

The West Crati Fault, Calabria (southern Italy): refined crustal extension rates constrained by geologic and GPS data

Marco Meschis^{1*}, Susanna Zerbini¹, Giovanni Lattanzi¹, Miriana Di Donato¹ and Silvia Castellaro¹

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Introduction

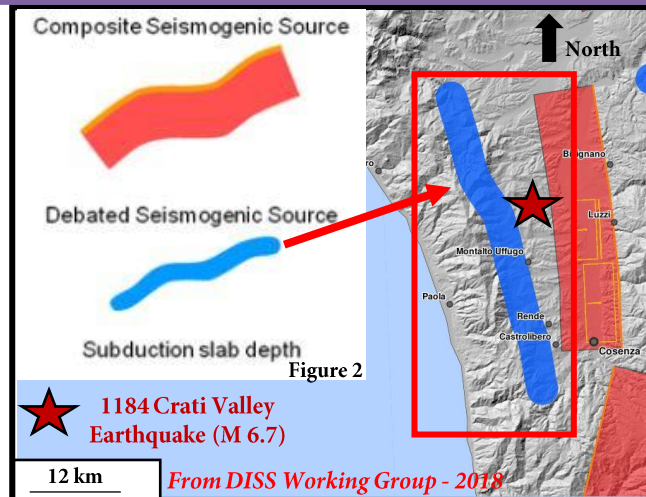
The aim of the study is to investigate if a relationship exists between historical seismicity, regional uplift and upper plate faulting activity. The study area is in southern Italy, within a region of the extending and uplifting Calabrian Forearc (Figure 1). In particular, we answer to address the following scientific questions:

- Is the West Crati Fault (about 40 km long) active? This is still debated according to DISS Catalogue (Figure 2; DISS Working Group - 2018)
- If so, is the faulting activity affecting the regional uplift signal as observed in other parts of the uplifting and extending Calabrian Forearc?
- Is the uplift varying with time? If so, why?
- Is there any relationship between regional uplift, local faulting and historical seismicity?

According to our very preliminary Results (Figure 3), answers are three YES and one NO!



Active normal fault map of central and southern Italy with extension directions. (modified from Faure Walker et al. 2012)

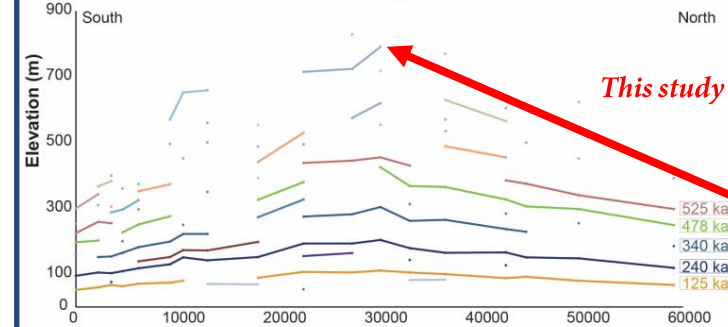


Approach

- Detailed GIS-based marine terrace mapping on the uplifting footwall of the West Crati Fault - **Done!**
- Synchronous correlation approach to model raised marine terraces, to overcome the "re-occupation problem" in regions with relatively low uplift rates as the Calabrian Forearc - **Done!**
- Analysis of GPS measurements – **work in progress...**
- Planned fieldwork (according to Covid-19 situation) to corroborate GIS analysis in the field - **Future work...**

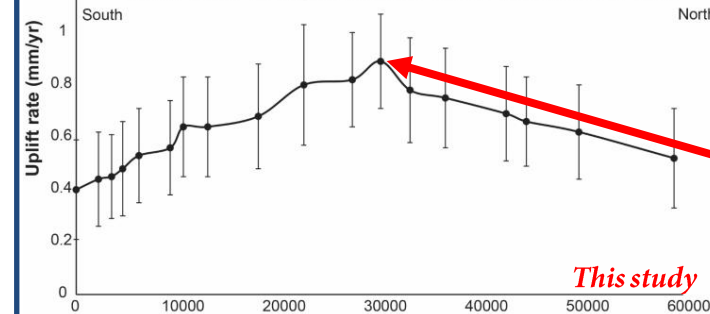
Preliminary Results

Palaeoshoreline elevations along the strike of the West Crati Fault



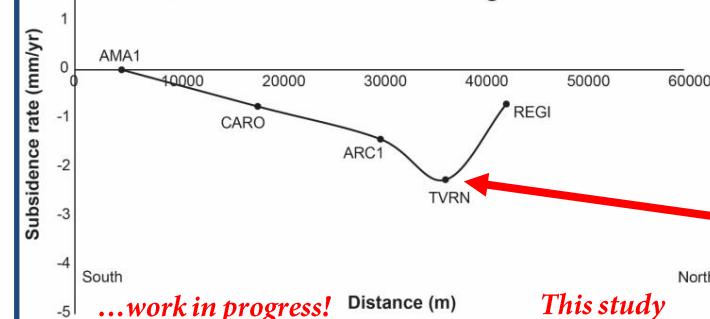
Along-strike mapped marine terraces are deformed by the long-term faulting activity.
Max uplift on the footwall fault centre

Uplift rates along the strike of the West Crati Fault



Uplift rates, constant through time, is changing along the strike of the fault.
Max uplift rate on the footwall fault centre.

GPS-measured subsidence along the fault strike



GPS-measured subsidence rates along the fault strike, on its hangingwall, show similarities with normal faulting deformation.
Max subsidence rates on the hangingwall fault centre

References:

- DISS Working Group (2018) - <http://diss.rm.ingv.it/diss/>
- Blewitt, G., W. C. Hammond, and C. Kreemer (2018), Harnessing the GPS data explosion for interdisciplinary science, Eos, 99, <https://doi.org/10.1029/2018EO104623>.

We thank Prof. Gerald Roberts for his insights on marine terraces



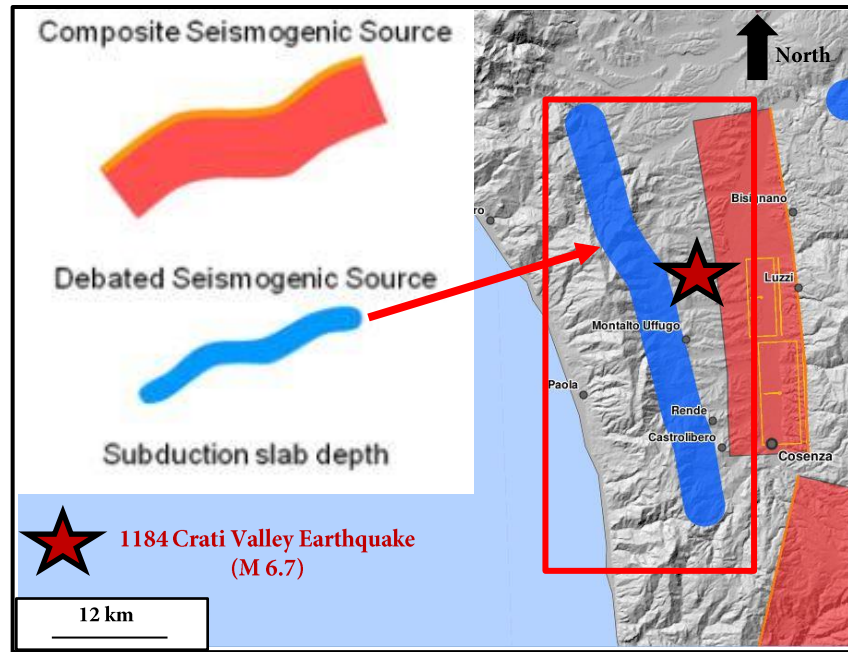
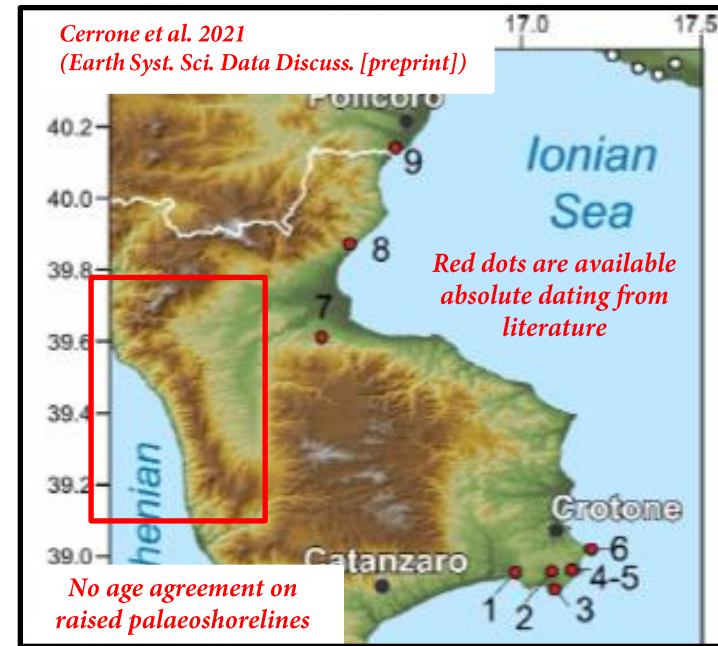
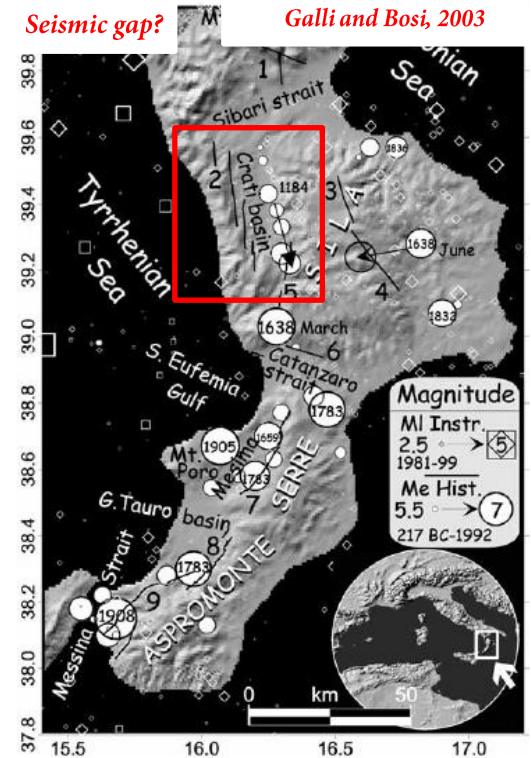
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Figure 3

The West Crati Fault, Calabria (southern Italy): refined crustal extension rates constrained by geologic and GPS data

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Some hypotheses to be tested...(ongoing work)

- Is the ~40-km long West Crati Fault active? This is still debated according to DISS Catalogue (DISS Working Group - 2018) - YES
- If so, is the faulting activity affecting the regional uplift signal as observed in other parts of the uplifting and extending Calabrian Forearc? YES
- Is the uplift varying with time? NO
- Is there any relationship between regional uplift, local faulting and historical seismicity? YES

No agreement on the ages of raised marine terraces and the related (fault-controlled?) uplift rate values



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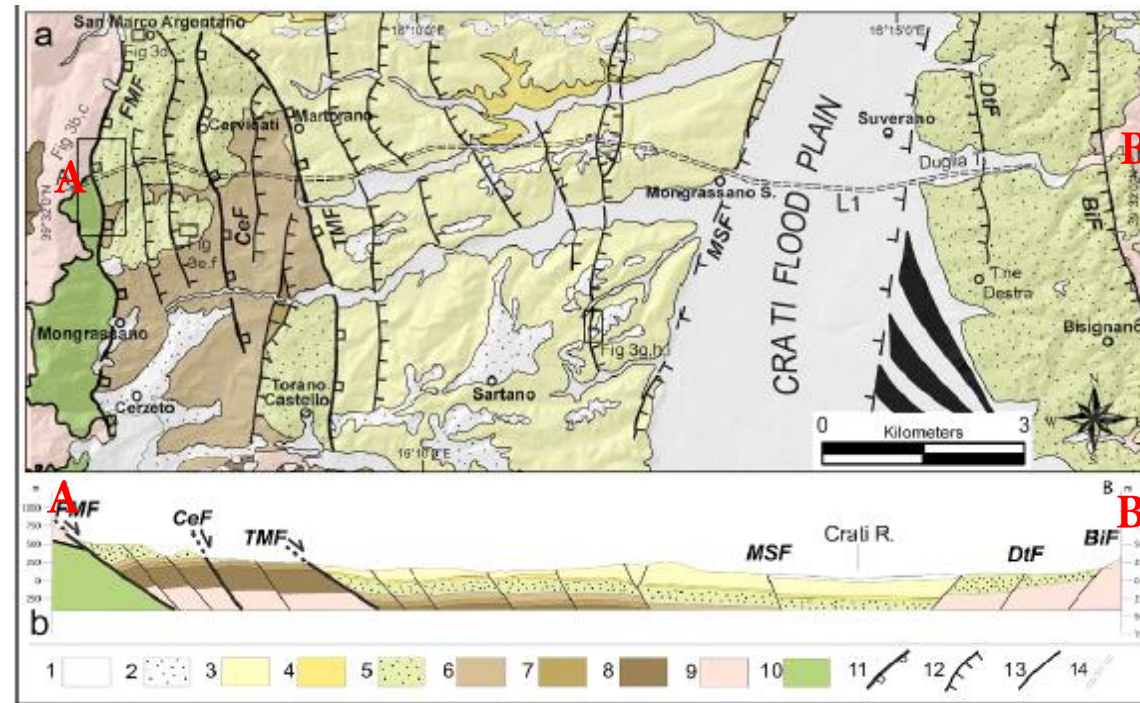
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Background

The Plio-Pleistocene Crati Basin, within the regionally uplifting Calabrian Forearc, is bounded by the E and W Crati Faults and affected by crustal extension (Monaco and Tortorici, 2000). Historically, it has been hit by damaging earthquakes (e.g. 1184 “Crati Valley” Eq - M 6.7 and 1854 “Cosentino” Eq - M 6.4). However, rates of extension through time are still matter of debate.

Indeed, several fault throw-rates have been proposed within a range of 0.4 – 1.4 mm/yr, for the West Crati Fault, by several authors (e.g. Tortorici et al. 1995, Spina et al. 2011, Brozzetti et al. 2017, Roda-Boluda et al. 2017). However, there is no agreement if these rates were constant or varying with time.

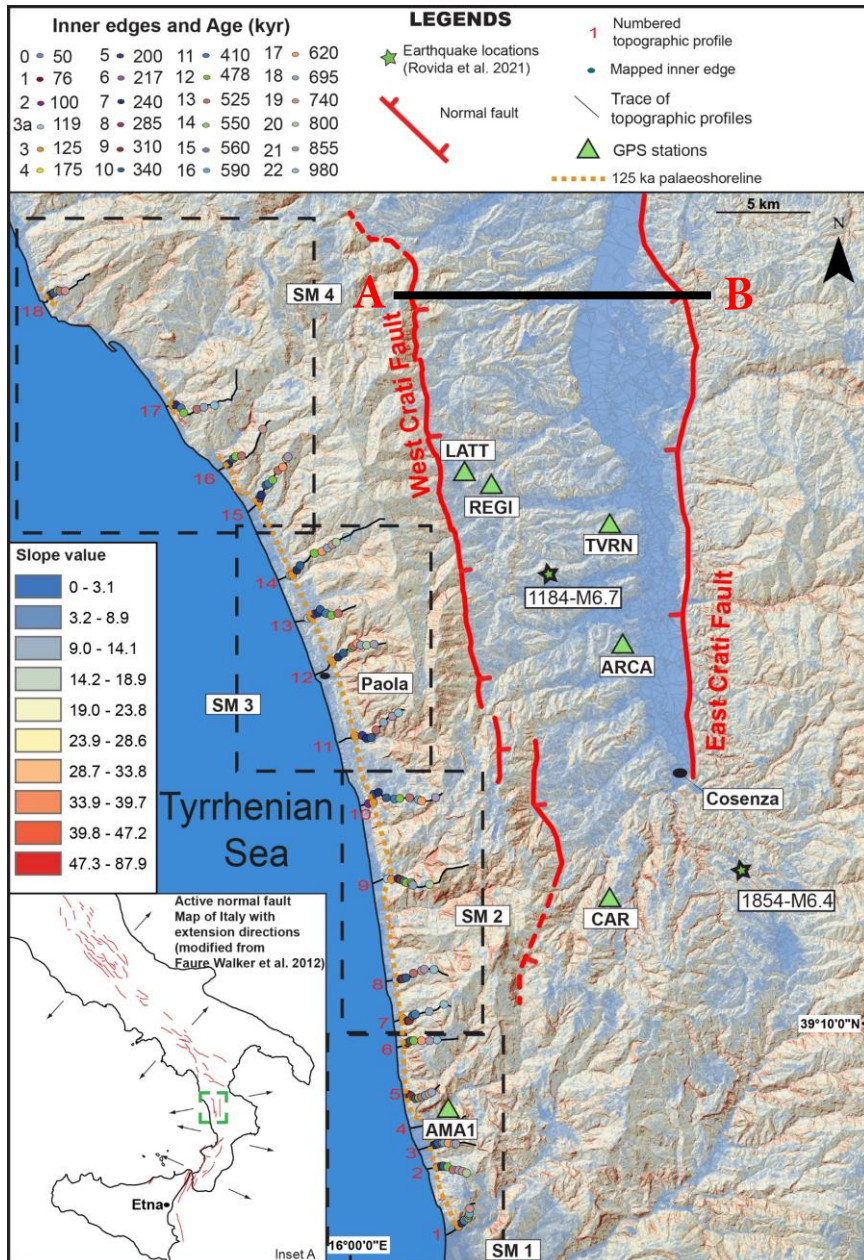
Furthermore, an ongoing debate has been discussing the onset of the faulting activity for the West Crati Fault, within range between 0.7 Ma and 2.5 Ma (Tortorici et al. 1995; Spina et al. 2011; Brozzetti et al. 2017; Roda-Boluda et al. 2017).



Brozzetti et al. 2017 - doi: 10.3301/IJG.2017.11



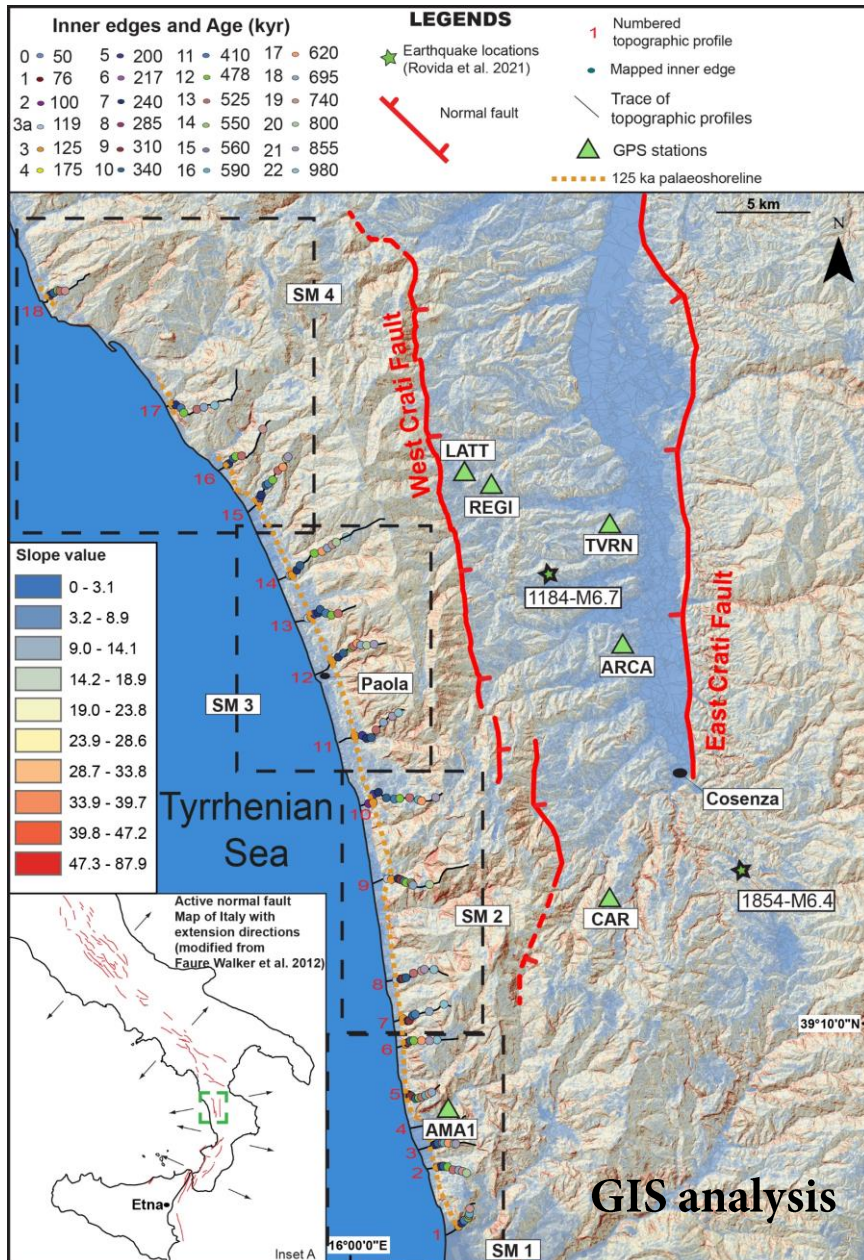
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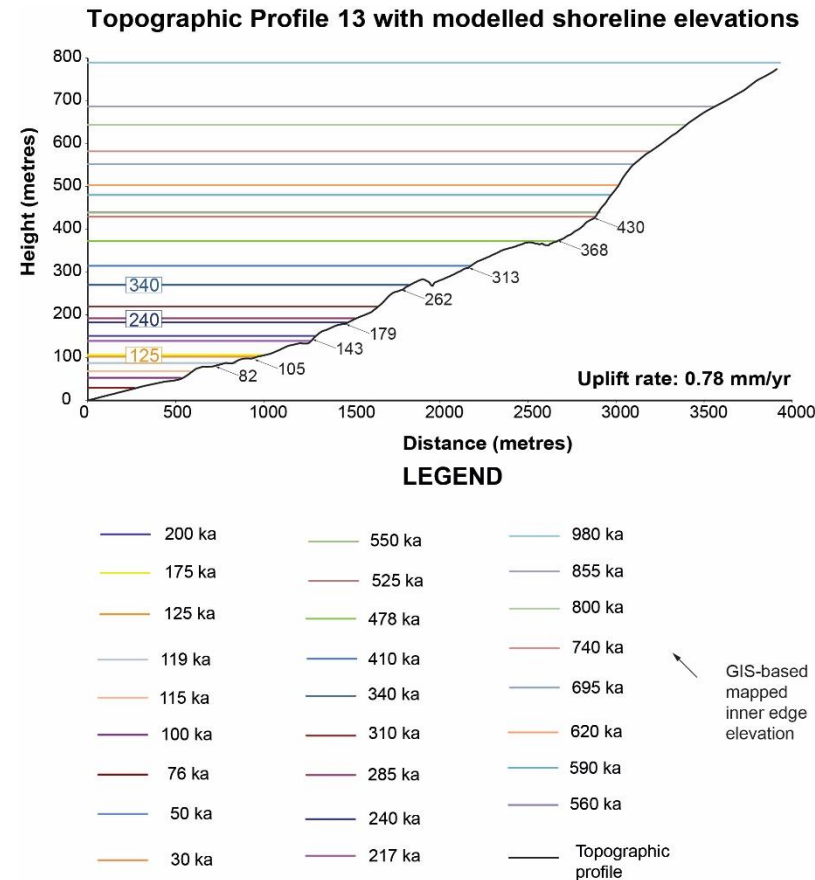
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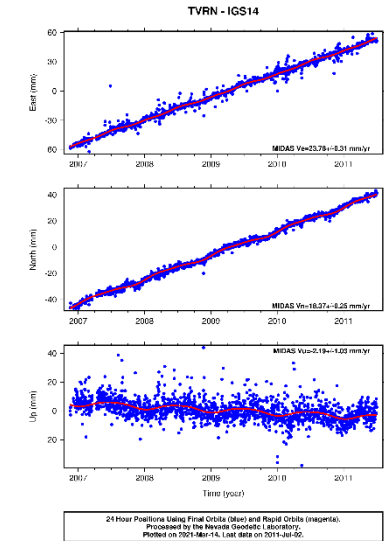


Approach

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Analysis of GPS measurements



Blewitt et al. 2018

J Geod (2014) 88:1203–1214
DOI 10.1007/s00190-014-0754-4

ORIGINAL ARTICLE

Detecting discontinuities in GNSS coordinate time series with STARS: case study, the Bologna and Medicina GPS sites

S. Bruni · Susanna Zerbini · F. Ralich · M. Errico · E. Santi

Bruni et al. 2014



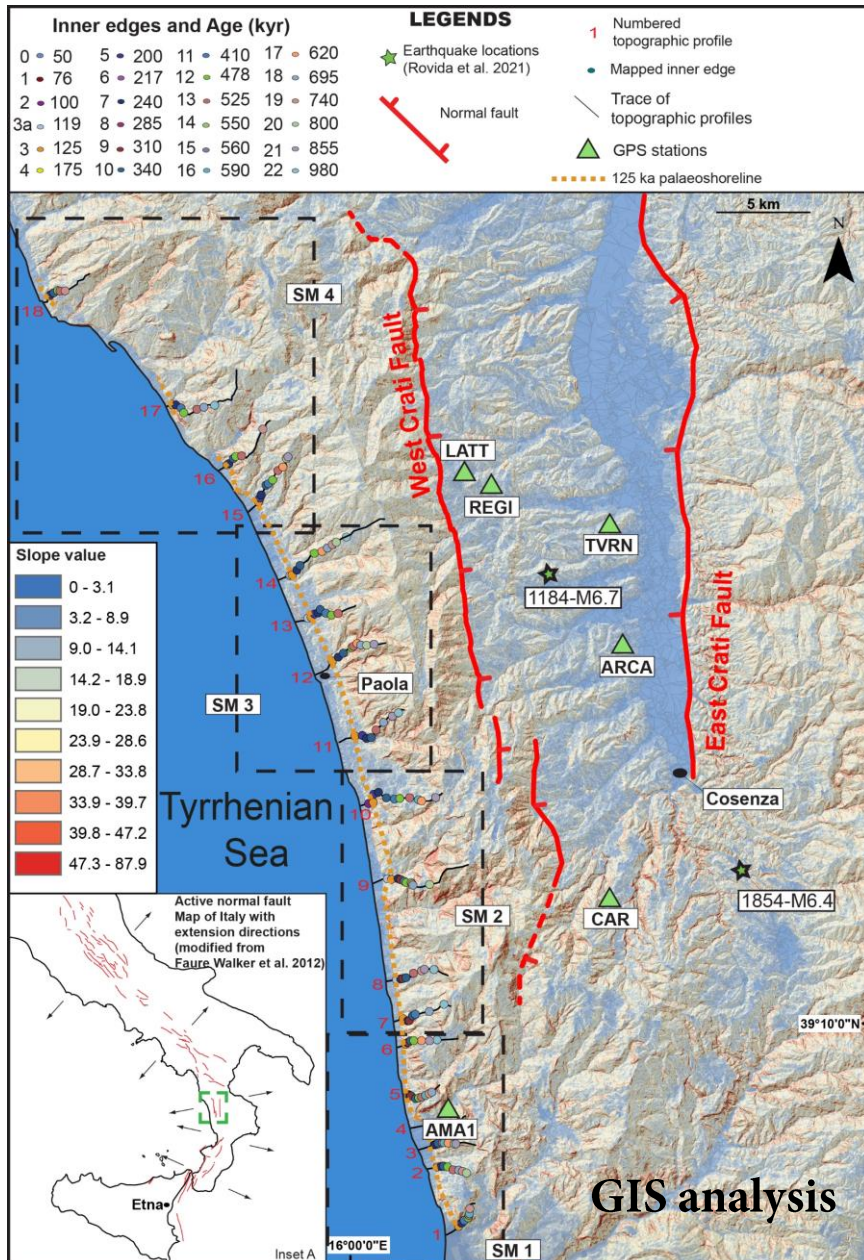
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Synchronous correlation approach to model raised marine terraces, as proposed by others (e.g. Roberts et al. 2013 QSR)

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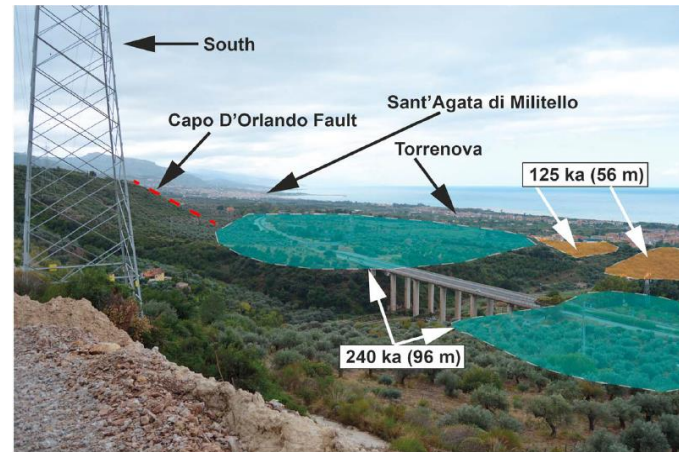
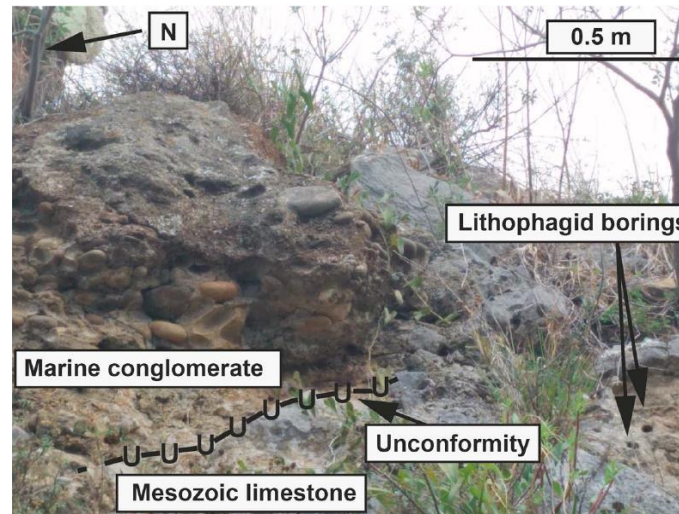
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Meschis et al. 2018

Marine terraces mapping – Future work

Fieldwork is planned aimed to corroborate our GIS analysis, following the approach of previous studies within the Calabrian Forearc (e.g. Roberts, Meschis et al. 2013, QSR; Meschis et al. 2018, Tectonics)

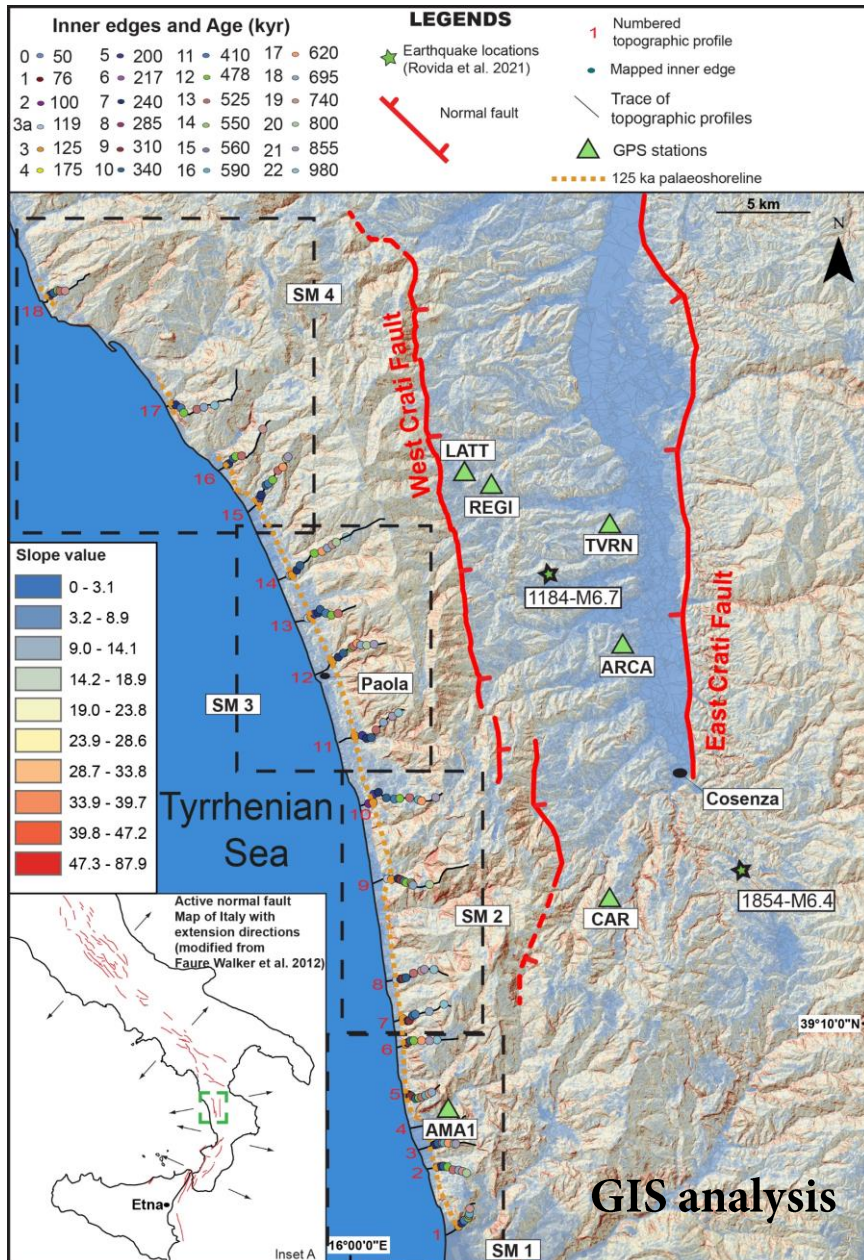


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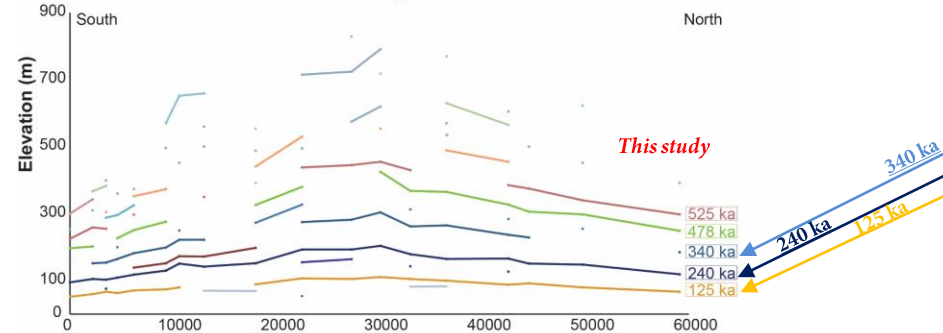
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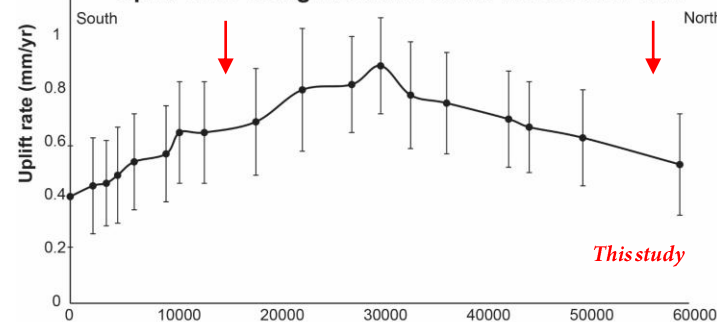
Preliminary Results

Palaeoshoreline elevations along the strike of the West Crati Fault



The most relevant sea level highstands are preserved according to our methodological approach such as the 125 ka, 240 ka and 340 ka, similarly to other investigations in the Mediterranean realm (e.g. Roberts et al. 2013; Meschis et al. 2018; Robertson et al. 2019)

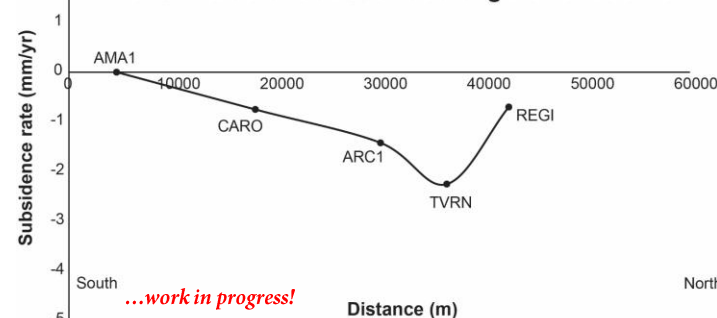
Uplift rates along the strike of the West Crati Fault



Long-term uplift rate is changing along the strike of the West Crati Fault, with higher values in centre of the footwall (0.82 mm/yr) and diminishing towards the fault tips (red arrows), with values of 0.4-0.5 mm/yr, in agreement with previous studies (e.g. Colella et al. 1987).

This suggests long-term crustal deformation. For the first time, we also show that uplift rate is constant over the last 1 My.

GPS-measured subsidence along the fault strike



Preliminary analysis of GPS measurements show higher rates of subsidence around the centre of the hangingwall, and lower rates towards the fault tips, suggesting short-term crustal deformation. Although, these subsidence rates may be amplified by secondary geological effects (e.g. landslides and anthropogenic effects – Cianflone et al. 2018) which cannot be ruled out, the shape of the recorded crustal deformation strongly resembles hangingwall tectonic subsidence.

Evidence that the West Crati Fault is active!

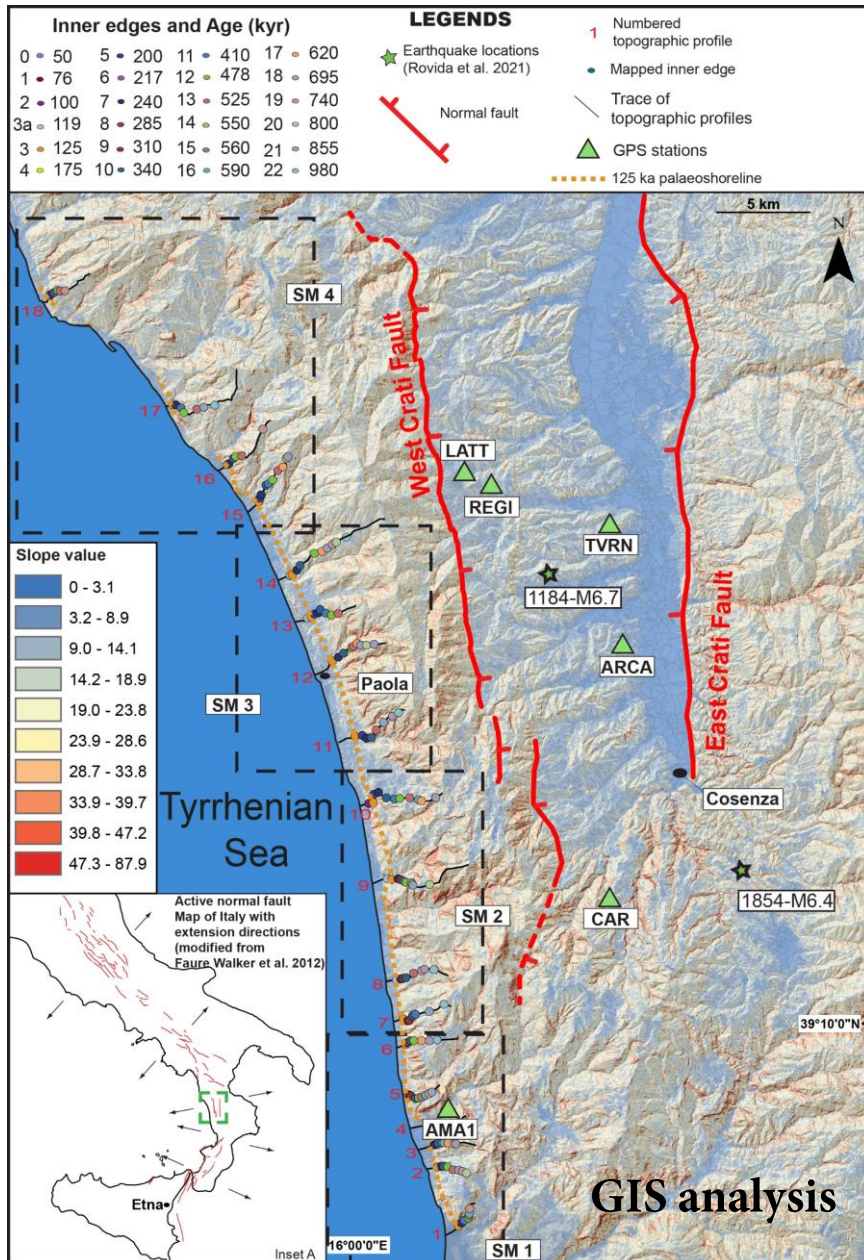


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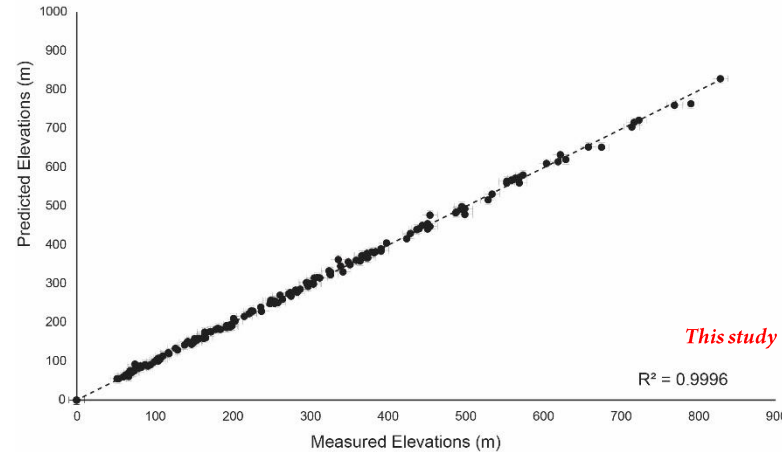
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Preliminary Results

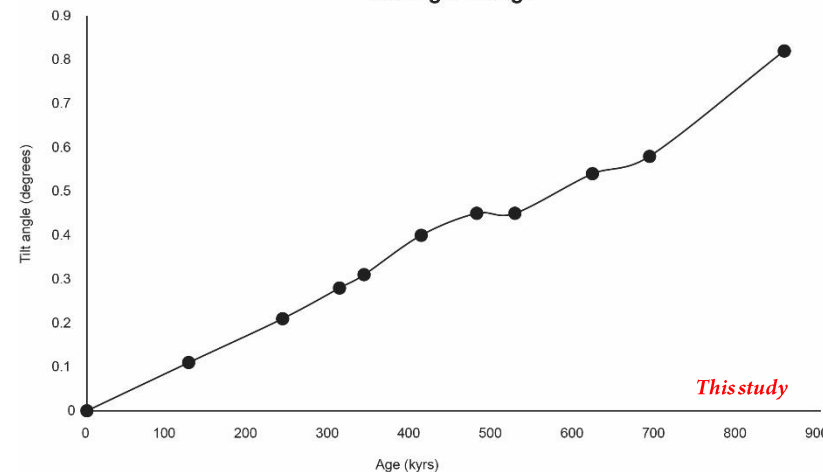
Measured vs Predicted Elevations



By using a synchronous correlation approach to study marine terraces, we iterate uplift rates scenarios to find the best match between the geomorphological signal of the mapped marine terraces and the “predicted” sea level highstands, starting from the simplest scenario of a constant uplift rate through time. We find an excellent match, with R^2 value >0.99 , as other studies showed in the Mediterranean realm (e.g. Roberts et al. 2013; Meschis et al. 2018 and Robertson et al. 2019).

For this reason, we don’t need to claim a more complicated scenario to explain the mapped geomorphology.

Tilt angle vs Age



We also calculate how much each single marine terrace, along the N-S strike of the fault, is tilted by the Late Quaternary faulting activity of the West Crati Fault. This graph shows that higher and older marine terraces have experienced a longer history of faulting activity, suggesting that the West Crati Fault is active. Note that tilted marine terraces are as old as 800 ka, suggesting that this fault is active since then, in agreement with some studies claiming a faulting activity onset ~ 1 Ma (Roda-Boluda et al. 2017).

Evidence that the West Crati Fault is active!



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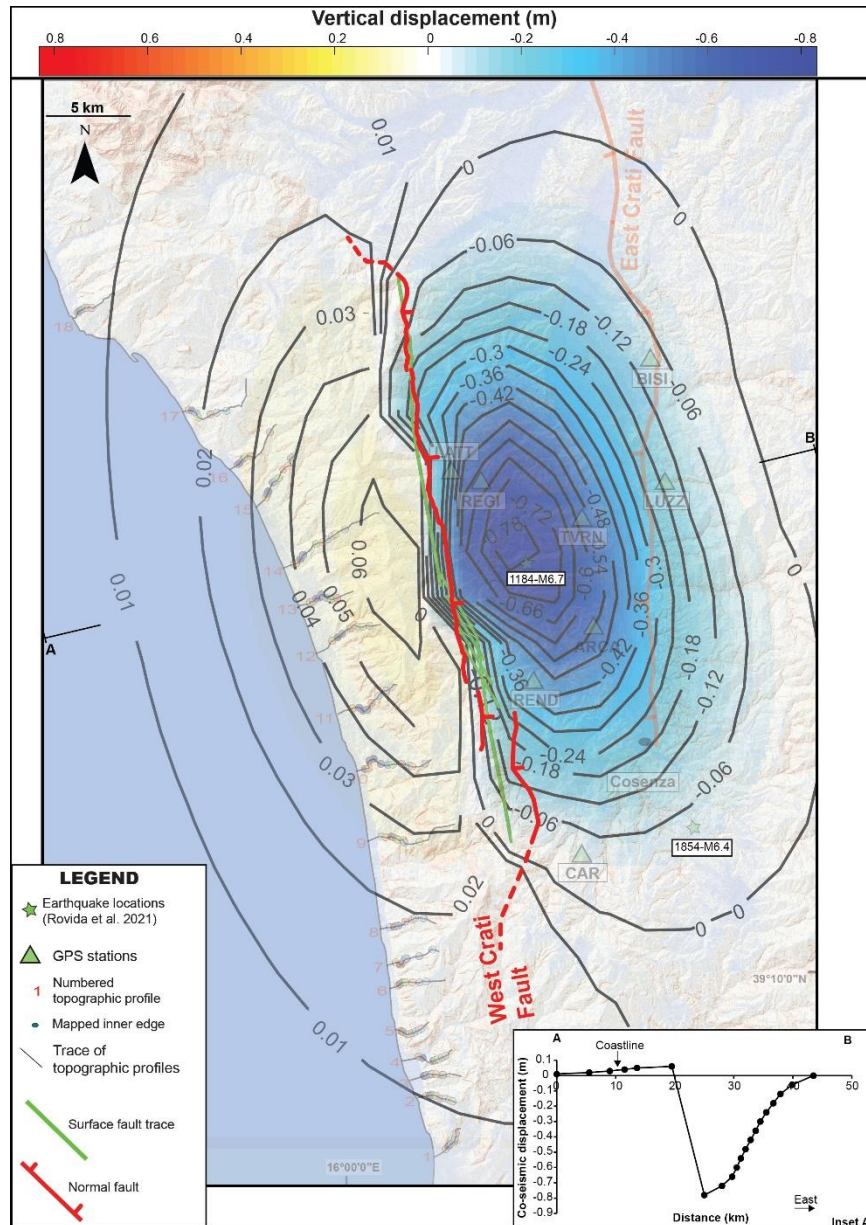
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Preliminary Results

We also simulate co-seismic vertical displacement assuming the simplest scenario that the entire 40 km West Crati Fault would rupture during a seismic event. We do this by inputting the curvilinear trace of the mapped West Crati Fault into the Coulomb 3.4 software (Toda et al. 2011), using a new Matlab code (Mildon et al. 2016). This code enables us to model vertical displacements arising from earthquakes on faults with variable-strike geometry. Indeed, it is well established that fault geometry influences Coulomb stress transfer (Toda et al. 2011; Mildon et al. 2016; Iezzi et al. 2018) and therefore will influence strain and displacements surrounding the causative fault.

We assume an averaged dip-angle of 45 degrees (e.g. Spina et al. 2011; Brozzetti et al. 2017) and an assumed max slip at depth of 3 m at around 9-10 km, for a total co-seismic rupture of ~40 km long. These values are typical for normal faulting-related earthquakes in the Apennines and the Calabrian Forearc (e.g. Cheloni et al. 2010; Serpelloni et al. 2012; Lavecchia et al. 2016; Walters et al. 2018; Meschis et al. 2019) to simulate reliable co-seismic vertical displacements.

We show that the co-seismic footwall uplift region (light yellow-coloured region defined by isolines of co-seismic uplift) coincides with the long-term footwall uplift deformation mapped by looking at raised marine terraces. Interestingly, the max co-seismic subsidence (dark blue region) coincides with the area where we show the maximum rate of GPS-related subsidence within the hangingwall of the fault. Moreover, maximum co-seismic subsidence coincides with the estimated location of the 1184 seismic event, as well as its estimated magnitude of 6.8. Note that we estimate a max co-seismic uplift and co-seismic subsidence, in the centre of the West Crati Fault, of 0.06 m and -0.78 m (Inset A) respectively, which are comparable with other normal faulting-related earthquakes such as the 2009 L'Aquila Earthquake (M 6.3) (Papanikolaou et al. 2010), 1983 Borah Peak (M 7.3) (Stein and Barrientos, 1985).



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Points for future discussion

- Our preliminary results show that “regional” uplift signal is affected by the “local” footwall uplift, suggesting that the West Crati Fault should be considered active. Furthermore, its faulting activity seems to have started at least 800 ka, but we cannot rule out that it can be older because some mapped and possibly deformed marine terraces are as old as 980 ka, in agreement with previous studies for this region (e.g. Roda-Boluda et al. 2017).
- Our preliminary results show that fault-controlled regional uplift rate is constant through time yet spatially changing along the strike of the West Crati Fault, suggesting that its slip-rate is constant through time, over the Late Quaternary. Other active normal faults in the Mediterranean realm have shown constant fault slip-rates over the Late Quaternary such as the Vibo Fault (Roberts et al. 2013), the Capo Orlando Fault (Meschis et al. 2018), the South-Central Crete Fault (Robertson et al. 2019). We, however, stress that more and future investigations are needed to resolve the current debate about the actual slip-rate for the West Crati Fault. Ongoing work on re-assessing geodetic measurements will help to refine it.
- If the ongoing Ionian subduction process can lead to megathrust earthquakes (e.g. Polonia et al. 2011; Gutscher et al. 2017; Carafa et al. 2018), crustal deformation within the upper plate has to be taken into account for future studies if uplift data from its upper plate are used for calculations of slip distribution on the subduction interface. We cannot simply consider “negligible” the effect of the “local” signal of the upper plate crustal faults, suggesting a review of long-term crustal deformation rates on upper plates above subduction zones.
- Constant rates through time of crustal deformation shown in this study are not surprising if we consider that the ongoing E-W crustal extension (Devoti et al. 2017) is accommodated by a few active faults across-strike. In other words, if more active faults across-strike are accommodating “distributed” strain, this will gradually change their slip-rates through time to maintain the regional deformation rate as described by some in the past (Cowie & Roberts, 2001). Indeed, the Calabrian Forearc is affected by crustal extension accommodated by “localized” strain on a few active faults across-strike.
- Speculation for future works can be made based on an old but simple concept that seismicity rates on brittle faults are controlled by strain-rates of viscous deformation at depth on faults shear zones (Cowie et al., 2013; Thatcher, 1983). Indeed, more investigations are needed to test if GPS measurements on the hangingwall of the West Crati Fault are showing an active shear zone, slipping at its long-term inter seismic rate, causing subsidence at the surface; indeed, slip in the upper crust is driven by slip on viscous shear zones in the lower crust, with viscous flow process on shear zones, as shown by previous investigations (Cowie et al., 2013; Sibson, 1977; Mildon et al. 2020).



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The West Crati Fault, Calabria (southern Italy): refined crustal extension rates constrained by geologic and GPS data

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We thank Prof. Gerald Roberts for his comments on marine terraces and normal faulting activity



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