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THE INQUA SCALE

AN INNOVATIVE APPROACH FOR ASSESSING EARTHQUAKE INTENSITIES BASED ON SEISMICALLY-INDUCED GROUND EFFECTS IN NATURAL ENVIRONMENT

SPECIAL PAPER

Working Group under the INQUA Subcommission on Paleoseismicity

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- Fault scarp of Borah Peak 28 October 1983 earthquake (M_s 7.3). Photo E. Vittori.
- Liquefaction during the 15 April 1979 Montenegro earthquake (M_w 6.9). Photo E. Iaccarino.
- Rock slide at Braulins during the 6 May 1976 Friuli earthquake (M_s 6.5). In Briseghella et al., 1976.

Background photograph:
Fault scarp of the 7 December 1988 Spitak (Armenia) earthquake (M_s 6.8). Photo courtesy of A. Kharakanian

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Index

Preface

Nearly two years ago the former Italian Agency for Environment Protection (ANPA) and the National Geological and Hydrographic-Mareographic Surveys merged to give birth to the Italian Agency for Environment Protection and for Technical Services (APAT). Among its many fields of activity, this agency, supervised by the Ministry of the Environment, is a national reference institution in the evaluation of the effects on the environment of natural and technological hazards. The law nr. 401/2001 has formalized such a role recognizing APAT as a partner of the Department of Civil Protection.

In particular, the environmental agency has been involved for many years in the field of seismic hazard evaluation for siting purposes, through its pioneering studies on active tectonics, palaeoseismology and macroseismicity and its intervention after the most relevant earthquakes in Italy of the last decades, interest inherited from its former chief role of nuclear regulatory body of Italy.

Therefore, APAT has eagerly welcomed the joint publication with INQUA of this monograph, which summarizes the state-of-the-art in a very promising field of earthquake hazard analysis: the earthquake intensity assessment based solely on its environmental effects, therefore not influenced by the presence and quality of human artefacts.

Such study, carried out by a group of researchers from many countries, with a significant contribution of Italian scientists from APAT and other institutions, leaves its preparatory stage with this volume distributed at the 2004 International Geological congress in Florence, where an INQUA specialist meeting is devoted to this subject. In the next future, field application of the newly devised macroseismic scale will allow its verification and refinement, making available a new practical tool in our effort toward a more comprehensive characterization of seismicity, which is one of the most ruinous natural hazards in many regions of the world.

The General Director

Giorgio Cesari

Presentation

The INQUA Scale, the new macroseismic intensity scale only based on earthquake environmental effects (EEE) that is described in this Report, is a multi-author undertaking, developed within the INQUA Subcommission on Paleoseismicity and under a close collaboration with APAT. The Scale has been presented during the XVI INQUA Congress, held in Reno, NV, USA, on July 23 to 30, 2003. Following the scientific discussion in this meeting, the Scale has been formally adopted for a trial time-window of 4 years (2003-2007), in order to present a new updated version at the next 2007 INQUA Congress in Cairn, Australia.

The INQUA Scale, relying solely on modifications to the geological medium, has the potential to become a tool of prime importance for understanding the strength of seismic events, and therefore for mitigating the related environmental risks. Of course, such an intensity scale is intended to integrate the existing scales, not to replace them.
In the practice of intensity assessment in the last 40 years or so very little advantage has been taken by the use of coseismic ground effects. The INQUA scale approach, instead, can encourage greater objectivity in the process of seismic intensity assessment through independence from the variable nature of man and his works, both for earthquakes of the historical and pre-historical periods and for those of today.
Here I resume the need and rationale for studying/creating a new scale, and for why this is in the domain of Quaternarists.
The intensity parameter is used in many parts of the world for seismic hazard analysis, and is destined to remain an important one in seismology, and earthquake geology and engineering. This is true for several reasons:

- Intensity studies enable the macroseismic field of historical and contemporary earthquakes to be reconstructed and, through this reconstruction, make it often possible to identify the seismogenic source.
- The isoseismal map of an earthquake makes possible the comparison between the attenuation derived using magnitude-distance relationships and the attenuation derived from the macroseismic field.
- The intensity values of an earthquake at various localities represent the combined effects of source-path and site conditions and could be very important in some cases from an engineering point of view.
- Original intensity scales are built on the observed consistency between severity (degree and extent) of ground effects and the local physical environment, which is also at the base of the concept of seismic landscape. In paleoseismology, when geologists assess the magnitude of past earthquakes, a single category of paleoseismic evidence (such as fault surface displacement, size of liquefaction features, and uplifted shorelines) is generally used. However, it could be helpful to check the assessed magnitude against other phenomena (mainly on the ground, in the epicentral area: for instance, quality and quantity of landslides, changes in topography) that are described in the intensity scales at the intensity degree coherent with the assessed magnitude and focal depth.
- Most important, this parameter allows the comparison among recent earthquakes and historical ones, based on the effects described in the intensity scale. In using earthquake

ground effects, this is particularly relevant for the highest degrees of the scale. In other words, the effects are compared rather than the calculated magnitudes of the earthquakes.

- It is proven that many natural effects occur only in the epicentral area (near field), and that they appear and start to become relevant at well-defined intensity levels. This means that a proper estimation of the intensity of an earthquake should take these effects into account.
- Experience from earthquake studies in the recent past clearly show that if the scales are applied essentially using only effects on man and the manmade environment, intensity will come to reflect mainly the economic development of the area that experienced the earthquake instead of its "strength".
- It is also our belief that by ignoring ground effects, it will not be possible to assess intensity accurately in sparsely populated areas and/or areas inhabited by people with different modes of existence, such as nomads.
- Furthermore the main problems arise for the highest degrees - XI and XII - where ground effects are the only ones that permit a reliable estimation of earthquake size. All the scales, in fact, show that in this range of intensity ground effects predominate.

This is obviously a task for Quaternarists. Intensity is a parameter used by seismologist, engineers and geologists. Establishing reliable relations between intensity and effects on the ground, however, is mainly a domain where Quaternary geology is involved. For instance, no assessment can be made in this line without a solid background on the local Quaternary stratigraphy and geochronology. Earthquake effects (such as liquefactions, sinkholes, many landslides and fault scarps) are mostly controlled by surficial deposits and the near surface stratigraphic setting, therefore the Quaternary evolution of the area must be known in some detail. Earthquake effects are present in all the natural environments, and specific experience in the various Quaternary processes (for instance, costal processes for tsunami effects) is of critical importance for a proper understanding and interpretation of their origin and evolution.
The intensity thus identified must then be connected, as for historical earthquakes, with a chosen source parameter—magnitude or seismic moment.
Finally, increasing evidence for the need of a new intensity scale based on ground effects only comes from the last strong earthquakes recently occurred in Greece and Iran. The observations from the Aug. 14, 2003, Mw6.2, Lefkada, and the Dec. 26, 2003, Mw6.5, Bam, earthquakes clearly show that for crustal events in this range of magnitude a macroseismic survey that does not include the ground effects can give a misleading picture of the earthquake size, and in particular a picture that is very difficult to be compared with the historical record of seismicity.

Director of the Department of
Land Resources and Soil Protection
Leonello Serva

Abstract

The debate originated within the Workshop of the Subcommission on Paleoseismicity held during the XV INQUA Congress in Durban, August 1999, emphasized the importance of developing a multi-proxy empirical database on earthquake ground effects that can be used by, and incorporated into, seismic-hazard assessment practices. The Subcommission selected this task as the primary goal for the past inter-congress period. An interdisciplinary Working Group (WG) was established, including geologists, seismologists and engineers, in order to formalize the collected data into a new scale of macroseismic intensity based only on ground effects: the proposed INQUA scale.

This paper illustrates the results of the research conducted by the WG, introduces the proposed INQUA scale, and discusses major issues related to this innovative approach to the intensity assessment. The INQUA scale first draft is due to Leonello Serva, based on the compilation and comparison of the three most commonly used intensity scales, i.e., the Mercalli-Cancani-Sieberg (MCS), Medvedev-Sponhouer-Karnik (MSK) and Mercalli Modified (MM). Eutizio Vittori, Eliana Esposito, Sabina Porfido and Alessandro M. Michetti produced a revised version, after (a) integration with the revised MM scale of Dengler and McPherson (1993) and (b) checking the scale against the description of coseismic ground effects and intensity assessments for several tens of historical and instrumental earthquakes in the world. This version of the INQUA scale, presented during the XVI INQUA Congress in Reno, July 23-30, 2003, is a joint contribution of the WG including new data, editing, comments and scientific discussion from Bagher and Jody Mohammadioun, Eugene Roghozin, Ruben Tatevossian, Aybars Gürpinar, Franck Audemard, Shmulik Marco, Jim McCalpin, Nils-Axel Mörner, and Valerio Comerci. At this stage, the newly revised MM scale for New Zealand (Hancox, Perrin and Dellow, 2002), kindly provided by Graeme Hancox, has been also taken into account.

The outstanding progress of paleoseismological and Quaternary geology research in the past decades makes available an entirely new knowledge for understanding the response of the physical environment to seismicity, thereby providing the basis for the proposed INQUA intensity scale. The INQUA scale allows to define the epicentral intensity starting from the VI – VII level, with increasing accuracy going towards the highest levels. In the intention of the WG, the INQUA scale should not be used alone, but in combination with the existing scales. In the intensity range up to IX – X the scale allows a comparison between environmental effects and damage indicators, emphasizing the role of primary tectonic effects, which are independent from the local economy and cultural setting. In the intensity range X to XII, the INQUA scale is arguably the only suitable tool for assessing the epicentral intensity. In summary, we regard the INQUA scale as an unreplaceable addition to all the existing scales up to the IX – X level, while it represent the substance of the epicentral intensity assessment for the highest degrees.

THE INQUA SCALE: AN INNOVATIVE APPROACH FOR ASSESSING EARTHQUAKE INTENSITIES BASED ON SEISMICALLY-INDUCED GROUND EFFECTS IN NATURAL ENVIRONMENT

Introduction

Exactly what is a major earthquake? And what type of tool can be used to effectively measure the size of such a catastrophic event? Though long addressed, this problem has yet to receive a really definitive answer despite the considerable effort expended. The effects produced by earthquakes at the surface have notably come under close scrutiny, recognizing the fact that they actually result from the cumulated effects of the source (vibrations generated during slip, finite deformations), of the propagation of seismic waves, and, lastly, of local site effects. Well before the introduction, in 1935 by Charles Richter, of the notion of "magnitude" based on measurements made on instrumentally-recorded motion, certain erudite seismologists (in the persons of Mercalli, Cancani, and Sieberg, among others), in the early years of the last century, devised the notion of the "intensity" of an earthquake at a given location, in the absence of any seismometer (e.g., Sieberg, 1930; Wood and Neumann, 1931). Here, it is indeed man himself, and the environment he has built for himself, that stand in lieu of seismic sensor: thus the manner in which earthquake vibrations affect human beings and objects, as well as damage incurred by man-made structures, are the main criteria upon which the scales of so-called "macroseismic" intensity repose. But, and "there's the rub," the drawback to these measurements is that they integrate, analogous to the response of a seismograph, the responses of the human apparatus, and the responses of buildings, both difficult to gauge, or "calibrate," precisely.

Might it then be possible to assess the size of earthquakes at their source on the sole basis of natural effects, thereby disposing of intermediaries (bearing in mind that human judgments and the behavior of his built environment are strongly influenced by socio-cultural factors that effectively resist all attempts to adequately codifying them in the intensity scales)? The need for a different approach to constructing such scales is hence clearly delineated, if for no other reason than that it is essential for us to be capable of obtaining a reliable measurement of the size of earthquakes — not only those known to have occurred during historical times, prior to the advent of the instrumental era, but also, and perhaps more importantly yet, those that took place before history was written, or even before the regions concerned knew human occupation. This new intensity scale accordingly aims at evaluating earthquake size from the sole evidence inscribed in the environment itself (the Earth herself, recounting her past) and more particularly in the epicentral zone.

The debate originated within the Workshop of the Subcommission on Paleoseismicity held during the XV INQUA Congress in Durban, South Africa, in August 1999, led to the recognition that developing a multi-proxy empirical database on earthquake ground effects that can be used by, and incorporated into, seismic-hazard assessment practices represents one important research challenge for earth scientists and engineers. Therefore, the Subcommission selected this task as the primary goal for the past inter-congress period 1999-2003. In particular, an interdisciplinary Working Group has been established comprised of geologists, seismologists and engineers, in order to formalize the collected data into a new scale of intensity based solely on ground effects, which in the following will be referred to as the INQUA scale. This paper illustrates the results of the work done by the Working Group, introduces the INQUA scale, and discusses the major issues relating to this innovative approach to the intensity assessment.

There is one very important aspect in introducing a new intensity scale into the practice. A great deal of work in seismic hazard assessment is accomplished in the world, and intensity is a basic parameter in this. Any "new word" in this research field must not result in dramatic changes. Intensity VIII, for instance, has to mean more or less the same "strength" of the earthquake, regardless of which macroseismic phenomena (anthropic or geological) it is assessed from. Obviously the proposed INQUA intensity scale based on ground effects is not intended to replace the existing scales. We are simply affording a means to factor in the modifications induced by the earthquake on the physical environment, and then to compare them with the effects taken into account by other scales. There, indeed, the combined observations of widely varied effects is most likely to yield a more representative estimate of intensity—which in turn, using modern events as test cases, can then be collated with such instrumental measurements as magnitude and seismic moment.

Intensity - Why today?

The intensity parameter is used in many parts of the world for seismic hazard analysis, and is destined to remain an important one in seismology, and earthquake geology and engineering. This is true for several reasons:

- Intensity studies enable the macroseismic field of historical and contemporary earthquakes to be reconstructed and, through this reconstruction, make it often possible to identify the seismogenic source. Figures 1 and 2 illustrate this point, by comparing the isoseismals from historical and contemporary earthquakes in the Southern Apennines of Italy.
- The isoseismal map of an earthquake makes possible the comparison between the attenuation derived using magnitude-distance relationships and the attenuation derived from the macroseismic field.
- The intensity values of an earthquake at various localities represent the combined effects of source-path and site conditions and could be very important in some cases from an engineering point of view.
- Original intensity scales are built on the observed consistency between severity (degree and extent) of ground effects and the local physical environment, which is also at the base of the concept of seismic landscape (Serva *et al.*, 1997; Michetti and Hancock, 1997; Serva *et al.*, 2002; see Figure 3). In paleoseismology, when geologists assess the magnitude of past earthquakes, a single category of paleoseismic evidence (such as fault surface displacement, size of liquefaction features, and uplifted shorelines) is generally used. However, it could be helpful to check the assessed magnitude against other phenomena (mainly on the ground, in the epicentral area: for instance, quality and quantity of landslides, changes in topography) that are described in the intensity scales at the intensity degree coherent with the assessed magnitude and focal depth.
- Most important, this parameter allows the comparison among recent earthquakes and historical ones, based on the effects described in the intensity scale. In using earthquake ground effects, this is particularly relevant for the highest degrees of the scale. In other words, the effects are compared rather than the calculated magnitudes of the earthquakes.

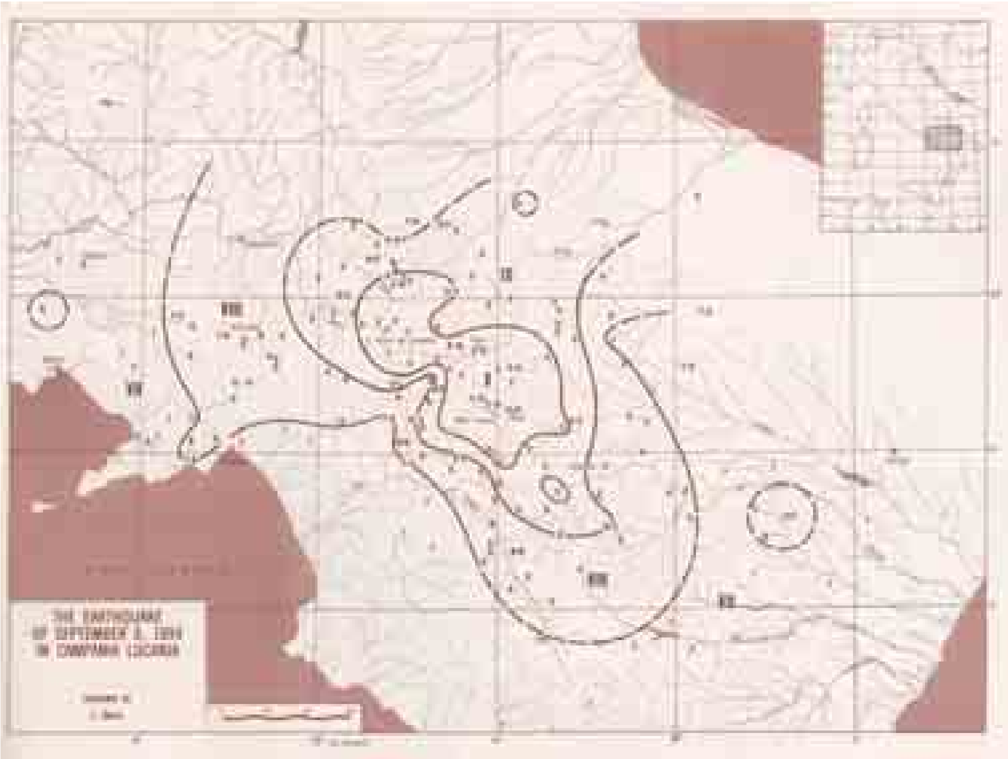

Figure 1: Isoseismal map for the 1694 Irpinia earthquake. After Postpischl, 1985a.

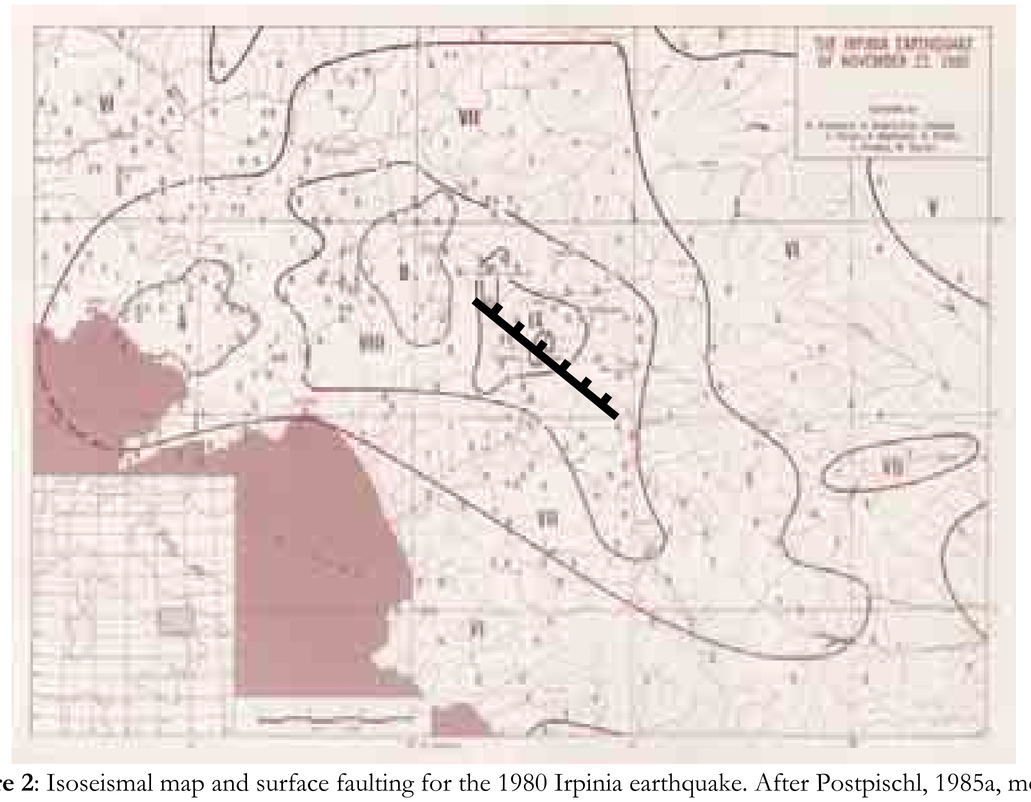

Figure 2: Isoseismal map and surface faulting for the 1980 Irpinia earthquake. After Postpischl, 1985a, modified.

The shortcomings of earlier scales — Why Intensity should be evaluated using ground effects

Earthquakes have often been described in historical chronicles, with more or less precise details, depending on the culture of the time or place, or even because of specific practical interests (e.g., Postpischl, 1985a, Ambraseys *et al.*, 1994; Boschi *et al.*, 1995; 1997; 2000). Countries with a rich historical heritage therefore have available a long record of earthquakes whose size can only be evaluated on the basis of their effects on man-made structures and in the environment, as reported in these chronicles. For this reason, specific scales (macroseismic scales) have been developed defining degrees of intensity expressed in Roman numerals that generally range between I and XII. In the original scales, intensity degrees were based essentially on a hierarchical classification of effects. In a general way, the diagnostic effects for the lower degrees are essentially those on people and animals, for the intermediate degrees those on objects and buildings, for the highest degrees, when the sensors related to the human environment are obviously useless because the earthquake is so strong that everything has been destroyed, those on the natural surroundings. The effects on the ground reported in the scales include primary, tectonic features such as surface faulting, and secondary, mostly shaking-induced phenomena, such as ground cracks, slope instabilities, and liquefaction (Table 1; Serva, 1994; Esposito *et al.*, 1997). These effects are, in fact, often cited in historical and contemporary reports and have the advantage of not generally being influenced by human practices, many of them depending on source parameters and local geology alone (e.g., Koizumi, 1966; Youd and Hoose, 1978; Keefer, 1984; Xue-Cai and An-Ning, 1986; Youd and Perkins, 1987; Umeda *et al.*, 1987; Papadopoulos and Lefkopoulos, 1993; Ambraseys and Srbulov, 1995; Esposito *et al.*, 1997; Rodriguez *et al.*, 1999). It is proven that many natural effects occur only in the epicentral area (near field), and that they appear and start to become relevant at well-defined intensity levels (Appendix 2). This means that a proper estimation of the intensity of an earthquake should take these effects into account.

However, over the past 40 years at least, proper attention has not been paid to these effects in estimating intensity because they were reputed to be too variable, and likewise because they were not properly weighted in the scales. For example, recent data indicate that some phenomena occur, or start to occur, at degrees other than the ones they are assigned to in the scales: liquefaction, for instance, starts at lower intensities (VI-VII, or even V; e.g., Keefer, 1984; Galli and Ferreli, 1995; Rodriguez *et al.*, 1999, Galli, 2000, Porfido *et al.*, 2002) and not at VII or IX as indicated in the scales. We argue that the existence of similar inconsistencies in the available macroseismic scales should not bring to the conclusion that ground effects are useless for assessing earthquake intensity. On the contrary, we believe that this is the result of several decades of research on earthquake engineering, Quaternary geology and paleoseismology, which brougth to the buildup of an entirely new knowledge in the study of coseismic environmental effects and their relations with a) the local tectonic and geomorphic setting, and b) the source parameters of the causative seismic event (e.g., Vittori *et al.*, 1991; McCalpin, 1996; Michetti and Hancock, 1997; Yeats *et al.*, 1997). The aim of our proposed scale is therefore to update the pre-existing scales by including this new knowledge into the earthquake intensity assessment. In fact, the problem of updating the intensity scales does also involve the effects on people and the manmade environment. For instance, a great deal of effort has been expended throughout the last century to increasing the robustness of the scales by improved definition and redistribution of the various typologies of damage to the different degrees of the scales. Along the same line, the new insights available today into the response of the physical environment to seismicity can lead to intensity evaluations which are better description of the real strength of the causative earthquake.

Table 1: Ground effects in the MCS-1930, MM-1931, MSK-1964 and Japanese (JAP) intensity scales (after Esposito *et al.*, 1997).

Cracks in saturated soil and/or loose alluvium:	
up to 1 cm:	MSK: VI
a few cm:	MSK: VIII: MM: VIII; MCS: VIII
up to lOcm:	MSK: IX; MM: IX
a few dm up to one meter	MSK: X; MCS: X
Cracks on road backfills and on natural terrigenous slopes over 10 cm	MSK: VII, VIII, IX; MM: VIII; MCS: VIII
Cracks on dry ground or on asphalted roads	MSK: VII, IX, XI: MCS: X, XI; JAP: VI
Faults cutting poorly consolidated Quaternary sediments	MSK: XI; MCS: XI
Faults cutting bedrock at the surface	MSK: XII; JAP: VII
Liquefaction and/or mud volcanoes and/or subsidence	MSK: IX, X; MM: IX, X; MCS: X, XI
Landslides in sand or gravel artificial dykes	MSK: VII, VIII, X; MM: VII; MCS: VII
Landslides in natural terrigenous slopes	MSK: VI, IX, X, XI; MM: X; MCS: X, XI; JAP: VI, VII
Rockfalls	MSK: IX, XI, XII; MM: XII; MCS: X, XI
Turbulence in the closed water bodies and formation of waves	MSK: VII, VIII, IX; MM: VII; MCS: VII, VIII
Formation of new water bodies	MSK: VIII, X, XII; MCS: XII
Change in the direction of flow in watercourses	MSK: XII; MCS: XII
Flooding	MSK: X, XII; MM: X; MCS: X
Variation in the water level of wells and/or the flow rate of springs	MSK: V, VI, VII, VIII, IX, X; MM: VIII; MCS: VII, X
Springs which dry out or are starting to flow	MSK: VII, VIII, IX

Also, the wide variability of some effects is not a good reason to exclude all seismically-generated natural phenomena from the scale. In most cases, this variability can be properly taken into account through a careful inspection of coseismic effects in the field, exactly in the same way as for the effects on humans and manmade environment. To improve the definition of the ground effects in the different degree of the scales, we checked our proposed scale against macroseismic data coming from the careful analysis of the earthquakes listed in Table 2. We carried out this comparison assuming the following notion.

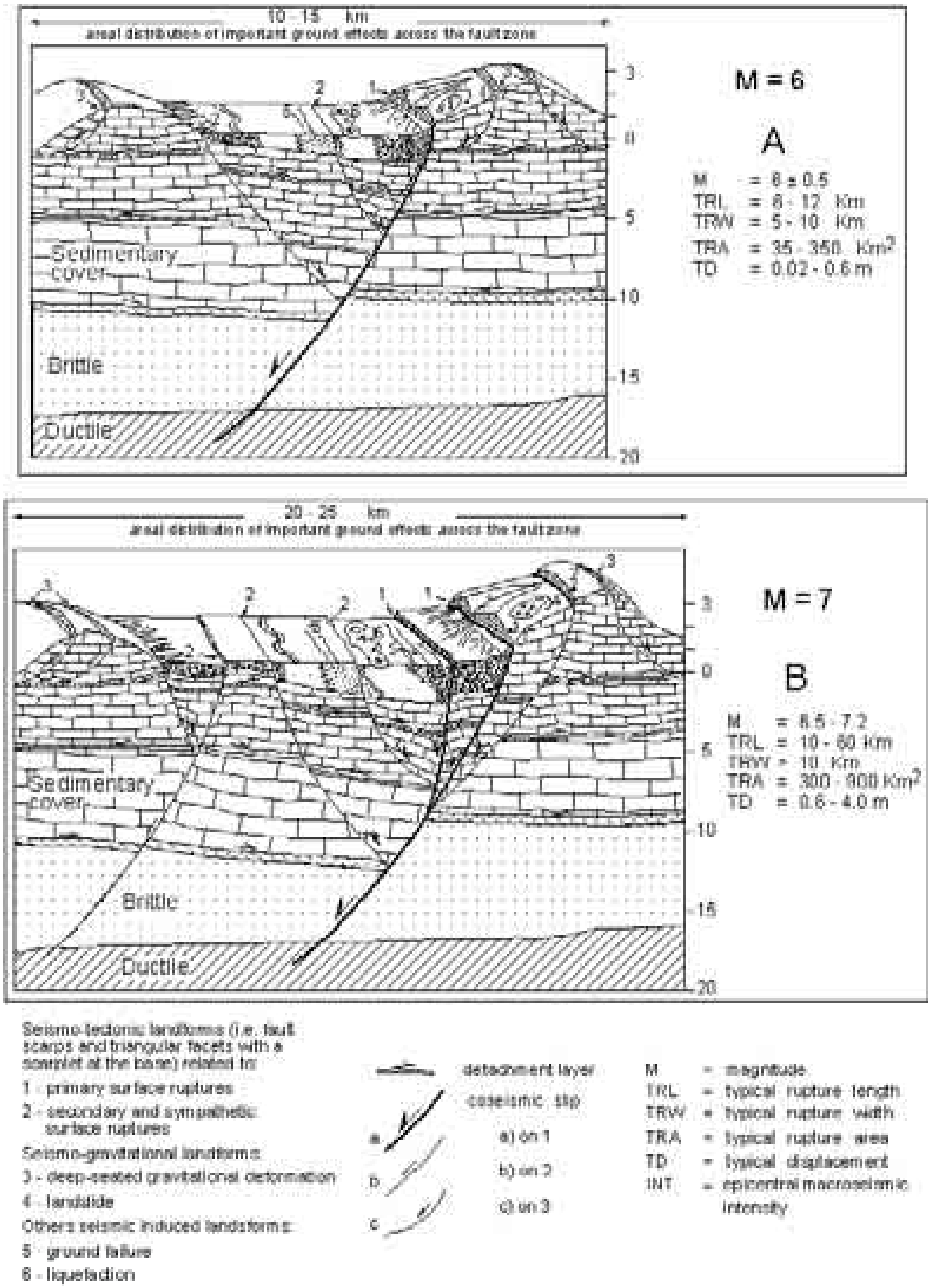

Figure 3: Seismic landscapes in the Apennines. Schematic block-diagram of two Quaternary intermountain basins associated with M ≅ 6 (A) and M ≅ 7 (B) normal faulting earthquakes; the picture illustrates the typical seismo-tectonic, sedimentary, and paleoseismological features due to the repetition of the coseismic ground effects over a geological time interval. Typical values of surface faulting parameters (rupture length, rupture width, rupture area, vertical displacement) are shown. After Serva *et al.*, 2002, modified.

On the basis of our knowledge, we are convinced that the macroseismic degrees in the scales have mainly been defined by looking at the effects on humans and anthropic structures (especially buildings), whereas ground effects have been assigned mainly by looking at the isoseismal lines. Although not explicitly specified by the authors of the early scales, this is in our opinion the reasoning behind the assignment of a given effect to a given intensity degree. In any case, this is the criterion we have adopted in this paper in order to ensure the internal consistency of the new scale, and to allow a straightforward integration with the other scales.

The supposed uncertainties lead to an increasing lack in the confidence in using ground effects as diagnostics, and progressively the effects on human perception and the anthropic environment (mainly buildings) became the only sensors analyzed for intensity assessment. Exemplifying this logic, in the latest proposal by the European Seismological Commission to revise the MSK scale (Grunthal, 1998), these effects are not reported in the scale per se, only in a brief appendix. We believe, however, that if this orientation is pursued, intensity will come to reflect mainly the economic development of the area that experienced the earthquake instead of its "strength" (Serva, 1994). It is also our belief that by ignoring ground effects, it will not be possible to assess intensity accurately in sparsely populated areas and/or areas inhabited by people with different modes of existence, such as nomads. This point has been already very clearly made by Dengler and McPherson (1993); this proposal for a new scale is the logic extension of their approach. Furthermore the main problems arise for the highest degrees - XI and XII - where ground effects are the only ones that permit a reliable estimation of earthquake size. All the scales, in fact, show that in this range of intensity ground effects predominate.

Because of all this, we deem it necessary that the seismological community (in a broad sense — all people involved in seismic risk analysis) should continue to using scales that take into account all the natural phenomena pertaining to each degree. In line with this, we propose here a scale that reports only ground effects, based on the knowledge currently available in this matter.

The scale has been compiled based on the descriptions reported in: a) the three most common intensity scales, i.e., Mercalli-Cancani-Sieberg (MCS, Sieberg, 1930), Medvedev-Sponhouer-Karnik (MSK, 1964) and Modified Mercalli (MM, Wood and Neumann, 1931; Richter, 1958); b) the paper by Dengler and McPherson (1993); c) the newly revised MM scale for New Zealand (Hancox *et al.*, 2002) and d) a collection of pertinent papers, studies, and reports (as listed in Appendix 1). It should be noted that the description for any degree can be directly integrated into the corresponding degree of any of the above scales. Obviously, where they are not explicitly mentioned, a degree incorporates all the effects found in the lower degrees, although commonly more amply expressed and over a wider extent.

General statements

Serva (1994) and Esposito *et al.* (1997), among others, have already discussed some of the problems that must be dealt with when attempting to use natural effects for intensity assessment. However we think it would be useful to note the following considerations affecting the proper use of this scale.

In the following description of the proposed INQUA scale, text in italics refers to those effects directly usable to define an intensity degree (e.g., jumping stones, soil cracking, surface faulting). The size and the frequency of occurrence of many other natural effects, however, are not controlled by earthquake magnitude and hypocentral depth alone. Rather, they appear primarily to be governed by the duration and level of motion (acceleration, velocity, displacement), as well as by the frequency content of shaking, on the one hand, and by the local morphology and lithology of the terrain, on the other (so-called *land vocation* or likelihood or sensitivity to a specific phenomenon). For example, landslides depend on slope angles, the mechanical properties of the involved lithologies, water saturation, the nature and extent of vegetation, man-made changes and previous events. Hence, when the likelihood of an effect's occurring varies considerably depending on a number of controlling parameters, the intensity threshold can also vary significantly. So, landslides may occur for very low-intensity events (even IV; e.g., Keefer, 1984; Rodriguez *et al.*, 1999), but can be absent even for the strongest events (XII).

For such effects to be able to be used in assessing intensity, they will need to be painstakingly evaluated on a case-by-case basis. These therefore are not indicated in our scale as determinant for intensity assessment. Notwithstanding the aforementioned limitations, we nevertheless believe that an accurate analysis, taking into proper account the land *vocation,* and therefore based on direct observations in the field, may allow intensity degree appraisal. For instance, in the Apennines of Italy, as well as in New Zealand, it is possible to determine well defined relationships between landslide distribution and earthquake magnitude, epicentre, isoseismals, faulting, geology, and topography (Porfido *et al.*, 2002; Hancox *et al.*, 2002). The analysis of the catalogues of Italian historical earthquakes (Postpischl, 1985a; 1985b; Boschi *et al.*, 1995; 1997; 2000) carried out by Romeo and Delfino (1997) shows that the triggering threshold for landslides, below which the number and size of the slides becomes negligible (< 5 %) is degree VI-VII, whereas for liquefaction it is ca. VII. During the recent, September – October 1997, Umbria-Marche earthquake swarm in Central Italy (maximum intensity VIII-IX), the size and frequency of rockfalls along road cuts, as well as that of fractures, sharply increase as one moves towards the inside of the epicentral area (Esposito *et al.*, 2000; Vittori *et al.*, 2000).

Effects in the epicentral area (near field) depend essentially on the high-frequency vibration of ground motion (acceleration) and its duration, as well as on very low frequency seismic waves due to directivity and fling (slip on the fault), which give rise in the near field to long-period, so-called "killer" pulses (cf., the August, 17, 1999, Izmit/Kocaeli, Turkey and the 1999, Taiwan, earthquakes; e.g., EERI, 1999; USGS, 1999). In the far field, the effects are generally linked with long-period surface waves, more prominent on horizontal components of motion, and having long duration.

In summary, the environmental effects observed during earthquakes can be classified as follows:

A) Effects occurring under conditions of precarious equilibrium:

    1) They also can be induced by other natural events or human activities;
    2) They usually occur in mountainous or hilly areas, and in wet terrain;
    3) The highest concentration and amplitude of such effects can indicate the epicentral area, but, alternatively, also the area most prone to this phenomenon;
    4) Such effects, in the absence of independent evidence of seismicity (effects on man or man-made structures), do not allow the positive recognition of an earthquake and its intensity.

B) Effects occurring under conditions of relatively stable equilibrium:

    1) Earthquake markers: ascribable, due to their nature (frequency of occurrence, size, and areal distribution) only to an earthquake as causative event.
    2) Intensity gauges (mainly relevant for strong earthquakes):

        a) Undoubtedly connected to earthquakes because not producible by other processes, even of exceptional intensity:
        b) In no way connected only to the environmental setting. Generally they occur in two cases:

- When the vertical component of acceleration is greater than gravity (in epicentral areas; e.g. Umeda *et al.*, 1987);
- When surface faulting takes place. It begins to show up for intensities around VIII, and, for the same tectonic environment, rupture length and offset are thereafter proportional to macroseismic intensity. An original relationship between surface faulting parameters and intensity for crustal earthquakes is here proposed (Figure 4 and Table 3).

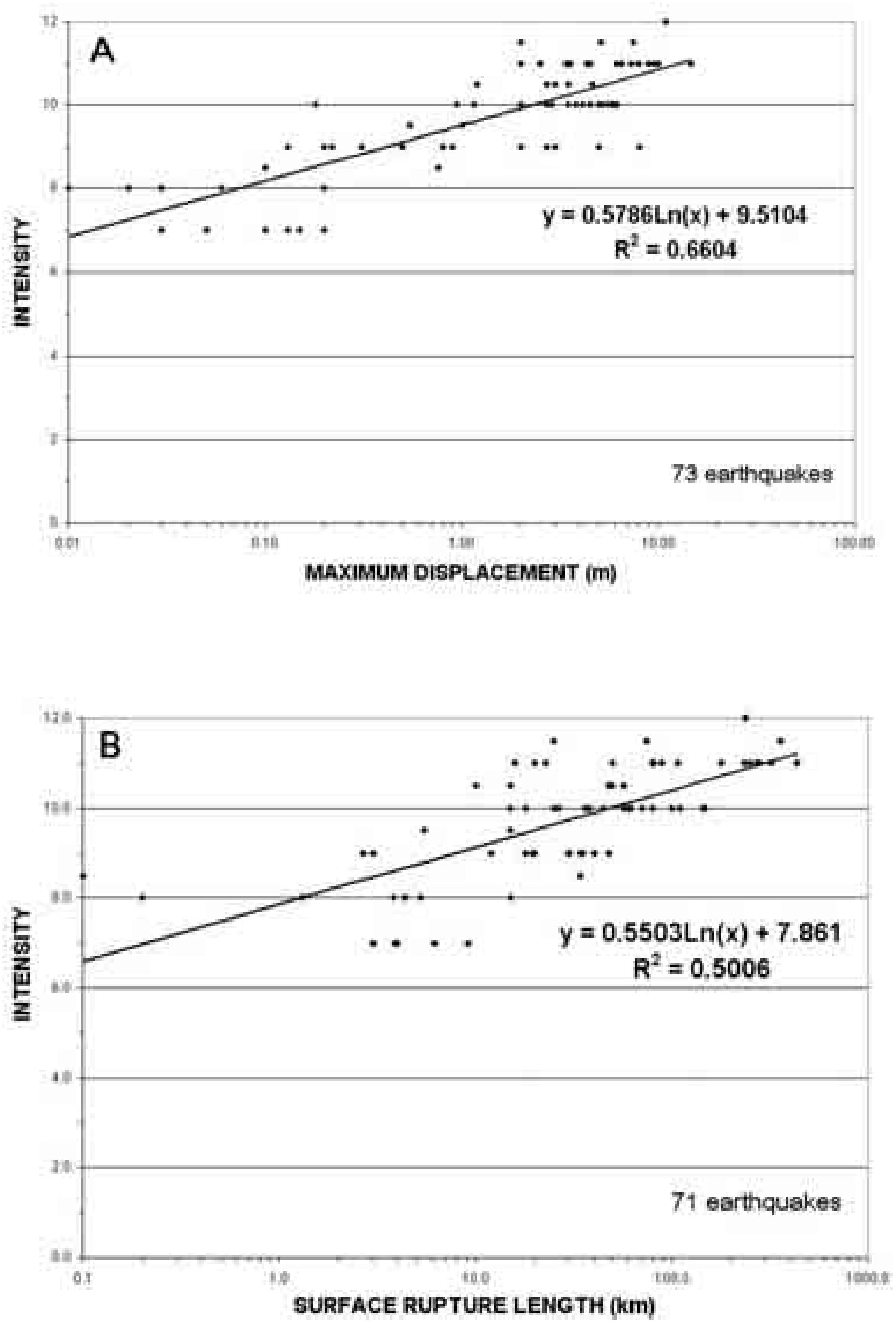

Figure 4: Diagram showing relations between epicentral intensity and surface faulting parameters for crustal earthquakes (4A, maximum displacement; 4B, rupture length); data from seismic events listed in Table 3. These are only preliminary results from a largely incomplete dataset. We have considered as outliers events with reported surface faulting and intensity below VII, considering as not credible such a low intensity. As a matter of fact, many other events have assigned macroseismic intensities too low when compared with their reported geological effects. This is one of the main issues addressed by the scale proposed here, which is based solely on the environmental effects of earthquakes.

The INQUA scale[1]

As already mentioned, the assignment of each environmental effect to its proper intensity interval in the following INQUA scale has been based on a careful reading of the most widely applied scales, i.e., the MM, MCS and MSK scales, integrated with more recent work indicated in the references and Appendix 1.

In particular, the diagnostics used in the INQUA scale have been compared and found consistent with the macroseismic data available for a sample of historical and contemporary Italian earthquakes, as listed in Table 2. We have accurately reviewed the surface effects of 115 earthquakes occurred in Italy since the XII century, documented in available catalogs and historical sources directly analyzed. The effects have been categorized according to the scheme in Table 4. Each effect has been associated to the macroseismic intensity attributed in the historical catalogs (Caputo and Faita, 1984; Postpischl, 1985a; 1985b; Boschi *et al.*, 1995; Tinti and Maramai, 1996; Boschi *et al.*, 1997; Azzaro *et al.*, 2001; CPTI, 1999; Boschi *et al.*, 2000) on the basis of local damage patterns.

About the intensity threshold for the occurrence of landslides, we have also taken into account the data of 40 earthquakes worldwide given in Keefer (1984), updated with other 36 events word-wide by Rodriguez *et al.* (1999), and 22 earthquakes in New Zealand (Hancox *et al.*, 2002). For the onset of liquefaction we have also considered the data for Venezuela given in Rodriguez *et al.* (2002).

As for primary faulting, we have based our analysis on a first screening of the Wells and Coppersmith (1994) and Yeats *et al.* (1997) dataset of earthquakes associated to surface faulting, integrated with some recent Italian and Mediterranean region events. The screening has been based on the availability of epicentral intensity values and it is still a work in progress. We have plotted the maximum displacement and the surface rupture length versus epicentral intensity, obtaining the plots in Figure 4.

This database of macroseismic data is subject to expansion and revision in order to incorporate more case histories; however, we are convinced that the sample of seismic events studied is large enough for validating the proposed scale with a resolution consistent with the scope of the present paper. For instance, we found several crustal earthquakes associated with rupture lengths of tens of kilometers for which an epicentral intensity of VIII or even of VII (MM or MSK) has been reported. With the INQUA scale, an epicentral intensity of X or XI would have been assigned, which is unequivocally a better description of the size of these events, both in terms of magnitude and of ground shaking level.

The degrees of the INQUA scale can be directly compared with the corresponding degrees of most of the twelve-degree scales referred to above, in view of the fact that the differences among these scales are not substantial in terms of the level of accuracy they can provide (Appendix 4). The INQUA scale is an innovative proposal — or perhaps is simply the recognition that the work accomplished by earthquake scientists in the first decades of the XX century is worth pursuing along the lines of its original inspiration. It reflects the present viewpoint of its authors, which is necessarily subject to modification in its details, notwithstanding their effort to integrate the largest database possible. Contributions and criticism from other researchers are expected and will be welcomed. They will in all probability provide the basis for a revised version, where new effects may be incorporated and grade intervals of occurrence and size of effects better constrained.

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[1] In order to give an immediate identity to this scale, we propose to name it "Inqua EEE Scale", where EEE would stand for "Earthquake Environmental Effects".

Definitions of intensity degrees

I, II No perceptible environmental effects

a) Extremely rare occurrence of small effects detected only from instrumental observations, typically in the far field of strong earthquakes.

III No perceptible environmental effects

a) Primary effects are absent.

b) Extremely rare occurrence of small variations in water level in wells and/or the flow-rate of springs, typically in the far field of strong earthquakes.

IV No perceptible environmental effects

a) Primary effects are absent.

b) A very few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon.

c) Rare occurrence of small variations in water level in wells and/or the flow-rate of springs.

d) Extremely rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells, especially within large karstic spring systems most prone to this phenomenon.

e) Exceptionally, rocks may fall and small landslides may be (re)activated, along slopes where equilibrium is already very unstable, e.g. steep slopes and cuts, with loose or saturated soil.

f) Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems.

g) Very rare temporary sea level changes in the far field of strong earthquakes.

h) Tree limbs may shake.

V Marginal effects on the environment

a) Primary effects are absent.

b) A few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon.

c) Extremely rare occurrence of significant variations in water level in wells and/or the flow-rate of springs.

d) Rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells.

e) Rare small rockfalls, rare rotational landslides and slump earth flows, along slopes where equilibrium is unstable, e.g. steep slopes, with loose or saturated soil.

f) Extremely rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).

g) Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems.

h) Occurrence of landslides under sea (lake) level in coastal areas.

i) Rare temporary sea level changes in the far field of strong earthquakes.

j) Tree limbs may shake.

VI Modest effects on the environment

a) Primary effects are absent.

b) Occasionally thin, millimetric, 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 (asphalt / stone) roads.

c) Rare occurrence of significant variations in water level in wells and/or the flow-rate of springs.

d) Rare occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells.

e) Rockfalls and landslides up to ca. 103 m3 can occur, especially where equilibrium is unstable, e.g. steep slopes and cuts, with loose / saturated soil, or weathered / fractured rocks. The area affected by them is usually less than 1 km^2.

f) Rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).

g) Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes.

h) Occurrence of landslides under sea level in coastal areas.

i) Occasionally significant waves are generated in still waters.

j) In wooded areas, trees shake; a very few unstable limbs may break and fall, also depending on species and state of health.

VII Appreciable effects on the environment

a) Primary effects observed very rarely. Limited surface faulting, with length of tens of meters and centimetric offset, may occur associated with volcano-tectonic earthquakes.

b) Fractures up to 5-10 cm wide 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. Centimetric cracks common in paved (asphalt or stone) roads.

c) Rare occurrence of significant variations in water level in wells and/or the flow rate of springs. Very rarely, small springs may temporarily run dry or be activated.

d) Quite common occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells.

e) Scattered landslides occur in prone areas; where equilibrium is unstable (steep slopes of loose / saturated soils; rock falls on steep gorges, coastal 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. The affected area is usually less than 10 km^2.

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

g) Possible collapse of karst vaults with the formation of sinkholes, even where the water table is deep.

h) Occurrence of significant landslides under sea level in coastal areas.

i) Waves may develop in still and running waters.

j) In wooded areas, trees shake; several unstable branches may break and fall, also depending on species and state of health.

VIII Considerable effects on the environement

a) Primary effects observed rarely. Ground ruptures (surface faulting) may develop, up to several hundred meters long, with offsets generally smaller than 5 cm, particularly for very shallow focus earthquakes, such as volcano-tectonic events. Tectonic subsidence or uplift of the ground surface with maximum values on the order of a few centimeters may occur.

b) Fractures up to 25 - 50 cm wide are 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.

c) Springs can 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.

d) Water temperature often change in springs and/or wells. Water in lakes and rivers frequently becomes muddy, as well as in springs.

e) 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. The affected area is usually less than 100 km^2.

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) Karst vaults may collapse, forming sinkholes.

h) Frequent occurrence of landslides under the sea level in coastal areas.

i) Significant waves develop in still and running waters.

j) Trees shake vigorously; some branches or rarely even tree-trunks in very unstable equilibrium may break and fall.

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

IX Natural effects leave significant and permanent traces in the environment

a) *Primary effects observed commonly. Ground ruptures (surface faulting) develop, up to a few km long, with offsets generally smaller than 10 - 20 cm. Tectonic subsidence or uplift of the ground surface with maximum values in the order of a few decimeters may occur.*

b) *Fractures up to 50 - 100 cm wide 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.*

c) Springs can change their flow-rate and/or elevation of outcrop to a considerable extent. Some small springs may even run dry. Variations in water level are observed in wells.

d) Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy.

e) *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. The affected area is usually less than 1000 km^2.*

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) Karst vaults of relevant size collapse, forming sinkholes.

h) Frequent large landslides under the sea level in coastal areas.

i) *Large waves develop in still and running waters. Small tsunamis may reach the coastal areas with tidal waves up to 50 - 100 cm high.*

j) Trees shake vigorously; branches or even tree-trunks in unstable equilibrium frequently break and fall.

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

l) In the epicentral area, small stones may jump out of the ground, leaving typical imprints in soft soil.

X Environmental effects become dominant

a) *Primary ruptures become leading. Ground ruptures (surface faulting) can extend for several tens of km, with offsets reaching 50 - 100 cm and more (up to ca. 1-2 m in case of reverse faulting and 3-4 m for normal faulting). Gravity grabens and elongated depressions develop; for very shallow focus earthquakes, such as volcano-tectonic events, 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.*

b) *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. The affected area is usually up to 5000 km^2.*

c) Many springs significantly change their flow-rate and/or elevation of outcrop. Some may run dry or disappear, generally temporarily. Variations in water level are observed in wells.

d) Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy.

e) Open ground cracks up to more than 1 m wide 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.

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) Large karst vaults collapse, forming great sinkholes.

h) Frequent large landslides under the sea level in coastal areas.

i) Large waves develop in still and running waters, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas, with tidal waves up to a few meters high.

j) Trees shake vigorously; branches or even tree-trunks very frequently break and fall, if already in unstable equilibrium.

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

l) Stones, even if well anchored in the soil, may jump out of the ground, leaving typical imprints in soft soil.

XI Environmental effects become essential for intensity assessment

a) Primary surface faulting can extend for several tens of km up to more than 100 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.

b) 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. Primary and secondary environmental effects can be observed over territory as large as 10000 km^2.

c) Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells.

d) Water temperature often change in springs and/or wells. Water in lakes and rivers frequently becomes muddy.

e) 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.

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) Very large karst vaults collapse, forming sinkholes.

h) Frequent large landslides under the sea level in coastal areas.

i) *Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas with tidal waves up to many meters high.*

j) Trees shake vigorously; many tree branches break and several whole trees are uprooted and fall.

k) In dry areas dust clouds may arise from the ground.

l) Stones and small boulders, even if well anchored in the soil, may jump out of the ground leaving typical imprints in soft soil.

XII Environmental effects are now the only tool enabling intensity to be assessed

a) Primary surface faulting can extend for several hundreds of km up to 1000 km, 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).

b) 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. Primary and secondary environmental effects can be observed over territory larger than 50000 km^2.

c) Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells.

d) Water temperature often changes in springs and/or wells. Water in lakes and rivers frequently becomes muddy.

e) 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.

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) Very large karst vaults collapse, forming sinkholes.

h) Frequent very large landslides under the sea level in coastal areas.

i) Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters overflow from their beds; watercourses change the direction of flow. Tsunamis reach the coastal areas with tidal waves up to tens of meters high.

j) Trees shake vigorously; many tree branches break and many whole trees are uprooted and fall.

k) In dry areas dust clouds may arise from the ground.

l) Even large boulders may jump out of the ground leaving typical imprints in soft soil.

In the **Appendix 5** the draft of a field survey form is proposed, for collection of data and rapid intensity estimate during field recognition following the future earthquakes. Clearly, the field test of the proposed scale should be a major task in the next future.

Intensity - fault parameter relationships: discussion and conclusions

Published empirical relationships between surface faulting parameters (i.e. rupture length, rupture area, rupture width, displacements) versus magnitude (e.g., Bonilla, 1978; Wells and Coppersmith, 1994), do not take into account dynamic parameters, notably stress drop, which varies versus fault length and slip type (cf. Mohammadioun and Serva, 2001). For instance, the systematic use, in the Wells and Coppersmith (1994) relation, of moment magnitude M (wherein stress drop is arbitrarily set at 30 bars) is liable to cause magnitudes to be either over- or underestimated. Accordingly, in order to assess the magnitudes of historical seismic events on the strength of paleoseismicity data, it is indispensable that rupture dynamics and the stress environment be taken into account. Recent paleoseismicity studies in the region of the San Andreas fault (Runnerstrom *et al.*, 2002) indicates that maximum displacement increases versus the depth of the seismogenic zone: displacement measured at the surface accordingly represents the lower limit of this parameters, and using it will unavoidably lead to an underestimation of magnitude.

The other primary effects of earthquakes (uplift and/or subsidence) are accounted for to a certain extent by relationships between magnitude and slip-rate (e.g., Slemmons and dePolo, 1986; Petersen and Wesnousky, 1995; Anderson *et al.*, 1996).

To date, there are no relationships linking primary ground effects and intensity. However, this connection is well evidenced in the description of the macroseismic scales for IX, X, XI, XII intensity degrees (see Table 1). We compiled new relationships using the data reported in Table 3 from a selected sample of crustal earthquakes. The data are plotted in Figure 4. We derived regression curves from the obtained values. This is a preliminary attempt that will be revised and updated by adding more detailed information on the earthquakes in Table 3, and including data from other surface faulting events.

We know that everybody can bring forward well-justified criticism concerning this approach, which we are willing to take into consideration. However, it is a fact that, within a given tectonic environment, intensity should increase if magnitude increases. It is entirely implausible that an earthquake of M = 6.5–7.0 should produce the same intensity as a M = 7.5–8 one. It is not physically correct, and macroseismic scales, if properly used, do not allow these values. Of course intensity XII, by definition, is where the scales saturate and therefore calls for professional judgment. In view of the preceding, the regressions in Figure 4 represent a very early stage of this endeavor. In fact, the purpose of publishing it is to provide a gentle provocation for the scientific community. We hope therefore that it will easily be proven false—but in the sense of Popper, 1934.

The use of ground effects for macroseismic intensity assessment is obviously affected by several uncertainties, as widely discussed in this paper. Most of the physical phenomena included in the proposed INQUA scale are relatively poor indicators of level, and should be considered carefully when used for intensity measurement. For the intensity levels lower than IX, the attempt of the INQUA scale is to bring environmental effects in line with the damage indicators. In this range, the INQUA scale should be used along with the other scales. For this reason, we have included as Appendix 4 a set of comparative tables to allow a direct integration between most commonly used scales and the INQUA proposed scale. However, in the intensity range between X and XII the distribution and size of primary tectonic effects is arguably the most useful diagnostic of the intensity level. As suggested in the proposed INQUA scale, field observations on fault rupture length and surface displacement should be therefore consistently implemented in the macroseismic study of past and future earthquakes.

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Table 2: Set of Italian earthquakes considered for testing and calibrating the proposed INQUA scale. For each earthquake we compared the distribution of ground effects and the macroseismic intensity assessed from persons and surroundings, and manmade structures of all kinds. Mm is macroseismically derived magnitude, except for most recent earthquakes where instrumental data are available. Numbers refers to sources listed in Appendix 1.

Earthquakes	Epicentral zone	Magnitude (Mm)	Reference
1169.02.04	East Sicily	6.6	15, 16, 17, 22, 27, 126, 146
1456.12.05	Central -Southern Italy	7.3	15, 16, 17, 27, 53, 107, 126
1511.03.26	Slovenia	7.2	15, 16, 17, 22, 27, 126, 146
1542.12.10	Siracusano	6.9	11,15, 16, 17, 27, 126, 146
1561.08.19	Vallo di Diano	6.4	15, 16, 17, 27
1570.11.17	Ferrara	5.3	15, 16, 17, 27, 126
1613.08.25	Naso	5.9	15, 16, 17, 27
1624.03.18	Argenta	5.4	15, 16, 17, 27, 126
1627.07.30	Gargano	7.0	11, 15, 16, 17, 22, 27, 126, 146
1638.03.27	Calabria	7.1	15, 16, 17, 22, 27, 146
1638.06.08	Crotonese	7.0	15, 16, 17, 27
1661.03.22	Romagna Apennines	5.6	15, 16, 17, 27, 126
1661.12.03	Montecchio	5.0	15, 16, 17, 27
1688.06.05	Sannio	6.4	15, 16, 17, 27 , 42, 126, 133
1690.12.23	Anconetano	5.3	15, 16, 17, 27
1693.01.09	Val di Noto	6.0	11, 15, 16, 17, 22, 27 , 126, 146
1694.09. 08	Irpinia-Basilicata	6.9	15, 16, 17, 27, 42, 126, 133
1703.01.14	Umbria-Lazio Apennines	6.7	15, 16, 17, 27, 126
1706.11.03	Maiella	6.7	15, 16, 17, 27
1726.09. 01	Palermo	5.7	15, 16, 17, 27 , 146
1731.03. 20	Foggiano	6.5	15, 16, 17, 22, 27 , 126, 146
1739.05. 10	Naso	5.5	15, 16, 17, 27
1743.02. 20	Basso Ionio	7.0	15, 16, 17, 22, 27, 126, 146
1751.07. 27	Umbria Apennines	6.2	15, 16, 17, 27
1755.12. 09	Vallese	6.0	15, 16, 17, 27
1781.04. 04	Romagna	5.9	15, 16, 17, 27, 126
1781.06. 03	Umbria-Marche Apennines	6.3	15, 16, 17, 27
1781.07. 17	Romagna	5.5	15, 16, 17, 27, 126
1783.02. 05	Calabria	6.8	15, 16, 17, 22, 27, 22, 59, 146
1786.12. 25	Riminese	5.7	15, 16, 17, 27, 126
1799.07. 28	Marche Apennines	5.9	15, 16, 17, 27, 126
1802.05. 12	Valle dell'Oglio	5.7	15, 16, 17, 27, 126
1805.07. 26	Molise	6.7	15,16, 17, 22, 27, 39, 42, 43, 44, 45, 52, 109, 125, 126 , 146
1808.04. 02	Valle del Pellice	5.7	15, 16, 17, 27, 126
1818.02. 20	Catanese	6.2	15, 16, 17, 22, 27, 126, 146
1818.09. 08	Madonie	5.3	15, 16, 17, 27
1819.02. 24	Madonie	5.4	15, 16, 17, 27
1823.03. 05	Northern Sicily	5.9	15, 16, 17, 22, 27, 126, 146
1826.02. 01	Basilicata	5.8	15, 16, 17, 27, 124
1828.02. 02	Casamicciola terme	4.5	15, 16, 17, 27
1828.10. 09	Valle dello Staffora	5.7	16, 17
1831.01.02	Lagonegro	5.4	27, 124, 27
1831.05. 26	Liguria occidentale	5.5	15, 16, 17, 27
1832.01. 13	Valle del Topino	6.1	15, 16, 17, 27
1832.03. 08	Crotonese	6.5	15, 16, 17, 22, 27, 146
1834.02. 14	Alta lunigiana	5.8	15, 16, 17, 27
1836.04. 25	Calabria settentrionale	6.2	15, 16, 17, 22, 27, 146
1846.08. 14	Toscana settentrionale	5.8	15, 16, 17, 22, 27,146

1851.08. 14	Melfi	5.6	15, 16, 17, 27, 124, 126
1853.04. 09	Caposele	5.9	15, 16, 17, 27 ,124, 126
1854.02. 12.	Casentino	6.1	15, 16, 17, 27
1855.07. 25	Vallese	5.8	15, 16, 17, 27
1857.12. 16	Basilicata	6.9	15, 16, 17, 27, 42, 123, 124, 125, 126
1859.01. 20	Trevigiano	5.2	15, 16, 17, 27
1865.07. 19	Mt. Etna area	5.1	10, 15, 16, 17, 27
1870.10. 04	Casentino	6.1	15, 16, 17, 27, 126
1873.03. 12	Southern Marche	6.0	15, 16, 17, 27
1873.06. 29	Bellunese	6.3	15, 16, 17, 27, 126
1875.03. 17	Romagna sud-orientale	5.8	15, 16, 17, 27, 126
1883.07. 28	Casamicciola terme	5.7	15, 16, 17, 27, 28, 63, 105
1887.02. 23	W Liguria	5.4	15, 16, 17, 22, 27, 126, 146
1887.12. 03	N Calabria	5.5	15, 16, 17, 27, 126
1894.08. 08	Mt. Etna area	5.3	15, 16, 17, 27
1894.11. 16	S Calabria	6.1	15, 16, 17, 22, 27, 146
1895.05. 18	Impruneta	4.8	15, 16, 17, 27
1897.12. 18	Umbria-Marche Apennines	4.8	15, 16, 17, 27
1898.06.27	Rieti	5.1	26, 27, 126
1899.06. 26	Valle del Bisenzio	4.8	15, 16, 17, 27
1899.07. 19	Albani Hills	4.8	15, 16, 17, 27
1904.02. 24	Marsica	5.8	10, 15, 16, 17, 27, 126
1905.04. 29	Alta Savoia	5.1	15, 16, 17, 27,
1905.09. 08	Calabria	7.1	15, 16, 17, 22, 27, 146
1908.07. 10	Carnia	5.1	15, 16, 17 27
1908.12.28.	S Calabria	7.1	15, 16, 17, 22, 27, 146
1909.08. 25	S. Toscana	5.1	15, 16, 17, 27
1910.06. 07	Irpinia –Basilicata	5.8	15, 16, 17, 27, 121
1911.10. 15	Mt. Etna area	5.2	10,15, 16, 17, 27, 126
1913.06. 28	N Calabria	5.4	15, 16, 17, 27
1914.05. 08	Mt. Etna area	4.9	10,15, 16, 17, 27 , 126
1915.01. 13	Avezzano	7.1	15, 16, 17, 27, 58, 110, 113, 126
1916.05. 17	N Adriatic Sea	5.4	15, 16, 17, 27
1916.06. 16	N Adriatic Sea	4.8	15, 16, 17, 27
1916.08. 16	N Adriatic Sea	5.4	15, 16, 17, 27
1919.06. 29	Mugello	6.0	15, 16, 17, 27
1919.09.10	S Toscana	5.4	15, 16, 17, 27, 126
1920.09. 07	Garfagnana	6.3	15, 16, 17, 27, 118, 126
1927.12. 26	Colli albani	4.8	15, 16, 17, 27
1928.03. 27	Carnia	5.8	15, 16, 17, 27
1930.07. 23	Irpinia	6.6	3,15, 16, 17, 27,114, 27, 44, 47, 125, 126
1933.09. 26	Maiella	5.8	15, 16, 17, 27, 126
1936.10. 18	Cansiglio	6.0	15, 16, 17, 27
1938.07. 18	Alpi Cozie	4.8	15, 16, 17, 27
1940.01. 15	Golfo di Palermo	5.3	15, 16, 17, 27
1945.06. 29	Valle dello Staffora	5.1	15, 16, 17, 27
1947.05. 11	Central Calabria	5.4	15, 16, 17, 27 , 126
1948.08. 18	Northern Puglia	5.1	15, 16, 17, 27
1956.05. 26	Santa Sofia	4.3	15, 16, 17, 27
1959.04. 05	Valle dell'Ubaye	4.8	15, 16, 17, 27
1961.10. 31	Antrodoco	5.1	15, 16, 17, 27
1962.08. 21	Irpinia	6.0	15, 16, 17, 27, 126
1968.01. 15	Valle del Belice	6.6	15, 16, 17, 27, 29, 126
1976.05. 06	Friuli	6.3	24, 27, 29, 60, 116
1976.09. 11	Friuli	5.8	15, 16, 17, 27
1976.09. 15	Friuli	6.2	15, 16, 17 ,27
1978.04. 15	Golfo di Patti	6.0	15, 16, 17, 27
1979.09. 19	Valnerina	5.8	15, 16, 17, 27

1980.11. 23	Irpinia-Basilicata	6.9	13, 15, 27 ,41, 42, 45, 46, 48, 108, 125, 126, 127, 128, 129
1982.03. 21	Golfo di Policastro	5.1	15, 16, 17, 27
1983.11. 09	Parmense	4.6	15, 16, 17, 19,27, 27
1984. 05.07	Abruzzi Apennines	5.4	15, 16, 17, 19, 27, 45
1990.12. 13	SE Sicily	5.1	15, 16, 17, 27, 40
1997.09. 20.	Umbria-Marche Apennines	6.0	1, 37, 38, 50, 51, 152
1998.09. 09	Lauria	5.6	108
2002.09. 06	Southern Tyrrhenian Sea	5.6	23, 31
2002.10. 31	San Giuliano	5.8	151

Table 3: Earthquakes considered for the analysis of relations between epicentral intensity and surface faulting parameters. Selected events for which best constrained data are available have been used for the diagrams in Figure 4. Where not available, we converted intensity values in the MM scale (for a comparison between the different scales see Shebalin *et al.*, 1974; Krinitsky and Chang, 1988; Reiter, 1991), and magnitude values to Ms (magnitude values for pre-instrumental earthquakes are derived from macroseismic data).

N	Location	Earthquake Name	EQ Date	Epicentral Intensity	References	Ms	Surface Rupture Length (km)	Max Displ. (m)
1	USA, Calif	Fort Tejon	09/01/1857	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html Sieh, K., 1978. Slip along the San Andreas Fault associated with the great 1857 earthquake. Bulletin of the Seismological Society of America, 68, 1421-1428. Grant L. and Sieh, K, 1993. Stratigraphic evidence for 7 meters of dextral slip on the San Andreas Fault during the 1857 earthquake in the Carrizo Plain. Bulletin of the Seismological Society of America, 83, 619-635. C.F. Richter, 1958, Elementary Seismology, San Francisco, California, W.H. Freeman, p. 768.	8.3	322.0	9.50
2	USA, Calif	Haiward	21/10/1868	9.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	6.8	48.0	0.90
3	USA, Calif	Owens Valley	26/03/1872	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html Vittori, E., Michetti, A.M., Slemmons, D.B., & Carver, G.A., (1993) - Style of recent surface deformation at the south end of the Owens Valley fault zone, eastern California, Geological Society of America, Abstracts with Program Volume 25, Number 5, April 1993, p. 159. C.F. Richter, 1958, Elementary Seismology, San Francisco, California, W.H. Freeman, p. 768.	7.6	108.0	10.00
4	Mexico	Pitaycachi	03/05/1887	11.5	Bull, W.B. and P.A: Pearthree, 1988. Frequency and size of Quateranry surface ruptures of the Pitaycachi Fault, Northeastern Sonora, Mexico, Bulletin of the Seismological Society of America, 78, 956-978. http://www.geo.arizona.edu/K-12/azpepp/education/history/pitay.html	7.4	75.0	5.10
5	Japan	Nobi	27/10/1891	11.0	http://www.hp1039.jishin.go.jp/eqchreng/6-2-2.htm Matsuda, T., 1974. Surface faults associated with Nobi (Mino-Owari) earthquake of 1891, Japan. Earthquake Research Inst., Univ. Tokyo, Spec. Bull. 13, 85-126.	8.0	80.0	8.00

6	Japan	Rikuu	31/08/1896	10.0	http://www.hp1039.jishin.go.jp/eqchreng/4-2-5.htm Matsuda, T., Yamazaky, H., Nakata, T. and Imaizumi T., 1980. The surface faults associated with the Rikuu earthquake of 1896. Earthquake Research Inst., Univ. Tokyo, Bull., 55, 795-855.	7.2	36.0	3.50
7	Turkey	Büyük Menderes Basin	20/09/1899	9.0	Ergin, K., Guclu, U and Uz, Z., 1967. A Catalog of Earthquakes for Turkey and Surrounding Area (11 A.D. to 1964 A.D.). ITU publications, No:24, Istanbul. Altunel, E., 1999. Geologic and geomorphologic observations in relation to 20 th september 1899 Menderes earthquake, western Turkey. Journal of the Geological Society, London, 156, 241-246.	7.0	40.0	2.00
8	USA, Calif	San Francisco	18/04/1906	11.0	http://neic.usgs.gov/neis/eqlists/USA/1906_04_18.html http://www.msu.edu/~fujita/earthquake/intensity.html Lawson, A.C., Chairman, 1908. The California earthquake of April 18, 1906 – Report of the State Earthquake Investigation Committee. Carnegie Institute, Washington, Pub. 87, v.1. C.F. Richter, 1958, Elementary Seismology, San Francisco, California, W.H. Freeman, p. 768.	7.9	432.0	6.10
9	Turkey	Mürefte Şarköy	09/08/1912	10.0	Ergin, K., Guclu, U and Uz, Z., 1967. A Catalog of Earthquakes for Turkey and Surrounding Area (11 A.D. to 1964 A.D.). ITU publications, No:24, Istanbul. Ambraseys, N.N. and Finkel, C.F. (1987). The Saros-Marmara Earthquake of 9 August 1912, Earthquake Eng. and Struct. Dyn. 15: 189-211. Altunel, E., Barka, A.A., akir, Z., Kozaci, Ö., Hitchcock, C., Helms, J., Bachuber, J. & Lettis, W. 2000. What goes on at the eastern termination of the November 12, 1999 Düzce earthquake, M=7.2, North Anatolian Fault, Turkey. American Geophysical Fall Meeting, California, USA, Abstracts, p. F816.	7.0	110.0	5.00
10	Italy	Avezzano	13/01/1915	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html Boschi E., G. Ferrari, P. Gasperini, E. Guidoboni, G. Smriglio and G. Valensise (Eds.), 1995, Catalogo dei forti terremoti in Italia dal 461 a. C. al 1980, 2. ING-SGA, Bologna, 973 p. Michetti A.M., Brunamonte F., Serva L. and Vittori E. (1996) - Trench investigations along the 1915 Fucino earthquake fault scarps (Abruzzo, Central Italy): geological evidence of large historical events. Journal of Geophysical Research, 101, 5921-5936.	7.0	23.0	2.00
11	USA, Nevada	Pleasant Valley	03/10/1915	10.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	7.6	62.0	5.80
12	China	Kansu	16/12/1920	12.0	Editorial Board for the Lithospheric Dynamics Atlas of China, State Seismological Bureau, 1989, Lithospheric Dynamics Atlas of China. Tav 24. Deng Q., Chen S., Song F.M., Zhu S., Whang Y., Zhang W., Burchfiel B.C., Molnar P., Royden L., and Zhang P., 1986. Variations in the geometry and amount of slip on the Haiyuan Fault Zone, China, and the surface rupture of the 1920 Haiyuan earthquake. Earthquake	8.5	237.0	11.00

					Source Mechanics, Geophysical Monograph 37, 169-182.			
13	Japan	Tango	07/03/1927	9.0	http://www.hp1039.jishin.go.jp/eqchreng/7-2-3.htm Yamasaki N. and Tada F., 1928. The Oku-Tango earthquake of 1927. Earthquake Research Institute, 4, 159-177.	7.7	18.0	3.00
14	Bulgaria	Papazili	18/04/1928	10.5	Bonchev S. and Bakalov P., 1928. Les tremblements de terre dans la Bulgarie du Sud les 14 et 18 avril 1928. Rev. Soc. Géol. Bulgare. Special Catalogue of Earthquakes of the Northern Eurasia (SECNE) Editors N.V.Kondorskaya and V.I.Ulomov. C.F. Richter, 1958, Elementary Seismology, San Francisco, California, W.H. Freeman, p. 768. Shebalin,N.V., Leydecker,G., Mokrushina,N.G., Tatevossian,R.E., Erteleva,O.O. & V.Yu.Vassiliev (1997): Earthquake Catalogue for Central and Southeastern Europe 342 BC - 1990 AD. -- Final Report to Contract ETNU - CT 93 - 0087	6.9	50.0	3.50
15	New Zealand	Hawkes Bay	02/02/1931	10.5	http://www.pnbhs.school.nz/Intranet/Art%20History/Art%20Deco%20Napier/earthquake.htm	7.8	15.0	4.60
16	China	Kehetuohai-E	10/08/1931	11.0	http://iisee.kenken.go.jp/net/hara/china.htm	7.9	180.0	14.60
17	Japan	Saitama	21/09/1931	7.0	http://www.hp1039.jishin.go.jp/eqchreng/5-2-5.htm	6.8	0.0	0.00
18	USA, Nevada	Cedar Mountain	21/12/1932	10.0	http://www.msu.edu/~fujita/earthquake/intensity.html C.F. Richter, 1958, Elementary Seismology, San Francisco, California, W.H. Freeman, p. 768. Slemmons, D.B., Jones, Austin E., and Gimlett, James I., 1965, Catalog of Nevada earthquakes, 1852 - 1960: Bulletin of the Seismological Society of America, v. 55, no. 2, p. 537 - 583.	7.2	61.0	2.70
19	China	Changma	25/12/1932	10.0	Peltzer, G., P. Tapponnier, Y. Gaudemer, et al., Offsets of late Quaternary morphology, rate of slip, and recurrence of large earthquakes on the Chang Ma fault, Gansu, China, J. Geophys. Res., 93, 7793-7812, 1988. Shih, Chen-liang, Wen-lin Huan, Kuo-Kan Yao, and Yuan-ding Hsie (1978). On the fracture zones of the Changmaearthquake of 1932 and their causes, Chinese Geophysics, 1(1), 17-46. Fu, Z., and Liu, G. (2001) Dynamic analysis on interaction between the Haiyuan-Gulang-Changma great earthquakein the north bounbady of the Tibetan plateau, Seismology and Geology, 23, 35-42 (in Chinese). http://iisee.kenken.go.jp/net/hara/china.htm	7.7	148.5	6.20

20	Turkey	Kirsehir	19/04/1938	9.5	Special Catalogue of earthquakes of the northern Eurasia (SECNE) Editors N.V. Kondorskaya and V.I. Ulomov, http://seismo.ethz.ch/gshap/neurasia/nordasiacat.txt Ergin, K., Guclu, U and Uz, Z., 1967. A Catalog of Earthquakes for Turkey and Surrounding Area (11 A.D. to 1964 A.D.). ITU publications, No:24, Istanbul. Ambraseys, 70	6.8	15.0	1.00
21	Turkey	Erzincan	26/12/1939	11.0	Ergin, K., Guclu, U and Uz, Z., 1967. A Catalog of Earthquakes for Turkey and Surrounding Area (11 A.D. to 1964 A.D.). ITU publications, No:24, Istanbul. Barka, A. 1996. Slip distribution along the North Anatolian fault associated with the large earthquakes of the period 1939 to 1967. BSSA, 86, 1238-1254. http://www.msu.edu/~fujita/earthquake/intensity.html Erhan Altunel, 2003, personal communication	8.0	360.0	7.50
22	USA, Calif	Imperial Valley	19/05/1940	10.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	7.2	60.0	5.90
23	Turkey	Erbaa	20/12/1942	10.0	Ergin, K., Guclu, U and Uz, Z., 1967. A Catalog of Earthquakes for Turkey and Surrounding Area (11 A.D. to 1964 A.D.). ITU publications, No:24, Istanbul. Erhan Altunel, 2003, personal communication.	7.3	45.0	3.50
24	Turkey	Ladik (Tosya)	26/11/1943	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html Ergin, K., Guclu, U and Uz, Z., 1967. A Catalog of Earthquakes for Turkey and Surrounding Area (11 A.D. to 1964 A.D.). ITU publications, No:24, Istanbul. Ambraseys, N.N., 1970. Some characteristics features of the Anatolian fault zone. Tectonophysics, 9, 143-165. Erhan Altunel, 2003, personal communication	7.5	270.0	4.50
25	Turkey	Çerkeş, Gerede, Bolu	01/02/1944	10.0	Ergin, K., Guclu, U and Uz, Z., 1967. A Catalog of Earthquakes for Turkey and Surrounding Area (11 A.D. to 1964 A.D.). ITU publications, No:24, Istanbul. Erhan Altunel, 2003, personal communication	7.4	100.0	4.50
26	Peru	Ancash	10/11/1946	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html Sebrier,M., J. L. Mercier,J.Machare, D. Bonnet, J. Cabrera, and J. L. Blanc, 1988. State of stress in an overriding plate situated above a flat slab: the Andes of central Peru, Tectonics, 7, 895-928, 1988.	7.3	20.0	3.50
27	Japan	Fukui	28/06/1948	11.5	http://www.msu.edu/~fujita/earthquake/intensity.html Tsuya, H., ed. 1950. The Fukui earthquake of June 28, 1948. Tokyo, Special Committee for the Study of the Fukui earthquake, 197 p., 2 pl. Kanamori, H. 1973. Mode of strain release associated with major earthquakes in Japan. Earth Planet. Sci. Ann. Rev. 1, 213-239.	7.3	25.0	2.00
28	USA, Calif	Fort Sage Mtns	14/12/1950	7.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	5.6	9.2	0.20

29	USA, Calif	Superstition Hills	23/01/1951	7.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	5.6	3.0	0.05
30	China	Danxiong	18/11/1951	11.0	http://iisee.kenken.go.jp/net/hara/china.htm Tapponnier, P., Mercier, J.,L., Armijo, R., H and Zhou, J., 1981. Field evidence for normal faulting in Tibet:. Nature 294, 410-4 Armijo, R., Tapponier, P., and Han, T.L. 1989. Late Cenozoic right-lateral strike-slip faulting in Southern Tibet. Journ. Geopphys. Res., 94, 2787-2838.	8.0	81.0	7.30
31	USA, Calif	Kern County	21/07/1952	10.5	http://www.msu.edu/~fujita/earthquake/intensity.html Buwalda, J. & St. Amand, P. 1955. Geological effects of the Arvin-Tehachapy earthquake. In: G. Oakeshott, Earthquakes in Kern County California during 1952. San Francisco, Calif. Dept. of Natural Resources, Division of Mines, Bulletin, 171, 41-56. Stein, R.S., & Thatcher, W. 1981. Seismic and aseismic deformation associated with the 1952 Kern County, California, earthquake and relationship to the Quaternary history of the White Wolf Fault. Journ. Geophys. res. 86, 4913-4928.	7.7	57.0	1.20
32	Turkey	Canakkale	18/03/1953	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html Ergin, K., Guclu, U and Uz, Z., 1967. A C of Earthquakes for Turkey and Surroundin (11 A.D. to 1964 A.D.). ITU publications, Istanbul. Ketin, I., & Roesli, F. 1954. Makroseismische Untersuchungen über das nordwestanatolesche Beben Wom 18 März 1953. Eclogae Geol. Helvetiae, 46, 187-208.	7.2	50.0	4.35
33	USA, Nevada	Rinbow Mountain	06/07/1954	9.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	6.8	18.0	0.31
34	USA, Nevada	Stillwater	24/08/1954	8.5	http://www.msu.edu/~fujita/earthquake/intensity.html Coffman, Jerry L., and von Hake, Carl A., 1970. Earthquake History of the United States, U.S. Department of Commerce, Publication 41-1, 208 p.	6.9	34.0	0.76
35	USA, Nevada	Dixie Valley	16/12/1954	10.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	6.8	45.0	3.80
36	USA, Nevada	Fairview Peak	16/12/1954	10.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	7.2	57.0	4.10
37	Mongolia	Gobi-Altai	04/12/1957	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html Florensov, N.A., and Solonenko, V.P. 1965. The Gobi-Altai earthquake. Moscow, Nauka, 1963.	7.9	250.0	9.00
38	USA, Alaska	Lituya Bay	10/07/1958	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html Plafker, G., Hudson, T., Bruns, T., and Rubin, M. 1978. Late Quaternary offsets along the Fairweather Fault and crustal plate interaction in southern Alaska.	7.9	280.0	6.50

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39	USA, Montana	Hebgen Lake	18/08/1959	10.0	http://www.msu.edu/~fujita/earthquake/intensity.html Coffman, Jerry L., and von Hake, Carl A., 1970. Earthquake History of the United States, U.S. Department of Commerce, Publication 41-1, 208 p. Myers, W.B. and Hamilton, W. 1964. Deformation accompanying the Hebgen Lake earthquake of August 17, 1959. U.S.G.S. Prof. Paper 435-I, 55-98.	7.3	26.5	5.50
40	USA, Calif	Parkfield	28/06/1966	7.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	6.4	38.5	0.20
41	Greece	Agios-Efstratios	19/02/1968	9.0	Van Gils, J.M. & G. Leydecker (1991): Catalogue of European earthquakes with intensities higher than 4. -- Commission of the European Communities - nuclear science and technology. 353 pp - ISBN 92-826-2506-0, Catal. No.: CD-NA-13406-EN-C. Brussels - Luxembourg. Pavlides, S.B., and Tranos, M.D. 1991. Structural characteristics of two strong earthquakes in the North Aegean: Ierissos, 1932, and Agios Efstratios, 1968. Jour. Structural Geology 13, 205-214. Shebalin,N.V., Leydecker,G., Mokrushina,N.G., Tatevossian,R.E., Erteleva,O.O. & V.Yu.Vassiliev (1997): Earthquake Catalogue for Central and Southeastern Europe 342 BC - 1990 AD. -- Final Report to Contract ETNU - CT 93 - 0087	7.2	3.0	0.50
42	USA, Calif	Borrego Mountain	09/04/1968	7.0	Stover C.W. & Coffman J.L., 1993, Seismi the United States, 1568-1989 (Revised) Geological Survey Professional Paper 152 418	6.8	31.0	0.38
43	Peru	Pariahuanca	24/07/1969	11.0	http://www.msu.edu/~fujita/earthquake/ty.html	5.7	5.5	0.40
44	China	Tonghai	04/01/1970	10.5	http://iisee.kenken.go.jp/net/hara/china.h	7.5	48.0	2.70
45	USA, Calif	San Fernando	09/02/1971	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html Coffman, J L., von Hake, Carl A., and Stover, Carl W., 1982, Earthquake history of the United States: Publication 41-1, Rev. Ed. (with supplement through 1980), National Oceanic and Atmospheric Administration and U.S. Geological Survey, Boulder, Colo., 258p.	6.5	16.0	2.50
46	China	Luhuo	06/02/1973	11.0	http://iisee.kenken.go.jp/net/hara/china.htm	7.3	89.0	3.60
47	Russia	Tadzhikestan	11/08/1974	7.0	V.I. Ulomov, R.P. Fadina, A.P. Katok, et al. (1977). Earthquakes in Middle Asia. In: I.V. Gorbunova, N.V. Kondorskaya, N.V. Shebalin (eds.), Earthquakes in the USSR in 1974, 1977, 49-98.	7.3	0.0	0.00
48	USA, Calif	Brawley	23/01/1975	6.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	4.6	10.4	0.20

49	China	Haicheng	04/02/1975	9.5	http://iisee.kenken.go.jp/net/hara/china.htm http://www.msu.edu/~fujita/earthquake/intensity.html	7.4	5.5	0.55
50	USA, Calif	Oroville	01/08/1975	8.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	5.6	3.8	0.06
51	Guatemala	Motagua	04/02/1976	11.0	http://www.msu.edu/~fujita/earthquake/intensity.html	7.5	235.0	3.40
52	Russia	Gazli, Uzbekistan	08/04/1976	8.0	Ulomov, V.I., M.G. Flenova, A.P. Katok, et al. (1980). Earthquakes in Middle Asia and Kazakhstan. In: I.V. Gorbunova, N.V. Kondorskaya, N.V. Shebalin (eds.), Earthquakes in the USSR in 1976, 1980, 27-39.	7.0	0.0	0.00
53	Russia	Gazli, Uzbekistan	17/05/1976	9.0	Ulomov, V.I., M.G. Flenova, A.P. Katok, et al. (1980). Earthquakes in Middle Asia and Kazakhstan. In: I.V. Gorbunova, N.V. Kondorskaya, N.V. Shebalin (eds.), Earthquakes in the USSR in 1976, 1980, 27-39.	7.3	0.0	0.00
54	China	Tangshan	27/07/1976	10.5	http://iisee.kenken.go.jp/net/hara/china.htm http://www.msu.edu/~fujita/earthquake/intensity.html	7.9	10.0	3.00
55	Greece	Thessaloniki	20/06/1978	9.0	Van Gils, J.M. & G. Leydecker (1991): Catalogue of European earthquakes with intensities higher than 4. -- Commission of the European Communities - nuclear science and technology. 353 pp - ISBN 92-826-2506-0, Catal. No.: CD-NA-13406-EN-C. Brussels - Luxembourg. Shebalin,N.V., Leydecker,G., Mokrushina,N.G., Tatevossian,R.E., Erteleva,O.O. & V.Yu.Vassiliev (1997): Earthquake Catalogue for Central and Southeastern Europe 342 BC - 1990 AD. -- Final Report to Contract ETNU - CT 93 - 0087	6.4	19.4	0.22
56	Germany	Swabian Jura	03/09/1978	7.5	Van Gils, J.M. & G. Leydecker (1991): Catalogue of European earthquakes with intensities higher than 4. -- Commission of the European Communities - nuclear science and technology. 353 pp - ISBN 92-826-2506-0, Catal. No.: CD-NA-13406-EN-C. Brussels - Luxembourg.	5.3	0.0	0.00
57	USA, Calif	Homestead Valley	15/03/1979	7.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	5.6	3.9	0.10
58	USA, Calif	Coyote Lake	06/08/1979	7.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	5.7	14.4	0.15
59	USA, Calif	El Centro	15/10/1979	9.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	6.7	30.5	0.80

60	Italy	Umbria (Norcia)	19/09/1979	8.5	Boschi E., E. Guidoboni, G. Ferrari, G. Valensise, and P. Gasperini (Eds.), 1997, Catalogo dei forti terremoti in Italia dal 461 a. C. al 1990, 2. ING-SGA, Bologna, 644 p. Blumetti A.M., Dramis F., Gentili B. & Pambianchi G. (1991) La struttura di Monte Alvagnano-Castel Santa Maria nell'area nursina: aspetti geomorfologici e sismicità storica. Rend. Soc. Geol. It., 13, 71-76, 5 fig.	5.9	0.1	0.10
61	USA, Calif	Greenville	24/01/1980	7.0	http://neic.usgs.gov/neis/eqlists/sig_1980.html	5.9	6.2	0.03
62	France	Arudy	29/02/1980	7.5	J.M. Van Gils, G. Leydecker, 1991, Catalogue of European earthquakes with intensities higher than 4 J. Fréchet,A. Rigo, A. Souriau, F. Thouvenot, Comparison of two damaging earthquake in France in 1996: Saint Paul de Fenoullet (Pyrenees) and Epagny (Alps) Gagnepain-Beyneix, J., H. Haessler et T. Modiano, The Pyrenean earthquake of February 29, 1980: an example of complex faulting, Tectonophysics, 85, 273-290, 1982 Lambert J., Levret-Albaret A. (dir), Cushing M. et Durouchoux C. 1996. Mille ans de séismes en France. Catalogue d'épicentres : paramètres et références. Ouest Editions, Presses Académiques, Nantes, 80p. Lambert J. (dir), Bernard P., Czitrom G., Dubié J.Y.,Godefroy P. et Levret-Albaret A. 1997 Les tremblements de terre en France : Hier, Aujourd'hui, Demain. Editions BRGM, Orléans, 196p	5.0	0.0	0.00
63	USA, Calif	Mammoth Lakes	27/05/1980	6.0	http://neic.usgs.gov/neis/eqlists/sig_1980.html	6.1	20.0	0.00
64	Mexico	Mexicali Valley	09/06/1980	7.0	http://neic.usgs.gov/neis/eqlists/sig_1980.html W. Ortega, J. Frez y F. Suárez, (1997) "The Victoria México, earthquake of June 9, 1980", Geof. Int., vol. 36-3, pp. 139-159.	6.4	0.0	0.00
65	Japan	Izu-Hanto-Toho	29/06/1980	7.0	http://neic.usgs.gov/neis/eqlists/sig_1980.html	6.2	0.0	0.00
66	Greece	Almyros	09/07/1980	8.0	Van Gils, J.M. & G. Leydecker (1991): Cat of European earthquakes with intensities than 4. -- Commission of the Eu Communities - nuclear science and techr 353 pp - ISBN 92-826-2506-0, Catal. No NA-13406-EN-C. Brussels - Luxembourg. Shebalin,N.V., Leydecker,G., Mokrushina,N.G., Tatevossian,R.E., Erteleva,O.O. & V.Yu.Vassiliev (1997): Earthquake Catalogue for Central and Southeastern Europe 342 BC - 1990 AD. -- Final Report to Contract ETNU - CT 93 - 0087	6.4	5.3	0.20
67	USA, Kentuc	Sharp-sburg	27/07/1980	7.0	http://neic.usgs.gov/neis/eqlists/sig_1980.html	4.7	0.0	0.00
68	Italy	South Apennines	23/11/1980	10.0	Van Gils, J.M. & G. Leydecker (1991): Cat of European earthquakes with intensities than 4. -- Commission of the Eu Communities - nuclear science and techr 353 pp - ISBN 92-826-2506-0, Catal. No NA-13406-EN-C. Brussels - Luxembourg. Boschi E., G. Ferrari, P. Gasperini, E. Guidoboni, G. Smriglio, and G. Valensise (Eds.), 1995, Catalogo dei forti terremoti in Italia dal 461 a. C. al 1980, ING-SGA, Bologna, 973 p.	6.9	38.0	1.15

69	North Yemen	Dhamer	13/12/1982	8.0	http://neic.usgs.gov/neis/eqlists/sig_1982.html	6.0	15.0	0.03
70	Russia	Kum-Dagh, Turkmenia	14/03/1983	8.0-9.0	S.S. Arefiev, V.M. Graizer, D.N. Zargarian, et al. (1985). Rupture in the source and aftershocks of the Kum-Dagh earthquake of March 14, 1983. In: N.V. Shebalin (ed.) Macroseismic and instrumental studies of strong earthquakes. Problems of engineering seismology, n.26, 1985, 27	5.7	20.0	0.13
71	Columbia	Popayan	31/03/1983	8.0	http://neic.usgs.gov/neis/eqlists/sig_1983.html	4.9	1.3	0.01
72	USA, Calif	Coalinga	02/05/1983	8.0	http://neic.usgs.gov/neis/eqlists/sig_1983.html	6.5	0.0	0.00
73	USA, Calif	Coalinga, Nunez	11/06/1983	6.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	5.4	3.3	0.64
74	USA, Idaho	Borah Peak	28/10/1983	9.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	7.3	34.0	2.70
75	Belgium	Liege	08/11/1983	4.5	Van Gils, J.M. & G. Leydecker (1991): Catalogue of European earthquakes with intensities higher than 4. -- Commission of the European Communities - nuclear science and technology. 353 pp - ISBN 92-826-2506-0, Catal. No.: CD-NA-13406-EN-C. Brussels - Luxembourg.	4.3	0.0	0.00
76	Russia	Gazli, Uzbekistan	19/03/1984	9.0-10.0	A.A. Abdukadyrov, G.Yu. Azizov, A.G. Aronov, et al. The Gazli earthquake of March 19, 1984 In: N.V. Kondorskaya (ed.), Earthquakes in the USSR in 1984, 1987, 67-85.	7.2	0.0	0.00
77	USA, Calif	Morgan Hill	24/04/1984	7.0	http://neic.usgs.gov/neis/eqlists/sig_1984.html	6.1	0.0	0.00
78	Italy	Perugia	29/04/1984	8.0	Boschi E., E. Guidoboni, G. Ferrari, G. Valensise, and P. Gasperini (Eds.), 1997, Catalogo dei forti terremoti in Italia dal 461 a. C. al 1990, 2. ING-SGA, Bologna, 644 p.	5.3	0.0	0.00
79	Italy	Lazio-Abruzzo	07/05/1984	8.0	Boschi E., E. Guidoboni, G. Ferrari, G. Valensise, and P. Gasperini (Eds.), 1997, Catalogo dei forti terremoti in Italia dal 461 a. C. al 1990, 2. ING-SGA, Bologna, 644 p.	5.8	0.0	0.90
80	England	North Wales	19/07/1984	6.0	http://neic.usgs.gov/neis/eqlists/sig_1984.html	4.7	0.0	0.00
81	Japan	Naganoken-Seibu	13/09/1984	5.0	http://neic.usgs.gov/neis/eqlists/sig_1984.html	6.1	0.0	0.00
82	Argentina	Mendoza	26/01/1985	7.0	http://neic.usgs.gov/neis/eqlists/sig_1985.html	5.9	0.0	0.00
83	New Guinea	New Britain	10/05/1985	8.0	http://neic.usgs.gov/neis/eqlists/sig_1985.html	7.1	0.0	0.00
84	New Guinea	New Ireland	03/07/1985	7.0	http://neic.usgs.gov/neis/eqlists/sig_1985.html	7.2	0.0	0.00
85	USA, Calif	Kettleman Hills	04/08/1985	6.0	http://neic.usgs.gov/neis/eqlists/sig_1985.html	5.9	0.0	0.00
86	Canada	Nahanni	05/10/1985	6.0	http://neic.usgs.gov/neis/eqlists/sig_1985.html	6.6	0.0	0.00
87	USA, Calif	N. Palm Springs	08/07/1986	7.0	http://neic.usgs.gov/neis/eqlists/sig_1986.html	6.0	9.0	0.01

88	USA, Calif	Chalfant Valley	21/07/1986	6.0	Stover C.W. & Coffman J.L., 1993, Seismicity of the United States, 1568-1989 (Revised), U.S. Geological Survey Professional Paper 1527, pp. 418	6.2	15.8	0.11
89	Greece	Kalamata	13/09/1986	10.0	http://neic.usgs.gov/neis/eqlists/sig_1986.html	5.8	15.0	0.18
90	Taiwan	Hualien	14/11/1986	7.0	http://neic.usgs.gov/neis/eqlists/sig_1986.html	7.8	0.0	0.00
91	New Zealand	Edge-cumbe	02/03/1987	10.0	http://neic.usgs.gov/neis/eqlists/sig_1987.html	6.6	18.0	2.90
92	USA, Calif	Whittier Narrows	01/10/1987	8.0	http://neic.usgs.gov/neis/eqlists/sig_1987.html	5.7	0.0	0.00
93	USA, Calif	Elmore Ranch	24/11/1987	6.0	http://neic.usgs.gov/neis/eqlists/sig_1987.html	6.2	10.0	0.20
94	USA, Calif	Supersti-tion Hills	24/11/1987	6.5	http://neic.usgs.gov/neis/eqlists/sig_1987.html	6.6	27.0	0.92
95	USA, Calif	Pasadena	03/12/1988	6.0	http://neic.usgs.gov/neis/eqlists/sig_1988.html	4.2	0.0	0.00
96	Russia	Armenia	07/12/1988	10.0	Dorbath, L., C. Dorbath, L. Rivera, et al. (1992). Geometry, segmentation and stress regime of the Spitak (Armenia) earthquake from the analysis of the aftershock sequence. // Geophys. Journal Inter. 108, 1992, 309-328.	6.8	25.0	2.00
97	USA, Calif	Loma Prieta	18/10/1989	9.0	http://www.msu.edu/~fujita/earthquake/intensity.html http://neic.usgs.gov/neis/eqlists/sig_1989.html	7.1	2.7	0.20
98	Algeria	Chenoua	29/10/1989	7.0	http://neic.usgs.gov/neis/eqlists/sig_1989.html	5.7	4.0	0.13
99	USA, Calif	Upland	28/02/1990	7.0	http://neic.usgs.gov/neis/eqlists/sig_1990.html	5.5	0.0	0.00
100	Iran	Rudbar-Tarom	20/06/1990	10.0	http://www.msu.edu/~fujita/earthquake/intensity.html	7.7	80.0	0.95
101	Russia	Racha, Georgia	29/04/1991	8.0-9.0	Papalashvili, V.G., O.Sh. Varazanashvili, S.A. Gogmachadze et al. (1997). The Racha-Java earthquake of April 29, 1991. In: *Earthquakes in the USSR in 1991*, 1997, 18-25.	6.9	0.0	0.00
102	USA, Calif	Sierra Madre	28/06/1991	7.0	http://neic.usgs.gov/neis/eqlists/sig_1991.html	5.1	0.0	0.00
103	Turkey	Erzincan	13/03/1992	9.0	http://www.yapiworld.com/editor/erzincan.htm Erdik, Mustafa and Beyen, Kemal, ' Intensity Assessments ' March 13, 1992 (MS:6.8) Erzincan Earthquake; A preliminary Reconnaissance Report, Bogazici University, May 1992	6.8	30.0	0.20
104	USA, Calif	Joshua Tree	23/04/1992	7.0	http://neic.usgs.gov/neis/eqlists/sig_1992.html	6.3	0.0	0.00
105	USA, Calif	Landers	28/06/1992	10.0	http://www.msu.edu/~fujita/earthquake/intensity.html http://www.eqe.com/publications/bigbear/bigbear.htm Assessed in the field by the Authors	7.6	85.0	6.00

106	USA, Calif	Big Bear	28/06/1992	8.0	http://www.eqe.com/publications/bigbear/bigbear.htm http://neic.usgs.gov/neis/eqlists/sig_1992.html	6.7	0.0	0.00
107	USA, Nevada	Little Skull Mtn	29/06/1992	8.0	http://pubs.usgs.gov/dds/2000/dds-058/Ch_J.pdf Smith, Kenneth D., Brune, James N., de Polo, Diane, Savage, Martha K., Anooshehpoor, Rasool, Sheeham, Anne F., (2001), The 1992 Little Skull Mountain earthquake sequence, southern Nevada Test Site. Bulletin of the Seismological Society of America, vol. 91, no. 6, pp.1595-1606.	5.4	0.0	0.00
108	USA, Oregon	Scotts Mills	25/03/1993	7.0	http://neic.usgs.gov/neis/eqlists/sig_1993.html Madin, I.P., G.P. Priest, M.A. Mabey, S.D. Malone, T.S. Yelin, D. Meier, March 25, 1993, Scotts Mills Earthquake- western Oregon's wake-up call, *Oregon Geology* 55, 51-57, 1993.	5.4	0.0	0.00
109	USA, Calif	Eureka Valley	17/05/1993	8.0	http://pubs.usgs.gov/dds/2000/dds-058/Ch_J.pdf Assessed in the field by the Authors	5.8	4.4	0.02
110	Russia	Neftegprsk	29/05/1995	9.0	Arefiev, S.S., E.A. Rogozhin, Tatevossian R.E., Rivera L., Cisternas A. (2000). The Neftegorsk (Sakhalin Island) 1995 earthquake: A rare interplate event. Geophys. J. Int., v. 143, 2000, 595-607.	7.6	35.0	8.10
111	Italy	Colfiorito Umbria-Marche	26/09/1997	9.0	Vittori E., G. Deiana, E. Esposito, L. Ferreli, L. Marchegiani, G. Mastrolorenzo, A.M. Michetti, S. Porfido, L. Serva, A.L. Simonelli & E. Tondi, 2000, Ground effects and surface faulting in the September-October 1997 Umbria-Marche (Central Italy) seismic sequence, Journal of Geodynamics, 29, 535-564.	6.0	12.0	0.80
112	Italy	Lauria S. Apennines	09/09/1998	8.0	Michetti A.M., L. Ferreli, E. Esposito, S. Porfido, A.M. Blumetti, E. Vittori, L. Serva & G.P. Roberts, 2000, Ground effects during the September 9, 1998, Mw = 5.6, Lauria earthquake and the seismic potential of the aseismic Pollino region in Southern Italy, Seismological Research Letters, 71, 31-46.	5.6	0.2	0.02
113	Turkey	Izmit	17/08/1999	10.0	http://www.ngdc.noaa.gov/seg/hazard/sig_srch.shtml Barka, Aykut A; Akyuz, H Serdar; Altunel, Erhan; Sunal, G; Cakir, Ziya; Dikbas, Aynur; Yerli, Baris; Armijo, R; Meyer, B; de Chabalier, J B; Rockwell, Thomas K; Dolan, J R; Hartleb, Ross D; Dawson, Timothy E; Christofferson, S A; Tucker, A; Fumal, T E; Langridge, Robert M; Stenner, H D; Lettis, William; Bachhuber, J; Page, W D, 2002, The surface rupture and slip distribution of the 17 August 1999 Izmit earthquake (M 7.4), North Anatolian Fault, Bulletin of the Seismological Society of America, vol.92, no.1, pp.43-60. Youd, T.L., Jean-Pierre Bardet and Jonathan D. Bray, Technical Editors, 2000, Kocaeli, Turkey Earthquake of August 17, 1999: Reconnaissance Report, Earthquake Spectra, Supplement A to	7.4	145.0	5.20

					Volume 16, EERI Publication Number 2000-03, Cd.			
114	Turkey	Düzce	12/11/1999	9.0	http://www.ngdc.noaa.gov/seg/hazard/sig_srch.shtml Hitchcock C., Erhan Altunel, Aykut Barka, Jeffrey Bachhuber, William Lettis, John Helms, Scott Lindvall, 2003. Timing of Late Holocene Earthquakes on the Eastern Düzce Fault and Implications for Slip Transfer between the Southern and Northern Strands of the North Anatolian Fault System, Bolu, Turkey, Turkish J. Earth Sci., 12, (2003), 119-136. Youd, T.L., Jean-Pierre Bardet and Jonathan D. Bray, Technical Editors, 2000, Kocaeli, Turkey Earthquake of August 17, 1999: Reconnaissance Report, Earthquake Spectra, Supplement A to Volume 16, EERI Publication Number 2000-03, Cd.	7.2	40.0	5.00

Table 4: Categories used for the analysis of secondary earthquake ground effects

Class of effect	*subset*
Hydrological anomalies	• Hydrological discharge rate/water level change • Hydrological-chemical-physical changes and turbidity • New springs • River overflows and lake seiches • Temporary sea level changes - tsunamis
Liquefaction and vertical movements	• Liquefaction and lateral spreading • Soil and backfilling compaction • Tectonic subsidence/uplift
Landslides **(based on Table II in Keefer, 1984)**	• Landslides in rock: rockfalls, rock slides, rock avalanches, rock slumps, rock block slides • Landslides in soil: soil falls, soil slides, soil avalanches, soil slumps, soil block slides, slow earth flows, soil lateral spreads, rapid soil flows, subaqueous landslides • karst vault collapses and sinkholes
Ground cracks	• Paved roads • Stiff ground • Loose sediments – wet soil

APPENDIX 1

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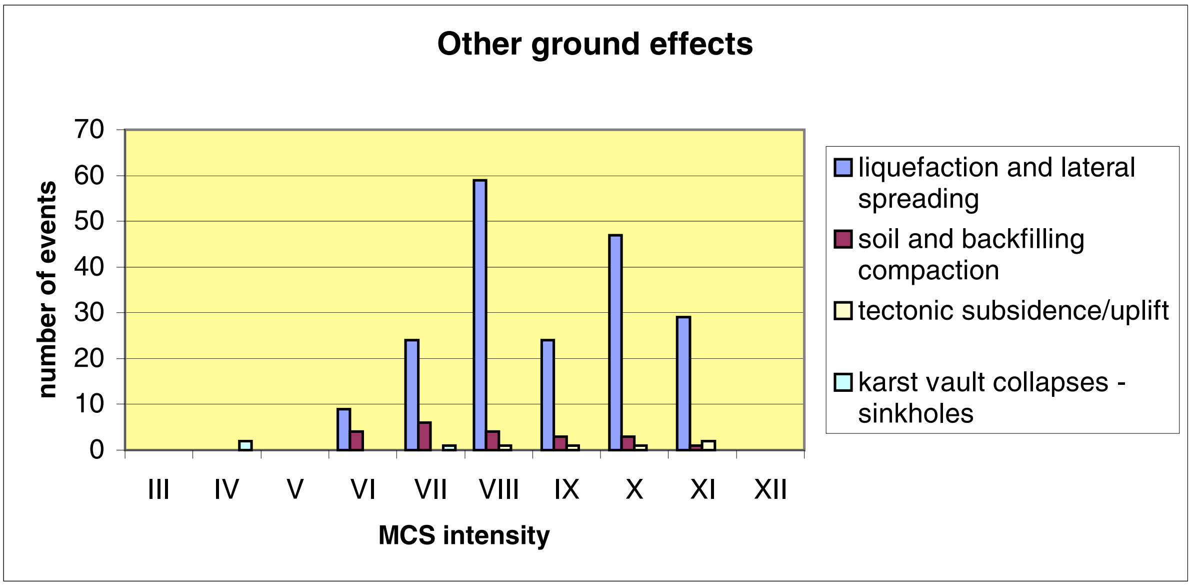
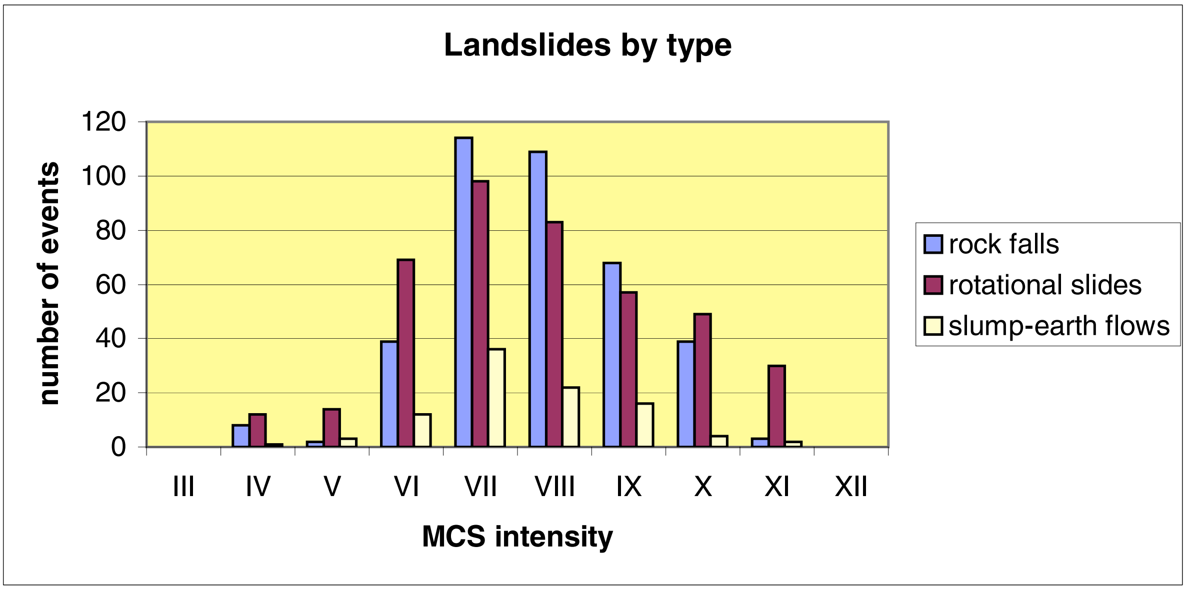
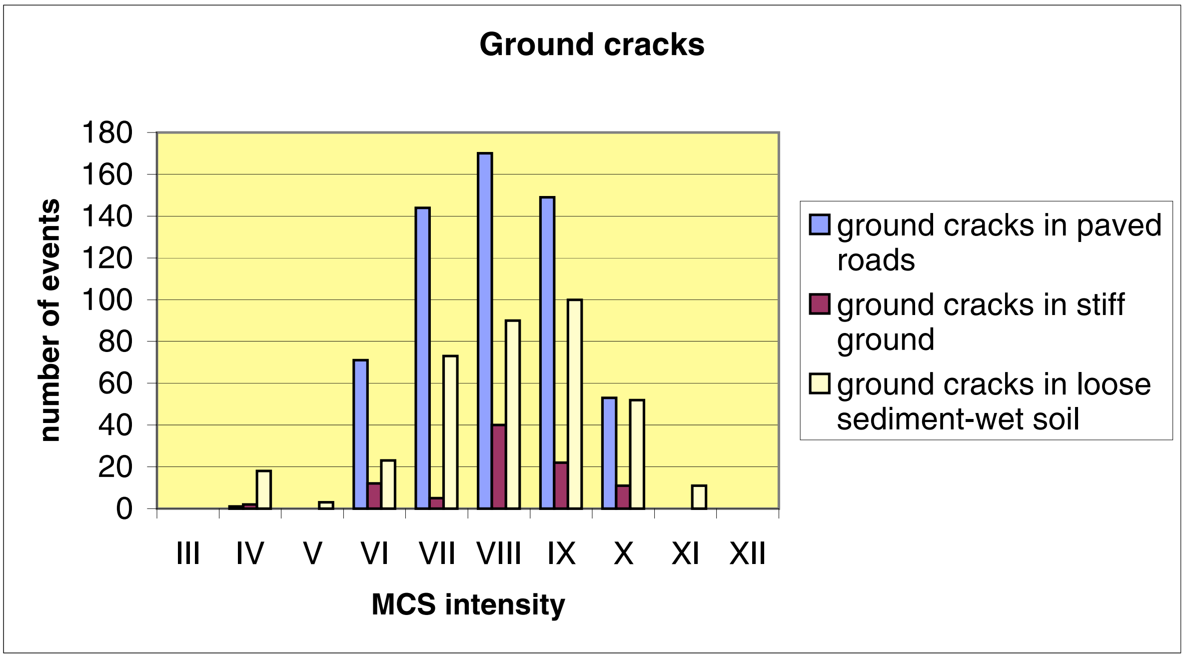
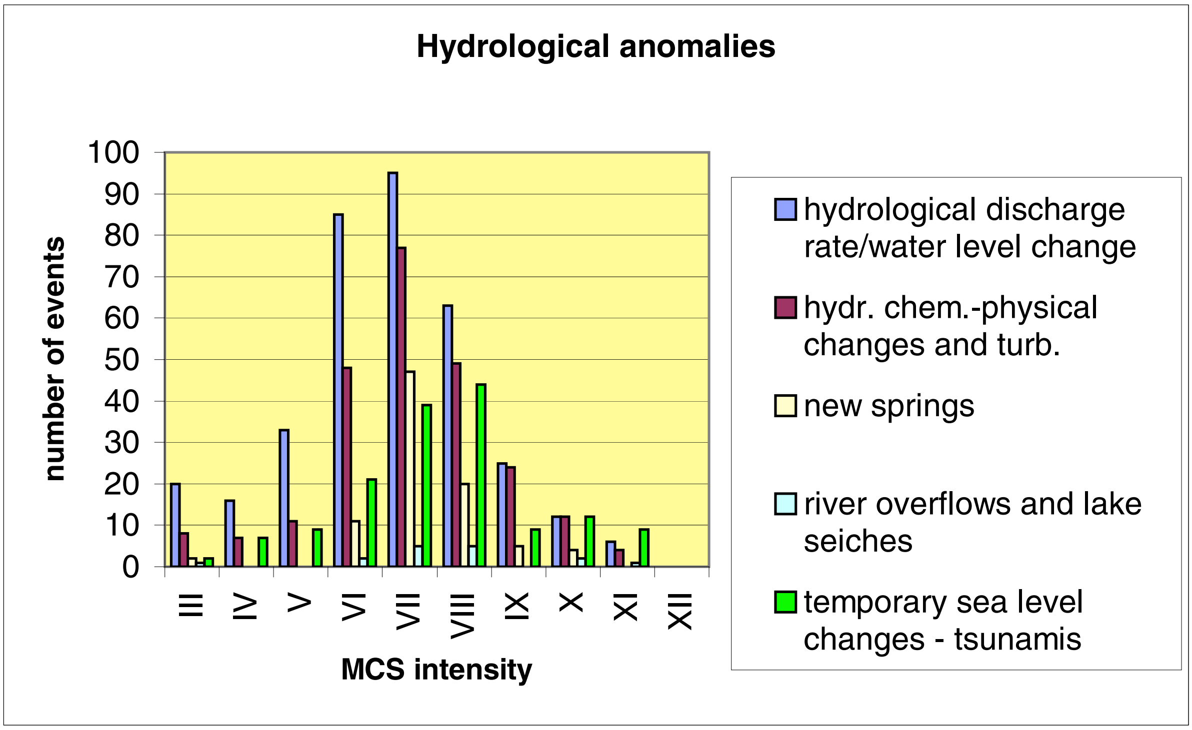
APPENDIX 2

Distribution of ground effects by type and macroseismic intensity for 114 Italian historical earthquakes


Other ground effects
number of events
70
60
50
40
30
20
10
0
III
IV
V
VI
VII
VIII
IX
X
XI
XII
MCS intensity
liquefaction and lateral spreading
soil and backfilling compaction
tectonic subsidence/uplift
karst vault collapses - sinkholes


Landslides by type
number of events
120
100
80
60
40
20
0
III
IV
V
VI
VII
VIII
IX
X
XI
XII
MCS intensity
rock falls
rotational slides
slump-earth flows


Ground cracks
180
160
140
120
100
80
60
40
20
0
number of events
III IV V VI VII VIII IX X XI XII
MCS intensity
ground cracks in paved roads
ground cracks in stiff ground
ground cracks in loose sediment-wet soil


Hydrological anomalies
100
90
80
70
60
50
40
30
20
10
0
number of events
III IV V VI VII VIII IX X XI XII
MCS intensity
hydrological discharge rate/water level change
hydr. chem.-physical changes and turb.
new springs
river overflows and lake seiches
temporary sea level changes - tsunamis

APPENDIX 3

Examples of geological effects of earthquakes

This appendix provides a collection of images of environmental effects of earthquakes. Most of the photographs show examples of surface faulting (Figs. A3.1-A3.20), the most spectacular effect of major earthquakes, which actually is the main geological evidence of their causative process.

Also, some examples are given of ground fractures, which are the most elusive among the geological effects of earthquakes. As a matter of fact, their origin is often argument of debate among scientists: surface faulting, hence a primary feature, or ground settlement (slide, lateral spread, liquefaction, soil compaction, etc..), due to ground shaking? A meticulous field investigation, although not always able to reconcile the different viewpoints, permits in general a satisfactory understanding of the underlying process.

Liquefaction events are frequent in loose recent coastal alluvial and lake sediments. Effects can be spectacular and source of high risk, where buildings, bridges, artificial basins are constructed above liquefaction-prone ground as in Njigata in 1964 (Fig. A3.28), Anchorage in the same year (Fig. A3.29), and in many other cases in the world (e.g., the failure of the Lower San Fernando dam in 1971).

Sinkholes are not frequently associated to earthquakes, but in peculiar conditions they might characterize the landscape and be a significant source of hazard (Figs. A3.34-35).

Landslides and rock falls are very common in the epicentral area, but may occur even far from it, where the equilibrium is already precarious (as it was likely the case at Cerda, Fig. A3.33); moreover, landslides may show up days after the event.

Hydrological changes and gas emissions are also elusive, being often temporary and difficult to document by images.

SURFACE FAULTING

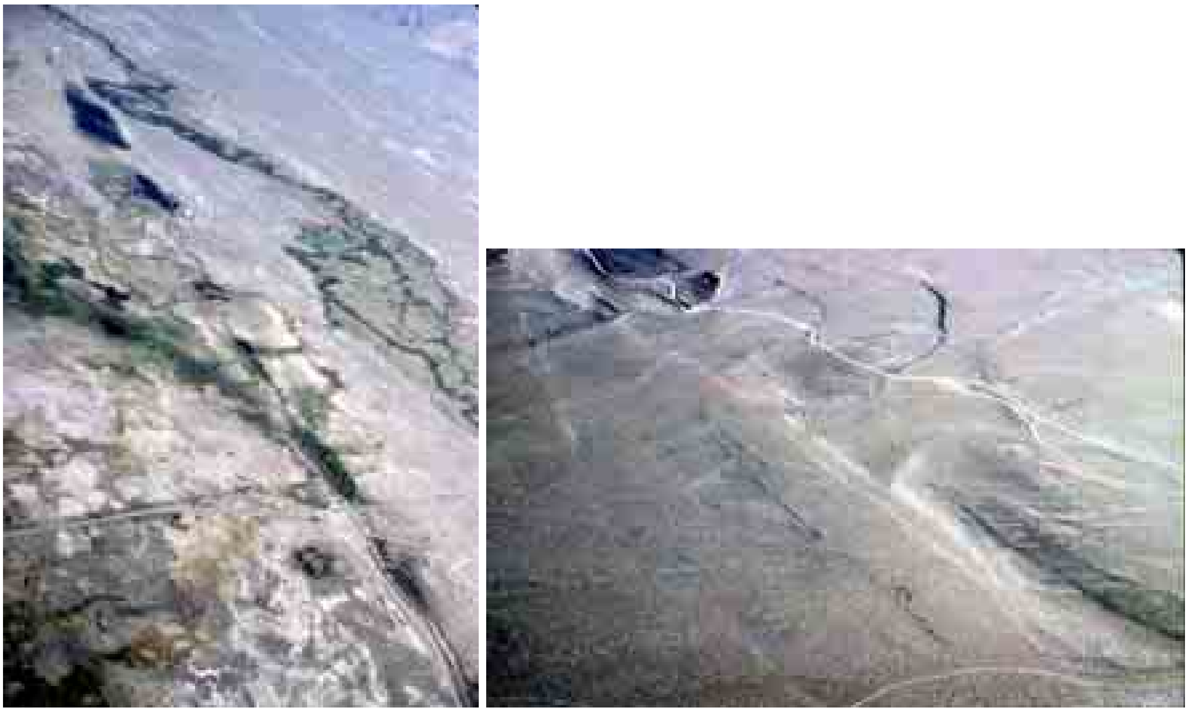


Figure A3.1 – Oblique aerial views of the Owens valley fault zone (eastern California), affected by more than 110 km of surface faulting during the 3 March 1872 earthquake (M_s 7.6) (Vittori et al., 2003). Photos E. Vittori.

Figure A3.2 – Fault scarp of Owens Valley 1872 earthquake (M_s 7.6), near Manzanar (Vittori et al., 2003). Photo E. Vittori.

Figure A3.3 – Fault scarp of Borah Peak 28 October 1983 earthquake (M_s 7.3). Epicentral Intensity IX MM. Photo E. Vittori.

Figure A3.4 – Fault scarp of Dixie Valley 16 December 1954 earthquake (M 7.2) (left). Close-up view of the scarp with Burt Slemmons for scale (right). The estimated epicentral intensity was X MM. Photos E. Vittori.

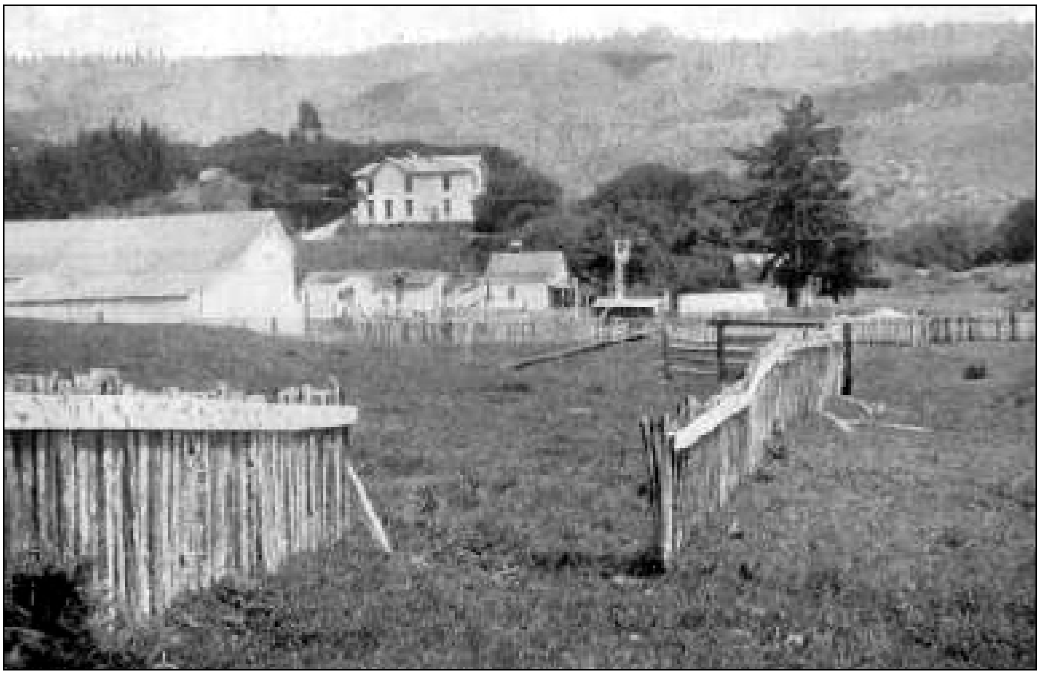


Figure A3.5 – 18 April 1906, San Francisco earthquake (M_s 8.3): ca. 250 cm of right-lateral fault movement northwest of Woodville, California. Photo G.K. Gilbert.

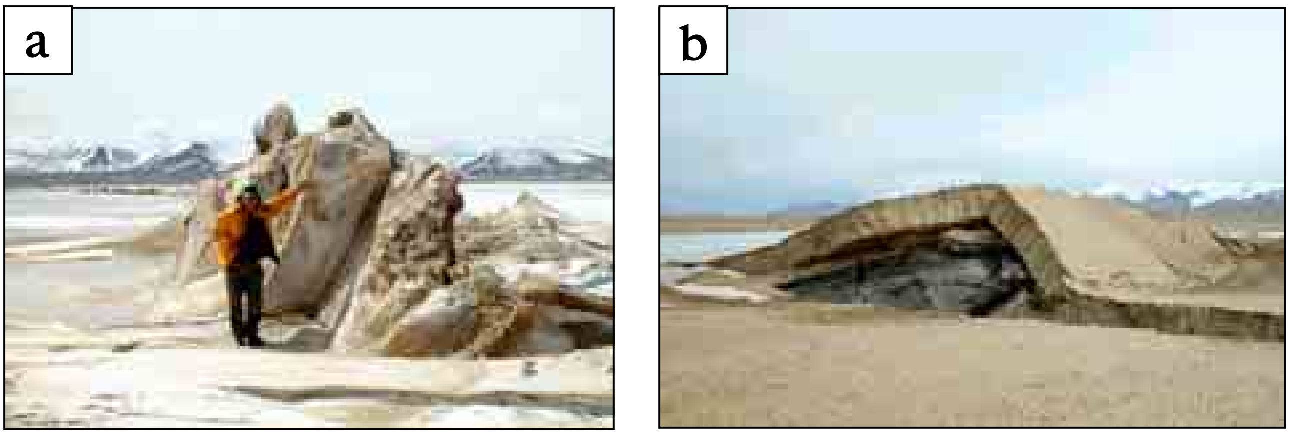


Figure A3.6 – 14 November 2001 Kunlun (NW China) earthquake (M_w 7.8): pushup structures on the frozen surface of Kushuiwan Lake (**a**) and west of Sun Lake (**b**). Photo courtesy of Bihong Fu.

Figure A3.7 – Left-lateral (5m) and vertical (0.7 m) faulting associated to the 16 July 1990 Luzon (Philippines) earthquake (M_s 7.8) (Yomogida and Nakata, 1994). Photo courtesy of T. Nakata.

Figure A3.8 – Aerial view of the fault rupture on northern Awaji Island due to 17 January 1995 Kobe earthquake (M_w 6.9). Photo courtesy of Y. Kinugasa.

Figure A3.9 - Fault scarp of the 7 December 1988 Spitak (Armenia) earthquake (M_s 6.8) a few days after the event. Photo courtesy of A. Kharakanian.

Figure A3.10 – Fault scarp of the 7 December 1988 Spitak (Armenia) earthquake (M_s 6.8) in October 1998. Photo E.Vittori.

Figure A3.11 – Cumulative effect of repeated earthquakes along the Chon Kemin fault zone (Kyrgyzstan). The last event (M_s 8.2) took place on January 3, 1911. Photo E. Vittori.

Figure A3.12 – Detail of the fault scarp of the 1911 (M_s 8.2) Chon Kemin (Kyrgyzstan) earthquake. Courtesy of D. Delvaux (for more details see http://www.uiggm.nsc.ru/issyk-kul/1911%20kem.htm).

Figure A3.13 – Fault scarp (ca. 1 m high) of the 13 January 1915 (M 7.0) Avezzano earthquake (from Oddone, 1915).

Figure A3.14 – Fault scarp in the Fucino basin (San Benedetto dei Marsi site) reactivated during the January 13, 1915 (Ms 7.0) Avezzano earthquake (Michetti et al., 1996). Photo E. Vittori.

Figure A3.15 – view of the Serrone active Fault on the northwestern side of the Fucino basin (Central Apennines). Its last reactivation (ca. 1 meter of normal slip) occurred in 1915, during the ruinous Avezzano earthquake (Ms = 7) (Michetti et alii, 1996). It is readily evident the post-LGM displacement (shown by the large offset of the regularized slope), indicating the occurrence of several coseismic reactivations during the Holocene. Photo E. Vittori.

Figure A3.16 – Aerial oblique view of the Parasano fault, another fault reactivated in the Fucino area during the 1915 earthquake. Photo G. Carver.

Figure A3.17 – (left) Slickenside reactivated at Senerchia during the Irpinia (southern Apennines) earthquake in 1980 (Ms 6.9). Photo courtesy of A. Pissart. (Right) scarp ca. 80 cm high at Piano di Pecore (Monte Marzano) formed during the same earthquake.

Figure A3.18 – Trench across a fault scarp along the Pollino active fault zone (located near the border between Basilicata and Calabria, Southern Apennines). No historical events are known in the area, but the trenches have revealed a Middle Age earthquake, with significant impact for seismic hazard (Michetti et alii, 1997). Photo E. Vittori.

Figure A3.19 – Fault rupture of the September 26, 1997 earthquake (M_w 6) in Umbria-Marche region (central Italy); Vittori et alii, 2000. Photo E. Vittori.

Figure A3.20 – Left-lateral faulting in the eastern slope of Etna volcano (Pernicana fault). Different segments of this fault move either by creep or stick-slip. More than half a meter of slip took place here during the october-november 2002 volcanic and seismic crisis. Photo E. Vittori

GROUND CRACKS

Figure A3.21 – September 19, 1985 Michoacan (Mexico) earthquake (M_s 8.0): scarp due to differential compaction in Mexico City. Photo E. Vittori.

Figure A3.22 – Ground cracks affecting a dirt road in a flat area near Isola (Umbria region), caused by the 1997 Umbria-Marche (Central Apennines) earthquake (Mw 6.0) (Esposito et alii, 2000; Vittori et alii, 2000). Photo S. Porfido.

Figure A3.23 – Ground cracks of debated origin affecting a paved road near San Giuliano (Molise region), caused by the 2002 Molise (Southern Apennines) earthquake (Ml 5.4). Photo E. Esposito.

Figure A3.24 – Ground cracks that can be followed for tens of meters in grass fields occurred during the 1976 Friuli, north-eastern Italy, earthquake, Ms 6.5 (left, from Cavallin et alii, 1977), and the 1997 Umbria-Marche earthquake (right, photo E. Vittori).

LIQUEFACTION AND COMPACTION

Figure A3.25 – Small liquefaction cones along fissures near the Belice River bridge, on the road for Montevago (Belice alluvial plain), produced during the 15 January 1968 Belice earthquake sequence (M_s 5.9); Michetti et alii, 1995. The preliminary estimate of the Inqua EEE Intensity would be around VIII.
Photo courtesy of M. Casirati.

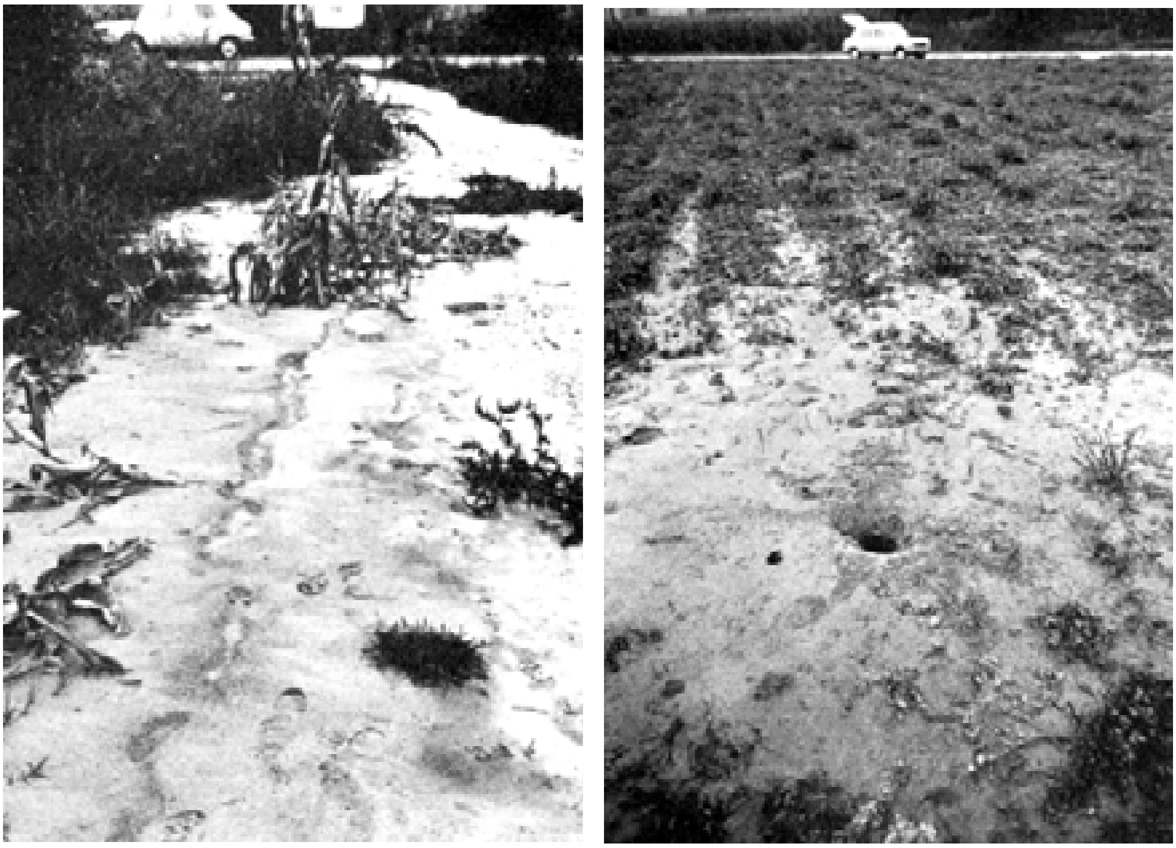


Figure A3.26 –liquefaction features in farmed land occurred during the 1976, Ms 6.5, Friuli earthquake in northeastern Italy (from Siro, 1977). The preliminary estimate of the Inqua EEE Intensity would be close to the degree IX.

Figure A3.27 – Ground failure (liquefaction of artificial embankment) along the seacoast during the 15 April 1979 Montenegro earthquake (M_w 6.9). The preliminary estimate of the Inqua EEE Intensity is X. Photo E. Iaccarino.

Figure A3.28 – Tilt of buildings at Kawagishi-Cho due to liquefaction following the June 16, 1964 Niigata (Japan) earthquake (M_s 7.5). The preliminary estimate of the Inqua EEE Intensity is XI.
Source: http://cee.uiuc.edu/sstl/education/liquefaction/

Figure A3.29 – Liquefaction of soil and lateral spreading of saturated soft clay and sand in Anchorage during the Alaskan Earthquake of March 27 1964 (M 8.6). The ground dropped on the average of 11 meters and houses slid about 150 to 180 meters. This effect, which determined a widespread change of the landscape, can be evaluated of Intensity XII in the Inqua EEE Scale. Source: http://cee.uiuc.edu/sstl/education/liquefaction/

Figure A3.30 – September 19, 1985 Michoacan (Mexico) earthquake (M_s 8.0): backfill compaction in the harbour facilities of Lazaro Cardenas. The preliminary estimate of the Inqua EEE Intensity is VIII. Photo E. Vittori.

ROCKFALLS AND SLIDES

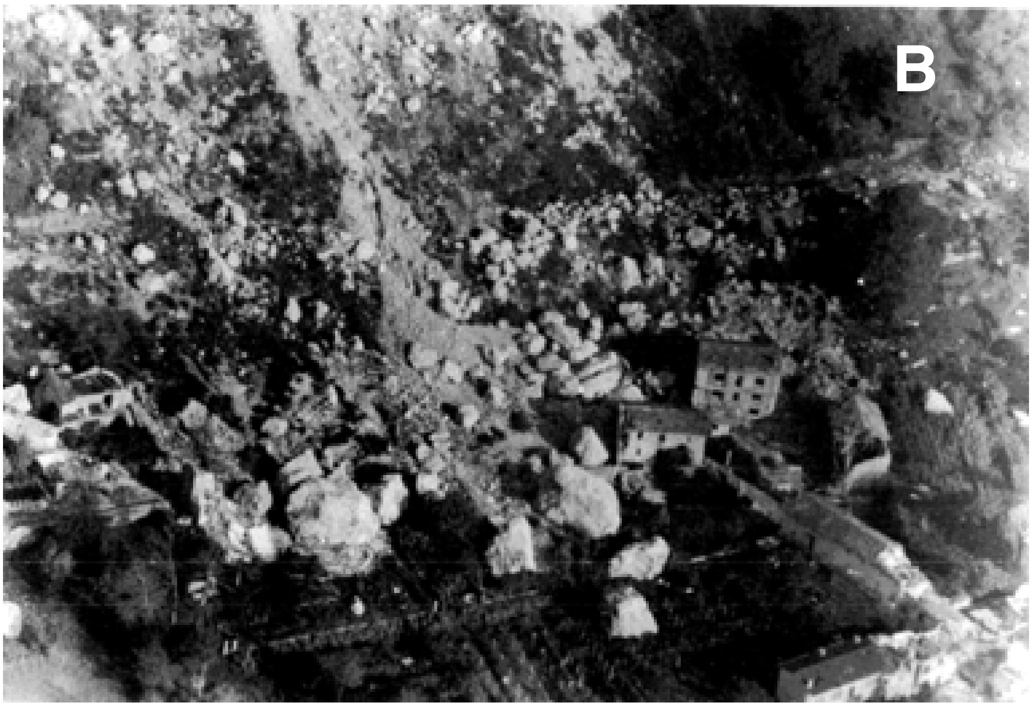


Figure A3.31 – A ruinous rock slide detached from the flank of Mt. Brancot destroyed several houses in the village of Braulins during the 6 May 1976 Friuli earthquake (M_s 6.5) (A: photo Bordin; B from Briseghella et alii, 1976). The local MCS Intensity was VIII-IX at Braulins.

Figure A3.32 – Crown of landslide menacing the emptied Acciano reservoir, induced by the 26 September 1997 Umbria-Marche earthquake (M_w 6.0). Photo E. Vittori.

Figure A3.33 – A: flank of a wide landslide occurred near Cerda (Palermo, western Sicily) following the September 6, 2002 (Ml 5.6) Palermo earthquake. B: particular of the crown. A local macroseismic intensity of V (EMS98) was estimated at Cerda. Photos M. Guerra and E. Vittori.

Figure A3.34 – Above: rock falls from the flanks of a narrow canyon near Bam (southern Iran) following the 26 December 2003 (Mw 6.5) Bam earthquake. Below: aerial view of rock falls and sinkholes from the same area. The local macroseismic intensity was IX MM (source: Eshghi and Zarè, 2004).

Figure A3.35 – Sinkholes near Bam (southern Iran) following the 26 December 2003 (Mw 6.5) Bam earthquake. The local macroseismic intensity was IX MM (source: Eshghi and Zarè, 2004).

Figure A3.36 – Minor rock falls from the flanks of paved roads near the epicentral area of the 1997 Umbria-Marche earthquake. The preliminary estimate of the Inqua EEE Intensity is VII. Photos E.Vittori.

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APPENDIX 4

Comparison between the INQUA scale and the MCS-1930, MM-1931, MM-1956, and MSK-1964 scales

for the comparison with the Japanese JMA scale see Table 1 the text

MCS Scale

Intensity	MCS Scale	INQUA Scale
I	**Imperceptible** Noticed only by seismographs.	**No perceptible environmental effects** Extremely rare occurrence of small effects detected only from instrumental observations, typically in the far field of strong earthquakes.
II	**Very weak** Noticed only by a very few persons, usually of a nervous disposition who are in perfectly quiet surroundings and who are nearly always on the highest floors of buildings.	**No perceptible environmental effects** Extremely rare occurrence of small effects detected only from instrumental observations, typically in the far field of strong earthquakes.
III	**Weak** Even in highly inhabited areas the quake is noticed only by a very small part of the population and only when at home. Is similar to the movement caused by a car going by at a very high speed. People usually recognize it as a seismic phenomenon only after having discussed it among themselves	**No perceptible environmental effects** Primary effects are absent. Extremely rare occurrence of small variations in water level in wells and/or the flow-rate of springs, typically in the far field of strong earthquakes.
IV	**Moderate** People outside of buildings do not normally notice the earthquake. It is usually identified by some persons, but not everybody who are inside the buildings, after observing a slight swaying of objects and furniture. Crystal ware and chinaware which are next to one another, shake as if a heavy truck were going along on a badly asphalted road. Windows shake, doors, beams and boards move, ceilings creak.	**No perceptible environmental effects** Primary effects are absent. A very few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon. Rare occurrence of small variations in water level in wells and/or the flow-rate of springs. Extremely rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells, especially within large karstic spring systems most prone to this phenomenon. Exceptionally, rocks may fall and small landslides may be (re)activated, along slopes where equilibrium is already very unstable, e.g. steep slopes and cuts, with loose or saturated soil. Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems. Very rare temporary sea level changes in the far field of strong earthquakes. Tree limbs may shake.

V	**Quite strong** People in the streets or in open spaces notice the earthquake even during daily activities. The earthquake is noticed in flats due to the movements of the whole building. Plants and delicate branches of bushes and trees can be seen moving as if they were blown by the wind. Hanging objects start swaying, e.g. curtains, traffic light, hanging lights and chandeliers which are not very heavy. Bells ring pendulum-clock either stop or sway with higher period. This depends on the direction of the earthquake, wether it is perpendicular or normal to the motion of the oscillation Sometimes pendulum-clocks, which have not worked for a long time start working again Alarm clocks go off. Electric light flickers or goes off due to the movements of the line. Small quantities of liquid, in containers filled to the rim, spill. Knik-knaks and similar objects are knocked over. Objects leaning against walls and light furniture can be slightly moved from their places. Furniture shakes, doors and windows can break. Most people sleeping are woken up. People sometimes even run out of the buildings into the streets.	**Marginal effects on the environment** Primary effects are absent. A few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon. Extremely rare occurrence of significant variations in water level in wells and/or the flow-rate of springs. Rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Rare small rockfalls, rare rotational landslides and slump earth flows, along slopes where equilibrium is unstable, e.g. steep slopes, with loose or saturated soil. Extremely rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table). Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems. Occurrence of landslides under sea (lake) level in coastal areas. Rare temporary sea level changes in the far field of strong earthquakes. Tree limbs may shake.
VI	**Strong** Everybody notices the earthquake with fright, so that many of them run into the streets. Some people feel them falling. Liquids move quite a lot. Pictures, books and similar objects fall from the walls and shelves. Chinaware breaks. Quite stable furnishings and even isolated pieces of furniture are moved or fall over. Bell of small churches and chapels ring and tower clocks strike. Well-built houses shows slight damages, e.g. cracks in the plaster, mouldings and walls renderings fall. Major, but not destructive damages, occur on not very well-built buildings. Some bricks and tiles can fall.	**Modest effects on the environment** Primary effects are absent. *Occasionally thin, millimetric, 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 (asphalt / stone) roads.* Rare occurrence of significant variations in water level in wells and/or the flow-rate of springs. Rare occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Rockfalls and landslides up to ca. 10^3 m^3 can occur, especially where equilibrium is unstable, e.g. steep slopes and cuts, with loose / saturated soil, or weathered / fractured rocks. The area affected by them is usually less than 1 km^2. *Rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).* Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes. Occurrence of landslides under sea level in coastal areas. Occasionally significant waves are generated in still waters. *In wooded areas, trees shake; a very few unstable limbs may break and fall, also depending on species and state of health.*

VII	**Very strong** Quite a few damages are caused on objects and furniture in flats, even heavy pieces. These fall over and/or break. Big bells toll. Watercourses, ponds and water bodies get wavy and cloudy due to the movements of the slime on the bottom. Parts of sand and gravel shores disappear. The water levels of the wells vary. Moderated damages occur to quite a few well-built buildings, e.g. small cracks in the walls. Quite big pieces of plastering and bricks fall. A lot of tiles fall. Quite a few chimneys are damaged by cracks, fallen tiles and stones. Chimneys, which were already damaged, fall on the roofs damaging them. Decoration of towers and high buildings, which were not very well applied, fall. Quite a lot of damages are caused to the plastering and structures of houses. Single houses not very well built or restored, fall down.	**Appreciable effects on the environment** Primary effects observed very rarely. Limited surface faulting, with length of tens of meters and centimetric offset, may occur associated with volcano-tectonic earthquakes. *Fractures up to 5-10 cm wide 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. Centimetric cracks common in paved (asphalt or stone) roads.* Rare occurrence of significant variations in water level in wells and/or the flow rate of springs. Very rarely, small springs may temporarily run dry or be activated. Quite common occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Scattered landslides occur in prone areas; where equilibrium is unstable (steep slopes of loose / saturated soils; rock falls on steep gorges, coastal 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. The affected area is usually less than 10 km^2. *Rare cases of liquefaction, with sand boils up to 50 cm in diameter, in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).* Possible collapse of karst vaults with the formation of sinkholes, even where the water table is deep. Occurrence of significant landslides under sea level in coastal areas. Waves may develop in still and running waters. In wooded areas, trees shake; several unstable branches may break and fall, also depending on species and state of health.

VIII	**Ruinous** Whole tree trunks sway lively or fall down. Very heavy pieces of furniture are moved far from their original places or even knocked over. Statues, milestones placed in the ground or even in churches, cemeteries, and parks rotate on their pedestals or are knocked down. Solid town walls of stones are opened and knocked down. Severe damages occur in about a fourth of the houses; some fall down and quite a few become uninhabitable. Most part of the framing falls in buildings. Wooden houses are either crushed or knocked down. In particular the falling of the church towers and smoke stacks cause much higher damages to the nearby buildings than the earthquake itself. Cracks are formed in slopes and the ground. Sand and slime in wet grounds come out.	**Considerable effects on the environement** *Primary effects observed rarely. Ground ruptures (surface faulting) may develop, up to several hundred meters long, with offsets generally smaller than 5 cm, particularly for very shallow focus earthquakes, such as volcano-tectonic events. Tectonic subsidence or uplift of the ground surface with maximum values on the order of a few centimeters may occur.* *Fractures up to 25 - 50 cm wide are 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.* *Springs can 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. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy.* 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. The affected area is usually less than 100 km^2. *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).* Karst vaults may collapse, forming sinkholes. Frequent occurrence of landslides under the sea level in coastal areas. Significant waves develop in still and running waters. *Trees shake vigorously; some branches or rarely even tree-trunks in very unstable equilibrium may break and fall.* *In dry areas, dust clouds may rise from the ground in the epicentral area.*

IX	**Destructive** About half of the stone houses are severely destroyed; quite a few collapse, most of them become uninhabitable. Framed houses are destroyed at the foundations and crushed. The fact that beams are torn away from their original places can often cause major damages to the buildings.	**Natural effects leave significant and permanent traces in the environment** *Primary effects observed commonly. Ground ruptures (surface faulting) develop, up to a few km long, with offsets generally smaller than 10 - 20 cm. Tectonic subsidence or uplift of the ground surface with maximum values in the order of a few decimeters may occur.* *Fractures up to 50 - 100 cm wide 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.* Springs can change their flow-rate and/or elevation of outcrop to a considerable extent. Some small springs may even run dry. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy. *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. The affected area is usually less than 1000 km^2.* *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).* Karst vaults of relevant size collapse, forming sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running waters. Small tsunamis may reach the coastal areas with tidal waves up to 50 - 100 cm high.* Trees shake vigorously; branches or even tree-trunks in unstable equilibrium frequently break and fall. In dry areas dust clouds may rise from the ground. In the epicentral area, small stones may jump out of the ground, leaving typical imprints in soft soil.

X	**Completely destructive** Very severe destruction of about ¾ of the buildings; most of them fall down. Very severe damages occur on solid wooden buildings and bridges; some of then are destroyed. Bank, dams, etc. are highly damaged. Railways are bent slightly and pipes (water, gas and water pipes) are cut off or broken or crushed. Cracks are formed in paved and asphalted streets, which are furthermore uplifted due to the pressure. Cracks, which width can be up to several decimetres form in thin, and above all, wet ground. In particular cracks almost a metre wide form parallel to watercourses. Not only does soil slide down hillslopes, but boulders roll down towards the valley. Rocks falls from the river embankments and cliffs. Sandy and muddy shores are moved, causing not important changes to the landscape. The water level of the wells varies continually. Rivers, canals, lakes , etc. become very wavy.	**Environmental effects become dominant** *Primary ruptures become leading. Ground ruptures (surface faulting) can extend for several tens of km, with offsets reaching 50 - 100 cm and more (up to ca. 1-2 m in case of reverse faulting and 3-4 m for normal faulting). Gravity grabens and elongated depressions develop; for very shallow focus earthquakes, such as volcano-tectonic events, 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.* *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. The affected area is usually up to 5000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Some may run dry or disappear, generally temporarily. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy. *Open ground cracks up to more than 1 m wide 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.* *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.* Large karst vaults collapse, forming great sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running waters, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas, with tidal waves up to a few meters high.* Trees shake vigorously; branches or even tree-trunks very frequently break and fall, if already in unstable equilibrium. In dry areas, dust clouds may rise from the ground. *Stones, even if well anchored in the soil, may jump out of the ground, leaving typical imprints in soft soil.*

XI	**Catastrophic** Entire stone buildings collapse. Only very well-built stone buildings or isolated (and very elastic) wooden huts manage to stand up to the earthquake. Even very solid and big bridges collapse due to the fall of stone pillars or iron ones which give away. Embankments and dams are taken to pieces. Railway lines are severely bent and crushed. Pipes in the ground are torn away from one another and are not longer repairable. Big movements of various extension occur in the ground, the intensity of which is determined by the type of terrain. Big cracks and cleavages are opened. In soft and marshy terrains the instability is mostly horizontal and vertical, thus causing the overflow of sandy and slimy water. Grounds crumbling and rock fall.	**Environmental effects become essential for intensity assessment** *Primary surface faulting can extend for several tens of km up to more than 100 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.* *Large landslides and rock-falls (> 10^5 – 10^6 m3) 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. Primary and secondary environmental effects can be observed over territory as large as 10000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently becomes muddy. *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.* *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.* Very large karst vaults collapse, forming sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas with tidal waves up to many meters high.* *Trees shake vigorously; many tree branches break and several whole trees are uprooted and fall.* In dry areas dust clouds may arise from the ground. *Stones and small boulders, even if well anchored in the soil, may jump out of the ground leaving typical imprints in soft soil.*

XII	**Absolutely catastrophic** No artifact can resist. The landscape change completely. Superficial and underground watercourses undergo the most different changes: waterfalls appear, water bodies disappear, rivers change their course.	**Environmental effects are now the only tool enabling intensity to be assessed** *Primary surface faulting can extend for several hundreds of km up to 1000 km, 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).* *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. Primary and secondary environmental effects can be observed over territory larger than 50000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells. Water temperature often changes in springs and/or wells. Water in lakes and rivers frequently becomes muddy. *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.* *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.* Very large karst vaults collapse, forming sinkholes. Frequent very large landslides under the sea level in coastal areas. *Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters overflow from their beds; watercourses change the direction of flow. Tsunamis reach the coastal areas with tidal waves up to tens of meters high.* Trees shake vigorously; many tree branches break and many whole trees are uprooted and fall. In dry areas dust clouds may arise from the ground. Even large boulders may jump out of the ground leaving typical imprints in soft soil.

Modified Mercalli Scale of 1931

Intensity	Modified Mercalli Scale of 1931	INQUA Scale
I	Not felt - or, except rarely under especially favourable circumstances. Under certain conditions, at and outside the boundary of the area which a great shock is felt: sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway - doors may swing, very slowly.	**No perceptible environmental effects** Extremely rare occurrence of small effects detected only from instrumental observations, typically in the far field of strong earthquakes.
II	Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons. Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced.	**No perceptible environmental effects** Extremely rare occurrence of small effects detected only from instrumental observations, typically in the far field of strong earthquakes.
III	Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first, duration estimated in some cases. Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movement may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly	**No perceptible environmental effects** Primary effects are absent. Extremely rare occurrence of small variations in water level in wells and/or the flow-rate of springs, typically in the far field of strong earthquakes.
IV	Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy, or heavily loaded trucks. Sensation like heavy body striking building, or falling of heavy objects to inside. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swing, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars slightly.	**No perceptible environmental effects** Primary effects are absent. A very few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon. Rare occurrence of small variations in water level in wells and/or the flow-rate of springs. Extremely rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells, especially within large karstic spring systems most prone to this phenomenon. Exceptionally, rocks may fall and small landslides may be (re)activated, along slopes where equilibrium is already very unstable, e.g. steep slopes and cuts, with loose or saturated soil. Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems. Very rare temporary sea level changes in the far field of strong earthquakes. Tree limbs may shake.

V	Felt indoors by practically all, outdoors by many or most. Outdoors direction estimated. Awakened many, or most. Frightened few - slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware, to some extent. Cracked windows - in some cases, but not generally. Overturned small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened or closed, doors, shutters, abruptly. Pendulum clocks stopped, started, or ran fast, or slow. Moved small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes, shaken slightly.	**Marginal effects on the environment** Primary effects are absent. A few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon. Extremely rare occurrence of significant variations in water level in wells and/or the flow-rate of springs. Rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Rare small rockfalls, rare rotational landslides and slump earth flows, along slopes where equilibrium is unstable, e.g. steep slopes, with loose or saturated soil. Extremely rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table). Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems. Occurrence of landslides under sea (lake) level in coastal areas. Rare temporary sea level changes in the far field of strong earthquakes. Tree limbs may shake.
VI	Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees, bushes, shaken slightly to moderately. Liquid set in strong motion. Small bells rang -church, chapel, school etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knick-knacks, books, pictures. Overturned furniture, in many instances. Moved furnishings of moderately heavy kind.	**Modest effects on the environment** Primary effects are absent. *Occasionally thin, millimetric, 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 (asphalt / stone) roads.* Rare occurrence of significant variations in water level in wells and/or the flow-rate of springs. Rare occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Rockfalls and landslides up to ca. 10^3 m^3 can occur, especially where equilibrium is unstable, e.g. steep slopes and cuts, with loose / saturated soil, or weathered / fractured rocks. The area affected by them is usually less than 1 km^2. *Rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).* Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes. Occurrence of landslides under sea level in coastal areas. Occasionally significant waves are generated in still waters. *In wooded areas, trees shake; a very few unstable limbs may break and fall, also depending on species and state of health.*

VII	Frightened all - general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-build ordinary buildings, considerable in poorly build or badly designed buildings, abode houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows, furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roof. Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.	**Appreciable effects on the environment** Primary effects observed very rarely. Limited surface faulting, with length of tens of meters and centimetric offset, may occur associated with volcano-tectonic earthquakes. *Fractures up to 5-10 cm wide 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. Centimetric cracks common in paved (asphalt or stone) roads.* Rare occurrence of significant variations in water level in wells and/or the flow rate of springs. Very rarely, small springs may temporarily run dry or be activated. Quite common occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Scattered landslides occur in prone areas; where equilibrium is unstable (steep slopes of loose / saturated soils; rock falls on steep gorges, coastal 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. The affected area is usually less than 10 km^2. *Rare cases of liquefaction, with sand boils up to 50 cm in diameter, in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).* Possible collapse of karst vaults with the formation of sinkholes, even where the water table is deep. Occurrence of significant landslides under sea level in coastal areas. Waves may develop in still and running waters. In wooded areas, trees shake; several unstable branches may break and fall, also depending on species and state of health.

VIII	Fright general - alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly - branches, trunks, broken off, especially palm trees. Ejected sand and mud in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls. Cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stack, towers. Moved conspicuously, overturned, very heavy furniture.	**Considerable effects on the environement** *Primary effects observed rarely. Ground ruptures (surface faulting) may develop, up to several hundred meters long, with offsets generally smaller than 5 cm, particularly for very shallow focus earthquakes, such as volcano-tectonic events. Tectonic subsidence or uplift of the ground surface with maximum values on the order of a few centimeters may occur.* *Fractures up to 25 - 50 cm wide are 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.* *Springs can 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. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy.* 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. The affected area is usually less than 100 km^2. *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).* Karst vaults may collapse, forming sinkholes. Frequent occurrence of landslides under the sea level in coastal areas. Significant waves develop in still and running waters. *Trees shake vigorously; some branches or rarely even tree-trunks in very unstable equilibrium may break and fall.* *In dry areas, dust clouds may rise from the ground in the epicentral area.*

IX	Panic general. Cracked ground conspicuously. Damage considerable in (masonry) structure build especially to withstand earthquakes: threw out of plumb some wood-frame houses build especially to withstand earthquakes; great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.	**Natural effects leave significant and permanent traces in the environment** *Primary effects observed commonly. Ground ruptures (surface faulting) develop, up to a few km long, with offsets generally smaller than 10 - 20 cm. Tectonic subsidence or uplift of the ground surface with maximum values in the order of a few decimeters may occur.* *Fractures up to 50 - 100 cm wide 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.* Springs can change their flow-rate and/or elevation of outcrop to a considerable extent. Some small springs may even run dry. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy. *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. The affected area is usually less than 1000 km^2.* *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).* Karst vaults of relevant size collapse, forming sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running waters. Small tsunamis may reach the coastal areas with tidal waves up to 50 - 100 cm high.* Trees shake vigorously; branches or even tree-trunks in unstable equilibrium frequently break and fall. In dry areas dust clouds may rise from the ground. In the epicentral area, small stones may jump out of the ground, leaving typical imprints in soft soil.

X	Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changed level of water in wells. Threw water on banks of canals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-build wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipe lines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.	**Environmental effects become dominant** *Primary ruptures become leading. Ground ruptures (surface faulting) can extend for several tens of km, with offsets reaching 50 - 100 cm and more (up to ca. 1-2 m in case of reverse faulting and 3-4 m for normal faulting). Gravity grabens and elongated depressions develop; for very shallow focus earthquakes, such as volcano-tectonic events, 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.* *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. The affected area is usually up to 5000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Some may run dry or disappear, generally temporarily. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy. *Open ground cracks up to more than 1 m wide 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.* *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.* Large karst vaults collapse, forming great sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running waters, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas, with tidal waves up to a few meters high.* Trees shake vigorously; branches or even tree-trunks very frequently break and fall, if already in unstable equilibrium. In dry areas, dust clouds may rise from the ground. *Stones, even if well anchored in the soil, may jump out of the ground, leaving typical imprints in soft soil.*

XI	Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments, often for long distances. Few, if any (masonry), structures remained standing. Destroyed large well-built bridges by the wrecking of supporting piers, or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipe lines buried in earthy completely out of service.	**Environmental effects become essential for intensity assessment** *Primary surface faulting can extend for several tens of km up to more than 100 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.* *Large landslides and rock-falls (> 10^5 – 10^6 m3) 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. Primary and secondary environmental effects can be observed over territory as large as 10000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently becomes muddy. *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.* *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.* Very large karst vaults collapse, forming sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas with tidal waves up to many meters high.* *Trees shake vigorously; many tree branches break and several whole trees are uprooted and fall.* In dry areas dust clouds may arise from the ground. *Stones and small boulders, even if well anchored in the soil, may jump out of the ground leaving typical imprints in soft soil.*

XII	Damage total - practically all works of construction damaged greatly or destroyed. Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc. numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.	**Environmental effects are now the only tool enabling intensity to be assessed** *Primary surface faulting can extend for several hundreds of km up to 1000 km, 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).* *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. Primary and secondary environmental effects can be observed over territory larger than 50000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells. Water temperature often changes in springs and/or wells. Water in lakes and rivers frequently becomes muddy. *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.* *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.* Very large karst vaults collapse, forming sinkholes. Frequent very large landslides under the sea level in coastal areas. *Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters overflow from their beds; watercourses change the direction of flow. Tsunamis reach the coastal areas with tidal waves up to tens of meters high.* Trees shake vigorously; many tree branches break and many whole trees are uprooted and fall. In dry areas dust clouds may arise from the ground. Even large boulders may jump out of the ground leaving typical imprints in soft soil.

Modified Mercalli Scale of 1956

Masonry A, B, C, D. To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the followig lettering(wich has no connection with the conventional Class A, B, C construction)

Classification of masonry:

Masonry A. Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak orizontally.

Intensity	Modified Mercalli Scale of 1956	INQUA Scale
I	Not felt. Marginal and long- period of large earthquakes	**No perceptible environmental effects** Extremely rare occurrence of small effects detected only from instrumental observations, typically in the far field of strong earthquakes.
II	Felt by persons at rest, on upper floor, or favourably placed.	**No perceptible environmental effects** Extremely rare occurrence of small effects detected only from instrumental observations, typically in the far field of strong earthquakes.
III	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.	**No perceptible environmental effects** Primary effects are absent. Extremely rare occurrence of small variations in water level in wells and/or the flow-rate of springs, typically in the far field of strong earthquakes.
IV	Hangings objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motorcars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of grade IV, wooden walls and frames crack.	**No perceptible environmental effects** Primary effects are absent. A very few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon. Rare occurrence of small variations in water level in wells and/or the flow-rate of springs. Extremely rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells, especially within large karstic spring systems most prone to this phenomenon. Exceptionally, rocks may fall and small landslides may be (re)activated, along slopes where equilibrium is already very unstable, e.g. steep slopes and cuts, with loose or saturated soil. Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems. Very rare temporary sea level changes in the far field of strong earthquakes. Tree limbs may shake.

V	Felt outdoors; direction estimated. Sleepers wakened. Liquid disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.	**Marginal effects on the environment** Primary effects are absent. A few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon. Extremely rare occurrence of significant variations in water level in wells and/or the flow-rate of springs. Rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Rare small rockfalls, rare rotational landslides and slump earth flows, along slopes where equilibrium is unstable, e.g. steep slopes, with loose or saturated soil. Extremely rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table). Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems. Occurrence of landslides under sea (lake) level in coastal areas. Rare temporary sea level changes in the far field of strong earthquakes. Tree limbs may shake.
VI	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, and so on, off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.	**Modest effects on the environment** Primary effects are absent. *Occasionally thin, millimetric, 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 (asphalt / stone) roads.* Rare occurrence of significant variations in water level in wells and/or the flow-rate of springs. Rare occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Rockfalls and landslides up to ca. 10^3 m^3 can occur, especially where equilibrium is unstable, e.g. steep slopes and cuts, with loose / saturated soil, or weathered / fractured rocks. The area affected by them is usually less than 1 km^2. *Rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).* Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes. Occurrence of landslides under sea level in coastal areas. Occasionally significant waves are generated in still waters. *In wooded areas, trees shake; a very few unstable limbs may break and fall, also depending on species and state of health.*

VII	Difficult to stand. Noticed by drivers of motor cars. Hangings objects quiver. Furniture broken. Damage to masonry D including cracks. Weak chimneys broken at roof line. Fall of plaster ,loose bricks, stones, tiles, cornices, unbraced parapets, and architectural ornaments. Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bell rising. Concrete irrigation ditches damaged.	**Appreciable effects on the environment** Primary effects observed very rarely. Limited surface faulting, with length of tens of meters and centimetric offset, may occur associated with volcano-tectonic earthquakes. *Fractures up to 5-10 cm wide 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. Centimetric cracks common in paved (asphalt or stone) roads.* Rare occurrence of significant variations in water level in wells and/or the flow rate of springs. Very rarely, small springs may temporarily run dry or be activated. Quite common occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Scattered landslides occur in prone areas; where equilibrium is unstable (steep slopes of loose / saturated soils; rock falls on steep gorges, coastal 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. The affected area is usually less than 10 km^2. *Rare cases of liquefaction, with sand boils up to 50 cm in diameter, in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).* Possible collapse of karst vaults with the formation of sinkholes, even where the water table is deep. Occurrence of significant landslides under sea level in coastal areas. Waves may develop in still and running waters. In wooded areas, trees shake; several unstable branches may break and fall, also depending on species and state of health.

VIII	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundation if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.	**Considerable effects on the environement** *Primary effects observed rarely. Ground ruptures (surface faulting) may develop, up to several hundred meters long, with offsets generally smaller than 5 cm, particularly for very shallow focus earthquakes, such as volcano-tectonic events. Tectonic subsidence or uplift of the ground surface with maximum values on the order of a few centimeters may occur.* *Fractures up to 25 - 50 cm wide are 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.* *Springs can 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.* *Water temperature often change in springs and/or wells.* *Water in lakes and rivers frequently become muddy.* 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. The affected area is usually less than 100 km^2. *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).* Karst vaults may collapse, forming sinkholes. Frequent occurrence of landslides under the sea level in coastal areas. Significant waves develop in still and running waters. *Trees shake vigorously; some branches or rarely even tree-trunks in very unstable equilibrium may break and fall.* *In dry areas, dust clouds may rise from the ground in the epicentral area.*

IX	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Conspicuous cracks in ground. In alleviated areas sand and mud ejected, earthquake fountains, sand craters.	**Natural effects leave significant and permanent traces in the environment** *Primary effects observed commonly. Ground ruptures (surface faulting) develop, up to a few km long, with offsets generally smaller than 10 - 20 cm. Tectonic subsidence or uplift of the ground surface with maximum values in the order of a few decimeters may occur.* *Fractures up to 50 - 100 cm wide 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.* Springs can change their flow-rate and/or elevation of outcrop to a considerable extent. Some small springs may even run dry. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy. *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. The affected area is usually less than 1000 km^2.* *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).* Karst vaults of relevant size collapse, forming sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running waters. Small tsunamis may reach the coastal areas with tidal waves up to 50 - 100 cm high.* Trees shake vigorously; branches or even tree-trunks in unstable equilibrium frequently break and fall. In dry areas dust clouds may rise from the ground. In the epicentral area, small stones may jump out of the ground, leaving typical imprints in soft soil.

X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. and mud shifted horizontally on beaches and flat land. Rails bent slightly.	**Environmental effects become dominant** *Primary ruptures become leading. Ground ruptures (surface faulting) can extend for several tens of km, with offsets reaching 50 - 100 cm and more (up to ca. 1-2 m in case of reverse faulting and 3-4 m for normal faulting). Gravity grabens and elongated depressions develop; for very shallow focus earthquakes, such as volcano-tectonic events, 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.* *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. The affected area is usually up to 5000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Some may run dry or disappear, generally temporarily. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy. *Open ground cracks up to more than 1 m wide 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.* *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.* Large karst vaults collapse, forming great sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running waters, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas, with tidal waves up to a few meters high.* Trees shake vigorously; branches or even tree-trunks very frequently break and fall, if already in unstable equilibrium. In dry areas, dust clouds may rise from the ground. *Stones, even if well anchored in the soil, may jump out of the ground, leaving typical imprints in soft soil.*

XI	Rails bent greatly. Underground pipelines completely out of service.	**Environmental effects become essential for intensity assessment** *Primary surface faulting can extend for several tens of km up to more than 100 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. Large landslides and rock-falls (> 10^5 – 10^6 m3) 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. Primary and secondary environmental effects can be observed over territory as large as 10000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently becomes muddy. *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.* *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.* Very large karst vaults collapse, forming sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas with tidal waves up to many meters high.* *Trees shake vigorously; many tree branches break and several whole trees are uprooted and fall.* In dry areas dust clouds may arise from the ground. *Stones and small boulders, even if well anchored in the soil, may jump out of the ground leaving typical imprints in soft soil.*

XII	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air	**Environmental effects are now the only tool enabling intensity to be assessed** *Primary surface faulting can extend for several hundreds of km up to 1000 km, 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).* *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. Primary and secondary environmental effects can be observed over territory larger than 50000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells. Water temperature often changes in springs and/or wells. Water in lakes and rivers frequently becomes muddy. *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.* *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.* Very large karst vaults collapse, forming sinkholes. Frequent very large landslides under the sea level in coastal areas. *Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters overflow from their beds; watercourses change the direction of flow. Tsunamis reach the coastal areas with tidal waves up to tens of meters high.* Trees shake vigorously; many tree branches break and many whole trees are uprooted and fall. In dry areas dust clouds may arise from the ground. Even large boulders may jump out of the ground leaving typical imprints in soft soil.

MSK Scale

Types of the structures (building not antiseismic)

Structure A: Buildings in field-stone, rural structures, adobe houses, clay houses.

B: Ordinary brick buildings, buildings of the large block and prefabricated type, half-timbered structures, buildings in natural hewn stone.

C: Reinforced buildings, well-built wooden structures.

Definition of quantity

Single, a few: about 5%

Many: about 50%

Most: about 74%

Classification of damage to buildings

Grade 1: Slight damage. Fine cracks in plaster; fall of small pieces of plaster.

Grade 2: Moderate damage. Small cracks in wall; fall of fairly large pieces of plaster; pantiles slip off; cracks in chimneys; parts of chimneys fall down.

Grade 3: Heavy damage. Large and deep cracks in walls; fall of chimneys.

Grade 4: Destruction. Gaps in walls; parts of buildings may collapse; separate parts of the buildings lose their cohesion; inner walls and filled-in walls of the frame collapse.

Grade 5: Total damage. Total collapse of buildings.

Intensity	MSK Scale	INQUA Scale
I	**Not noticeable** The intensity of the vibration is below the limit of sensibility; the tremor is detected and recorded by seismographs only.	**No perceptible environmental effects** Extremely rare occurrence of small effects detected only from instrumental observations, typically in the far field of strong earthquakes.
II	**Scarcely noticeable(very slight)** Vibration is felt only by individual people at rest in house, especially on upper floor of buildings.	**No perceptible environmental effects** Extremely rare occurrence of small effects detected only from instrumental observations, typically in the far field of strong earthquakes.
III	**Weak, partially observed only** The earthquake is felt indoors by a few people, outdoors only in favourable circumstances. The vibration is like that due to the passing of a light truck. Attentive observers notice a slight swinging of hanging objects, somewhat more heavily on upper floor.	**No perceptible environmental effects** Primary effects are absent. Extremely rare occurrence of small variations in water level in wells and/or the flow-rate of springs, typically in the far field of strong earthquakes.

IV	**Largely observed** The earthquake is felt indoors by many people, outdoors by a few. Here and there people awake, but no one is frightened. The vibration is like that due to the passing of a heavily loaded truck. Windows, doors and dishes rattle. Floors and walls creack. Furniture begins to shake. Hanging objects swing slightly. Liquids in open vessels are slightly disturbed. In standing motor-cars the shock is noticeable.	**No perceptible environmental effects** Primary effects are absent. A very few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon. Rare occurrence of small variations in water level in wells and/or the flow-rate of springs. Extremely rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells, especially within large karstic spring systems most prone to this phenomenon. Exceptionally, rocks may fall and small landslides may be (re)activated, along slopes where equilibrium is already very unstable, e.g. steep slopes and cuts, with loose or saturated soil. Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems. Very rare temporary sea level changes in the far field of strong earthquakes. Tree limbs may shake.
V	**Awakening** (a) The earthquake is felt indoors by all, outdoors by many. Many sleeping people awake. A few run outside. Animals become uneasy. Buildings tremble throughout. Hangings objects swing considerably. Pictures knock against walls or swing out of place. Occasionally pendulum clocks stop. Unstable objects may be overturned or shifted. Open doors and windows are thrust open and slam back again. Liquid spills in small amounts from well-filled open containers. The sensation of vibration is like that due to a heavy object falling inside the building. (b) Slight damage of grade I in buildings of type A is possible. (c) Sometimes change in flow of spring.	**Marginal effects on the environment** Primary effects are absent. A few cases of fine cracking at locations where lithology (e.g., loose alluvial deposits, saturated soils) and/or morphology (slopes or ridge crests) are most prone to this phenomenon. Extremely rare occurrence of significant variations in water level in wells and/or the flow-rate of springs. Rare occurrence of small variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Rare small rockfalls, rare rotational landslides and slump earth flows, along slopes where equilibrium is unstable, e.g. steep slopes, with loose or saturated soil. Extremely rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table). Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes, where the water table is shallow within large karstic spring systems. Occurrence of landslides under sea (lake) level in coastal areas. Rare temporary sea level changes in the far field of strong earthquakes. Tree limbs may shake.

VI	**Frightening** (a)Felt by most, indoors and outdo Many people in buildings are fright and run outdoors. A few persons lose balance. Domestic animals run out of stalls. In a few instances dishes glassware may break, books fall dov Heavy furniture may possibly move small steeple bells may ring.. (b) Damage of grade 1 is sustained in single buildings of type B and in many of type A. Damage in a few buildings of type A is of grade 2. (c) In a few cases cracks up to widths of 1 cm possible in wet ground; in mountains occasional landslides; changes in flow of springs and in level of well-water are observed.	**Modest effects on the environment** Primary effects are absent. *Occasionally thin, millimetric, 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 (asphalt / stone) roads.* Rare occurrence of significant variations in water level in wells and/or the flow-rate of springs. Rare occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Rockfalls and landslides up to ca. 10^3 m^3 can occur, especially where equilibrium is unstable, e.g. steep slopes and cuts, with loose / saturated soil, or weathered / fractured rocks. The area affected by them is usually less than 1 km^2. *Rare cases of liquefaction (sand boil), small in size and in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).* Extremely rare occurrence of karst vault collapses, which may result in the formation of sinkholes. Occurrence of landslides under sea level in coastal areas. Occasionally significant waves are generated in still waters. *In wooded areas, trees shake; a very few unstable limbs may break and fall, also depending on species and state of health.*
VII	**Damage to buildings** (a) Most people are frightened and run outdoors . Many find it difficult to stand. The vibration is noticed by persons driving motor-cars. Large bells ring. (b) In many buildings of type C damage of grade 1 is caused; in many buildings of type B damage is of grade 2. Many buildings of type A suffer damage of grade 3, a few of grade 4.In single instances landslips of roadway on step slopes; cracks in roads; seams of pipelines damaged ; cracks in stone walls (c) Waves are formed on water, and water is made turbid by mud stirred up. Water levels in wells change, and the flow of springs changes. In a few cases dry springs have their flow restored and existing springs stop flowing. In isolated instances parts of sandy or gravelly banks slip off	**Appreciable effects on the environment** Primary effects observed very rarely. Limited surface faulting, with length of tens of meters and centimetric offset, may occur associated with volcano-tectonic earthquakes. *Fractures up to 5-10 cm wide 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. Centimetric cracks common in paved (asphalt or stone) roads.* Rare occurrence of significant variations in water level in wells and/or the flow rate of springs. Very rarely, small springs may temporarily run dry or be activated. Quite common occurrence of variations of chemical-physical properties of water and turbidity of water in lakes, springs and wells. Scattered landslides occur in prone areas; where equilibrium is unstable (steep slopes of loose / saturated soils; rock falls on steep gorges, coastal 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. The affected area is usually less than 10 km^2. *Rare cases of liquefaction, with sand boils up to 50 cm in diameter, in areas most prone to this phenomenon (hihgly susceptible, recent, alluvial and coastal deposits, shallow water table).* Possible collapse of karst vaults with the formation of sinkholes, even where the water table is deep. Occurrence of significant landslides under sea level in coastal areas. Waves may develop in still and running waters. In wooded areas, trees shake; several unstable branches may break and fall, also depending on species and state of health.

VIII	**Destruction of buildings** (a)Fright and panic; also persons driving motor-cars are disturbed. Here and there branches of trees break off. Even heavy furniture moves and partly overturns. Hanging lamps are in part damaged. (b)Many buildings of type C suffer damage of grade 2 , a few of grade 3. Many buildings of type B suffer damage of grade 3 and a few of grade 4, and many buildings of type A suffer damage of grade 4 and a few of grade 5.Occasional breakage of pipe seams. Memorials and monuments move and twist. Tombstones overturn. Stone walls collapse.	**Considerable effects on the environement** *Primary effects observed rarely. Ground ruptures (surface faulting) may develop, up to several hundred meters long, with offsets generally smaller than 5 cm, particularly for very shallow focus earthquakes, such as volcano-tectonic events. Tectonic subsidence or uplift of the ground surface with maximum values on the order of a few centimeters may occur.* *Fractures up to 25 - 50 cm wide are 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.* *Springs can 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.* *Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy.* 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. The affected area is usually less than 100 km^2. *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).* Karst vaults may collapse, forming sinkholes. Frequent occurrence of landslides under the sea level in coastal areas. Significant waves develop in still and running waters. *Trees shake vigorously; some branches or rarely even tree-trunks in very unstable equilibrium may break and fall.* *In dry areas, dust clouds may rise from the ground in the epicentral area.*

IX	**General damage to buildings** (a) General panic; considerable damage to furniture. Animals run and fro in confusion and cry. (b) Many buildings of type C suffer damage of grade 3, a few of grade 4. Many buildings of type B show damage of grade 4, a few of grade 5 . Many buildings of type A suffer damage of grade 5. Monuments and column falls. Considerable damage to reservoirs; undergrounds pipes partly broken. In individual cases railway lines are bent and roadways damaged. (c) On flat land, overflow of water, sand and mud is often observed. Ground cracks to widths of up to 10 cm, on slopes and river banks more than 10 cm; furthermore a large number of slight cracks in ground; falls of rock, many land slides and earth flows; large waves on water. Dry wells renew their flow and existing wells dry up.	**Natural effects leave significant and permanent traces in the environment** *Primary effects observed commonly. Ground ruptures (surface faulting) develop, up to a few km long, with offsets generally smaller than 10 - 20 cm. Tectonic subsidence or uplift of the ground surface with maximum values in the order of a few decimeters may occur.* *Fractures up to 50 - 100 cm wide 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.* Springs can change their flow-rate and/or elevation of outcrop to a considerable extent. Some small springs may even run dry. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy. *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. The affected area is usually less than 1000 km^2.* *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).* Karst vaults of relevant size collapse, forming sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running waters. Small tsunamis may reach the coastal areas with tidal waves up to 50 - 100 cm high.* Trees shake vigorously; branches or even tree-trunks in unstable equilibrium frequently break and fall. In dry areas dust clouds may rise from the ground. In the epicentral area, small stones may jump out of the ground, leaving typical imprints in soft soil.

X	**General destruction of buildings** (b) Many buildings of type C suffer damage of grade 4, a few of grade 5. Many buildings of type b show damage of grade 5; most of type A have destruction category 5; critical damage to dams and dykes and severe damage to bridges. Railway lines are bent slightly. Underground pipes are broken or bent. Road paving and asphalt show waves. (c) In ground, cracks up to widths of more than 10 cm, sometimes up to 1 m. Broad fissures occur parallel to water courses. Loose ground slides from steep slopes. From river banks and steep coasts considerable landslides are possible. In coastal areas displacement of sand and mud; change of water level in wells; water from canals, lakes, rivers etc. thrown on land. New lakes occur.	**Environmental effects become dominant** *Primary ruptures become leading. Ground ruptures (surface faulting) can extend for several tens of km, with offsets reaching 50 - 100 cm and more (up to ca. 1-2 m in case of reverse faulting and 3-4 m for normal faulting). Gravity grabens and elongated depressions develop; for very shallow focus earthquakes, such as volcano-tectonic events, 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.* *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. The affected area is usually up to 5000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Some may run dry or disappear, generally temporarily. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently become muddy. *Open ground cracks up to more than 1 m wide 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.* *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.* Large karst vaults collapse, forming great sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running waters, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas, with tidal waves up to a few meters high.* Trees shake vigorously; branches or even tree-trunks very frequently break and fall, if already in unstable equilibrium. In dry areas, dust clouds may rise from the ground. *Stones, even if well anchored in the soil, may jump out of the ground, leaving typical imprints in soft soil.*

XI	**Catastrophe** (b) Severe damage even to well-built buildings, bridges, water dams and railway lines; highways become useless; underground pipes destroyed. (c) Ground considerably distorted by broad cracks and fissures, as wells as by movement in horizontal and vertical directions; numerous land slips and falls of rock The intensity of the earthquake requires to be investigated in special way.	**Environmental effects become essential for intensity assessment** *Primary surface faulting can extend for several tens of km up to more than 100 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.* *Large landslides and rock-falls (> 10^5 – 10^6 m3) 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. Primary and secondary environmental effects can be observed over territory as large as 10000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells. Water temperature often change in springs and/or wells. Water in lakes and rivers frequently becomes muddy. *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.* *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.* Very large karst vaults collapse, forming sinkholes. Frequent large landslides under the sea level in coastal areas. *Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters may overflow from their beds. Tsunamis reach the coastal areas with tidal waves up to many meters high.* *Trees shake vigorously; many tree branches break and several whole trees are uprooted and fall.* In dry areas dust clouds may arise from the ground. *Stones and small boulders, even if well anchored in the soil, may jump out of the ground leaving typical imprints in soft soil.*

XII	**Landscape changes** (a) Practically all structures above and below ground are greatly damaged or destroyed (c) The surface of the ground is radically changed. Considerable ground cracks with extensive vertical and horizontal movements are observed. Fall of rock and slumping of river banks over wide areas; lakes are dammed; waterfalls appear; and river are deflected. The intensity of the earthquake requires to be investigated in a special way.	**Environmental effects are now the only tool enabling intensity to be assessed** *Primary surface faulting can extend for several hundreds of km up to 1000 km, 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).* *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. Primary and secondary environmental effects can be observed over territory larger than 50000 km^2.* Many springs significantly change their flow-rate and/or elevation of outcrop. Frequently, they may run dry or disappear altogether. Variations in water level are observed in wells. Water temperature often changes in springs and/or wells. Water in lakes and rivers frequently becomes muddy. *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.* *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.* Very large karst vaults collapse, forming sinkholes. Frequent very large landslides under the sea level in coastal areas. *Large waves develop in still and running water, and crash violently into the shores. Running (rivers, canals) and still (lakes) waters overflow from their beds; watercourses change the direction of flow. Tsunamis reach the coastal areas with tidal waves up to tens of meters high.* Trees shake vigorously; many tree branches break and many whole trees are uprooted and fall. In dry areas dust clouds may arise from the ground. Even large boulders may jump out of the ground leaving typical imprints in soft soil.

APPENDIX 5

Inqua EEE Scale field survey form

Notes on the application of the Inqua EEE scale

This document is a first draft proposal of a form aimed at summarizing in the field the main elements characterizing each environmental effect of an earthquake, so that a local intensity can be assigned to the site.

Instructions on how to use this form are not provided here, being most of the keys self-explaining (hopefully). The form is conceived in such a way to be filled in the field with a minimum effort even by a not trained specialist, although a specific experience is highly advisable.

At this stage, all the information has been packed in a single double-faced sheet. However, more information (sketches, notes, photographs) can be provided in additional sheets. Anyway, a longer form may be adopted in the future, if needed. Another goal of the working group is the realization of a sort of database of environmental effects of earthquakes, so changes to this draft form might result necessary to make it more suitable to this end.

Critical evaluation by earthquake geologists, especially by their field testing during surveys after an earthquake, is clearly necessary to bring this draft form to a factual efficiency. To this end it is proposed here. Feedback is therefore not only expected, but it will be greatly welcome.

INQUA Earthquake Environmental Effects EEE Scale

Sheet 1: Generalities

Earthquake

Region ______________________________ Time ______________ Magnitude *Ml Ms Mb Mw* _______

Intensity *MM EMS MSK JMA*________ Latitude ____________ Longitude_____________ datum_______________

Observation point

Nr. _______ Date/hour ______________ Surveyor ________________________ Locality ________________________________

Lat _____________ Lon ______________ Km from epicentre _____ Local Intensity *MM EMS*____ Site PGA ____ Photos *yes no*

Geomorphological setting - *mountain slope – mountain valley – hillslope – alluvial fan – bajada – delta - alluvial plain – marsh - sea/river cliff – river/lake bank – sea/lake shore - arid-semiarid flat – desert - other:*_______________________________

Brief description ____

____

____

Main effects of seism on artefacts *damage/collapse of single/multiple buildings bridge viaduct tunnel railway highway paved/unimproved road* ____

Environmental effect

Geologic origin*: tectonic / ground shaking* *newly formed / reactivated*

Surface faulting – open fissures in bedrock - mole track - ground crack - slope movement - sinkhole - ground settling/liquefaction/lateral spread - hydrologic anomaly - gas emission - moved/overturned stone

Other ____

Non geologic ***noise light-emission fire vegetation:*** *burnt grass, swinging trees, broken branches, fallen fruits...*

Brief description ____

____

____

Major affected lithology rock *densely cleaved massive stratified intrusive metamorphic volcanic lava/pyroclastic sedimentary shale/sandstone/conglomerate/limestone/salt hard/semi-pseudo-coherent* – loose sediment *soil/clay/silt/sand/gravel colluvium backfill* – **Sedimentary environment** *marine shore fan deltaic alluvial lacustrine marsh slope arid/temperate/humid*

Notes____

Frequency of observed feature in the area

single/multiple number ______ over ________ km^2 *Already/never* triggered by earthquakes

Maximum dimension length ____m width ____m area ______m^2 volume ______m^3

Average dimension length ____m width ____m area ______m^2 volume ______m^3

Notes ____

Sketch

INQUA Earthquake Environmental Effects EEE Scale

Sheet 2: Details

Earthquake
Region ____________________ Time ______________

Observation point
Nr. _______ Date/hour _____________ Surveyor _____________________ Locality ____________________________

Surface faulting
strike ______ **dip** _____

normal/reverse/oblique/strike-slip dextral/sinistral - total length ____km - nr of segments ___ - aligned/en-echelon right/left stepping

maximum vertical offset ____cm horizontal offset ____cm - average vertical offset ____cm horizontal offset ____cm

displaced feature for direct measurement ______________________________

single/multiple scarp – other features *push-up/pull-apart/gravity graben*

Notes ____

____

Ground cracks
Type fracture - mole track **strike** ______ **dip** _____ Displacement ____ cm sense of displacement_____________

Maximum length _____ m - number of features ______ over a distance of ____ m – maximum opening _____ cm

Shape straight/sinuous/curvilinear ____________________ - **Possible origin** surface faulting/slide/ground settling/detachment

Notes ____

Slope movement
Type rock fall – deep-seated slide (sackung) - rotational slide – slump - earth flow - soil slip – other ____________________

Maximum dimension of blocks _____ m^3 over a distance of ____m – Total volume _____ m^3 - **Humidity** *very/moderately/no wet*

Age *very old/recent/new* **Activity** *partial/total already active/quiescent*

Velocity *extremely/very/moderately rapid/slow* **Time delay** for manifestation of motion _____ hours

Notes ____

____

Ground settlement - collapse
Type liquefaction – compaction – lateral spread - subsidence – bulge – sinkhole – other ____________________

Maximum diameter _____ m - number of features ______ over a distance of ____ m – maximum lowering/uplift _____ cm

Shape round/elliptical/elongated/squared ____________________ positive/negative cone - **Humidity** *very/moderately/no wet*

Depth of water table ____ m – water/sand ejection –

Velocity *extremely/very/moderately rapid/slow* **Time** delay/advance for manifestation of feature _____ hours

Notes ____

____

Hydrologic anomaly
Effects *overflow/drying up/appearance of springs/waves/water fountain/variation of water table/discharge rate/temperature/chemistry/turbidity* **where** *spring/river /lake/well/fountain/aqueduct other* ________________

Temperature change ___C° – Discharge change ____l/s

Changed chemical component/s _________________________ - Permanent/temporary change lasted for ___hours

Tsunami: maximum wave height ____m length ____m Extent of affected coast ______ km

Velocity *extremely/very/moderately rapid/slow* - **Time** delay/advance for manifestation of feature ___hours

Notes ____

____

Intensity attribution
IV V VI VII VIII IX X XI XII

Based principally on existing INQUA tables/other Intensity scale/new assessment and ____________________________

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