How field observations and rock dating help improve the assessment of seismic hazard

Sam Mitchell, Gerald Roberts, Joanna Faure Walker, Francesco Iezzi, Claudia Sgambato, Jennifer Robertson, Zoë Mildon, Athanassios Ganas, Ioannis Papanikolaou, Elias Rugen

Background

How do ruptures form during earthquakes?

Destructive earthquakes occur when faults move suddenly. When a fault moves, the surface can rupture, exposing the fault above the ground e.g. as limestone fault scarps (see photos on the right).

What do fault scarps tell us about earthquakes?

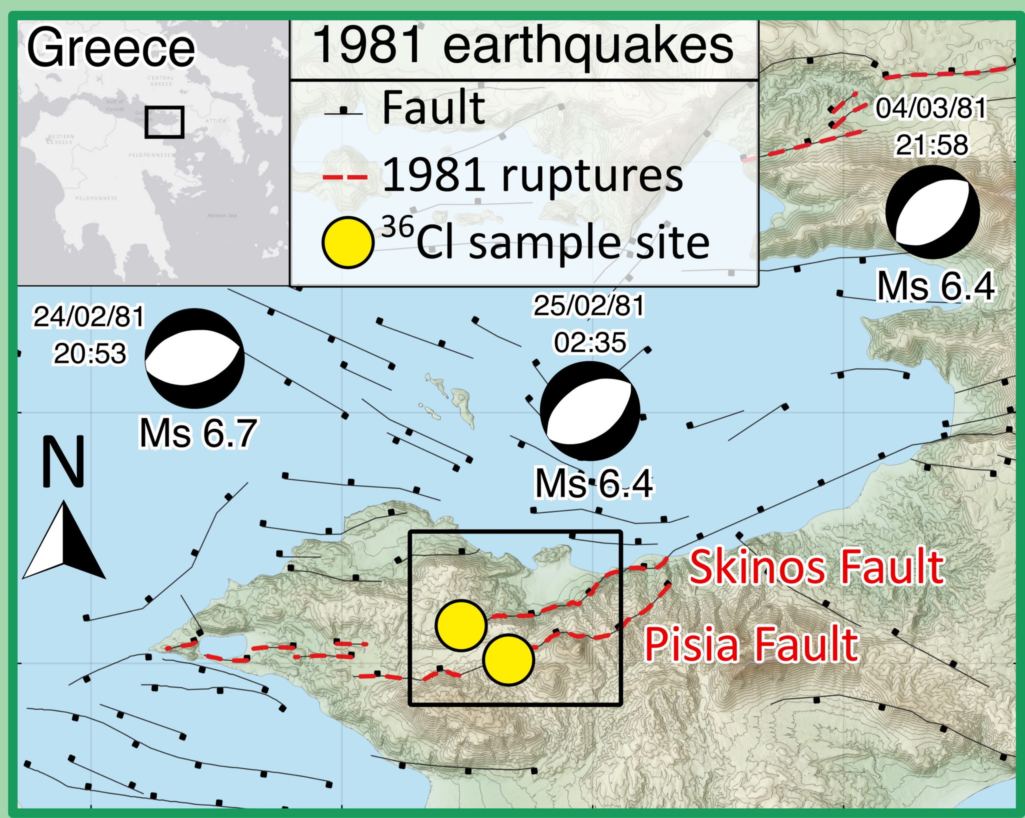
The entire exposed scarp has been formed over thousands of years during multiple earthquake events. Sampling and dating ^{36}Cl from limestone faults can help us to see when a fault was going through periods of fast and slow activity, thus, telling us when the highest earthquake activity took place.

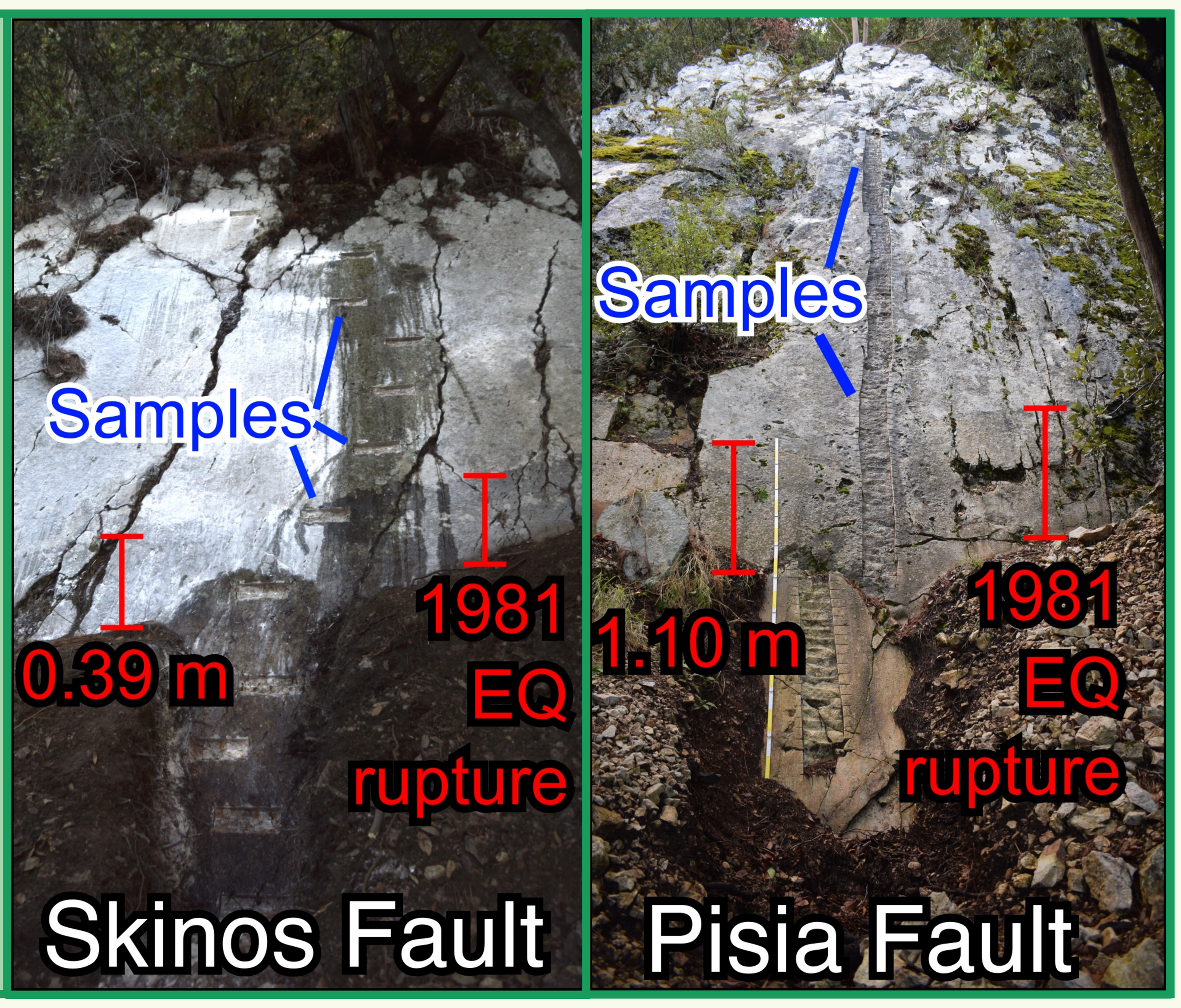
What do ruptures tell us about earthquakes?

Individual earthquake rupturing events can be identified by geomorphological observations of e.g. lichen-free stripes on fault planes, which show how much a fault moved during a single earthquake.

What do we study?

We show how analysing multi-millennia slip histories and rupture displacements can tell us about the slip relationship between two faults in Greece, which both had earthquakes in 1981, and show that the findings reveal new insights for the assessment of seismic hazard.





Movement relationships between the faults

1981 earthquakes (field observations)

What happened?

During the 1981 earthquakes in Greece, two closely spaced (~1-2 km of separation) parallel faults, the Skinos and Pisia Faults, slipped and ruptured only hours apart from each other.

What was unusual?

It is rare for across-strike parallel faults to slip in the same earthquake sequence.

What did we find?

The ruptured sections of both fault were located in the zone of overlap (~10 km) between both faults.

What was measured?

213 sites of the ruptures were found along both faults and the amount of displacement of the lichen-free stripes was measured.

What do the measurements show?

The Skinos Fault ruptured with a double maxima profile along the length of the fault and the Pisia Fault ruptured with a single asymmetrical profile along the length of the fault.

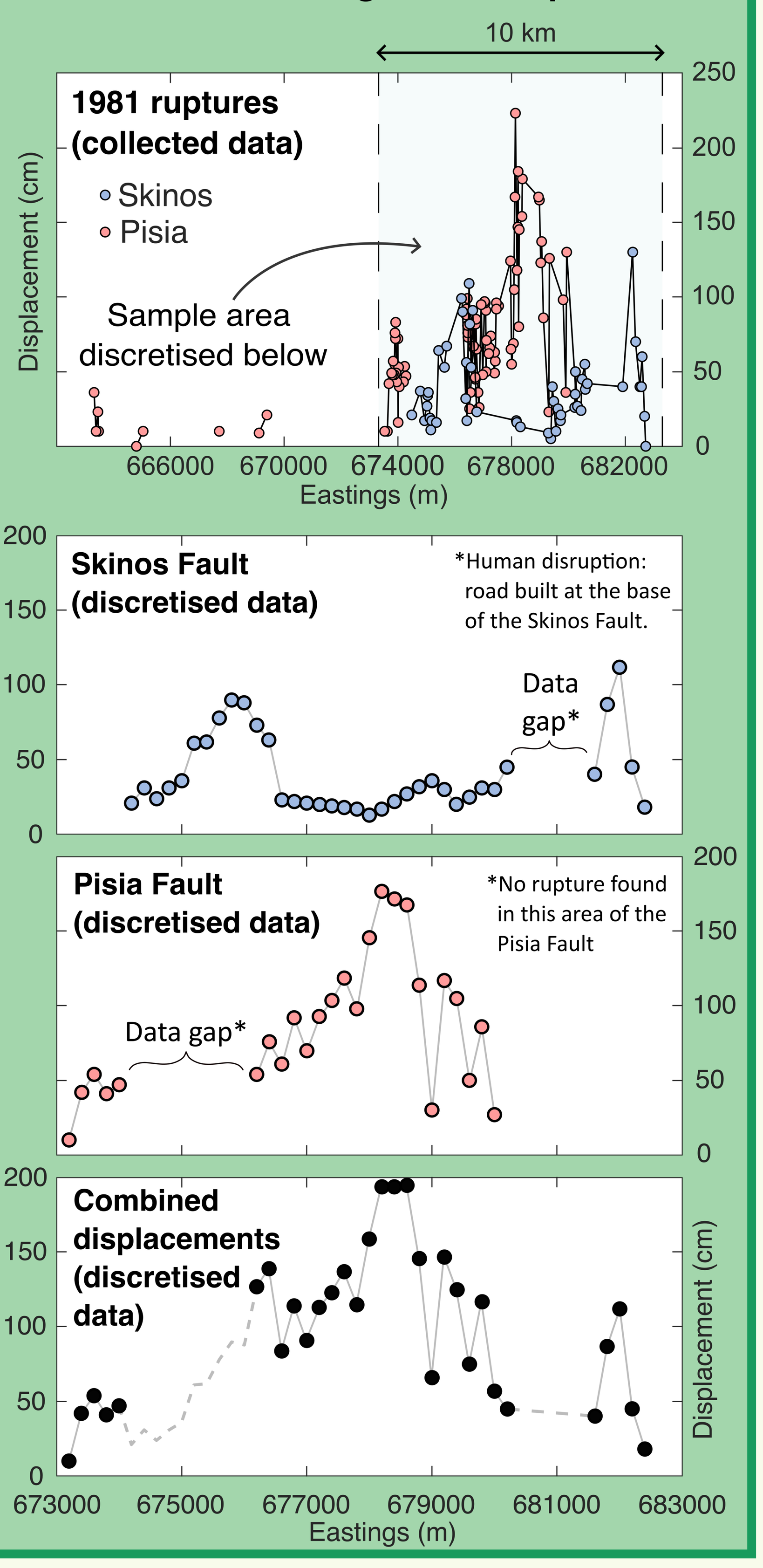
What do the ruptures on the two faults look like summed together?

In general, the combined displacements show a single symmetrical profile.

What does this tell us?

Comparing the ruptures on each fault shows that the slip on both faults are spatially out of phase with each other; when one fault has a deficit of slip, the other fault has a slip maxima, and vice versa. Furthermore, the combined ruptures reveal a symmetrical shape profile, which likely implies the faults are working together; when one fault has a slip deficit, the other fills in the slip.

Variations in displacement across the two faults during the earthquakes



Earthquake histories over thousands of years (rock exposure dating)

How to get a fault slip history from ^{36}Cl?

When a limestone rock is exposed at the surface, cosmic rays start to bombard the rock causing it to start accumulating ^{36}Cl. The longer the rock is exposed for, the more ^{36}Cl accumulates. Therefore, ^{36}Cl increases up an exposed limestone fault as these faults displace vertically during earthquakes. By sampling up a fault, the sampled ^{36}Cl can tell us when different sections of a fault were exposed, thus, telling us the slip history of a fault.

What do the fault slip histories show?

Time period (kyrs)	Skinos Fault slip-rate	Pisia Fault slip-rate
9.4 – 6.0	Low	High
6.0 – 2.2	High	Low
2.2 – 0.0	Moderate	Moderate

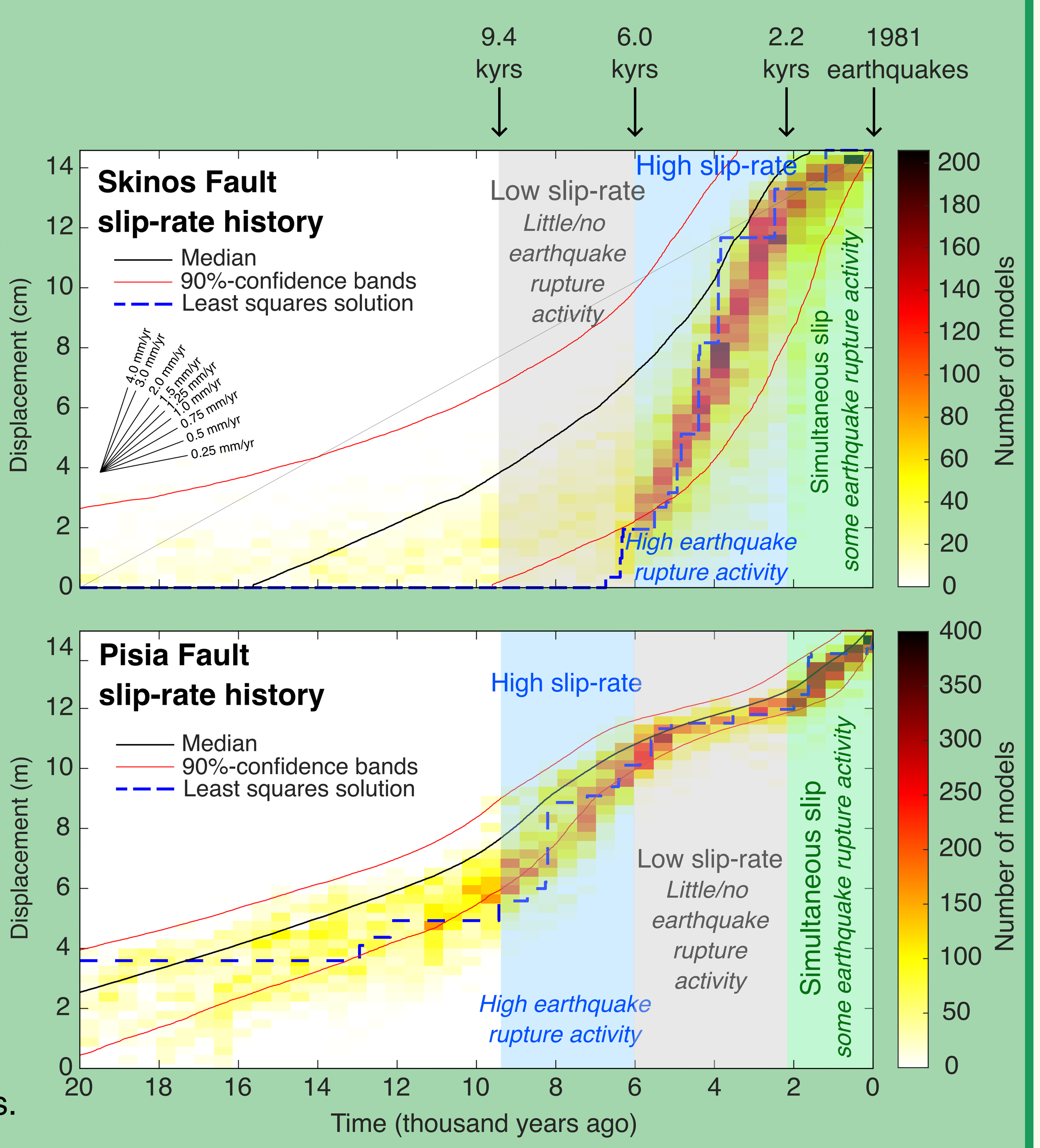
What are the slip relationships between the faults?

The faults were temporally out of phase each other (9.4 to 2.2 kyrs); when one fault has a high slip-rate, the other has a low slip-rate, and vice versa. Recently (2.2 kyrs to present), the faults are simultaneously slipping, as evidenced by the 1981 earthquakes.

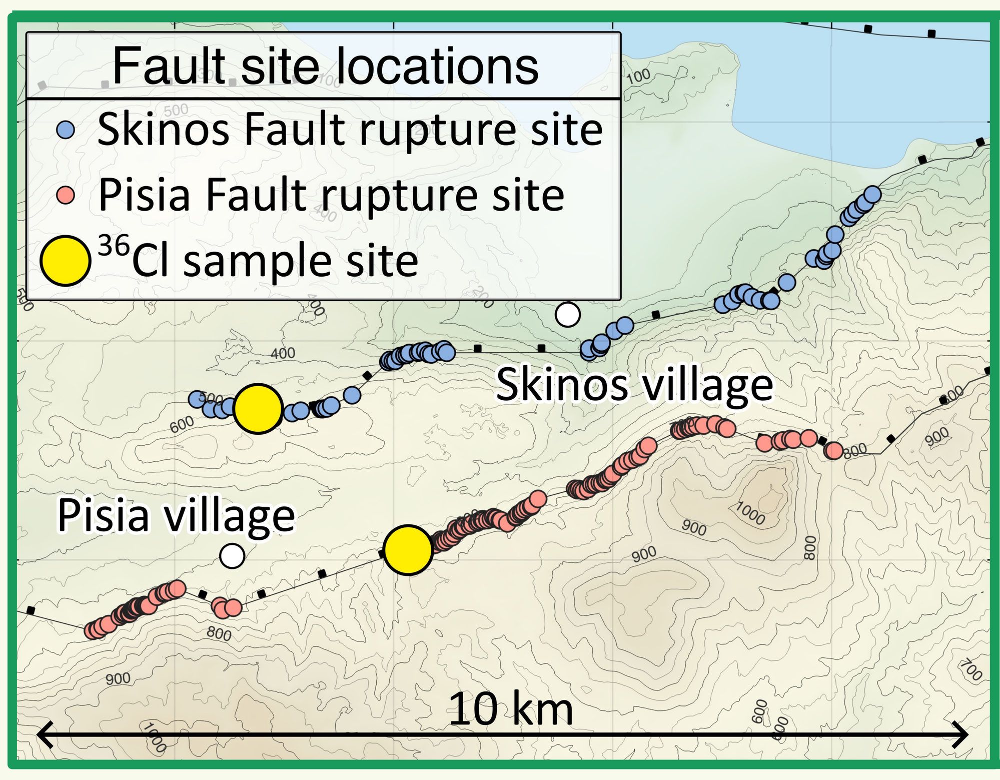
What does this tell us?

The faults are working together; when one fault is not slipping, the other concentrates slip and when they slip simultaneously, they evenly distribute slip between both faults.

Variations in displacement across the two faults through time



Insights for the assessment of seismic hazard



What were the key findings?

The two parallel faults show slip relationships which indicate the faults are working together; spatially out-of-phase slip during the 1981 earthquakes, temporally out-of-phase slip from 9.4 kyrs to 2.2 kyrs and simultaneous slip from 2.2 kyrs to the present day.

How can this help improve the assessment of seismic hazard?

- Across-strike parallel faults are considered to be unlikely to slip during the same earthquake sequence yet this was not the case for the Pisia and Skinos Faults, in which the slip on both faults was concentrated in the zone of overlap between the faults during the 1981 earthquakes, as shown by the field observations. Slip histories also indicate that the faults have slipped synchronously in the last 2.2 kyrs.
- Both faults slipping together would indicate higher magnitude earthquakes than the faults slipping individually.
- Despite both faults slipping together in 1981, most of the time (9.4 kyrs to 2.2 kyrs) the faults take it in turns and slip separately, not together.
- Past earthquakes likely change in amount of displacement, and thus size of earthquake, from one event to the next, as implied by our slip histories.
- Rupture assumptions indicate a symmetrical profile, yet our results show they are not. Despite, the combined profile of both faults showing a symmetrical profile, individually, each fault did not show a single symmetrical profile, thus showing the complexity of faults in relation to surface hazard displacement.

Scan to view article on 1981 earthquake rupture observations

X: @structuralsam
Email: sam.mitchell.21@ucl.ac.uk

NERC SCIENCE OF THE ENVIRONMENT
UCL
Birkbeck UNIVERSITY OF LONDON