Seismic Hazard Assessment for Guayaquil City (Ecuador): Insights from Quaternary Geological Data

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Guayaquil City, the chief fluvial and maritime Port of Ecuador, is located in the estuarine zone of the lower Guayas River Drainage Basin (South of the Ecuadorian Seaboard). This city has the largest urban residents with 2.156.636 inhabitants (Source: INEC, 2001); and together with Quito, the Capital's Nation city represents the 80% of the Industrial Production. However, this industrialized city is threatened by free from earthquakes. In fact, its closeness with significant seismogenetic structures makes it highly susceptible to tectonic events. The few available seismic hazard studies for the area of Guayaquil have been based essentially on seismological data. These studies have analyzed: (1) damage estimation to residential buildings (i.e., houses, schools, hospitals, etc.) (Argudo et al., 1993); (2) life-loss estimation models to the chief urban areas; and (3) assessment of Guayaquil seismic hazard through an adopted seismogenetic structure capable of generating large earthquakes. For instance, the Radius Project (Radius Project, 1999; http://geohaz.org/radius/LACont.htm) selected as reference structure the Subduction Zone, capable of generating magnitude 8 earthquakes, and located about 200 Km NW of Guayaquil.
In this paper, we discuss the contribution that detailed geological data can provide to the seismic hazard surveys of the area of Guayaquil city. We reviewed in detail the main seismic events that struck the study area and described capable seismogenetic structures through historical seismic data (implement it to the GIS tool); which will be applied to understand the actual situation of Guayaquil and its possible ground environmental effects as a consequence of moderate to strong earthquakes. For this study, we made a GIS database composed of 939 instrumental and historical intensity data (in the range of MM Intensity VI-XI) measured in 122 Ecuadorian seismic events (from 1557 to 2000). Information on these events has been provided by CERESIS Seismic Intensity Catalogue (www.ceresis.org/new/es/index.html), and from Web pages of some governmental entities (www.igp.gob.pe; www.igepn.edu.ec).
The most destructive historical earthquake that struck Guayaquil (with MM IX) occurred on 14th May 1942 (Mw 7.8), causing moderate to high damage in the central urban area (Argudo et al., 1993). The earthquake occurred near the subducting Carnegie Ridge off the coast of Ecuador, where the Nazca Plate subducts beneath the South American Plate. The instrumental epicenter was located up to 240 Km NW from Guayaquil city.
Moreover, other seismogenetic structures have also generated significant earthquakes that struck the area causing moderate to high effects to the Guayaquil suburban and urban sectors. The most representative are:
(A) The 9th July 1653, Guayaquil earthquake: it was located in the surrounding of the current city with MM Intensity of VII. Previous seismic hazard studies have not mentioned this event, perhaps, because of the scarce information available in the historical record.
(B) The 18th August 1980, earthquake (Ms 6.1) whose instrumental epicenter was located up to 28 Km NW from Guayaquil, with MM Intensity measured of VII-VIII. Seismic shaking was felt very strongly in the center and southern part of the city. For their epicentral locations, both the 9th July 1653 and the 18th August 1980 earthquakes could be tectonically linked to the active Colonche fault and to a potential Quaternary uplifting of the Chongon Colonche Ridge.
(C) The 12th Dec 1953, Tumbes earthquake (Northwest Perú and South Ecuador, Ms 7.3), whose instrumental epicenter was located up to 155 Km SW from Guayaquil city, the MM Intensity measured for Guayaquil was of VI-VII (Silgado, 1957). The possible seismogenetic structure which generated this seismic event is still not well defined. Based on our surveys, this earthquake could be

linked to the Jubones-Tumbes Fault or to the capable Amistad Fault (see also the other Abstract by Chunga et al. in this vol.).

(D) The 27th July 1971, earthquake (Ms 7.5), whose instrumental epicenter was located up to 290 Km SE from Guayaquil, is the most distant event that produced significant effects in Guayaquil, with MM Intensity of VII. This event could be linked to the Macuma reverse Fault (Prov. Morona Santiago).

(E) The 4th February 1797, Riobamba earthquake (epicentral MM: XI): is considered as the strongest historical earthquake recorded in Ecuador (www.igepn.edu.ec/sismologia/sismicidad/historica/efectos.htm). The instrumental epicenter was located up to 150 Km NE from Guayaquil city. The MM Intensity in Guayaquil has not been measured neither studied in detail (e.g. Argudo et al., 1993). This event has been attributed to the capable Pallatanga strike slip Fault (this fault crosses the western Andean Cordillera and joins the Gulf of Guayaquil), which is characterized by slip rates ranging from 1 to 5 mm/yr (USGS, 2003; http://pubs.usgs.gov/of/2003/ofr-03-289/). This large seismic event should be taken in account for future detailed paleoseismological studies, inasmuch as, its closeness to the Continental Megashear (composed by a right-lateral fault system about 2200 Km long, extended from the Gulf of Guayaquil, on the Pacific coast until the surrounding of Caracas, on the Caribbean coast) makes it an excellent test site.

All these historical facts emphasize the importance of understanding the main ground natural effects caused by earthquakes, such as: natural subsidence or acceleration of anthropogenic subsidence (at present day, this last phenomenon is observed in the southwest sector of Guayaquil), ground cracking, liquefaction or settlement of soils, massive rockfalls and landslides and other effects common to earthquakes that have occurred in similar geologic settings. In fact, the lithologic characteristics of the soil on which Guayaquil lies is very uneven. For instance: (1) the commercial and urban center rest on unconsolidated Holocene alluvial clay deposits interbedded with silty and clayey sand sediments; (2) the southwestern and southern part of the city, where it is concentred the less developed urban area, directly lies on filling in marshland; (3) in the northern part of the city: a) the residential areas rest on consolidated stratified silt siliceous deposits, belonging to the Guayaquil Formation (Danian age, Cretaceous-Tertiary contact) and as well upon volcano-sedimentary successions appertain to the Cayo Formation (Late Cretaceous age); b) the marginal urban areas lie on unstable foothills; and c) in the Kennedy Norte residential zone, large buildings lie on soft-sediments. Indeed, these lithologic characteristics would create suitable conditions for amplification of ground motions.

Therefore, for assessing the impact of seismically-induced ground effects in natural environment, we recommend to apply the new INQUA Intensity Scale which could be a powerful tool for the engineering community, allowing to properly taking into account the geological setting and the geotechnical aspects in the seismic hazard surveys.

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The 12 Dic, 1953, Earthquake, Ms 7.3, Ecuador-Peru border region: A Case Study for Applying the New INQUA Intensity Scale

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The INQUA Scale is a newly proposed Macroseismic Intensity Scale, based solely on Earthquake Environmental Effects (EEE). This Scale has been discussed during the two Local Meetings carried out in Guayaquil, Ecuador. One of the points raised throughout the Meetings, was the importance of post-earthquake damage assessment. Moreover, we briefly reviewed the modern antiseismic building codes, in order to reconsider data relative to damage on buildings and make them confrontable with those of historical earthquakes. It's obvious, in fact that ancient buildings were constructed with different engineering standard from present ones. Regarding the INQUA Scale, the participants, technical and scientific community, has considered this new Scale as an excellent tool for the environmental analysis of past and contemporaneous Ecuadors earthquakes.
Indeed, the closeness of the Ecuador to the Subduction Zone (where the Nazca Plate subducts beneath the South American Plate) and the significant active and capable seismogenetic structures that affect the continental block, make it highly susceptible to tectonic and tsunamigenic events. Historically, from 1557 to 2000, 122 seismic events have been reported in Ecuador (in the range of MM Intensity VIXI). The following earthquakes generated important tsunamis along the Ecuador's coastal range: (A) The 31st Dec 1906, earthquake, Ms 8.8, located about 138 Km W from Tortuga, Prov. Esmeraldas. This earthquake is classified as the sixth largest earthquake worldwide in the past 100 years. (B) The 2nd Oct 1933, earthquake, Ms 6.9, located offshore from Peninsula Sta. Elena. (C) The 12th Dec 1953, earthquake, Ms 7.3, located up to 23 Km NW from Tumbes, Peru-Ecuador border region. (D) The 19th January 1958, earthquake, Ms 7.8, Ecuador-Colombia boundary. (E) The 12th Dec 1979, earthquake, Ms 7.9, located offshore from San Lorenzo, Ecuador-Colombia boundary. (Espinoza, 1992; Chunga et al., 2002).
Information about several earthquakes was recompiled in order to apply the INQUA Scale. In particular, we have selected the 12th Dec 1953, earthquake (Ms 7.3) as a sample event, because of two reasons: (a), the necessity to improve the information available for this event in Ecuador, and (b) the bibliographic documentations retrieved, that provide us an excellent description of the ground environmental effects in several cities close to the epicentral area (i.e., Silgado, 1957; www.vivatumbes.com/tumbes_1925/Terremoto.htm). The 1953 earthquake, struck the South Ecuador-Northwest Peru border region at 12.31 am local time, with 7.3 Ms magnitude and VII-VIII Intensity (MM-1931 Scale) (Silgado, 1953). Its epicenter was located offshore 23 Km NW from Tumbes and 155 Km SW from Guayaquil. The maximum intensities was felt in Tumbes-Corrales-Celica, respectively.
In the Tumbes and Corrales populations (Perú), 6 dead and at least 20 injuries were reported. Many local witnesses perceived a time shaking of about 40 seconds. Numerous material damages to both, Peruvian (San Juan, Zorritos, Santa Cruz, El Alto y Talara) and Ecuadorian (Gonzamaná, Celica, Azogues, Malacatos) villages occurred. Minor damage was reported in the Guayaquil city. Still, the tectonic source of this event has not been well-defined. According to our preliminary surveys, it seem possible to suggest a linking with either active faults (Jubones-Tumbes or Amistad) close to the epicentral area, associated to the compressive geodynamic model of the Subduction Zone. The Isoseismals of this earthquake were elongated about NW-SE (see Intensity Map of Silgado, 1957), almost parallel to the trend of the Jubones-Tumbes fault. For its closeness to this seismogenetic structure, and for its similar structural trend, the 1953 earthquake, could have direct relationship with the fault previously mentioned.

The documentation retrieved (Silgado, 1957) gave us an well description on the ground environmental effects accompanying the 1953 earthquake. The most significant effects occurred at the following sites: (1) large and deep cracks affecting alluvial soil with NW-SE trending reached up to 40 cm wide at Tumbes, on the Panamericana road, and up to 1.5 m wide between Zorritos and Tumbes; (2) significant liquefactions in alluvial sediments were observed in the Puerto Pizarro estuaries and other localities; (3) dry springs were activated in the Quebrada Bocapan; (4) significant earthquake fountains, 60 cm high, and sandy ground cracks with E-W trending were generated in the Puerto Pizarro seashore; (5) small landslides affecting loose sediments were frequent in the epicentral area, among them: El Alto, the surrounding of Zorritos, and many other villages along the Tumbes River canyon and flat settings. Small tsunamis with run-up heights of 20 cm were reported in La Libertad, northern coastal of the Peninsula St. Elena (Ecuador), about 138 Km NW from epicenter (Espinoza, 1992). Based on these field reconnaissance, carried out by Silgado (1957), and on our preliminary assessment, INQUA Intensity of IX should be well assigned to Tumbes and one INQUA Intensity VIII to the Corrales (Perú) and Celica (Ecuador) settings.

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Applying the INQUA Scale to Some Historical and Recent Peruvian Earthquakes

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This is a first approximation using INQUA scale to evaluate Peruvian earthquakes. Different macroseismic intensity scales were used to evaluate historical and instrumental seismicity, these scales are based on the damage caused during a seismic event, human observations, and a few effects in the nature. MM (Modified Mercalli Intensity Scale) and MSK-64 (Medvedev-Sponheuer-Karnik Intensity Scales) are more used in Peru but these intensities scales can not be used in uninhabited places, then the INQUA scale can be a valid tool to use in all places, taking into account the geological features too.
Historical intensity data are available for the most significant events occurred in Peru but this information is only available from 1471 after Spaniards arrived to Peru, these intensity data were used to estimate the magnitudes and rupture lengths for historical earthquakes.
Recently, the historical earthquakes were re-evaluated using MSK-64 scale and from 1979 the Geophysical Institute of Peru uses MSK-64 scale with a form of survey addapted by Ocola (1979) to Peruvian reality.
Peru is located in an active tectonic zone, most of the seismicity being produced from the subduction process when the Nazca Plate is subducting below the South American Plate. Nevertheless, many earthquakes are caused by crustal deformation and geological fault reactived originating great intensities. In this work was we used the INQUA Scale to evaluate 15 earthquakes occurred from 1687 to the present time, these earthquakes have more information and their sources are subduction or geological fault. A first testing with two earthquakes was used in Huancayo (1969, 6.0 Mw, h = 40 km) and Moyobamba (1990, 6.6 Mw, h = 24 km, and 1991, 6.5 Mw, h = 20 km) events, both earthquakes were generated by geological fault reactivated.
From the point of view of seismic engineering, it is necessary to have a real seismic zonation considering geological and ground features in each region of Peru, we considered the INQUA scale jointly with the other intensity scales, it will be a valuable contribution to be considered in future building codes.

INQUA intensity Scale Evaluation for the 1980 Southern Italy "Historical" Earthquake

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Within the framework of INQUA (International Union for Quaternary Research) activities, an important topic regards the "INQUA EEE Scale" (Michetti et al., 2004) for assessing earthquake intensities based only on the seismically-induced ground effects in natural environment (EEE stands for Earthquake Environmental Effects).
To improve the INQUA EEE Scale reliability, moderate-to-strong earthquakes, worldwide, are being analyzed by various working groups, in order to compare the obtained intensity values with those assessed with conventional scales (such as MM, MCS, MSK, EMS, JMA).
To this aim, we present here the revision and reinterpretation of the geological effects produced by the November 23rd 1980, Irpinia-Basilicata (Southern Italy) earthquake (Ms=6.9 NEIC, nucleation depth 10-12 km, epicentral intensity I0=X MCS), collected in the field soon after the event by several multidisciplinary groups (e.g., Carmignani et al., 1981), including some of the authors (EE and SP). The earthquake was a complex event, involving at least three distinct rupture episodes on different fault segments in a time span of approximately 40 seconds (Westaway, 1993). Over 300 localities were damaged with the loss of about 3, 000 lives.
The earthquake induced primary and secondary effects distributed in an area of nearly 30, 000 km2 principally located in the Campania and Basilicata regions. Tectonic surface ruptures, soil cracks, landslides, liquefaction, deep seated gravitational deformations and hydrological anomalies were observed.
After 20 years, we have decided to analyze the original evidence collected in the field by a) reviewing about 100 scientific papers, and b) performing new air photo interpretation, field surveys and interviews of eye witnesses. As a result, we have identified the most likely source of the 40 seconds event (Blumetti et al., 2002) and revealed the occurrence of numerous undocumented secondary effects (Esposito et al 1998, Porfido et al., 2002).
Coseismic surface faulting occurred over a length of almost 40 km, with a normal maximum displacement to the NE nearing 1 m at Mt. Marzano. A second rupture about 8 km long occurred ca. 40 seconds later on a SW dipping fault system between Muro Lucano and Santomenna with a maximum observed offset of 30 cm.
More than 200 landslides (mostly rock falls and pre-existing rotational and slump earth flows) were triggered over an area of 22, 000 km2, with single volumes sometimes exceeding 1 million cubic m. Ground cracks were also widespread in the epicentral area, as well as liquefaction phenomena, although the latter were generally modest in size. Hydrologic anomalies were reported even very far from the epicentre, in zones of low macroseismic intensity (IV MCS).
The application of the INQUA EEE scale to the above listed coseismic effects has allowed to reconstruct an autonomous macroseismic field, to be compared with the MCS-MSK intensity field (Postpischl et al., 1985).
The analysis of the most recent strong "historical" earthquakes in Italy based on the INQUA EEE scale serves as a test of the approach to be adopted to improve the comparability of the many older earthquakes listed in the Italian seismic catalogue.

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Testing the New INQUA Intensity Scale in Greek Earthquakes

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The new INQUA seismic intensity scale is an important challenge in the fields of macroseismology and earthquake geology. Therefore, testing of the new scale is of critical importance with the aim to calibrate the scale, to compare it with conventional scales as well as to improve it. Such testing has been attempted in particular cases of Greek earthquakes selected on the basis of some certain criteria that maximize the prospects for successful testing. More presicely, the selected earthquakes have in common that they were strong and their macroseismic effects included not only damage in buildings and other structures but also ground failures of several types like local landslides, rock-falls, ground fissures and soil liquefaction. In addition, the macroseismic fields of the selected earthquakes were studied and intensities in conventional scales were assessed during post-event field surveys undertaken by the authors. As a consequence, the observational material is reliable and detailed enough and, therefore, provides a good basis to test the new INQUA seismic intensity scale. On the basis of the above criteria we selected to test intensities related with the next earthquakes: Kyllini, NW Peloponnese, 16 October 1988 (Ms = 5.8), Athens, Attika, 7 September 1999 (Ms = 5.9), Lefkada island, Ionian Sea, 14 August 2003 (Ms = 6.3). An inventory of macroseismic effects as well as of conventional intensities has been created for each one of the studied earthquakes. On the basis of the macroseismic effects inventory intensities in the new INQUA scale were determined. A comparison between the conventional and new intensities has been made and the results are evaluated as regards the efficiency and possible future improvement of the new INQUA scale.

The Database of Coseismic Environmental Effects as a Tool for Earthquake Intensity Assessment within the INQUA EEE Scale Project

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Refining the record of relevant Holocene natural events, and therefore of past seismicity, is one of the goal of the Dark Nature Project. Hazard forecast and risk mitigation must be based on high-resolution paleo-records. In this paper, we discuss new methodological approaches for the study of earthquake ground effects, allowing a better comparison between seismological and paleoseismological evidence.
In the last years, scientists dealing with seismic hazard assessment have started to acknowledge the potential substantial role of earthquake environmental effects (EEE) for earthquake intensity assessment. In fact it has become evident that EEEs should be taken into account for the following reasons:
i) compared to traditional macroseismic scales, they ensure a higher comparability at the global scale, as EEEs are free from the influence of cultural and technological aspects;
ii) all the effects on humans commonly used to calibrate intensity of shaking, suffer from saturation beyond intensity IX-X of the modern 12-degrees macroseismic scales;
iii) they allow to extend the time span of earthquake catalogues to prehistoric times. In fact, surface faulting and other secondary effects (principally liquefaction) related to prehistoric events can be in some cases dated and sized through detailed paleoseismological investigations.
In 1999, based on these general statements, an international group of geologists, seismologists and engineers promoted the compilation of a new scale of intensities based only on environmental effects (EEE Scale). A draft version of this scale was presented at the 14th INQUA Congress in Reno (2003), after an appraisal of the environmental effects induced by about 150 earthquakes distributed worldwide. A first update came one year later (Michetti et al., 2004) at the 32nd IGC in Florence.
A 4-years long international project (2003-2007) approved by INQUA and carried out by the INQUA TERPRO SubCommission on Paleoseismicity, http://www.apat.gov.it/site/en-GB/Projects/INQUA_Scale/default.html) is revising the present version of the scale, by analyzing the EEEs triggered by recent and historical earthquakes. In particular, several Regional Working Groups are testing the scale with well-documented seismic events occurred in their country. The ultimate goal of the project is to present the final version of the scale at the 15th INQUA Congress (in Cairns in 2007).
Either coseismic environmental effects and man-made structures are strongly influenced by the site stratigraphy and morphology. In general, as commonly occurred for the conventional macroseismic scales applied to historical events (MM, MCS and partly MSK), the local EEE intensity value is attributed through an "expert" evaluation based on the description reported in the scale for that specific effect, i.e., without the statistical approach followed by the most recent conventional scale (EMS).
Wherever possible, the local EEE intensity should be evaluated taking into account not the single effect, which typically occurs at a site, but all the effects observed within a limited area of "uniform" geology (locality), for example a river valley, mountain slope, large hill, a village or part of it, etc.. Therefore, the archiving process should be done at two levels of progressive detail (locality level and site level). In traditional macroseismic studies, the scale of locality level is typically a village, while a single macroseismic object (i.e. a single building), where damage degree can be defined but not intensity, is an analogue of site.
In order to ensure the objectivity of the testing procedure, participants to the project have agreed on the need to store information regarding EEEs into a database precisely defined in its structure and

format, which follows the draft form initially adopted for the field survey. Actually, only a rigorous approach ensures the comparability of environmental effects triggered by earthquakes occurred in geologically and tectonically very different settings. This database, conceived as the tool to effectively store and retrieve information regarding past and new earthquakes by the participants to the project, is already accessible in the web page of the project and will be periodically updated with the contributes from the regional WGs.

The EEE database has a relational structure kept as simple as possible. Several masks facilitate the input of data, from the most general to the most detailed ones. There are four main tables in agreement with the logical approach of the EEE Scale. So, each record in the table "Earthquake" is associated with one-to-many records in the "Locality" sub-table and each record in "Locality" is associated to one-to-many records in its EEE Sites sub-table.

As the main table "Earthquake" presents general information on the seismic event, including surface faulting parameters, the table "Locality" reports all the information about the locality where one or more coseismic effects have occurred, i.e. location (coordinates, altitude) and local expression of the earthquake (e.g., local macroseismic intensity, site PGA).

The table "Site" summaries the characteristics of the site (location, geomorphological environment, etc.) and the type of effect (surface faulting, slope movements, ground cracks, ground settlements, hydrological anomalies, tsunami, not geological effects). Information about the effect size, as requested in the EEE scale, can be archived in detail according to the type of effect. Information about damages on man-made structures (buildings, bridges, roads, etc.) in the same site, can be archived in a proper table "Effects on man-made structures". In order to standardize the descriptions of the effect and the site, data input is helped through the selection of attributes from a predefined menu.

Finally, it is possible to assess the range of EEE intensities (minimum and maximum values) compatible with the size of the effect and its features. As the data input for a locality has been completed, it is possible to assess the EEE intensity for that locality on the basis of all EEE effects occurred within that locality.

Moreover, in order to map the field of EEE local intensities, the EEE database allows to generate a table of localities with coordinates and EEE local intensities, that can be exported and loaded on a GIS project.

In addition, a proper "EEE form" devoted to field annotations immediately after a seismic event has been prepared, due to the common difficulty to work directly with a database directly in the field during an emergency. This form contains the same fields and structure of the EEE database.

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Damaged Cave Deposits Record 200, 000 Years of Paleoseismicity: Dead Sea Transform Region

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Geological research of past earthquakes, typically retrieving records from soft sediment deformations, can benefit from the study of rockfalls and damaged deposits in caves. Dating of damaged speleothems and deposits overgrowing rockfalls constrains the dates of the damaging earthquakes. We have compiled a long-term (200 kyr) paleoseismic record at the Soreq and Har-Tuv caves, near Jerusalem, Israel. The study caves, located 60 km west of the Dead Sea Transform (DST), record earthquake damage from DST ruptures (and possibly, smaller local intraplate events on faults that have not reached the surface or have yet to be observed). The study caves are outside of the rift zone and most likely record stronger and less frequent earthquakes.
Non-seismic sources of collapse, such as ice-movements, ground subsidence, and cave-bears, cited often as alternative origins of cave damage, were considered and refuted. Neither ice cover, nor perma-frost, have occurred in this region during the investigated period. Ground subsidence does not pose a problem since the cave floors are solid carbonate rock. The caves have only non-natural openings, and therefore cave-bears have not entered. The study caves offer an excellent opportunity for paleoseismic research as they contain a large amount of fallen cave deposits of all types and sizes, such as stalactites, stalagmites, soda-straw speleothems, and pillars, as well as other forms of damage. The two study caves present the opportunity to correlate between two nearby sites.
Comprehensive maps of the Soreq and Har-Tuv caves were prepared and demonstrate dominant EW and NW-SE orientation of fractures, and dominant EW and NS orientation of collapsed speleothems. The prevailing orientations of collapsed speleothems are parallel or perpendicular to the trend of the DST. These preferential orientations of collapse strongly support a seismic source of collapse. We identified "new generations" of speleothem growth on top of collapses. This post-collapse precipitation constrains ages of collapse. Unconformities between the collapses and the in-situ regrowth were recognized, and termed paleoseismic "contacts". Laminae above and below each unconformity were separated and dated by the 230Th/234U mass spectrometry and other methods. The pre- and post-seismic dates of a collapse bracket the period within which the earthquake occurred. The closer in age the pre- and post-seismic deposits are, the better constrained the earthquakes age is. When dating post-seismic regrowth on collapsed bedrock (as opposed to collapsed speleothem), only the post-seismic age is available. We also drilled cores into the flowstone floor and discovered laminae that embed fallen small stalactites (known in the literature as soda-straw formations). We dated the laminae that embed the fallen stalactites, which give the age of the seismic event. We also compared the oxygen stable isotopic record (d18O) of the laminae adjacent to the tectonic unconformities with the extensive well-dated stable isotope record of Soreq Cave speleothems, as was reconstructed for the last 185 kyr by Bar-Matthews et al. (2000) and Ayalon et al. (2002), for paleoclimate purposes. This stable isotope technique comparison improves and corroborates the U/Th ages.
Thirty-eight collapses were sampled and dated of which at least 13 (up to 18) separate events were dated. Dating of simultaneous collapses at different areas of the same cave and in the two different caves also strongly supports a seismic source of damage. The one Holocene event observed in the cave correlates with lacustrine seismites dated in cores from the Dead Sea and with an archeologically recorded earthquake. An event dated to ~ 13 ka is recorded by two collapses, for which there is no known dated contemporaneous soft sediment record in the region to correlate with. Most Dead Sea sediments recovered so far show a prominent hiatus at the Pleistocene-Holocene transition. For the period between 75 to 20 ky, we identified 4 events, 2 events (at 51.0-

52.0 and 35.5-40.5 ka) correlate with seismites in the Lisan record (at 52 and 39 ka). Another event (at 46.5-46.7 ka) coincides with a hiatus in the lacustrine sections from 49 to 44 ka. An event at 70.2-72.8 ka correlates with a cluster of seismites in the pre-Lisan section. Twelve cave events older than 75 ka are at present the only dated paleoseismic record for this period in the region. Future work on the middle to lower Pleistocene Amora formation can be potentially correlated with our cave record. Overall, the karst paleoseismic record supports the lacustrine seismite evidence.

The long dating range of calcite cave deposits and their potential for recording seismic events can vastly increase the length of the seismic record. The long Late Pleistocene cave record is useful for correlation with other records and for substantiation of the method, while the Holocene events are valuable for seismic hazard assessment. The unique opportunity to compare the stable isotope profiles of the speleothem seismites with the extensive paleoclimate record of the caves improves the accuracy of the seismite ages.

Using the INQUA Scale for the Assessment of Intensity: Case Study of 14/08/2003 Lefkada Earthquake, Greece

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The Lefkada (Ionian Islands, Greece) earthquake of 2003 (Mw=6.2, Ms=6.4) occurred few kilometers offshore the northwestern part of the island. According to the National Observatory of Athens, Institute of Geodynamics (NOAGI), its focus was located at 38.790 N, 20.560 E at depth h = 12 km. The maximum intensity has been evaluated as VIII (EMS), Papadopoulos et al. (2003), at Lefkada municipality. Few hours after the event, field surveys have been conducted in order to report the ground failures triggered by the earthquake.
The aim of this research is to compare the intensity parameters of the 2003 earthquake based on the EMS scale, with those assessed using the INQUA intensity scale. The intensity values, provided by the INQUA scale, are based solely on the ground effects.
This event was selected because of: a) the shock caused ground failure at several sites while the structural damages were few, b) the historical seismicity of the area indicates that at least two events during the 20th century (1914 and 1948) induced similar phenomena on the island, and c) these two past events occurred before the application of the first Greek seismic code (1959) to the building's construction.
In particular, the 2003 earthquake caused considerable effects on the northern part of the island where the reported rockfalls-landslides were widespread while liquefaction occurrences were observed at the municipality of Lefkada. On the southern part, the environmental effects are classified as marginal to modest; the rockfalls were rare and occurred along slopes where equilibrium is unstable. Building damages were reported mainly at the town of Lefkada (northern part) while many port facilities have been damaged in the whole island. Intensity values in the range between V to VIII have been assessed by Papadopoulos et al. (2003) for the 14/08/2003 event based on the EMS scale.
The historical records of the island provide well-documented information about ground failure triggered by two past earthquakes (27/11/1914 and 30/06/1948). According to the available seismic catalogues (e.g., Papazachos et al. 2000) these events had approximately the same source characteristics as the shock of 2003. Moreover, the reported environmental effects were distributed at the same sites of those triggered by the last earthquake. Galanopoulos (1950) reported that rockfalls and sand crater, probably due to densification, triggered by the 1914 and 1948 earthquakes at the road of Tsoukalades-Ag. Nikitas and the Pefkoulia beach respectively (similar phenomena were observed during the field observations, few days after the event of August 14th, 2003). The induced structural damages were significant, since many houses collapsed while others were severely damaged. For the seismic events of 1914 and 1948 the intensity values were in the range between VIII to IX based on Rossi-Forel scale, Critikos (1916), and between VII and X based on Mercalli-Graden scale, Galanopoulos (1950), respectively. These values had been assessed for the northern part of the island. The maximum epicentral intensities of these past earthquakes were evaluated as IX (MM scale) in both cases according to Papazachos et al., 2000.
The first Greek seismic code was issued in 1959, after the devastating Kefalonia's earthquake of 1953, and it was revised in 1984. A new revision took place in 1992 and updated in 2000 and 2003. According to the 1992 Greek Seismic code, the PGA coefficient for the Lefkada's seismic zone was established to a=0.36g with a spectral magnification factor βo = 2, 5. Obviously, the implementation of this code contributed to the amelioration of the building strength. Therefore, the low-rise buildings of Lefkada were not heavily damaged by the event of 2003.
The intensity values of the 2003 earthquake (INQUA scale), that were assessed at 18 sites on Lefkada's island based on field observations, were compared with those provided by Papadopoulos

et al. 2003 and with the evaluated intensity parameters of the past events. This comparison's conclusions are:

a) the major differences between the evaluated intensity parameters for the 2003 event, based on INQUA and EMS scale, are concentrated mainly at 4 sites, i.e. at the villages of Nydri (VII-INQUA, V EMS scale), Lygia (VII INQUA, V+ EMS), Kalamitsi (VII INQUA, V EMS) and Ag. Nikitas (VII+ INQUA, VI+ EMS),

b) at the same sites are also observed significant differences among the intensity values of the past events with the values of the last one, based on EMS scale,

c) the intensity values based on INQUA scale are more closed to the assessed values of the past events than the evaluated intensities based on EMS scale.

Study of the Verny, 1887, Earthquake in Central Asia: Using Environmental Effects to Scale the Intensity

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The goal is to get mutually consistent assessments of intensity of shaking based on environmental and macroseismic effects caused by earthquake. Simultaneously, database structure for storing information on ground effects is discussed. Although all macroseismic scales prior to EMS98 include environmental effects for intensity assessment as their integral part, we make difference between environmental and macroseismic effects. Environmental effects are all kind of consequences of an earthquake (faults, ground cracks, landslides, rockfalls, etc.) observed in nature. Macroseismic effects refer only to human and man-made structure reactions to an earthquake. To measure the first type of effects, the Earthquake Environmental Effect (EEE) based INQUA scale [Michetti et al., 2004] is used. To measure macroseismic effects we'll use EMS98 [European Macroseismic Scale, 1998]. The Verniy, May 28 (June 9), 1887, earthquake is a large seismic event in Central Asia. It practically completely destroyed the regional center Verniy (later on Alma-Ata) and caused death tolls. An expedition was sent in epicentral area of the earthquake soon after its occurrence. The expedition collected and published [Mushketov, 1890] materials on the earthquake effects both in localities and in natural environment. As the case study represent historical earthquake it enables to verify if also in this situation the EEE information could be fit to rigid database structure and format. The presentation proves perspectives of environmental effects as a tool to calibrate earthquakes, if INQUA scale is used properly.