다. 제방과 흙댐의 심한 피해가 초래된다. 심각한 산사태가 진앙지로부터 200 – 300 km 이상 떨어진 지점에서도 발생할 수 있다. 해안지역의 해수면 아래에서 매우 큰 규모의 산사태가 자주 발생한다.*

e) 나무들이 심하게 흔들리고; 많은 나뭇가지와 나무기둥들이 찢어지고 떨어진다. 많은 나무들이 뽑히거나 떨어진다.

f) *액상화가 넓은 지역에 걸쳐 발생하고 수 m가 넘는 수직 침하, 광범위한 큰 모래화산, 그리고 광범위한 심각한 측방 확산 현상을 결정하면서 넓은 평탄한 지역들의 지형을 바꾼다.*

g) 건조한 지역에서는 땅으로부터 먼지 구름이 상승한다.

h) 또한 매우 큰 바위가, 토양에 전형적인 흔적을 남기면서, 매우 완만한 사면에서 조차도 공중으로 날아 오르고 먼 거리를 이동할 수 있다.

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figg. 3

# 3. - Applications of ESI 2007 intensity scale

The ESI 2007 intensity scale has been succefully applied to recent, historical and palaeo-earthquakes (cfr. Chapter 5 for a full list of references published in the period 2008-2014).
In the following, some recent and historical case-studies, representative of different seismotectonic environments put the focus on some key questions with the aim to outline the added value provided by the use of ESI intensity scale.

## 3.1. - The June 27, 1957, Muya (Baikal) earthquake

TATEVOSSIAN R. (1)

### *Introduction*

Baikal is a distinctive zone of active continental rift located in Central Russia. Systematic studies of palaeoearthquakes in this area started in the early 1960s. The first regional catalogue of palaeoearthquakes was published some years later (Kondorskaya & Shebalin, 1977): in this catalogue, even surface rupture length (L) and the maximum palaeoseismic surface displacement are reported as well as the corresponding magnitudes (Ma and ML).

The 1957 Muya earthquake (MS = 7.6) is the largest instrumentally recorded seismic event in the region. Source mechanisms are shown in figure 1. Surface ruptures associated with the earthquake were studied during several field investigations and summarized in reports and papers by Kurushin (1963), Solonenko (1965), Solonenko *et alii* (1966, 1985), Kurushin *et alii* (2007).

### *Surface faulting pattern*

Surface faulting associated to the Muya earthquake occurred on a WNW trending en echelon fault systemIt can be grouped into three main segments: western, central, and eastern (fig.3.1a and 3.1b).

In the western segment, surface faulting marks the edges of a small graben. Its southern boundary is controlled by a normal fault with a right-lateral slip component. Horizontal slip is about one meter m and vertical offset is 1.2 – 1.3 m. Left-lateral slip (0.3 m) accompanied by some normal faulting was observed close to the northern boundary. A transition zone links western and central segments. Its northern branch is a normal fault (1.4 m offset) with a left-lateral slip component (0.25 m).

The southern branch is a NNW trending pressure zone, most probably associated with thrusting. The fault system in the central segment is expressed by sequences of shear, extension, and thrust structures composing a zone of left-lateral strike-slip, where fragmentary vertical offsets are found. The vertical offset does not exceed 3.3 m and the horizontal slip is 1 m.

(1) Institute of Physics of the Earth, RAS, Moscow, Russia.

The eastern segment is located at the pediment of the Udokan Range and is composed of extensional structures. Steep dip of the fault to the north is evidence of normal faulting. The amplitude of the offset varies along the fault from 0 to 1.5 m. There are no traces of horizontal slip in this fault segment. The total length of proven surface faulting is ca. 20 km, although some publications pointed out that the eastern segment might extend for another 5 km.

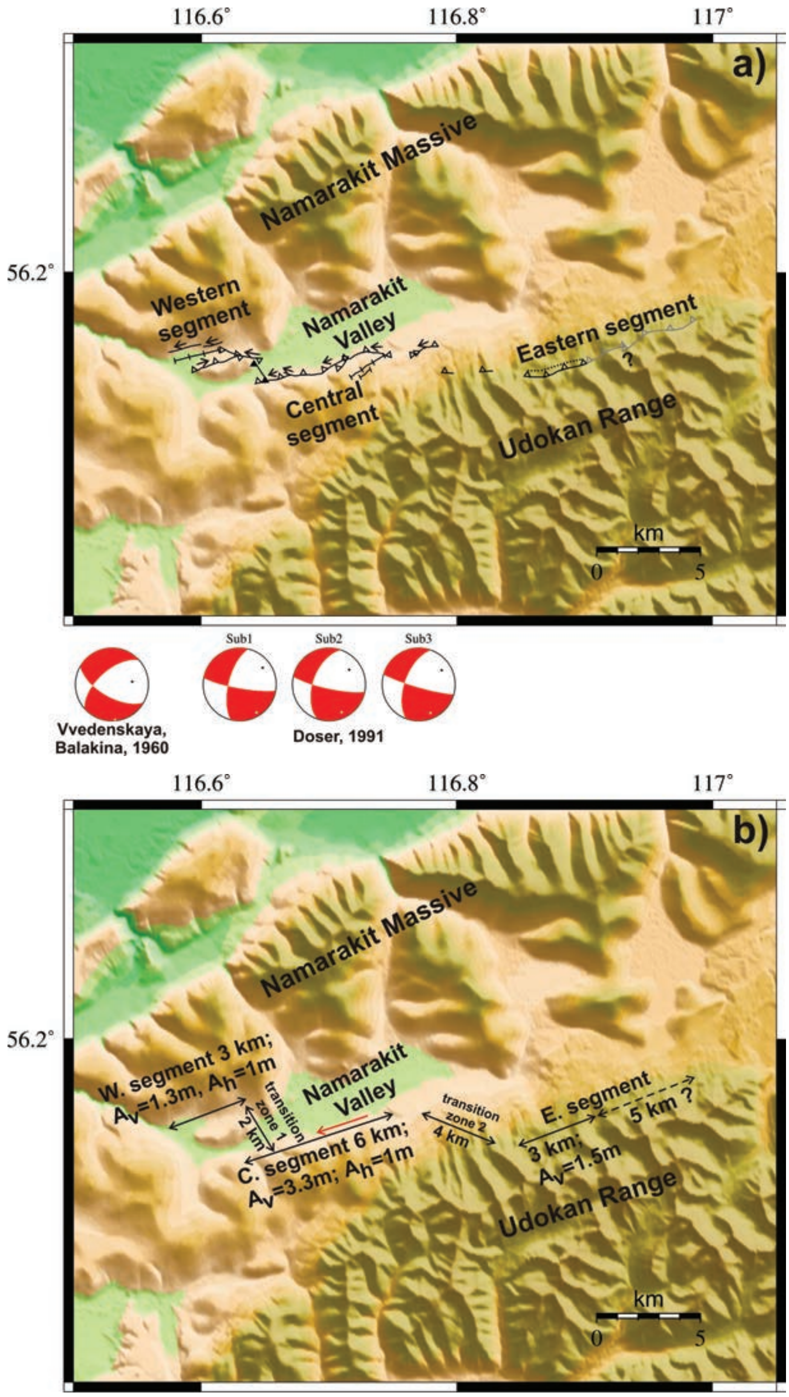


Fig. 3.1 - Geological effects, instrumental epicenter, and focal mechanisms of the Muya earthquake. a) surface faulting; Sub1, Sub2, Sub3 are mechanisms of sub-events. Arrows show slip direction. The question mark indicates a doubtful portion of the surface faulting. b) generalized scheme
- *Effetti geologici, epicentro stumentale e meccanismi focali del terremoto di Muya. a) fagliazione superficiale; Sub 1, Sub 2, e Sub 3 sono meccanisimi relativi a repliche minori. Le frecce indicano la direzione dello scorrimento. Il punto interrogativo indicata un segmento incerto di fagliazione superficiale; b) schema generalizzato.*

### *MSK and ESI intensity assessment*

Macroseismic information is summarized in Fig. 3.2, based on questionnaires collected in the Institute of the Physics of the Earth, RAS, in 1958 and data from SOLONENKO *et alii* (1958). Noteworthy is the far-reaching extension of the felt area (over 700 km away from the surface faulting zone).

The epicentral intensity of the Muya earthquake can be assessed based on the total length of surface faulting using the ESI 2007 intensity scale: epicentral intensity $I_0$ = X corresponds to 20-25 km total rupture length. Maximum vertical offset associated to normal faulting (3.3 m) is also in agreement with intensity X .

Results of the two assessments are consistent: the localities closest to the surface faulting zone are at a distance of 50 km. This explains why maximum observed macroseismic intensity is much lower than $I_0$, not exceeding 8 degree. Therefore, if only macroseismic effects in localities are considered for epicentral intensity assessment, as recommended by EMS98 (European Macroseismic Scale; GRÜNTHAL, 1998), $I_0$ would be underestimated of at least two degrees.

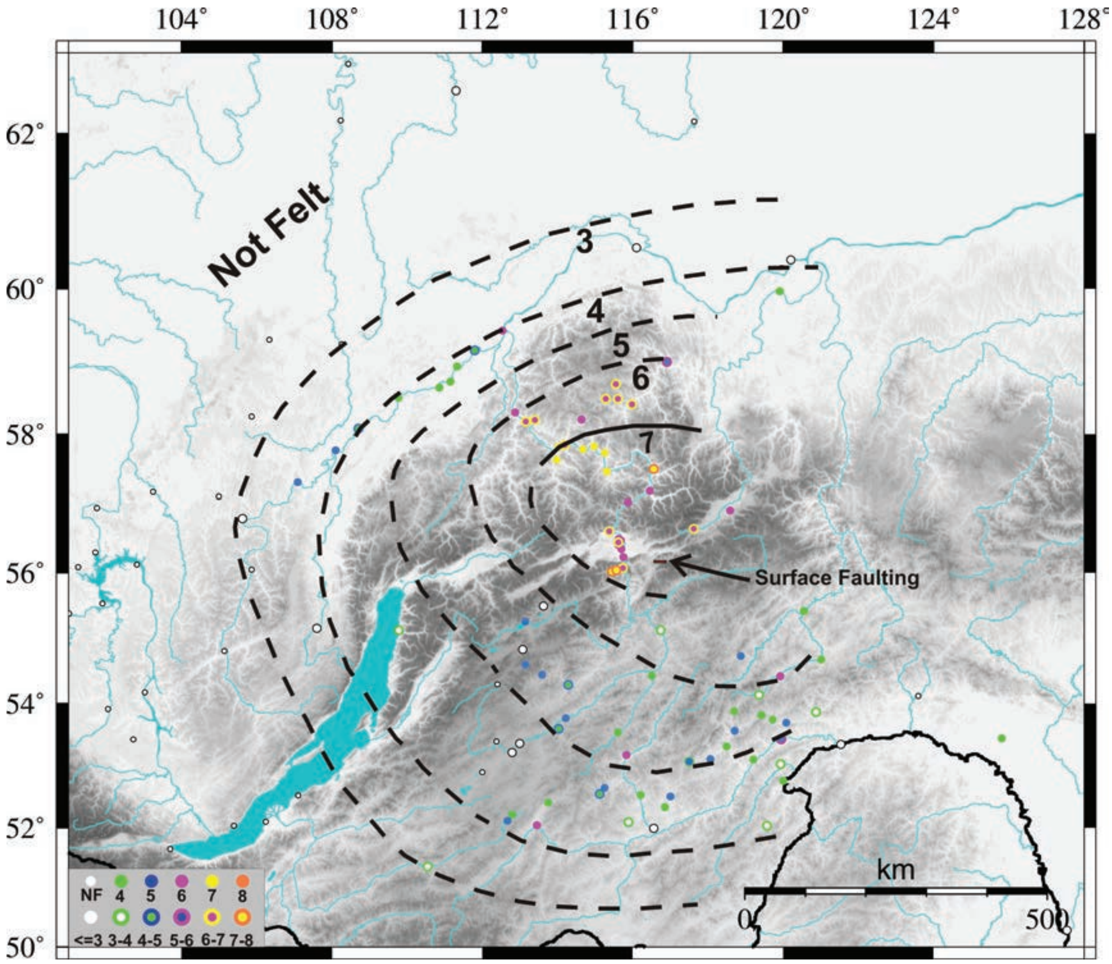


Fig. 3.2 - Isoseismal map of the Muya earthquake. Intensity degrees in the MSK scale.
- *Mappa delle isosiste del terremoto di Muya. Gradi di intensità nella scala MSK*

### *Discussion*

The epicentral locations determined instrumentally differ from each other by more than 100 km (fig. 1a). The instrumental hypocenter depth varies between 10 to 22 km. Macroseismic data are more consistent with a depth of 20 km. This depth, together with the Ms = 7.6, is in agreement with a felt radius of 700 km. The relatively short surface faulting zone (20-25 km) is in agreement with a deeper source.

For the sake of comparison, the 2003 Altai earthquake (Ms = 7.4) was accompanied by 70 km of surface ruptures (SRL). According to Wells and Coppersmith (1994), a 20-25 km SRL corresponds to magnitude 6.6, which is one order of magnitude lower than the Muya earthquake. However, a rupture length of 25 km and an offset of 3.3-4 meters indicates a magnitude value in the range of 7.3-7.6, comparable to the instrumental Ms (7.6). A short SRL with large offset (3.3-4 m) could be representative of a source with high stress drop, and possibly this is characteristic of the regional seismicity. This hypothesis may explain why the surface rupture lengths reported in the Baikal region are less than 45 km. A deeper seismic source zone could also be partially responsible for this.

The first motion mechanism (Vedenskaya & Balakina, 1960) corresponds to normal faulting with a left-lateral strike-slip component steeply dipping to the south (Fig. 1a). In general, this solution is consistent with the geometry of surface faults and the kinematics of faulting. The body wave-form inversion at teleseismic distances features three sub-events, each almost pure strike-slip (Doser, 1991). The solution with three sub-events is in better accordance with the observed segmentation of the surface fault zone, but it is in contradiction with vertical offset everywhere larger than horizontal slip. A possible reason might be that under extension stresses, strike-slip movement along en echelon sub-parallel faults requires normal faulting at the surface to accommodate shear deformation. According to this hypothesis, a normal fault component at the surface is not representative of the source in general, and its amplitude can be anomalously large, compared to the surface fault length.

In conclusion, such a case-study demonstrates the usefulness of environmental parameters in order to avoid underestimating the earthquake intensity, and the influence of tectonic and structural setting on the coseismic effects, to be considered also in the palaeoseismic evaluations.

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figg. 3 , tab. 1

# 3.2. - The July 26, 1805, Molise (Southern Italy) earthquake

ESPOSITO E. (1), GUERRIERI L. (2), PORFIDO S. (1), VITTORI E. (2), BLUMETTI A.M. (2)

## *Introduction*

The 1805 Molise earthquake caused the loss of at least 5,000 lives and determined severe damage over a wide sector of the Southern Apennines. The seismic sequence was characterized by a mainshock (21:01 GMT, macroseismically derived magnitude Ma = 6.6) followed a few hours later by two important aftershocks.

The epicentral zone was centered on the Bojano plain ($I_0$ = X MCS), and an area of about 2,000 km² was affected by MCS intensities ≥VIII. The macroseismic epicenter of the mainshock (fig. 3.3) was located at Frosolone ($I_{max}$ = XI MCS, Esposito *et alii*, 1987) according to the descriptions in contemporary reports. The epicenter of the second shock (21:56 GMT) was located at Morcone, some tens of kilometers to the SE.

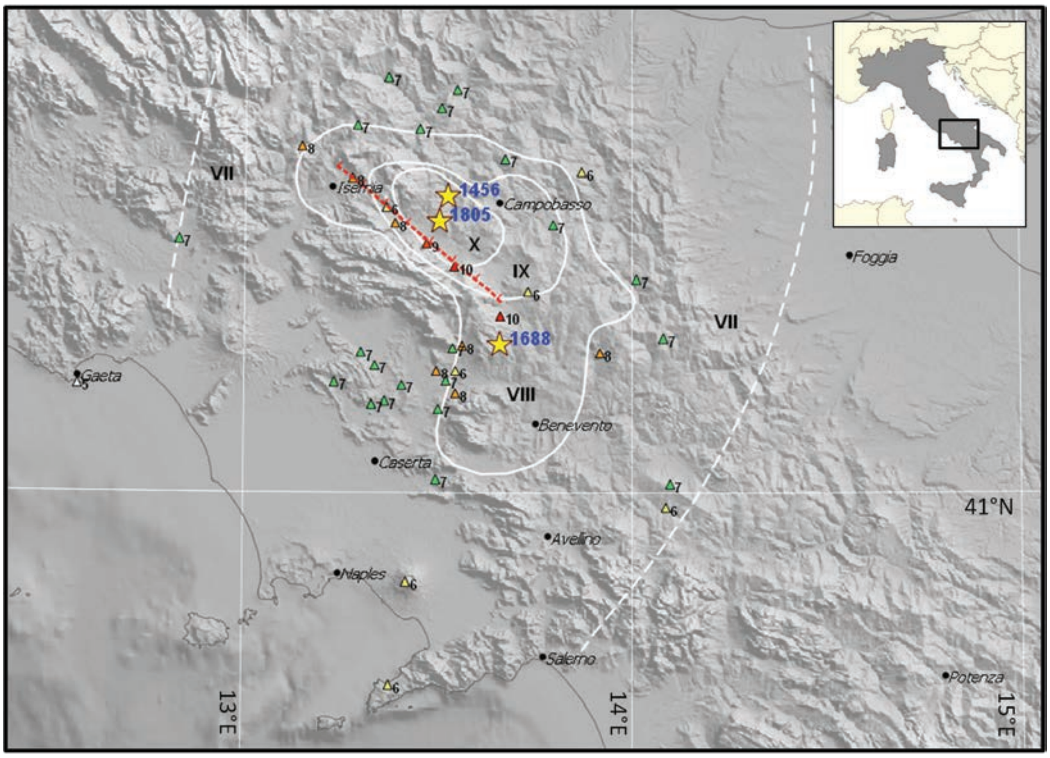


Fig. 3.3 - The 1805 Molise earthquake: comparison of MCS and ESI macroseismic intensity fields. White lines: MCS isoseismals (MCS degrees in roman numerals, after Esposito *et alii*, 1987). Triangles: ESI local intensities (after Serva *et alii*, 2007). Stars identify the epicenters of three major historical earthquakes.

*- Il terremoto del 1805 in Molise: confronto tra i campi macrosismici MCS ed ESI. Linee bianche: isosiste MCS (gradi MCS in numeri romani; Esposito et alii, 1987). Triangoli: intensità locali ESI (Serva et alii, 2007). Le stelle identificano gli epicentri dei tre terremoti storici più forti avvenuti nell'area.*

(1) Istituto per l'ambiente marino costiero, CNR, Napoli, Italy.
(2) Geological Survey of Italy, ISPRA, Roma, Italy.

## *Geological framework and historical seismicity*

The Bojano Basin (Molise, Southern Apennines) is a tectonic depression elongated in a NW direction (Fig. 3.4) and bordered on the SW edge by the Meso-Cenozoic carbonate platform sequence of the Matese Mountains and on the NE side by the pelagic and transitional sequence of the Sannio Hills (e.g., CORRADO *et alii* 1997; DI BUCCI *et alii*, 1999). The current morphology is the result of extensional tectonic activity, which has affected this area at least since the Middle Pleistocene. The master segmented normal fault of the Bojano Basin follows the SW border of the tectonic depression for a total length of at least 30-40 km (e.g., RUSSO & TERRIBILE, 1995; BRANCACCIO *et alii*, 1997; GUERRIERI *et alii*, 1999).

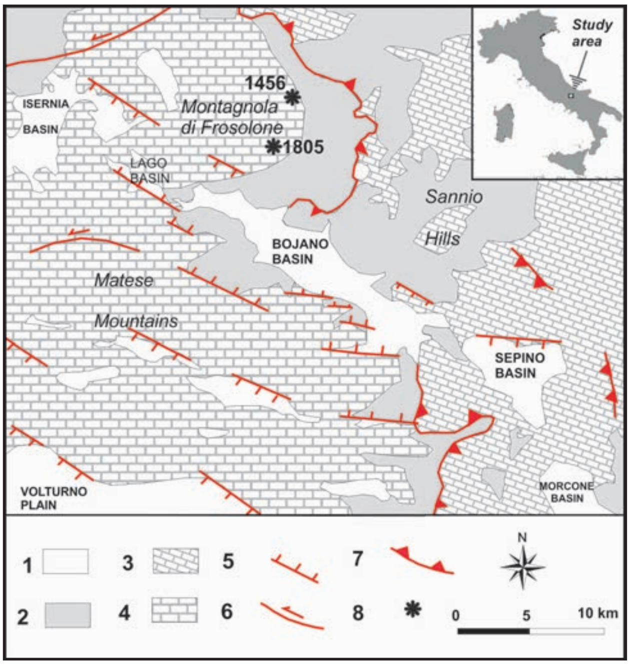


Fig. 3.4 - Geological sketch of the Bojano Basin and surrounding areas. Faults marked as thick lines belong to the Bojano fault system, which controlled the Quaternary continental evolution of the Bojano basin and adjacent basins (Morcone, Sepino and Lago). Legend: 1. Continental deposits (Quaternary); 2. Flysch deposits (Miocene); 3. Pelagic and transitional sequences of the Sannitic Unit (Meso-Cenozoic); 4. Neritic and transitional sequences of the Apennine Platform Unit (Meso-Cenozoic); 5. Main normal fault (Quaternary); 6. Main strike-slip fault (Pliocene?); 7. Main thrust (Neogene); 8. Epicenter of historical earthquake.
*- Schema geologico del bacino di Bojano e aree adiacenti. Le faglie indicato con linee spesso appartengono al sistema di faglie di Bojano, che ha controllato l'evoluzione continentale quaternaria del bacino di Bojano e dei bacini adiacenti (Morcone, Sepino e Lago). Legenda: 1. Depositi continentali (Quaternario); 2. Depositi di flysch (Miocene); 3. Sequenze pelagiche e di transizione delle Unità Sannitiche (Meso-Cenozoico); 5. Faglia diretta principale (Quaternario); Faglia trascorrente principale (Pliocene?); Sovrascorrimoento principale (Neogene); 8. Epicentro di terremoto storico.*

Historical seismicity catalogues (POSTPISCHL, 1985; ROVIDA *et alii*, 2011) indicate at least three strong historical earthquakes (December 5, 1456, I0 = XI MCS, Ma = 7.2; June 5, 1688, $I_0$ = XI MCS, Ma = 6.7; July 26, 1805, I0 = X MCS, Ma = 6.6; epicenter locations in Fig. 3.4) centered on the Bojano Basin. Furthermore, trenching investigations at the NW and SE tips of the Bojano Basin (Patalecchia fault segment, BLUMETTI *et alii*, 2000; Campochiaro fault segment, GALLI *et alii*, 2003) have provided stratigraphic evidence along the same extensional fault system for at least two Holocene palaeoearthquakes, strong enough to produce surface faulting (tens of cm of vertical offset). Instrumental data in the Bojano area reveal remarkable seismic activity over recent decades, characterized by frequent, low-energy seismic sequences (largest magnitudes around 4.0).

## *Earthquake Environmental Effects*

The historical reports for the 1805 earthquake allow about one hundred seismically induced environmental effects to be identified, mostly in the near-field area, although some of them were reported as far away as 70 km from the epicenter (ESPOSITO *et alii*, 1987; PORFIDO *et alii,* 2002).

The most relevant effects documented in contemporary sources are described in table 3.1 and mapped in fig. 3.5. Among these, vertical ground displacements of about 1.5 m occurred at Guardiaregia and Morcone, to be interpreted as primary effects. Along the antithetic fault, a long fracture reported between Pesche, Miranda and Sant'Angelo in Grotte may also be interpreted as evidence of surface faulting. This fact would indicate that the total rupture length is about 40 km, with maximum displacements of about 150 cm (Guardiaregia). Consequently, the ESI epicentral intensity value is equal to X.

The earthquake also triggered a number of secondary effects (slope movements, hydrological anomalies, liquefaction). At least 26 landslides (mainly rock falls, topples, slumps, earth flows and slump earth flows) were recorded, including an earth flow at San Giorgio la Molara (Benevento) that affected the course of the Tammaro River, an earth flow at Acquaviva di Isernia, a rotational slide at San Bartolomeo in Galdo (Benevento), and a rotational slide-flow at Calitri (Avellino) (Esposito *et alii*, 1987; Esposito *et alii*, 1998; Porfido *et alii*, 2007; Serva *et alii*, 2007). In 29 localities, principally around Bojano (Biferno springs) and the Matese Massif, 48 hydrological anomalies were reported, mainly changes in water discharge from springs.

Flow increases were observed in at least 16 springs, mainly SSW of the Matese Mountains. New springs appeared at San Salvatore Telesino (Caserta), Morcone (Benevento), the Matese Mountains, and Bojano (Campobasso). A new spring at Bojano was active for about two months after the earthquake (Esposito *et alii*, 1987; Esposito *et alii*, 2001, Porfido *et alii*, 2002). Only one case of liquefaction was reported at Cantalupo. Furthermore, anomalous sea waves were observed in the gulfs of Naples and Gaeta (Caputo & Faita, 1984; Esposito *et alii*, 1987, Tinti & Maramai, 1996).

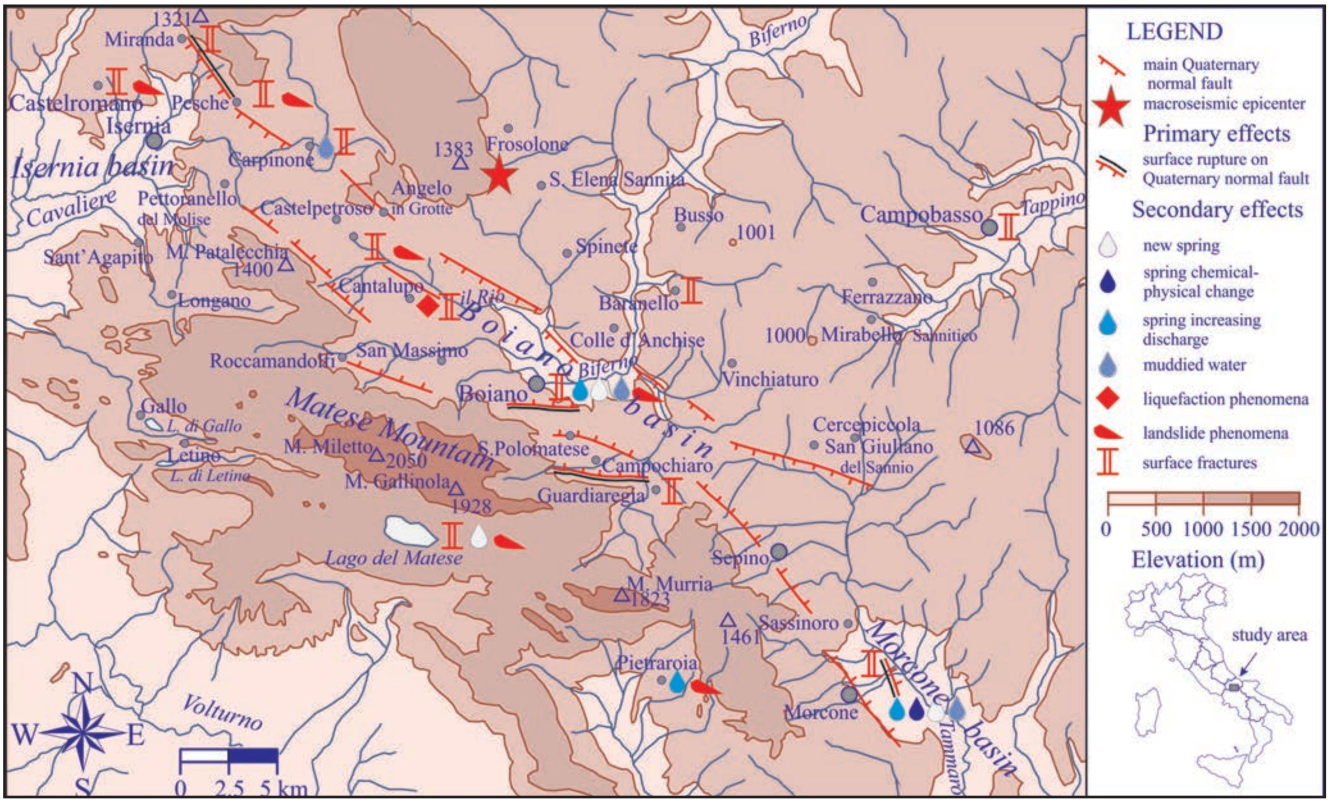


Fig. 3.5 - Distribution of the geological effects reported for the 1805 Molise earthquake (after Porfido *et alii*, 2002).
*- Distribuzione degli effetti geologici del terremoto del Molise del 1805 (da Porfido et alii., 2002).*

Tab. 3.1 - *Descriptions of relevant environmental effects induced by the 1805 Molise earthquake.*
- Descrizione degli effetti ambientali rilevanti indotti dal terremoto del 1805 in Molise.

| **Location** | **Type** | **Description** | **Historical source** |
|---|---|---|---|
| Pesche, Miranda and S.Angelo in Grott | Surface faulting | A very long fracture was surveyed from Miranda , Pesche up to S. Angelo in Grotte. "*Especially in the upper mountain from Miranda to S. Angelo in Grotte were opened for about an half palm".* | FORTINI (1806) |
| Guardiaregia | Surface faulting | *"Very evident and deep fractures with offsets up to seven palms"* (about 150 cm according to, ESPOSITO *et alii*, 1987). | BARATTA (1901) |
| Morcone | Surface faulting & hydrological changes | *"flames from the ground ... were seen near the inn, where horrible chasms opened over a length of about one third of a mile, some of which had the ground overthrown at a height exceeding six palms (one Neapolitan palm is equal to 26.45 cm), and of which the width was over three palms and comparable the depth. These fractures now can be seen from far away, because the grass along the crevasses is desiccated as it had been on fire. In one such crevasse I observed a pear tree, that, in that moment (of the earthquake), lost all its unripe fruits, threw many branches to the ground and, of the ones left, many are now desiccated. In the same place the soil was completely disturbed, as it had excavated by innumerable moles. Here a spring increased its flow rate, leaving a slight smell of sulphur. A new spring gushed out from the ground...".* | CAPOZZI (1834) |
| Bojano | Karst collapses | *The day after the 26 July event, two chasms opened within the Matese Mts at a bout an half the slope of Bojano.* | BARATTA (1901) |
| Cantalupo, | Liquefaction | Several contemporary eye-witnesses documented a liquefaction characterized by sand-volcanoes in the surficial fluvio-lacustrine deposits near the Cantalupo village. | ESPOSITO *et alii*, 1987 |
| S.Giorgio La Molara | Landslide | *Along the Tammaro river up to the Molini of Cardinale Ruffo, remarkable vertical as well as horizontal fissures (1922 steps long and about 800 steps wide). The topgraphic surface was dislocated of about 15 palms and poplars trees were divelted and shifted for 13 – 20 palms. ….The Tammaro river was deviated for about 50 palms as a consequence of this slope momement…..* | ESPOSITO *et alii*, 1987 |
| Acquaviva di Isernia | Landslide | *"A forest about 20 miles wide was devasteted. The ground was failured and trees were eradicated".* | BARATTA (1901) |
| Bojano | Appearance of new springs, Turbidity, chemical variation | *The day before the main shock, some springs located near Bojano were anomalously turbid and hot. Four days later, three large water rivers flooded very quickly the surrounding cultivated fields. The anomaly in water discharge persisted for about 20 days. A new spring opened at Bojano and it is still working.* | PEPE (1806) POLI (1805) |

## *Discussion*

The application of the ESI 2007 intensity scale based on secondary effects has allowed local intensity values to be assigned for about 50 municipalities (SERVA *et alii*, 2007), with values from V to X (triangles in fig. 3.3). The total area of relevant ground effects (ESI local intensities ≥ VII) amounts to about 5,300 km². Accordingly, the ESI epicentral intensity is equal to X.

In conclusion, this case study has clearly shown that primary as well as secondary effects, when properly taken into account, can be a very helpful tool for:

- intensity assessment: in fact, two independent applications of the ESI 2007 intensity scale, from the total area of secondary effects and from the extent of surface faulting, yielded the same epicentral intensity value (ESI $I_0$ = X). This is also consistent with damage-based assessments, since the independently assessed MCS epicentral intensity is also equal to X;
- identification of the seismogenic source: the scenario of secondary effects allows the seismogenic source to be located on the SW border of the Bojano basin. This is in very good agreement with local evidence of surface faulting reported in historical documents at Morcone, Guardiaregia and Pesche.

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 125 - 132
figg. 3

# 3.3. - The November 2, 2002, Denali (Alaska) earthquake

COMERCI V. (1), MICHETTI A.M. (2), SERVA L. (1), VITTORI E. (1)

## *Introduction*

The 2002 Denali Fault earthquake (Mw = 7.9) is the largest strike-slip earthquake in North America in more than 150 years. Although it occurred at a time when a wealth of digital instruments were deployed all over the world, only a few were relatively close to the fault rupture (HANSEN *et alii*, 2004; MARTIROSYAN, 2004). The epicenter was located 135 km S of Fairbanks and 283 km north of Anchorage; and also 22–25 km east of the Mw 6.7 Nenana Mountain earthquake that occurred eleven days earlier, on October 23.

The complex sequence of ruptures began with an oblique thrust along a N-dipping plane, corresponding to a 48 km long segment of the previously unrecognized E-trending Susitna Glacier thrust fault (fig. 3.6).

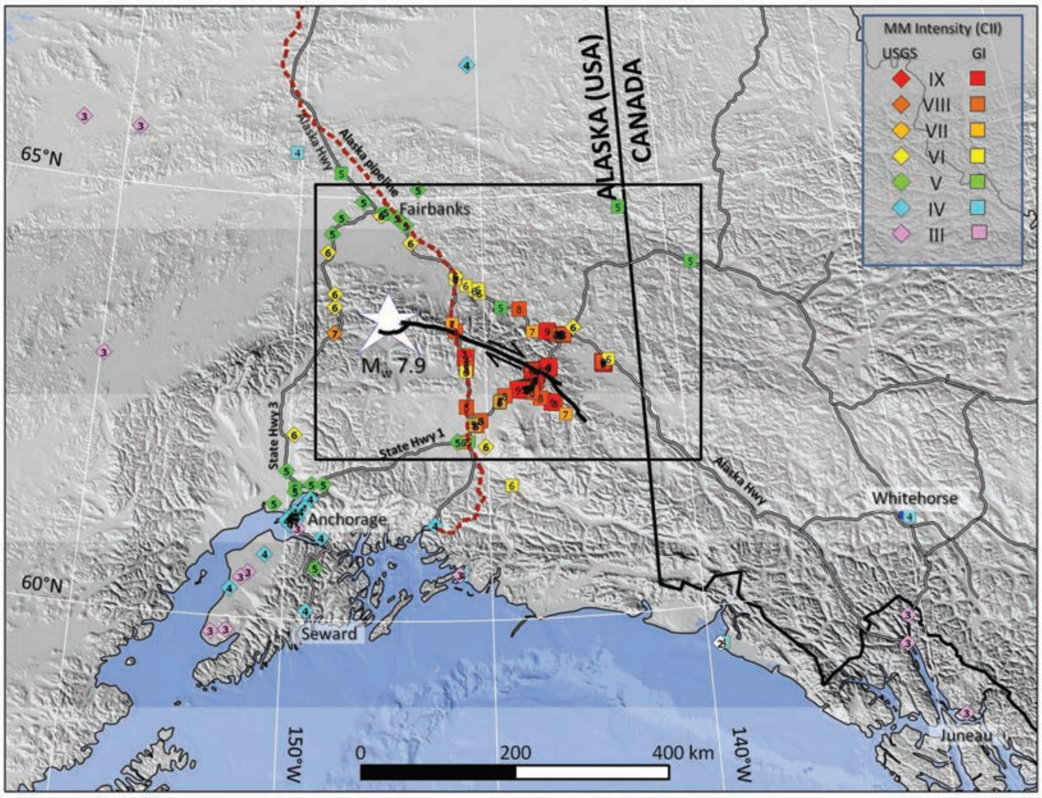


Fig. 3.6 - The 2002 Denali earthquake: CII (Community Internet Intensity) distribution based on the report materials (MARTIROSYAN, 2004). The star indicates the epicenter. The fault ruptures are plotted, simplified, according to EBERHART-PHILLIPS *et alii* (2003). The box encloses the epicentral area shown in fig. 3.7.

*- Il terremoto di Denali del 2002: distribuzione delle intensità CII (Community Internet Intensity) in base al contenuto dei rapporti (Martirosyan, 2004). La stella indica l'epicentro. Le rotture di faglia sono plottate, semplificate, secondo EBERHART-PHILLIPS et alii (2003). Il riquadro indica l'area epicentrale dettagliata in fig. 3.7.*

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(2) Dipartimento di Scienze Chimiche e Ambientali, Università dell'Insubria, Como, Italy.

The rupture continued with right-lateral horizontal slip along the main trace of the Denali fault. Eventually, it split off the Denali fault onto the more southeast-trending Totschunda fault (Eberhart-Phillips *et alii* 2003; Aagaard *et alii*, 2004; Crone *et alii*, 2004; Frankel, 2004; Hansen *et alii*, 2004; Haeussler, 2009).

The total rupture length was on the order of 330 km, and the maximum measured offsets were 8.8 m of horizontal displacement west of the Denali and Totschunda fault junction, and over 5 m of vertical displacement on the Susitna Glacier fault (Eberhart-Phillips *et alii* 2003; Crone *et alii*, 2004). More than 16,000 aftershocks were recorded by the end of December 2002, mostly located along the surface rupture within the upper 11 km of the crust (Eberhart-Phillips *et alii*, 2003; Ratchkovski *et alii*, 2003; Hansen *et alii*, 2004).

Seismograms show that slip and energy release were heterogeneous along the Denali fault. Three sub-events were identified (Eberhart-Phillips *et alii*, 2003; Frankel, 2004) and a total seismic moment equivalent to Mw 7.9 inferred from GPS data, consistent with the geodetic moment derived by Interferometric Synthetic Aperture Radar data (Wright *et alii*, 2004). The first sub-event (Mw 7.2), located near the instrumental epicenter, was associated with the rupture along the Susitna Glacier Fault. The second sub-event (Mw 7.3) was 50 to 100 km east of the epicenter, where the surface offset of the Denali Fault reaches over 6 m. It is noteworthy that, despite it, the Trans-Alaska Pipeline did not suffer any oil spill thanks to a technical solution based on the experience of the 1964 Alaska earthquake (Honegger *et alii*, 2004). According to Aagaard *et alii* (2004), the geometry of the faults and the orientation of the regional stress field caused slip on the Susitna Glacier fault to load the Denali fault. The third sub-event, about 130 to 220 km east of the epicenter, had the largest seismic moment, equivalent to about Mw 7.6, and was located in the region with a maximum surface offset of 8.8 m.

An average rupture velocity of 3.5 km/s, close to the shear wave velocity at the average rupture depth, was found. However, the portion of the rupture 130–220 km east of the epicenter appears to be a supershear, with an effective rupture velocity of about 5.0 km/sec (Frankel, 2004). Moreover, the initial thrust sub-event produced the largest high-frequency energy release per unit fault length, while relatively little high-frequency energy was released along the 60-km portion of the Totschunda fault at the southeast end of the rupture (Frankel, 2004).

The earthquake propagated primarily unilaterally to the east and released most of its energy along slip patches far from the hypocenter locations (Arda Ozacar & Beck, 2004). According to Eberhart-Phillips et al. (2003), the larger surface offsets correlate with the locations of high moment release found in the inversions of geodetic and strong-motion data. The geologic, geodetic and strong-motion data sets show increased slip 50 to 100 km and 150 to 230 km east of the epicenter. The seismic moments calculated from strong-motion inversion (Mw 7.8) and from the teleseismic waveforms (Mw 7.9; Kikuchi & Yamanaka, 2002) agree well with the Mw 7.8 calculated from the surface slip (Eberhart-Phillips *et alii*, 2003).

The effects of rupture directivity are particularly remarkable for the Denali fault event. Ground shaking effects were reported as far away as 3500 kilometers from the epicenter, added to local bursts of seismic activity at similar distances in volcanic and geothermal areas, although only lying in the direction of the Denali rupture propagation (Eberhart-Phillips *et alii*, 2003; Cassidy & Rogers, 2004; Moran *et alii*, 2004).

## *Surface faulting pattern and secondary geological effects*

Several papers have described the surface faulting of the 2002 earthquake (e.g. EBERHART-PHILLIPS *et alii*, 2003; CRONE *et alii*, 2004; HAEUSSLER *et alii*, 2004; HAEUSSLER, 2009). The slip on the Susitna Glacier thrust fault averaged about 4 m, generating structures ranging from simple folds on a single trace to complex thrust-fault ruptures and pressure ridges on multiple, sinuous strands, in a deformation zone locally more than 1 km wide. A maximum vertical displacement of 5.4 m on the south-directed main thrust was measured (CRONE *et alii*, 2004). The principal surface break occurred along 226 km of the Denali fault, with average right-lateral offsets of 4.5–5.1 m and a maximum offset of 8.8 m near its eastern end. The Denali fault trace is commonly left stepping and N side up. Finally, slip transferred southeastward onto the Totschunda fault and continued for another 66 km where dextral offsets averaged 1.6 – 1.8 m. The transition from the Denali fault to the Totschunda fault occurred over a complex 25-km-long transfer zone of right-slip and normal fault traces.

Secondary geological effects of the 2002 Denali earthquake were mostly slides, liquefaction and ground cracks (fig. 3.7). Thousands of landslides were triggered, primarily rock falls and rock slides, that ranged in volume from a few cubic meters to tens of millions of cubic meters (i.e., the rock avalanches that covered much of the McGinnis Glacier) (EBERHART-PHILLIPS *et alii*, 2003; HARP *et alii*, 2003; HANSEN *et alii*, 2004; JIBSON *et alii*, 2004, 2006). Other large rock avalanches (up to several million cubic meters) were triggered along the Black Rapids and West Fork Glaciers. The pattern of landsliding and liquefaction effects was unusual: the number and concentration of slides was much less than could be expected for an earthquake of this magnitude (suggesting a deficiency in high-frequency shaking), and the landslides were concentrated in a narrow zone about 30 km wide that straddled the fault-rupture zone over its entire 300 km length. Despite the overall sparse landslide concentration, the earthquake triggered large rock avalanches that clustered along the western third of the rupture zone (the area of the first two sub-events), where acceleration levels and ground-shaking frequencies are thought to have been the highest. The narrow concentration of rock falls, rock slides, and large rock avalanches along the fault-rupture zone suggests that the highest accelerations generated by this earthquake did not extend far from the fault zone; moreover, the overall area of 10,000 km2 affected by landslides was significantly smaller than that triggered by other earthquakes of comparable magnitude (HARP *et alii*, 2003 and references therein). Liquefaction features were observed over a distance much greater than that of landslides, extending out from the surface rupture for approximately 100–120 km. In addition, the liquefactions were more extensive and more severe to the east, in the vicinity of the third sub-event, on the Holocene alluvial deposits of the Robertson, Slana, Tok, Chisana, Nabesna and Tanana Rivers (EBERHART-PHILLIPS *et alii*, 2003; KAYEN *et alii*, 2004). The large areal distribution of liquefaction features compared to the limited zone of landslides suggests that minimum shaking levels and duration requirements for liquefaction were more extensive than those needed to trigger rock falls and rock slides and that the third sub-event had a longer duration and period of shaking than the previous two (HARP *et alii*, 2003; KAYEN *et alii*, 2004; JIBSON *et alii*, 2006).

As expected, many hydrological anomalies also followed the earthquake, such as the generation of water waves, water spill from swimming pools, seiches in lakes and rivers, muddy well waters, affecting distances of up to 3500 km across western Canada and in the Seattle basin, WA (CASSIDY & ROGERS, 2004; BARBEROPOULOU *et alii*, 2006; Sil, 2006).

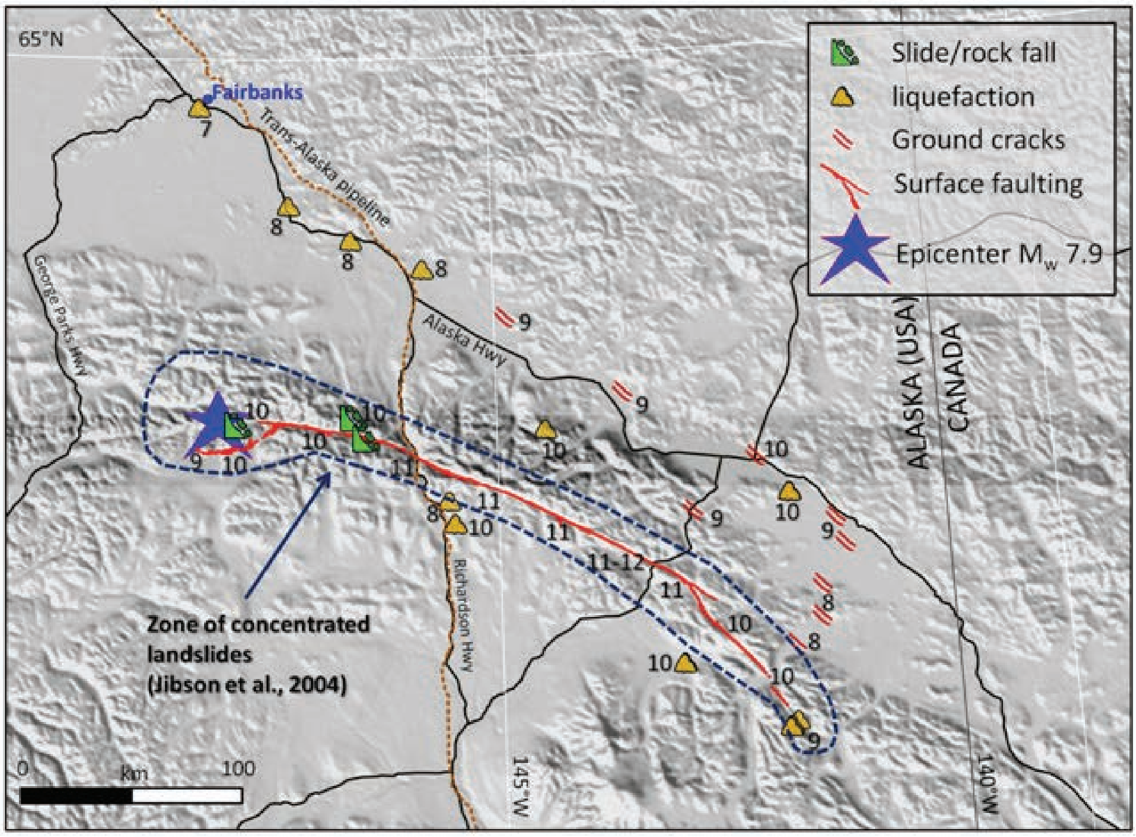


Fig. 3.7 - The 2002 Denali earthquake: distribution of geological effects based on survey data from authors cited in text. The fault ruptures are plotted, simplified, according to Eberhart-Phillips *et alii* (2003).
*- Terremoto di Denali del 2002: distribuzione degli effetti geologici in base ai dati rilevati dagli autori citati nel testo. Le rotture di faglia sono plottate e semplificate in base a* Eberhart-Phillips *et alii (2003).*

## *MMI and ESI Intensity assessments*

A macroseismic survey (Community Internet Intensity) was carried out initially by the US Geological Survey and later expanded by the Geophysical Institute of the University of Alaska Fairbanks, by collecting data in the near-field zone (Martirosyan, 2004). The combined dataset contains intensities for more than 155 inhabited locations: the maximum intensity, IX MMI, was reported in 29 of these. Of the 29 intensities IX, 28 are located in the eastern part of the ruptured fault, and the average distance for the intensity IX sites from the fault is 27 km (Martirosyan, 2004). A majority of the intensity data comes from localities very far (tens to hundreds km) from the fault, and more than 70% of the intensities provided are V MMI or less. The spatial distribution of the intensity data is strongly inhomogeneous, insofar as the area is sparsely populated. Clearly, this poses serious difficulties for assessing a reliable earthquake epicentral intensity.

In this study, the earthquake environmental effects (EEE) reported in several papers (Eberhart-Phillips *et alii*, 2003; Crone *et alii*, 2004; Kayen *et alii*, 2004; Haeussler, 2009) have been analyzed, in order to assess local intensities according to the ESI 2007 scale. The localities with diagnostic EEEs number 131; the resulting ESI intensities range between VII and XII. The ESI intensities have been evaluated based on evidence of surface faulting (primary effect), slope movements, liquefaction and ground rupture features (secondary effects). The characteristics of the analyzed effects, with the relative intensity evaluation, are reported in the EEE Catalogue, hosted by ISPRA in the framework of the INQUA TERPRO Focus Area on Paleoseismicity project “A global catalogue and mapping of Earthquake Environmental Effects” (see Chapter 4).

## *Discussion*

In figure 3.8 is shown a macroseismic map derived from the MM intensities combined with the ESI 2007 intensities, which can be useful to better define the ground motion of the earthquake.

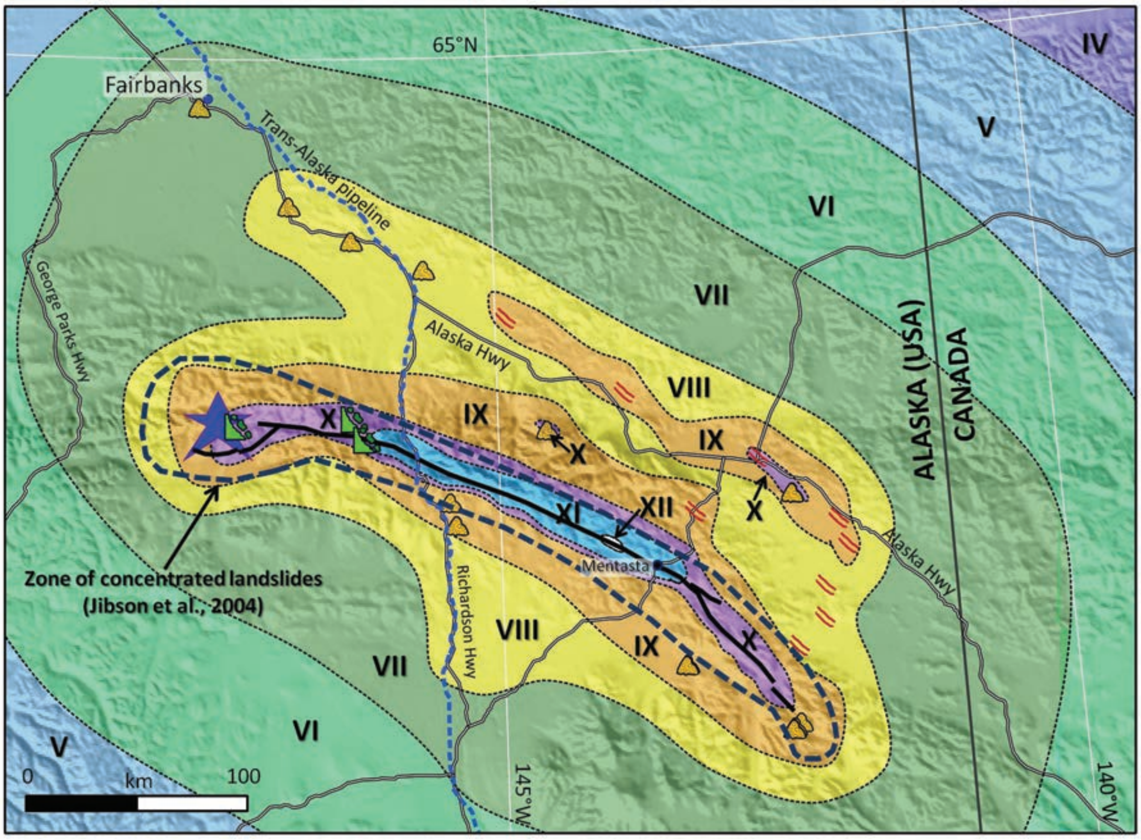


Fig. 3.8 - The 2002 Denali earthquake: macroseismic intensity field based on CII and ESI2007 intensities. The maximum ESI 2007 intensity degree based on the amount of slip is XII, but the resulting $I_0$ is XI.
*- Il terremoto di Denali del 2002: campo di'intensità macrosismica basato sulle intensità CII e ESI 2007. Il massimo grado di intensità ESI 2007 in base all'entità dello slip risulta pari a XII, ma l'intensità epicentralè* $I_0$ *è invece pari a XI.*

Based on the maximum primary EEE, i.e. the maximum horizontal slip of 880 cm and the total surface rupture length of 340 km, the maximum intensity, according to the ESI scale, is XII. However, the maximum vertical offset of 540 cm (with a dubitative measure of 642 cm) and the spatial distribution of secondary effects (landslides and liquefactions), with a total affected area of at least 40,000 km$^2$, lead to an epicentral intensity estimation of XI, although close to XII. The distribution and characteristics of EEEs allow locating the macroseismic epicenter W of Mentasta, broadly ESE of the instrumental epicenter, and near the third sub-event.

In conclusion, this study of the Denali 2002 earthquake, confirming the importance of collecting primary and secondary EEEs in order to define the complex nature of earthquakes (either in terms of ground motion and slip segmentation), has allowed a more reliable epicentral intensity to be assessed: no less than XI, possibly XII, based on the ESI scale. Actually, the maximum intensity proposed earlier (IX MM; Martirosyan, 2004) appears to underestimate the earthquake by at least two degrees as compared with its magnitude. Hence, the intensity evaluation based on damage is liable to be too poorly constrained in sparsely populated areas, and geological effects can dramatically improve its assessment.

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*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), p. 133-134
fig. 1

# 4. - The EEE Catalogue

Nowadays, a significant amount of data about Earthquake Environmental Effects is available for a very large number of recent, historical and paleo-earthquakes. However available information is located in several different sources (scientific papers, historical documents, professional reports), and often difficult to access.

The EEE Catalogue has been promoted with the aim to properly retrieve the available information about EEE at global level and archive it into a unique database, in order to facilitate their use for seismic hazard purposes. Its implementation has been endorsed at global level by the INQUA TERPRO Project #0811, through a Working Group coordinated by ISPRA - Geological Survey of Italy.

A first official release of the EEE Catalogue has been done in the frame of the XVIII INQUA Congress, held in Bern in July 2011. However, the implementation of the EEE catalogue is always in progress at http://www.eeecatalog.sinanet.apat.it/login.

Data can be explored on a public interface (fig. 4.1) based on Google Earth at http://www.eeecatalog.sinanet.apat.it/terremoti/index.php


Fig. 4.1. - The public interface of the EEE Catalogue, developed on Google Earth http://www.eeecatalog.sinanet.apat.it/terremoti/index.php.
- *Interfaccia pubblica dell'EEE Catalogue, sviluppata su Google Earth http://www.eeecatalog.sinanet.apat.it/terremoti/index.php.*

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 135 - 138
figg. 3

# 4.1. - Towards a global catalogue of earthquake environmental effects: the EEE Catalogue

GUERRIERI L. (1), BAIOCCO F. (1), BLUMETTI A.M. (1), BRUSTIA E. (1), COMERCI V. (1), ESPOSITO E. (2), LUCARINI M. (1), MICHETTI A.M. (3), PORFIDO S. (2), SCARAMELLA A. (1), SERVA L. (1), VITTORI E. (1)

## *Introduction*

The EEE catalogue collects the characteristics, size and spatial distribution of coseismic effects on nature in a standard way from modern, historical and paleoearthquakes. For each event, we have assessed epicentral and local intensities based on EEE data through the ESI 2007 scale (Michetti *et alii*, 2007), that integrates and completes the traditional macroseismic intensity scales, allowing to assess the intensity parameter also where buildings are absent or damage-based diagnostics saturates. This procedure has allowed an objective comparison in terms of earthquake intensity, for events occurred in different areas and/or in different periods.

The information is collected at three levels of increasing detail (Earthquake, Locality, Site). Also available imagery documentation (photographs, video, sketch maps, stratigraphic logs) can be uploaded into the database.

The quality of the database in terms of completeness, reliability, and resolution of locations is strongly influenced by the age of the earthquake so that it is expected to be very variable. Nevertheless, even where the information is less accurate (historical earthquakes), the documented effects are typically the most relevant i.e. most diagnostic for intensity assessment. Similarly, the information from paleoseismic investigations, although poorly representative of the entire scenario, still includes significant data (i.e. local coseismic fault displacements) very helpful of a minimum size of the earthquake.

## *The added value*

The major added value of the EEE Catalogue in terms of seismic risk is the possibility to explore the scenarios of environmental effects induced by past earthquakes and therefore identify the areas where the anthropic settlements and infrastructures are more exposed to this source of potential hazard. To this end, a good accuracy of EEEs location becomes crucial. Typically, EEEs from recent earthquakes are mapped with good accuracy immediately after the event. Nevertheless, even for some historical earthquakes it is possible to retrieve with very good detail this information. It is the case of the December 28th, 1908 Messina Straits earthquake and consequent tsunami (fig. 4.2), where the EEE Catalogue allows to locate the earthquake/tsunami effects over the present urban texture with a spatial resolution of a few meters, pointing out the areas characterized by the highest risk.

(1) Geological Survey of Italy, ISPRA, Roma, Italy.
(2) Istituto per l'Ambiente Marino Costiero, CNR, Napoli, Italy.
(3) Dipartimento di Scienze Chimiche e Ambientali, Università dell'Insubria, Como, Italy.

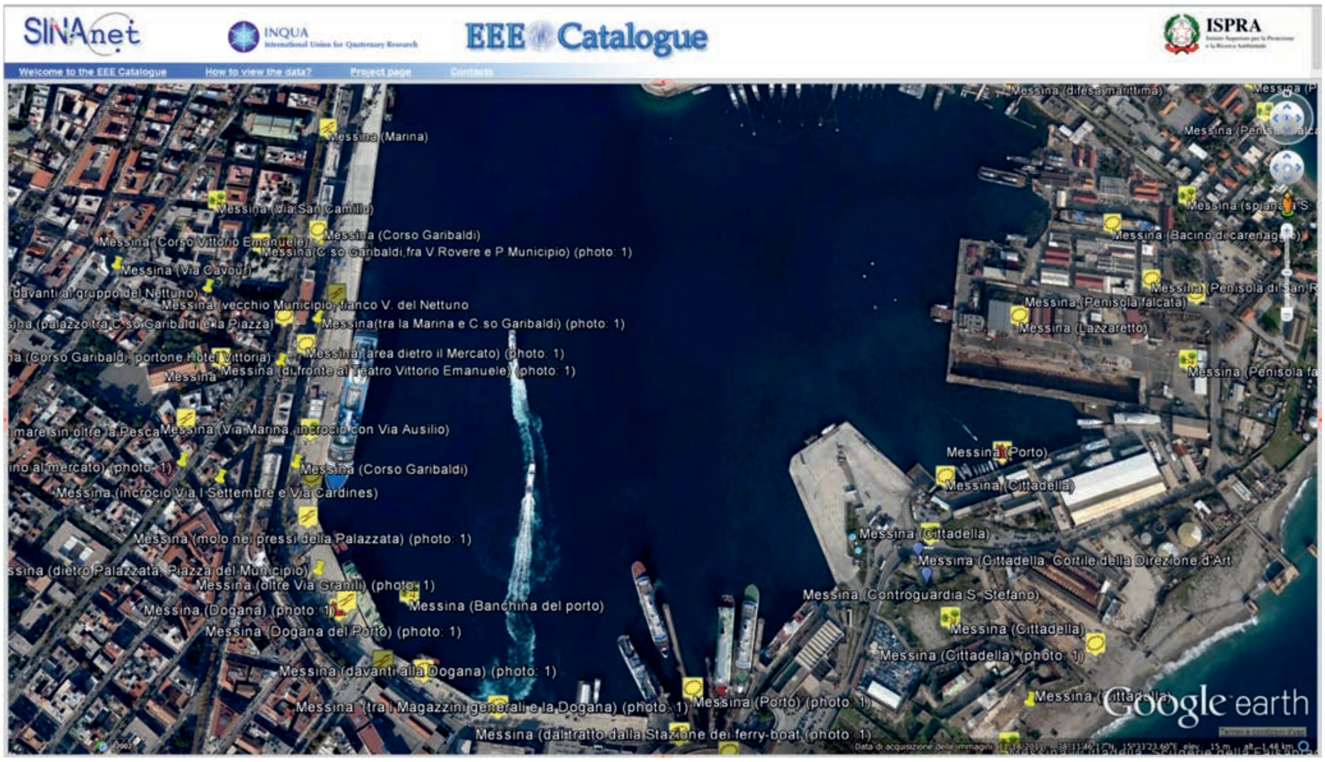


Fig. 4.2 - EEEs induced by the December 28, 1908 Messina Straits, Italy, earthquake in the area of the Messina harbour. If information from contemporary sources is very precise, it is possible to use the EEE Catalogue also for local seismic microzonation.
*- EEEs indotti dal terremoto del 28 Dicembre 1908 nell Stretto di Messina (Italia), nella zona del porto di Messina. Se le informazioni contenute nelle fonti contemporanee sono molto precise è possibile utilizzare l'EEE Catalogue anche per microzonazione sismica locale.*

Furthermore, the EEE Catalogue allow to reveal possible trends in the spatial distribution of primary and secondary effects. For example, figure 4.3 shows the spatial distribution of EEEs induced by the October 8 2005, Muzaffarabad, Pakistan, earthquake (Ali *et alii*, 2009): it is quite evident that the location and amount of surface faulting is consistent with the spatial distribution of coseismic slope movements, in terms of both areal density and size.

A similar result is shown by the spatial distribution of EEEs induced by the 1811-1812 New Madrid, Missouri, earthquakes, mapped in figure 4.4. Indeed, the most relevant primary and secondary effects are located along the Mississippi valley near New Madrid, consistently with the surface projection of the causative faults, and unquestionably provide diagnostic elements for assessing an epicentral intensity equal to XI.

## *Final remarks*

The recent catastrophic earthquakes occurred in Japan and New Zealand have clearly pointed out that traditional seismic hazard assessment based only on vibratory ground motion data need to be integrated with information about the local vulnerability of the territory to earthquake occurrence.
The collection of Earthquake Environmental Effects provided by the EEE Catalogue aims at identifying the areas most vulnerable to earthquake occurrence. This information must complement traditional SHA based on PGA maps.

Moreover, based on EEE characteristics, size and spatial distribution it is possible i) to assess the earthquake intensity through the ESI scale, and ii) to objectively compare the earthquake intensity of events occurred in different areas and/or in different periods.

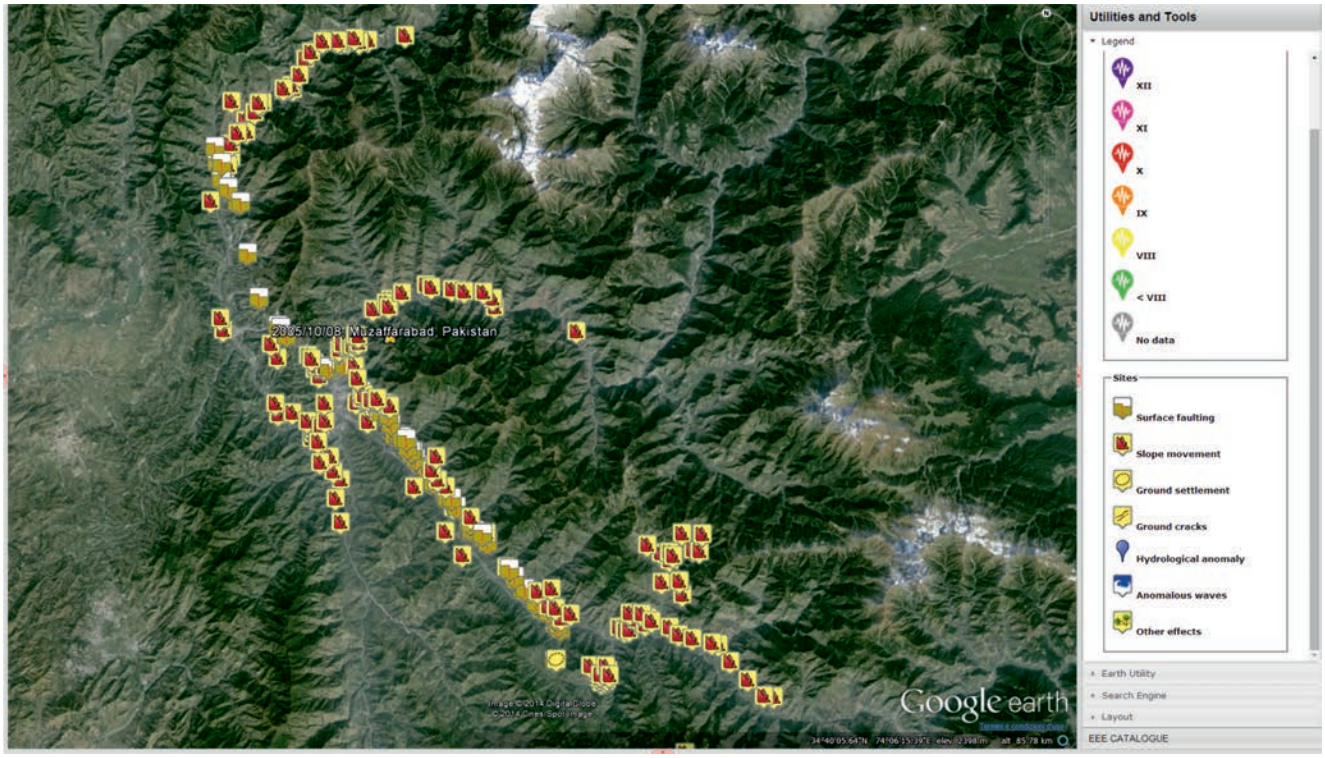


Fig. 4.3 - Surface faulting and slope movements induced by the October 8, 2005 Muzaffarabad, Pakistan, earthquake.
*- Fagliazione superficiale e movimenti di versante indotti dal terremoto dell'Ottobre 2005 a Muzaffarabad (Pakistan).*

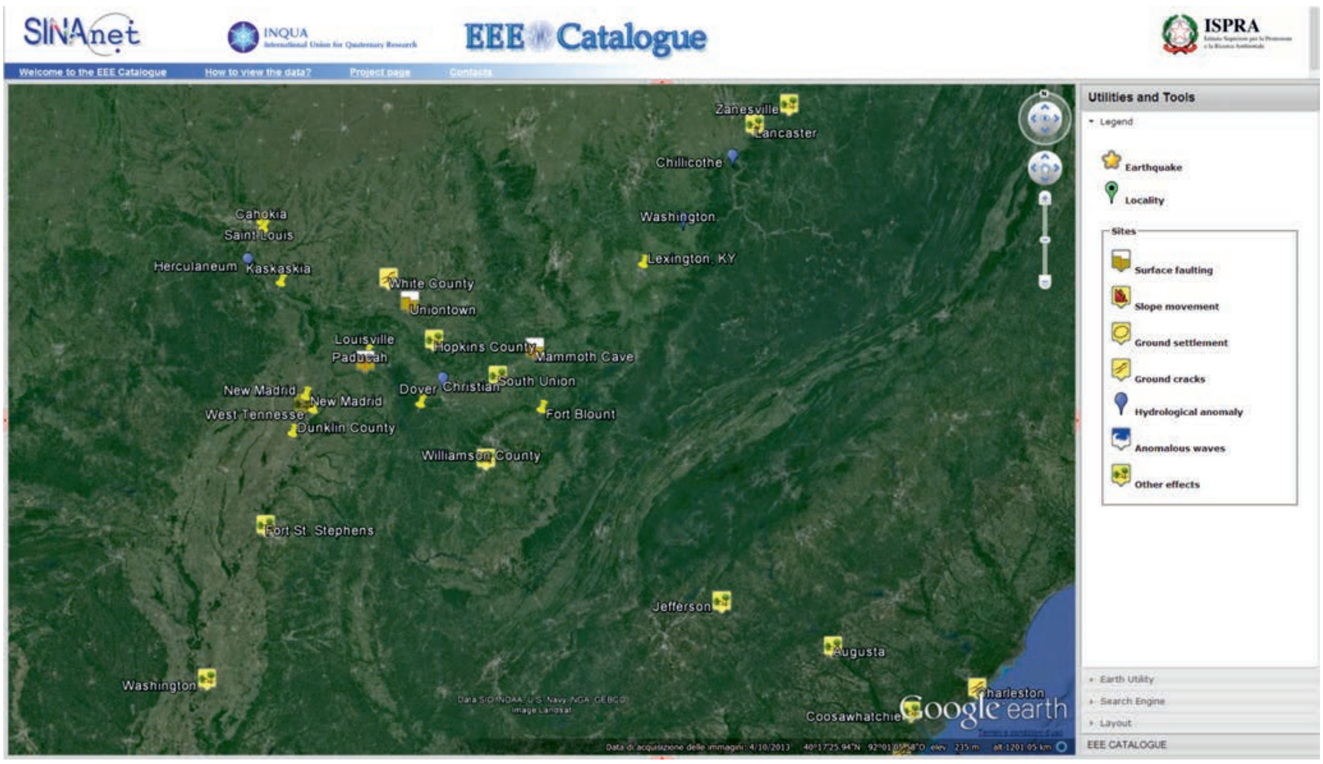


Fig. 4.4. - EEE induced by the December 16 1811 New Madrid, Missouri,USA, earthquake. Primary and secondary effects indicative of intensity XI in the ESI 2007 scale are located in the epicentral area along the Mississippi Valley.
*- EEE indotti dal terremoto di New Madrid (Missouri, USA) del 16 Dicembre 1811. Gli effetti primari e secondary indicativi di intensità XI nella scala ESI 2007 sono localizzati nell'area epicentrale lungo la valle del Mississippi.*

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 139 - 146
figg. 6

# 4.2. - EEE Catalogue: guidelines for public consultation and remote compilation

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## *Introduction*

These guidelines are aimed at supporting the consultation and remote compilation of the EEE Catalogue, a database infrastructure designed to collect information on Earthquake Environmental Effects.

Data are collected at three levels of progressive detail (Earthquake, Locality, Site), corresponding to three different tables:

1) The Earthquake Table contains general information about the seismic event.

2) *The Locality Table contains information about the characteristics of a specific locality where some EEEs have occurred. Local intensity assessment (from ESI or traditional scales) must be provided at this level.*

3) *The Site Table contains information at the site of each EEE including detailed characteristics on the type of earthquake.*

The quality of the datasets is expected to be very different according to the earthquake date (modern, historical or paleoevents), in terms of completeness, reliability, and resolution of locations. Nevertheless, the EEE Catalogue is aimed at collecting EEEs data that are helpful for intensity assessment, beyond their differences in data quality. In fact, effects documented in historical sources are frequently the most remarkable effects (i.e. the most diagnostic) and therefore can be conveniently used for intensity evaluation. Similarly, considering paleoearthquakes, the dataset deriving from paleoseismic investigations cannot be representative of the entire scenario, but includes anyhow significant data (i.e. local coseismic fault displacements) which are very helpful for a minimum measure of the earthquake energy.

## *Public consultation*

http://www.eeecatalog.sinanet.apat.it/terremoti/index.php

From this URL, it is possible to consult the public version of the EEE Catalogue developed on Google Earth.

Through this interface, it is be possible to explore (fig. 4.5):

- some general information about the earthquake visible on a Google Baloon, by clicking on the epicentre (yellow star) (A);
- the pattern of coseismic ruptures (primary or secondary), surveyed or interpreted, by clicking on the gray triangle corresponding to Rupture Zone and activating the box Rupture Zone (B);

(1) Geological Survey of Italy, ISPRA, Roma, Italy

- the geographic distribution of localities (green drops) and sites (classified in 7 EEE categories), by clicking on the gray triangle corresponding to Locality level and activating the box Locality (C);
- the precise location of each Locality and Site by zooming in detail on it (red box in detail in C);
- some general information about the Locality (e.g. local intensity) and Site (e.g. EEE Clasisication, Description, Reference and photograph) visible on a Google Baloon, by clicking on the Locality (D) and Site (E);
- the entire database and photogallery (including maps, video, and other .pdf documents) related to a specific earthquake, by clicking on the earthquake string in the ToC (F).

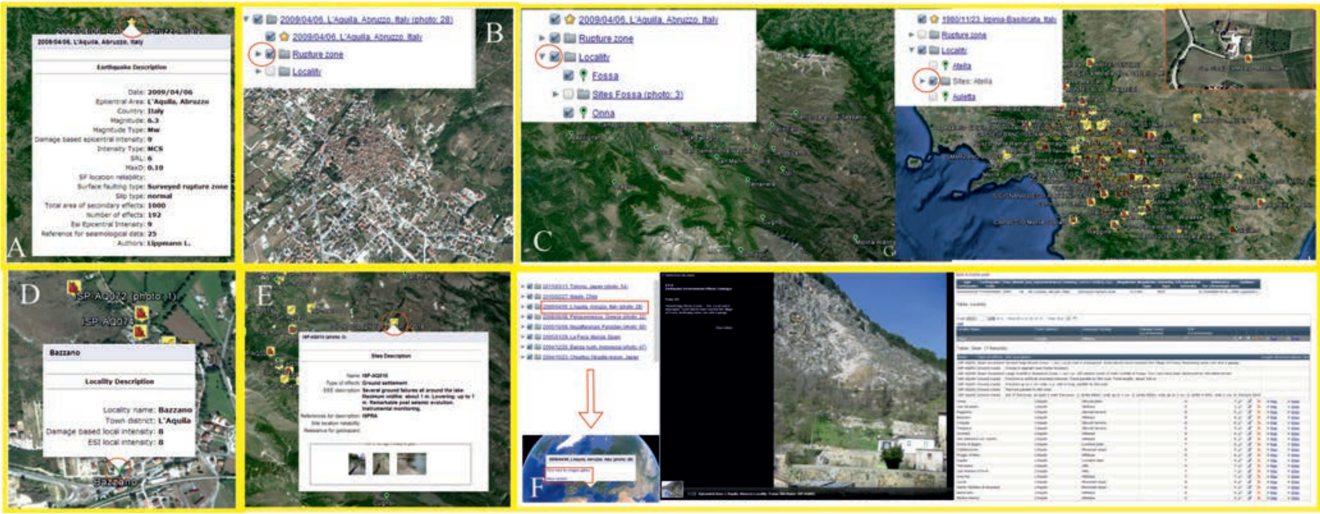


Fig. 4.5. - How to explore data into the EEE Catalogue (see text for details).
*- Come si esplorano i dati nell'EEE Catalogue (si veda il testo per i dettagli).*

## ***Remote compilation*** http://www.eeecatalog.sinanet.apat.it/login

This Web Implementation interface is developed to support the remote compilation of the EEE Catalogue. Therefore the access is restricted to Compilers.

Before starting the Web Implementation, a new Compiler is kindly requested to:

1) go to http://www.eeecatalog.sinanet.apat.it/admin/login.php and register for log-in (i.e. choose a username and a password);
2) create a record of earthquakes specifying for each earthquake record at least date, epicentral area and list of authors (i.e. compilers);
3) send an email to the EEE Catalogue Administrator (luca.guerrieri@isprambiente.it) reporting your username and the list, for editing authorization.

Only one Compiler is authorized to edit each individual earthquake record. Therefore, in case more than one Author will contribute to compile the same earthquake record, they are expected to share the same username.

At the end of the Web Implementation phase, compilers are requested to send an email asking for validation and publication. Data collected in each earthquake record will be verified by a Scientific Committee in terms of technical (i.e. standardization) and scientific quality.

For each table only some selected fields are displayed. By clicking the Lens button it will be possible to open the entire table.

Earthquake records can be edited only by authorized compilers: by clicking on the Edit button it will be possible to modify data and save them with the Edit button, located at the bottom of the mask. For some fields, compilers will be requested to select from a menu.

Data compilation must be done at three different levels of generalization (Earthquake, Locality and Site). Below are provided some detailed information about the characteristics of fields referred to the tables Earthquake, Locality and Site.

Moreover, it is possible to upload:

- the pattern of coseismic ruptures as linear elements (.previously edited as .kml file), at Earthquake level;
- photgraphs, sketches or videos documented a single effect, at Site level.

Table Earthquake (fig. 4.6)

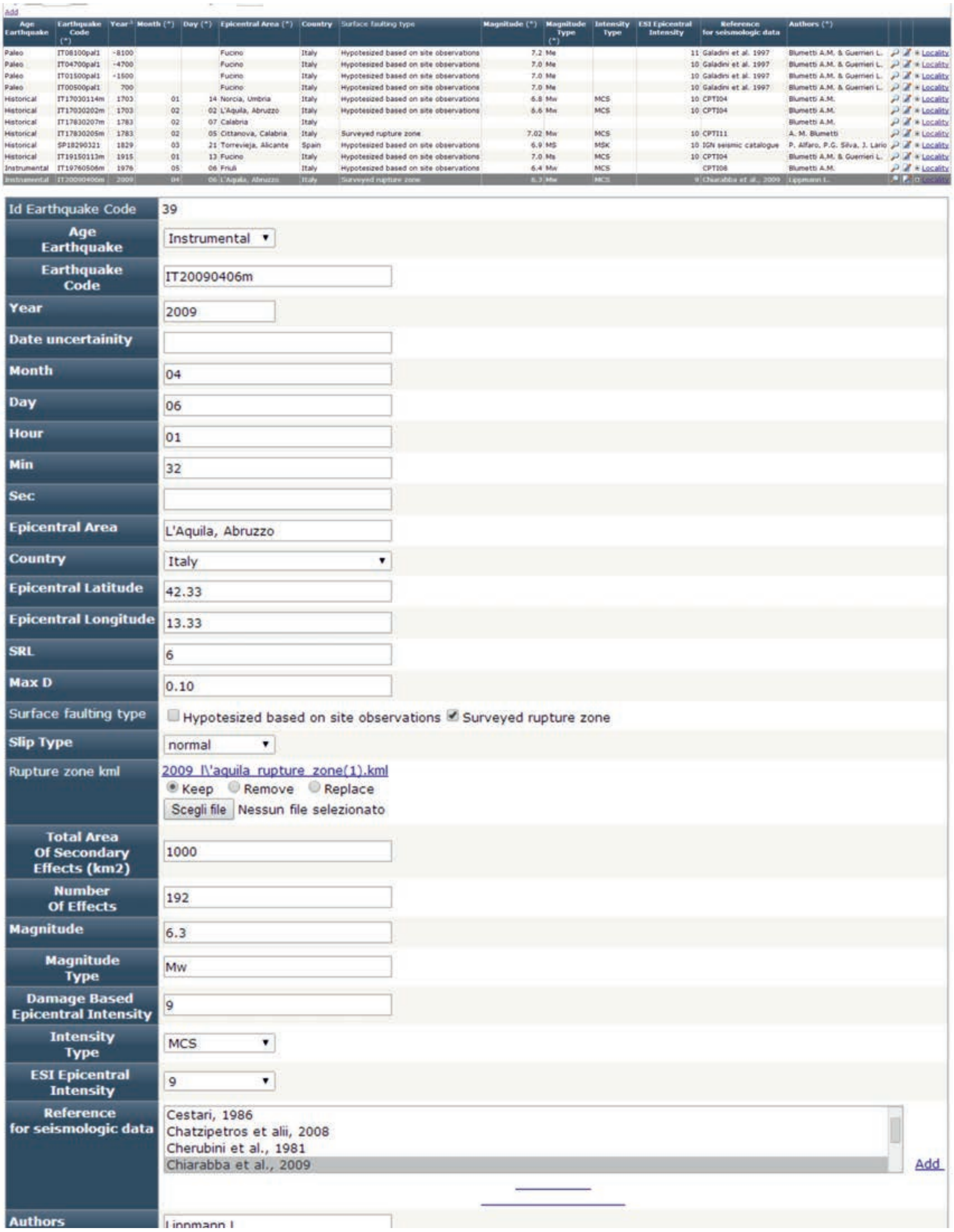


Fig. 4.6 - The Table Earthquake.
- *La tabella Earthquake.*

***Age Earthquake:*** *select among Paleo, Historical or Instrumental*
***Earthquake Code****: it is composed by 11 digits. It is the primary key (univocal) for the table "Earthquake". It is defined by the Scientific Secretary according to the following:*
For recent and historical earthquakes:
*2 digits country code = the initial letters of the country (please refer to the epicenter);*
*8 digits for date (yyyymmdd);*
*1 digit according to the type of shock (M = main shock; a = aftershock; f = foreshock).*
*Example: GR20041211m*
For paleoearthquakes:
*2 digits for country code;*
*5 digits for year (0yyyy if lower than 10,000 years)*
*3 digits for "pal"*
*1 digit for progressive integer (in case of two events of the same age in the same country);*
*Example: IT17500pal1; SP06540pal2*
***Year, Month, Day:*** *dates are referred to the Christian calendar division, where AD = Positive; BC = Negative. Only Year is mandatory.*
***Date Uncertainties****: It is an estimate, in years, of the degree of uncertainty of the date. It is a mandatory field for paleoearthquakes which are affected by a dating uncertainty. It can be used also for historical earthquakes in case of important uncertainties in date (> than 1 year). In case of exact date, this field can be empty.*
***Hour, Min, Sec:*** *These are optional fields.*
**Epicentral Area:** This is a mandatory field.
**Country:** This is a mandatory field.
**Epicentral Latitude and Longitude**: Coordinates of the epicentres. Mandatory fields.
**SRL**: Surface Rupture Length = the total length of coseismic surface faulting, in km.
**MaxD**: the Maximum Displacement, in m.
Surface faulting type: choose the best option between Hypotesized based on site observations or Surveyed rupture zone (typical of recent events).
**Slip Type**: select between the options (optional field);
**Rupture Zone: create** a rupture zone as .kml with linear elements and upload.
**Total area of Secondary Effects**: this field should be filled at the end of the compilation of the record. The measure unit is $km^2$. This is a mandatory field for the ESI epicentral intensity assessment.
**Number of Effects**: This field should be filled at the end of the compilation of the record as a measure of the wealth of information behind the ESI intensity assessment.
**Damage based Epicentral Intensity** and **Intensity Type:** These two fields record the epicentral intensity values and type using traditional damage-based macroseismic scales. These are mandatory fields for recent and historical earthquakes (of course, empty for paleoearthquakes).
**Magnitude and Magnitude Type**: These two fields record magnitude values and types. These are optional fields (of course, empty for paleoearthquakes).
**ESI epicentral intensity**: This mandatory field records the ESI epicentral intensity value based on the total distribution of surface faulting and/or the total area of secondary effects. In case available data do allow this assessment, this field should be filled with the maximum value among ESI local intensities (see next).
**References:** select the reference for seismological data.
**Authors**: the Authors of the compilation of this record. Not more than 2 authors are allowed to compile the same earthquake record. This field is filled by the Scientific Secretary.

## Table Locality (fig. 4.7.)

Page 1 of 2 Records 1 to 20 of 27 Page Size 20

Add

| Locality Name | Town /district | Geomorph Setting | Damage based Local intensity | ESI Local Intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fossa | L'Aquila | Hillslope | 7 | 8 | | | | Map | Sites |
| Onna | L'Aquila | Alluvial plain | 9 | 7 | | | | Map | Sites |
| San Nicandro | L'Aquila | Hillslope | 6 | 5 | | | | Map | Sites |
| Paganica | L'Aquila | Alluvial terrace | 8 | 9 | | | | Map | Sites |
| Bazzano | L'Aquila | Hillslope | 8 | 8 | | | | Map | Sites |
| L'Aquila | L'Aquila | Alluvial terrace | 8 | 8 | | | | Map | Sites |
| Tempera | L'Aquila | Alluvial terrace | 9 | 9 | | | | Map | Sites |
| Ovindoli | L'Aquila | Hillslope | 6 | 6 | | | | Map | Sites |
| San Demetrio ne' Vestini | L'Aquila | Hillslope | 6 | 8 | | | | Map | Sites |
| Civita di Bagno | L'Aquila | Lowland plain | 7 | 6 | | | | Map | Sites |
| Collebrincioni | L'Aquila | Mountain slope | 6 | 8 | | | | Map | Sites |
| Poggio di Roio | L'Aquila | Hillslope | 8 | 8 | | | | Map | Sites |
| Aquilio | L'Aquila | Lowland plain | 7 | 6 | | | | Map | Sites |
| Terranera | L'Aquila | Hills | 5 | 7 | | | | Map | Sites |
| San Martino D'Ocre | L'Aquila | Hills | 7 | 7 | | | | Map | Sites |
| Arischia | L'Aquila | Hillslope | 7 | 7 | | | | Map | Sites |
| Lucoli | L'Aquila | Mountain slope | 6 | 6 | | | | Map | Sites |
| Santo Stefano di Sessanio | L'Aquila | Mountain slope | 6 | 6 | | | | Map | Sites |
| Barisciano | L'Aquila | Hillslope | 6 | 6 | | | | Map | Sites |
| Molina Aterno | L'Aquila | Hillslope | 5 | 5 | | | | Map | Sites |

View Table: Locality

Back to List Add Edit Delete Sites

| | |
|---|---|
| Earthquake Code | IT20090406m |
| Locality Name | Fossa |
| Town /district | L'Aquila |
| Locality Latitude | 42.29284 |
| Locality Longitude | 13.48683 |
| Locality Altitude (meters) | 644 |
| Local PGA | |
| Geomorph Setting | Hillslope |
| Damage based Local intensity | 7 |
| ESI Local Intensity | 8 |

Fig. 4.7. - The Table Locality.
*- La tabella Locality.*

**Locality Name**: the name of the locality (es. village) representing an area linked to a specific local intensity assessment. It is a mandatory field.
**Town / District**: the name of a town or a district representing a geographic area which includes more than one localities (es. province). It is a mandatory field.
**Local Latitude and Longitude**: Coordinates of the locality. Mandatory fields.
**Locality altitude**: An average value of the altitude of the locality in meters.
**Local PGA:** Local measure of Peak Ground Acceleration, when available. It is a optional field.
**Geomorphological setting**: describe the geomorphological setting of the locality focusing on where EEEs have been recorded. It is a mandatory field.
**Damage based local intensity:** Local intensity value based on traditional macroseismic scales. It is an optional field but recommended for intensity comparisons.
**ESI local intensity**: Local intensity value based on ESI scale. Mandatory field.

Table Site (fig. 4.8.)

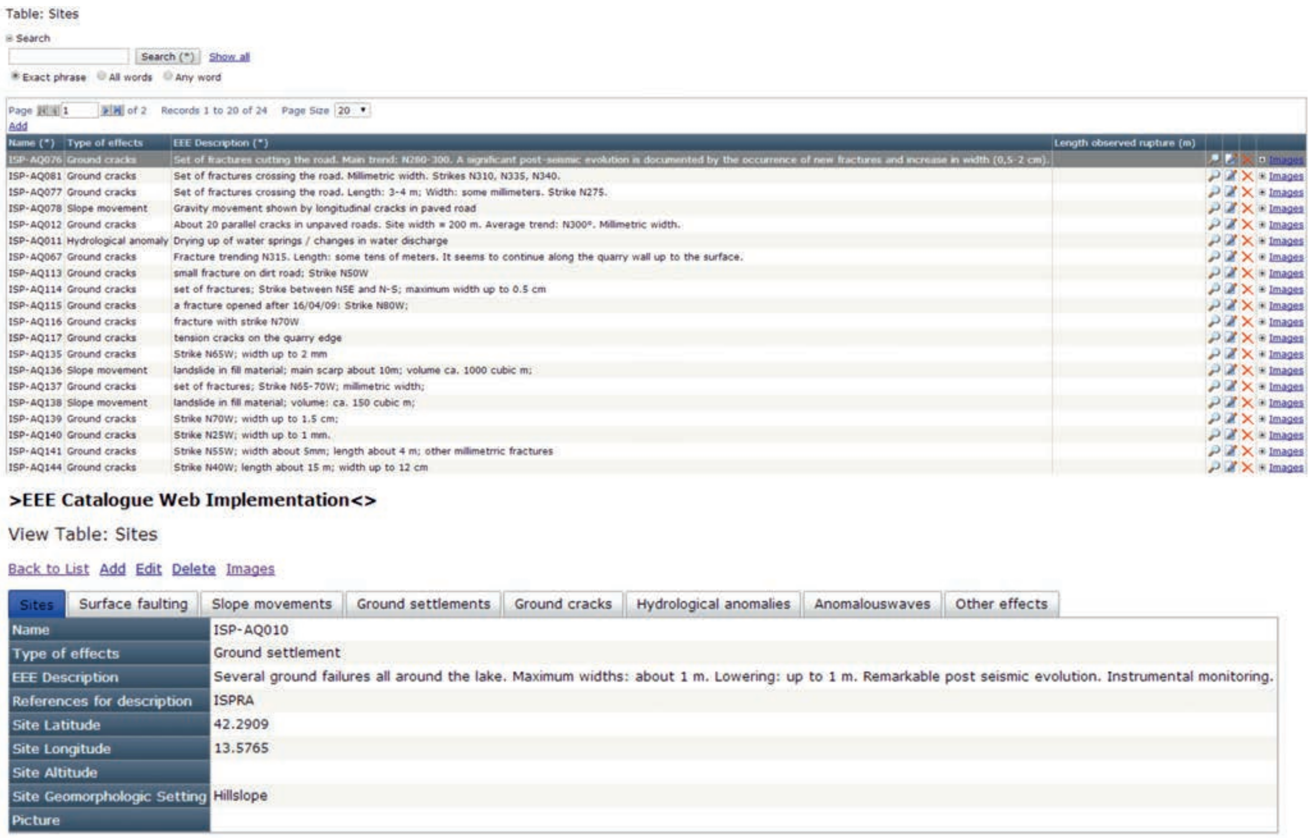

Table: Sites

Search

Search (*) Show all

Exact phrase All words Any word

Page 1 of 2 Records 1 to 20 of 24 Page Size 20

Add

| Name (*) | Type of effects | EEE Description (*) | Length observed rupture (m) | | | | |
|---|---|---|---|---|---|---|---|
| ISP-AQ076 | Ground cracks | Set of fractures cutting the road. Main trend: N280-300. A significant post-seismic evolution is documented by the occurrence of new fractures and increase in width (0,5-2 cm). | | | | | Images |
| ISP-AQ081 | Ground cracks | Set of fractures crossing the road. Millimetric width. Strikes N310, N335, N340. | | | | | Images |
| ISP-AQ077 | Ground cracks | Set of fractures crossing the road. Length: 3-4 m; Width: some millimeters. Strike N275. | | | | | Images |
| ISP-AQ078 | Slope movement | Gravity movement shown by longitudinal cracks in paved road | | | | | Images |
| ISP-AQ012 | Ground cracks | About 20 parallel cracks in unpaved roads. Site width = 200 m. Average trend: N300°. Millimetric width. | | | | | Images |
| ISP-AQ011 | Hydrological anomaly | Drying up of water springs / changes in water discharge | | | | | Images |
| ISP-AQ067 | Ground cracks | Fracture trending N315. Length: some tens of meters. It seems to continue along the quarry wall up to the surface. | | | | | Images |
| ISP-AQ113 | Ground cracks | small fracture on dirt road; Strike N50W | | | | | Images |
| ISP-AQ114 | Ground cracks | set of fractures; Strike between N5E and N-S; maximum width up to 0.5 cm | | | | | Images |
| ISP-AQ115 | Ground cracks | a fracture opened after 16/04/09: Strike N80W; | | | | | Images |
| ISP-AQ116 | Ground cracks | fracture with strike N70W | | | | | Images |
| ISP-AQ117 | Ground cracks | tension cracks on the quarry edge | | | | | Images |
| ISP-AQ135 | Ground cracks | Strike N65W; width up to 2 mm | | | | | Images |
| ISP-AQ136 | Slope movement | landslide in fill material; main scarp about 10m; volume ca. 1000 cubic m; | | | | | Images |
| ISP-AQ137 | Ground cracks | set of fractures; Strike N65-70W; millimetric width; | | | | | Images |
| ISP-AQ138 | Slope movement | landslide in fill material; volume: ca. 150 cubic m; | | | | | Images |
| ISP-AQ139 | Ground cracks | Strike N70W; width up to 1.5 cm; | | | | | Images |
| ISP-AQ140 | Ground cracks | Strike N25W; width up to 1 mm. | | | | | Images |
| ISP-AQ141 | Ground cracks | Strike N55W; width about 5mm; length about 4 m; other millimetric fractures | | | | | Images |
| ISP-AQ144 | Ground cracks | Strike N40W; length about 15 m; width up to 12 cm | | | | | Images |

**>EEE Catalogue Web Implementation<>**

View Table: Sites

Back to List Add Edit Delete Images

Sites | Surface faulting | Slope movements | Ground settlements | Ground cracks | Hydrological anomalies | Anomalouswaves | Other effects

| | |
|---|---|
| Name | ISP-AQ010 |
| Type of effects | Ground settlement |
| EEE Description | Several ground failures all around the lake. Maximum widths: about 1 m. Lowering: up to 1 m. Remarkable post seismic evolution. Instrumental monitoring. |
| References for description | ISPRA |
| Site Latitude | 42.2909 |
| Site Longitude | 13.5765 |
| Site Altitude | |
| Site Geomorphologic Setting | Hillslope |
| Picture | |

Fig. 4.8. - The Table Site.
- *La tabella Site.*

**Site Name:** the toponym of the site where a specific EEE has occurred. It is a mandatory field.
**Site Latitude and Longitude:** coordinates of the site. Mandatory fields.
**Site Altitude:** The altitude of the site in meters. It is a optional field.
**Site geomorphologic Setting**: describe the geomorphological setting of the site. It is a optional field.
**Type Of Effects:** Select from the menu: Surface faulting; Slope movements; Ground settlements; Ground cracks; Hydrological anomalies; Anomalous waves; Other effects. **It is a mandatory field.**
EEE Description: The real description of the EEE. It is a mandatory field.References For Description: Select one or more references for the source of the above description. It is a mandatory field.

Images (fig. 4.9.)

It is possible to upload an image of the effect (picture, sketch map, paleoseismological log, other document). Only JPEG formats will be accepted (size < 2 M). Select type of image, reference (the source of the image) and the caption.

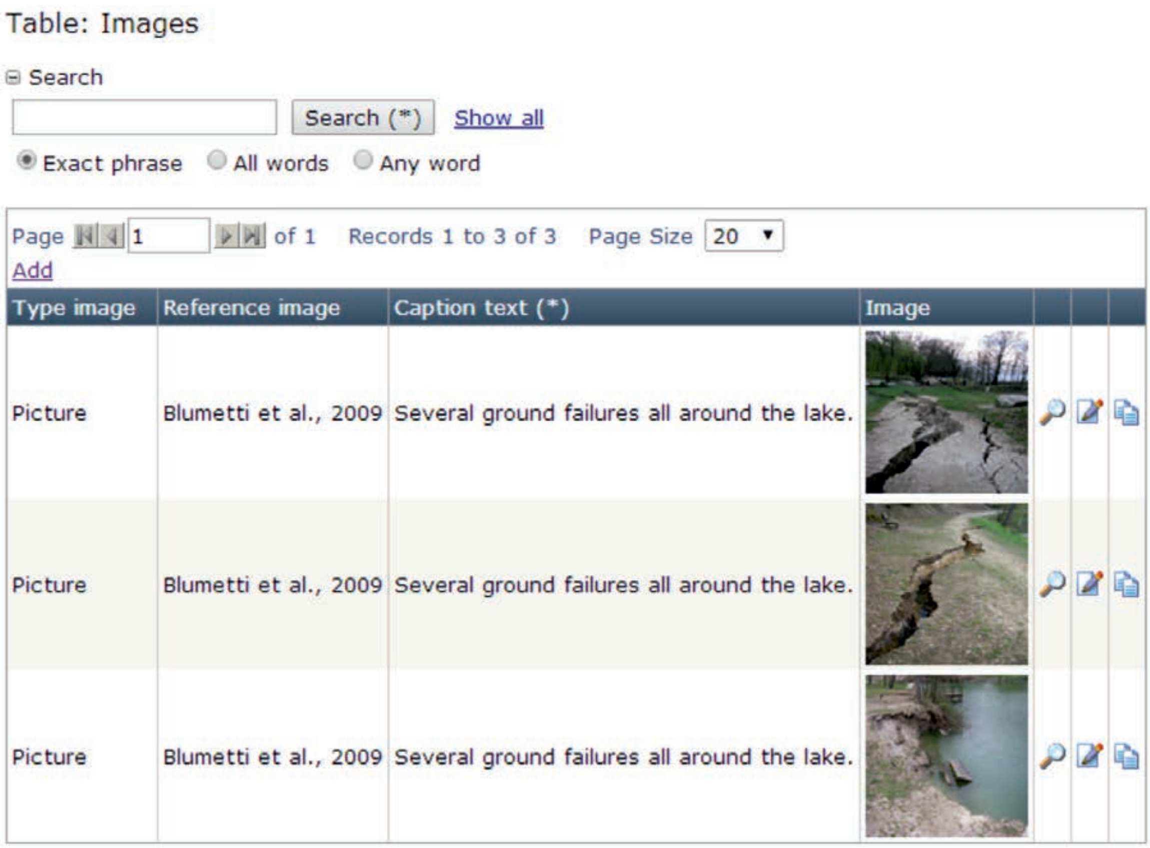

Table: Images

Search

Search (*) Show all

Exact phrase All words Any word

Page 1 of 1 Records 1 to 3 of 3 Page Size 20

Add

| Type image | Reference image | Caption text (*) | Image | | | |
|---|---|---|---|---|---|---|
| Picture | Blumetti et al., 2009 | Several ground failures all around the lake. | | | | |
| Picture | Blumetti et al., 2009 | Several ground failures all around the lake. | | | | |
| Picture | Blumetti et al., 2009 | Several ground failures all around the lake. | | | | |

Fig. 4.9. - The Table Images.
*- La tabella Images.*

Details on EEEs

In case Compilers have more detailed information about the characteristics of a single EEE you are describing, they are kindly requested to record them, by clicking on the detailed tables of each type of effects (from the Table sites, in editing mode).
*Although these fields are not mandatory: however, it is recommended to fill them whenever it is possible since these are basic data for ESI intensity evaluation.*

References (fig. 4.9a)

From the tag Reference it is possible to add short references (e.g. Wegener et al., 2011) and full references (containing authors, year, title, and article references). No specific formats have been developed for full references.

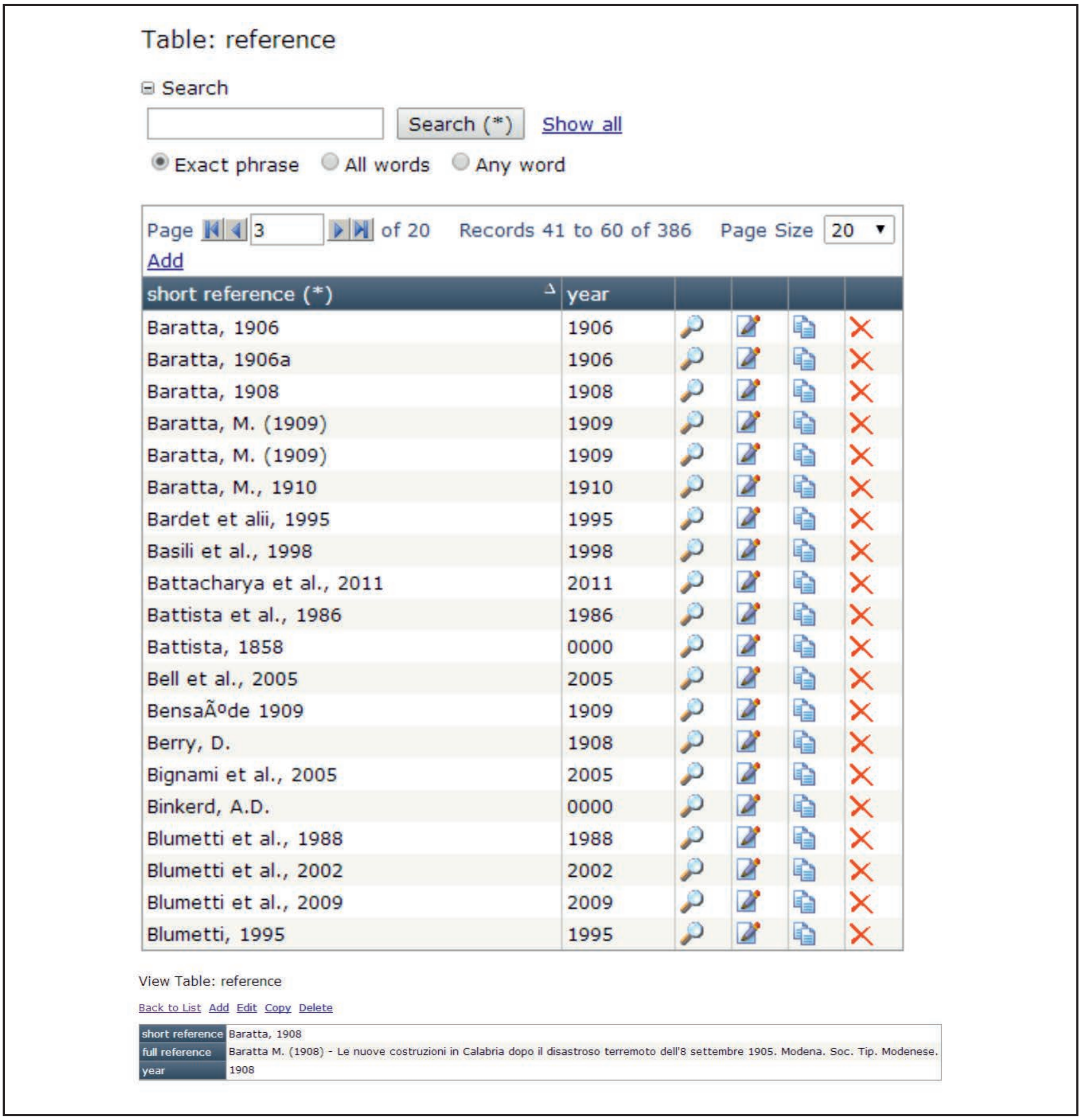

Table: reference

⊟ Search

Search (*) Show all

Exact phrase All words Any word

Page 3 of 20 Records 41 to 60 of 386 Page Size 20

Add

| short reference (*) | year |
|---|---|
| Baratta, 1906 | 1906 |
| Baratta, 1906a | 1906 |
| Baratta, 1908 | 1908 |
| Baratta, M. (1909) | 1909 |
| Baratta, M. (1909) | 1909 |
| Baratta, M., 1910 | 1910 |
| Bardet et alii, 1995 | 1995 |
| Basili et al., 1998 | 1998 |
| Battacharya et al., 2011 | 2011 |
| Battista et al., 1986 | 1986 |
| Battista, 1858 | 0000 |
| Bell et al., 2005 | 2005 |
| BensaÃºde 1909 | 1909 |
| Berry, D. | 1908 |
| Bignami et al., 2005 | 2005 |
| Binkerd, A.D. | 0000 |
| Blumetti et al., 1988 | 1988 |
| Blumetti et al., 2002 | 2002 |
| Blumetti et al., 2009 | 2009 |
| Blumetti, 1995 | 1995 |

View Table: reference

Back to List Add Edit Copy Delete

| | |
|---|---|
| short reference | Baratta, 1908 |
| full reference | Baratta M. (1908) - Le nuove costruzioni in Calabria dopo il disastroso terremoto dell'8 settembre 1905. Modena. Soc. Tip. Modenese. |
| year | 1908 |

Fig. 4.9a. - The Table Reference.
*- La tabella Reference.*

## *Some suggestion for data compilation*

For an easier data compilation, Compilers should preliminary start:

1) to organize data at earthquake, locality and sites level. Localities and sites MUST have a geographic reference. The system will use geographic coordinates (latitude and longitude) in decimal degrees (please use . to separate integers).
2) to prepare the list of references of documents used as source of information
3) to save all additional imagery material (photograps, sketch maps, paleoseismic logs, vides, .pdf documents) into a specific folder.

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 147 - 152
figg. 7

# 4.3. - Documentation of earthquake-induced environmental effects based on tools: Earthquake Geo Survey application

PAPATHANASSIOU G. (1), KOPSACHILIS V. (2)

## *Introduction*

One of the activities of the INQUA TERPRO Focus Area on Paleoseismology and Active Tectonics, in the frame of the INQUA Project 1299 - EEE METRICS (PARAMETRIZATION OF EARTHQUAKE ENVIRONMENTAL EFFECTS: Relationships between source parameters and ESI-2007 Intensity for Modern, Historic, Ancient and Paleo Earthquakes), is the development of an application that could be used by earth-scientists and engineers during field surveys for reporting the earthquake-induced environmental effects. The development of this application is the first step of the INQUA TERPRO Focus Area on Paleoseismology and Active Tectonics in the new era of online information-exchange.

In order to achieve this, it was decided to develop an application that can be used by IOS and android mobile devices e.g. smartphones and tablets. The called Earthquake Geo Survey application is mainly designed based on the Earthquake Environmental Effects form, proposed by the INQUA TERPRO SubCommission Group for reporting earthquake-induced deformations (Michetti *et alii* (2007), and the recommendations of GEER, Geotechnical Extreme Events Reconnaissance, (GEER, 2011) regarding data processing after a post-earthquake reconnaissance field survey.

In particular, via this application the user is able to document on-fault and off-fault effects, collect GPS waypoints (in decimal degrees using WGS84) and indirectly geo-tag the collected photos. The type of effects that can be reported and described in detail are surface faulting (on-fault effects) and off-fault effects including slope failures, liquefaction, tsunami, ground cracks, hydrological anomalies and other effects like trees shaking (fig. 4.10). For example, regarding the earthquake-induced liquefaction phenomena, the user can select a subtype of liquefaction from a list including the three most characteristic ones (ejection of sandy material, subsidence and lateral spreading), describe in detail the failure within an extra field, report the maximum diameter of sand boils, select either water or sand ejection and finally locate the site by activating the GPS and take a photo of the liquefaction manifestation. In addition, the macroseismic intensity can also be evaluated using the ESI-07 scale and the relevant chart that is provided.

Moreover, a crucial issue that arises during field surveys is the preparation of preliminary maps, delineating areas and indicating sites, where environmental effects were reported and they should be further investigated in detail. In order to address to this issue, it was designed that the data, collected during the field survey, to be saved on the SD card of the smarthphone/tablet as kmz file and consequently directly imported to Google Earth and other GIS application for further processing. In addition, it was designed that the collected data be plotted with different symbols-icons depending on the type of failure

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(2) Department of Geopgraphy, University of Aegean, Greece

in order to produce maps showing the spatial distribution of one-type or combination of earthquake-induced failures including relevant geo photo. Furthermore, new functions are planned to be developed for increasing the usefulness of the application e.g. activation of the compass in order to be used for reporting surface faulting and the direct linkage to the web site of Earthquake Environemntal Effects for on-line presenation of the collected data.

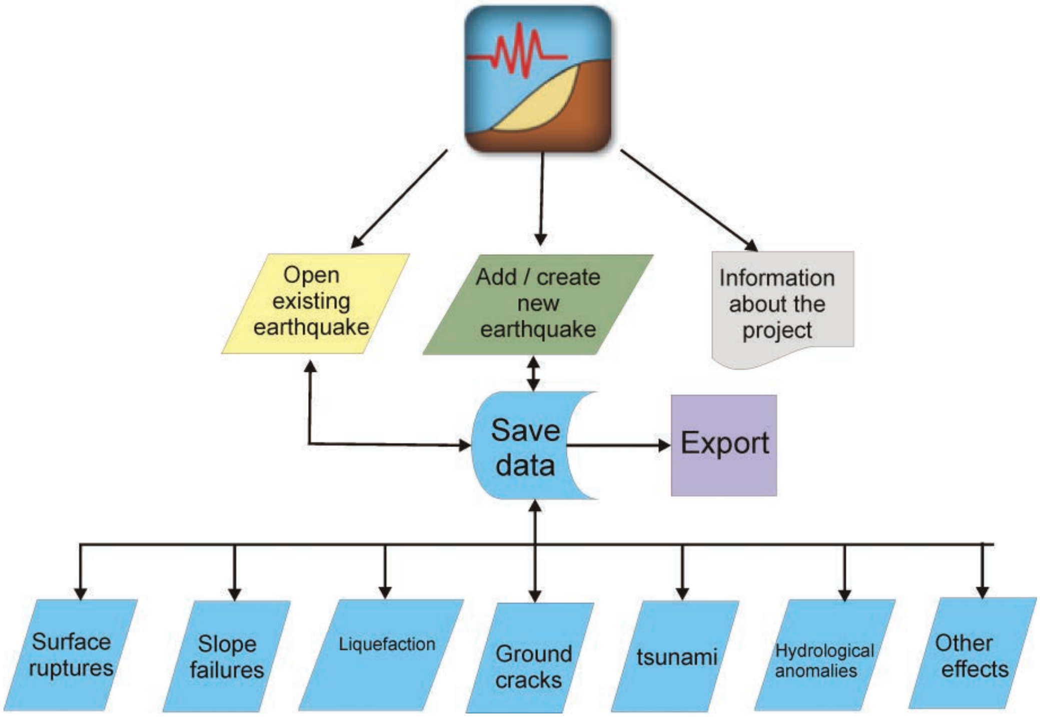


Fig. 4.10. - Flowchart of the Earthquake Geo Survey.
- *Diagramma di flusso dell'Earthquake Geo Survey.*

## *Data Model*

The main concepts of the Data model of the Earthquake Geo Survey application are earthquake and environmental effects, which are represented in the application according to OOP (object-oriented Programming) principles as classes.

The earthquake class is used for describing the earthquake itself by the following attributes: code, date (dd/mm/yy), earthquake magnitude, magnitude type (Mw or Ms), ESI epicentral intensity, epicentral area, country, longitude and latitude (WGS84). The class representation is depicted in figure 4.11.

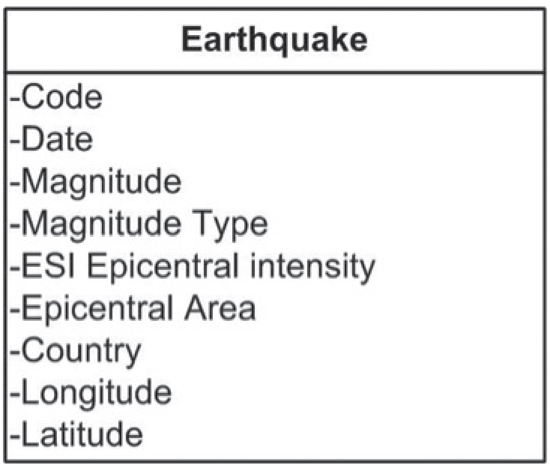


Fig. 4.11. - Earthquake Class.
- *Campi a livello Earthquake.*

Environmental effects classes describe the documenting earthquake-induced effects, following the recommendations provided by the EEE form (Michetti *et alii*, 2007), and have been grouped into 7 types. In particular, the types of effects that can be reported and described are: surface faulting, slope failures, liquefaction, tsunami, ground cracks, hydrological anomalies and other effects. Each effect is described by different attributes depending on its effect type. For example, dip information might be meaningful for a surface faulting effect and do not apply for a slope movement effect. However, all effect types share common attributes such as ID and Longitude/Latitude. For that reason our data model was designed according to class inheritance principle.

In our model, the Effect class is used as a parent class and there are seven more child classes that represent each effect type (fig. 4.12). The common attributes which are ID, Subtype, Date, Description, Longitude, Latitude, ESI-07 scale and Photo) are represented by the Effect parent class. Each child class hold attributes that are specific to the effect type and also inherits the attributes from its parent class Effect. For example, a slope movement effect is represented by the Slope Movement class and is described by the attributes ID, Subtype, Date, Description, Longitude, Latitude, ESI-07 Scale, Photo, Blocks Dimension and Total Volume.

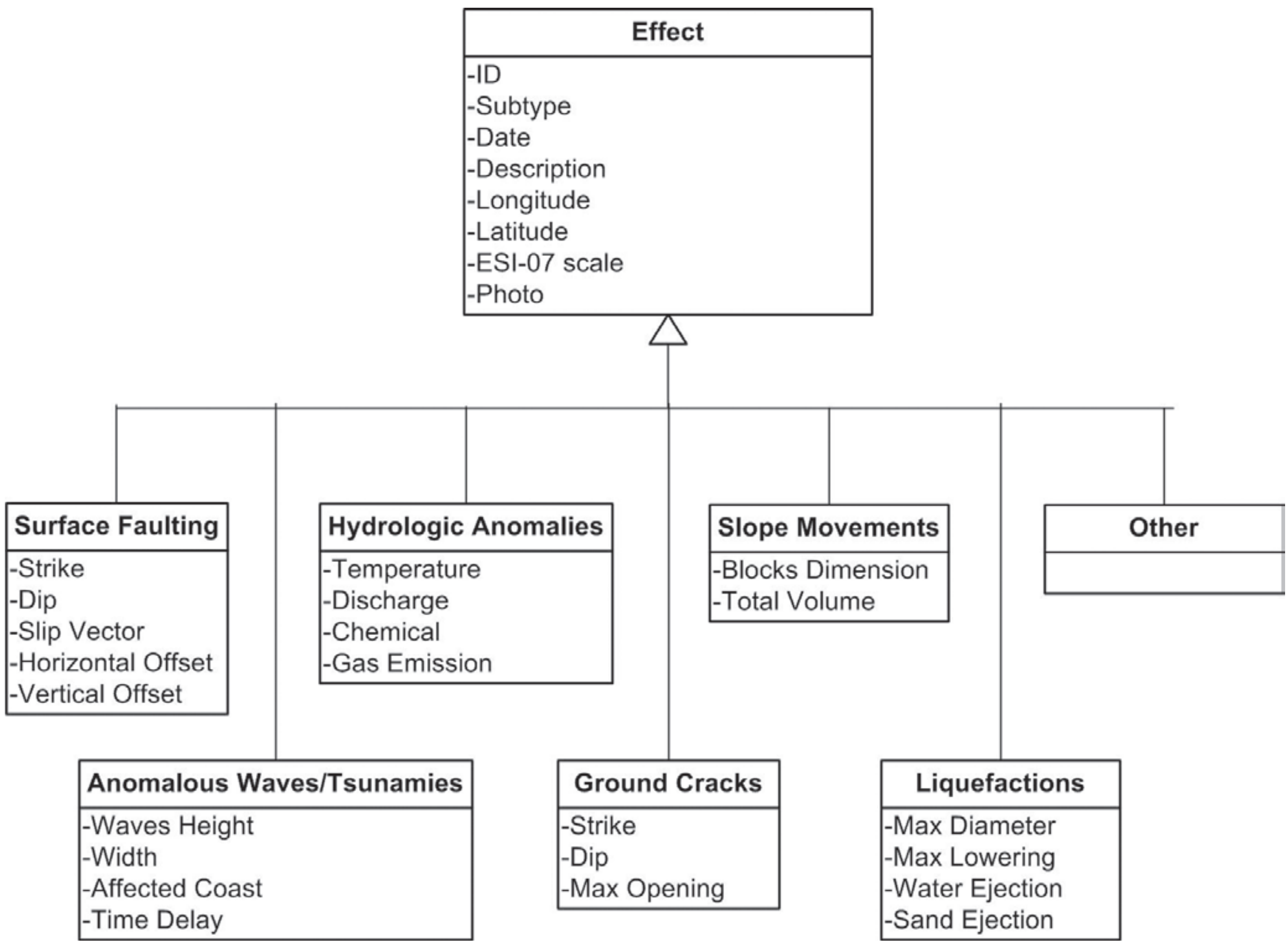


Fig. 4.12. - Effect Class Diagram.
*- Diagramma dei campi a livello Effects.*

## *KML structure*

As it was previously mentioned, the collected data are stored in KML (Keyhole Markup Language) files. KML is an XML notation for expressing geographic annotation and was developed for use with Google Earth, which is a software for viewing of Earth satellite imagery, maps and user defined overlays of geographic information (GEER, 2011). Each KML file holds information about an earthquake, visualization styles and earthquake's environmental effects in XML elements. At the top of each KML document XML elements name, Timestamp and Extended Data holds information about the earthquake itself such as name, date, magnitude etc.

Style XML elements define styles for effect visualization in Google Earth. Each effect, depending on its type, is visualized in Google Earth with its type symbol (icon) and a custom information popup. The Effect icon is similar to the icons proposed by Silva *et alii* (2008) in order to maintain the consistency between the ESI-07 scale and the application. Therefore, in KML document there are seven Style elements, one for each effect type. In these elements, the type symbol and info popup template are defined.

In KML document, each effect is described by a Placemark XML element and there are as many Placemark XML elements as effects. Placemark elements contain sub-elements that fully describe an effect (fig. 4.13). In particular, the Name sub-element holds ID, the StyleUrl sub-element associates this effect with a visualization style depending on its type, thePoint sub-element holds longitude and latitude, the TimeStamp sub-element holds effect's reporting date and finally, the ExtendedData sub-element contains more sub-elements that hold other information that fully describe the effect such as subtype, description, ESI-07 scale and name of the photograph.

```
<Placemark>
    <name>q1</name>
    <styleUrl>#Surface Faulting</styleUrl>
    <Point><coordinates>26.55899175,39.106032150000004</coordinates></Point>
    <TimeStamp><when>24-3-2013</when></TimeStamp>
    <ExtendedData>
        <Data name="Type"><value>Surface Faulting</value></Data>
        <Data name="Subtype"><value>Oblique</value></Data>
        <Data name="Description"><value></value></Data>
        <Data name="photo"><value>q1.jpg</value></Data>
        <Data name="esi"><value>3</value></Data>
</Placemark>
```

Fig. 4.13. - Placemark XML element.
- *Placemark XML.*

## *Application development*

At present time the Andorid application has been released and can be downloaded from the web site of Play Store https://play.google.com/store/apps/details?id=org.inquaterpro.seismicsurveyapp, while the design of the iOS application structure has been already started. Earthquake Geo Survey application for Android was developed in Eclipse IDE (Integrated Development Environment). Eclipse is the recomended IDE for android application development as it supports the Android Development Tools (ADT) plugin, and integrates the Android SDK (Software Development Kit) which is essential for application developing for Android Devices. The programming language used for the application development is Java.

During development phase, the application was tested on a HUAWEI U8180 device with the following features: Android 2.2.2 OS, 2.8 in. display, capacitive touch screen, 512MB memory, 3.15 megapixel camera, 4 GB SD card, and GPS. The application runs on devices with Android 2.2 OS version or newer and it requires access to camera and GPS receiver features and permission to write to device's external storage.

Each earthquake is stored in a KMZ file that are compressed KML files containing zero or more supporting files such as images. KMZ files are stored in device SD card under Earthquake GeoSurvey folder. The application makes use of the device GPS receiver in order to capture effect's location (longitude and latitude) in WGS84 coordinate system. Camera enables application users to take pictures for an effect and thus, each photo can be tagged with location.

### *Step-by-step guide to documenting earthquake-induced environmental effects*

In this section is presented the procedure that should be followed by users in order to document the environmental effects during a post-earthquake reconnaissance survey.

Initially, a new earthquake file should be created in order to add an effect. In order to achieve this, the user should click on *New Earthquake* Button at the application's home screen (fig. 4.14, left). At the new screen, there is an earthquake form that the user should fill with current earthquake-related data (fig. 4.14, right). To create the earthquake file the user should click at the *Save* Button at the bottom of the screen and a KMZ file will be created and stored in the SD card of the device. The name of the created file is the one that the user entered in the *Code* field.

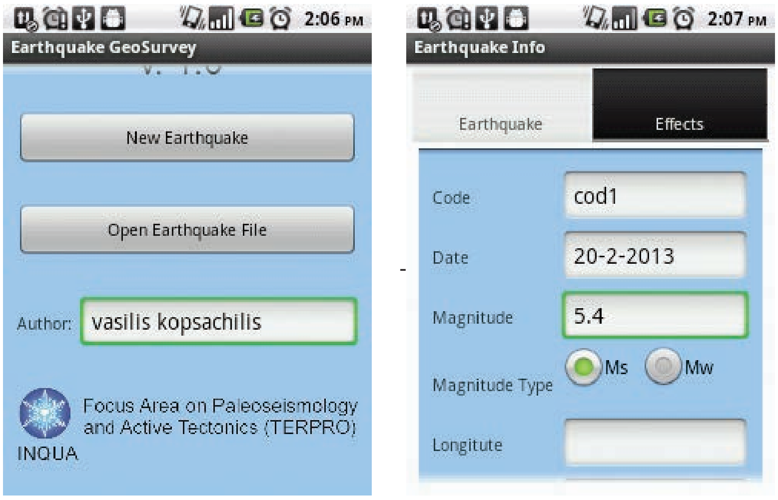


Fig. 4.14. - Home Screen (left) and Earthquake Screen (right).
*Schermata a livello Home (sinistra) e a livello Earthquake (destra).*

Now the user can add an effect to current earthquake by clicking on the Effects Tab at the top of the screen and then by clicking at Add New Effect Button (fig. 4.15, left). We should note that at this time the effect list is still empty for the selected earthquake. Selecting the effect type that will be documented (fig. 4.15, right), the appropriate effect type screen will appear.

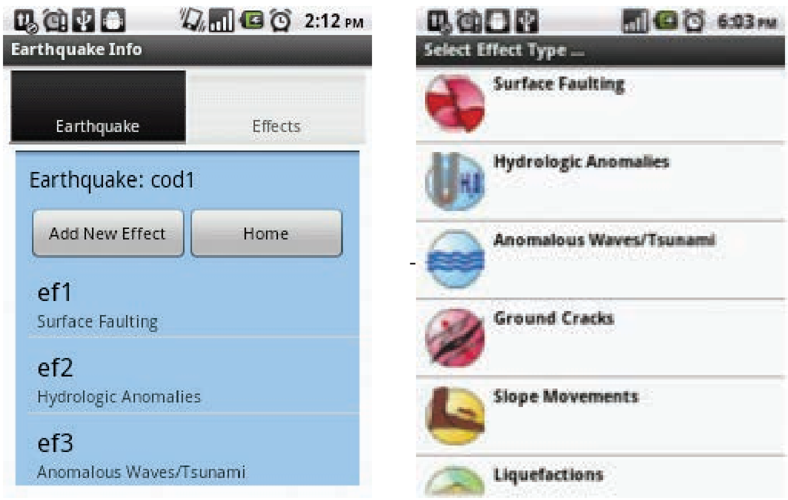


Fig. 4.15 - Effect List Screen (left) and Effect Types Screen (right).
*Schermate relative alla Lista degli effetti (sinistra) e ai Effects Type (destra).*

The relevant Effect Screen contains a form with fields that the user should fill in order to describe the effect while the effect location can be captured by clicking on the *GPS Off* button. This will activate the GPS receiver, and after a few seconds the longitude and latitude of the user location will be captured. User can add a photograph from the effect place by clicking at the *Photo* button. When the user fill the form, can add the effect to the earthquake file by clicking at the *Add Effect* button at the bottom of the screen. He can return to the effect list screen and preview the newly added effect by clicking at the *Effect List* button.

Once the earthquake file is created, it can be used by Google Earth and other GIS applications. In Google Earth, the collected data are plotted with different symbols depending on the type of failure and when the user clicks on an effect an information popup appears containing information about the effect and a picture. In figure 4.16 is shown part of the outcome of the field survey, conducted after the Feb. 3, 2014 Cephalonia earthquake, and particularly the sites where liquefaction phenomena were triggered in the waterfront area of the city of Argostoli.


Fig. 4.16 - Example of Google Earth Visualization.
- *Esempio di visualizzazione mediante Google Earth.*

*Mem. Descr. Carta Geol. D'It.*
XCVII (2015), pp. 153 - 164

# 4.4. - Cataloguing the EEEs induceded by the 1783 5th February Calabrian earthquake: implications for an improved seismic hazard

BLUMETTI A.M. (1), GUERRIERI L. (1), PORFIDO S. (2)

## *Introduction*

A series of strong seismic events occurred in Calabria (Southern Italy) in 1783, triggering a very long seismic sequence lasting about three years.

The first main shock occurred on 5th February (Intensity 11 MCS; Mw about 7; Rovida et al., 2011), causing more than 30,000 casualties and drastically changes in the local landscape. This event was followed by other strong shocks in the night and during the following days. Particularly, on 6th February, a strong earthquake (Intensity 8.5 MCS; Mm 5.8; (Working Group CPTI, 1999) triggered in Scilla, along the cliff of the Monte Paci, a huge rock avalanche (5 $Mm^3$ inland and 3 $Mm^3$ in the off shore zone), generating a disastrous tsunamis (TINTI *et alii* 1996; GRAZIANI *et alii*, 2006). On 7th February another catastrophic event rocked the Mesima Valley (Intensity 10.5 MCS; Mw about 6.7; ROVIDA *et alii*, 2011) followed by another strong event on 28th March, in the Catanzaro area (Io = 11 MCS, Mw about 7; ROVIDA *et alii*, 2011). The epicentres and local macroseismic intensities of three major shocks are located in figure

Environmental Effects (EEEs) caused by these seismic events have been fully documented by contemporary reports (COCCIA, 1783; DE LEONE, 1783; DE DOLOMIEU, 1784; GRIMALDI, 1784; SARCONI, 1784; CARISTINA, 1786; VIVENZIO, 1788; GALANTI, 1792; CARBONE GRIO, 1884) and reviewed by scientific papers in more recent time (GALLI & BOSI, 2002 on primary effects; COTECCHIA *et alii*, 1986 & GALLI, 2000, BOZZANO *et alii*, 2010, PORFIDO *et alii*, 2011, on secondary effects).

In this note, we will focus on the EEEs produced by the first main shock occurred on 5th February. All the effects described in different historical sources and recent papers have been carefully reviewed and catalogued in the EEE Catalogue.

http://www.eeecatalog.sinanet.apat.it/terremoti/index.php

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(1) Geological Survey of Italy, ISPRA, Roma, Italy.
(2) Istituto per l'Ambiente Marino Costiero, CNR, Napoli, Italy.


Fig. 4.17. - Three main shocks of the 1783 seismic sequence in Calabria occurred on 5th February, 7th February and 28th March (source: ROVIDA *et alii*, 2011).
*- Le tre scosse principali della sequenza sismica del 1783 in Calabria, avvenute il 5 e il 7 Febbraio e il 28 Marzo (fonte: ROVIDA et alii, 2011).*

## *Description of primary and secondary EEEs*

Descriptions of EEEs related to the 1783 seismic sequence were reported by scientists and experts mainly sent in the epicentral area by the Bourbon government to survey any effect produced by the earthquake. The most detailed and reliable report focused on the descriptions of EEEs referred to the 5th February event was provided by Sarconi (1784) in the *Istoria,* a "travel diary" of a scientific expedition headed by M. Sarconi (Secretary of the Royal Academy of Sciences and Fine Arts of Naples) sent in Calabria by F. Pignatelli (Bourbon General Vicar for Calabria). This scientific report is accompanied by a large number of draws by the architects Schiantarelli and Stili documenting in many cases the occurrence of EEEs.

Primary EEEs

Among all the EEEs, some of them were described as a set of cracks that were particularly impressive due to their length, continuity, geometry, and orientation. For instance, De Dolomieu (1784) wrote "… *almost along all the length of the chain the deposits resting against the granite… slipped on this steep slope, and descended a little lower. And then a 9–10 miles long rift formed between the sandy and the stiff terrain, and this rift goes continuously from San Giorgio to Santa Cristina following the bottom of the foothill…*" (cfr. other descriptions in Galli & Bosi 2002).

Taking into account all the descriptions, the fracture occurred at the foot of the Aspromonte hillslope can be easily interpreted as a 25 km-long evidence of surface faulting (fig. 4.18).

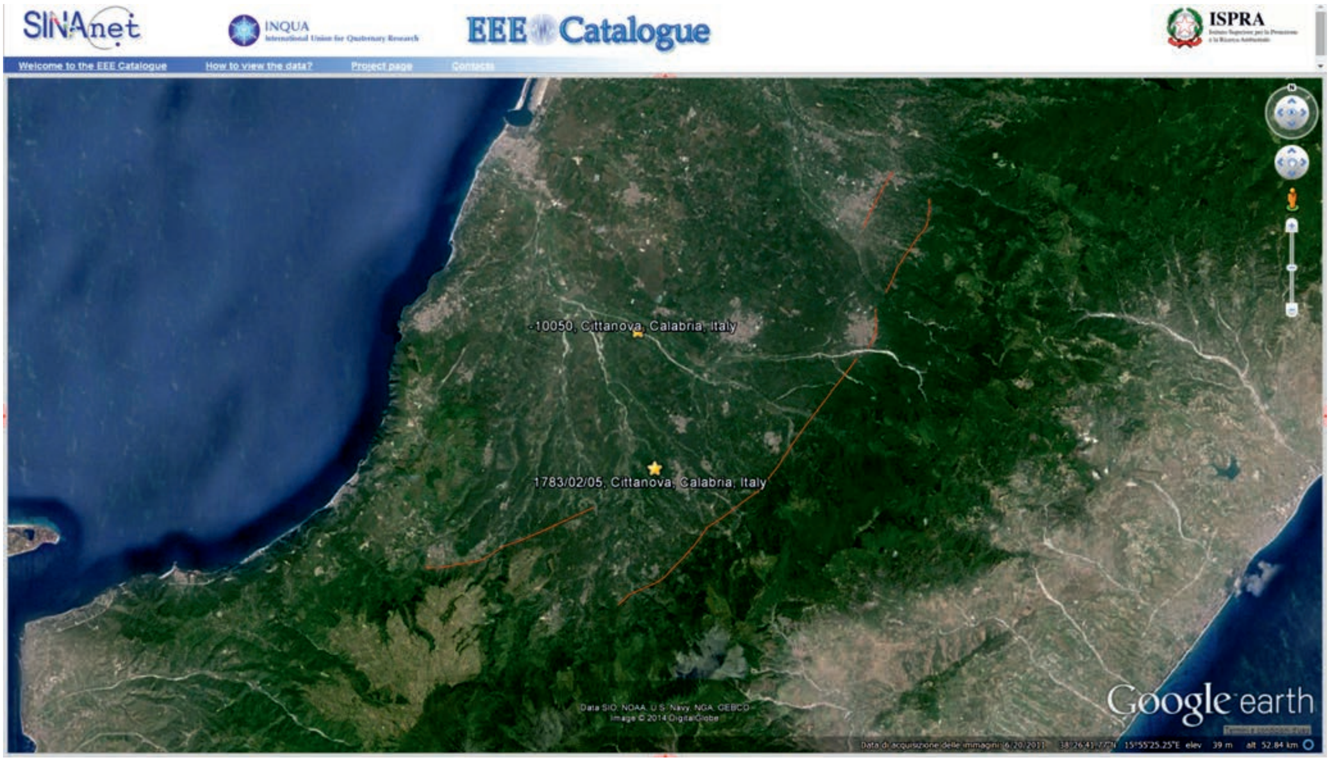


Fig. 4.18. - Screenshot of the EEE Catalogue focused on the 1783 5th February surface faulting pattern (linear and site evidence). Considering all the segments, the total rupture length is about 35 km.
- *Screenshot dell'EEE Catalogue focalizzato sulla fagliazione superficiale del 5 Febbraio 1783 (evidenza lineare e puntuale). Considerati tutti i segmenti riattivati, la lunghezza della rottura totale è pari a 35 km.*

These fractures were firstly interpreted as evidence of surface faulting by Cotecchia et al. (1969, 1986): these Authors interpreted the historical descriptions as evidence of "fault reactivation" and hypothesized that the scarp at the foot of the Aspromonte range was related to the 1783 seismogenetic fault. A detailed map of the geomorphic changes triggered by the earthquake (COTECCHIA *et alii*, 1986) points out the seismogenic structure as a continuous line between Santa Cristina and Cittanova. More recent studies (GALLI & BOSI, 2002), have provided the evidence for the reactivation of other two fault segments (Polistena-Cinque Fondi and S.Eufemia): in this hypothesis, the total rupture length will increase up to 35 km.

Based on the descriptions provided by Sarconi (1784), Galli and Bosi (2002) located a paleoseismic trench in the epicentral area of the 5th February shock near Cittanova. The site was selected using a draw by Schiantarelli showing the Mercante Road affected by surface faulting (fig. 4.19; SARCONI, 1784). The trench was excavated across the fault scarp located on the left side of the picture, exposing displaced alluvial and colluvial deposits (GALLI & BOSI, 2002). Paleoseismic investigations produced more detailed stratigraphic information about previous surface faulting events in the same point.


Fig. 4.19. - Details from an original draw by P. Schiantarelli (a member of the expedition head by M. Sarconi) showing the displacement of the Cittanova plain and of the Mercante Road due to the 5th February earthquake. Two en echelon steps are visible, the lower being measured by two members of the Bourbon expedition.
*- Un dettaglio tratto daun disegno originale di P. Schiantarelli (un membro della spedizione guidata da M. Sarconi) Details from an original draw by P. Schiantarelli (a member of the expedition head by M. Sarconi) mette in evidenza la dislocazione della piana di Cittanova e la Strada Mercante a cause del terremoto del 5 Febrraio. Sono visibili due segmenti en-echelon, di cui quello inferior è stato misurato dalla spedizione borbonica.*

The same Authors excavated another trench along the so-called Cittanova fault, in the old settlement of Santa Cristina d'Aspromonte, at the contact between granites and continental deposits. The surface expression of this fault is characterized by a double scarp, about 0.8 m high totally, that, according to the historical observations, was formed during the 1783 event. Since the old Santa Cristina site is at the tip of the reactivated fault, the height of this scarp should be taken as a minimum for the offset produced by the coseismic surface faulting occurred during the 5th February 1783 earthquake.

Secondary EEEs

The 1783 seismic sequence was accompanied by a huge amount of ground effects induced by the seismic shaking (secondary effects) that caused a "geomorphogenetic crisis" (COTECCHIA *et alii*, 1986): in particular, landslides, liquefaction phenomena and rivers diverted or dammed by landslides.

*Slope movements:* the 5th February 1783 earthquake triggered so many landslides that about the 60% of the epicentral area was affected and about a half of the villages were dragged to the valley by landslides and consequently destroyed. Many of these villages directly affected by landslides (i.e. Terranova Sappo Minulio, Molocchiello, Cosoleto, Oppido Mamertina) were drawn by P. Schiantarelli, one of the architect of the Borbonic expedition, (i.e.: Sarconi, 1784; fig. 4.20).

A lot of descriptions of these effects are available: among them, Vivenzio (1788) about the town of Terranova reported: "*mass of buildings crumbed and mixed with the soil*" and about the Oppido area: "*it was so large the derangement caused by the earthquake of February 5th, that instantaneously in many places the ground sinked, entire hills were translated with horizontal movements and the river beds jumped from the bottom to the top*"

De Dolomieu (1783) about the Molocchiello village wrote: "*It was situated in front of the town of Terranova and at the same elevation, on a small plateau of a mile length and of 200 "passi" large, between the Solì and Marro rivers, which flow at its foot in deep valleys. A part of the village fell down on the right, the other on the left, and it doesn't remain any soil where it was situated but a donkey's back crest so thin, that one cannot walk on it".*

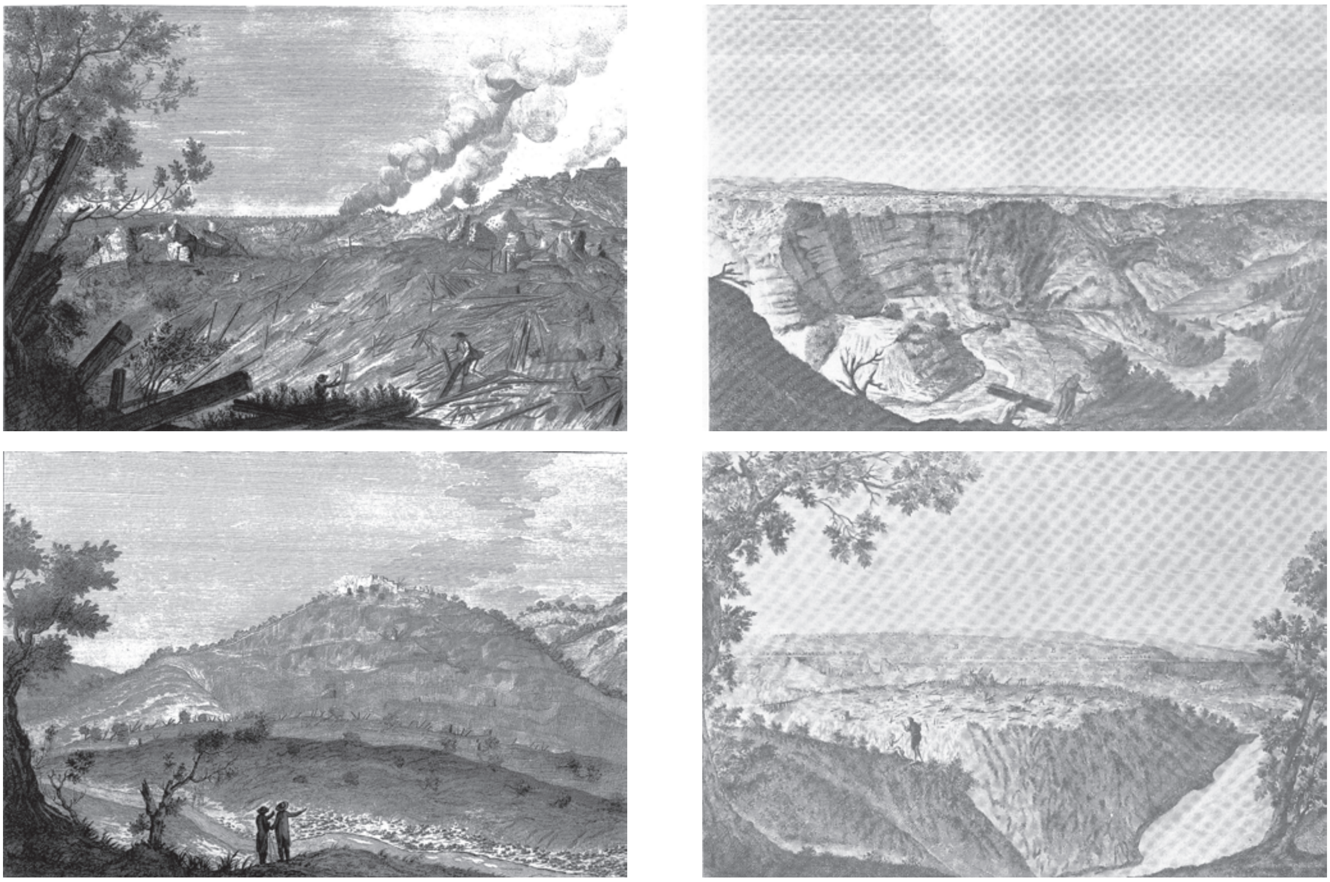

Fig. 4.20. - The original draws by P. Schiantarelli pointing out the coseismic landslides that affected some of the villages destroyed by the 5th February 1783 earthquake. A) Terranova Sappo Minulio; B) Oppido Mamertina; C) Molocchiello; D) Cosoleto. In the foreground the San Bruno lake formed by the damming of the Lindò river.
*- Disegni originali di P. Schiantarelli che mettono in evidenza le frane cosismiche che hanno interessato alcuni villaggi distrutti dal terremoto del 1783. A) Terranova Sappo Minulio; B) Oppido Mamertina; C) Molocchiello; D) Cosoleto. In primo piano il lago di San Bruno formatosi dallo sbarramento lungo il fiume Lindò.*

In figure 4.21 it is shown a screen shot from the EEE catalogue centered in the epicentral area of the 5th February shock, pointing out the areal distribution of slope movements. The relevance of the coseismic landslides is not fully evidenced by this image: in fact, since landslides were very widespread and somewhat coalescent, each point corresponding to a single landslide does not represent the real extension of the phenomenon. Anyway, details about the extent and other characteristics of the slope movements are available as attribute in the EEE catalogue.

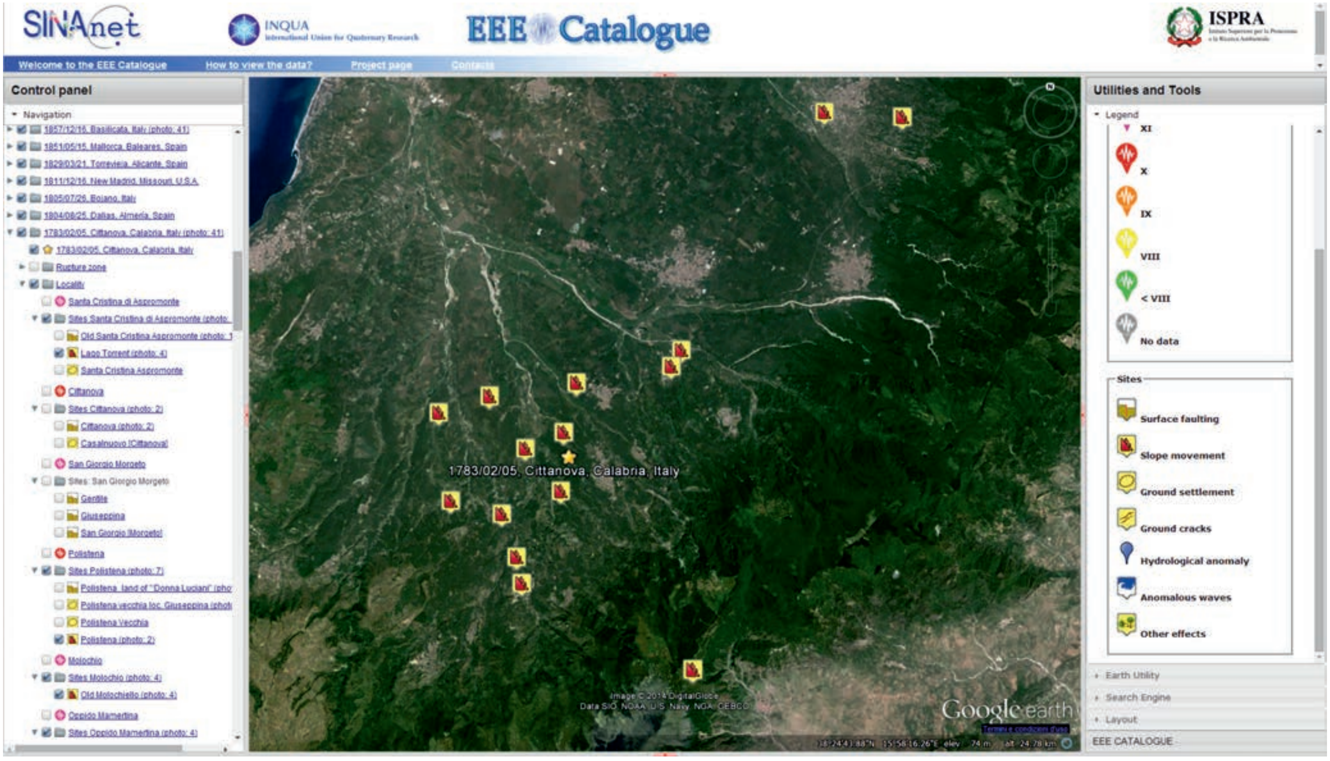


Fig. 4.21. - Screen shot from the EEE catalogue focused on the slope movements induced by the 5th February 1783 Calabria earthquake.
- *Screen shot dall'EEE Catalogue focalizzato sui movimenti di versante indotti dal terremoto del 5 Febbraio 1783 in Calabria.*

A more realistic scenario is provided by the original map provided by Vivenzio (1788) showing the 215 lakes formed by the coseismic landslides that dammed the river courses (fig. 4.22)

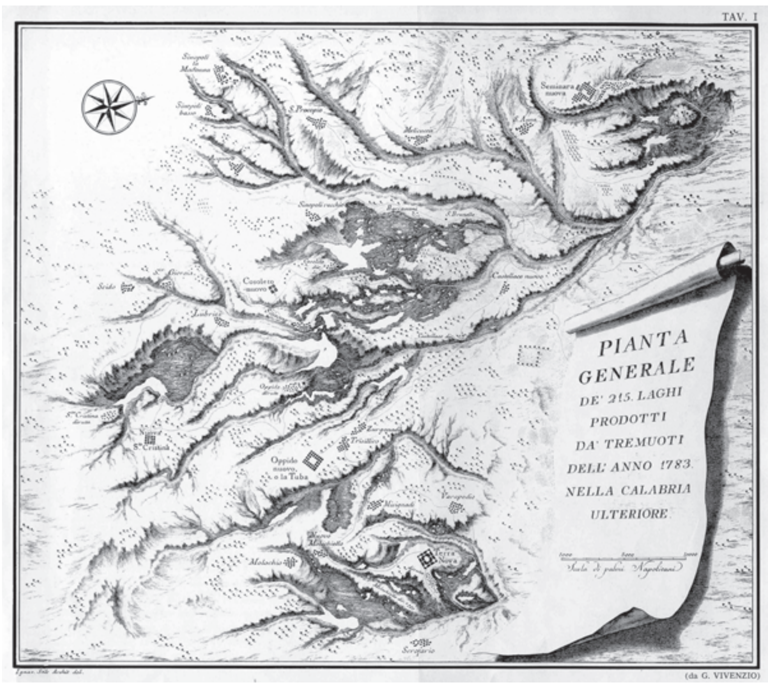


Fig. 4.22. - Location map of 215 lakes formed due to landslides, during the February 5th 1783 earthquake (after Vivenzio, 1788).
- *Mappa dei 215 laghi formatisi a seguito di fenomeni franosi, durante il terremoto del 5 Febbraio 1783 (Vivenzio, 1788).*

Cotecchia *et alii* (1969; 1986) dedicated a monography to “the geomorphogenetic crisis” triggered by the 1783 earthquakes. These Authors studied the Sarconi (1784) report together with other scientific reports (Grimaldi, 1784; Vivenzio, 1788) and carefully described and mapped many of the coseismic landslides that are still preserved in the landscape, after 200 years (fig. 4.23).

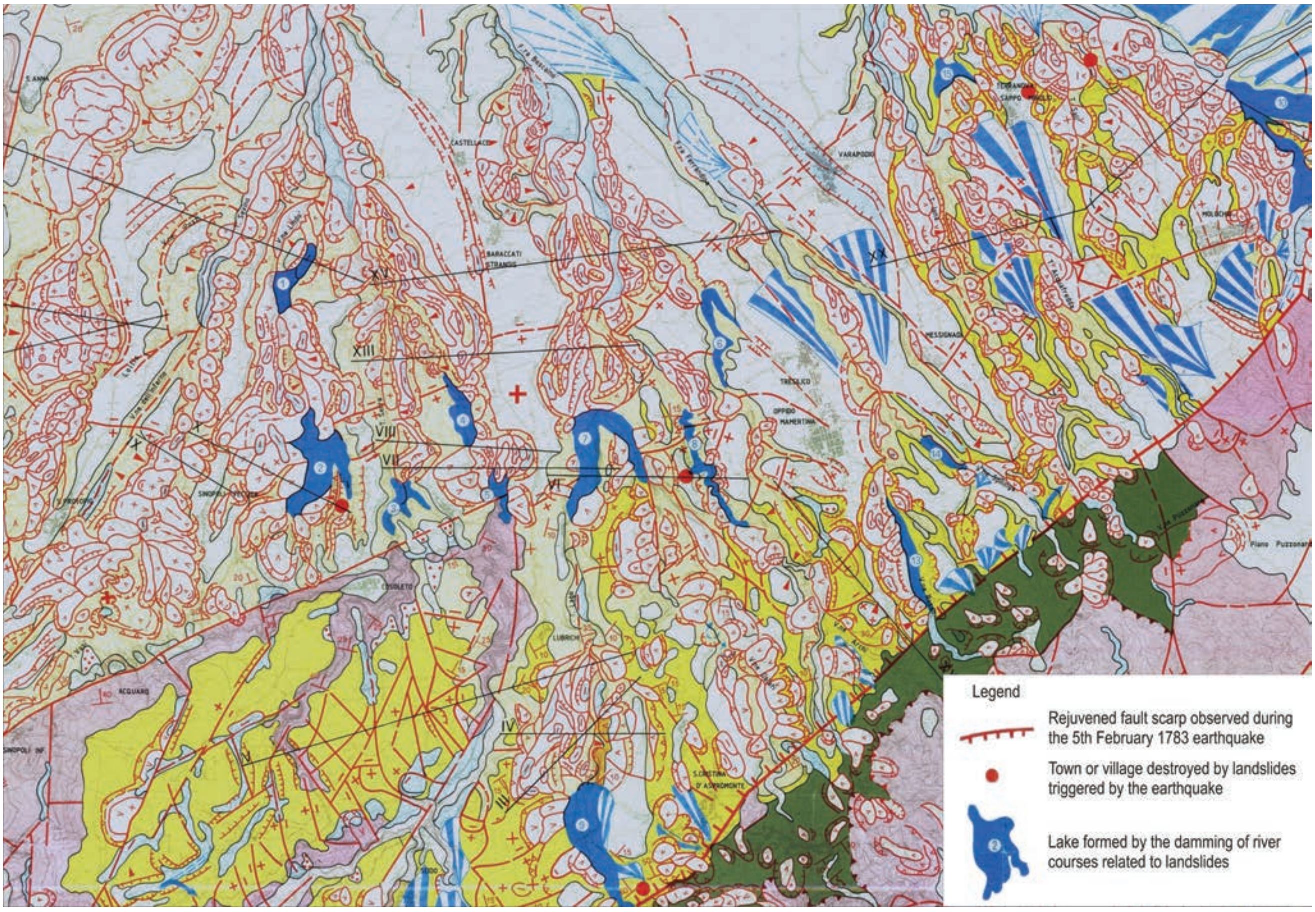


Fig. 4.23. - Details from the map of the geomorphic changes triggered by the 5th February earthquake (after Cotecchia *et alii*, 1986).
- *Stralcio della mappa delle modifiche geomorfologiche indotte dal terremoto del 5 Febbraio 1783 (Cotecchia et alii, 1986).*

Cotecchia *et alii*, (1986) classified most of the slides as earth-blocks, with translational movement along horizontal or gently sloping surfaces situated only a few meters below the valley bottom. They called these features “seismites” using the term normally used to indicate the characteristic deformation of sediments induced by the seismic shaking, to point out their relevance.

*Liquefaction phenomena:* In the epicentral area of the 5th February shock liquefaction phenomena were also widespread and impressive, being also very often strictly related to the slope movements. For example a DGPV that involved the whole area among Polistena, Cinquefondi and San Giorgio Morgeto, was due to the occurrence of liquefaction in depth within the sandy strata (Guerricchio *et alii*, 2008).

Also liquefaction phenomena were fully surveyed and drawn (fig. 4.24 Sarconi, 1784) and therefore collected into the EEE Catalogue (fig. 4.25): they were described as eruptions of groundwater with sand which reached a height of several feet with formation of “craters” (De Dolomie, 1784) that occurred mostly in the epicentral area, but also very far away from it (Galli, 2000). Also the extensive ground lowering that sometime involved important building was reported (cfr. fig. 4.24, right; Sarconi, 1784), obviously due to liquefaction occurrence.

Fig. 4.24. - Liquefaction phenomena occurred: (left) in the Rosarno plain; (right) at Terranova town (S. Cristina well in the courtyard of the Celestini Frier 's Monastery). After Sarconi (1784).

- *Fenomeni di liquefazioni avvenuti nella piana di Rosarno (a sinistra) e nella città di Terranova (pozzo di S.Cristina nella campagna del monastero dei Celestini). Da Sarconi (1784).*

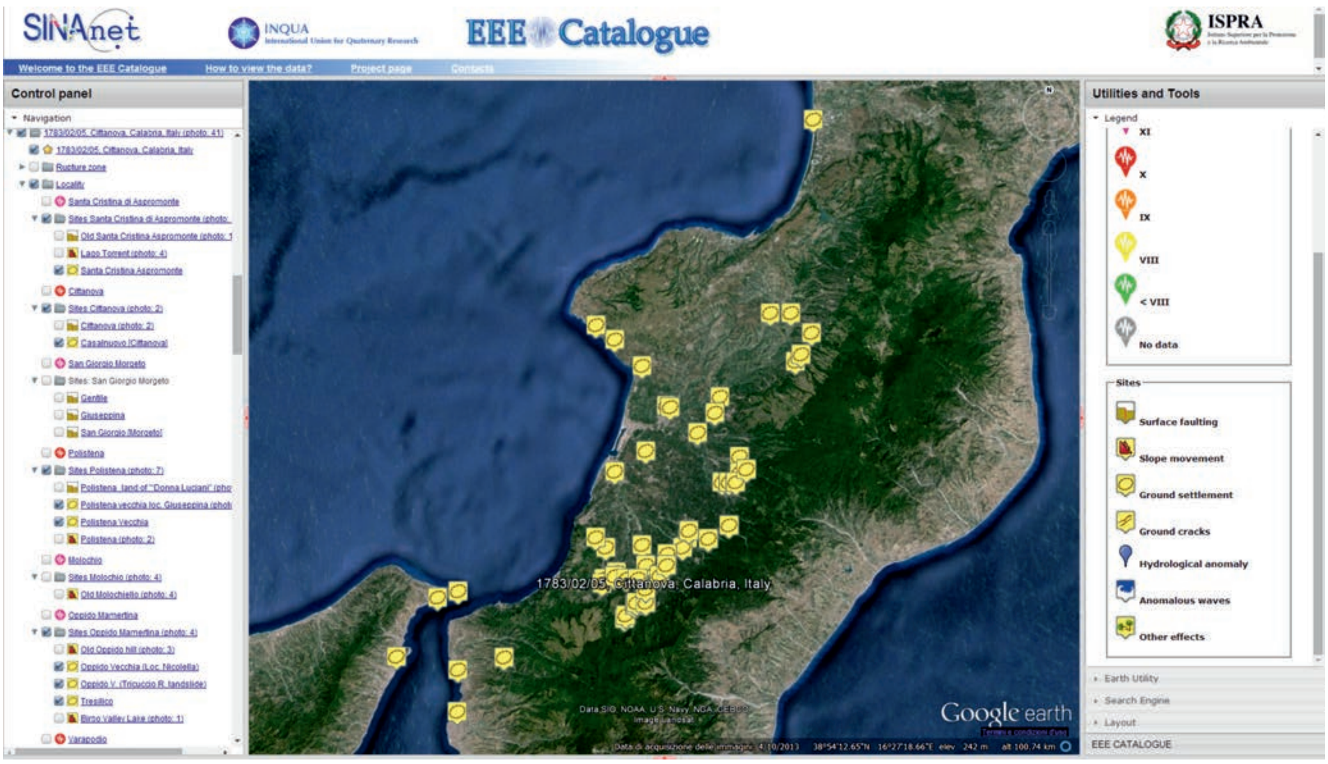


Fig. 4.25. - Screen shot from the EEE catalogue focused on the liquefaction phenomena induced by the 5th February 1783 Calabria earthquake.

- *Screen shot dall'EEE Catalogue focalizzato sui fenomeni di liquefazione indotti dal terremoto della Calabria del 5 Febbraio 1783.*

## *Evaluation of ESI epicentral and local intensity values*

Based on the characteristics and size of Earthquake Environmental Effects stored into the EEE Catalogue, it has been possible to evaluate ESI epicentral and local intensities.
The extent of normal surface faulting (rupture length about 35 km; maximum displacements at least in the order of 0.8 m) and the total area affected by secondary effects (about 3,500 km$^2$), clearly indicate that the ESI epicentral intensity is equal to X.

The evaluation of 38 ESI local intensity values (tab. 4.1, fig. 4.26), ranging from VII to XI intensity degree, has been done taking into account all the effects occurred in each individual locality.

In four localities (Santa Cristina di Aspromonte, San Giorgio Morgeto, Molochio and Oppido Mamertina), ESI local intensity values have reached intensity degree = XI, higher than epicentral intensity. This is most likely due to specific characteristics of the local territory and to a very high density of secondary effects (e.g. landslides and liquefactions) that caused catastrophic changes in the local landscape.

Comparing the distributions of ESI and MCS local intensity values, it is possible to point out:

- a good correspondence (< one degree) for 37% of the localities and a difference never larger than two degrees. Only 13 % of the localities show differences larger than one intensity degree;
- in case of difference, ESI intensity values appear to be generally lower than MCS ones (21 cases). Instead, only in three cases ESI intensity values (San Giorgio Morgeto, Soriano Calabro and San Lucido) are larger than MCS values.

Considering that ESI 2007 intensity scale has been calibrated on the MM and MSK intensity scales, while MCS intensity scale provides values larger than the other scales (typically about one degree higher) it is possible to outline a substantial consistency between the ESI and MCS scenarios. In fact, most of the local seismic amplifications due to site effects are recorded in larger damages to buildings but also in greater effects on natural environment. Nevertheless, it has to be noted that these latter effects could be surveyed also where effects on buildings are absent, such as in sparsely populated areas. This is not the case of most of the localities hit by the 1783 event, but could explain larger ESI intensity values in three localities, confirming its added value.

## *Conclusions*

The sequence of strong earthquakes that hit the Calabria region in 1783 caused huge damage in terms of dead toll (more than 30,000) and extensive destruction (MCS $I_0$ = 11) but also produced dramatic changes in the landscape induced by the occurrence of a huge amount of EEEs.

In particular, landslides and liquefactions associated to the 5$^{th}$ February seismic shock affected a remarkable portion of the territory (about 60%), and caused the formation of more than two hundreds of temporary lakes. Thanks to several contemporary survey reports, the available documentation about such EEEs is very detailed and complete, even if it is an historical earthquake occurred more than two hundreds years ago.

For this reason, it has been very important to collect this information into the EEE Catalogue: in fact, beyond the obvious advantage of making available such information on a public source in a standard way, this effort has also allowed to better use the collected data for an improved seismic hazard assessment. In fact, the huge amount of observations related to the EEEs induced by this historical event, has allowed to compare it with modern events in terms of other EEEs scenarios available in the EEE Catalogue. Moreover, the evaluation of epicentral and local intensities based on EEEs through the ESI 2007 intensity scale, has provided an independent and valuable assessment of seismic hazard of the Calabria region, that conveniently integrates the current SHA which is based only on the effects of historical earthquakes on buildings and infrastructures.

Tab. 4.1. - *MCS and ESI local intensity values for 38 localities affected by EEEs associated to the 5th February 1783 Calabria earthquake.*
- Valori di intensità locali second le scale MCS ed ESI per 38 località interessate da EEEs associati al terremoto della Calabria del 5 Febbraio 1783.

| | MCS Local intensity | ESI Local Intensity |
|---|---|---|
| Santa Cristina di Aspromonte | 11 | 11 |
| San Giorgio Morgeto | 10 | 11 |
| Molochio | 11 | 11 |
| Oppido Mamertina | 11 | 11 |
| Cittanova | 11 | 10 |
| Polistena | 10.5 | 10 |
| Varapodio | 11 | 10 |
| Terranova Sappo Minulio | 11 | 10 |
| Cosoleto Vecchio | 11 | 10 |
| Castellace | 11 | 10 |
| Cinquefrondi | 10.5 | 10 |
| Lubrichi | 11 | 10 |
| Seminara [Vecchia] | 10 | 10 |
| Sitizano | 11 | 10 |
| Delianuova | 11 | 10 |
| Platì | 9 | 9 |
| Soriano Calabro | 7 | 9 |
| Rosarno | 10 | 9 |
| San Fili | 10 | 9 |
| Laureana di Borrello | 9.5 | 9 |
| Maropati | 10 | 9 |
| San Procopio | 10.5 | 9 |
| Santa Anna | 10 | 9 |
| Radicena | 11 | 9 |
| Scrofario | 11 | 9 |
| Scido | 11 | 9 |
| Gioia Tauro | 10 | 9 |
| Drosi | 10 | 8 |
| Nicotera | 9 | 8 |
| Messina | 8 | 8 |
| Gallico | 9 | 8 |
| Reggio di Calabria | 8.5 | 8 |
| Calanna | 9 | 8 |
| Joppolo | 8 | 8 |
| Coccorino | 8 | 8 |
| San Lucido | 6 | 7 |
| Torre Faro | 8 | 7 |
| Ganzirri | 7.5 | 7 |
| Maida | 6.5 | 7 |

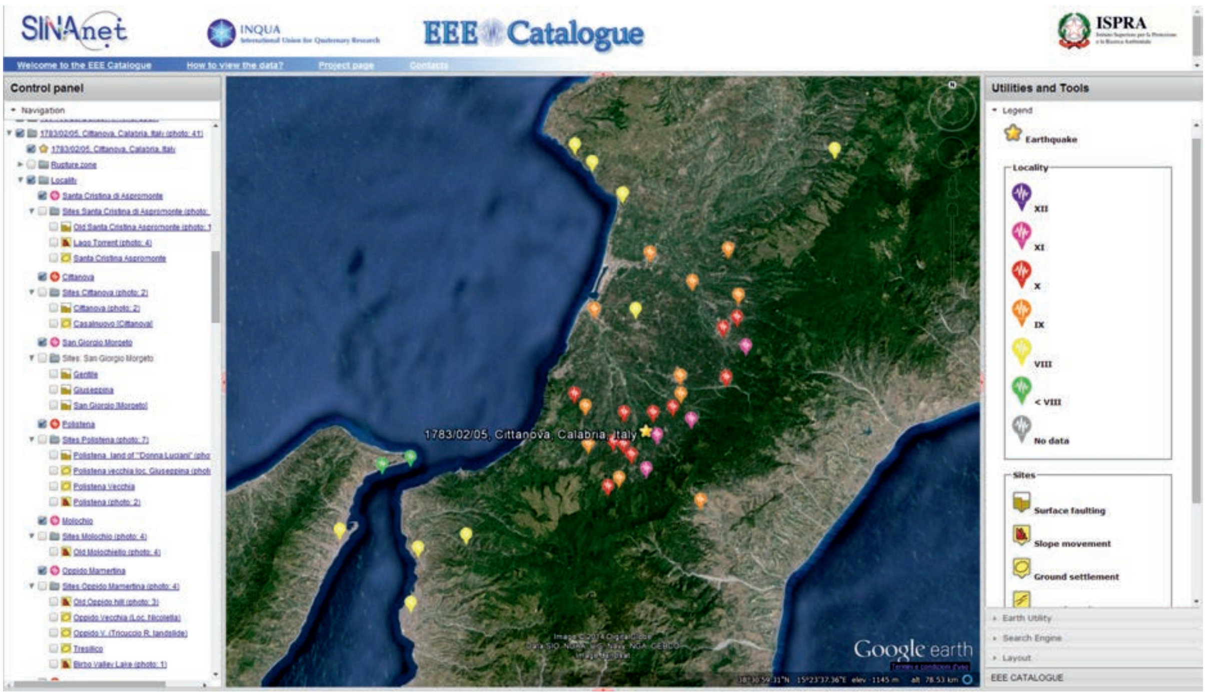


Fig. 4.26. - Screen shot from the EEE catalogue focused on the localities with ESI local intensity value associated to the 5th February 1783 Calabria earthquake.
- *Screen shot dall'EEE Catalogue focalizzato sulle località con intensità ESI riferite al terremoto del 5 Febbraio 1783 in Calabria.*

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# 5. - References related to the ESI 2007 intensity scale, the EEE Catalogue and related INQUA projects (2007-2014)

After the publication of the ESI intensity scale in 2007, numerous scientific papers and reports have been focused on Earthquake Environmental Effects data collection from recent, historical and paleo earthquakes, and seismic intensity evaluations based on EEE data through the ESI 2007 scale. These works have been mostly but not exclusively conducted in the frame of the INQUA TERPRO SubCommission on Paleoseismicity activities and projects.

Below is reported a list of references published in the period 2007-2014, of:

- papers published on peer reviewed journals or in the proceedings of international scientific conferences;
- reports focused on the field surveys of EEEs induced by recent earthquakes;
- extended abstracst mostly submitted in the proceedings of workshops sponsored by INQUA TERPRO SubCommission on Paleoseismicity or other similar symposia.

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## Extended abstracts presented to INQUA events (2008 – 2014)

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A. Shapira A. - *On the rate of seismic activity along the Dead Sea Transform.*

Baer G. - *Recent crustal movements along the Dead Sea fault.*

Michetti A.M. - *The ESI 2007 scale and new catalogue of earthquake environmental effects.*

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King G. - *Slip Partitioning by Elastoplastic Propagation of Oblique Slip at Depth.*

Okumura K. - *Segmentation model of a long fault zone based on the size and temporal stability of the segment boundaries.*

Wesnousky S. - *Neotectonics, geodesy, and seismic hazard in the northern Walker Lane.*

Ota Y. - *Active Touhuangping Fault and its tectonic significance in the northwestern Taiwan.*

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