Paleoseismology, methods and examples

Paleoseismology

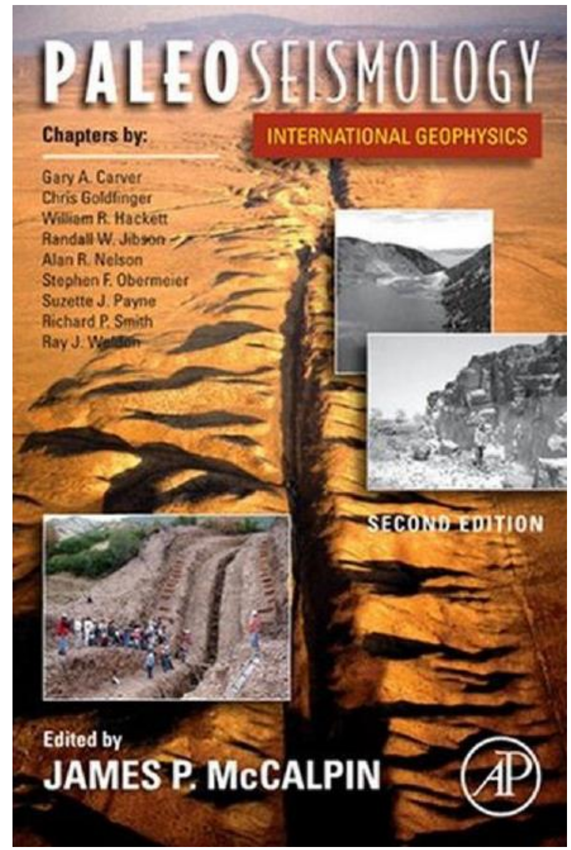
- behaving of seismogenic fault in geological history

Paleoseismology studies **<u>prehistoric</u>** earthquakes from geological record

Seismologists - data measured instrumentally during earthquakes

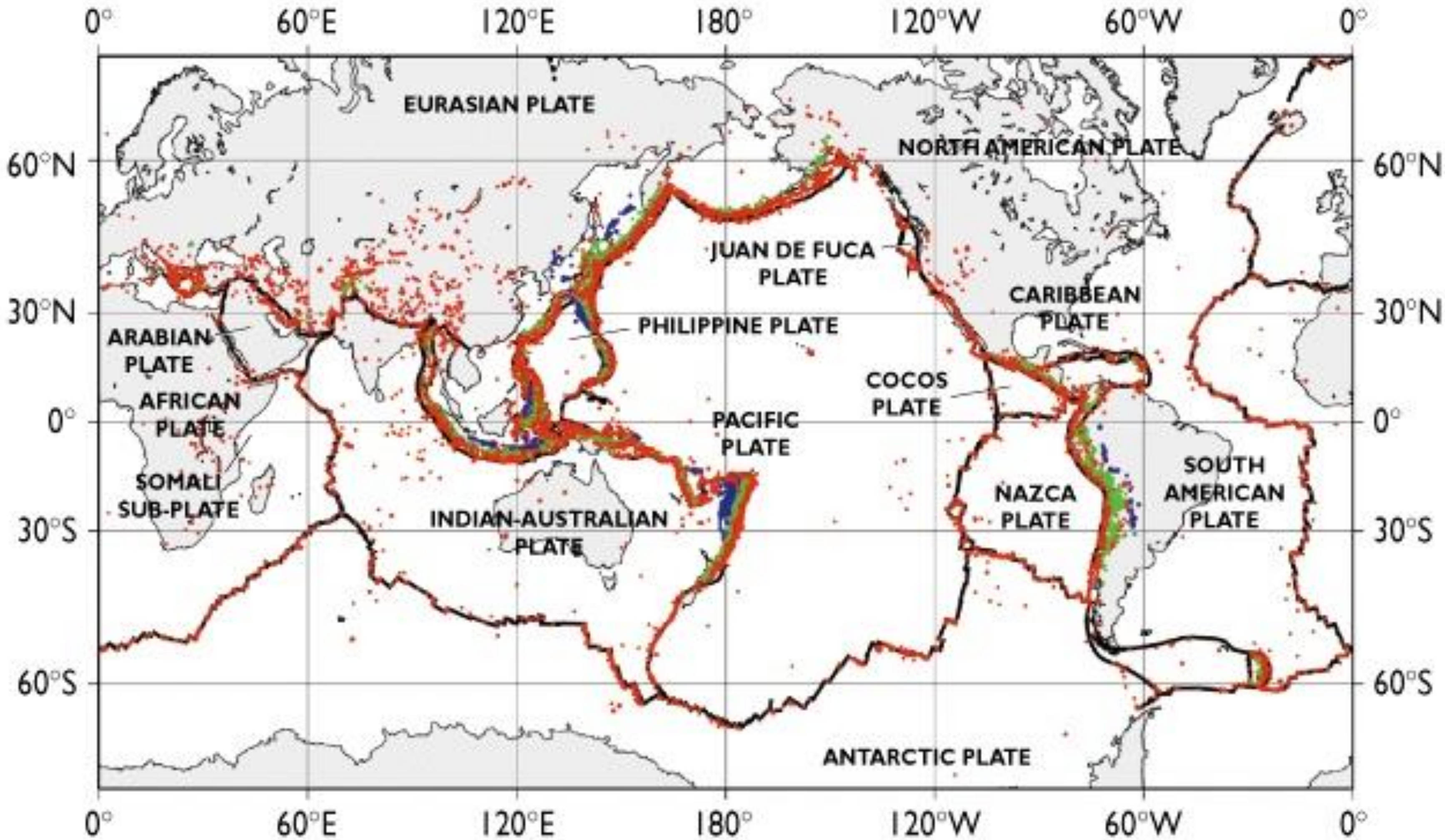
X

Paleoseismologists interpret **geological phenomena** accompanied by individual EQs



McCALPIN, J. (2009). *Paleoseismology.* San Diego: Academic Press.

Why?



Present day seismicity – plate boundaries, intraplate regions
Catastrophic EQs – sometimes in areas with faults with no present day seismicity, - seismic cycle – longer reccurence interval (China, New Zealand)

Most areas – record of historical EQs only several hundred yrs (historical and instrumental seismicity)

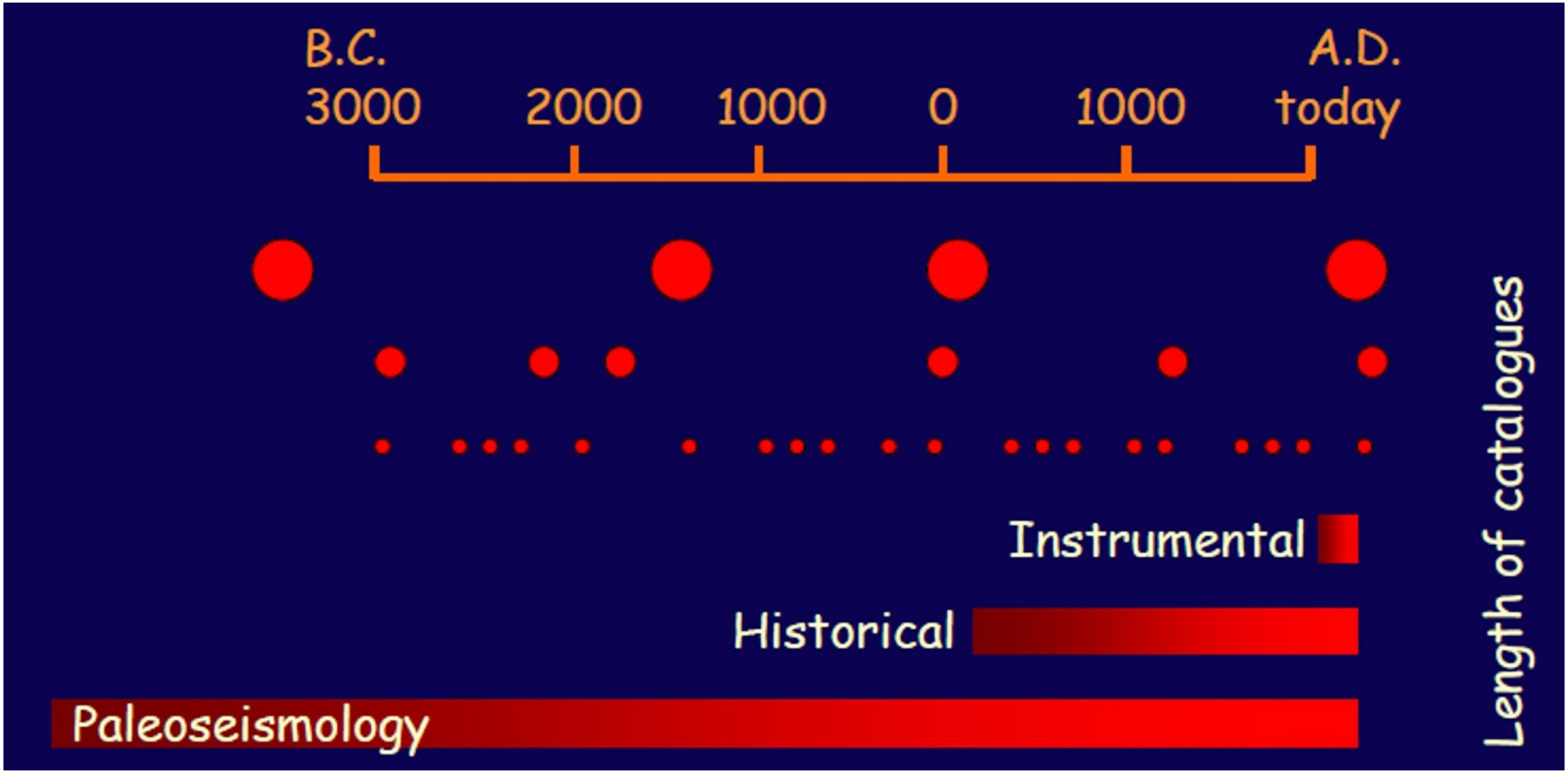
X some active faults expressed in morphology and geology – no historical seismicity or large EQs

China and Middle-East – record thousands yrs and more, still not long enough; fault active millions yrs – 3,000 yrs – only little part of faulting history

Seismic hazard assessment – based on very short period of record of historical EQs, it may cause 2 problems:

❖ overestimation of probability of future EQs based on historical large EQs, but with long recurrence interval (seismic energy is released)

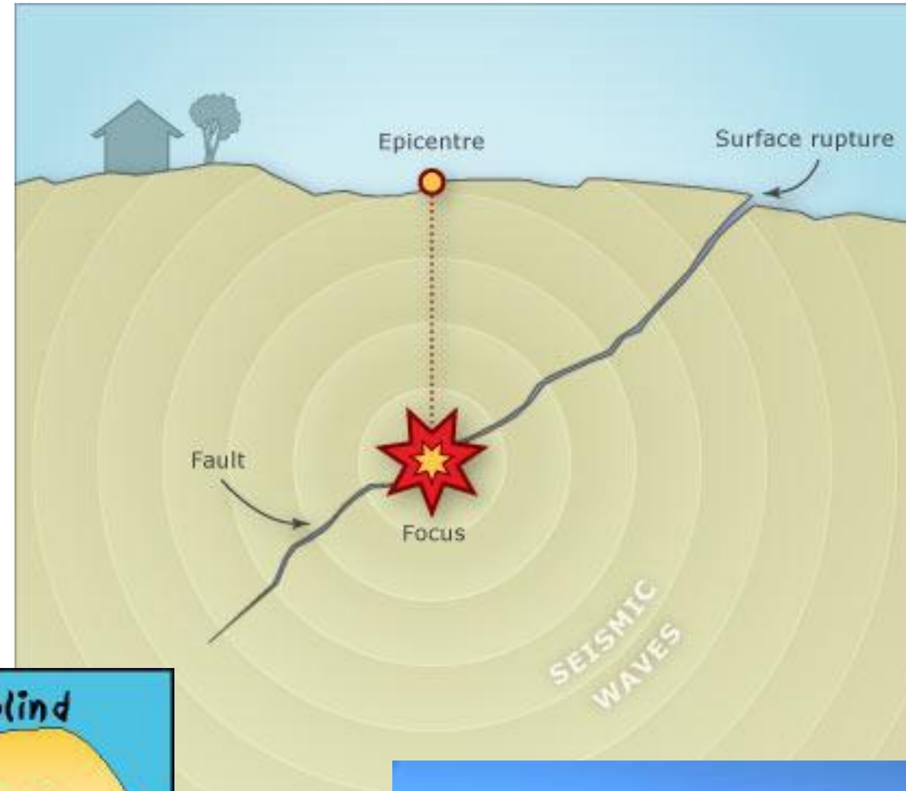
❖ underestimation – in areas with seismogenic faults but no historical record (strain accumulation)

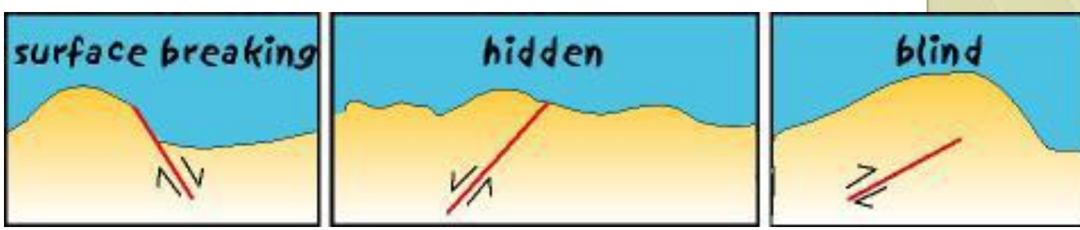


Paleoseismology extends record of EQs into the geological past

Earthquakes catalogues too short

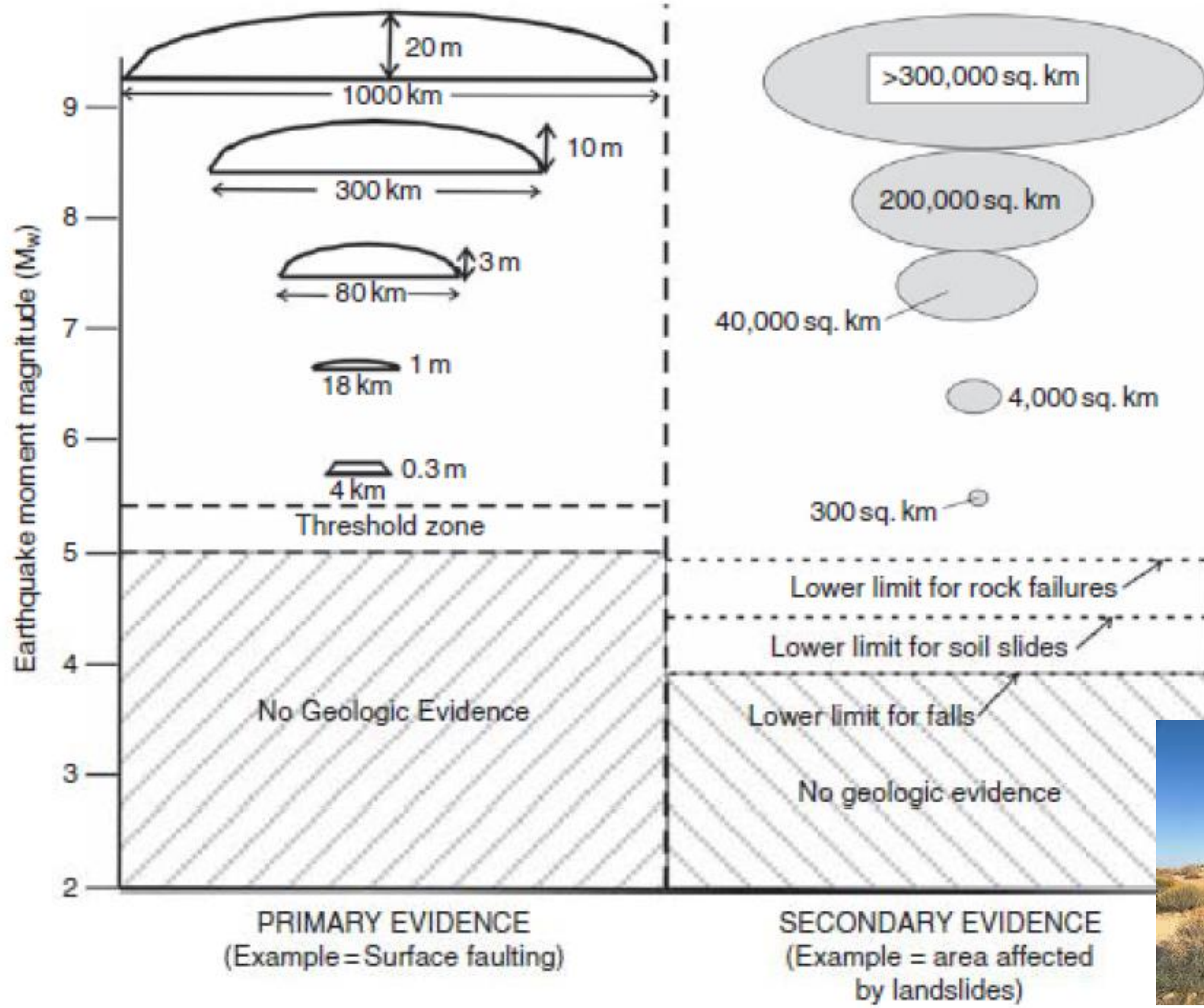
Premise – EQ only larger M > 6 can create permanent deformation on the surface → topografic instability → new processes erosion and accumulation → new landforms and sturctures → geological record of EQ





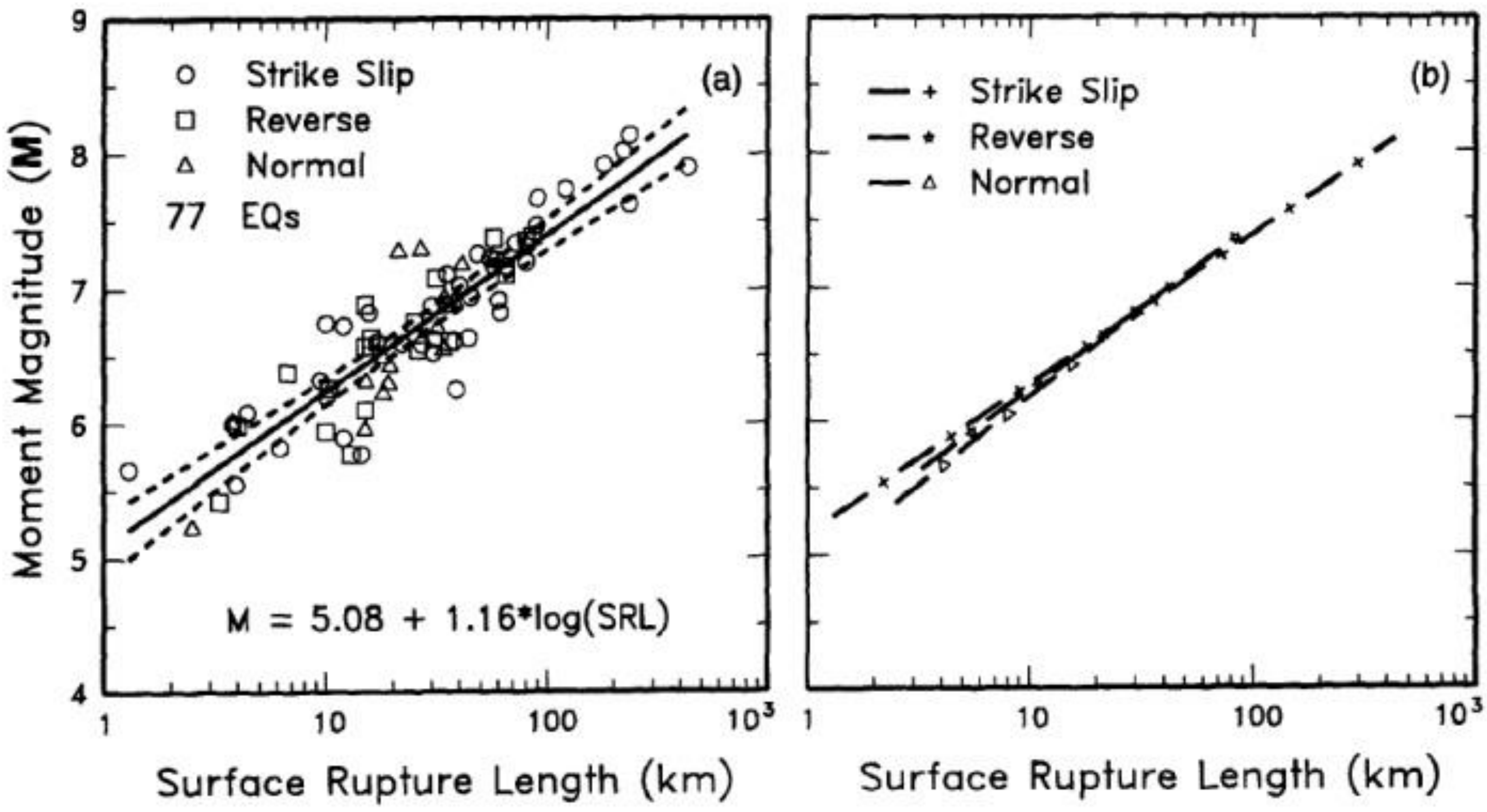
Smaller EQ - rarely geological expression created or survives
Fault type – normal faults M ≥ 6.3; strike-slips – California i – M = 6.25-6.5,
Depth of seismogenic crust – deeper needs higher magnitude

Loma Prieta 1989 M=6.9, 2m slip in depth 3-18km, no surface rupture
Gujarat 2001 M=7.7, blind fault, 1-4m in depth 9-15km,



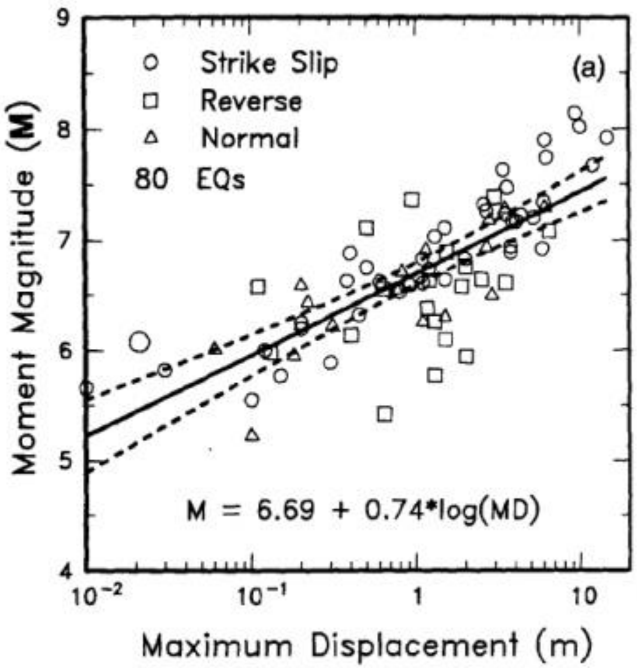
Empirical relationships based on observation from historical EQs

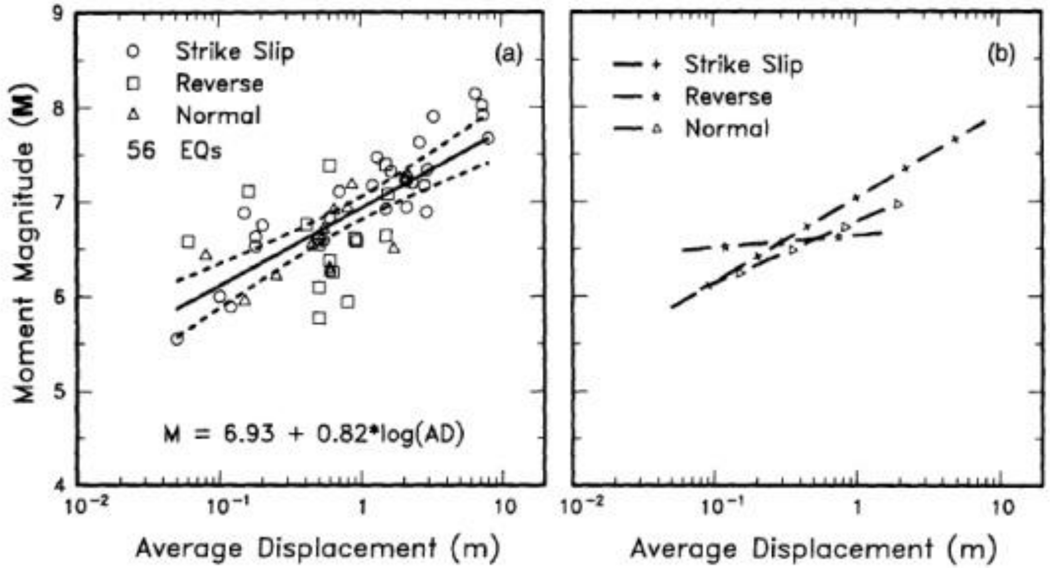
Relationships: fault length, amount of displacements, size of Magnitude
e.g. fault 80km long can generate EQ Mw=7.5 and displacement 3m



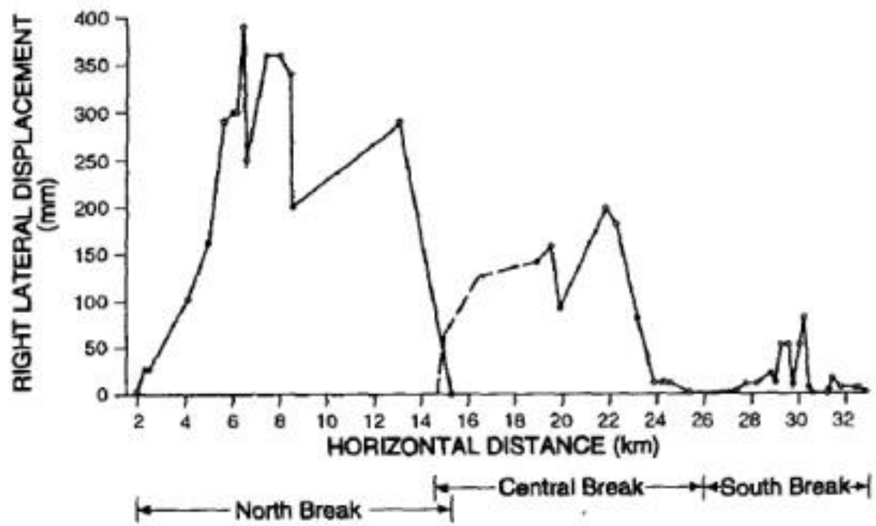
Empirical relationships – historical EQs (421), focis depth <40km, Mw > 4.5

Wells, and Coppersmith 1992



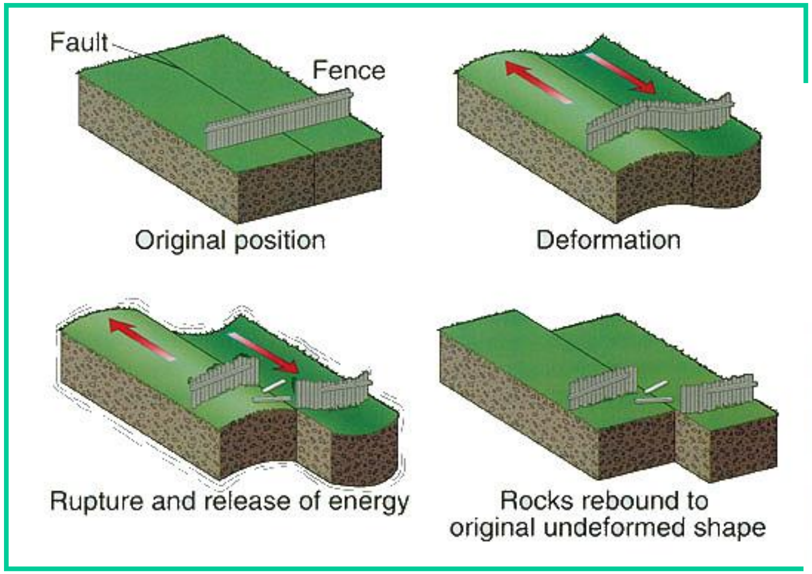


Average of multiple displacement measurements along the fault



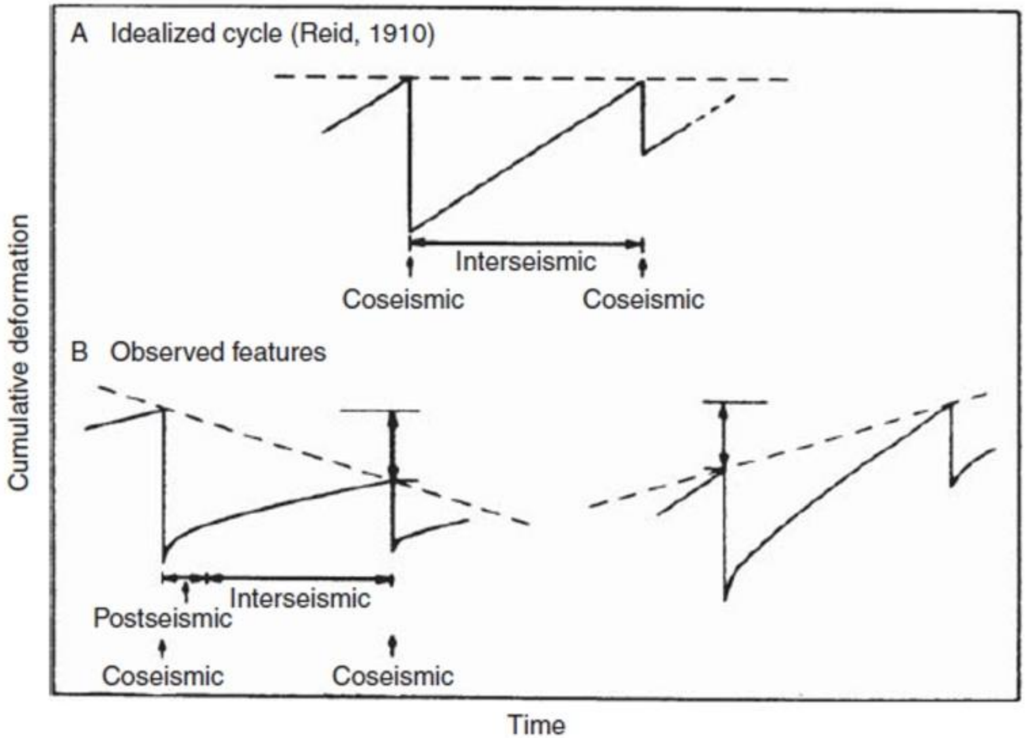
9. 4. 1968, Borego Mts, CA

Seismic cycle – elastic model



Idealized cycle -

characteristic earthquake



Earthquake deformation cycle

Paleoseismological study of faults

- Localisation and geometry (geomorphology, geological mapping)
- Slip rate – faulting velocity (= displacement/time)
- Slip per event – characteristic displacement during individual EQs
- Recurrence period – (repeated EQ, frequency EQ)
- Elapsed time – time from the last EQ
- Maximum potential magnitude

Chronological reconstruction of movements

- stratigraphic, structural, geomorphological, biological, archeological evidence
- dating of displaced features or movement indicators

- dating of multiple movements (EQs) - recurrence interval, long-term slip-rate, vaiability of movements during EQs

➡ predict localisation and magnitude of future EQs

Methods

– direct observations of dislocated objects – on the surface or in **trenches**, outcrops

- young sediments, fine grained, stratified - well recognizable displacemnt of layers, not thick

  Alluvial fans, lake sediments X debris flow

- datable material– chronology of movements

Evidence of earthquakes (EQ) in geological profiles in a trench

A) Difference in cumulative offset

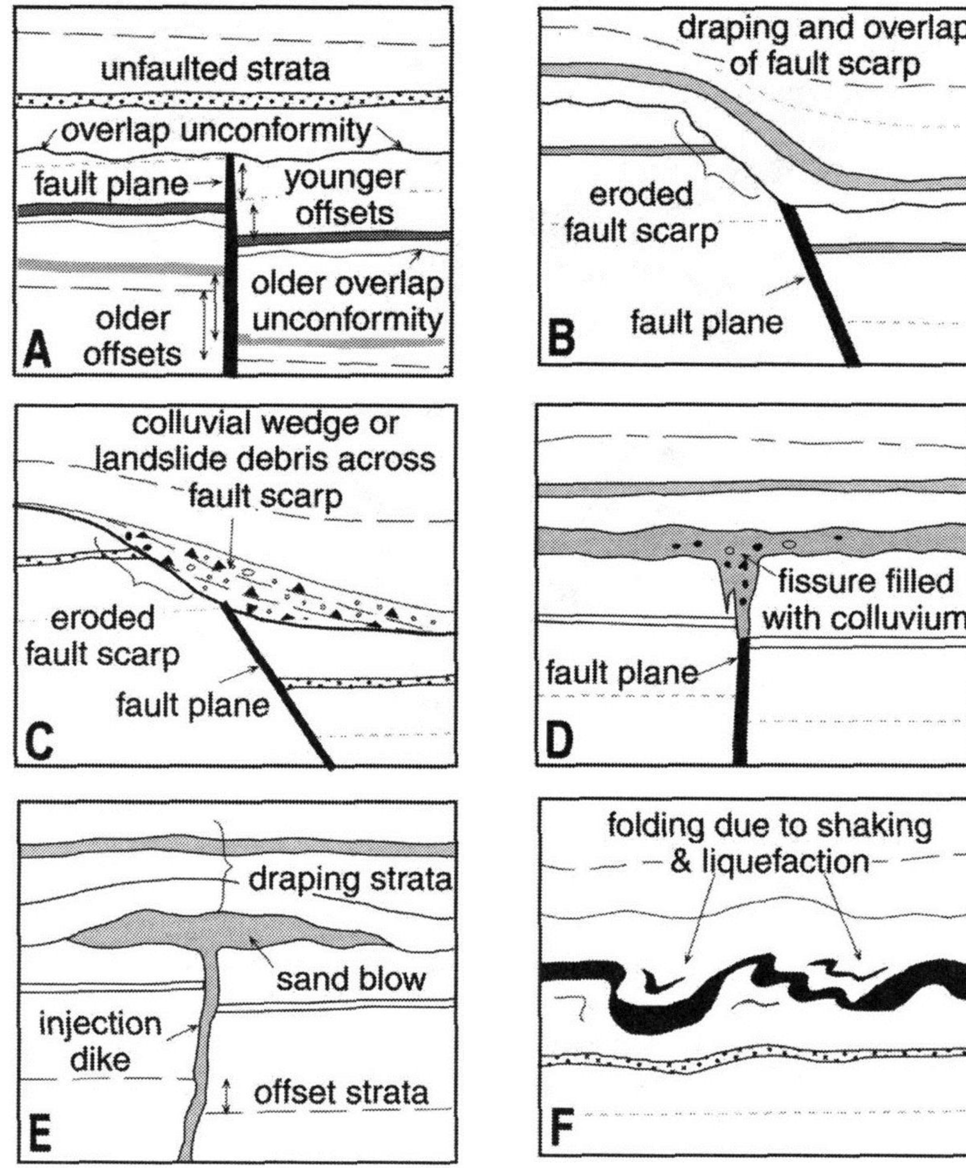
B) Buried fault scarp

C) Coluvial wedge- typical for sudden movement

D) Filled fissures by overlying material

E) Sand dykes

F) Liquefied layers



Allen (1986)

Repated EQs

- Difference in cumulative offset

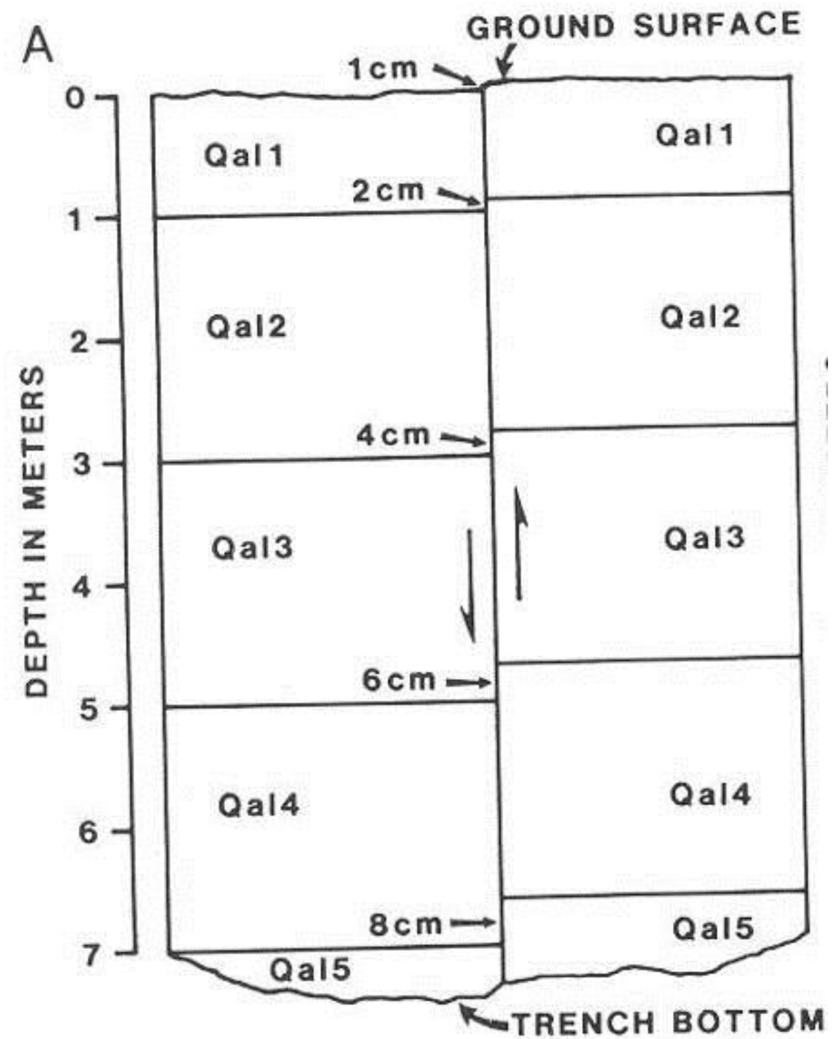
? How many: retrodeformation

4 events – vertical offset 2cm

Oldest layer - (Qal5) all 4 events, cumulative 8cm

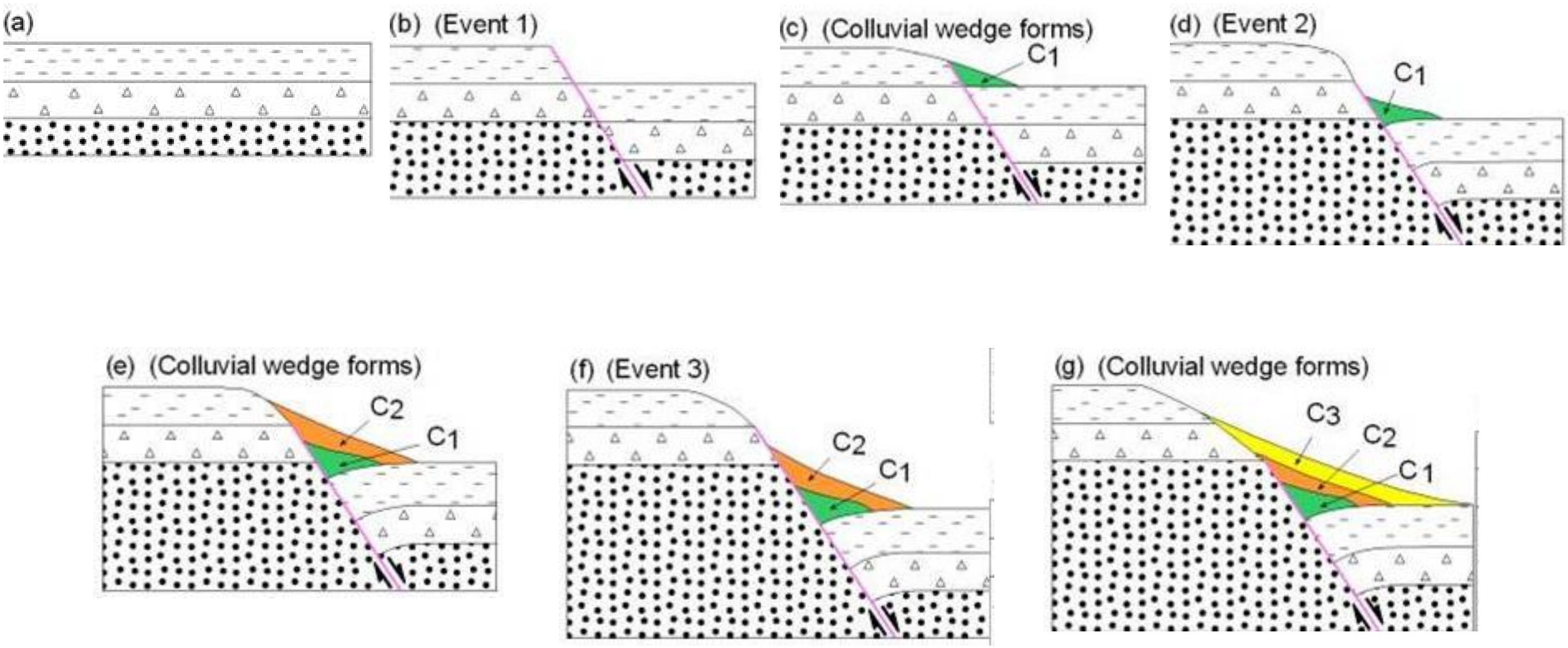
Youngest (Qal1) has experienced only 1 event → 2 cm on the layer base, but 1 cm on the surface!

Surficial erosion



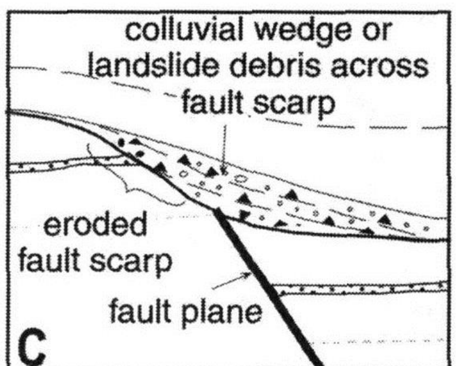
Normal faulting

Colluvial wedge

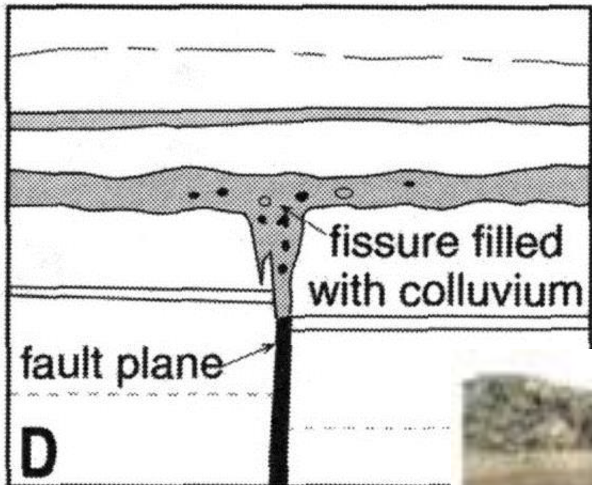


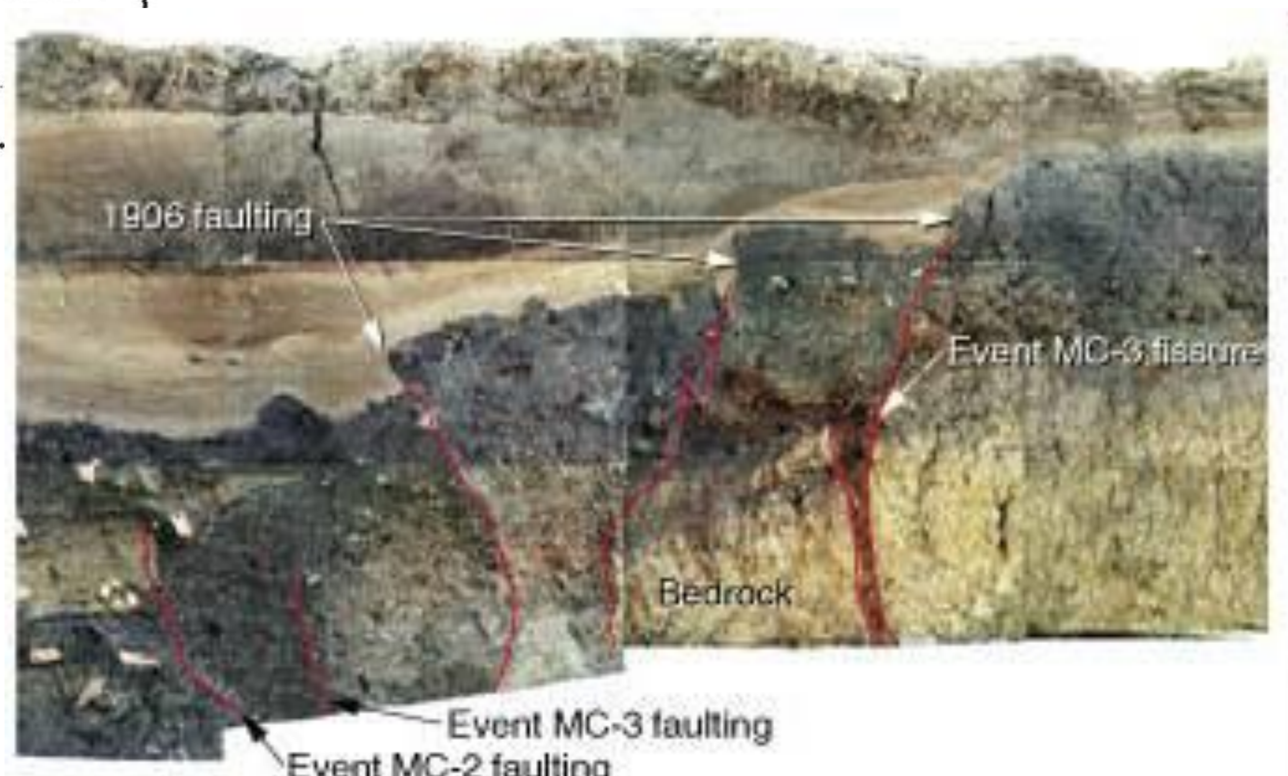
Gravitational instabilty

Fault scarp derived material - wedge



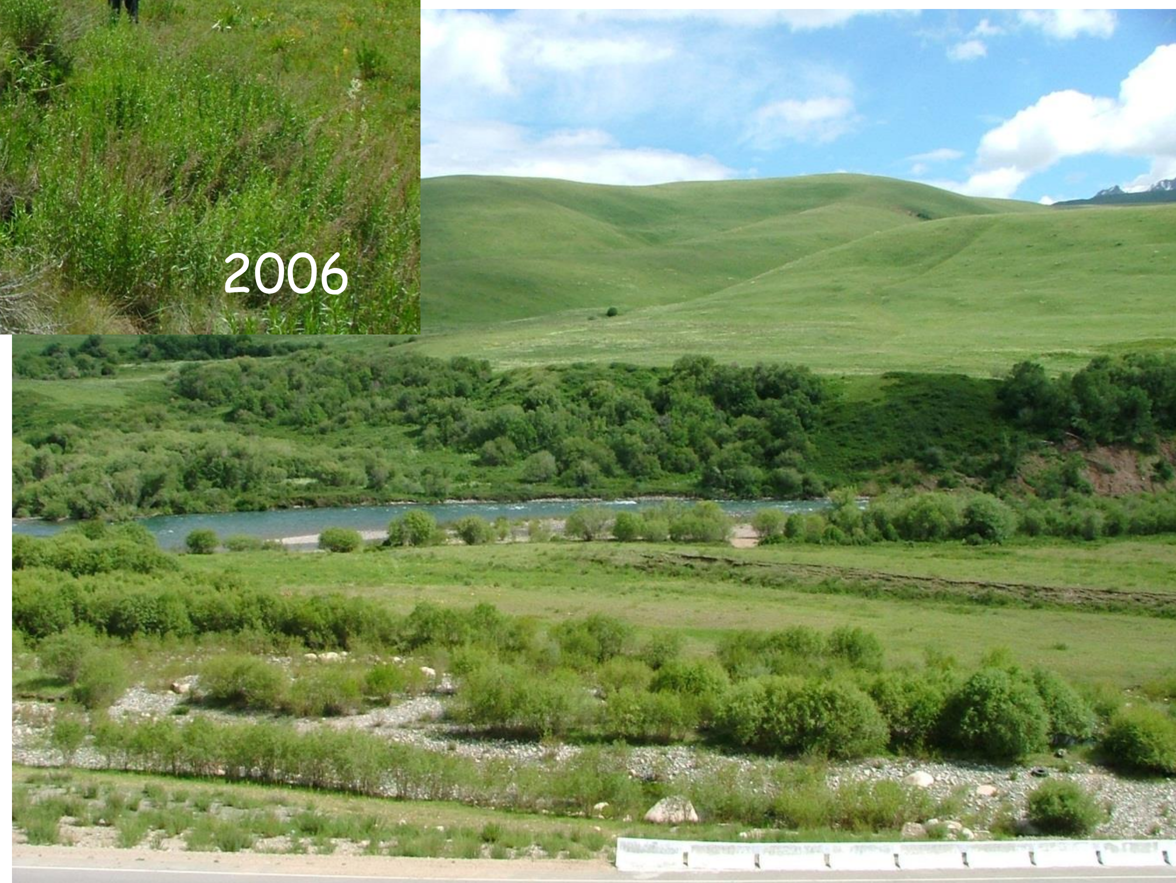
- **Filled fissure**





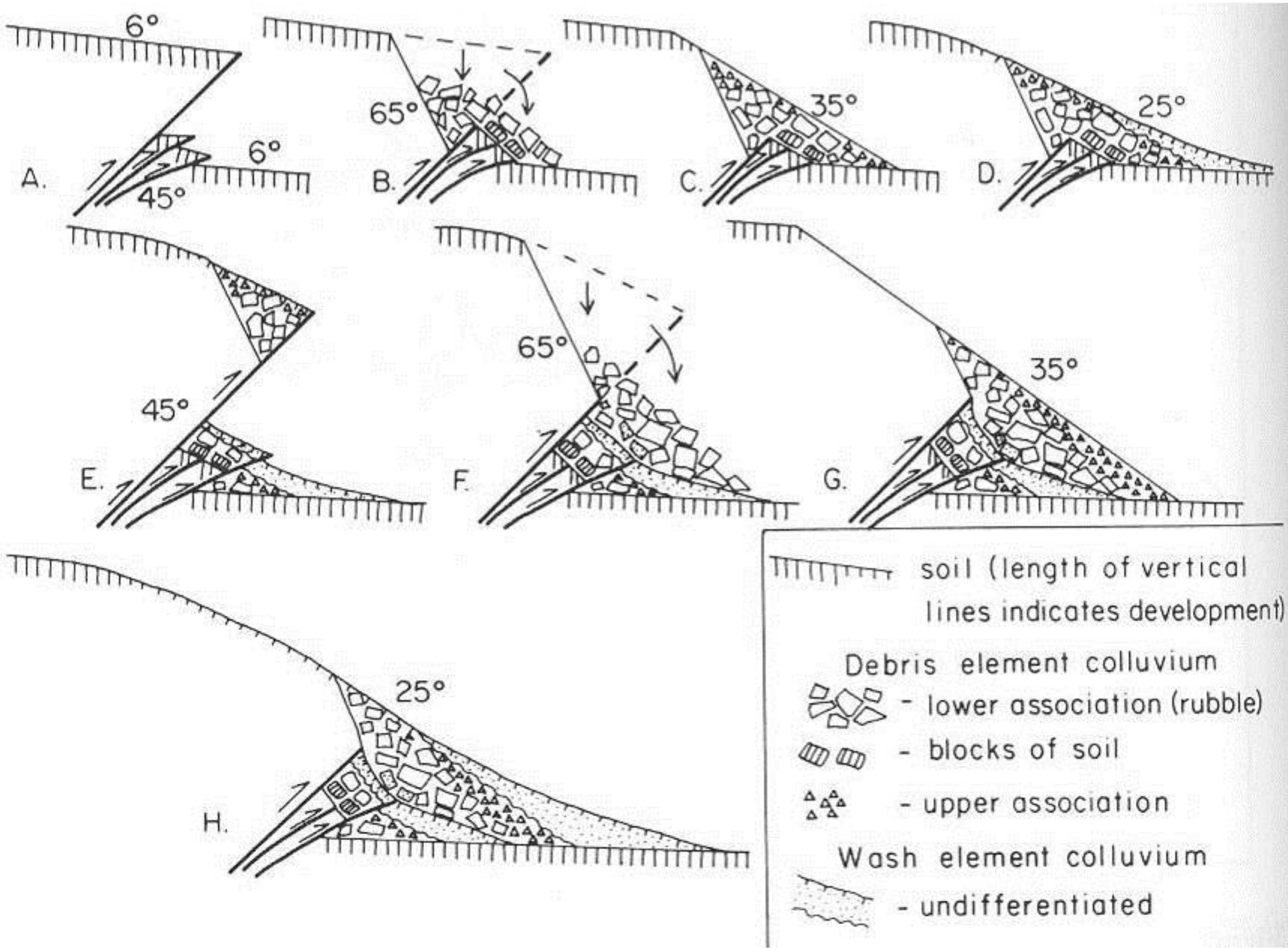
Aremogna-Cinquemiglia fault - Italy

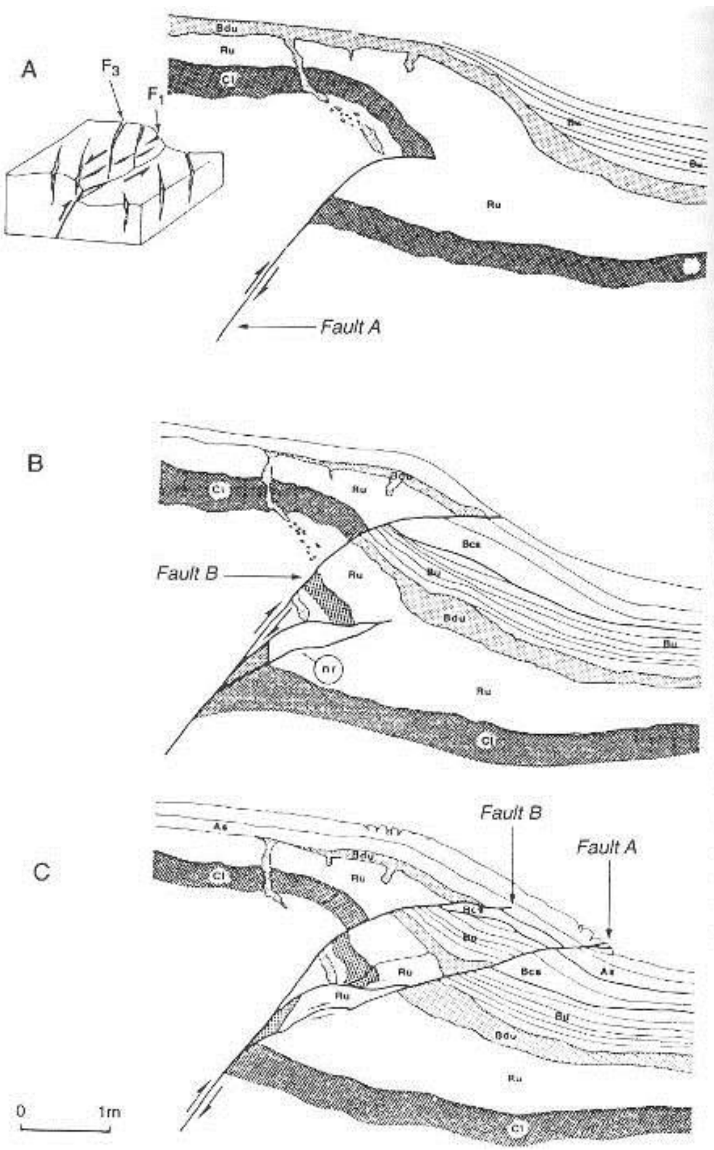
Reverse faulting

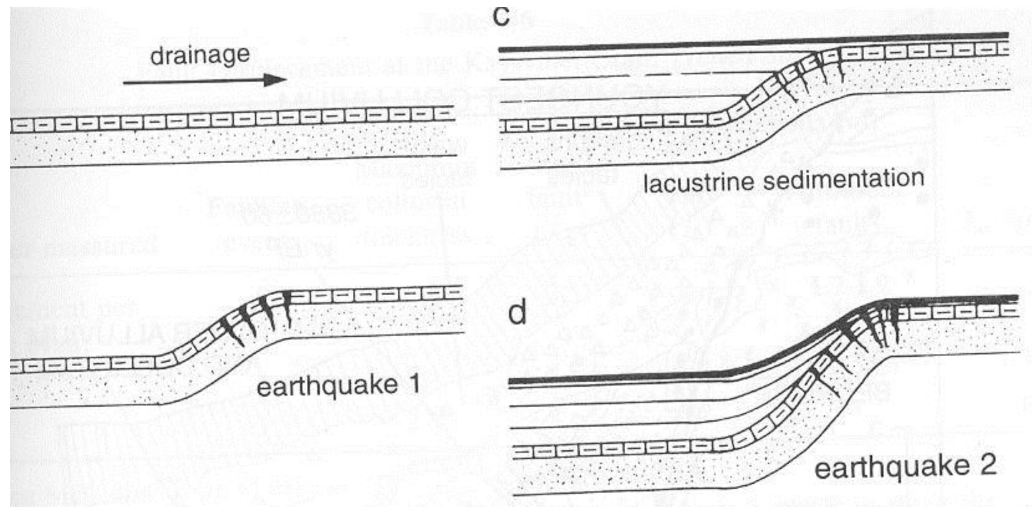


Suusamyr, 1992, M=7,4
Kyrgyzstan

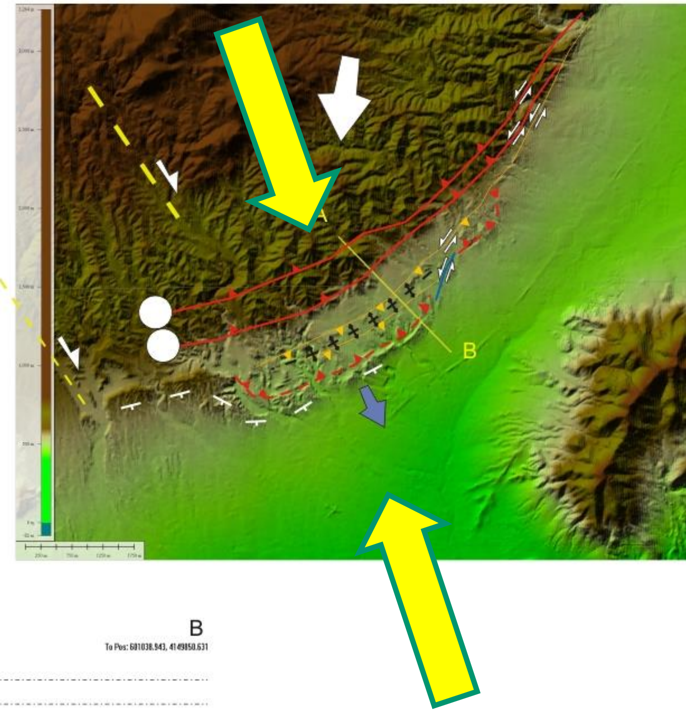
Reverse faults – colluvial wedge

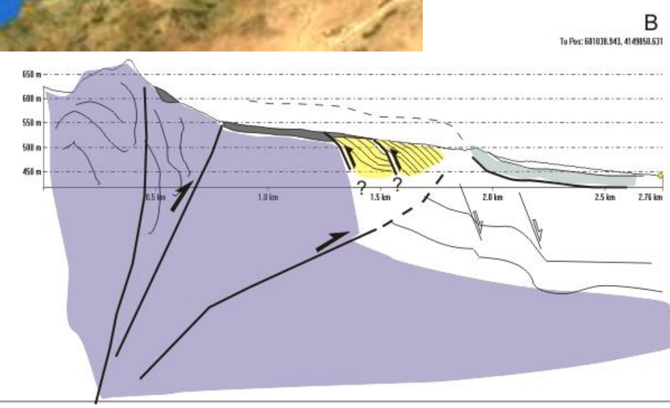



A
F3
F1
Fault A
B
Fault B
C
Fault B
Fault A
0
1m

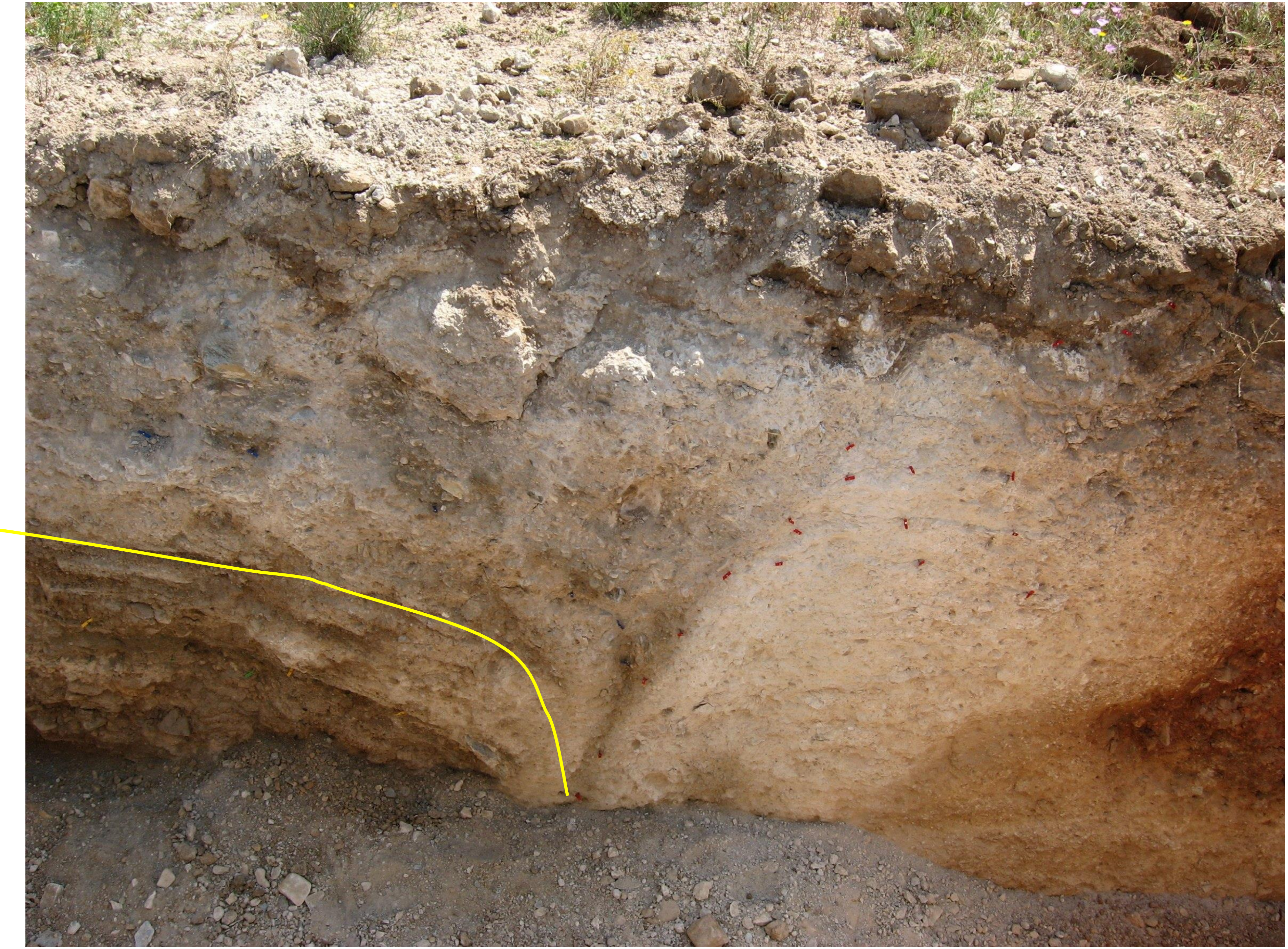

drainage
earthquake 1
c
lacustrine sedimentation
d
earthquake 2

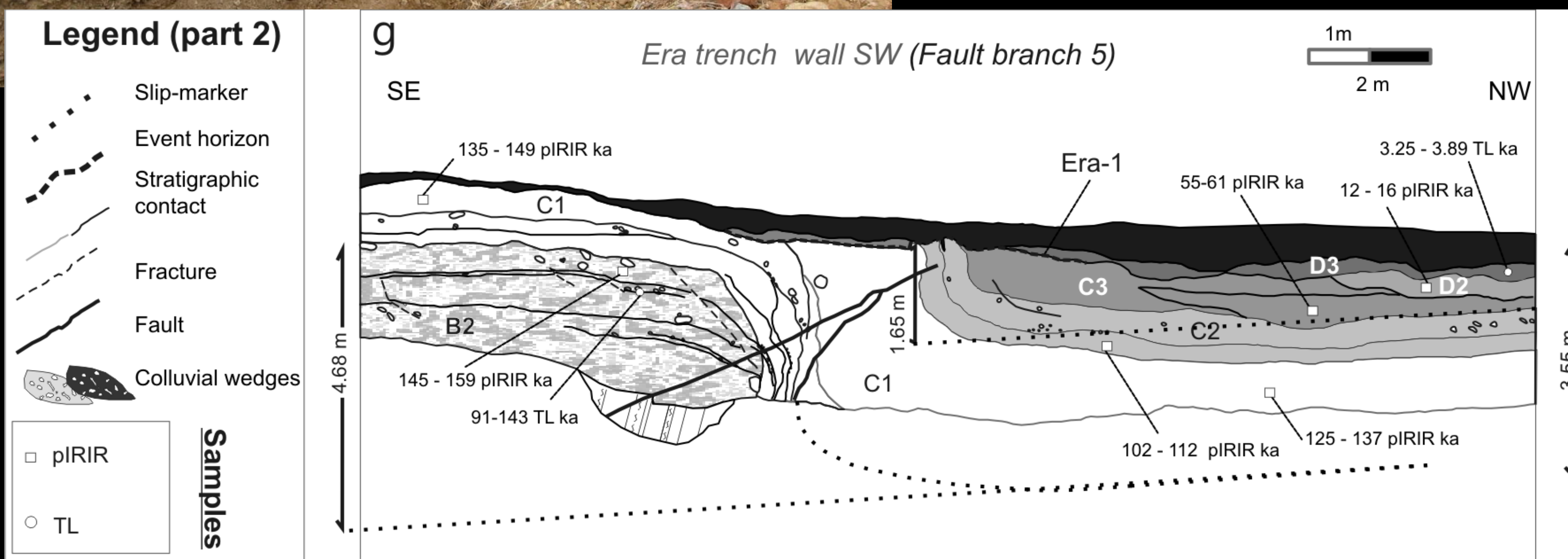
Alhama de Murcía fault (Spain)





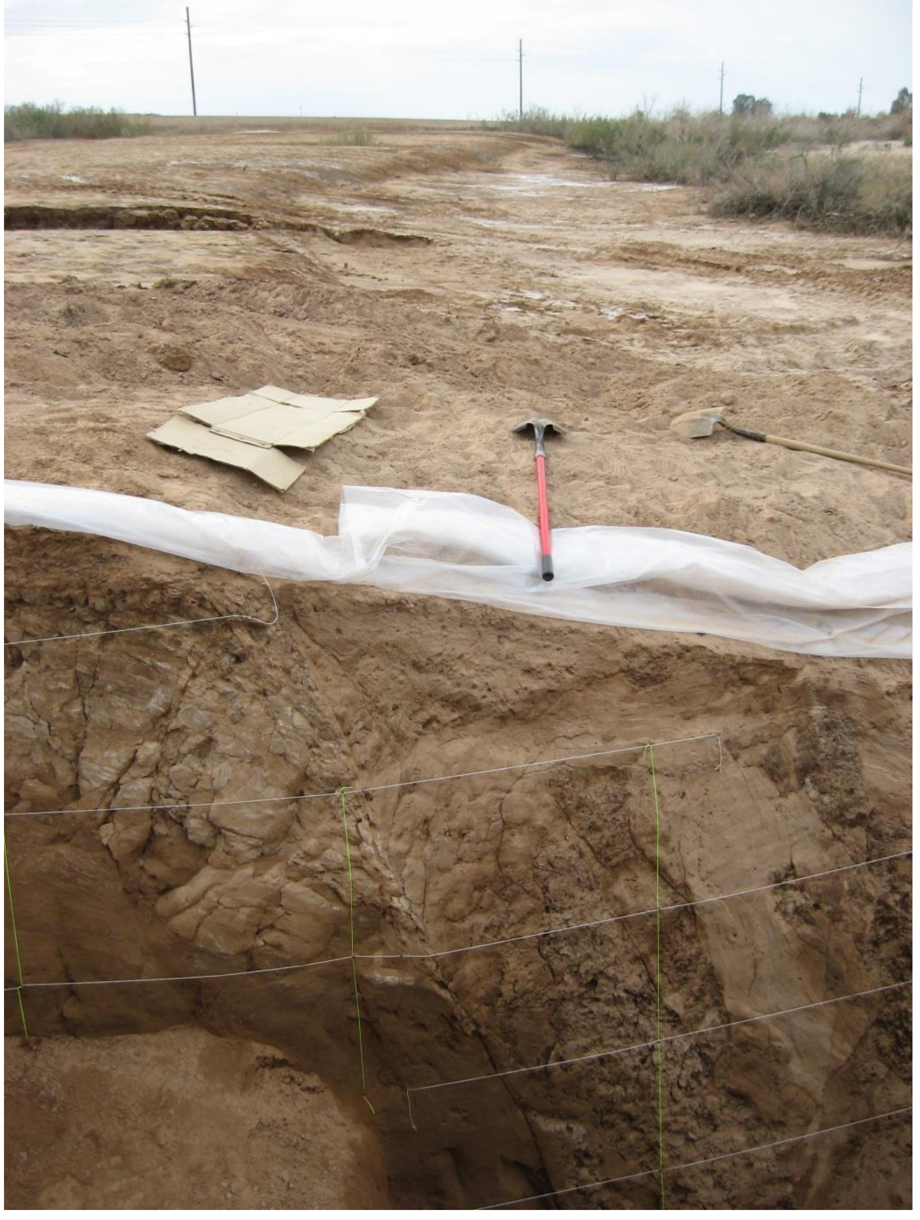
Various kinematics related to different stress diection


Legend (part 2)
Slip-marker
Event horizon
Stratigraphic contact
Fracture
Fault
Colluvial wedges
pIRIR
TL
Samples
g
Era trench wall SW (Fault branch 5)
1m
2 m
SE
NW
135 - 149 pIRIR ka
Era-1
3.25 - 3.89 TL ka
55-61 pIRIR ka
12 - 16 pIRIR ka
C1
D3
C3
D2
B2
C2
1.65 m
4.68 m
C1
145 - 159 pIRIR ka
91-143 TL ka
102 - 112 pIRIR ka
125 - 137 pIRIR ka

Fault scarp and colluvial wedge on strike-slip fault

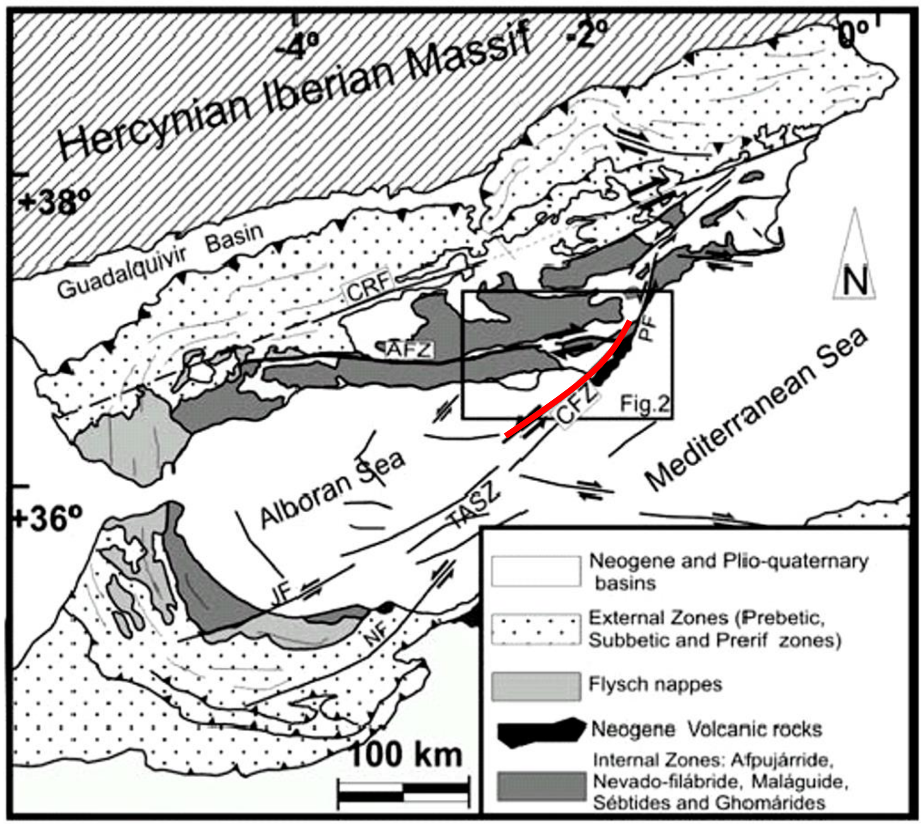
Imperial fault, 1940 M=7.6m offset, 60km




Case study

Carboneras fault zone – Spain

Carboneras

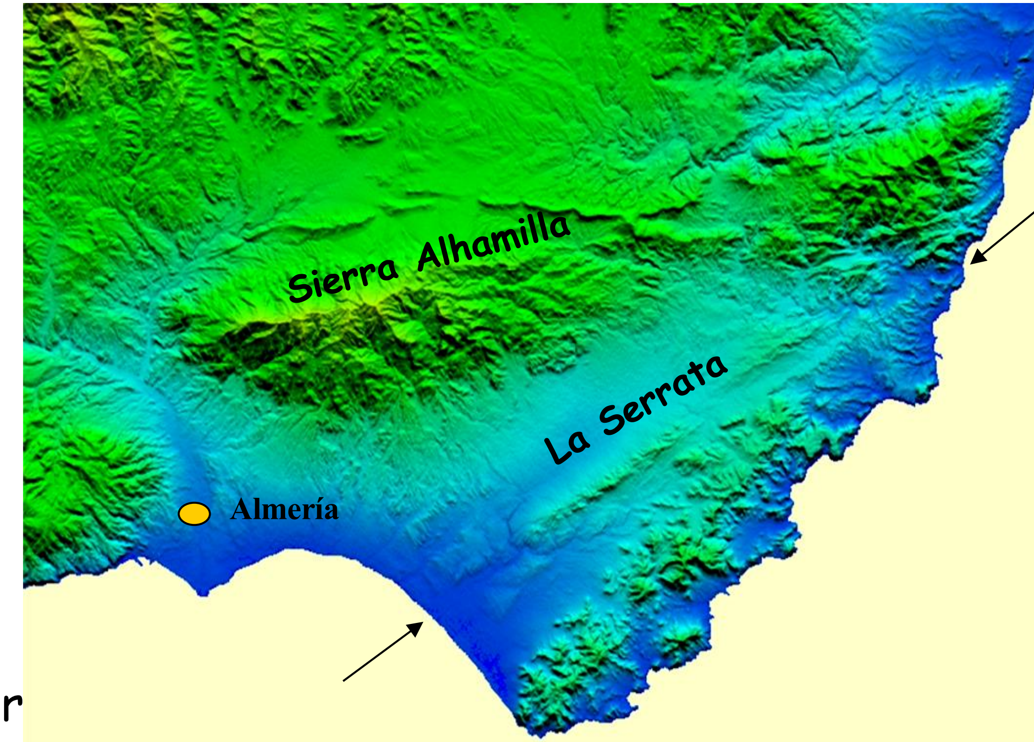


- Collision zone Europe x Africa plate
- Southern margin of Alpine orogen
- Part of Bettic Cordillera

– outer zone (nappe from Mesozoic to Tertiary rocks) paleo-margin of Iberian plate

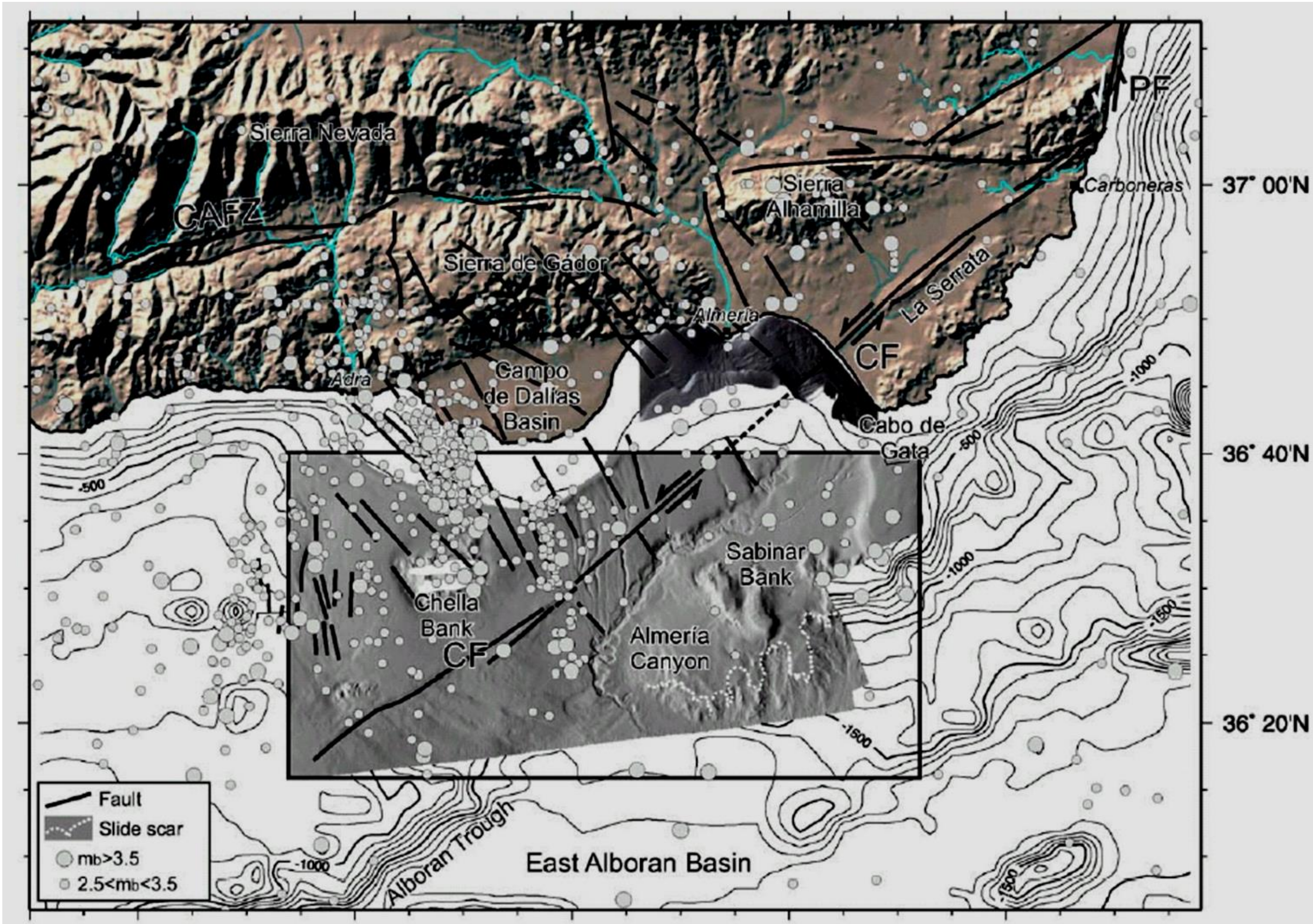
- inner zone– metamorphic complex + Neogene to Quaternary sediments – intramontane basins bounded by faults NE-SW

Masana E. et al.



Carboneras - formed in the last period of collision of inner and outer zone of Betic cordillera in early Miocene

- Miocene to Quaternary – stress field rotation
  - normal faults - mid-Miocene – part of rifting (volcanism)
  - reverse faults – early Pleistocene (formation of small mountains e.g. La Serrata)
  - strike-slips – left-lateral (up to present-day)

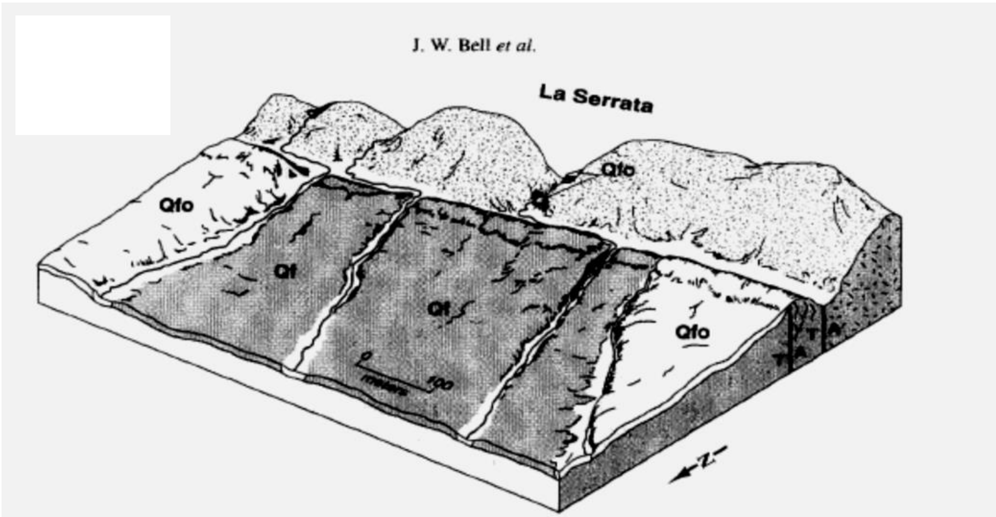


- seismicity – SE margin of Iberian peninsula – permanent shallow earthquakes M < 5,5 (transversal faults now without seismicity – Carboneras)
- last 2.000 years – at least 50 larger earthquakes

Previous studies in 90th

1) Study of evidence of left-lateral movements dated by radiometric dating of marine terraces and their recent uplift

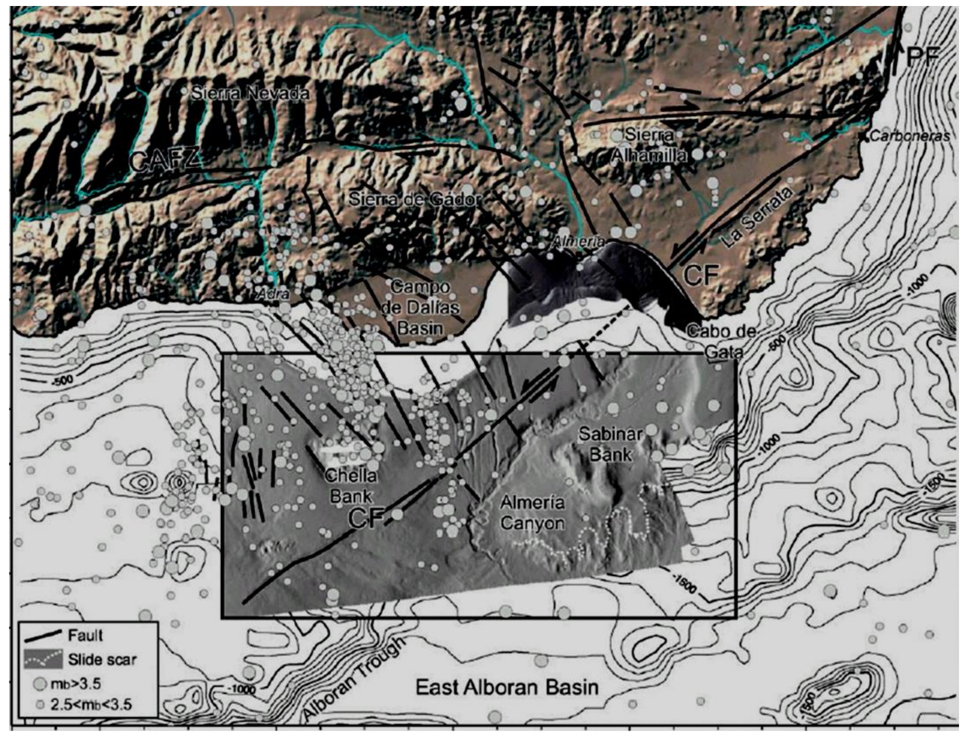
2) Measuring and dating of left-lateral movements based on offset channels

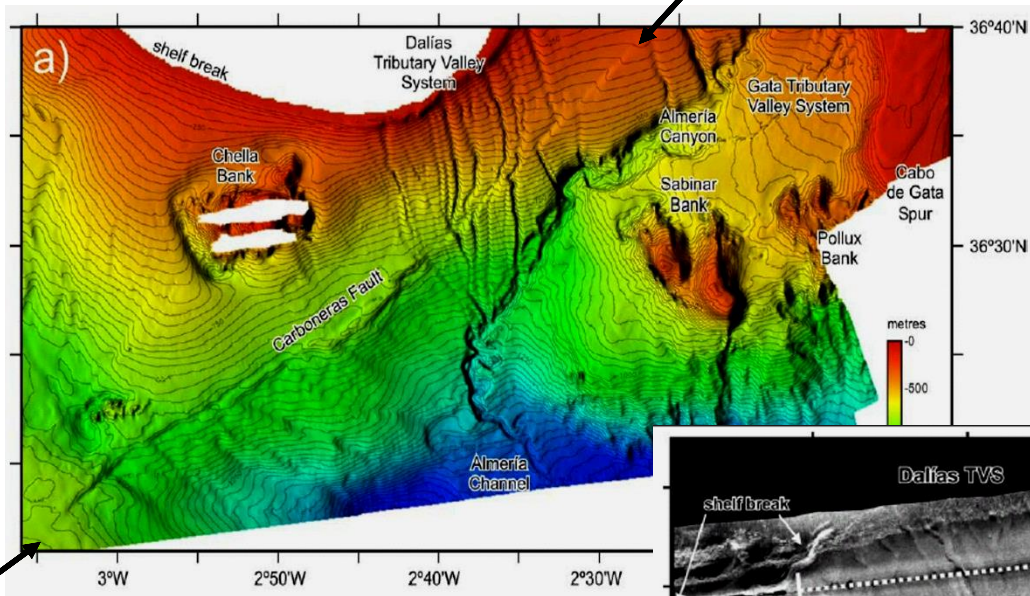


Movements in late Quaternary- relatively slow, **mainly vertical**, horizontal movements of 80-100m offset channels in La Serrata – older than 100.000 years

Methods of study of Carnoboneras fault on the sea

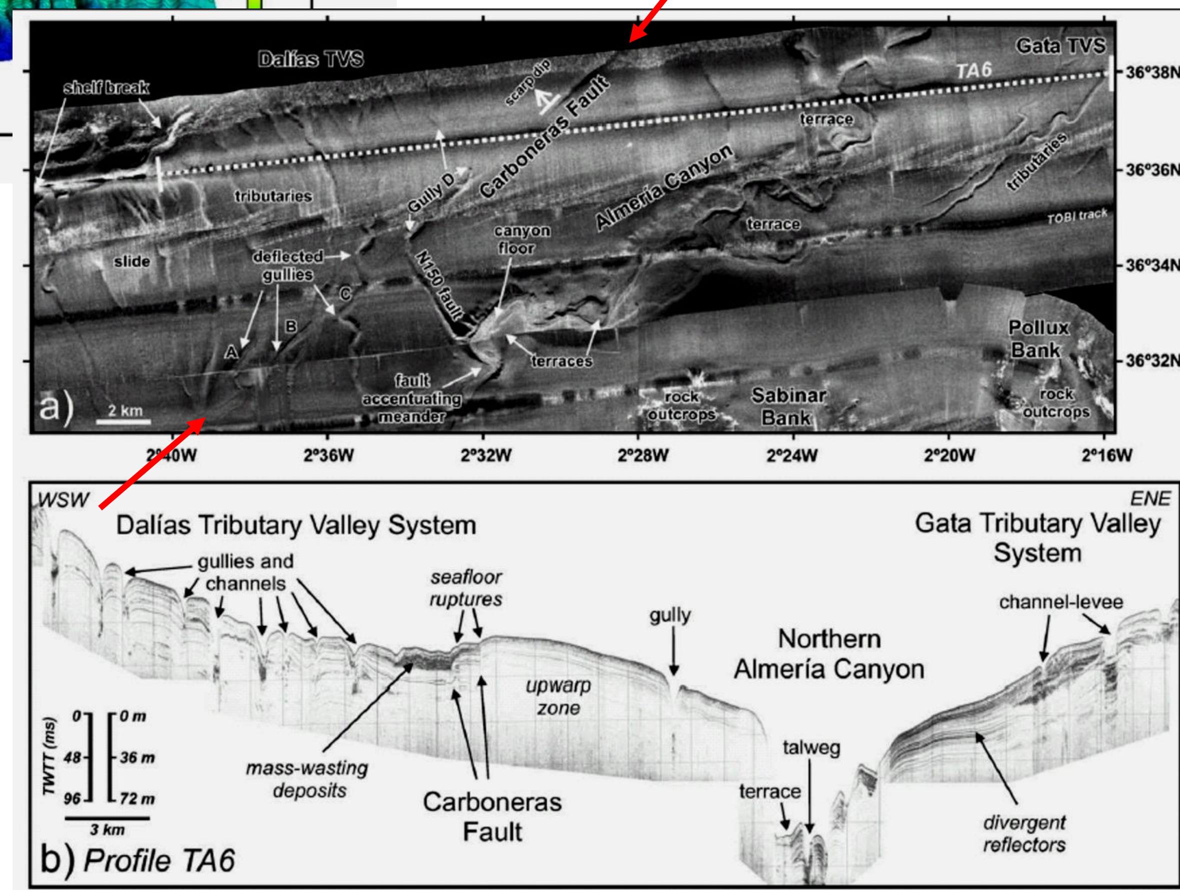
- Bathymetry
- Sidescan sonography
- High resolution seismic reflection
- Marinne sediments samples analysis
- Dating of the sediments



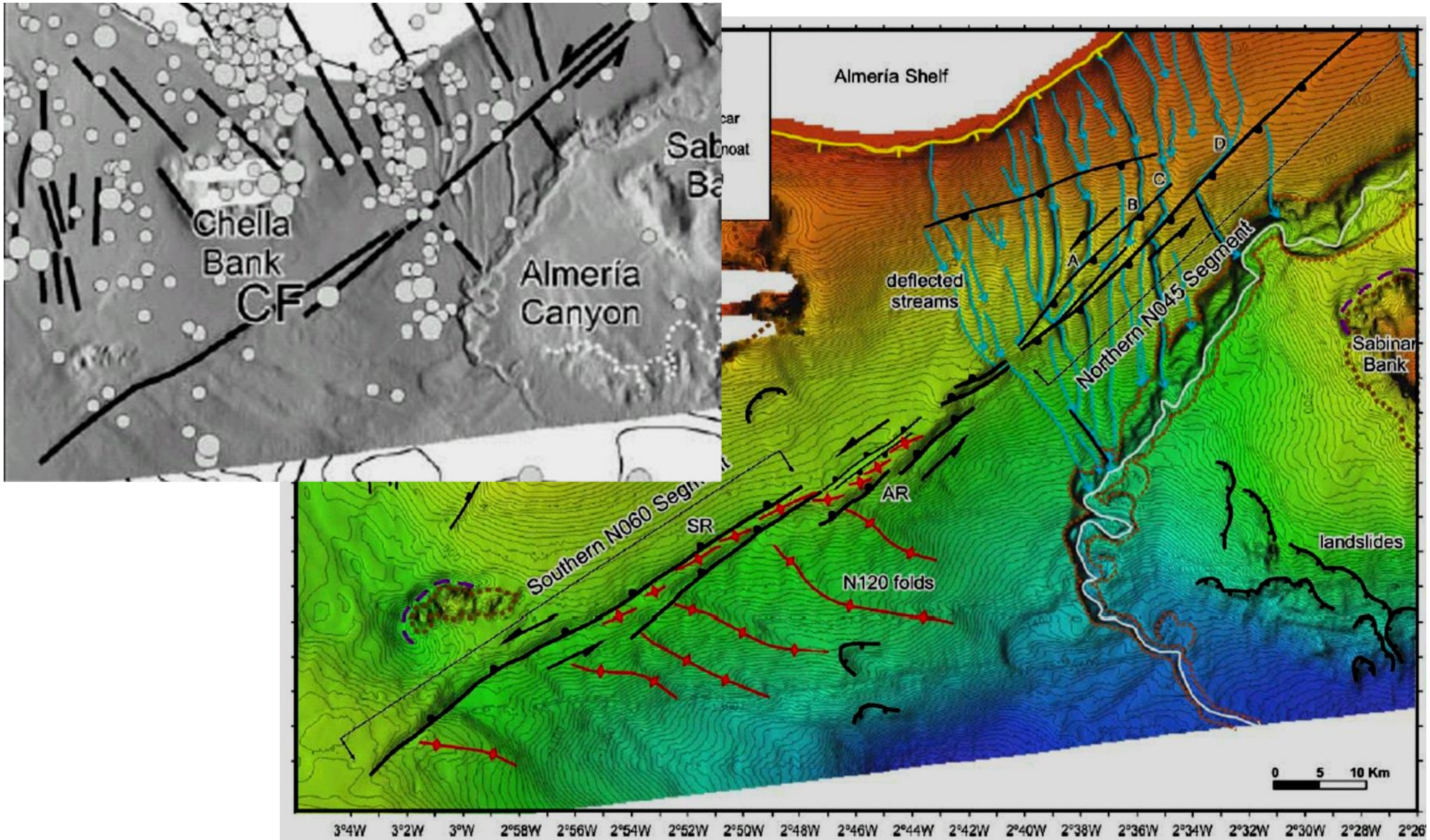


Bathymetry

Sonography - high resolution



Seismic profilling



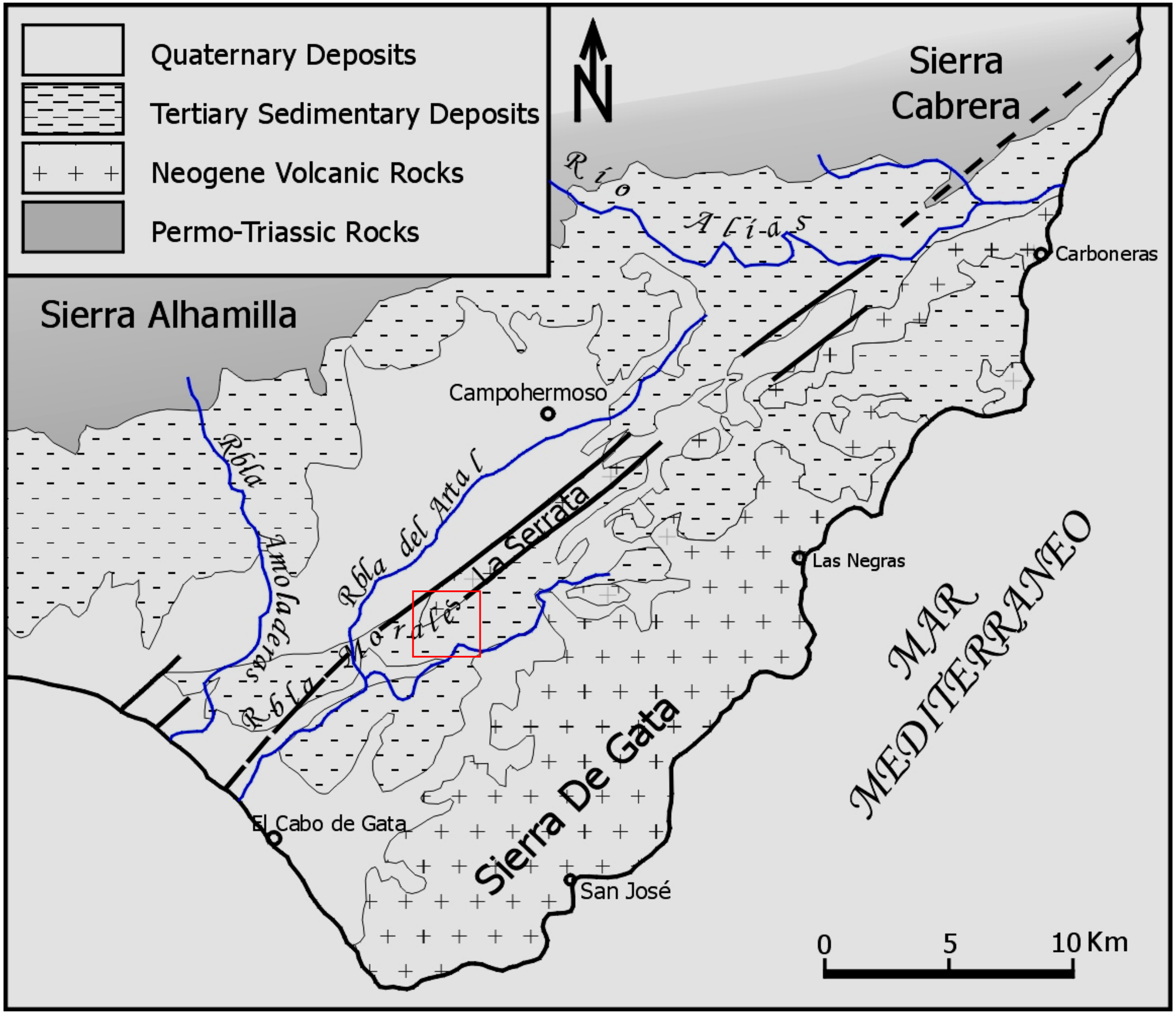
Results: Carboneras fault zone – 5-10 km wide, 100 km long, subvertical faults,

Drainage network on the inland margin – deflected,

Morphology formed by horizontal movements – **pressure ridges, water gaps, late Holocene sediments, landslides.**

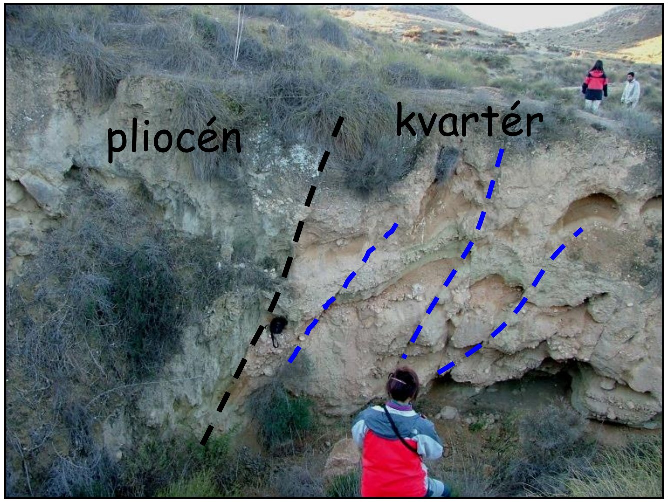
Methods of fault study on the land - offshore

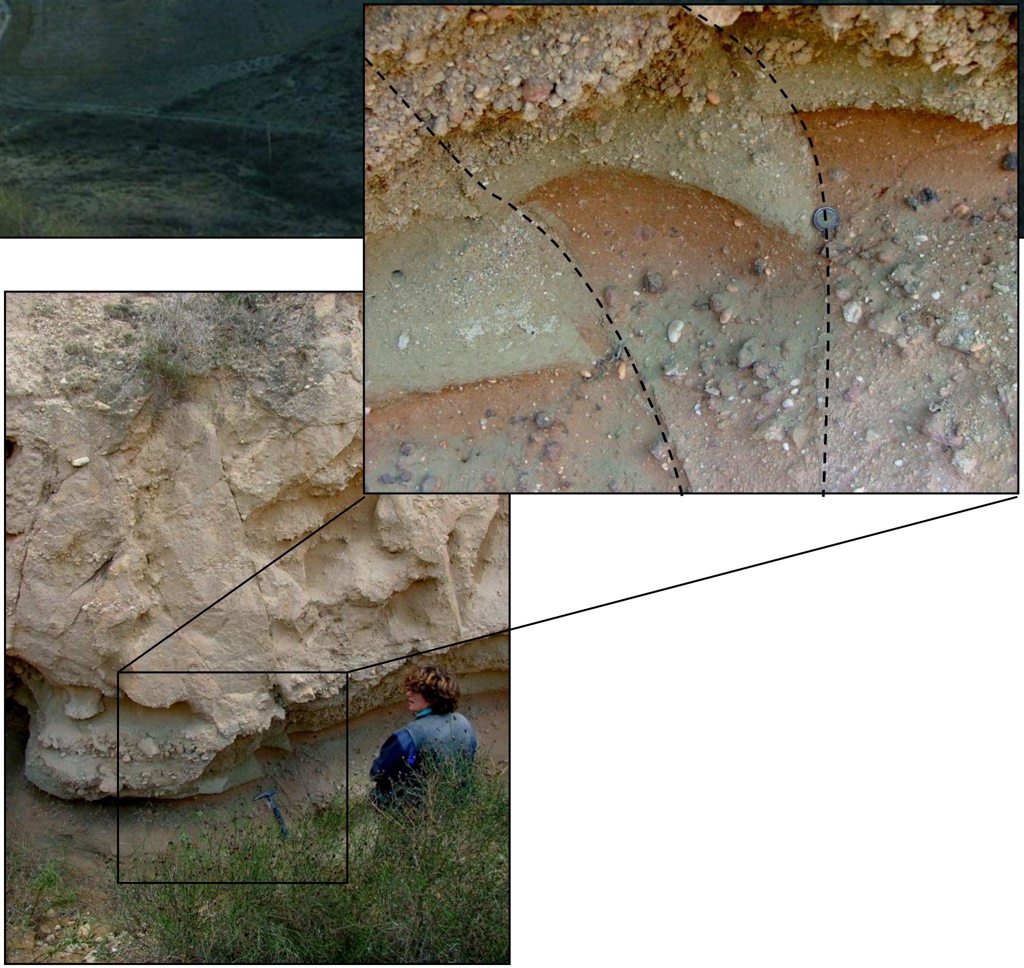
- Photointerpretation – air photos
- Geomorphological mapping of dislocated landforms
- Structural mapping (faults)
- Sedimentology (identification of generations of alluvial fans)
- Microtopography (total station)
- Geophysics (georadar, electrotomography – fault tracing and goundwater level)
- Paleoseismic trenching
- Dating of materials cut by the fault

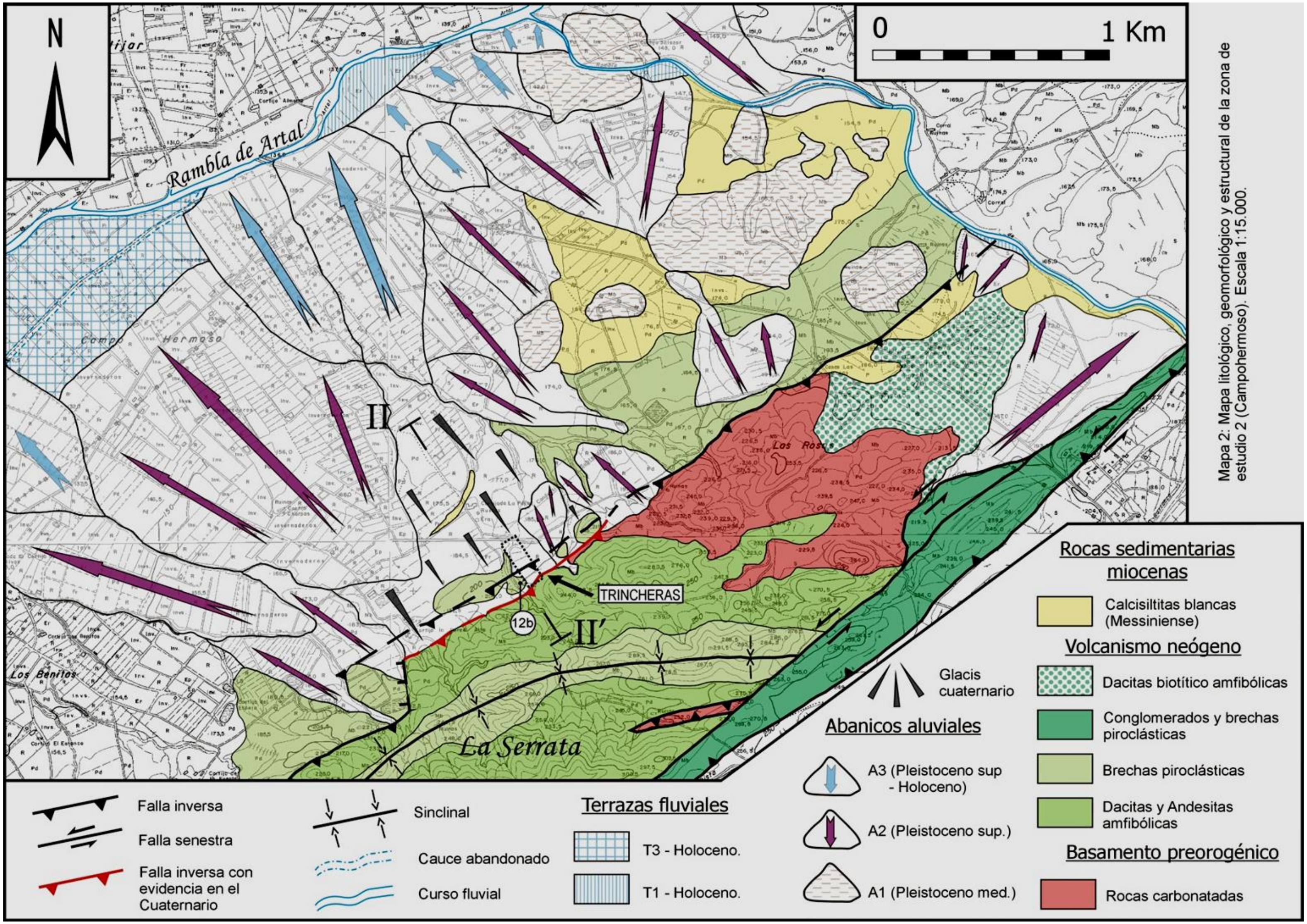


El Hacho
2005

La Serrata

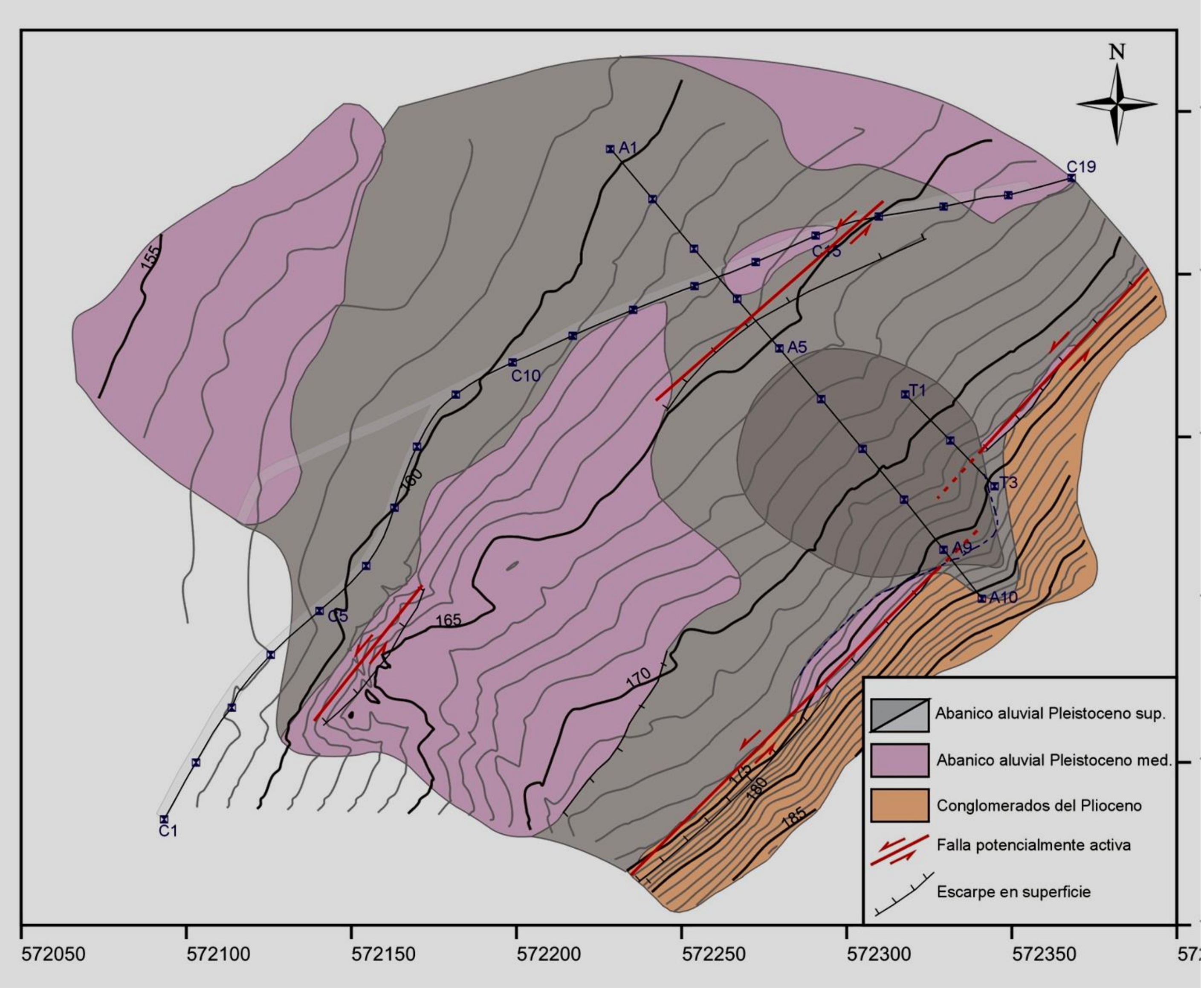






3 generations of alluvial fans – Mid and Late Pleistocene/Holocene
- 3 various generations of fault movements (erosion - accummulation)

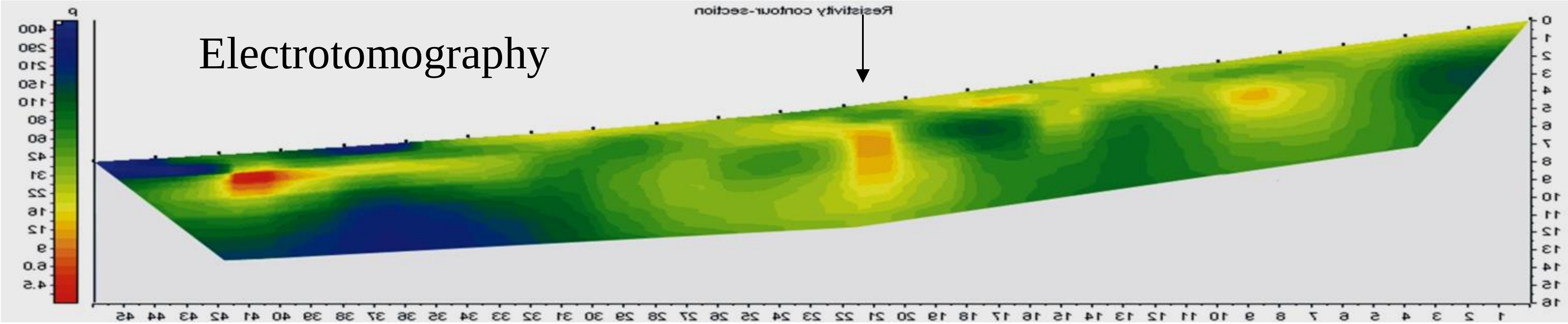
Paleoseismic trenches

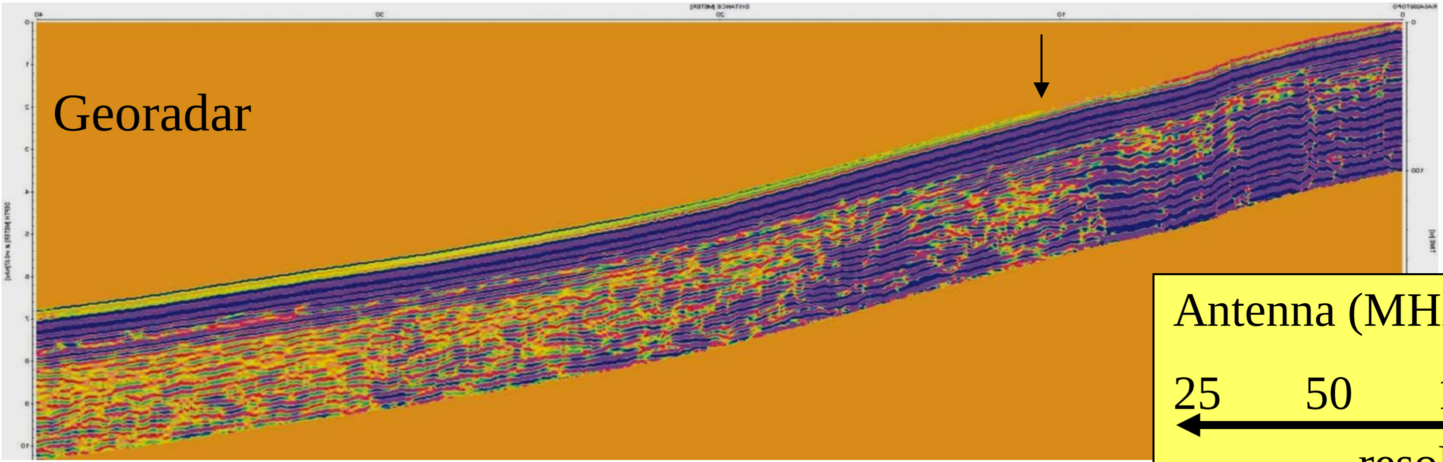


- all 3 alluvial fan generations (chronology)
- visible morphological scarps (0.7m)

Geophysics

- fault position and characterictsics of the material at the depth





Antenna (MHz):

25 50 100 200

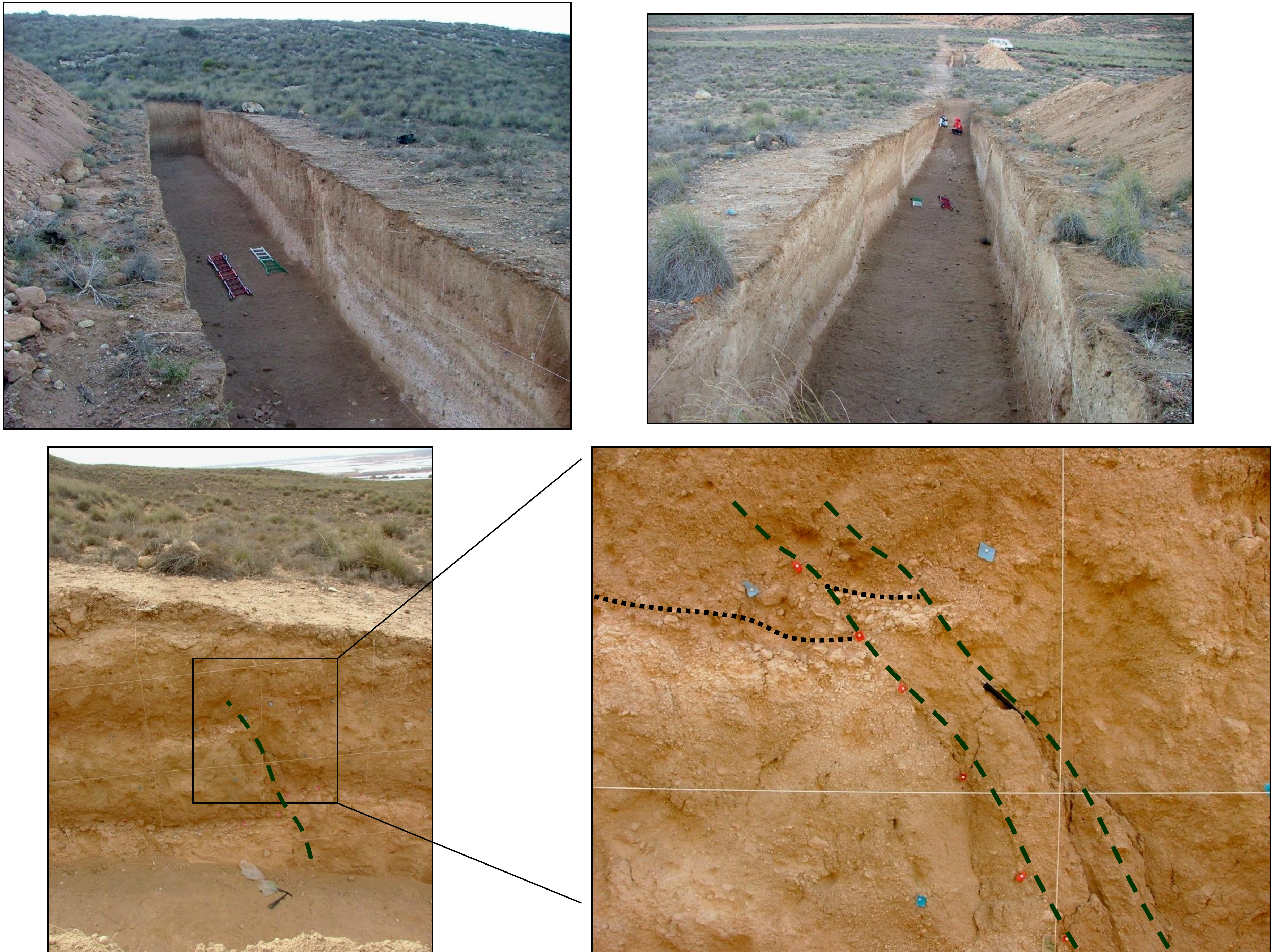
- resolution +

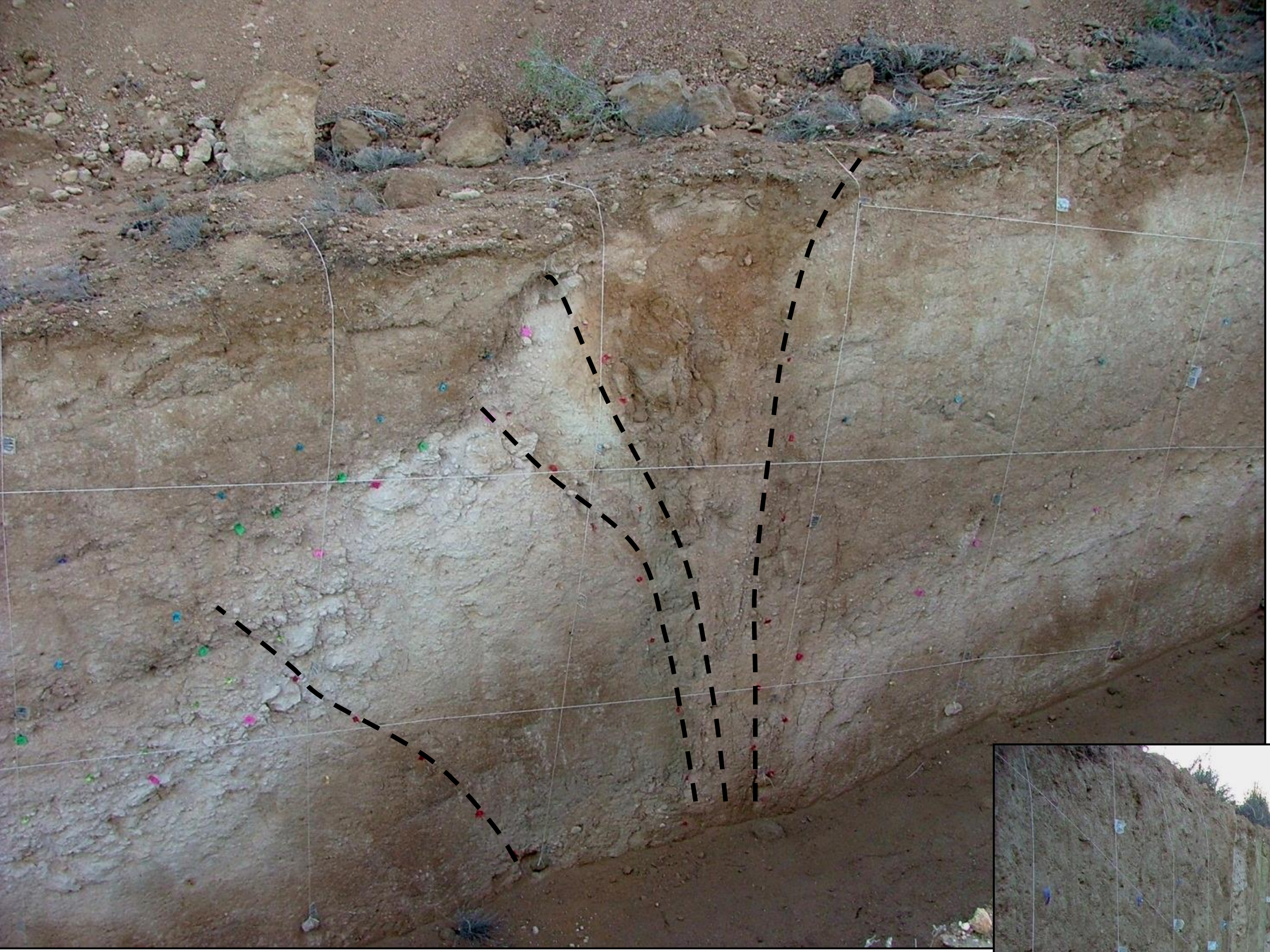
+ reach -

November 2005

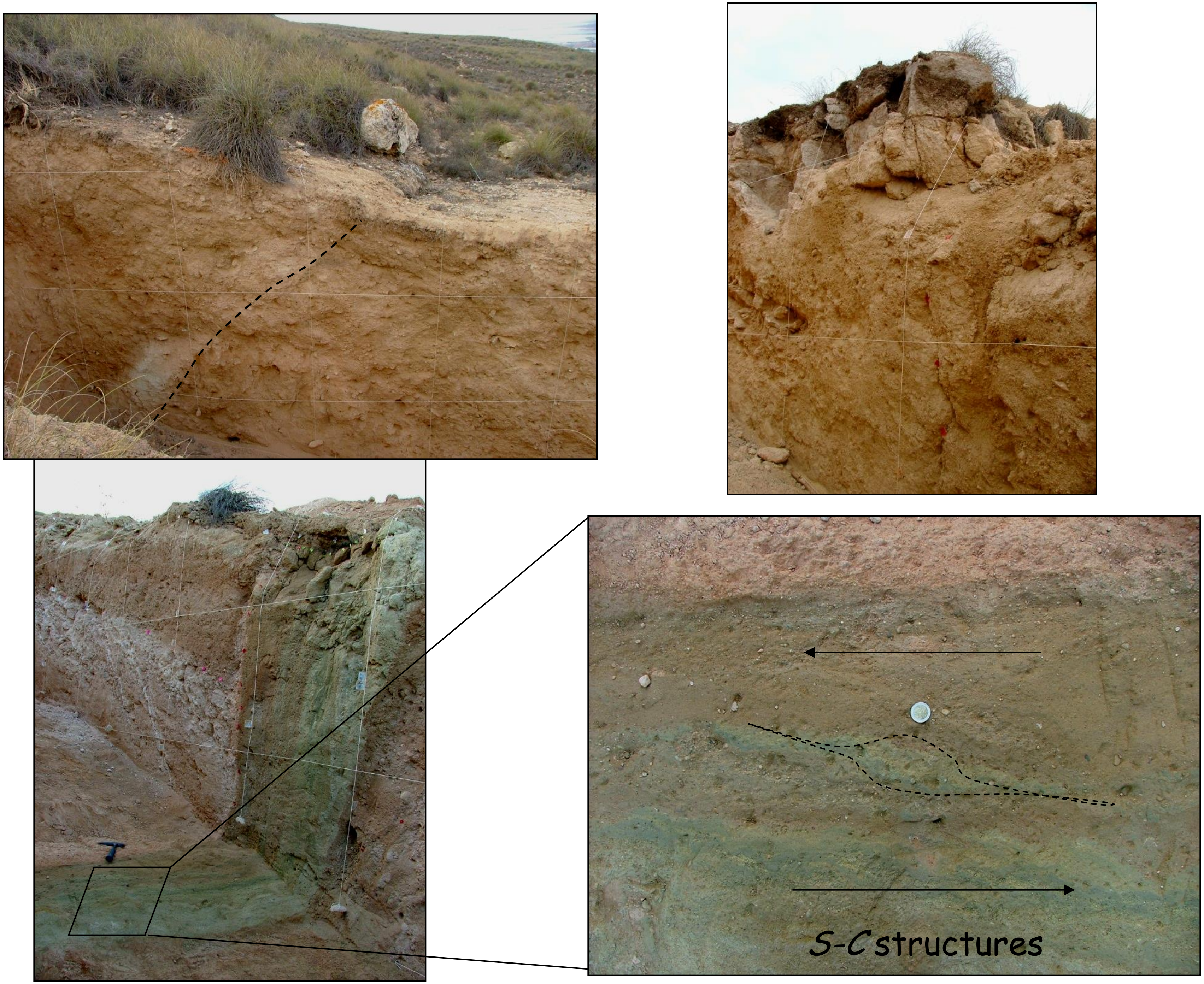
Cleaning the wall, grid

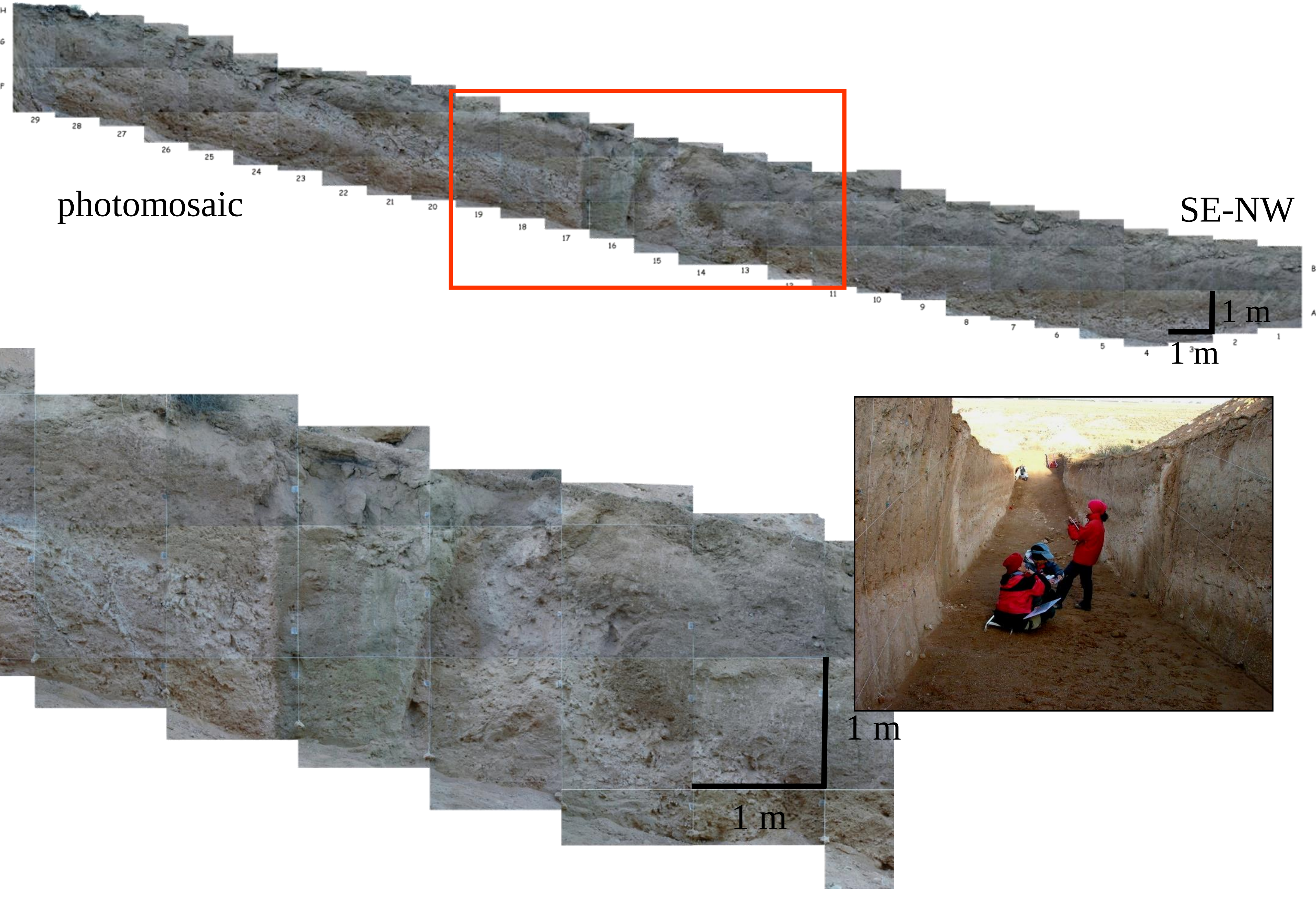
Identification of sedimentary layers and dislocations/faults



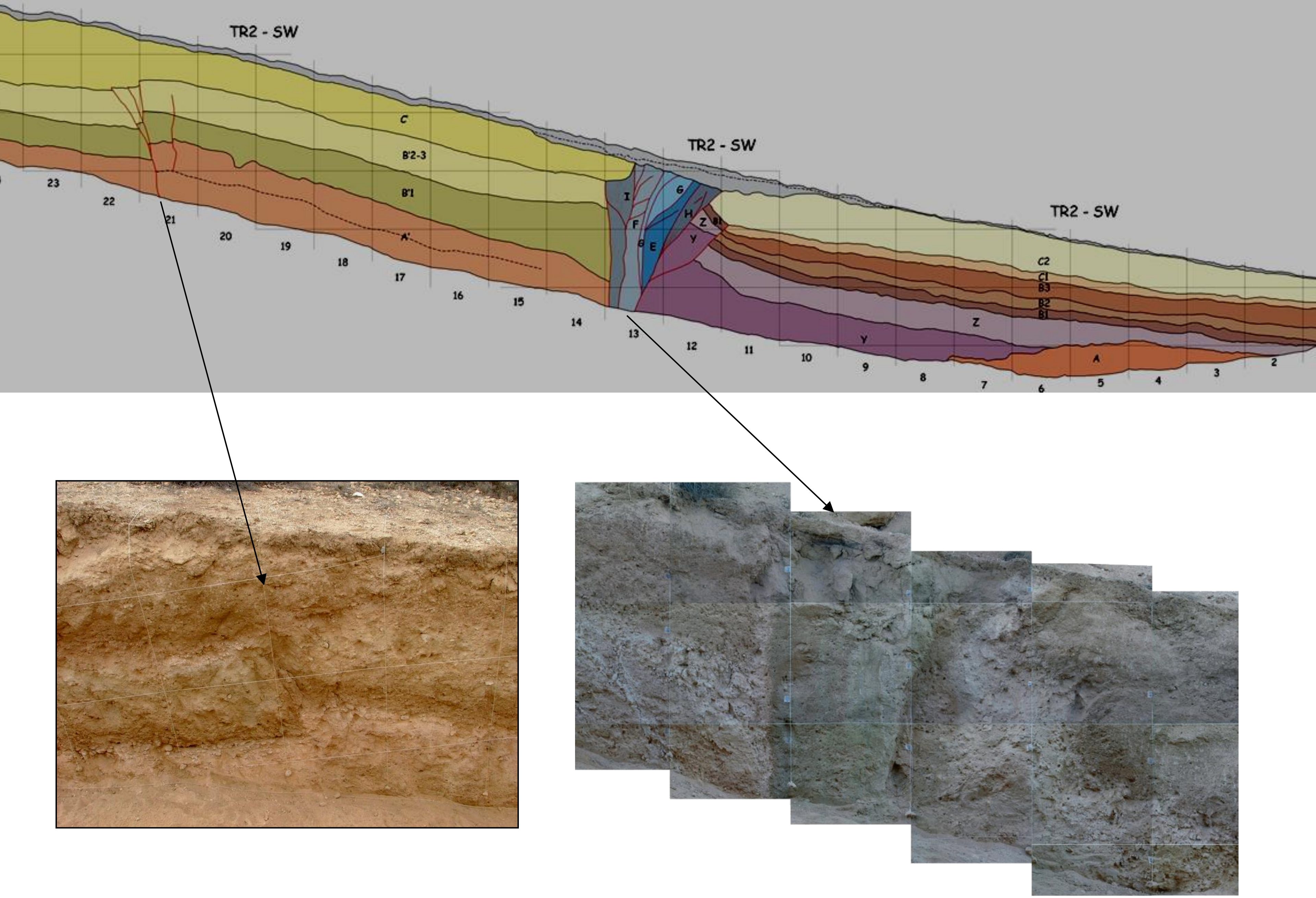


- Complex structure
  - flower structure
  - transpressive regime
- Horizontal movements
- strike-slips with vertical component-
- Repeated movements


S-C structures



photomosaic
SE-NW
1 m
1 m
1 m
1 m


TR2 - SW
TR2 - SW
TR2 - SW
C
B'2-3
B'1
A'
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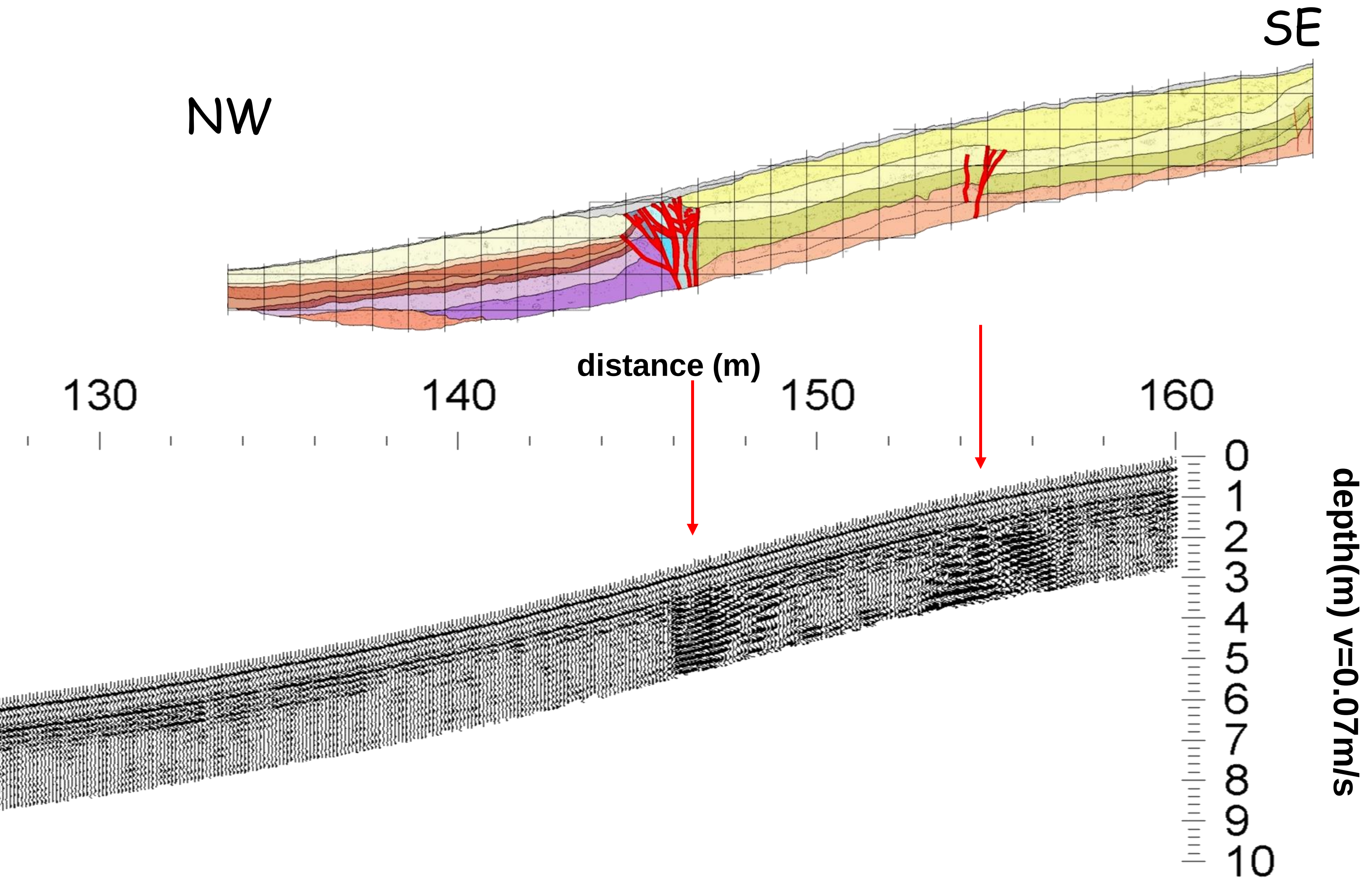
situation in situ versus geophysics



Dating – material cut by the seismic event

- **^{14}C radiocarbon dating method** → organic material and carbonatic shells (reach 40 thousands year) – charcoal, gastropodus, organic material, wood, etc.

14C – in living organism, added from the environment, it decays, after death of organism, ratio of 14C/stabile 12C changes

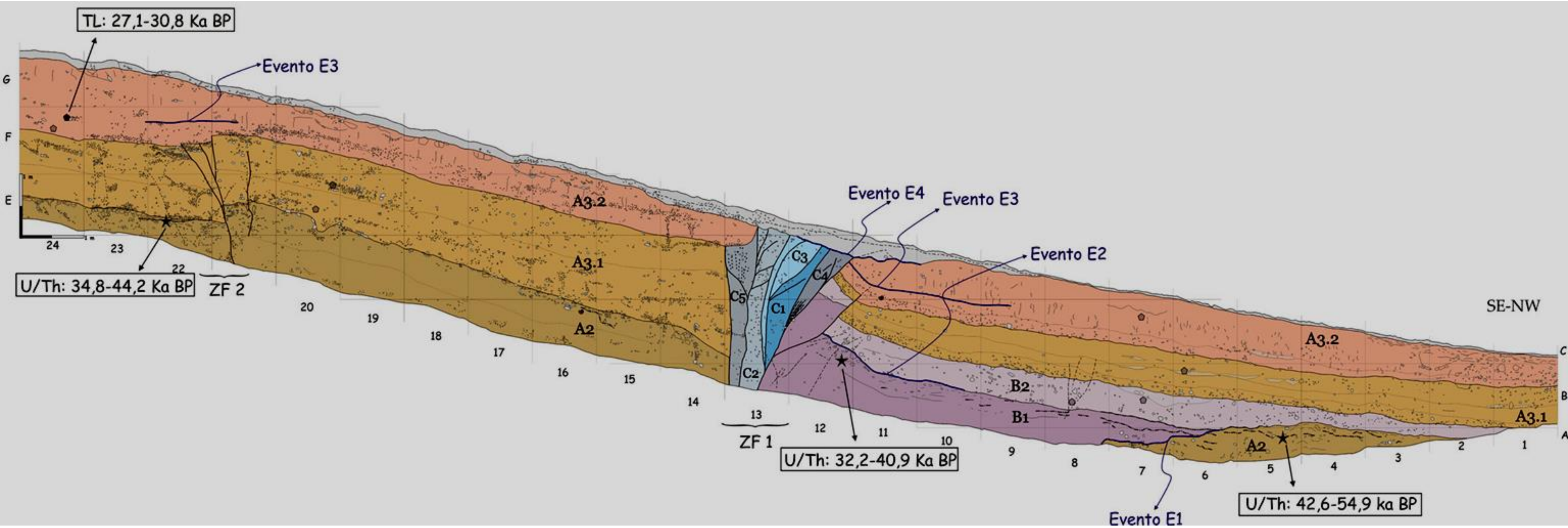
- **Optically stimulated luminiscence OSL –** electrones trapped in crystal lattice of sand grains - released by light activation or stimulation. (reset – zero signal). After finishing of sedimentation – signal increases due to radioactive decay. Luminiscence relased by light activation in the lab is proportional to sediments age (the time until which the electrones were accummulated – until next reset (reach 250-300 thousands yrs)

- **Thermoluminiscence TL** → fine-grained sediments (100 thousands yrs)

- **U/Th** → carbonatic material (reach 300 thousands years) – **laminar caliche**

❖ interpretation of trench logs, assessment of type and amount of movements

reconstruction of deformation (retrodeformation)



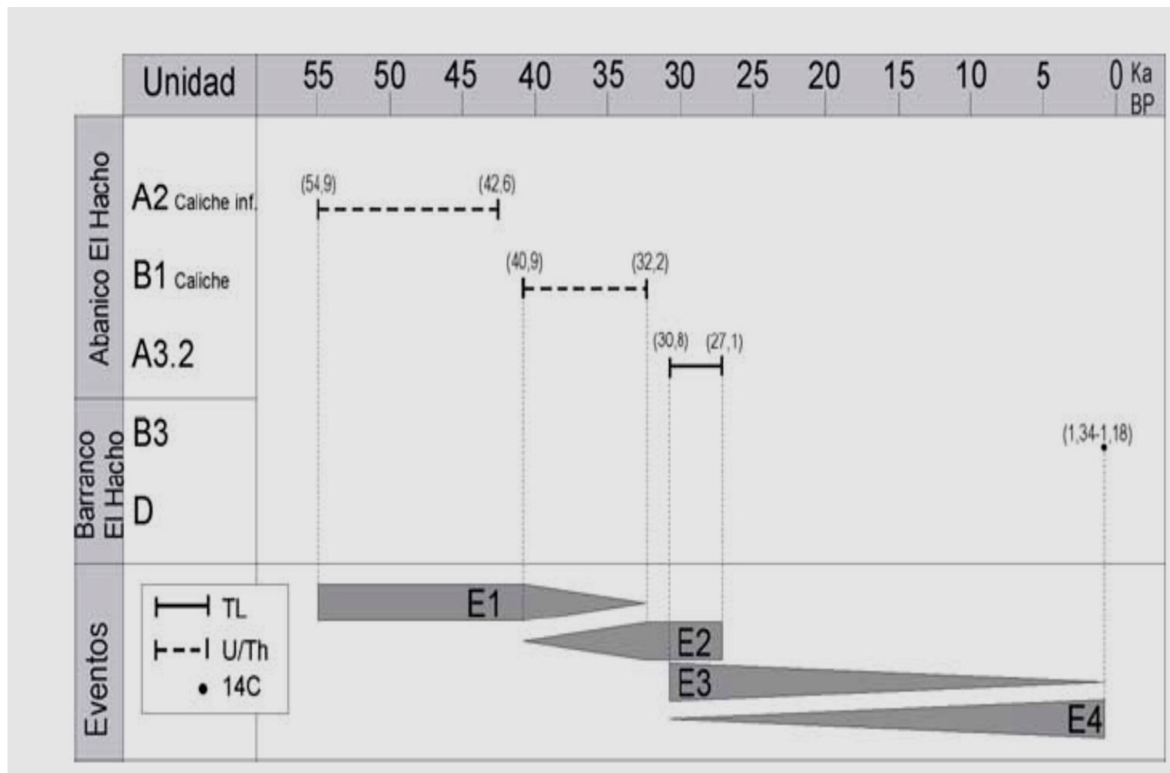
❖ laboratory results of dating

chronology of tectonic activity on the Carboneras fault

Results: Trench analysis and dating on Carboneras fault:

- B_1, B_2 – colluvial wedge were recognized (surface degradation after suddent event) – earthquake
- Minimum 4 earthquakes during last 50 thousands years
- Recurrence period – min. 14 thousands yrs
- Last event – minim 1310 years ago
- Empiric relationship Magnitude X Displacement for 2 events – minim.

M= 6.59 and 6.97



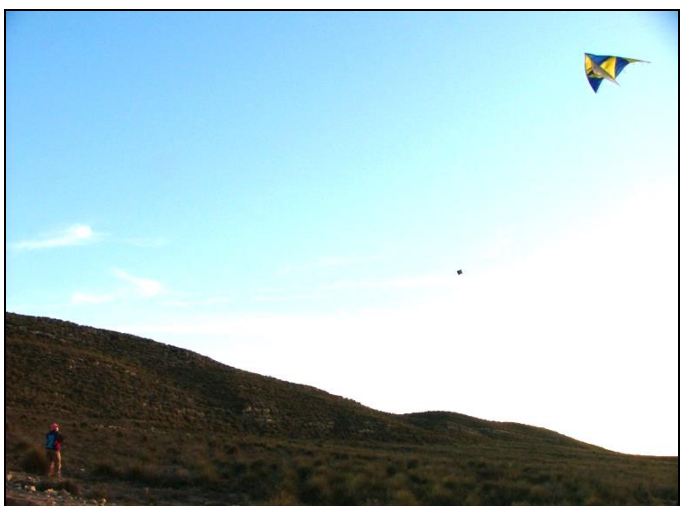
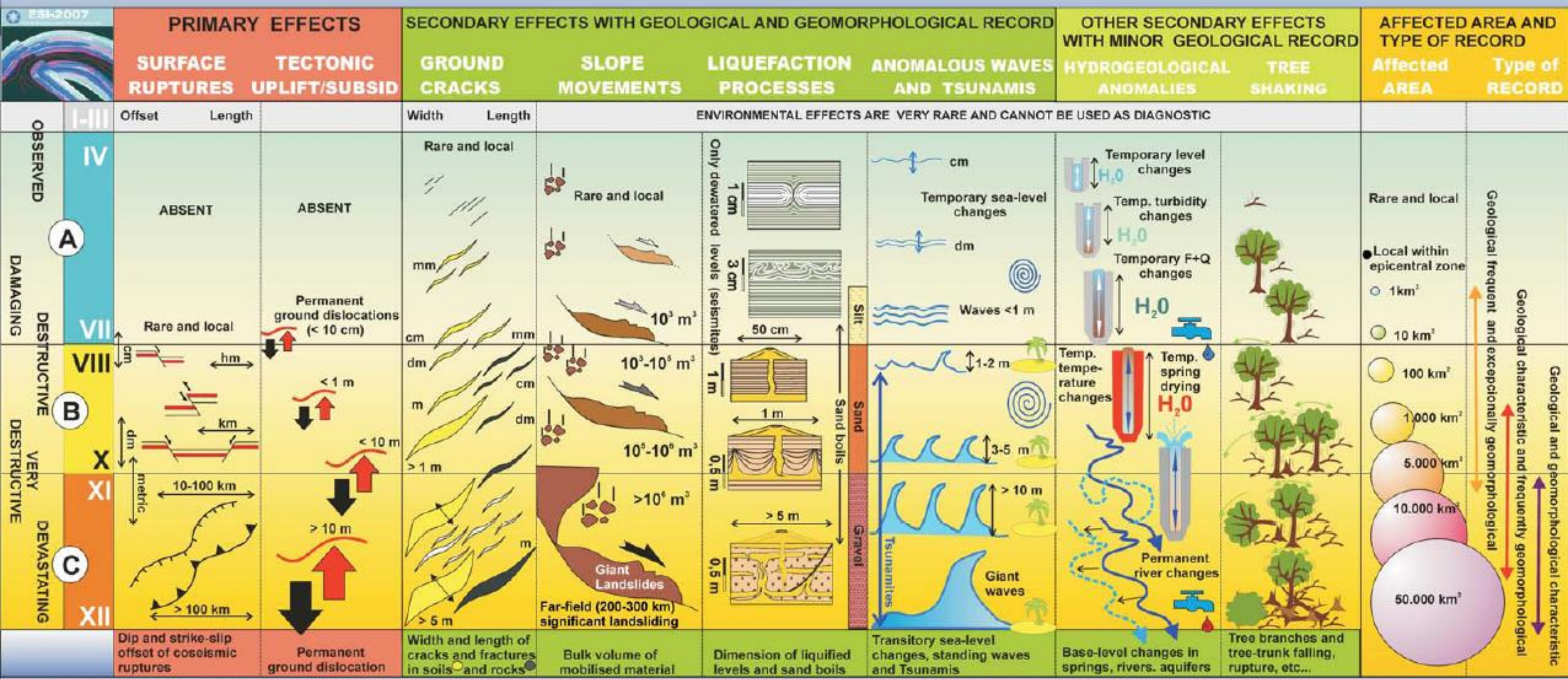


CHART OF THE INQUA ENVIRONMENTAL SEISMIC INTENSITY SCALE 2007 - ESI 07



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