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PRELIMINARY REPORT

ON THE L'AQUILA M_W=6.2 (M_L=5.8) EARTHQUAKE (6^{TH} OF APRIL 2009), ABRUZZO, CENTRAL APENNINES, ITALY

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1) Introduction

On Monday the 6th of April 2009 a strong earthquake struck the city of L' Aquila and the surrounding villages producing extensive damages, about 300 fatalities and more than a thousand of injuries. The earthquake was assessed as a Mw=6.2 or M_L=5.8 (source INGV) or Mw=6.3 (USGS), having a normal faulting mechanism of N147^o striking and dipping about 43^o towards the SW. The earthquake occurred on one of the NW-SE trending normal faults that form part of the 800km long segmented normal fault system (Figure 1a) that accommodates the extension in the Apennines (e.g. Anderson and Jackson 1987, Roberts et al. 2002). These faults tend to generate strong events from M=5.5 up to M=7.0 and depending on the magnitude and the earthquake depth can produce from minor to significant environmental effects. In the central Appenines faults are characterized by pure dip slip faulting with a mean fault slip direction of 222^o ± 4^o (Roberts and Michetti 2004).

L' Aquila has been assessed as an area of relatively high seismic hazard (Slejko et al. 1998, GNDT-SSN 2001, Rebez et al. 2001). Based on the historical record the town has suffered intensity IX or higher at least three times in the past (in 1349 A.D., 1461 A.D. and 1703 A.D.) (Boschi et al. 1999). The 1703 event was part of a seismic sequence that struck the area.

However, the damage of L' Aquila in 1703 is not attributed to the L' Aquila fault, but most probably to the nearby Barete fault that lies westwards (Figure 1b). The Barete fault (or Arischia fault) was activated during the final third earthquake of the sequence on the 2nd of February 1703, where surface ruptures and liquefaction phenomena were reported near the village of Pizzoli (Blummeti 1995). Finally, seismic hazard maps from geological fault slip-rate data also show that the hangingwall centre of the L' Aquila fault is characterised by high shaking frequency for intensities ≥IX (Figure 1b) reaching up to 80 times over the last 18.000 yrs (Roberts et al. 2004). This is attributed to the combined effects of three closely spaced active faults, two of which exhibit high throw-rates exceeding 1 mm/yr (Campo Imperatore and L' Aquila faults).

2) Active Faults

The highest damages were recorded in the Aterno valley (Figure 2) that is bounded northwards by the L' Aquila fault. The L'Aquila fault is a 37 km long structure that strikes northwest-southeast and downthrows to the southwest (Roberts and Michetti 2004). Its southern tip is located near Civitaretenga village (2 km east of Caporciano) and its northern tip is located towards the western end of Mt. San Franco (Figure 3, Figure 4). This fault has a rather complex structure, since it comprises several overlapping segments some of which are antithetic to the main SW dipping (Figure 5a) fault plane (Papanikolaou et al. 2005). These antithetic planes are nicely observed northwards the village of Barisciano (Figure 5b and 5c), have fresh looking fault planes and maybe linked to the possible active NE dipping fault in the southern part of the valley. In a few words the strain in the area is accommodated on multiple closely spaced synthetic and antithetic overlapping segments. Therefore, the fault zone is characterised by distributed displacement on several overlapping faults that break up the footwall and the hanging wall into smaller blocks. The latter implies that searches for potential primary surface ruptures should extend over a large area. This fault has a reported throw-rate of 0.3-0.4 mm/yr (Galadini and Galli, 2000) based on offset Quaternary terraces (Bertini and Bosi, 1993) and up to 1.1mm/yr towards it centre that decreases to 0.7mm/yr near Mt. Franco and 0.3mm/yr towards Caporciano, based on the throws of the postglacial scarps (Papanikolaou et al. 2005). Many Pleistocene palaeolandslides of tectonic origin are reported for this fault concealing the position of the fault trace close to the valley (Demangeot, 1965; Bagnaia et al., 1992).

Extensive damages along the Aterno valley can also be produced by the activation of the Campo Imperatore fault. The Campo Imperatore fault is an impressive NW-SE trending normal fault that downthrows to the SW, crosses the highest elevation peaks and displays a postglacial scarp which displaces post-glacial valley bottom sediments (Figure 3). Giraudi and Frezzoti (1995) show a 16-18m high scarp for the Venacquaro valley and a 10-11m high scarp for the Maone valley implying an average slip-rate of 0.88-1 mm/yr for the Venacquaro valley and 0.67-0.78mm/yr for the Maone valley. The postglacial scarp and the slip-rate decreases eastwards as shown by Papanikolaou et al. 2005 (0.37mm/yr, 6.5km east of Val Maone) and Galli et al. (2002) based on trenching and offset alluvial fans (0.68 mm/yr towards the southeastern part of the fault close to Mt. Prena).

3) Field Observations and Interpretations

A survey took place (7-9th April) 24 hours after the mainshock in order to search for potential earthquake environmental effects (EEE) that were expected due to the strong magnitude and examine the damage pattern. Usually shallow events higher than M=6.0 tend to produce primary surface ruptures, whereas events that are between 5.5 and 6.0 are usually poorly expressed as discontinuous traces or fractures showing inconsistent or no net displacement (Bonilla et al. 1984, Darragh and Bolt 1987, Bonilla 1988, Michetti et al. 2000), which many times are assessed as secondary ruptures. Following the above we focused our attention in finding possible primary surface ruptures that were expected due to the strong magnitude in the most prominent fault plane outcrops in the area. According to the literature data three major faults can produce extensive damage to the area of L' Aquila (Roberts et al. 2004). These are the L' Aquila, Barete (or elsewhere known as Arischia or Mount Marine fault) and the Campo Imperatore faults. No primary surface ruptures were identified that are directly related to the major fault outcrops of the Barete and the L' Aquila faults. As far as the Campo Imperatore fault is concerned we checked the Montechristo segment, but we had no access to the main fault scarps of the Campo Imperatore fault, leaving an important gap to our observations. In particular, the fault outcrops in the Venacquaro and Maone valleys as reported from Giraudi and Frezzoti (1995), the scarp profile locality 13 from Papanikolaou et al. (2005), the road to the observatory of the Campo Imperatore fault as well as the trenching sites of Galli et al. (2002), have not been checked since there was no access. No significant landslides were recorded towards the southwestern flanks of the Campo Imperatore and Mt. Franco and minor damages were observed to the villages situated on the hanginwall of the Campo Imperatore fault. A few rockfalls were observed towards the NW tip of the L' Aquila fault in the Mt. Franco segment, but the postglacial fault plane shows no signs of reactivation (Figure 4). The rockfalls occurred on the immediate hangingwall and near the fault trace, involving cemented glacial debris, but this site is also disturbed by the road cut (Figure 4).

Moreover, the villages of Camarda, Barisciano, Caportsiano which are founded on the hangingwall of both faults are also characterized by little damages.

Overall, the environmental effects are assessed as minor compared to the official magnitude release estimate (Mw=6.2). This maybe attributed to the depth of the mainshock that was estimated at about 12km, whereas most of the major aftershocks occurred at 15km depth (source INGV), unless we miss important environmental effects on the Campo Imperatrore main fault outcrop area. Even though no primary surface ruptures were observed, tens of secondary ruptures have been recorded reaching up to several tens of meters long, near the villages of Onna and Fossa (Figure 3, Figure 6, Figure 7). The village of Onna suffered the highest damages and should be the macroseismic intensity epicenter (Figure 8). These secondary ruptures are all strictly NW-SE trending parallel ($150^{o} \pm 20^{o}$) to the activated fault plane and the existing L' Aquila fault segments, implying that they are closely associated to the event. These ruptures are mostly observed near the river embankments are several tens of meters long and up to 30cm wide, as well as on the manmade road embankments (Figure 6). Overall, these secondary ruptures appear in artificial and natural structures that are prone to rupturing. Most of these ruptures were transverse to the road network, producing cracks in paved roads that are several meters long and having offsets both horizontal and vertical of several cm (up to 6cm). In a non-paved road that links the village of Onna with the village of Fossa these ruptures were also aligned for a few tens of meters to the NW-SE trending road trace (Figure 7b). Local people reported to us that some of these ruptures were formed and some others were extended following the first large aftershock (Mw=5.6) that occurred on the 8^{th} of April. It is expected that several other secondary ruptures may exist near this epicentral zone. Many Pleistocene palaeolandslides of tectonic origin are reported for the L' Aquila fault (Demangeot, 1965; Bagnaia et al., 1992), however no significant landslides both in terms of their numbering and volume were recorded. Finally, extensive rockfalls were observed towards the southern boundary of the Fossa village where the steep limestone cliffs outcrop.

Following the above, an Environmental Seismic Intensity (ESI 2007) of VII-VIII (Michetti et al. 2007) is assessed between the villages of Onna and Fossa. This intensity value is significantly lower than the structural damage of Onna, which most probably experienced an MM intensity X. The environmental effects reflect mostly the "strength" of the earthquake rather than the economic development and the structural characteristics of the buildings (Serva, 1994). This implies a large discrepancy between the earthquake environmental effects and the damage pattern.

The majority of the damages in these villages relate to old masonry buildings (Figure 8). However, in the town of L' Aquila several modern buildings collapsed or sustained severe damages (Figure 9), implying that the construction quality is not the only cause for such damages. Several modern multi-store buildings are characterized by crumbling masonry and collapsed fill walls. This is systematically observed towards the ground and first floor of these buildings, which probably experienced higher stresses than the higher floors. The L' Aquila sedimentary basin is characterised by unfavourable site specific conditions. The basin is filled with a few hundred meters of lacustrine sediments that overlie the bedrock (Blumetti et al. 2002), producing significant ground motion amplification effect at low frequencies (De Luca et al. 2005). This amplification is mostly attributed to the couple of hundred meters thick lacustrine sediments. This may also explain the discrepancy between the higher damages compared to the relatively low environmental effects that have been recorded. The latter should be considered by the local authorities for the future planning, because the faults in the area have the capacity to generate stronger than the recent Mw=6.2 event, which partly relieved the stress in some of the fault segments.

4) Conclusions

Overall, two main scenarios are promoted. According to the first scenario and based on the environmental effects described above and the damage pattern where the villages that are located in the hangingwall of the main fault segments of both faults experienced little damages, this earthquake has most probably activated one of the fault segments of the L'Aquila fault that bounds the northern part of the Aterno valley is situated within the basin and probably did not reached the surface. This scenario implies a large discrepancy between the Earthquake environmental effects (VII-VIII) and the damage pattern (X), which is probably unprecedented for such a shallow event. The second scenario implies that primary surface ruptures and significant earthquake environmental effects did occur towards the main fault scarp of the Campo Imperatore fault. If the primary surface ruptures did occur in the Campo Imperatore, then following some reports of the local people the secondary ruptures we recorded may be related to the first large aftershock Mw=5.6. Still we are uncertain which of the two scenarios do actually apply. However, until access to the snow-covered Campo Imperatore is established and a detailed search would be feasible, none of the two scenarios can be promoted.

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Figures

Figure 1. a) Map of Italy showing the active faults and the NE-SW extension, b) Map showing how many times each locality receives enough energy to shake at intensities ≥ IX over the last 18.000 yrs (Roberts et al. 2004). The epicenter is located in an area that is characterized by a high frequency and lies in the hangingwall of three major faults (the L' Aquila (AF), the Barete (BF) and the Campo Imperatore (CIF) faults).

Figure 2. View of the Aterno Valley and the Campo Imperatore.

Figure 3. Topographic map (numbers are in UTM coordinates) showing the fault segments (modified from Roberts and Michetti (2004), Papanikolaou et al. (2005)), the towns and the localities where Earthquake Environmental effects were observed. The transparent box shows the inaccessible area towards Campo Imperatore.

Figure 4. View of the rockfalls and the postglacial scarp in the Mt. Franco. a) Distant view of the postglacial scarp, b) Close up view of the postglacial scarp at the road section, showing the upper and the lower slopes. c) The rockfalls involved cemented glacial debris in the immediate hangingwall of the fault a few meters away from the fault trace, but this site is also disturbed by the road cut.

Figure 5. View of the a) main SW dipping and b), c) antithetic NE dipping scarps of the L' Aquila fault northwards Barisciano village.

Figure 6. View of the secondary ruptures near the village of Onna. All secondary ruptures are NW-SE ($150^o \pm 20^o$) trending parallel to the activated fault plane and the existing active faults and appear in artificial and natural structures that are prone to rupturing. a) Secondary ruptures several tens of meters long and up to 30cm wide, near the river embankments. b),c),d) transverse ruptures in paved roads that are several meters long and having offsets of several cm (up to 6cm) both horizontal and vertical. Local people reported to us that some of these ruptures were formed and some others were extended following the first large aftershock (Mw=5.6) that occurred on the 8th of April.

Figure 7. View of the secondary ruptures between the villages of Onna and Fossa. a) Ruptures on paved road. b) The cracks were violent so that they ruptured also the asphalt pebbles. c) NW-SE trending ruptures in a non-paved road that links the village of Onna with the village of Fossa.

Figure 8. a) View of the extended damages and collapses towards the village of Onna. b) Collapsed bridge about 1km southwest from the village of Onna.

Figure 9. View of the damages in the town of L' Aquila. Damages and collapses were inflicted not only in old masonry buildings, but in several modern buildings as well. Several modern multi-store buildings are characterized by crumbling masonry and collapsed fill walls. This is particularly observed towards the ground and first floor of these buildings, which probably experienced higher stresses than the higher floors. Finally, several public buildings such as schools and municipality buildings suffered significant damage.

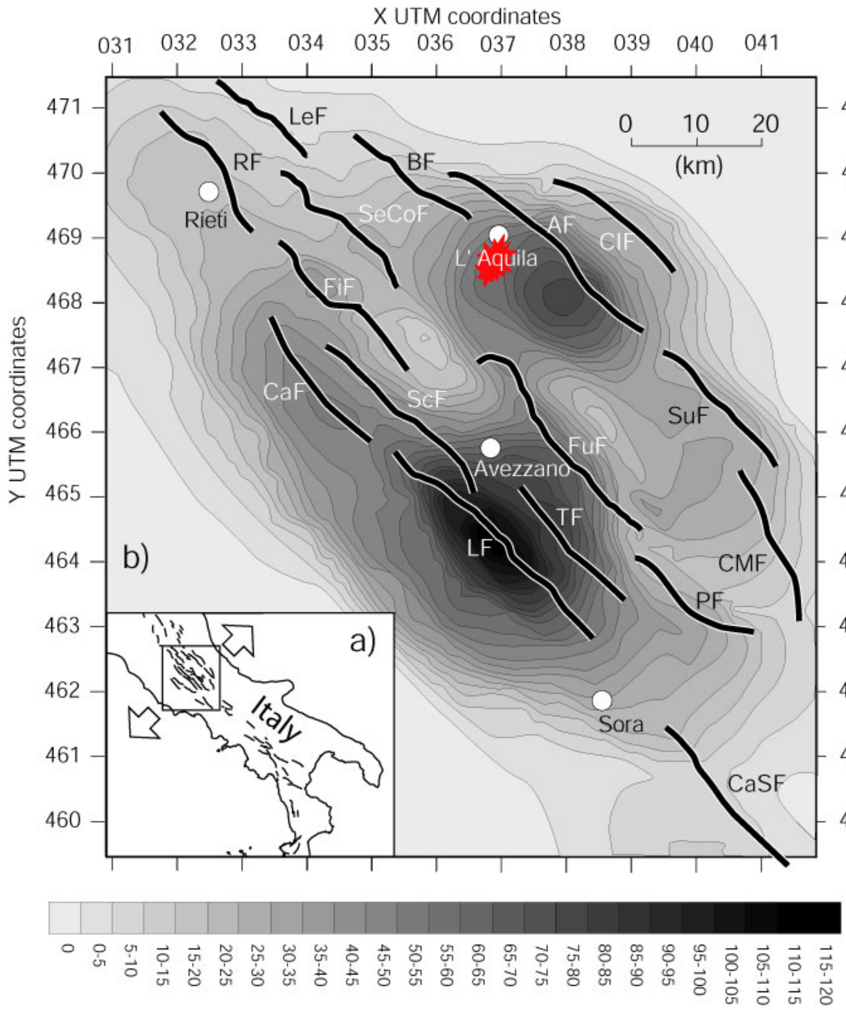
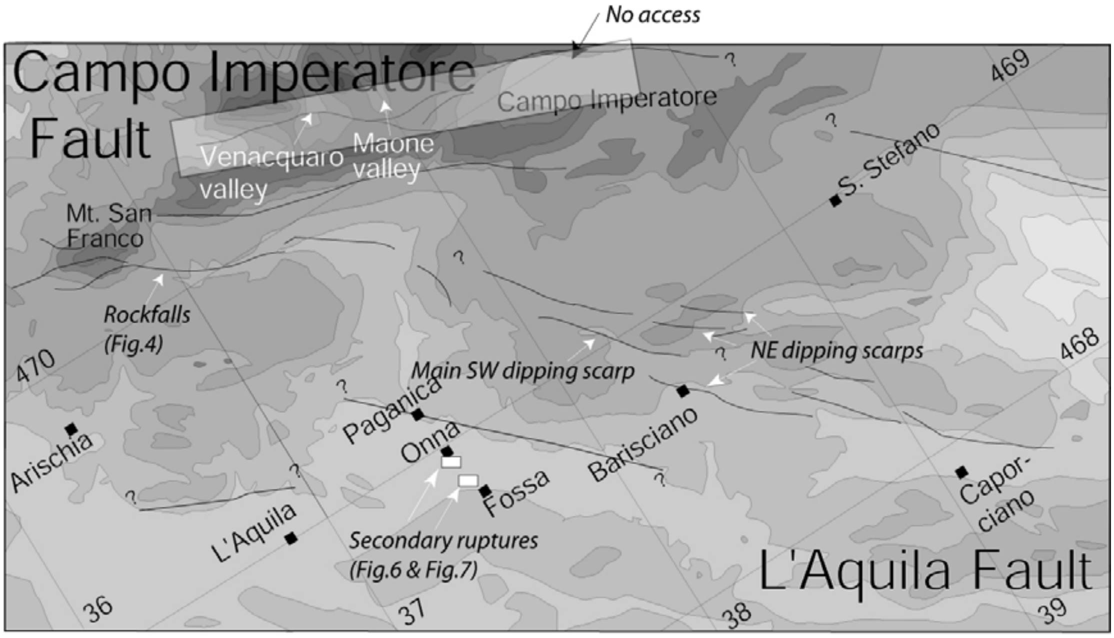


Figure 1

Figure 2



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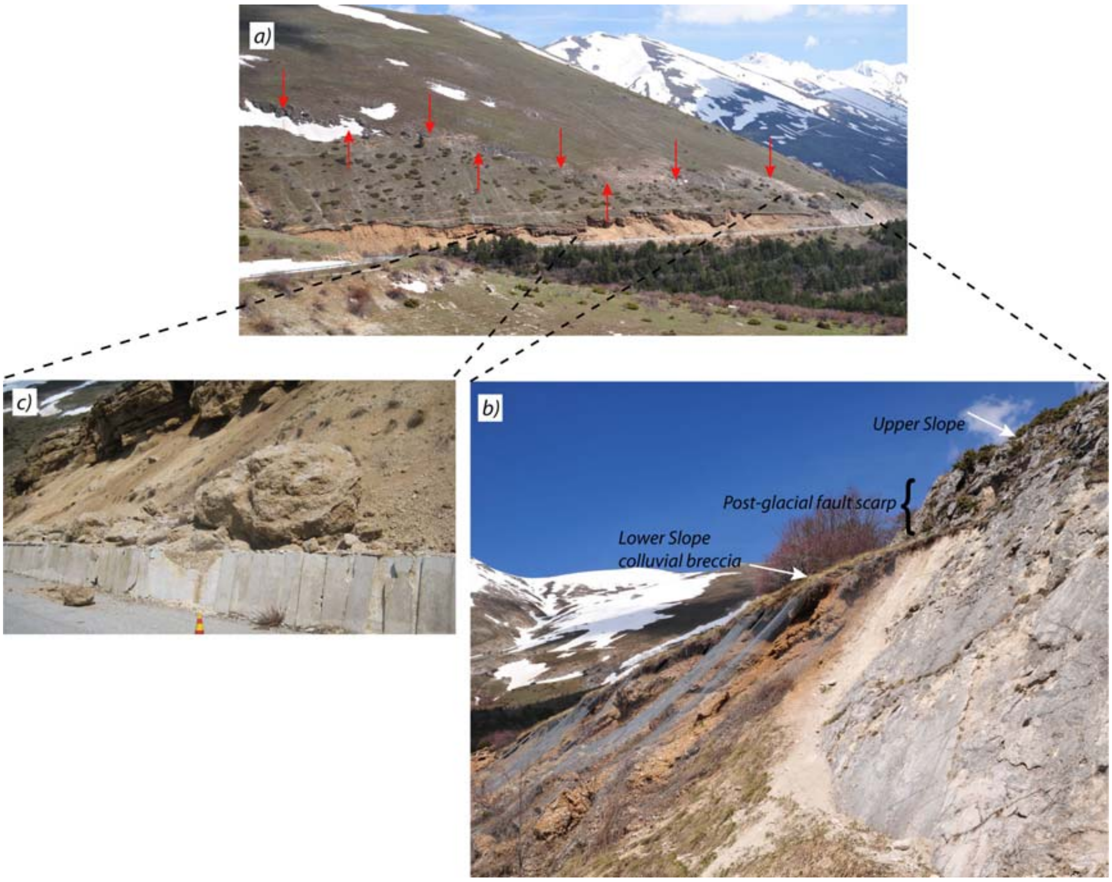

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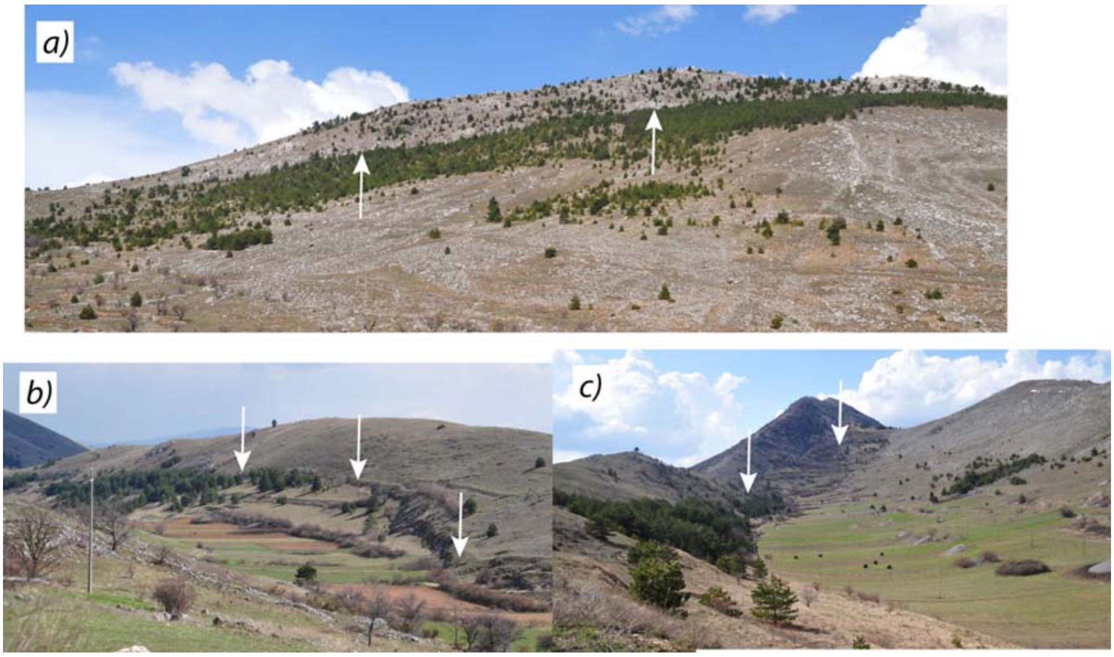

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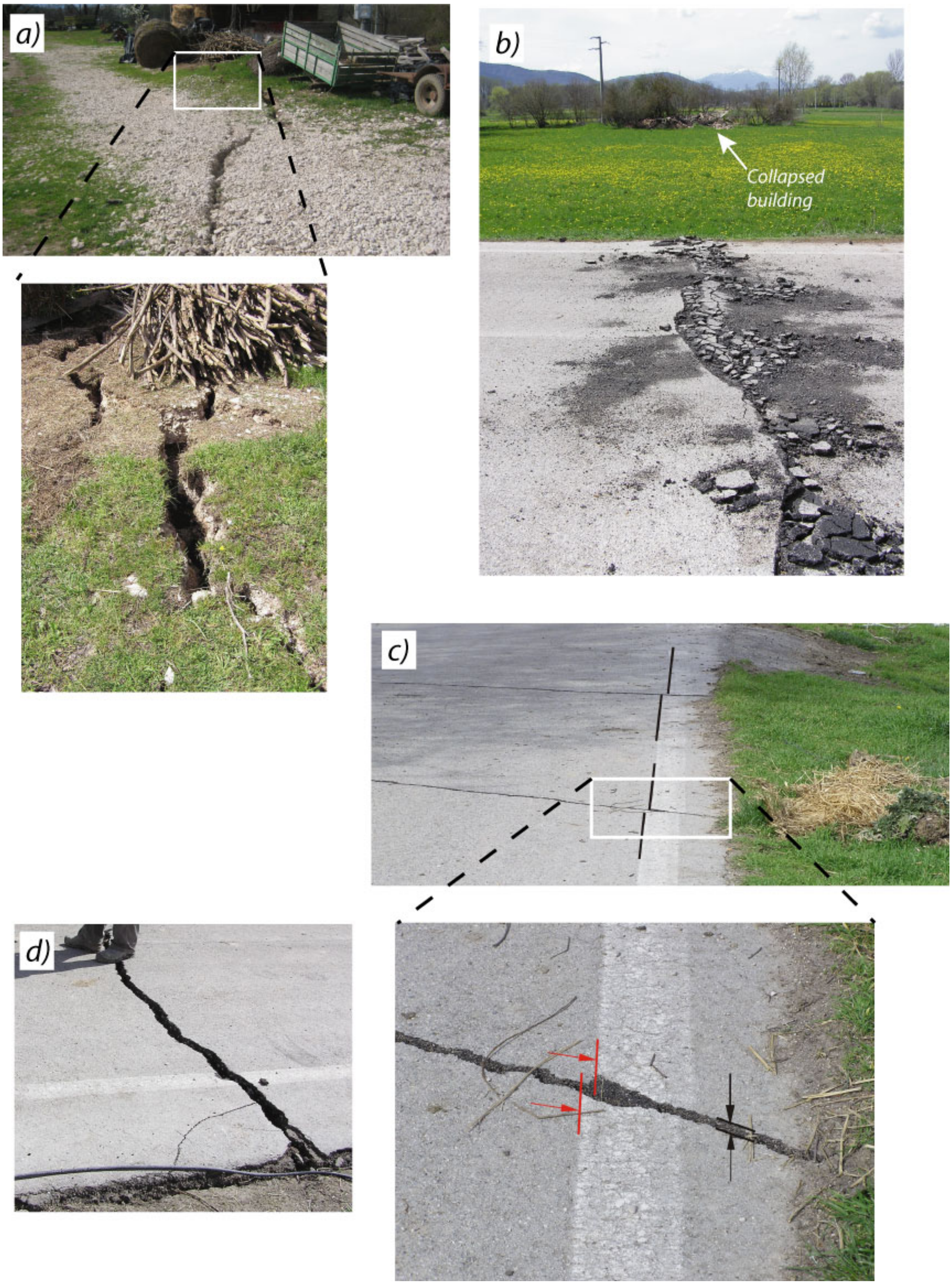

Figure 6

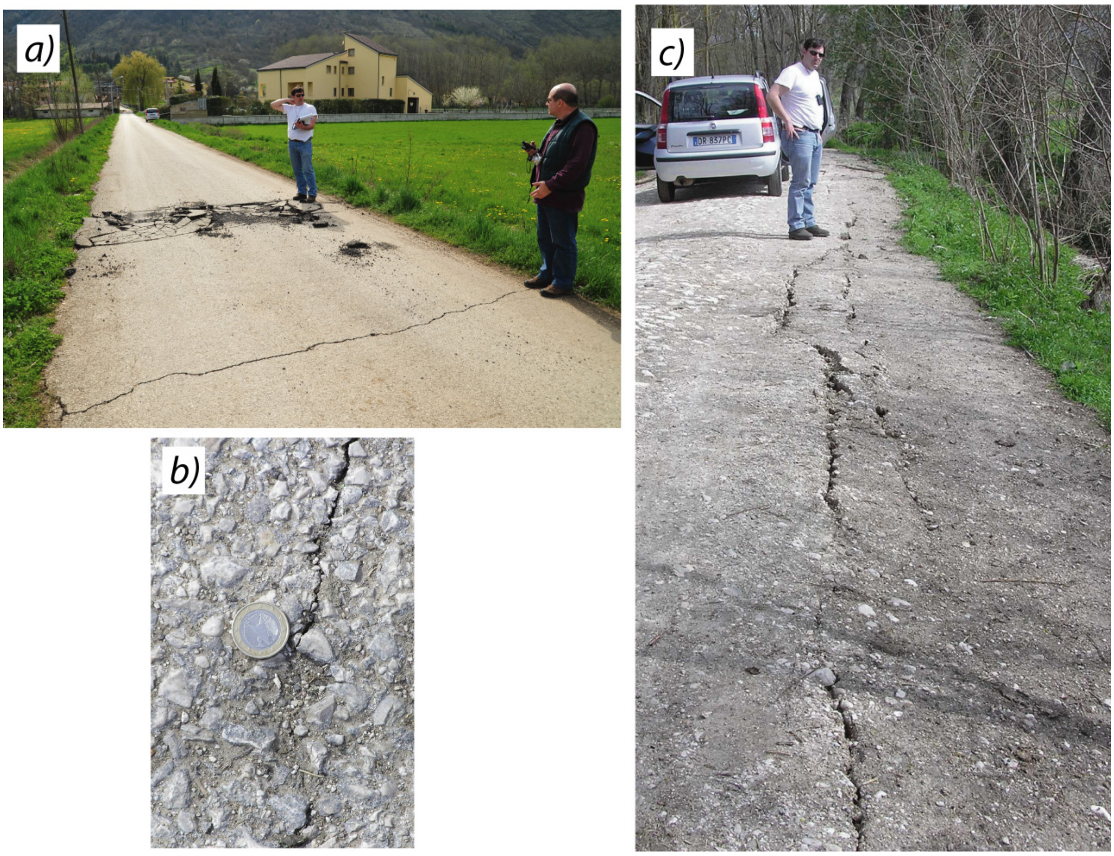

Figure 7

a)

b)

Figure 8

Figure 9