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Solid Earth
Discussions

Interactive comment on "A reversed hierarchy of active normal faults: the 6 April 2009, M_w 6.3, L'Aquila earthquake (Italy)" *by* L. Bonini et al.

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We thank Anonymous Reviewer#2 for his/her comments, and respond to him/her as follows:

Comment a):

(1) Historical earthquakes have occurred on faults with a clear surface expression. (2) Trench data shows that large historical earthquakes have reached the surface (3) A fault that has an earthquake in 2009 may still have a lower slip-rate than that which has not had an earthquake for hundreds of years (slip rates on faults in this region are of the order of 0.1mm/yr – 2mm/yr and thus recurrence intervals of many thousand years are common). Although the notion of blind faults in the Apennines is not new, the idea

that they represent the majority of potential seismic sources is not consistent with most of the literature.

Page 124 Lines 25 – 28: There is no evidence for this. Even if one does believe the blind fault theory proposed in this paper, there have been other earthquakes (both recent and in the historical record (see Galli et al., 2008 for a review of surface faulting revealed by trench data)) that have occurred on the faults with the greatest surface expressions. It seems they are basing their ideas of all Italian Apennine earthquakes on the interpretation of one event, an interpretation that is unlikely to be widely accepted.

Response a):

The wide-range criticism raised by Reviewer#2 confirms that our conclusions do not follow the interpretations proposed by mainstream Italian active faulting and paleo-seismology researchers. Given enough space and time we would like to address all of these issues: how many historical earthquakes are really known to have ruptured faults with a clear surface expression? Trench data expose surface faults, but who can prove all of them are really and directly connected to the fault at seismogenic depth? What does the literature really say against blind faulting being one of the most important mechanisms in Italy? The paleoearthquake catalogue prepared by Galli and corworkers (their Table 1) lists 56 paleoevents, but these refer to less than 20 faults countrywide, for some of which the primary nature of the observed breaks is highly controversial: isn't this just a fraction of the number of potentially surface-breaking earthquakes in Italy (M 6+)?

The approach we propose is indeed a new one. It is based on ideas developed after the most recent earthquakes in Italy, which systematically surprised the scientific community as for the seismogenic faults activated, and on a careful examination of the existing data, of their true merit and of their uncertainties. We are not trying to demonstrate that paleoseismology is not a reliable tool for investigating large earthquakes of the past, but we want to focus on what exactly is seen at the surface following a significant earthquake. Our seismotectonic reconstruction of the 2009 L'Aquila earthquake does not deny that there may be surface deformation and faulting: we propose, however, that in complex tectonic areas, where pre-existing faults intersect with the seismogenic faults interact with them, the surface expression of seismogenic sources may not be easily detectable and may sometimes be misleading. For instance, the recent activity of the Paganica fault could have been detected by paleoseismological analyses, yet no trench was cut across it before the L'Aquila earthquake, while several other faults nearby have been investigated in detail. Why? A possible explanation is that the surface expression of this structure is weaker than that of other faults in the L'Aquila area, and hence less attractive for peleoseismological research. This is one of the main points of our paper and this is why we wrote: "What is absolutely crucial for the geological reconnaissance work is that in the field these highly diverse faults may exhibit a reversed hierarchy, the most obvious being the least relevant to fault-based seismic hazard assessment and vice-versa."

Comment b):

I also think the analogue model needs to be justified – they seem to have used parameters that fit their interpretation, but have not shown what the results would look like if the fault were not assumed to be blind. Overall I think the conclusions need to be put in the context of the literature more and the analogue modelling assumptions need to be justified.

Response b):

Our analogue model is based on well established rules and materials (e.g. Shellart, 2000). We used it as an experimental approach to test a specific idea and support a clearly described model. More specifically, we reproduced crustal bending to demonstrate that this mechanism implies a style of surface deformation that is kinematically, geometrically and structurally compatible with what has been observed by many in the study area. We did not carry out analogue models of surface-breaking faults because

of the wide literature already existing on this topic. For instance, the papers by Withjack and Schlische (2006) and Miller and Mitra (2011) describe analogue models for surface-breaking faults. We know well their models and referenced them in our paper, but our aim was to test a different seismotectonic setting (see section 3). We tested our scheme, critically presenting and discussing our results in the perspective given by the aforementioned literature, without reproducing models that have been known to the scientific community for years. The results of this analysis are presented in the section called "Blind and surface faulting: an alternative model". The surface expression of the earthquake causative fault is evident from this section and from the figures. Keeping in mind that surface warping is predicted by the dislocation theory and is observed in DInSAR-based elaborations, what we learned from the models is that an upper crustal fault whose tip is buried at 3 km depth may create surface breaks that are compatible in size, extent and location with those observed in Paganica.

Comment c):

Page 119 Line 14: "the region is criss-crossed by many 5-10 km-long normal faults".. It should be noted that the region also has many faults longer than 5-10km (e.g. Boncio et al., 2004; Cinque et al., 2000; Faure Walker et al., 2010; Galadini and Galli, 2000).

Response c):

There are some, but not many. At any rate we are willing to rewrite this sentence.

Comment d):

Page 120 Line 26 some authors found greater surface offsets (e.g. Boncio et al., 2010; Roberts et al., 2010)

Response d):

We may add these references discussing where the above mentioned authors found greater surface offset.

Comment e):

Page 123 Lines 23-25 – This needs examples and references.

Response e):

We may add more examples, e.g.: Khalil and McClay, 2002; Jackson et al., 2006; Kaven and Martel, 2007.

Khalil, S.M., and McClay, K.R (2002). Extensional fault-related folding, northwestern Red Sea, Egypt. Journal of Structural Geology, 24, 743-762. Jackson, C.A.L., R.L. Gawthorpe, I.R. Sharp (2006). Style and sequence of deformation during extensional fault-propagation folding: examples from the Hammam Faraun and El-Qaa fault blocks, Suez Rift, Egypt. Journal of Structural Geology, 28, 519-535. Kaven, J. O., and S. J. Martel (2007), Growth of surface-breaching normal faults as a threeâĂŘdimensional fracturing process, J. Struct. Geol., 29, 1463–1476, doi:10.1016/j.jsg.2007.05.007.

Comment f):

Technical Comments Page 123 Line 25-26: This sentence needs to be rewritten

Response f):

We may rewrite this sentence.

Comment g):

References (note this is a small sample of what could be included) Boncio, Lavecchia and Pace (2004), Defining a model of 3D seismogenic sources for Seismic Hazard Assessment applications: The case of central Apennines (Italy), Journal of Seismology, 8, 407-425 Boncio, Pizzi, Brozzetti, Pomposo, Lavecchia, Di Naccio, and Ferrarini, (2010), Coseismic ground deformation of the 6 April 2009 L'Aquila earthquake (central Italy, Mw6.3), Geophys. Res. Lett., 37, L06308, doi:10.1029/2010GL042807 Cinque, Ascione, and Caiazzo, Distribuzione spazio-temporale e caratterizzazione della fagliazione quaternaria in Appennino meridionale, in: Galadini F., Meletti C., and Rebez

A. (Eds), Le ricerche del GNDT nel campo della pericolosita sismica (1996- 1999), CNR-Gruppo Nazionale per la Difesa dai Terremoti - Roma, 203-218, 2000 Faure Walker, Roberts, Sammonds, and Cowie, (2010), Comparison of earthquake strains over 102 and 104 year timescales: insights into variability in the seismic cycle in the central Apennines, Italy, Journal of Geophysical Research 115, B10418 Galadini and Galli, (2000) Active Tectonics in the Central Apennines (Italy) – Input Data for Seismic Hazard Assessment, Natural Hazards 22, 225-270 Galli, Galadini, and Pantosti, (2008), Twenty years of paleoseismology in Italy, Earth Science Reviews, 88, 89-117 Galli, Messina, Giaccio, Peronace and Quadrio, (2012), Early Pleistocene to late Holocene activity of the Magnola fault (Fucino fault system, central Italy), Bollettino di Geofisica Teorica ed Applicata, 53, doi: 10.4430/bgta0054 Roberts, Raithatha, Sileo, Pizzi, Pucci, Faure Walker, Wilkinson, McCaffrey, Phillips, Michetti, Guerrieri, Blumetti, Vittori, Cowie, Sammonds, Galli, Boncio Bristow, Walters, (2010), Shallow subsurface structure of the 2009 April 6 Mw 6.3 L'Aquila earthquake surface rupture at Paganica, investigated with ground-penetrating radar. Geophysical Journal International 183(2), 774-790 doi:10.1111/j.1365-246X.2010.04713.x

Response g):

We may add these papers in the reference list and briefly discuss their results and implications.

Interactive comment on Solid Earth Discuss., 5, 117, 2013.