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Interactive comment on "From mapped faults to earthquake magnitude: A test on Italy with methodological implications" *by* Fabio Trippetta et al.

Valensise

gianluca.valensise@ingv.it

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Submitted by Gianluca Valensise, Roberto Basili, Pierfrancesco Burrato, Michele Carafa, Francesca Cinti, Riccardo Civico, Paolo Marco De Martini, Deborah Di Naccio, Umberto Fracassi, Fabrizio Galadini, Vanja Kastelic, Daniela Pantosti, Mara Monica Tiberti, and Paola Vannoli

The geology of Italy is normally considered to be extraordinarily complex, which makes it very fascinating but also quite difficult to investigate. The authors of this paper indeed make an exception, as they approach Italian geology as if major scientific questions concerning the relationships between earthquakes and their causative faults could be

addressed by following a handful of simple, universally recognised rules.

We doubt this is the case. In fact, we argue that Trippetta and co-workers did not consider at least two decades of literature on the relationships between seismogenic faulting at upper-mid crustal levels and brittle faulting at shallow crustal depth. Their paper is essentially a GIS exercise;, backed by references that are generally highly selective, often inappropriate and sometimes very old. For instance, a very general statement such as "Larger earthquakes characterize the Apennines southern portion (Calabria), with historical seismic events that reached magnitudes up to 6.9-7.5" is backed by a reference to Cello et al. (2003), a 15 years-old paper dealing with a specific earthquake in Val d'Agri, 50 km north of Calabria, and to Gasparini et al. (1985), a 33 years-old paper that belongs to a distant past of seismotectonics in Italy. A simple reference to the Catalogo Parametrico dei Terremoti Italiani (CPTI), the Italian reference parametric catalogue, would have been enough; it would also have prevented a mistake, since no M 7.5 earthquake is reported anywhere in Italy.

The conclusions of the paper are based on several misconceptions, leading to results that could have catastrophic outcomes for seismic risk mitigation in Italy, if taken seriously by any authority in charge. Its main misconception probably rests in the assumption that "...all considered faults are active or can be potentially reactivated..." (section 4.2, page 9 of the manuscript). It is unfortunate that the fault database that should support this bold statement is not accessible (see Petricca, P., et al., Revised dataset of known faults in Italy, GFZ Data Services, https://doi.org/10.5880/fidgeo.2018.003, http://pmd.gfz-potsdam.de/panmetaworks/, 2018; the first link leads to an error page, while the second leads to a generic page of the GFZ website).

Simply put, Trippetta and co-workers maintain that they can obtain the Potential Expected Maximum Magnitude of earthquakes (PEMM) from any fault that appears in their (currently inaccessible) compilation, which includes (from the caption of their Figure 2): âĂć the Structural Model of Italy at the 1:500,000 scale; âĂć the Italian Geological Maps at the 1:100,000 scale; âĂć the GNDT database of active faults (Galadini et al., 2000); âĂć the ITHACA database (Michetti et al., 2000); âĂć selected active faults from complementary (complementary to what?) studies published by different authors.

Notice that three of these studies refer explicitly to active - or at least capable - faults, but the other two sets, which happen to be the most numerous, do not. Also notice that Trippetta and co-workers subdivided each dataset into Class A (high quality), that includes "...exposed faults where subsurface and surface data allow for a detailed and reliable characterization of fault length...", and class B (low quality), containing "...buried and off-shore faults investigated mainly by seismic surveys, for which a precise characterization of fault length cannot be achieved...". Finally, notice that Trippetta and co-workers deliberately ignore the down-dip dimension (width) of the faults.

A basic consideration is that by assembling faults from such different and non-homogeneous sources, Petricca et al. inevitably put together a) alternative views on the same faults, possibly stemming from widely alternative conceptual models; b) faults that are mutually exclusive due to their geometry (typically, faults crossing each other in the subsurface: if one fault ends against another, its seismic potential based solely on length is largely overestimated); c) faults that cannot be simultaneously active, or reactivated, in the current stress regime; and d) blind faults whose actual length may be strongly biased by the availability and density of subsurface data.

In our opinion it is extremely unsafe to derive the maximum earthquake magnitude from the length of a fault of which we do not even know (a) if it is active or if it can be reactivated (e.g. whether or not it cuts or deforms deposits of a specified age or it is suitably oriented with respect to the current stress regime), and (b) whether and how it is connected with a deep-seated seismogenic source. For decades earthquake geologists have investigated the surface expression of presumed active faults to gain insight into their long-term behaviour and seismogenic potential. The main purpose of such studies is to distinguish between active and non-active faults (sealed, truncated, or misoriented with respect to the current stress field). From this paper we learned that this is no longer necessary, as any mapped fault has the potential of generating a large

earthquake.

Trippetta and co-workers propose a very simplistic approach to a rather complicated problem, based on criteria and assumptions that are not exposed in the text. A revealing exercise is to simply look at the faults that actually generated the most recent and well investigated earthquakes in Italy. To this end, we focused on Italian seismicity of the past 50 years (Table 1). According to the latest version of CPTI (https://emidius.mi.ingv.it/CPTI15-DBMI15/), 32 earthquakes of magnitude equal or larger than 5.5 occurred during this interval, plus the three largest shocks of the 2016 central Apennines sequence (shown in bold italics).

The question to ask is: for how many of these earthquakes could the authors declare a positive relationship between the magnitude and the surface length of the presumed earthquake causative fault? âĂć probably for the Amatrice and Norcia shocks of the 2016 sequence; âĂć not for the 6 April 2009, Mw 6.3, Aquilano earthquake, for which the fault dataset supplied by Trippetta and co-workers in their Supplementary Data (Dataset-S1-ItalianFaults.kmz: Figure 1) shows a fault that is less than 1 km in length, reportedly taken from the Structural model of Italy and included in Class A. This fault is at least 15 times shorter than the fault necessary to generate a Mw 6.3 earthquake, and it does not even coincide with the surface ruptures observed following the 6 April 2009 mainshock; âĂć not for the 23 November 1980, Mw 6.8 Irpinia-Basilicata earthquake, for which the Class A subset of the dataset used by Trippetta and co-workers, derived from the Ithaca database, reports a ≈10 km-long fault; nearly four times shorter than the 38 km-long rupture reported in the classical paper by Pantosti and Valensise (1990), among those used by Wells and Coppersmith (1994) to derive their empirical relationships. At any rate, even this ≈10 km-long fault was not known prior to the earthquake; âĂć and finally, nor for the 1968 Belice, 1976 Friuli, 1984 Abruzzo, 1990 Potentino, 1997 Colfiorito, 2002 Molise, 2012 Pianura emiliana earthquakes, whose causative faults were most likely blind.

One could argue that the earthquakes that occurred over the past 50 years were not very large, on average, and hence are not representative of the problem at hand. But even the M 7+ earthquakes that have occurred in the early 20th century, the 1908 Messina Straits and the 1915 Avezzano (both of Mw 7.1 according to CPTI), provided contrasting evidence; âĂć no surface breaks have ever been reported for the $\approx$40-km-long source of the 1908, Messina Straits earthquake, whose causative fault was most likely blind. Nevertheless, the Class A subset of the dataset used by Trippetta and co-workers, derived from GNDT, does report a $\approx$36-km-long offshore fault, probably based on geodetic evidence, showing that this dataset in fact reports a combination of inferred seismogenic sources and actual surface faults; âĂć for the 1915, Avezzano earthquake the Class A subset of the dataset used by Trippetta and co-workers, derived from both the Ithaca and GNDT datasets, reports a $\approx$15-km-long fault. This fault accounts only partially for the 30-50-km-long fault that is needed to justify a Mw 7.1 event. The reported faults appear as the surface projection of a deeper portion of the seismogenic fault and do not follow the reported coseismic breaks.

In summary, it is likely that none of these earthquakes have been generated by a surface fault reported in Petricca et al.'s database and having the characteristics upon which the paper by Trippetta and co-workers is based. In other words, for none of these earthquakes could the magnitude be derived with confidence based solely on the reported length of their surface trace, which is systematically shorter than that observed (or inferred) after the earthquake. But if the proposed approach does not work on relatively large and recent earthquakes for which there is good control on the causative fault and on the magnitude, why should it work for older events and, most importantly for future ones?

The largest earthquakes require an additional consideration. Virtually no 20-40-km-long fault has ever been reported in the areas that were struck by the largest Italian earthquakes prior to their occurrence; but such long faults do occur in areas of more mature geology were seismicity is minimal or absent, such as in the Alps. This might indicate that currently active, seismogenic dip-slip faults (recall that most Italian upper

crustal earthquakes are generated by normal, reverse or thrust faults) are normally characterised by a discontinuous surface expression. The established basic geology of the orogens seems to show that when their activity stops, some of these faults are uplifted and rejuvenated along with their associated landscape, making them appear more continuous, more mature and downright ominous, right at a time of their evolution when they are no longer a concern for seismic hazard.

At the opposite end of the spectrum lie some catastrophic Italian earthquakes of the past few centuries that occurred in foreland areas and that reportedly were not accompanied by surface faulting. Such is the case of the 1693 Eastern Sicily earthquake, the largest in the Italian earthquake catalogue (Mw 7.3).

Under these ill-posed assumptions (assuming that any mapped fault is potentially active, or can be reactivated; mixing faults that may be mutually exclusive; disregarding the post-orogenic rejuvenation of many faults, etc.), the results obtained by Trippetta and co-workers - and plastically represented in their Figures 11 and 12 - are all but unexpected. They show very high-magnitude values of the PEMM for the less-reliable Class B faults; a circumstance that can be simply explained considering that buried fault traces obtained by interpolating sparse data over wide areas will necessarily appear longer than faults within an exposed fault system. It is true that we may have yet to see some exceptionally large crustal earthquake, i.e. larger than any earthquake already known to the historical record; but without adopting any criteria regarding the likelihood of these large ruptures, such scenario is totally at odd with the unique historical, archaeological and palaeoseismological richness of the Italian earthquake record. This information provides the basis for a much more mindful way to estimating the magnitude of future large earthquakes, also in view of the frequency-magnitude distribution of earthquake occurrence.

The bottom line is that the approach proposed in the paper by Trippetta and co-workers goes against the knowledge acquired during decades of seismic hazard studies in Italy and the rest of the world. It does not predict anything useful but is potentially dangerous and very costly, if not put in the right perspective. The authors never admit that their results are pointless, even when they remark (Page 12) that "... the negative occurrences are very limited...", i.e. that the number of predicted magnitudes that are larger than those observed in the historical record outnumbers by far the opposite case, resulting in the very asymmetric pattern shown in Figure 12. In fact, they refer to a "...limited difference... between PEMMs and the catalogued earthquake magnitudes..." (!), neglecting the obvious consideration that magnitude is a logarithmic quantity, implying that a 0.2 increase in Mw, for example from 6.0 to 6.2, doubles the seismic moment. For a typical continental fault having an aspect ratio in the range 2-3 and standard scaling for coseismic slip, doubling the moment implies that fault length may increase by over 20%. For a magnitude increase of 0.5, for example from 6.0 to 6.5, the seismic moment becomes 5.6 times larger, which may require a fault that is 100% or more longer than that necessary to generate the smaller earthquake.

In commenting their rather disappointing results the authors invoke potential incompleteness of the earthquake catalogue, which is always possible locally, but is also very unlikely for a work that considers the whole of Italy and all the data available in the richest earthquake catalogue worldwide. This record has certainly missed specific events but is reliable enough to constrain the frequency-magnitude distribution of Italian seismicity. A piece of information that a study about the estimates of earthquake magnitude cannot neglect.

Trippetta and co-workers conclude by stating that "...more detailed studies should be developed...". This is always a good thing to do, except for the fact that detailed studies of Italian faults do exist and are often more accurate and to the point with respect to what is proposed here.

The conclusions of this paper are worrisome, in consideration of the large number of areas where the authors envision the possibility of M 7.5 and larger earthquakes, that is to say earthquakes bigger than the largest magnitude ever recorded in Italy, without any consideration as to how frequently this may occur. In a standard PSHA approach

these large magnitudes would be assigned a very low probability of occurrence, leading to a minimal statistical impact on the expected ground shaking for short average return periods. The information about the possible largest earthquakes may generate a great deal of confusion if not appropriately communicated. We cannot imagine how the residents of Bologna, Ancona, Pescara, but also Padua, Trento, Vicenza and even Venice, cities lying in areas that are currently considered mid- to low-hazard, would react to knowing that very large earthquakes may occur below their feet at any moment.

Another major flaw in the approach taken by Trippetta and co-workers lies in their discretisation of seismogenic zones into 25x25 km sub-areas. Of course, some discretisation is inevitable, but one has to be aware that a 25x25 km cell may host a 35 km-long fault, at the most. According to the equation proposed by Leonard (2010), the empirical law adopted by Trippetta and co-workers, a 35 km fault length corresponds to a Mw 6.8 earthquake. Hence, any larger earthquake will necessarily encompass two or more cells. A close inspection of Figures 7 and 8 of the paper, however, reveals that several cells filled in red or dark red, which according to the adopted colour-coding should correspond to an expected Mw in the range 7.4 to 7.8, occur isolated, i.e., surrounded by cells for which the expected PEMM is much smaller. According to same equation by Leonard (2010), this magnitude range corresponds to a fault length in the range 78 to 135 km, which should involve a minimum of 2 to 4 adjacent cells, depending on fault strike. An isolated cell capable of a Mw 7.4 earthquake is hence a seismological paradox that has no physical meaning, as the earthquake causative fault will necessarily extend to adjacent cells.

We are a group of INGV seismologists and earthquake geologists who regularly provide active faulting data and seismogenic models to Italian, European, and global SHA practitioners, and to the Italian Civil Protection authorities. As such we are especially concerned that inaccurately collected fault data, inconsistent elaborations and unjustified conclusions such as those presented by Trippetta and co-workers may be implicitly validated by appearing in a respectable journal such as Solid Earth, thus becoming embedded in the literature. In addition to that, chasing the problem of the occurrence of very large earthquakes with an overly simplistic approach is the most effective way to shift our attention from the areas where earthquakes in the Mw range 6-0-7.0 are more likely to hit. These areas include most of the eastern Alps, various portions of the Apennines, most of Calabria and several parts of Sicily. Encouraging earthquake retrofitting in these areas should be the main target of any responsible seismological community.

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Please also note the supplement to this comment:
https://www.solid-earth-discuss.net/se-2018-98/se-2018-98-SC1-supplement.pdf

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2018-98, 2018.

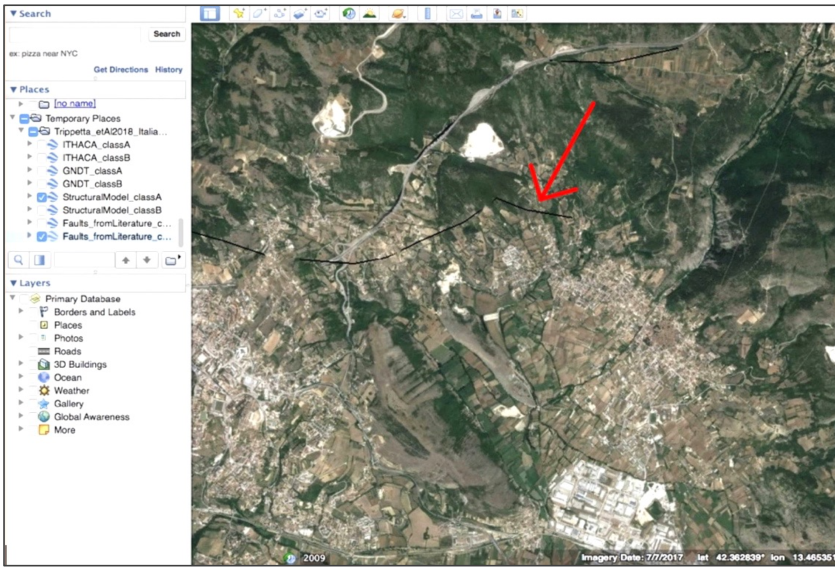

Figure 1 - The Paganica Fault (shown by the red arrow) as reported in the database provided w