Consiglio Nazionale delle Ricerche
Istituto di Ricerca per la Protezione Idrogeologica

European Project DAMOCLES (EVG1-1999-00027P)

DETAILED REPORT OF ASSISTANT CONTRACTOR CNR IRPI PERUGIA FOR FIFTH PROGRESS MEETING

Reporting period: April 2002 – October 2002

Fausto Guzzetti
(F.Guzzetti@irpi.cnr.it)

Assistant Contractor: CNR-IRPI Perugia
Responsible Scientist: Fausto Guzzetti

Address: via della Madonna Alta, 126
06128 Perugia, Italy
Phone: +39 075.5014.413
Fax: +39 075.5014.420
Email: F.Guzzetti@irpi.cnr.it

Summary

We report on the results obtained by CNR-IRPI Perugia in the period April to October 2002. The research activities focused on two of the five project working packages, namely: WP2, *Development of a GIS hazard assessment methodology using field data, available databases and model developments*, and WP5, *Dissemination of the project deliverables*. Activities carried out in the framework of WP2 aimed at the further testing of the 3-dimensional rock fall simulation program STONE. The program was tested by the CNR IRPI outside the areas originally selected for the DAMOCLES project, and in particular in the Yosemite Valley, in central California, USA, and in the Nera River Valley, Umbria Region, Central Italy. Tests aimed at verifying the software performance in different physiographical environments and at evaluating the possibility of using the program outputs to determine rock fall hazards and risk along the transportation network. Activities carried out in the framework of WP5 consisted mainly in the maintenance and update of the DAMOCLES web sites, contributing to the dissemination of the project results and deliverables. The main project web site was updated whenever new information was made available by the partners. The availability of a new release of the GIS-software used to publish maps on the web allowed for the transfer of the GIS web server on a Linux-based system. The change, transparent to the end user, made the system more robust and less prone to network attacks and consequent failures.

Section 1 - Objectives of the Reporting Period

The main objectives of the research activities conducted at CNR IRPI in the period April – October, 2002 can be summarized as follows:

WP2: Test of the 3-dimensional rock fall modelling software STONE in different physiographical regions. Comparison of the modelling results against field data on rock fall occurrence. Evaluation of rock fall hazards and risk in selected test areas, with emphasis on the risk to the transportation network.

WP5: Maintenance and updating of the DAMOCELS web sites, helping disseminating the information on the project deliverables. Continuation of the experiment aimed at testing the possibility of publishing on the Internet landslide inventory, landslide hazard, and other thematic maps. Update of the GIS software tools used for publishing geographical information on the web.

Section 2 - Scientific and Technical Progress Made

Working Package 2

The rock fall simulation program STONE (*Guzzetti et al*., 2002) was tested in two different areas, namely: a portion of the Yosemite Valley, in central California (USA), and a section of the Nera River Valley, in the Umbria region (Italy). Tests were aimed at verifying the software performance in different physiographical environments and at evaluating the possibility of using the program outputs to determine rock fall hazards and risk along the transportation network.

The Yosemite Valley is located in the previously glaciated headward segment of the Merced River canyon in central Sierra Nevada, California. The valley has very steep rock cliffs, 1,000 metres high or more. Rock falls and minor rock slides occur frequently from the steep rock slopes, posing a severe treat to the more than 3 millions annual visitors (*Wieczorek and Jäger*, 1996; *Wieczorek et al.*, 1992). To ascertain the rock fall hazards and risk in the Yosemite Valley we performed a rock fall simulation using STONE. For the Yosemite Valley, a DEM with a ground resolution of 10 x 10 m was prepared using topographic contour lines from the U.S. Geological Survey 1:24,000-scale maps. Rock fall release points were identified as DEM cells having a slope steeper than 60 degrees, an assumption based on the location of historical rock falls. This rather simple approach allowed identifying 61,435 grid cells (10 x 10 m in size) as possible sources of rock falls, i.e., 6.1 km^2, in plan view; approximately 7% of the Yosemite Valley. Correcting for the steep topographic gradient, this is an area of about 19.1 km^2. Maps of the normal and tangential energy restitution coefficients and of the rolling friction coefficient were produced from a surficial geological map. Modelling parameters were calibrated at a few sites where detailed cartographic information on historical rock fall events was available. At these sites the simulation consisted in launching several hundreds rock falls from the area that was identified in the field as the detachment zone of the rock fall. The model results were then compared visually and quantitatively with the extent of the rock fall area mapped in the field (Figure 1). Model parameters were adjusted and the simulation repeated until the result was judged satisfactory, i.e., there was good agreement between the modelled and the mapped rock fall.

Using the modelling parameters calibrated at the test sites, a rock fall model was then prepared for the entire Yosemite Valley. The only difference was that only 10 boulders were launched from each rock fall source cell. Figure 2 is a three-dimensional representation of a section of the Yosemite Valley portraying the map of the rock fall count computed by STONE. The image was obtained by overlaying the map of the rock falls count on a three-dimensional scene prepared using the available DEM. Colours show the rock fall count, from few (1-2 boulders, yellow) to numerous (more than 500 boulders, blue). Figures 2 clearly shows the local concentration of rock fall trajectories along steep channels and the lateral spreading of rock fall trajectories on talus slopes and debris cones. These features would hardly be seen using a two-dimensional simulation program working on a pre-defined slope profile (*Guzzetti et al*., 2002).

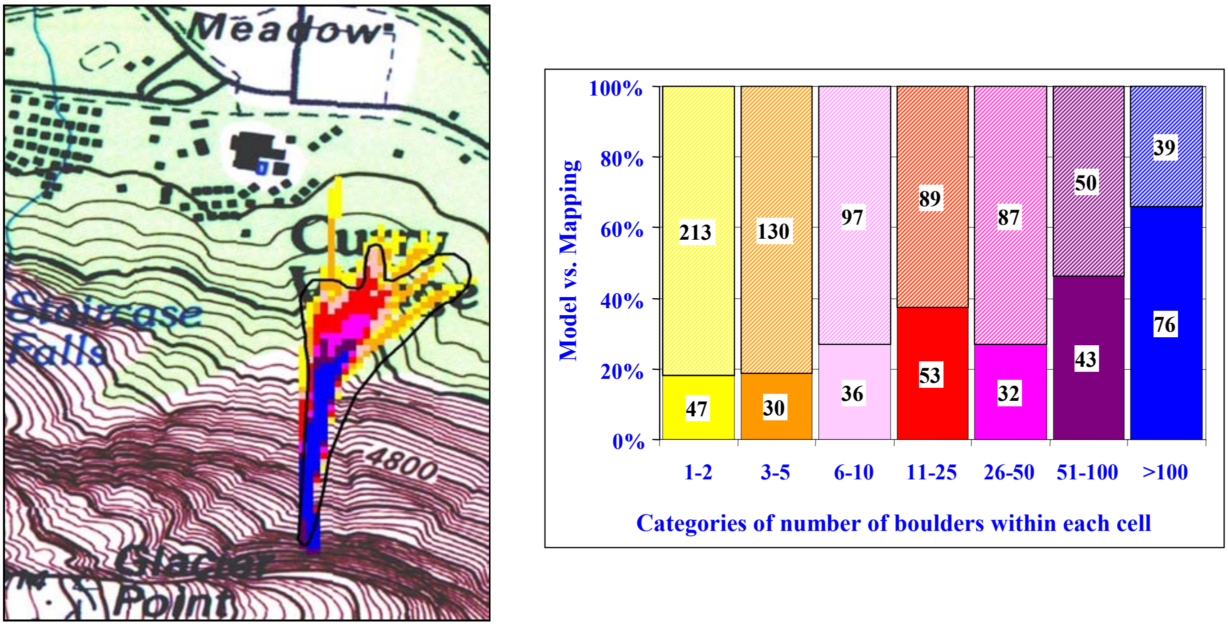

Figure 1. Comparison between the Glacier Point rock fall, of 16 November 1998 near Curry Village, Yosemite Valley, USA (thick black line), and a rock fall simulation performed by STONE (colours). Original scale 1:24,000. Histogram shows the number of cells falling inside (solid colour) and outside (oblique pattern) the mapped landslide. Figures in the coloured bars are number of cells.

The model results were compared with a map of rockfall talus (*Wieczorek and Jäger*, 1996) and with a geomorphic assessment of rock fall hazard based on potential energy referred to as a shadow angle approach, recently completed for the Yosemite Valley (*Wieczorek et al*., 1998, 1999). The STONE computer model was a better representation of the rock fall hazard than that provided by the shadow angle concept. This is mostly because the apex of the fans used for representing the shadow line is somewhat arbitrary and does not well represent all potential rock fall sources, but only those that have produced large talus fans.

The combined analysis of a spatially distributed rock fall simulation model with the distribution of the roads and trails in the Yosemite Valley identified the sections of the roads and trails that are potentially subject to rock falls. The roads and trails were classified according to the number of expected rock fall trajectories, considered to be a proxy of the rock fall hazard. In the Yosemite Valley there are approximately 166.5 km of roads and trails, of which 31.2

percent (~ 52 km) intersect an area of possible occurrence of rock falls. Limiting the analysis to the roads and trails that intersect an area of possible rock fall occurrence, about 25% of the roads and trails are subject to low (1-2 boulders) hazard, 31% to moderate hazard (3-10 boulders), 30% to high hazard (11-50 boulders), and 14% to very high hazard (more than 50 boulders). If one considers all the roads and trails in the Yosemite Valley, 7.8% of the infrastructure is subject to low hazard, 9.7% to moderate hazard, 9.4% to high hazard, and only 4.3% to high rock fall hazard.

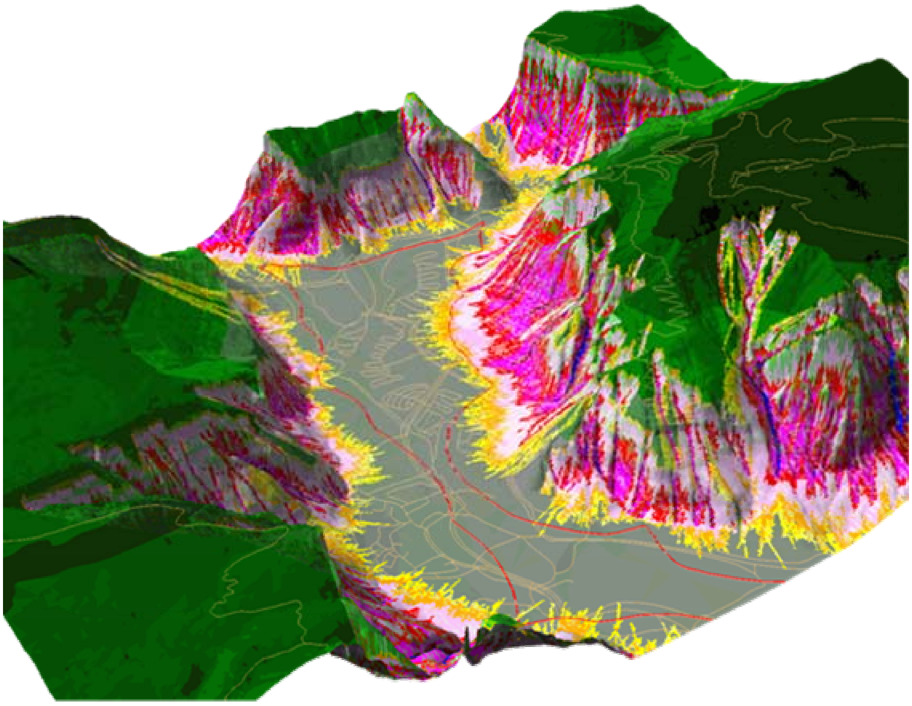

Figure 2. Three dimensional view of the rock fall hazard in the eastern section of the Yosemite Valley. Colours show rock fall count. Yellow, 1-2 boulders; orange, 3-10; pink, 11-50; red, 51-100; light violet, 101-250; dark violet, 251-500, > 500, blue. Red line is the 22° shadow angle line of *Wieczorek et al.* (1998). Light brown lines are roads and trails.

The Nera River, a tributary of the Tiber River, flows from north to south across the Umbria-Marche Apennines in a deep and narrow valley. Two national roads, the SS 320 and the SS 209, and a few villages are located along the valley bottom. The villages and the roads are frequently affected by rock falls. On October 1997, aftershocks of the Umbria-Marche earthquake triggered tens of rock falls, ranging in size from few cubic decimetres to 200 cubic metres (*Antonini et al.*, 2002). Rock falls caused severe and widespread damage mostly to the transportation network. The two national roads were interrupted at several locations and remained closed for weeks after the earthquakes while rock fall elastic barriers were installed and the existing artificial tunnels were repaired, reinforced or extended. These costly defensive measures were set up without any specific assessment of rock fall hazard and the associated risk along the road network.

We used STONE to quantitatively evaluate rock fall hazard in an area of about 48 km^2 centred on the village of Triponzo. In this area seismically induced rock falls were numerous in the fall of 1997 (*Antonini et al.*, 2002). The aim of the analysis was to determine rock fall hazards and risk along the transportation network, and to evaluate to what extent the new defensive measures reduced rock fall risk in the valley. The source areas of rock falls were mapped from vertical aerial photographs, and checked in the field. A total of 2.2 km^2 of rock fall source areas were identified, corresponding to 4.6% of the study area. Parameters controlling the loss of energy at impact points and during rolling were obtained from a surface geology map prepared updating the existing large scale geological map through the analysis of aerial photographs and filed surveys. Maps of the expected rock fall count, a proxy for the probability of being hit by rock falls, and of the expected maximum velocity and flying height, proxies for rock fall intensity, were used to evaluate the rock fall hazard. This was accomplished considering the three variables as independent and of the same relevance. The rock fall modelling revealed that about 7.1 km^2, 14.8% of the study area, can be affected by rock falls. The figure includes the rock fall source areas.

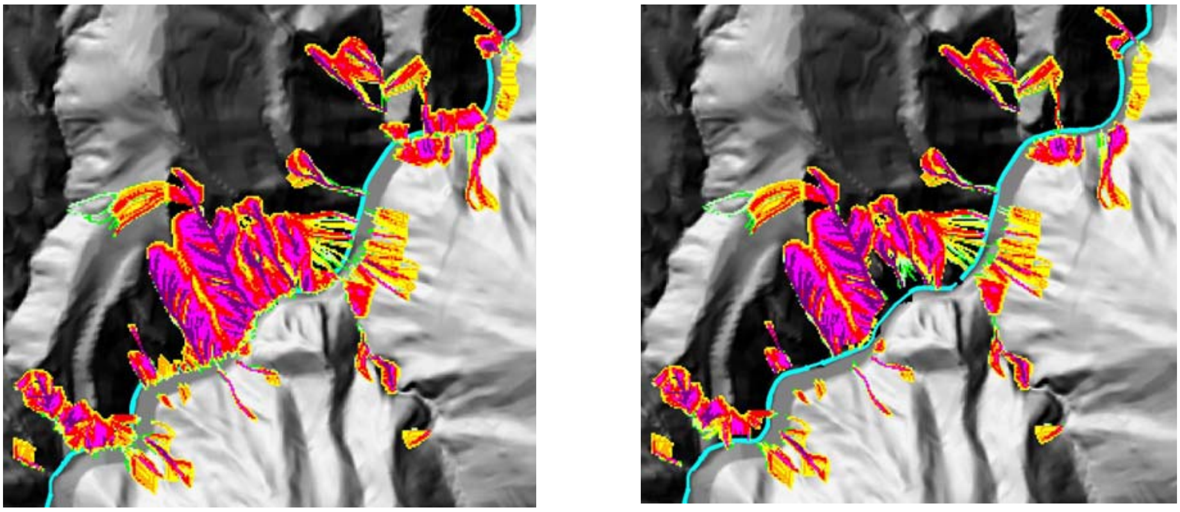

Figure 3. Nera River Valley. Comparison of rock fall simulation models. Left: the model does not consider the presence of rock fall defensive barriers. Right: the model takes into consideration the presence and the location of the rock fall elastic barriers.

A map of the transportation network was combined in a GIS with the rock fall hazard map produced by STONE to obtain a preliminary map of rock fall risk along the roads. Of the 32 kilometres of roads shown in the map, 8.7 km were found to be potentially affected by rock falls. This is equivalent to 27.2%. Since the location and types of the new rock fall defensive measures were known, their efficacy in reducing rock fall risk could be evaluated. This was accomplished in three steps. First, the areas where passive revetment nets were installed were excluded from the areas considered as possible sources of rock falls, and a new model was prepared. The total length of roads subject to landslide risk decreased to 6.1 km (19.1%). This indicates that the installation of the passive revetment nets reduced by about 10% the total length of roads subject to rock fall risk. We then considered the presence and location of the active elastic rock fences. For simplicity, fences where considered 100% efficient in stopping rock falls i.e., the possibility for a boulder to go over a fence or to brake trough a fence was excluded. The new simulation revealed that the total length of roads subject to rock fall risk decreased to 2.9 km, 9.3% of the entire road network (Figure 3). As a last step we attempted a check of the efficiency of the new elastic fences. This was accomplished by comparing the height of the rock fall trajectories with the height of the rock fences where the latter were installed. The analysis revealed that about 25% of the elastic rock fall fences can be over passed by flying boulders. This indicates that despite the considerable reduction in the risk of rock falls, residual risk still exists along the roads of the Nera River valley.

Two scientists were involved in the activities of WP2, for a total of about 140 working hours.

Working Package 5

The WP5 deals with the dissemination of the project results and deliverables. Activities within WP5 are co-ordinated by the project leader, Prof. James C. Bathurst (University of Newcastle upon Tyne). The activities at CNR IRPI Perugia focused on the maintenance and upgrade of the DAMOCLES web site, and on the update and improvement of the GIS-based web system for the publication on the Internet of thematic and landslide hazard maps.

The most relevant activity consisted in the implementation of the GIS-web server on a new computer, courtesy of CNR IRPI. The availability of a new release (release 4.0) of the ESRI Arc-IMS software used to publish maps and other geographical information on the web, made it possible to transfer the GIS-based web site from a Windows-based system to a Linux-based system. The change was totally transparent to the end user, and made the system more robust and less prone to network attacks, and subsequent degraded services or failures typical of Windows systems. Additional activities included: a) updating the web software "apache" whenever new stable releases, security fixes or patches were made available, b) updating the web site whenever a new deliverable or new information was made available by the partners, and c) correcting errors and inconsistencies in the several web pages making up the DAMOCLES web site.

Two scientists were involved in the activities of WP5, for a total of about 60 working hours. A software and GIS expert was involved in the activities of WP5, for a total of about 60 hours. The cost of the latter consultancy was not charged to the DAMOCLES project, but was paid by CNR IRPI grants.

Section 3. Milestones and Deliverables Obtained

Working Package 2

Deliverables produced in WPS include rock fall hazards maps and preliminary rock fall risk assessment for the Yosemite Valley, California (USA), and for the central part of the Nera River Valley, in the Umbria region of central Italy.

The rock fall hazard map for the Yosemite Valley covers an area of about 85 km^2, and shows the count of the rock fall trajectories computed by STONE, together with a map of the rock fall shadow angle (*Wieczorek et al*., 1998), and the location of a few single rock fall boulders mapped in the field. Information on rock fall hazard is superimposed on U.S. Geological Survey, colour topographic maps at 1:24,000 scale. The map is currently being considered for a joint US Geological Survey – CNR IRPI publication at 1:24,000 scale. Whether the U.S. National Park Service will adopt the computer model shown in the map as an alternative or as integration to the 22° shadow angle line to define the limit of hazardous rock fall areas is unknown.

The rock fall hazard assessment completed for a section of the Nera River Valley allowed for a preliminary assessment of rock fall risk, for the identification of the sites where newly installed rock fall defensive measures may be inadequate, and for the estimation of the residual risk in the study area. The Perugia Province, responsible for the maintenance and (partly) for the safety of the State Roads SS 320 and SS 209, is currently investigating the possibility of using the outcomes of the rock fall risk assessment to plan new defensive measures aimed at mitigating rock fall risk in the Nera River Valley.

Working Package 5

The outcomes of the project meetings, the morphological and geological descriptions of the study areas, the descriptions of the models that were developed or applied by the partners, the material distributed during the DAMOCLES training activities, and the information on the other project deliverables (publications, reports, etc.) were made available to the public domain through the DAMOCLES web site at the internet URL http://damocles.irpi.pg.cnr.it. In particular:

- the project coordinator (Prof. James C. Bathurst) contributed the minutes of the Saragoza meeting.
- the University of Padua (Prof. Mario A. Lenzi) provided an updated description of the Rio Lenzi Study area (Veneto Region, Italy) and the teaching material used at the DAMOCLES training course held at the University of Padova, on September 2002, on the application of the debris flow models developed by the Padua team.
- the University of Milano Bicocca (Prof. Giovanni B. Crosta) provided updated information on the Pioverna study area (Lombardy Region, Italy).

Section 4. Deviations from the Work Plan and their Impact on the Project

As previously mentioned, the time spent on the two working packages by CNR IRPI personnel was the following:

WP2: Two scientists, for a total of 140 working hours.

WP5: Two scientists, for a total of 60 working hours.

Concerning the time spent on the two Working Packages, no significant deviation from the original work plan was observed. However, testing of the rock fall simulation program STONE outside the originally established study area (i.e., the Pioverna catchment, in Lombardy Region) was not foreseen. We decided to take this opportunity because a) the tests originally planned were completed ahead of schedule and with positive results, and b) new, high quality data were made available by the U.S. Geological Survey, for the Yosemite Valley study area, and by the CNR IRPI, for the Nera River Valley study area. The new test sites allowed verifying the software STONE in very different geographical regions. The porting of the GIS-based web server on a Linux-based system was also unforeseen. Albeit this represents a deviation from the original work plan, the impact on the project is positive.

Section 5. Coordination of Information between Partners and Communication Activities

The research activities carried by the CNR IRPI Perugia within WP2 were conducted in cooperation with Gerald F. Wieczorek of the U.S. Geological Survey, Reston National Centre, USA (for the Yosemite Valley case study), and with geologists and geomorphologists at the CNR IRPI Perugia Centre (for the Nera River Valley case study). Little interaction occurred with the other partners.

The technical activities for the maintenance and update of the project web site (WP5) were carried out independently by CNR IRPI whenever new information on the study areas, on the models, or on the project deliverables was made available by the project coordinator or by one of the partners.

Section 6. Difficulties Encountered at Management and Coordination Level

There have been no difficulties during the reporting period.

Section 7. Plan and Objectives for the next period

The DAMCLES project is coming to its end. Only four months remain until the conclusion of the project. Activities related to WP2 can be considered complete and no further modelling will be performed at CNR IRPI. The remaining time will be spent summarizing the results obtained. We expect to spend most of the of the project remaining time (a total of about 100 hours) working on WP5. We will continue to update the project web sites, publishing the project reports and the information provided by the other partners. Due to initially unforeseen changes in the organization of the CNR computer network, in the next months we will change the internet address of the project web site. The new URL will become http://damocles.irpi.cnr.it. The old web address will remain active for several months. As originally planned, the DAMOCLES web site will be maintained for three years after the end of the project, i.e., at least until March 2006.

Section 8. Publications

During the reporting period the CNR IRPI team has prepared a paper describing the application of STONE in the Yosemite Valley, California. The paper was recently submitted for publication to an international, peer-reviewed journal.

Guzzetti, F., Reichenbach, P. & Wieczorek, G.F.: Rockfall hazard and risk assessment in the Yosemite Valley, California, USA. Submitted to: *Natural Hazards and Earth Systems Science*, 2002.

A second paper describing an attempt to model rock fall hazards and the associated risk along the transportation network in the central part of the Nera River valley, in central Italy, is currently being prepared, and will soon be submitted to an international, peer-reviewed journal.

Guzzetti, F., Reichenbach, P. and Ghigi, S.: Rock fall hazard and risk assessment along the transportation network in the Nera valley, Central Italy. To be submitted to *Engineering Geology*, 2002.

In addition, two abstracts describing preliminary results of the work carried out in the Yosemite Valley and the Nera River valley were presented at the XXVI General Assembly of the European Geophysical Society.

Ghigi, S., Guzzetti, F., Reichenbach, P., and Detti, R.: Preliminary assessment of rock fall hazard and risk in the central part of the Nera Valley, Umbria Region, Central Italy. EGS02-A-00925, *Geophysical Research Abstracts*, 4, 2002, ISSN 1029-7006, Nice, 21-26 April 2002.

Guzzetti, F., Reichenbach, P., and Wieczorek, G.F.: Rock-fall hazard in the Yosemite Valley, California. EGS02-A-01191, *Geophysical Research Abstracts*, 4, 2002, ISSN 1029-7006, Nice, 21-26 April 2002.

Section 9. References

Antonini, G., Ardizzone, F., Cardinali, M., Galli, M., Guzzetti, F. and Reichenbach, P.: Surface deposits and landslide inventory map of the area affected by the 1997 Umbria-Marche earthquakes. *Boll. Soc. Geol. It.*, Special Volume 1, Part 2, 843-853, 2002.

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