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Uncertainty in strain-rate from field measurements of the geometry, rates and kinematics of active normal faults: implications for seismic hazard assessment

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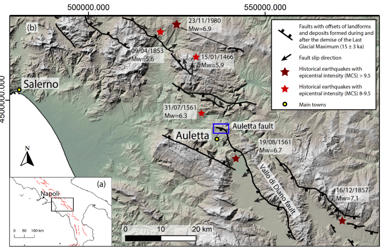
OVERVIEW

INTRODUCTION

Fault data are rarely used in probabilistic seismic hazard assessment (PSHA), and calculations often rely on planar fault geometry and a single value of slip-rate. However, faults show variable geometry and changes in slip-rates along their lengths, due to structural variations [1][2][3][4].
If fault parameters are to be used in seismic hazard to calculate recurrence intervals, it is important to consider those variations and understand the uncertainty relating to the use of a single measurement to represent the slip-rate [5].



Location map of the study area. Some of the strongest Italian earthquakes occurred in this area. For example, the Mw 6.81 1980 eq, Irpinia and the Mw=7.1 eq in 1857, Val d'Agri. Modified from Sgambato et al., 2020

OBJECTIVES

Data on the geometry, kinematics and rates of deformation across the active Auletta normal fault scarp in the Southern Italian Apennines are presented, in order to determine:
• how detailed the mapping of those parameters and the fault trace need to be to calculate a representative strain-rate;
• what aspects of the geometry and kinematics would introduce artificial variability in the strain-rate if not measured in the field.

METHODS

STRUCTURAL MAPPING

- To understand the relationship between the geometry, kinematics and rates of deformation, we collected structural field measurements, such as fault strike, dip, slip vector azimuth and plunge, and post 15±3 ka offset across the scarp.
- The kinematics of the faulting was measured at 20 locations across the whole fault from striations and corrugation on slickensides of the fault plane.
- The data have also been averaged along 8 sections of the fault, these values are used for the strain-rate calculations.

SCARP PROFILES

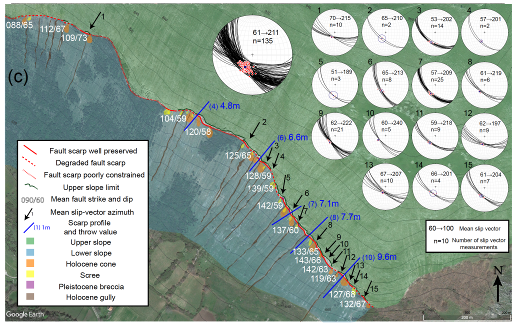
- The surface offsets across active normal fault scarps in the Italian Apennines have formed since the Last Glacial Maximum (LGM-12-18 ka), allowing the calculation of average throw-rates across the active faults in the Apennines over the last 15±3 kyr [6].
- To measure the variations in throw-rates along the fault, we constructed the scarp profiles with a systematic approach, avoiding biases due to exclusion of sites of minimum throws, using a meter ruler and clinometer to record the slope inclination.

STRAIN RATE

- To understand the importance of detailed throw-rate profiles, we calculated the strain-rate across the Auletta fault, using all the measurements of throw, and then progressively removing one measurement, re-calculating the strain-rate for each degradation step.
- Then, we calculated the strain-rates by imposing boxcar or triangular slip-distributions, following a method by Faure Walker et al. (2018)[5].

RESULTS

STRUCTURAL MAPPING

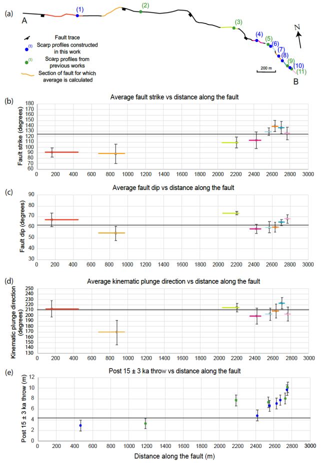


Modified from Sgambato et al., 2020

Figure above shows a detailed geological and structural map of the southeast section of the fault scarp. Note the high variability of fault geometry; throw and slip vector are influenced by such variations.

THROW VARIATIONS

Average values calculated within 8 sections of the fault, based on variations of the fault plane. The figure shows variations of throw along the fault.



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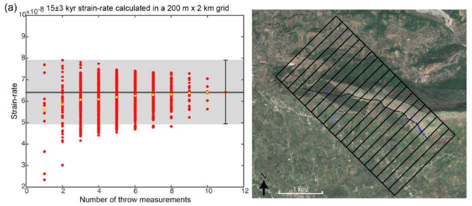
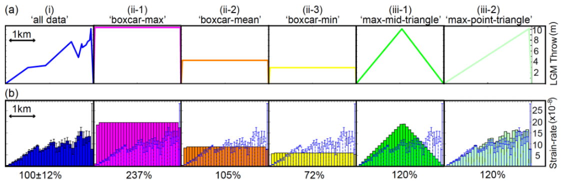
STRAIN RATE



Strain rate values, calculated by discretising the fault on a grid with boxes of 200 m x 2 km size. When using only one value of throw (values on the left), the calculated strain-rate shows a high variability.



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15kyr strain-rates in a regular 100 m x 2 km grid, calculated using all available data and degraded dataset. Using one value of throw changes the strain-rate value.

CONCLUSIONS

- Variations in throw are detectable at a local scale (<200 m), and are due to changes in strike and dip of the fault.
- The local anomalies in throw can affect strain-rate calculations, to the point that using only one value of throw averaged across the whole fault can produce a factor of 3.5x difference in strain-rate.
- Using the short fault segment studied as an analogy for a longer fault, we suggest that measurements of slip-rates need to be taken approximately every 2 km to accurately capture the variation in throw along a fault of about 30 km so that the strain-rate and hence moment release rate across that fault can be calculated and used in seismic hazard assessment.
- Where this detail is not available, the use of fewer data can be considered acceptable when a larger scale is used to evaluate the strain-rate across a fault, but this implies a higher uncertainty that must be considered within PSHA calculations.

MORE INFO

Full article: Sgambato et al. 2020

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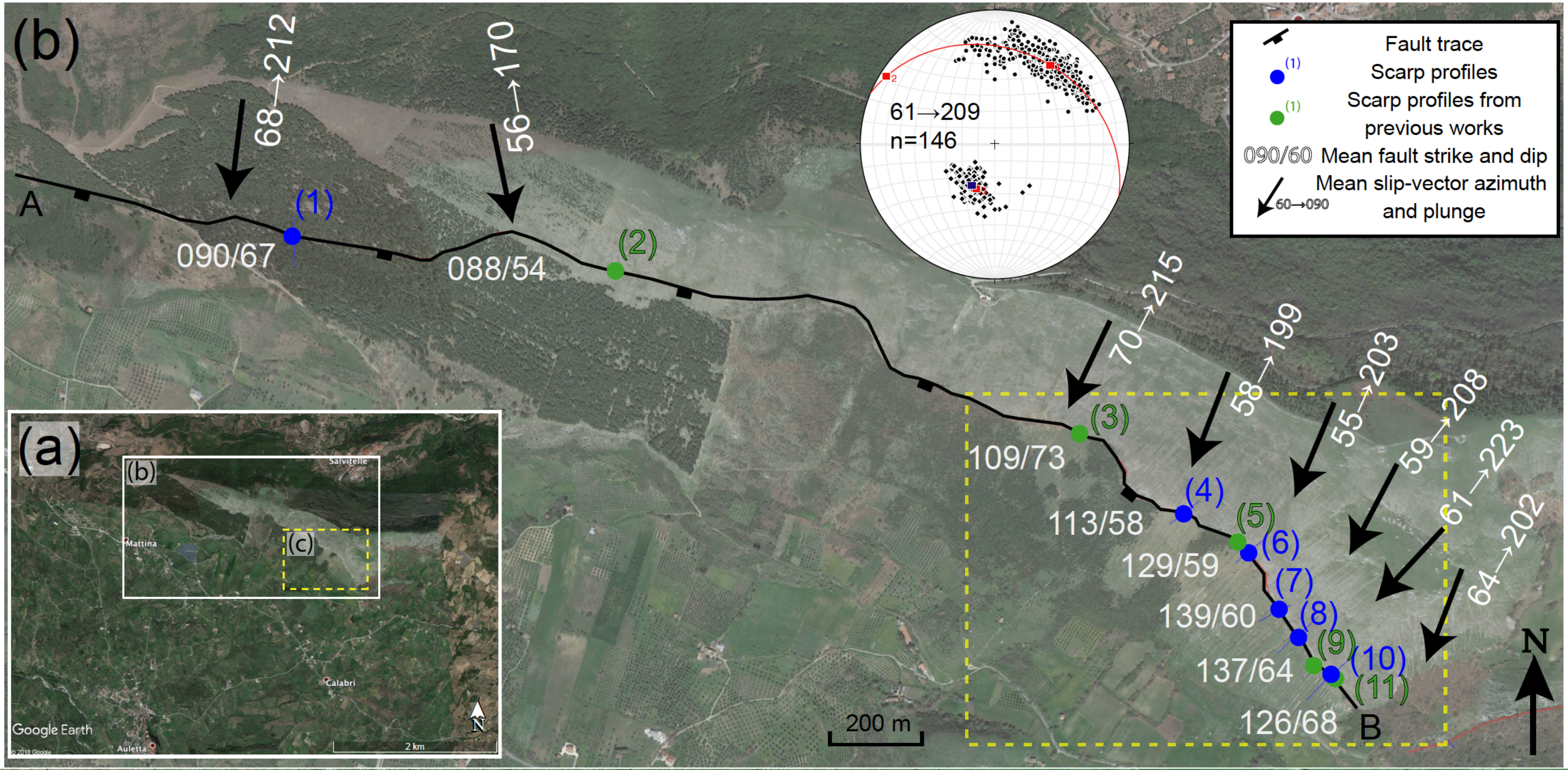
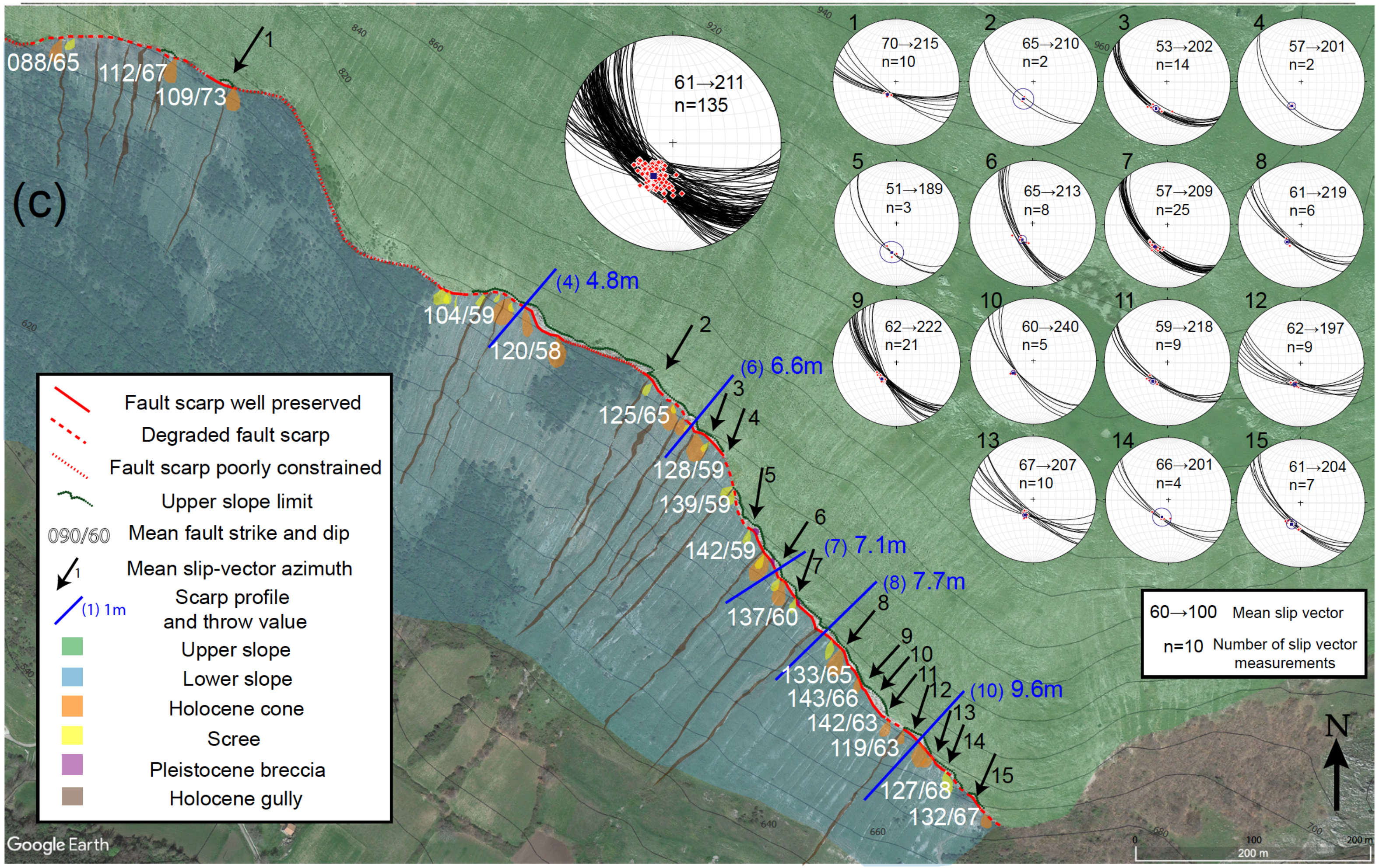
The London NERC Doctoral Training Partnership



Modified from Sgambato et al., 2020

Map of the Auletta fault. All the data collected have been averaged along 8 sections of the fault; figure above shows the average strike, dip, slip direction and plunge. These values, along with the throw measurements, are used for the strain-rate calculations.



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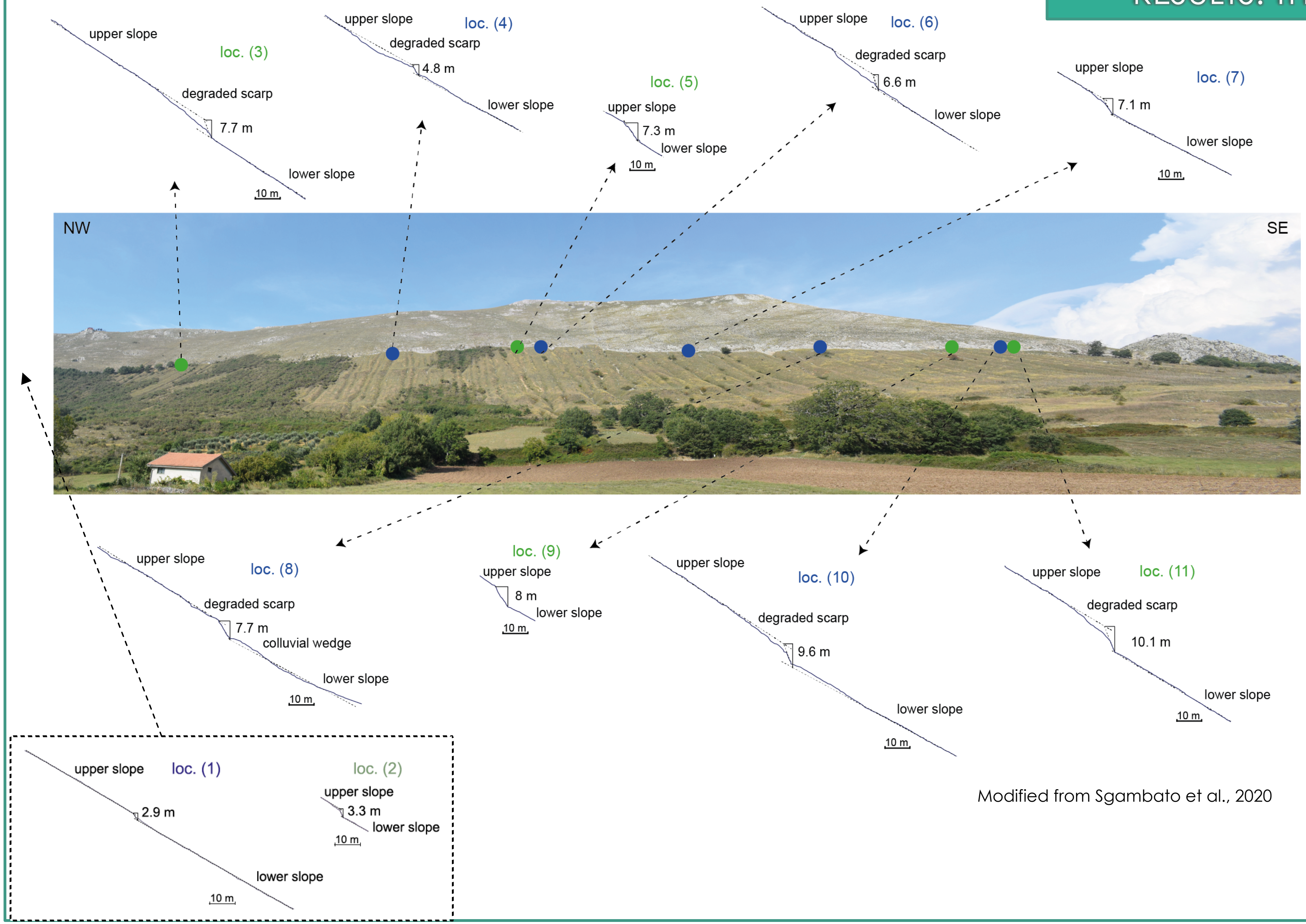
- Map of the southeast section of the Auletta fault. The map highlights the variability of strike, which is attributed to the natural corrugations affecting the fault plane both at small and large scales.
- Values of strike for the whole fault are in the range of N088° - N139°, and dip 45°-76°.
- Mean slip vector is 61->209, suggesting a dip-slip or slightly sinistral oblique motion, towards SSW.

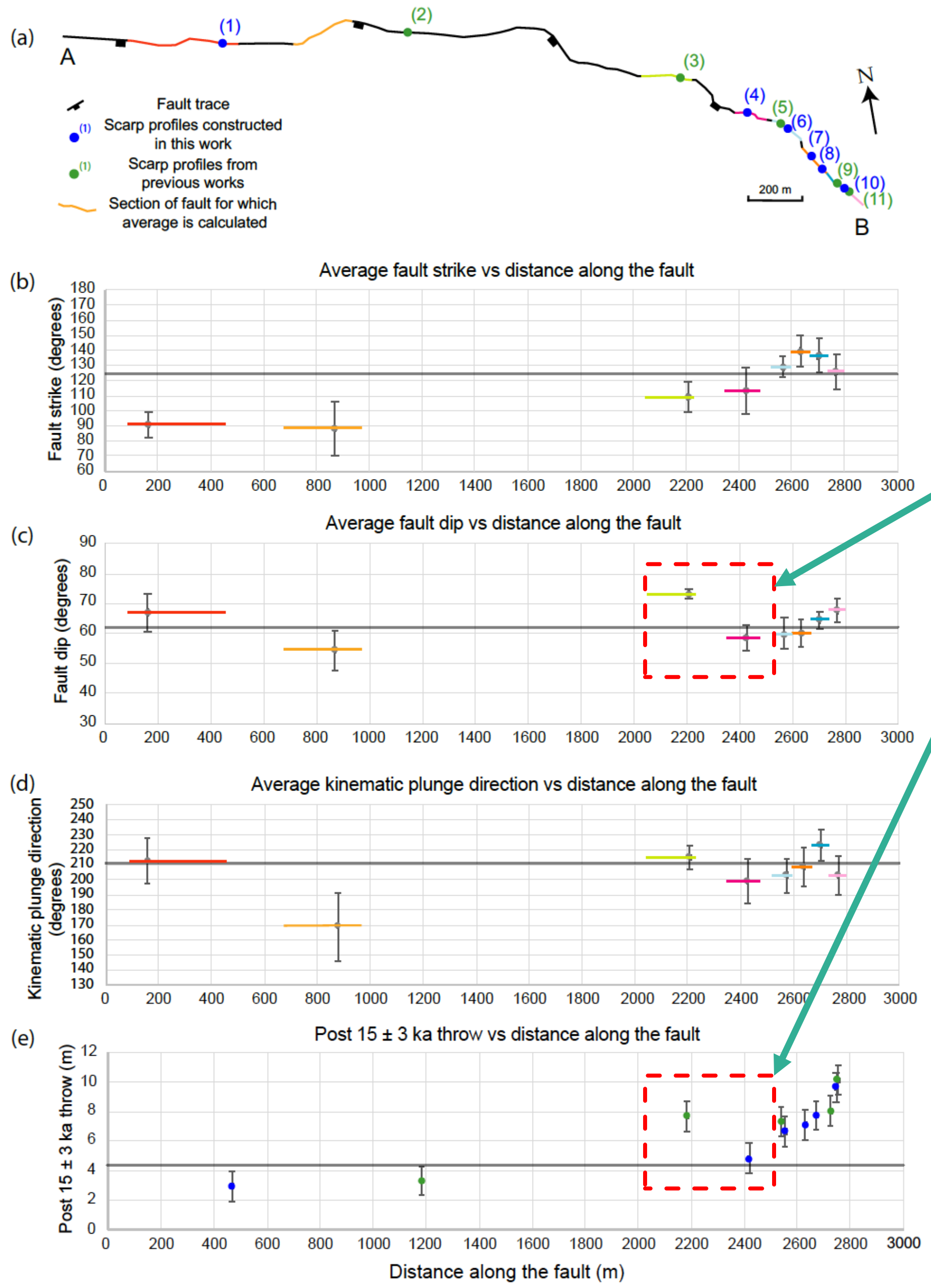
RESULTS: THROW VARIATIONS



Modified from Sgambato et al., 2020

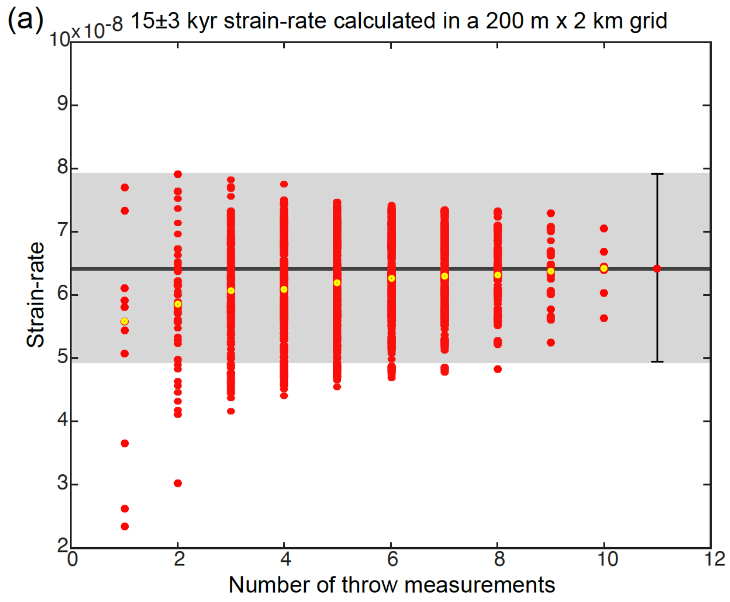
- Figure showing the location of scarp profiles 1-11.
- The throw has a minimum value of 2.9 m, measured at the NW section of the fault (loc. 1), suggesting that at this location we are closest to the tip of the fault.
- The throw does not show a maximum in the centre of the fault section, because the entire fault probably includes the Vallo di Diano fault to the SE (see map in Overview section), so our data only covers the area close to the NW tip of this overall structure.

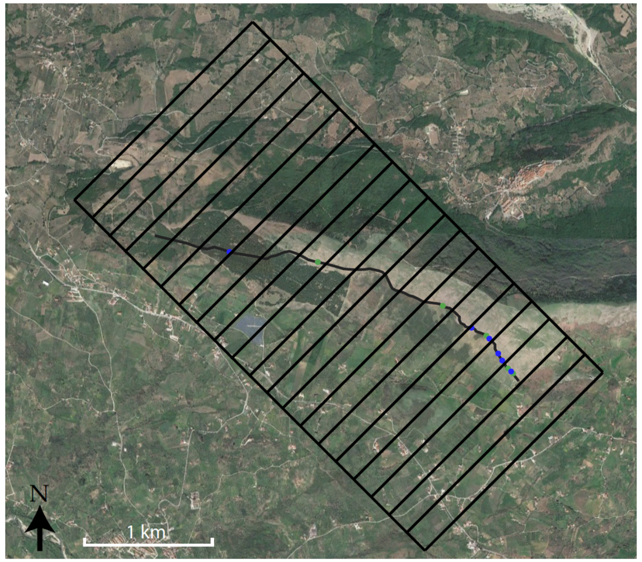
RESULTS: THROW VARIATIONS

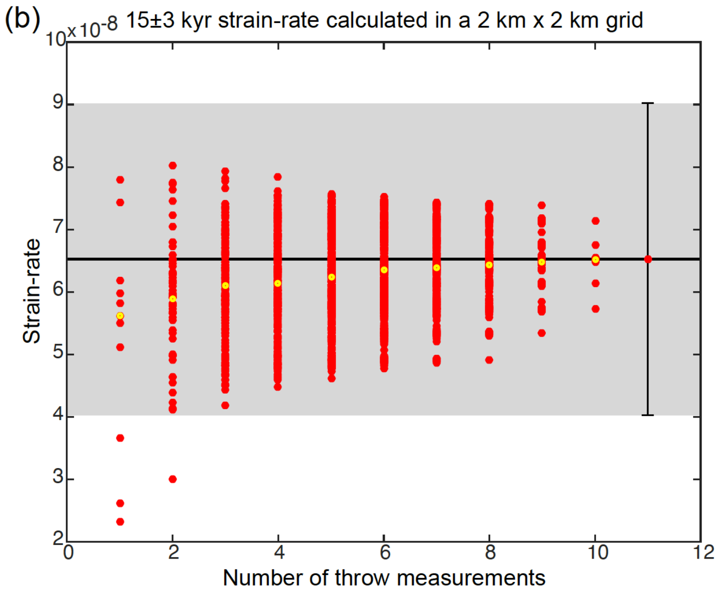


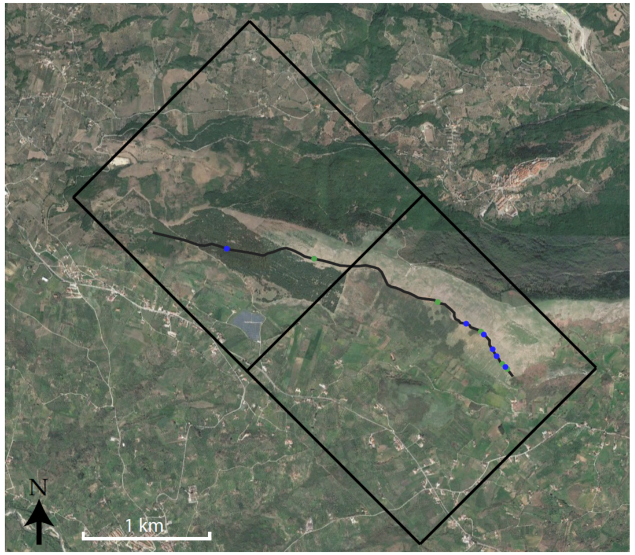
- The throw gradually decreases towards the NE tip of the fault, from a maximum value of 10.1 m.
- Variations are observed along the fault; for example, a local increase at about 2200 m, where throw is 7.7 m. These anomalies coincide with structural complexities, such as along-strike bends in the fault plane, where the fault dip is greater.
- The throw-rate is as low as 0.19 ±0.04 mm/yr for a minimum value of 2.9 m, and 0.67 ±0.14 mm/yr, using the maximum measured throw value of 10.1 m; thus, the rates of deformation differ by a factor of ~3.5.

Modified from Sgambato et al., 2020









Sgambato et al., 2020

RESULTS: STRAIN RATE

- Figure (a) shows strain rate values, calculated by discretising the fault on a grid with boxes of 200 m x 2 km size.
- To compare the uncertainty relating to the use of different scales of observations, we calculated the strain rate using boxes of 2 km x 2 km size (b).
- Note the convergence of the strain-rates towards the all data model, as more throw measurements are progressively added.
- When using only one value of throw, the calculated strain-rate shows a high variability.
- With strain-rates differing ~2.8 and ~0.8 times the 'all data' case, this shows that using a single value is not a rigorous way to measure strain-rate.

RESULTS: STRAIN RATE

all the available data

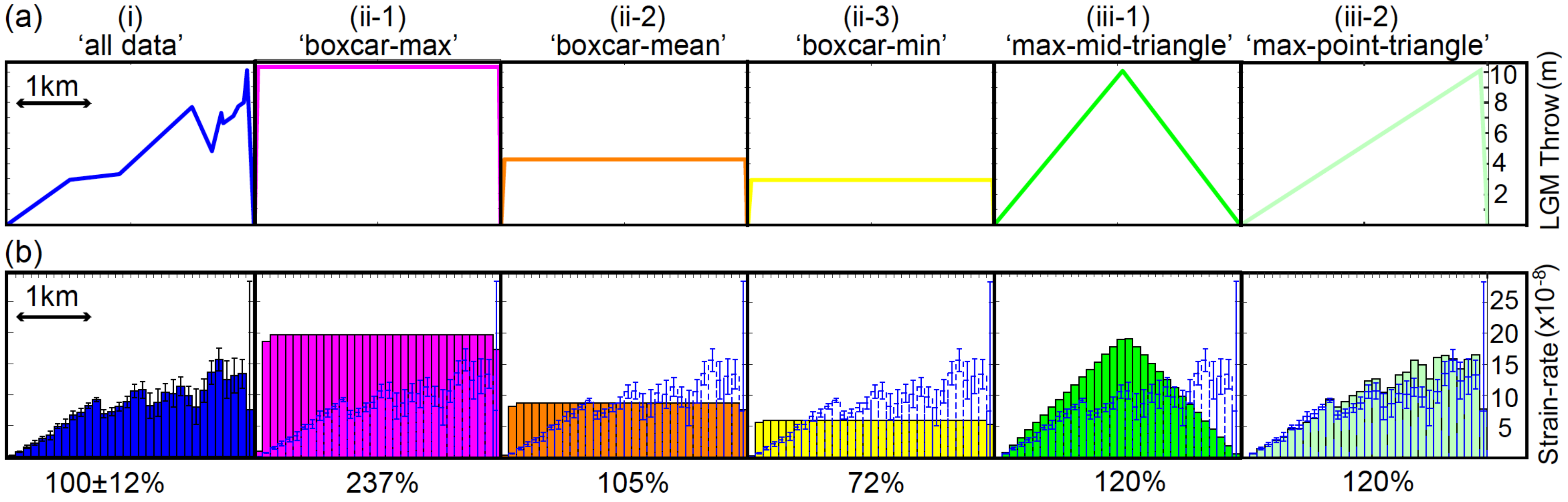
single maximum value of throw, projected along the whole fault

mean value calculated from all throw measurements and projected along the fault

minimum measured throw value along the fault

maximum throw value, placed at the centre of the fault, and decreasing it to the fault tips

maximum throw value placed in location where it has been measured on the fault



Sgambato et al., 2020

- Calculations of strain-rate in a 100 m x 2 km grid boxes, by imposing boxcar or triangular slip-distributions show variations of 237%, 105%, 72%, 120% of the 'all data' profile.
- This shows that degrading data by extrapolating a single throw value along a fault changes calculated strain-rates across the fault.
- Thus, the strain-rate is highly affected by the local changes in throw, which are strongly dependent on the fault structural complexity.

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