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Evaluation of the seismogenic potential in key areas of the central and southern Apennines through analysis of speleothem vulnerability

Ferranti L. (1), Valentini A. (2), Pace B. (2), Vasta M. (3), Colella A. (1), Montagna P. (4)

(1) Dipartimento di Scienze della Terra, dell'Ambiente, e delle Risorse, Università degli Studi Federico II, Napoli.
(2) DiSPUTer, Università degli Studi G. d'Annunzio, Chieti.
(3) Dipartimento INGEO, Università degli Studi G. d'Annunzio, Chieti.
(4) ISMAR – CNR, Bologna

With the contribution of:
Calcaterra D. (1), De Massis J. (2), Di Bianco S. (1), La Rocca N. (3), Maschio L. (1), Ramondini M. (4), Berardi D. (5), Teodoro P. (2), Vassallo M. (6)
(1) Dipartimento di Scienze della Terra, dell'Ambiente, e delle Risorse, Università degli Studi Federico II, Napoli.
(2) DiSPUTer, Università degli Studi G. d'Annunzio, Chieti.
(3) Gruppo Speleologico Sparviere, Alessandria del Carretto, Cosenza,
(4) Dipartimento di Ingegneria Civile, Edile ed Ambientale, Università degli Studi Federico II, Napoli.
(5) Associazione Geonaturalistica Gaia Montesilvano, Pescara.
(6) INGV, L'Aquila.

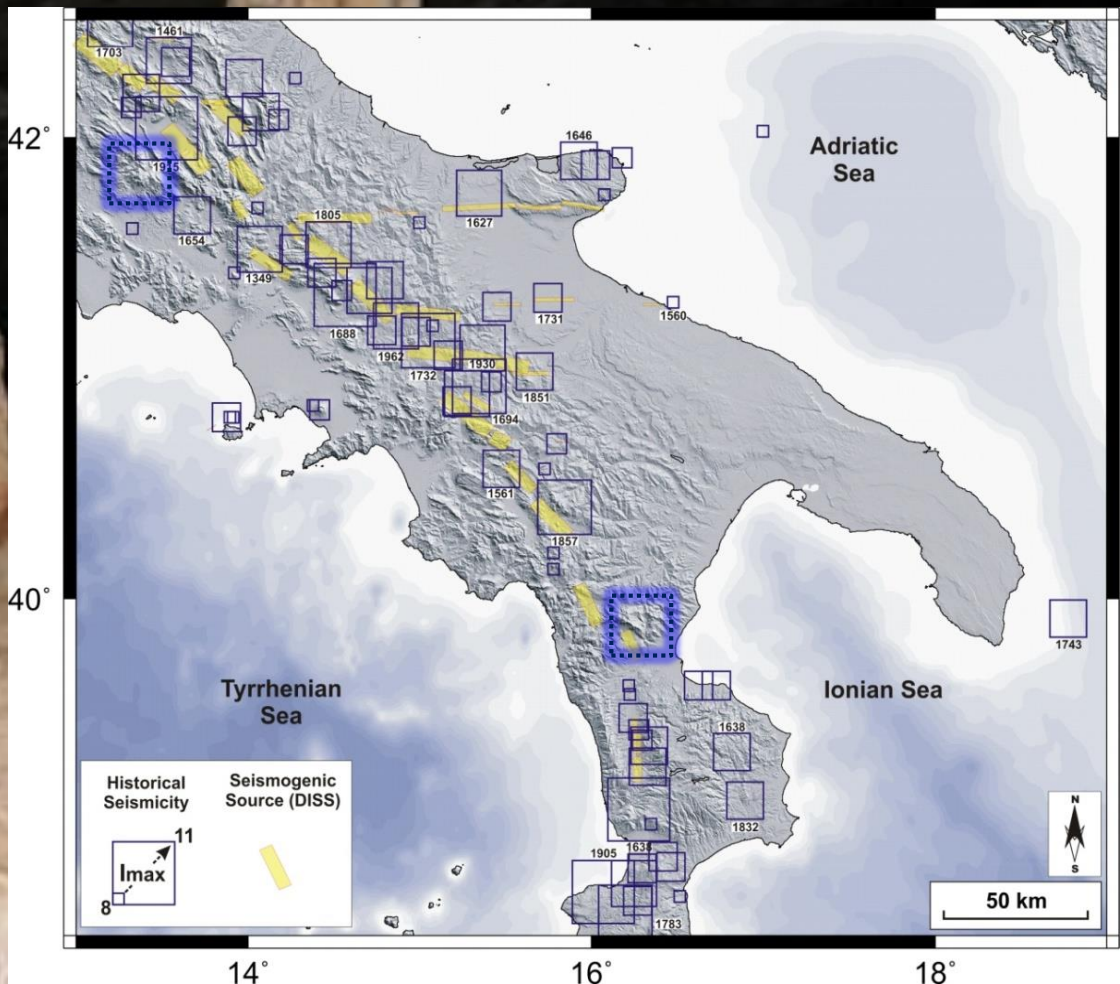
Aims

1. Improvement of existing paleoseismological databases (this is what speleosismologists would like to do..., but we want more)
2. Assessment of the peak ground acceleration (PGA) threshold experienced, OR NOT, during past earthquakes, using a numerical model approach
3. Detection of the causative seismogenic sources & paleoearthquake size

WHERE:

-Liri valley (W of Fucino Basin) (Central Apennines)

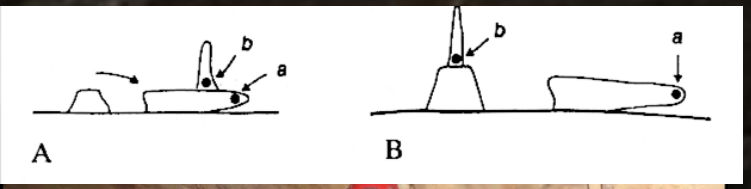
-Pollino Range (Southern Apennines)

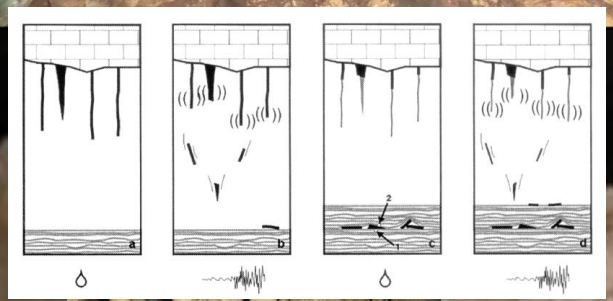


Palano et al., 2011

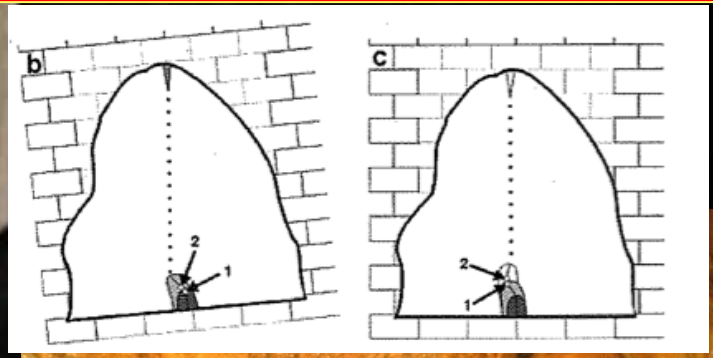
Speleoseismological markers

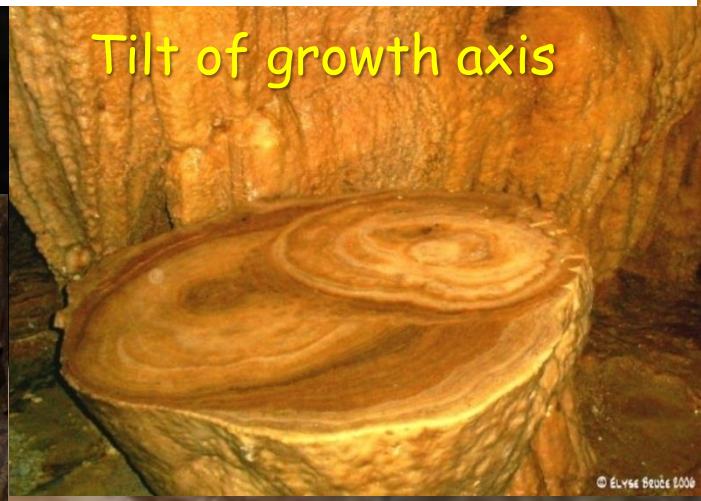
The stalactite-stalagmite oscillatory system





Bedrock-speleothem rigid displacement





STEP 1: Cave data collection (the dirty work…)

- Selection of required features (concretions within near-surface rooms, wide range of speleothem shapes).

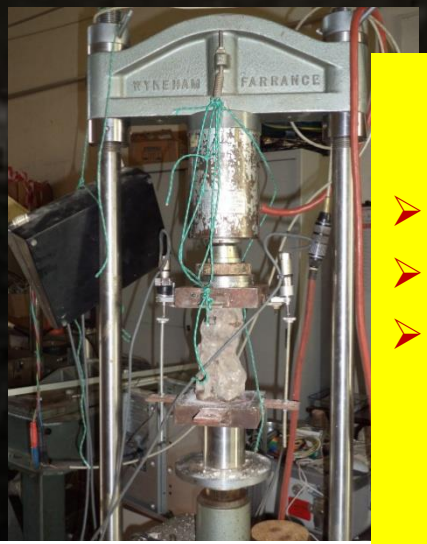
- Recording of speleothem geometry (length & diameter of both broken and unbroken speleothems). N ~200 (Pollino caves) & ~50 (Grotta Cola)

- Collection of samples for (N~30) radiometric dating -> paleoseismological frame

STEP 2: Speleothem geomechanics

- Static tests on a representative speleothem population (~30) from individual caves.

Output: failure tensile stress and sample mechanical properties (Young modulus, density)



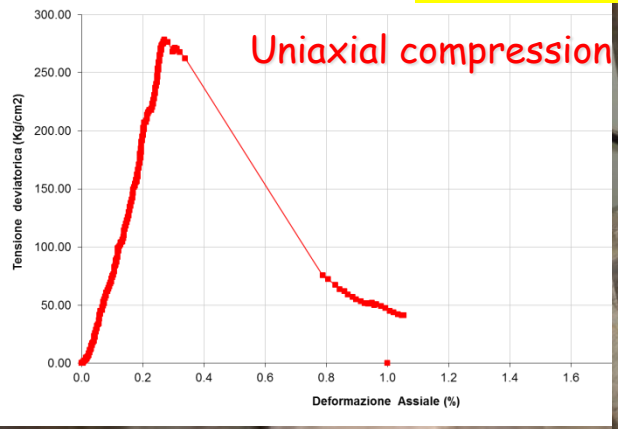
Sforzo/Deformazio

STATIC TESTS AV. RESULTS

- Young modulus = 10.000 Mpa
- Density = 2450 g/cm^3
- Tensile Failure stress = 0,8 Mpa

ALL VALUES IN AGREEMENT WITH PUBLISHED RESULTS USED FOR ANALITYCAL MODELS

Ultrasound analysis



STEP 3: Numerical modelling of PGA thresholds and sources

Finite element method (FEM), SAP2000 software

Input:

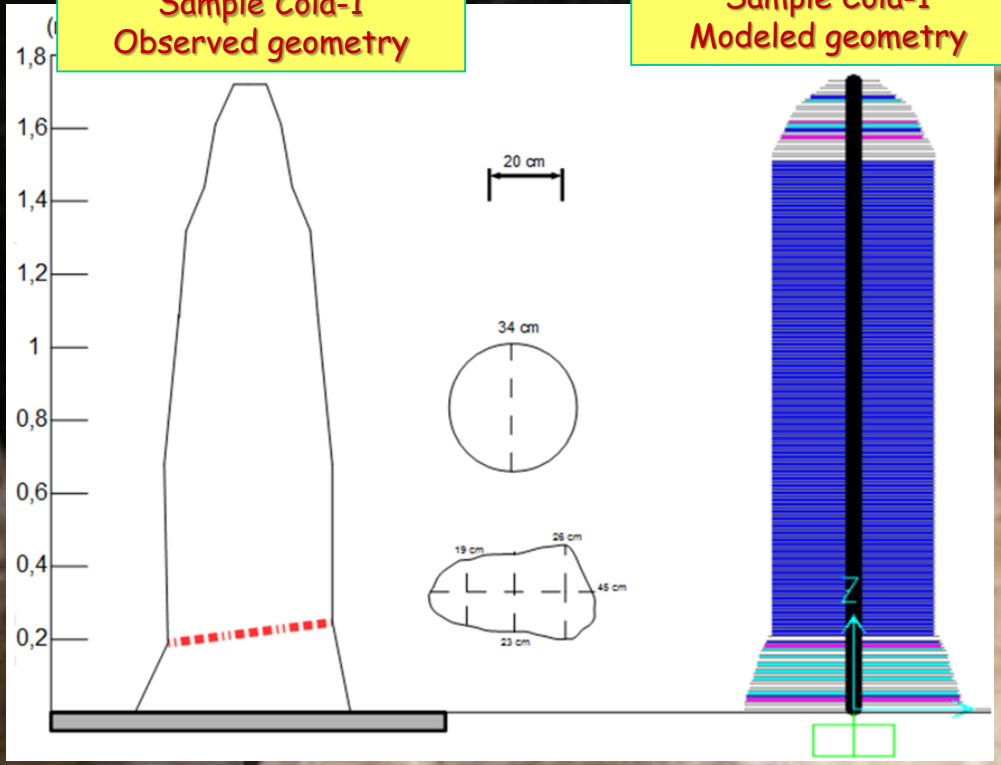
-Speleothem shape (length, diameter); ->MEASURED IN CAVE

- Speleothem mechanical properties (density, Young modulus, tensile stress); -> FROM STATIC TESTS

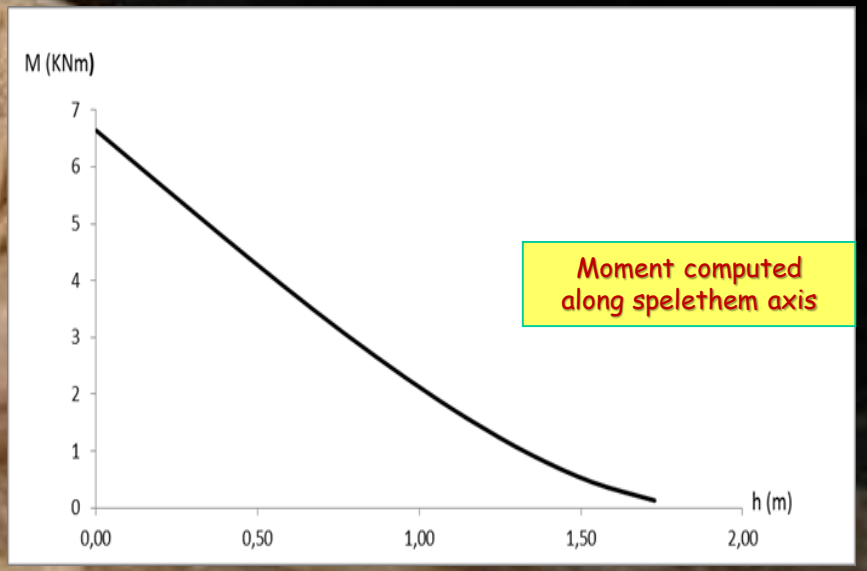
- Seismic input (seismogenic source distance, Moment magnitude, ground motion prediction equations)

Output: Moment (M) and tensile failure stress (σ_T) along speleothem axis; fundamental frequency (f_0)

Sample Cola-1
Observed geometry



Sample Cola-1
Modeled geometry

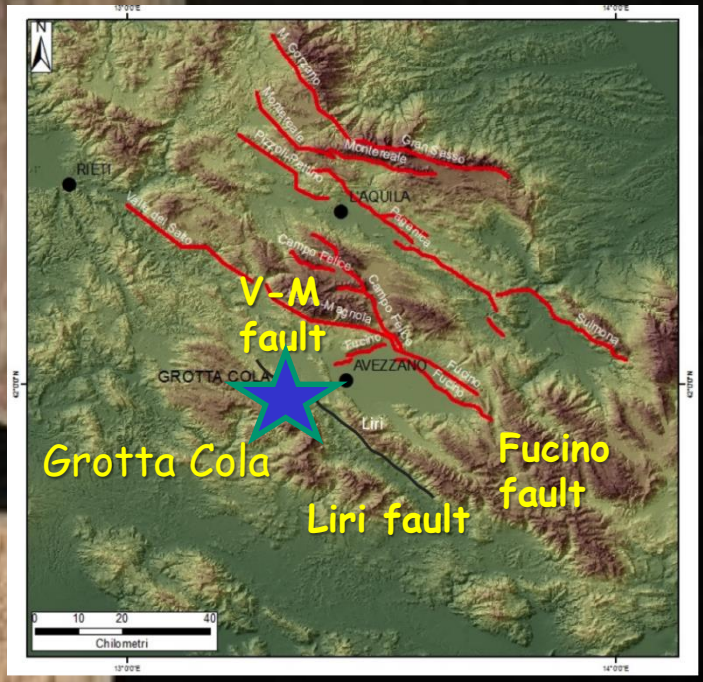


Moment computed along spelethem axis

Differently from the analytical model approach, speleothems have been treated with a quasi-real geometry!

Central Apennines: Grotta Cola

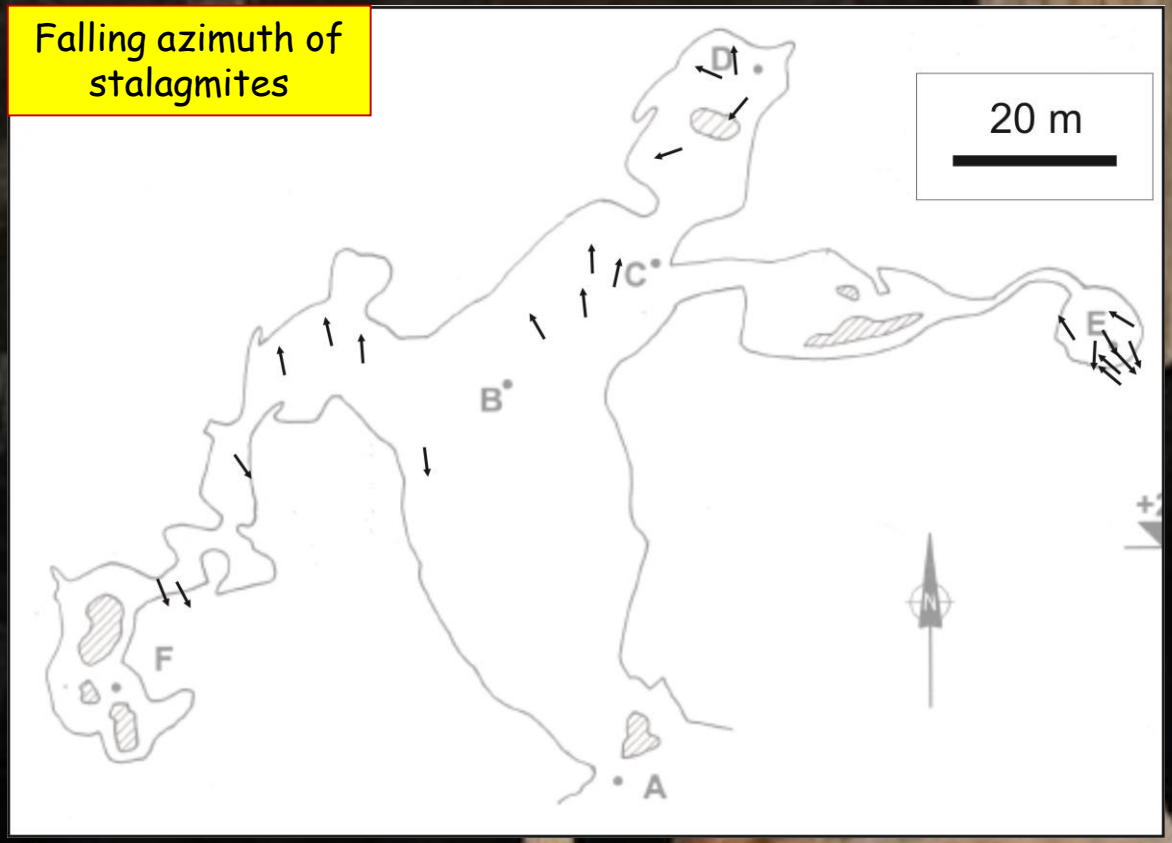
Tha cave is full of fallen speleothems



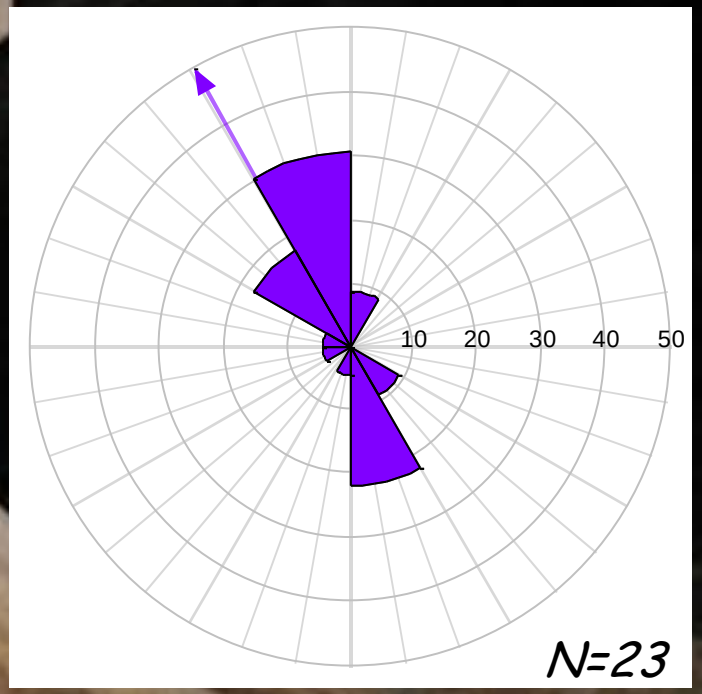
Post-fall stalagmite

Grotta Cola - Structural analysis

Falling azimuth of stalagmites



•Fall azimuth is predominantly to NNW.

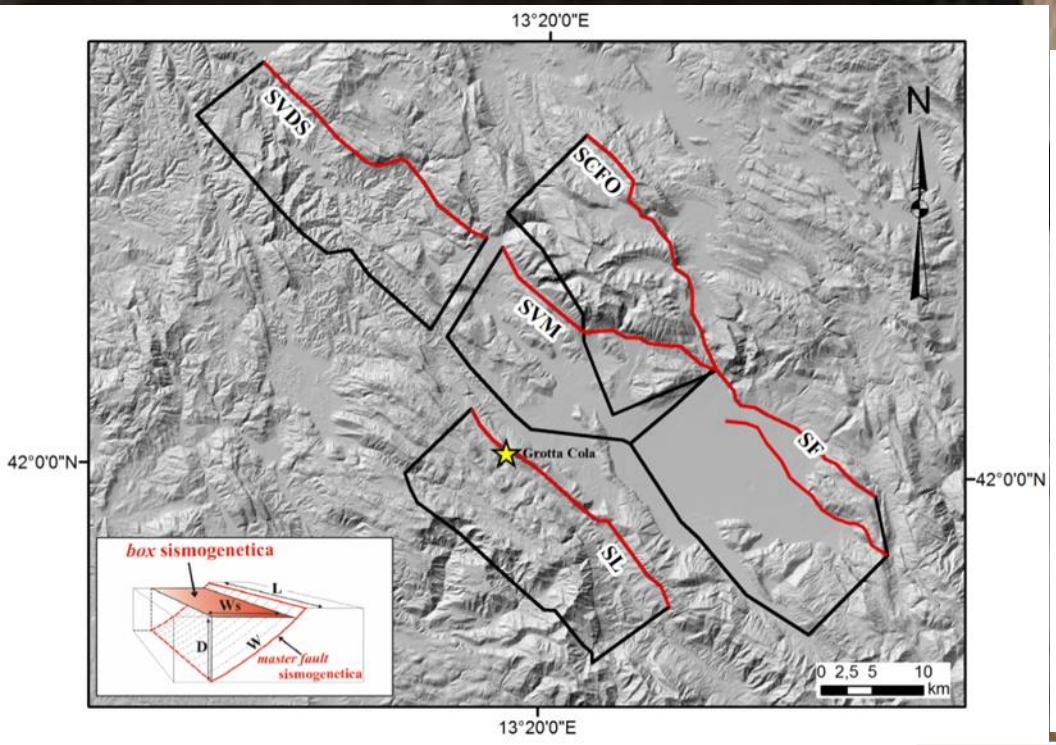


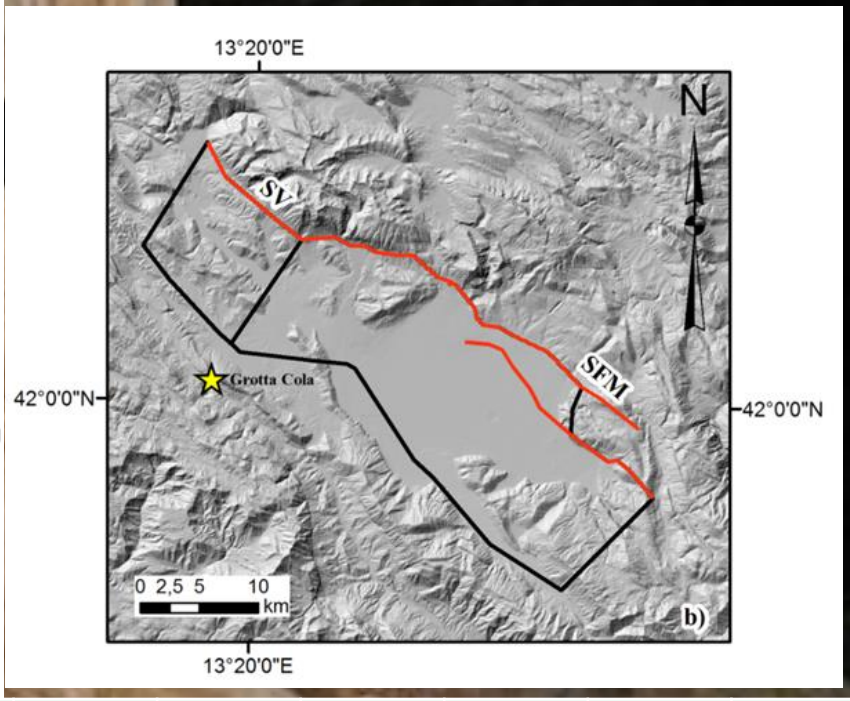
•The falling azimuth of stalagmites is thought to lie within the plane of the radiating energy.
•At Grotta Cola, observations are consistent with a ~NNW-SSE striking causative source

Grotta Cola – Seismic input_1

The seismic input has been computed for 7 **seismogenic sources**

Fucino (SF), Velino-Magnola (SVM), Campo Felice-Ovindoli (SCFO), Valle del Salto (SVDS), Liri (SL), Fucino-Magnola (SFM) e Velino (SV).





SF	SVM	SCFO	SVDS	SL	SFM	SV
6.6 ± 0.3	6.6 ± 0.2	6.4 ± 0.3	6.6 ± 0.2	6.7 ± 0.2	6.8 ± 0.2	6.1 ± 0.2

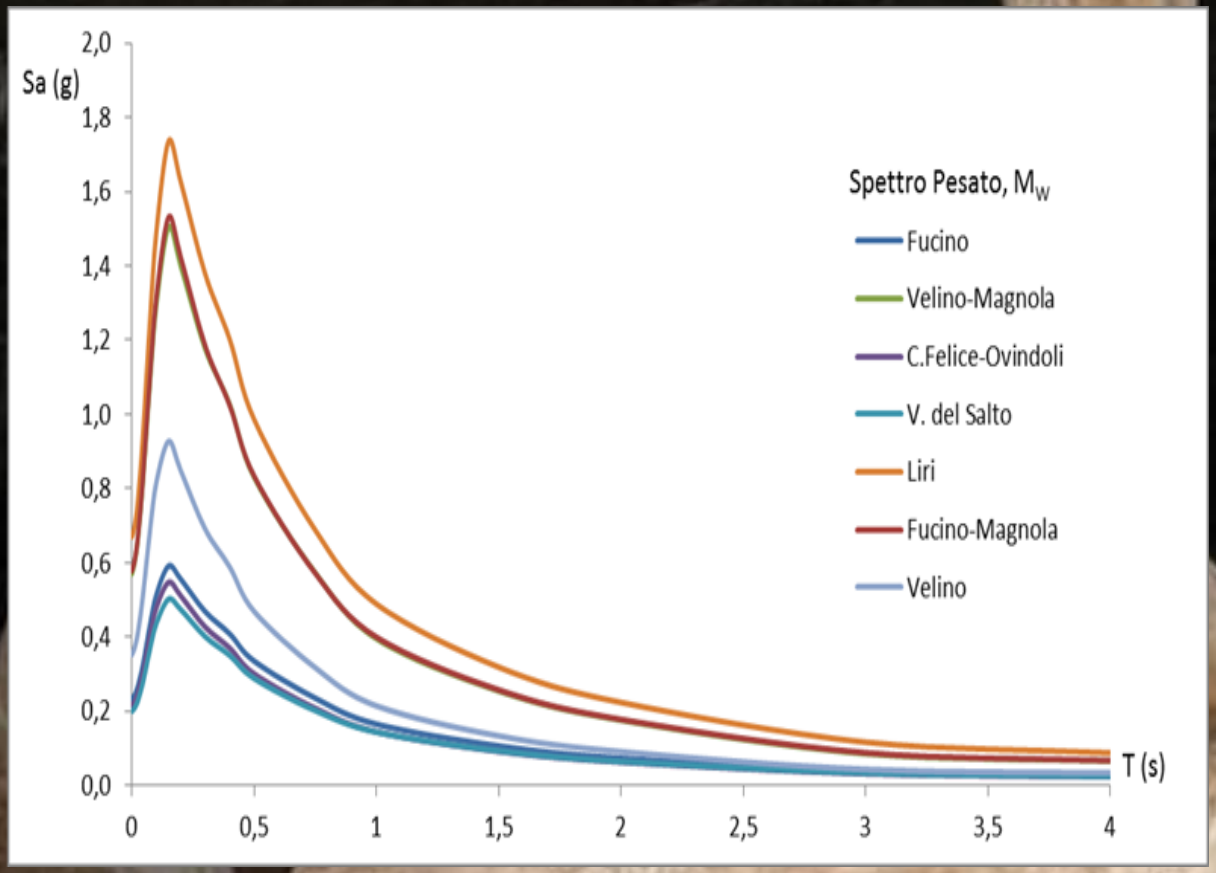
- Parameters:

1) Distance Cave-Seismogenic source

2) Moment Magnitude (from published work)

Grotta Cola – Seismic input_2

- Weighted set of four ground motion prediction equations (SHARE project: Akkar and Bommer, (2013); Cauzzi e Faccioli, (2008); Chiou and Youngs, (2008); Zaho et al., (2006)



Weighted spectra	PGA (g) M_w + sD
SF	0.30
SVM	0.69
SCFO	0.29
SVDS	0.24
SL	0.76
SFM	0.67
SV	0.43

Significant PGA are only reached for Velino-Magnola, Fucino-Magnola, and Liri faults

Sample Cola-1 – FEM modelling

Input:

Geometry & geo-mechanical input:

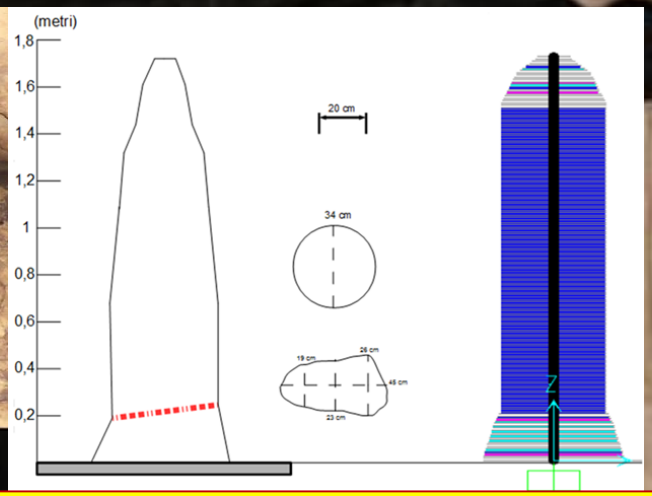
Heigth (H) = 1.73 metri; *Diameter (D)* = variable

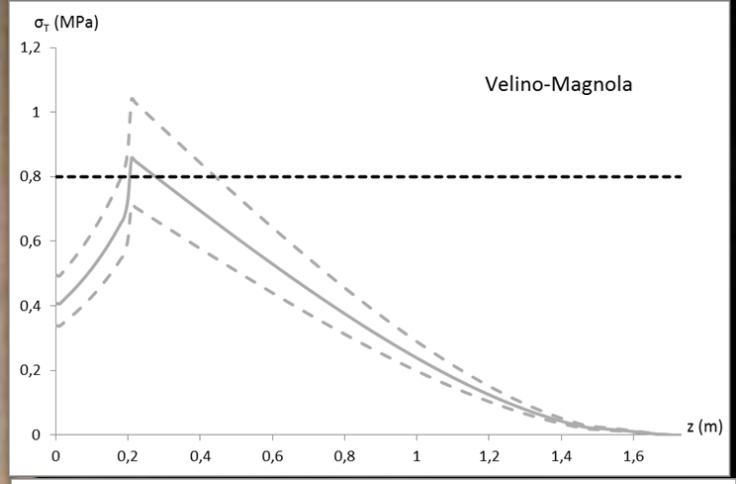
Density (ρ) = 2450 kg/mc;

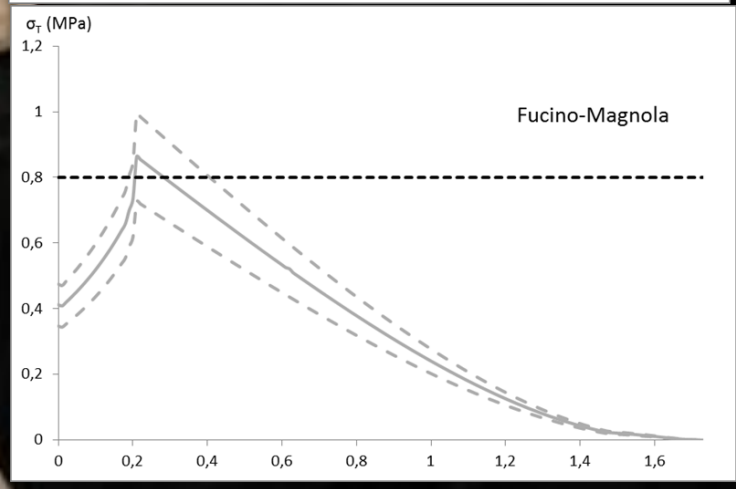
Young Modulus (E) = 10000 Mpa

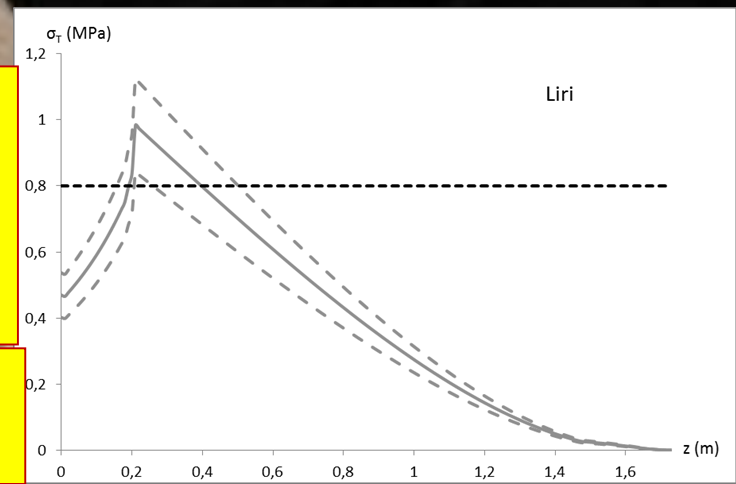
Minimum tensile failure stress (σ) = 0.8 MPa

Seismic input: Velino-Magnola, Liri, Fucino-Magnola







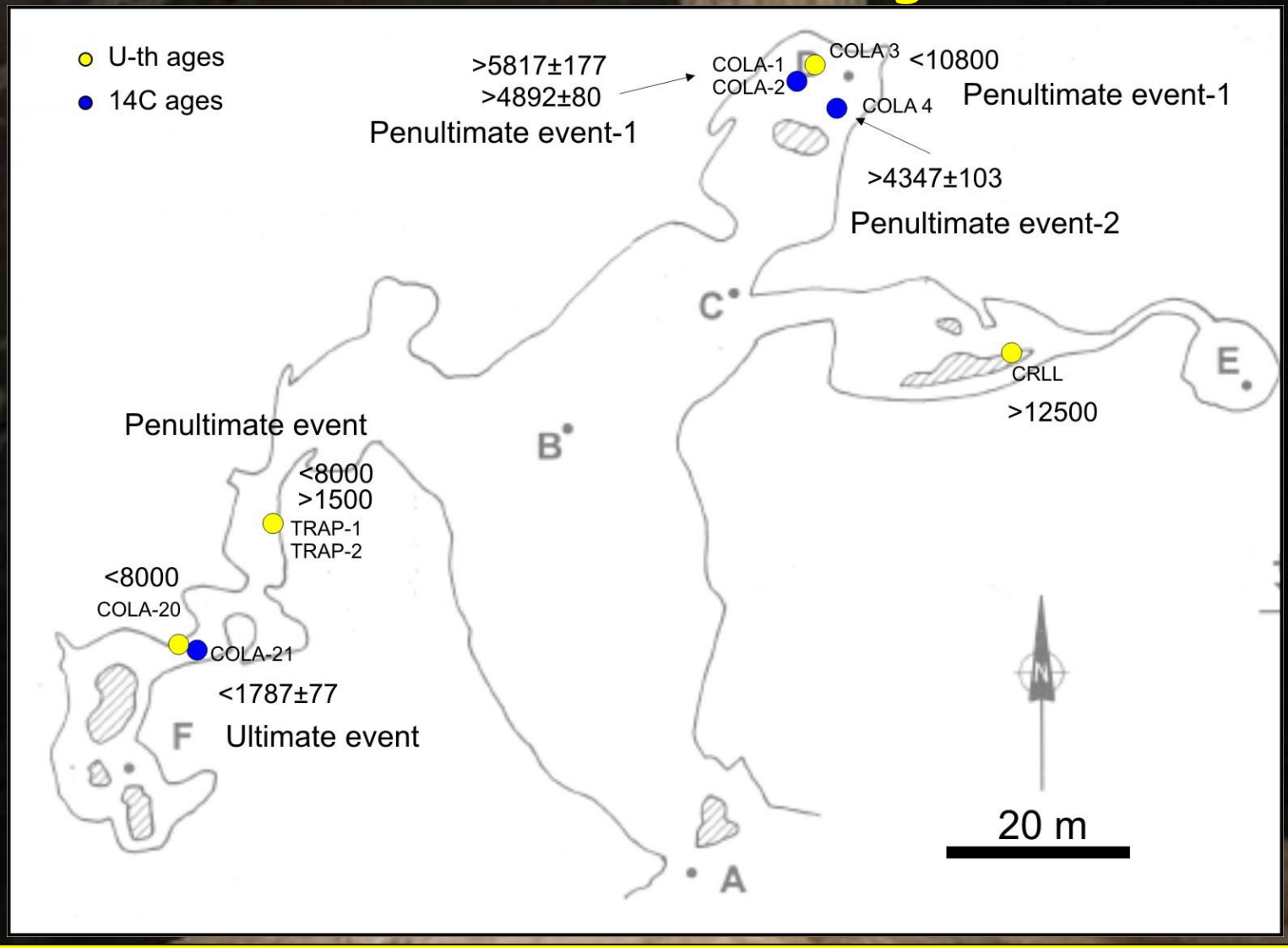


Results:

The 3 sources (Velino-Magnola, Liri, Fucino-Magnola) out of 7 were found capable of exceeding the 0.8 Mpa minimum tensile failure stress for sample Cola-1 at the exact rupture point (~20 cm; speleothem neck)

Predicted pattern of σ along the axis of Cola-1 produced by slip on the Magnola, Liri, Fucino-Magnola

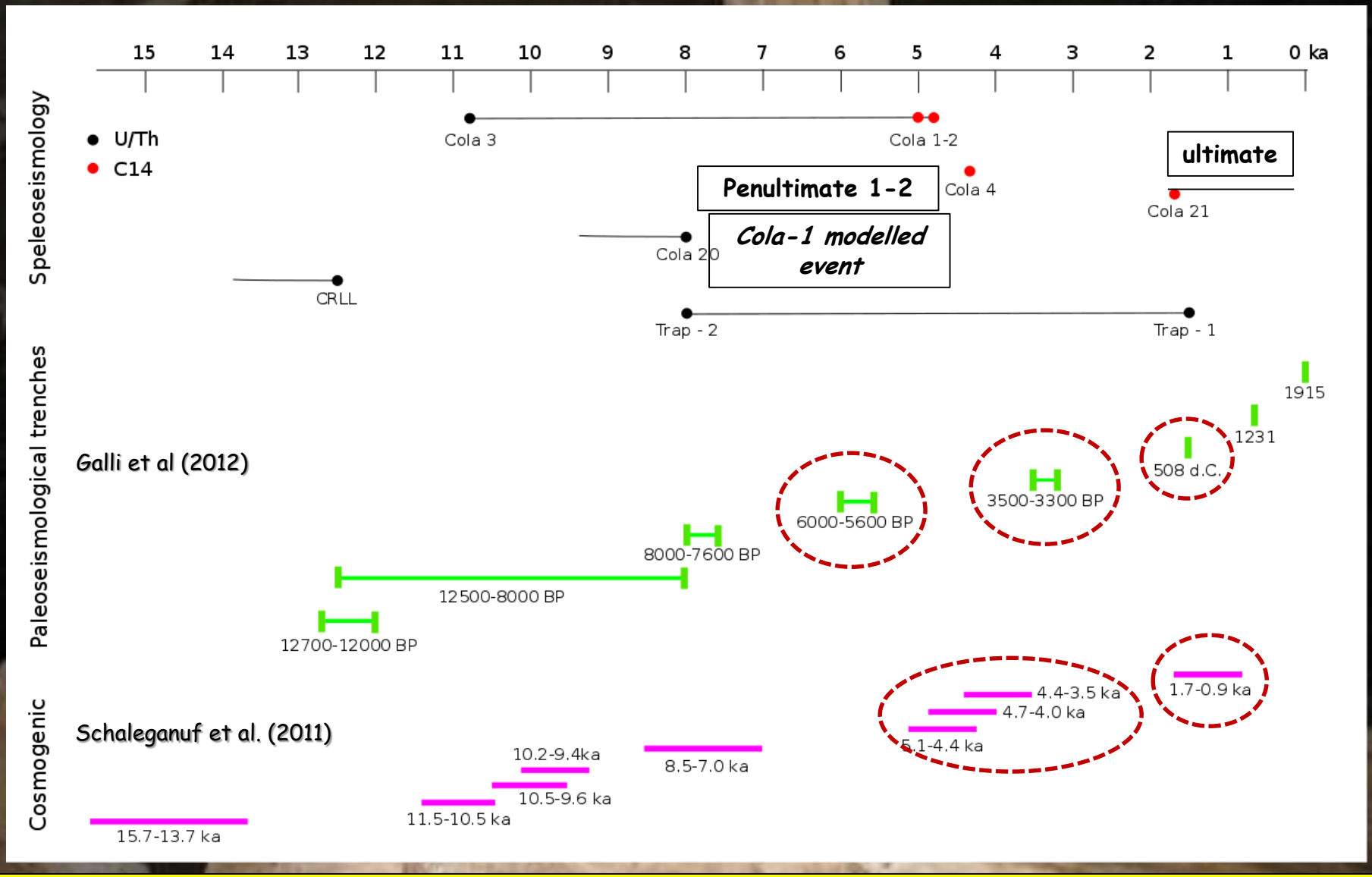
Grotta Cola – Paleoseismological events



Two fall events:

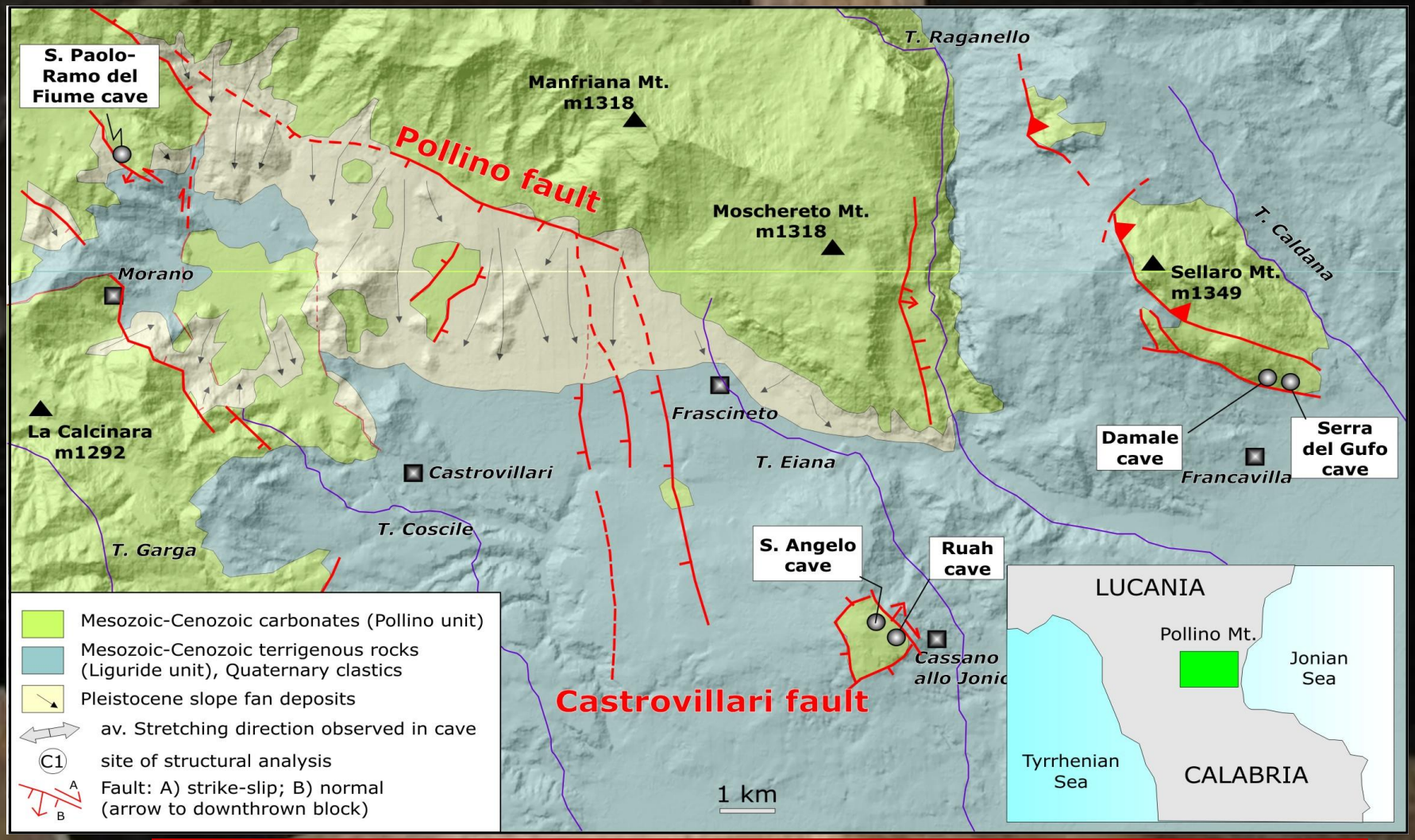
- Penultimate (maybe two distinct events) at ~(8-)5.8 & ~4.9-4.3 ka;
- Ultimate just after ~1.8 ka;
- No evidence for 1915 -> vulnerable speleothems were not available after ultimate?

Grotta Cola – Paleoseismological correlation



•Speleoseismological events broadly consistent with timing of earthquakes documented by cosmogenic and trench data for the Magnola fault

Southern Apennines: Pollino caves



Pollino-Castrovillari fault system

- Serra del Gufo, Damale, Ruah, S. Angelo caves: **footwall**
- S. Paolo-Ramo del Fiume (Morano) cave: **hanging-wall**

Hanging-wall cave: S. Paolo-Ramo Fiumer (Morano)

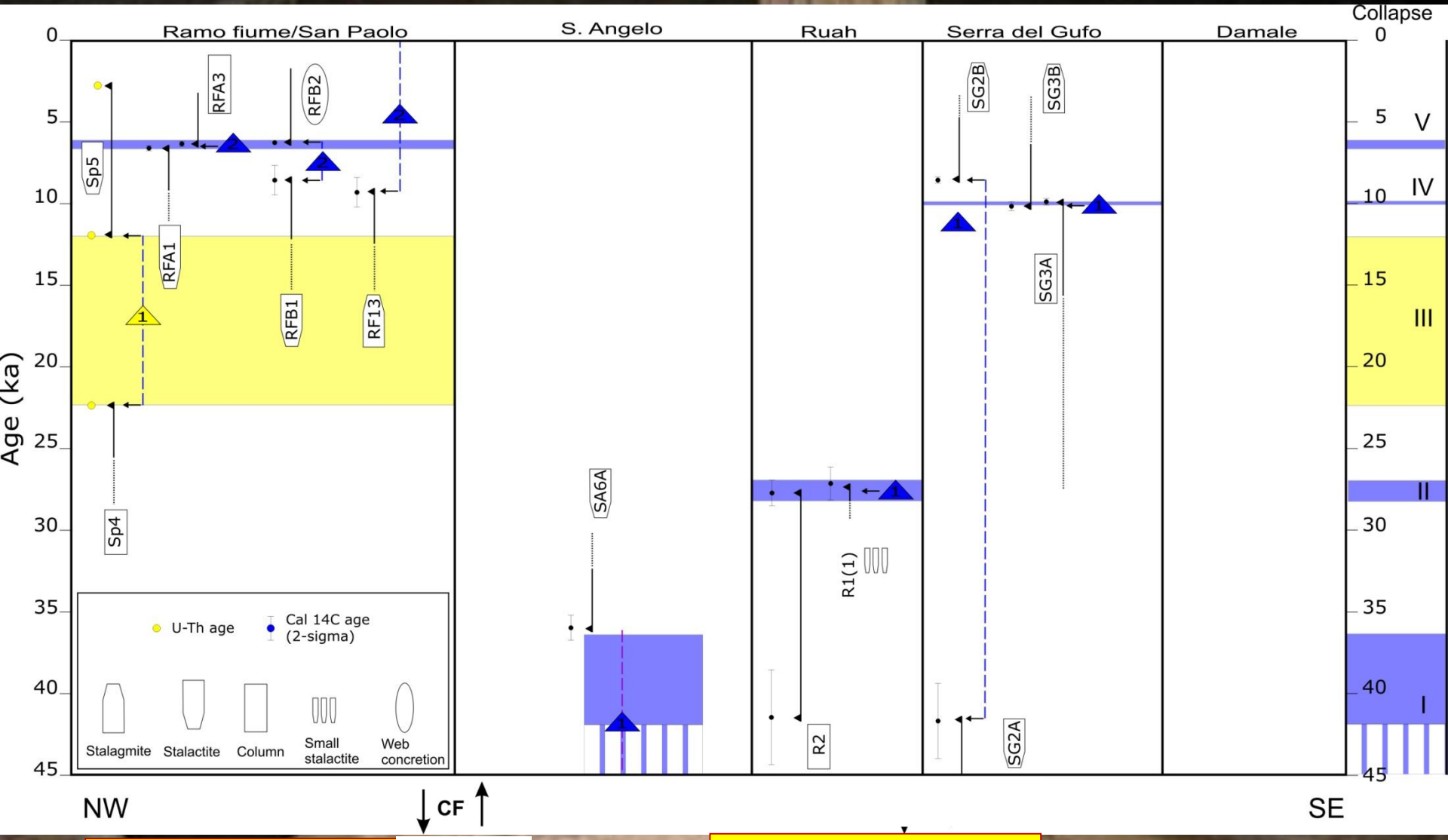
- Active speleothem growth
- Few speleothems breakage observed
- Slender (vulnerable) speleothems unbroken

Footwall caves: Serra del Gufo

- Poorly active speleothem growth
- Few fallen and tilted speleothems
- Slender (vulnerable) speleothems unbroken

A situation totally different wrt Grotta Cola!

Pollino - Paleoseismological results



HANGING-WALL

CF+PF

FOOTWALL

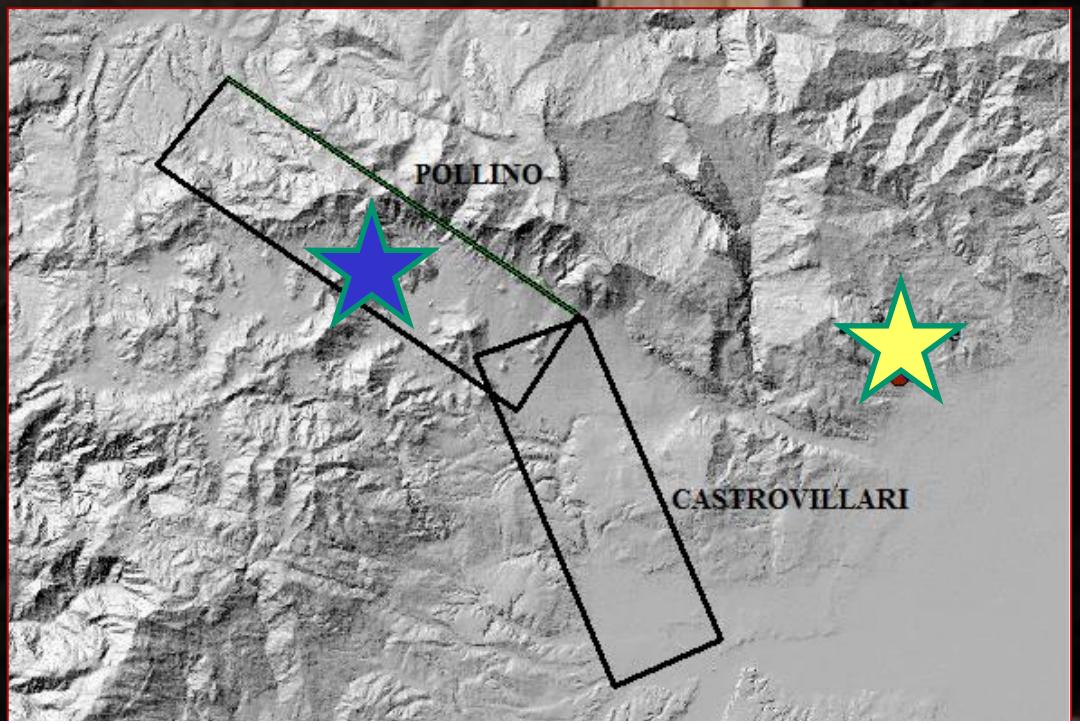
Summing the evidence from FW & HW caves we have **four** fall events in the last **~30 ka**). Tilt of growth axes are older (45-45 ka)

Pollino – Seismic input

Seismic input computed for 3 seismogenic sources

Pollino fault (PF), Castrovillari fault (CF), and the combined Pollino-Castrovillari faults

San Paolo-Ramo del Fiume (HANGING-WALL)

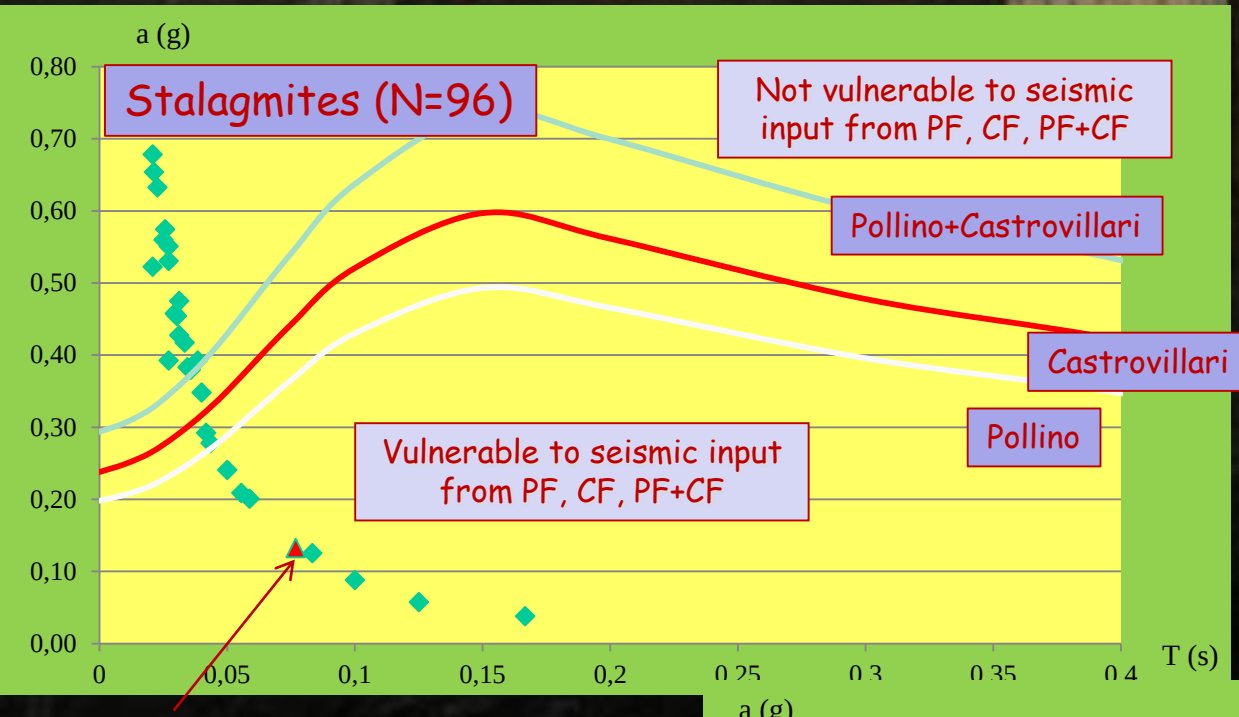


Damale-Serra del Gufo (FOOTWALL)

Source	PGA (Mmax) S.d.Gufo	PGA(Mmax) S.Paolo	M
Pollino	0.19	0.66	6.3 ± 0.2
Castrovillari	0.22	0.34	6.2 ± 0.2
Pollino+Castrovillari	0.28	0.63	6.5 ± 0.2

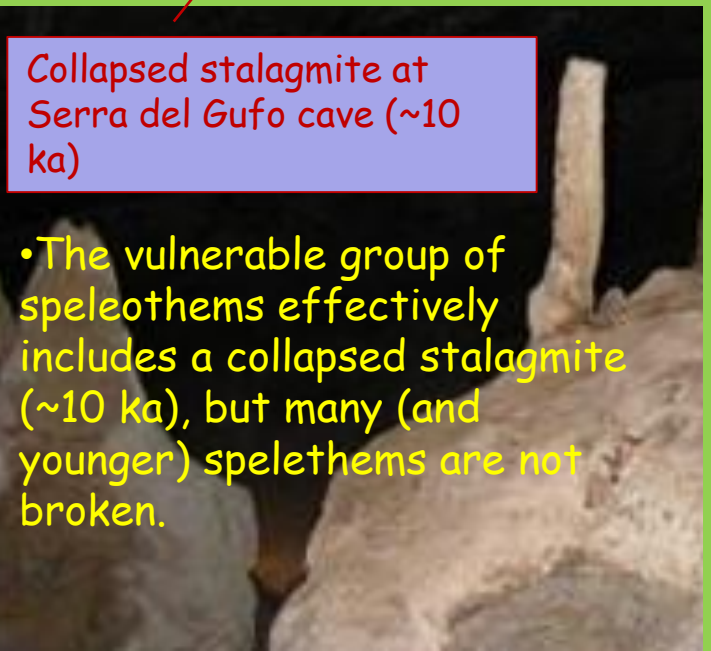
PGA computed for the Serra del Gufo and Damale caves (footwall, yellow star) and for San Paolo – Ramo del fiume cave (hanging-wall, blue star)

Pollino – FEM modelling results



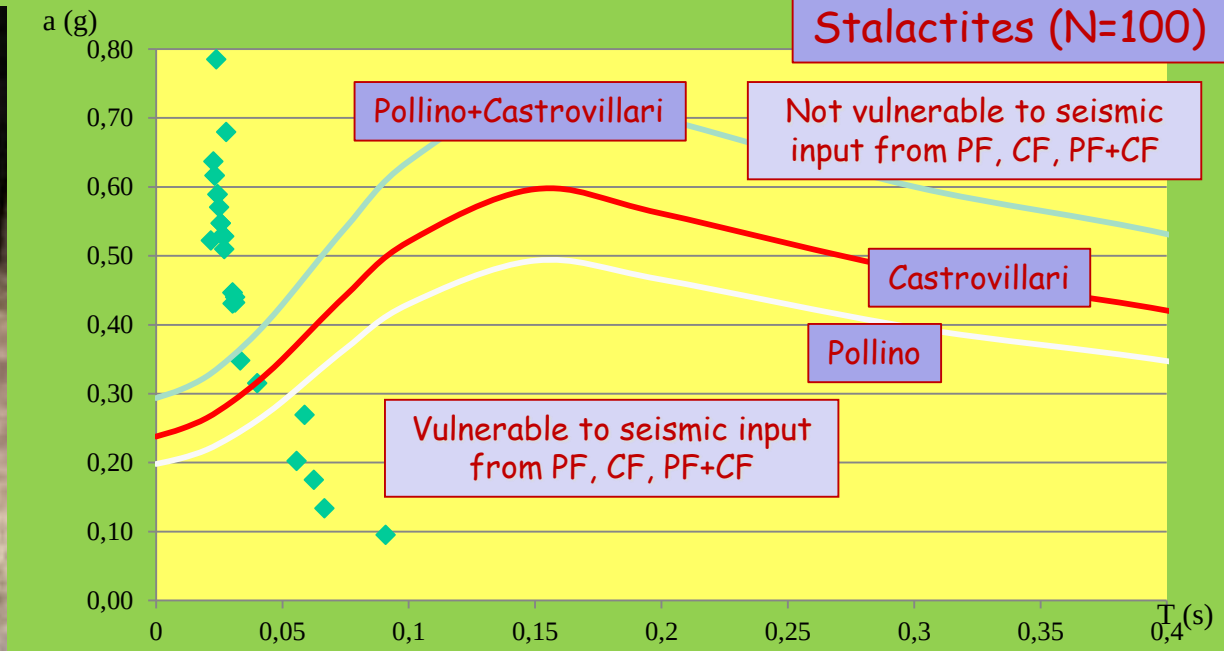
Serra del Gufo and Damale Caves (FOTWALL)

- A large number of speleothem has geometry resulting in a spectral acceleration below the treshold predicted for the three faults.

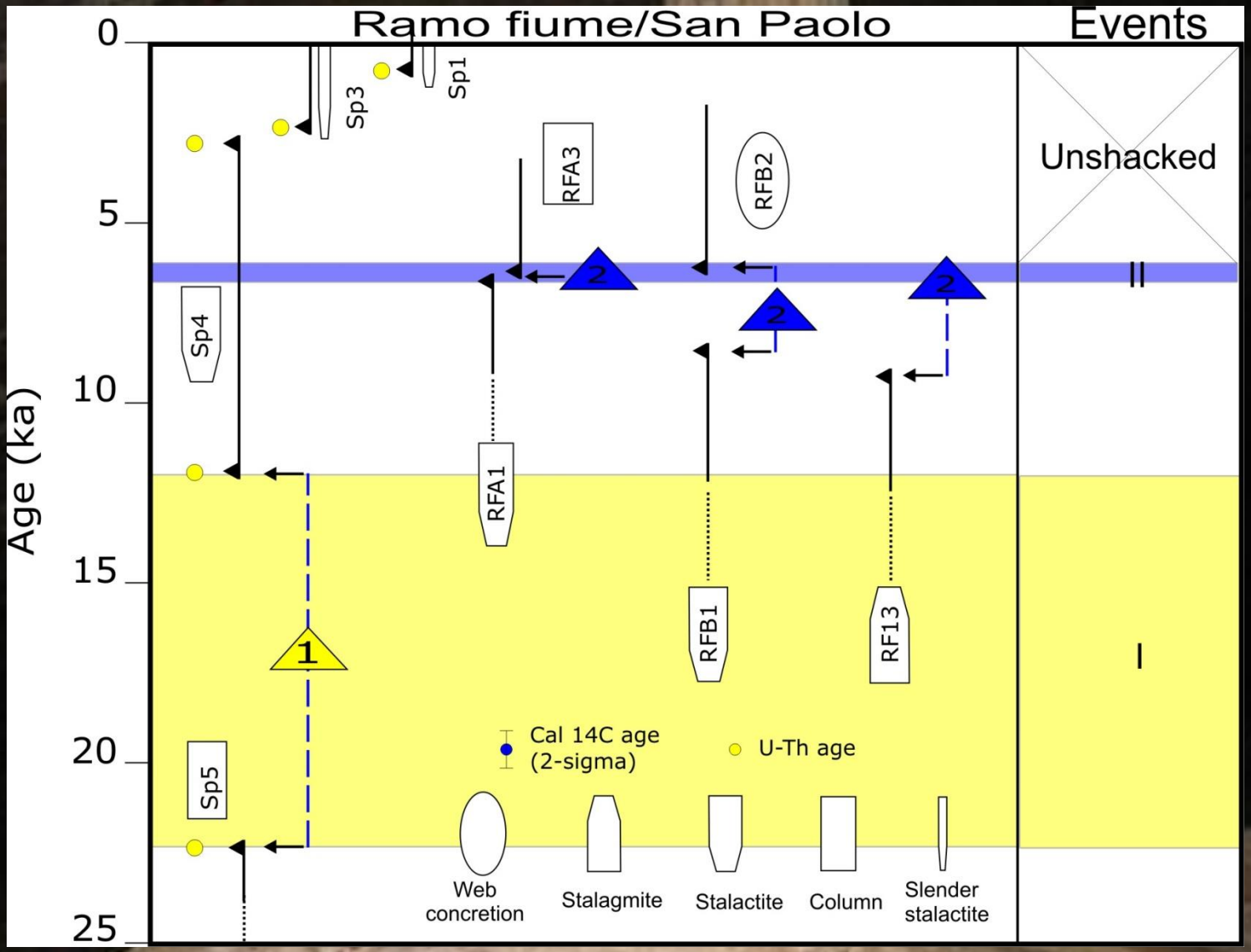


Collapsed stalagmite at Serra del Gufo cave (~10 ka)

- The vulnerable group of speleothems effectively includes a collapsed stalagmite (~10 ka), but many (and younger) spelethems are not broken.



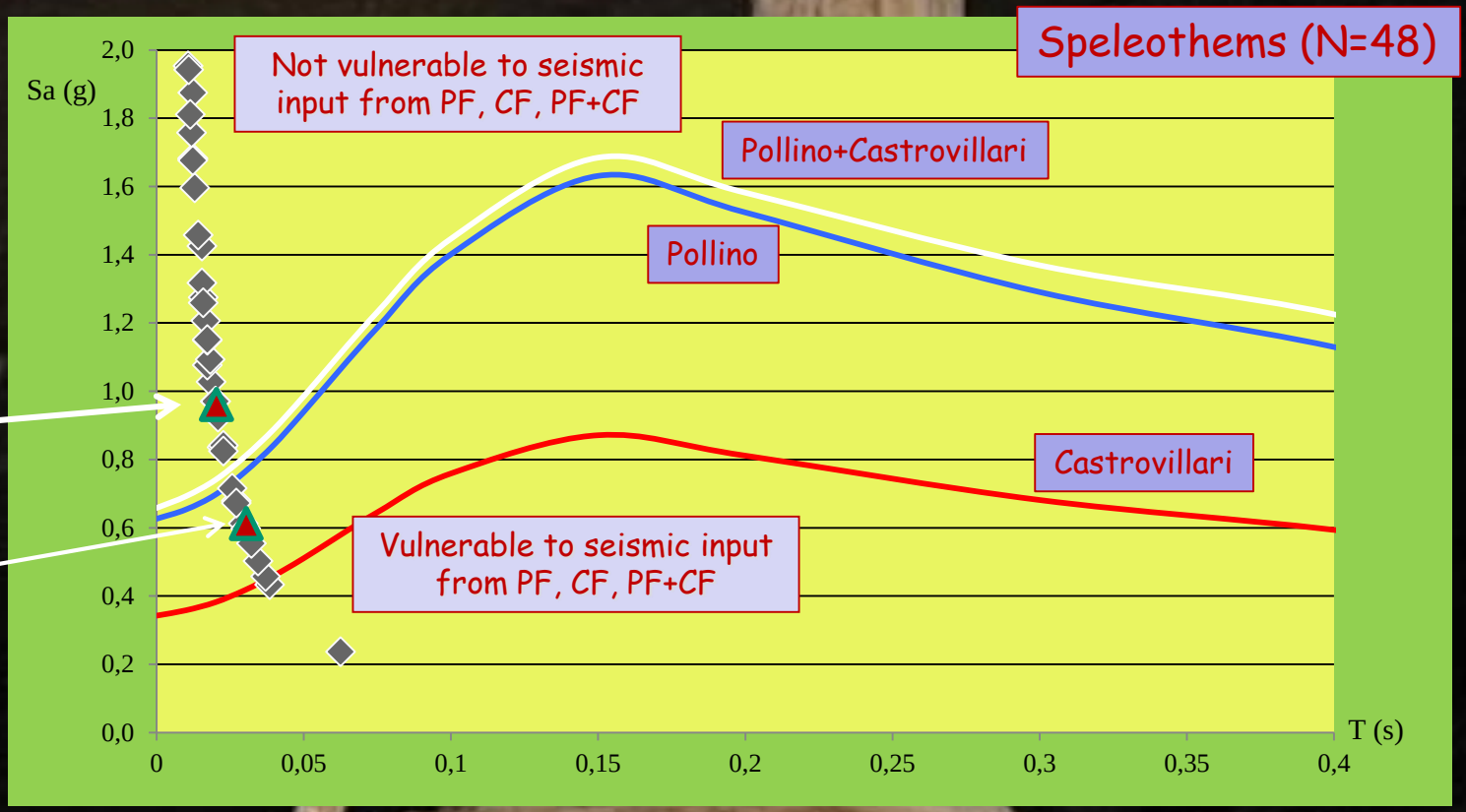
S.Paolo-Ramo Fiume (HW cave) – event constraints



Two fall events in the last **~20 ka** (23-13 and 7 ka). Importantly, no breaking evidence since ~ 7 ka

Pollino – FEM modelling results

San Paolo – Ramo del fiume Cave (HANGING-WALL)



Unbroken stalactite SP1 (0.7-0 ka)

Unbroken stalactite SP3 (2.3-0 ka)

- Few speleothems are vulnerable to seismic input from CF. More of them are vulnerable from PF & PF-CF
- Slender (and vulnerable) spelethems are unbroken since ~ 2.3 ka

Conclusions

•First semi-quantitative & integrate speleoseismological analysis in the Apennines for detecting seismogenic sources amd size of past events;

• Capability of the FEM numerical modelling for calculation of acceleration tresholds;

• Liri valley: paleoevents at ~6-4 ka and ≤1.8 ka, consistent with independent finding on the Magnola fault; link with Fucino faults and even activity of Liri fault cannot be excluded;

• Pollino: four fall events in the last ~30 ka, possibly originated on the Pollino, Castrovillari or (more likely) Pollino+Castrovillari faults.

• However, slender (vulnerable) stalactites at Morano cave are not deformed, suggesting no strong earthquake has occurred on these faults probably in the last ~7 ka and more likely in the last 2.3 ka

Thanks!