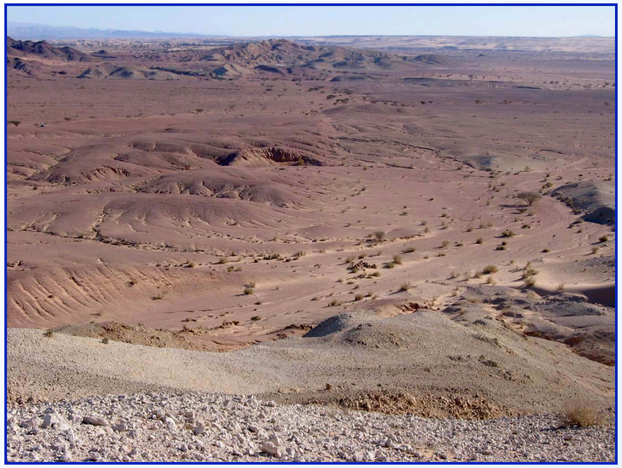
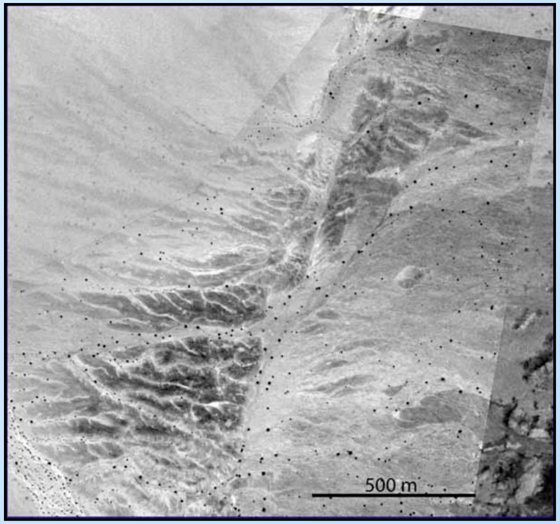


Investigating the kinematics and seismic behavior of an active strike-slip fault: Example of the southern Dead Sea fault

Maryline Le Béon,

Department of Geosciences,

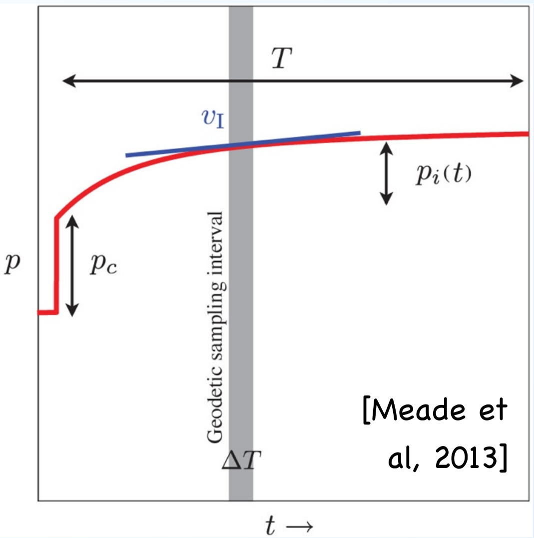
National Taiwan University



NCU, March 3rd 2015

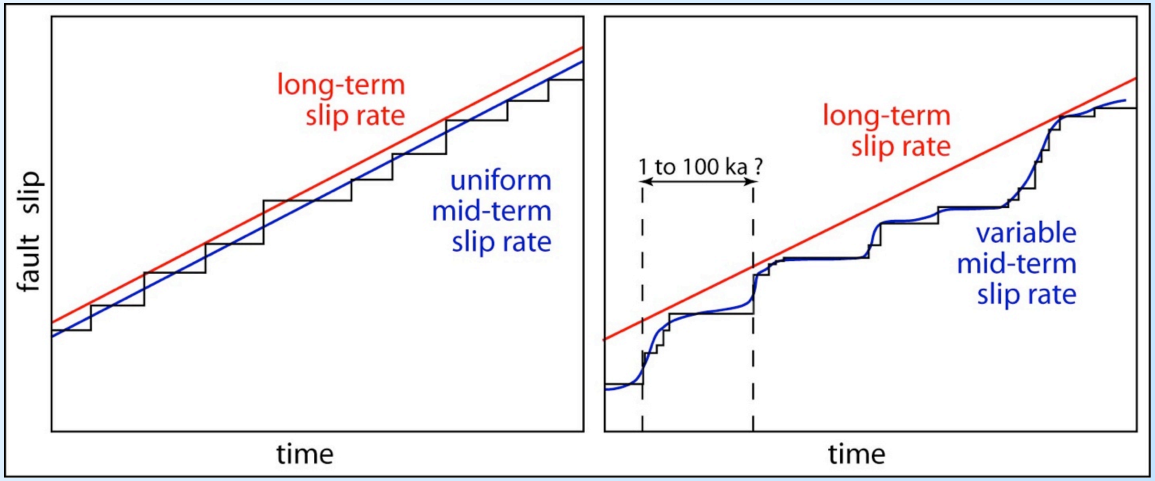
Hot questions

Interseismic deformation :



Quasi-static ? or **Dynamic ?**

Temporal distribution of earthquakes :



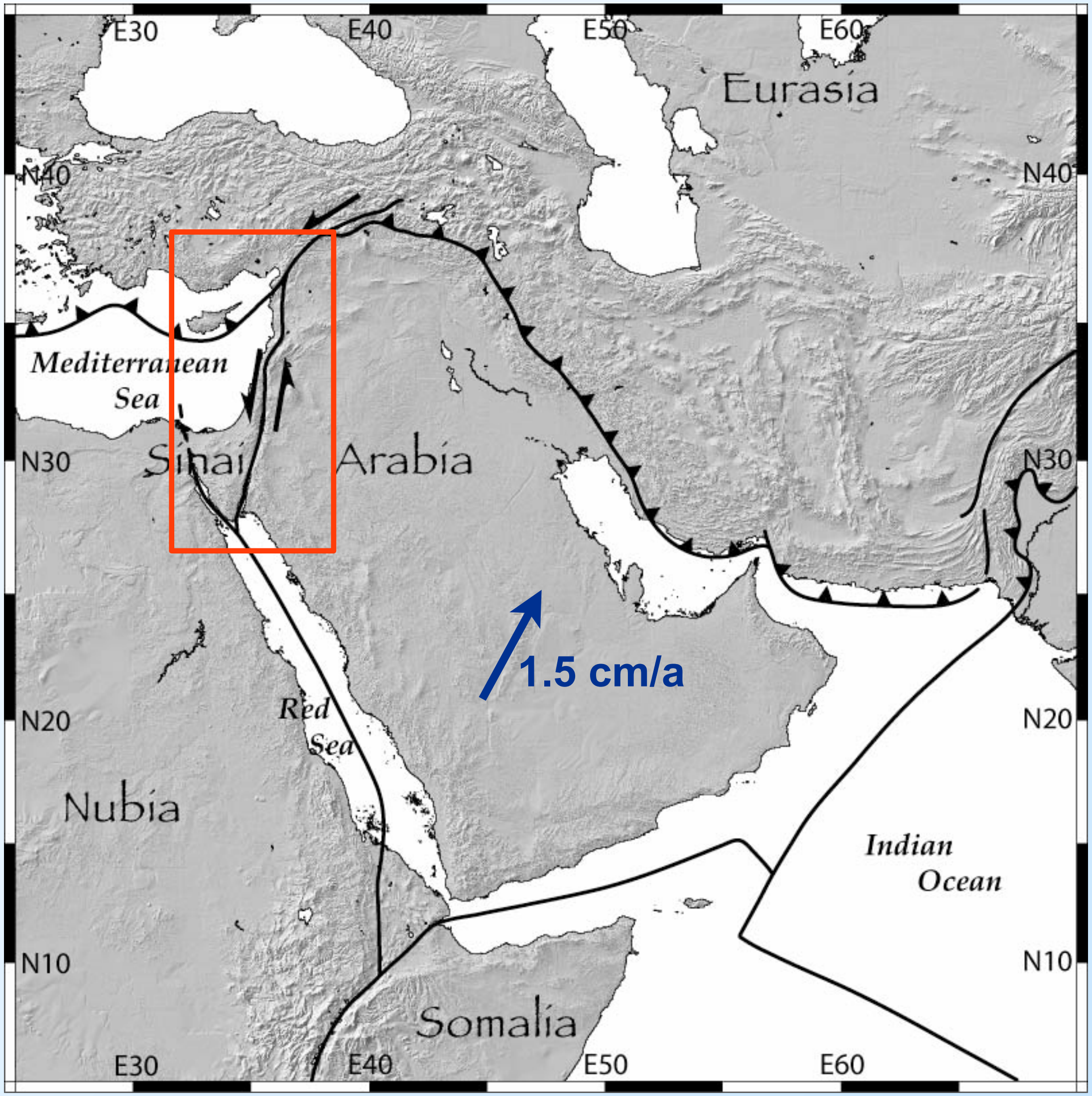
Modified from Chéry & Vernant 2006

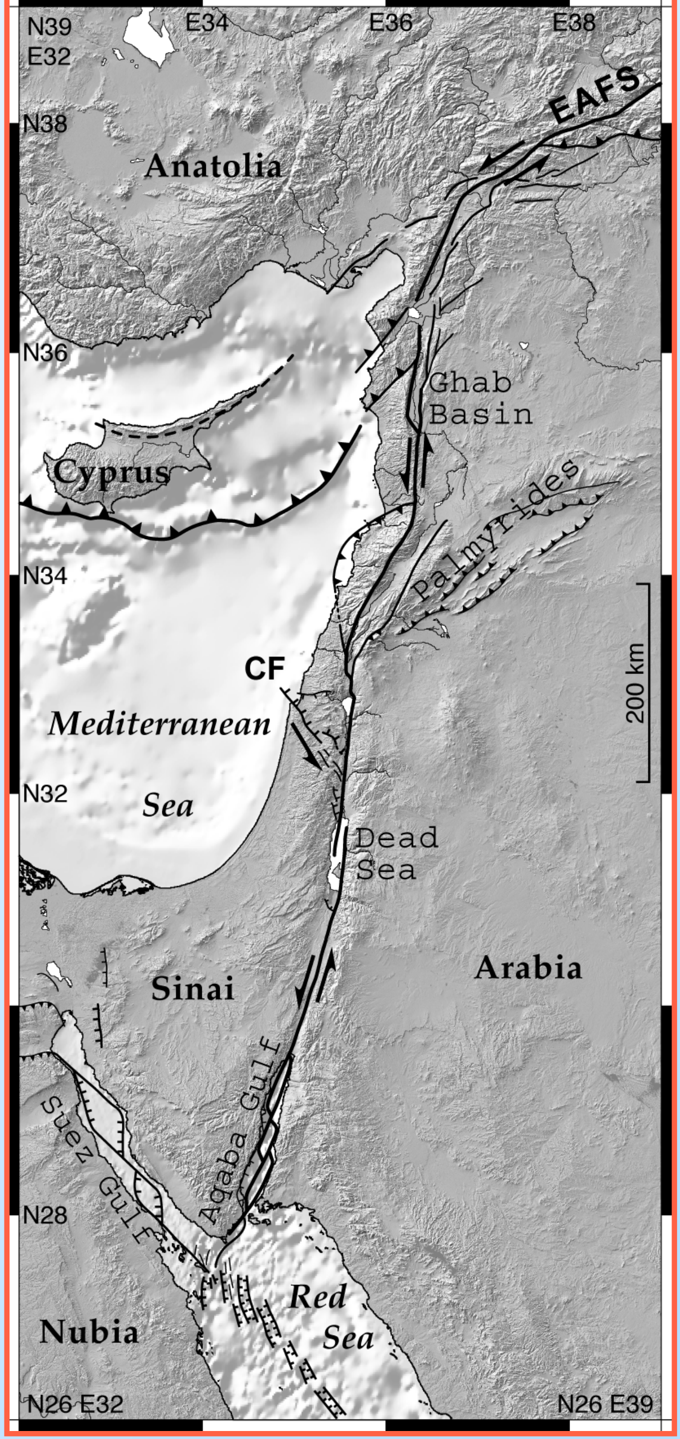
Quasi-periodic cycles ? OR **Clusters + periods of quiescence ?**

=> Approach : Compare fault slip rates determined at different time scales

First reviews: Meade et al, 2013; Vernant, 2015

Dead Sea fault regional setting





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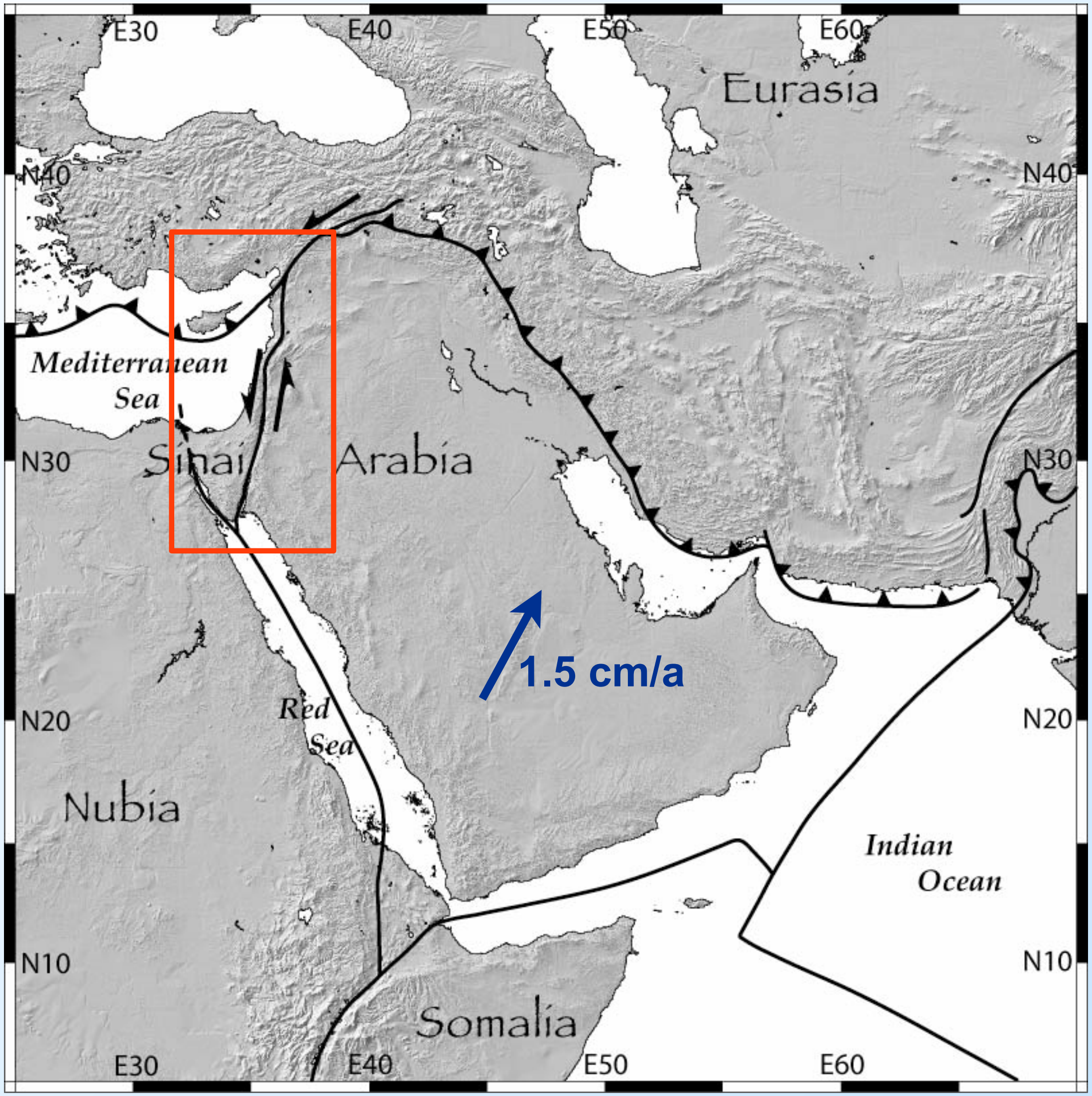
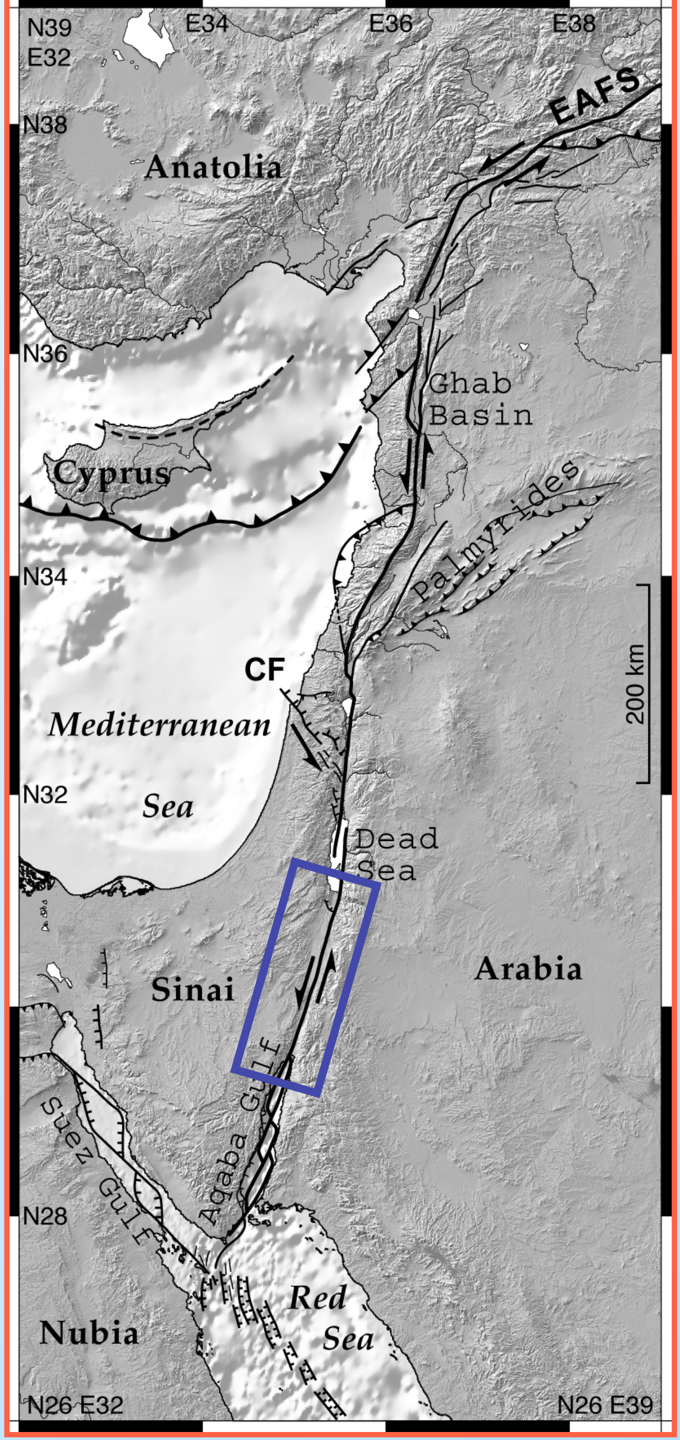
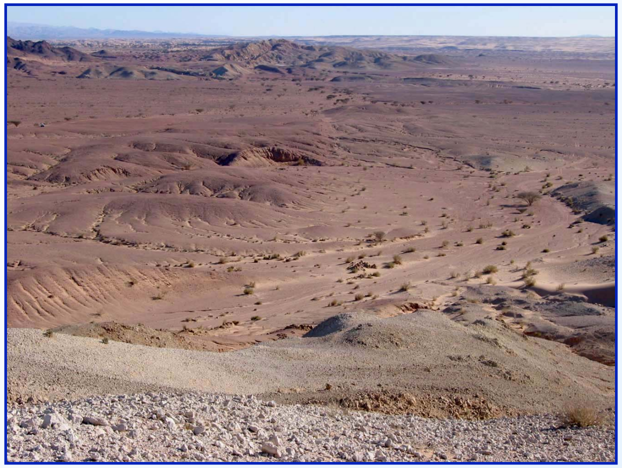






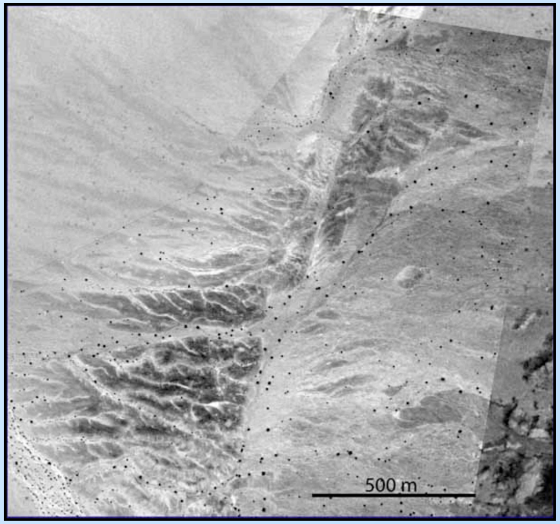
Tectonic Geomorphology :
10-100ka cumulative fault slip

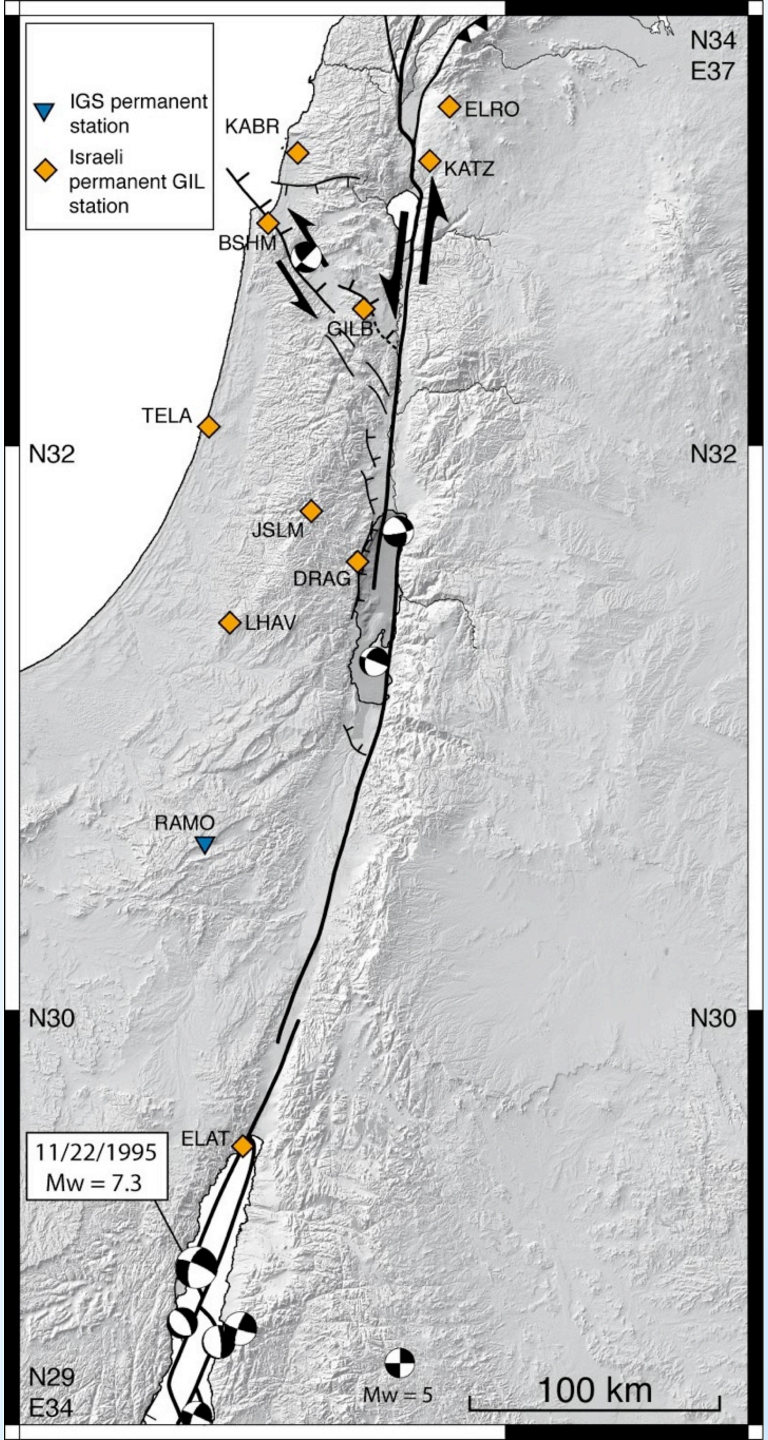
Quaternary
Geochronology :
dating offset deposits

A multi-disciplinary and multiple time scale approach collocated on a single fault segment

GPS :
Present-day fault slip rate

Paleo-seismology :
paleo-earthquake occurrence





GPS data acquisition and processing

- **Previous work** : Pe'eri et al, 2002

  Wdowinski et al, 2004

- Data:

- **17 sites** ; up to 90 km away from the fault

- **2 campaigns**: 1999 and 2005; 48 h sessions ;

  2 permanent sites

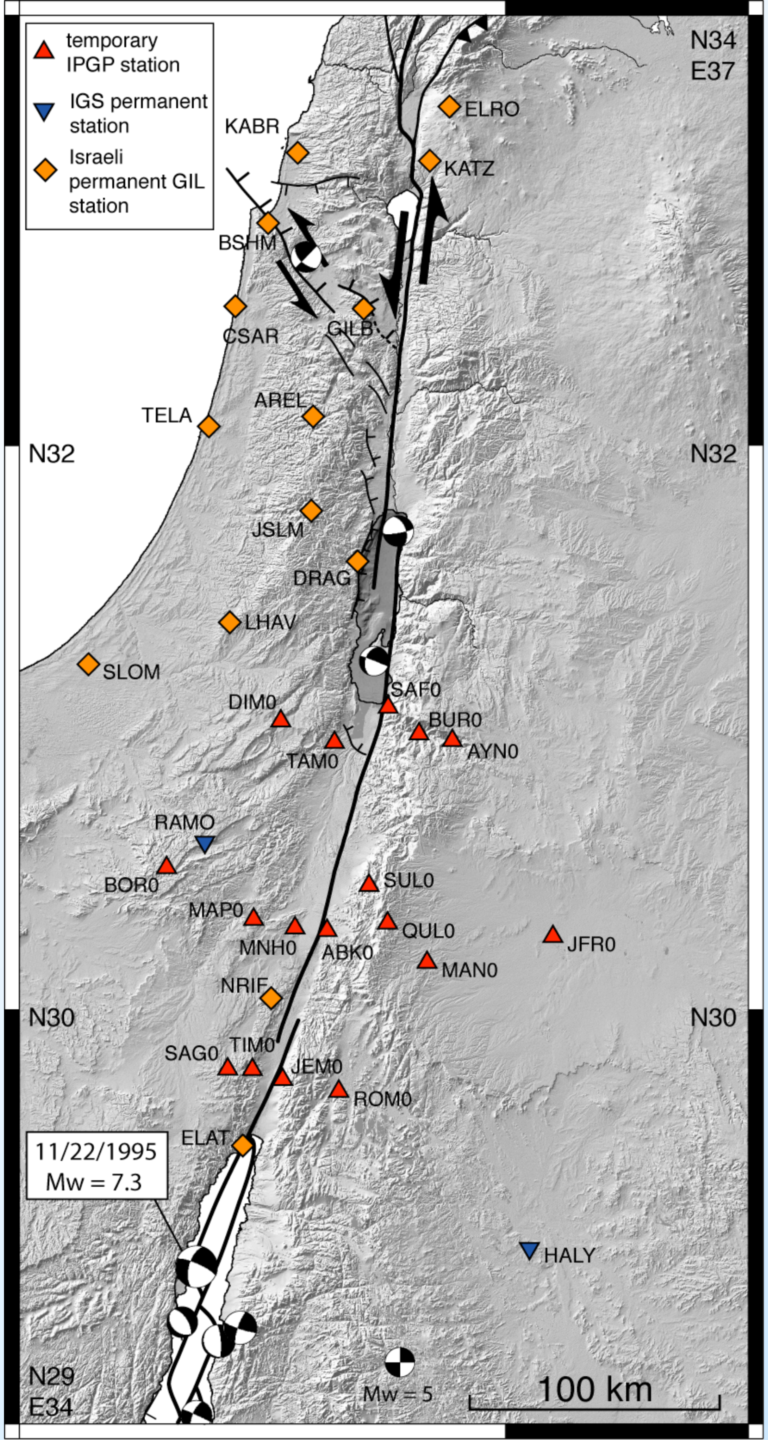
- **IGS and Israeli permanent stations**

  additional sessions in 2002, 2004 and 2006

- Processing: - GAMIT/GLOBK software

  - **ITRF2000** reference frame

  (Altamimi et al, 2002)



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  (Altamimi et al, 2002)

Horizontal velocity field

Presented **relative to site RAMO**

(rotation of Arabia plate removed)

Post-seismic relaxation related to 1995 Nuweiba earthquake ?

Comparison to similar earthquakes (Landers, Izmit)

=> Data set not affected

Pure strike-slip motion along Wadi Araba fault

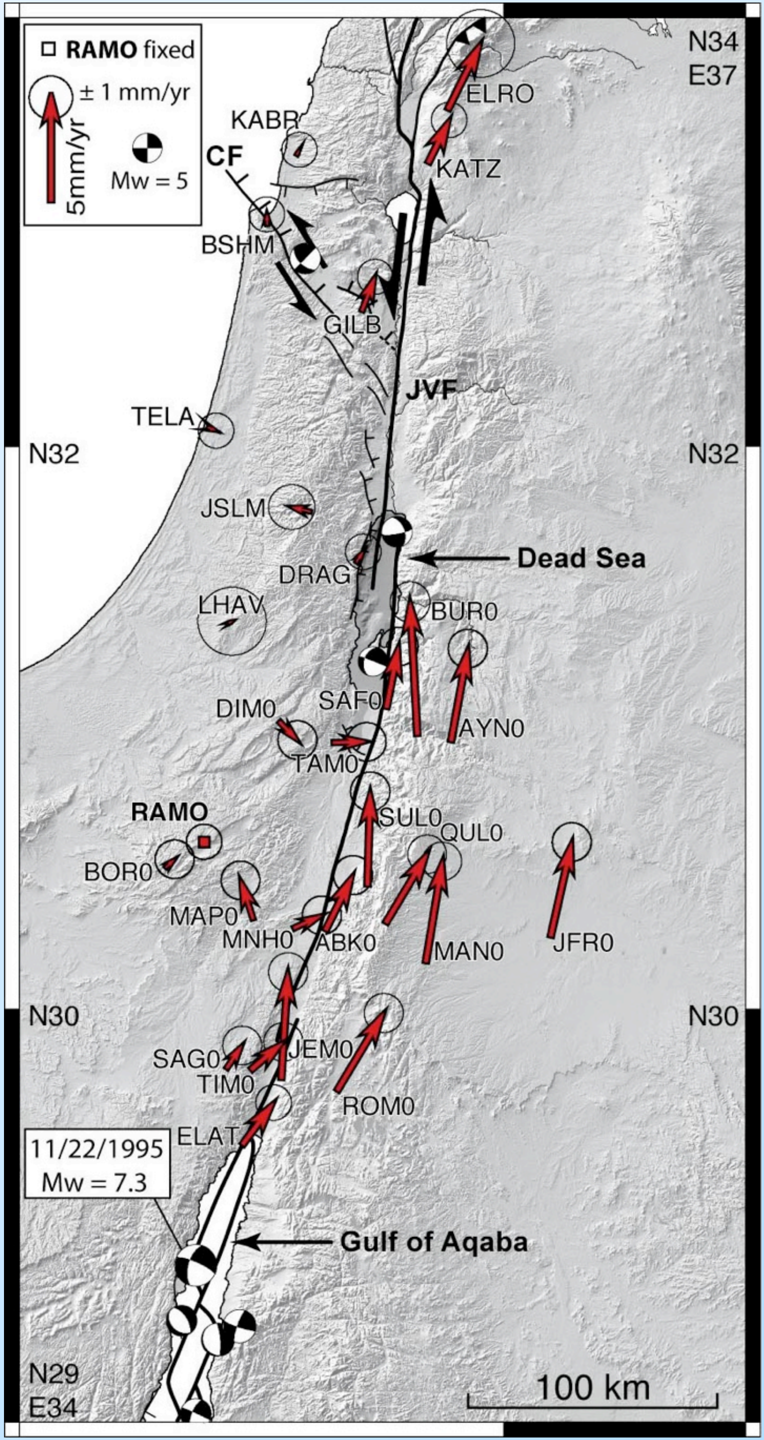
Eastward increase of velocity

Modeling of fault-parallel velocities :

Locked-fault model (Savage and Burford 1973)

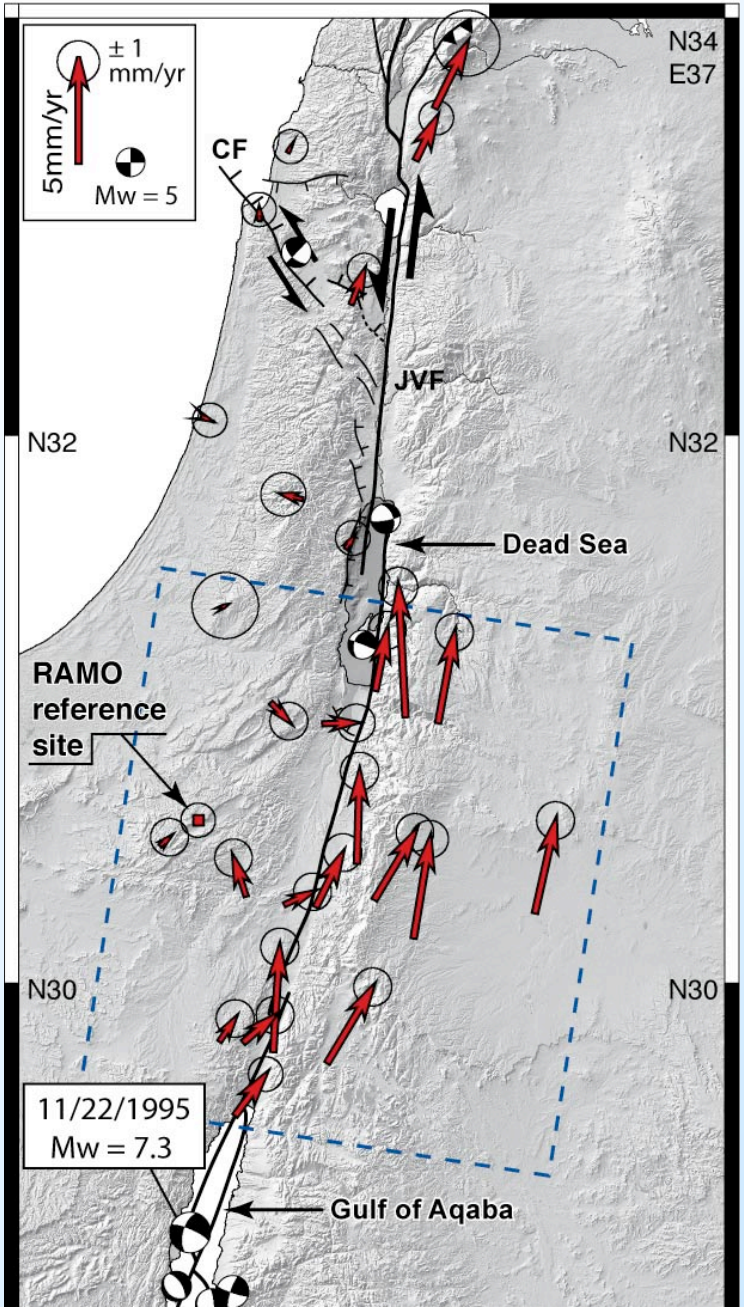
$$\mathbf{v(x)} = \mathbf{a} + \frac{\mathbf{V}}{\Pi}.\mathbf{arctan}\left[\frac{\mathbf{x}}{\mathbf{D}}\right]$$

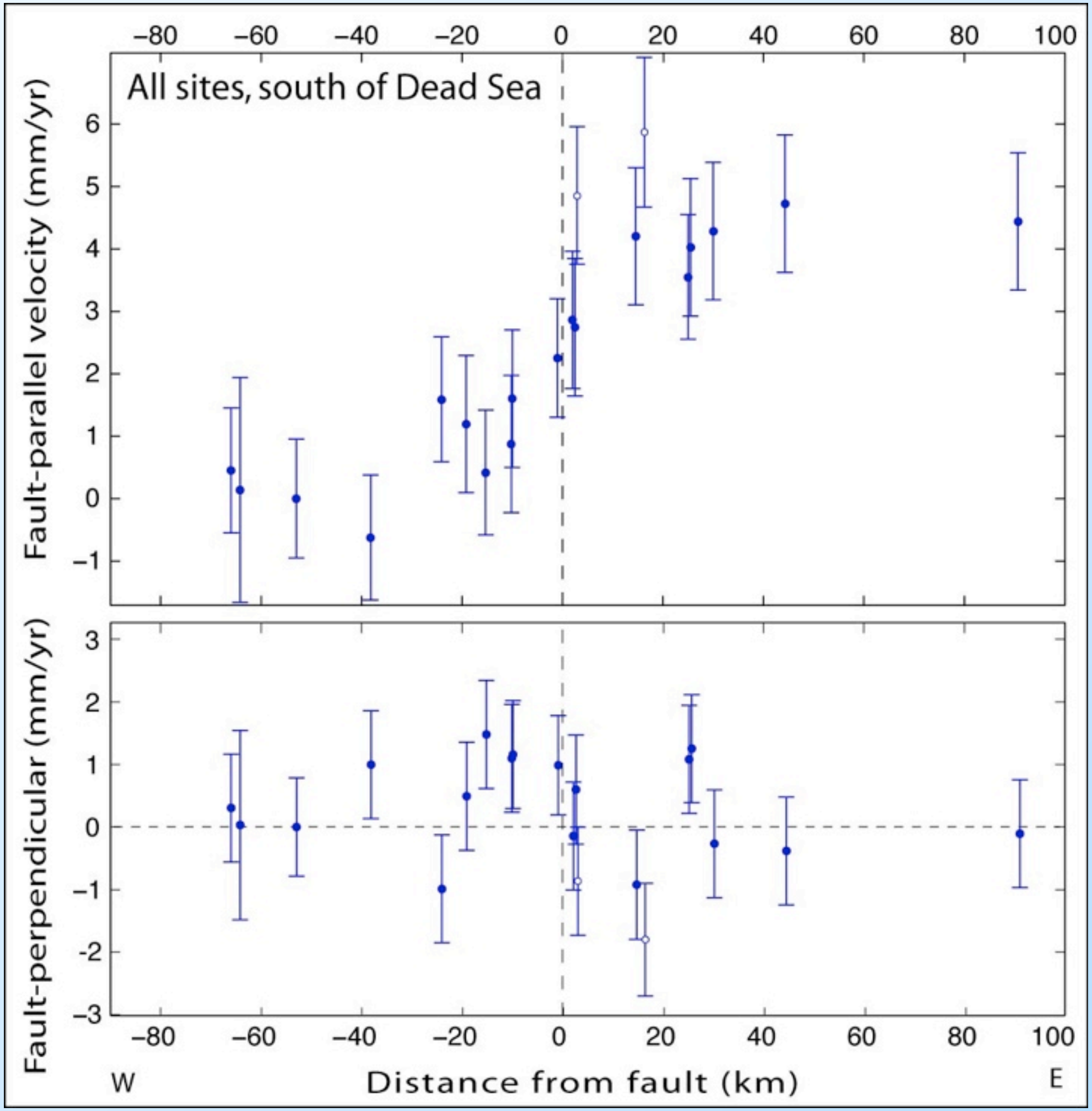
V : slip on dislocation plane below locking-depth **D**



Present-day fault slip rate

Le Béon et al, 2008, JGR



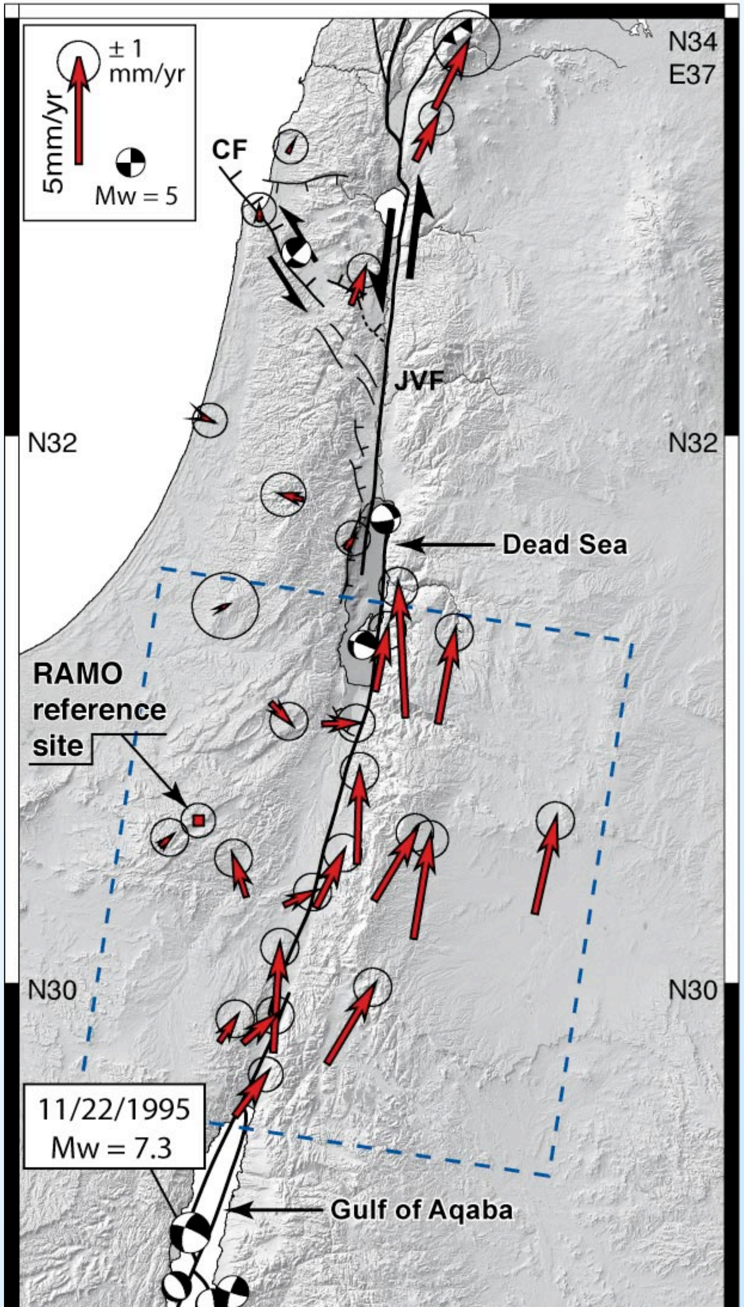


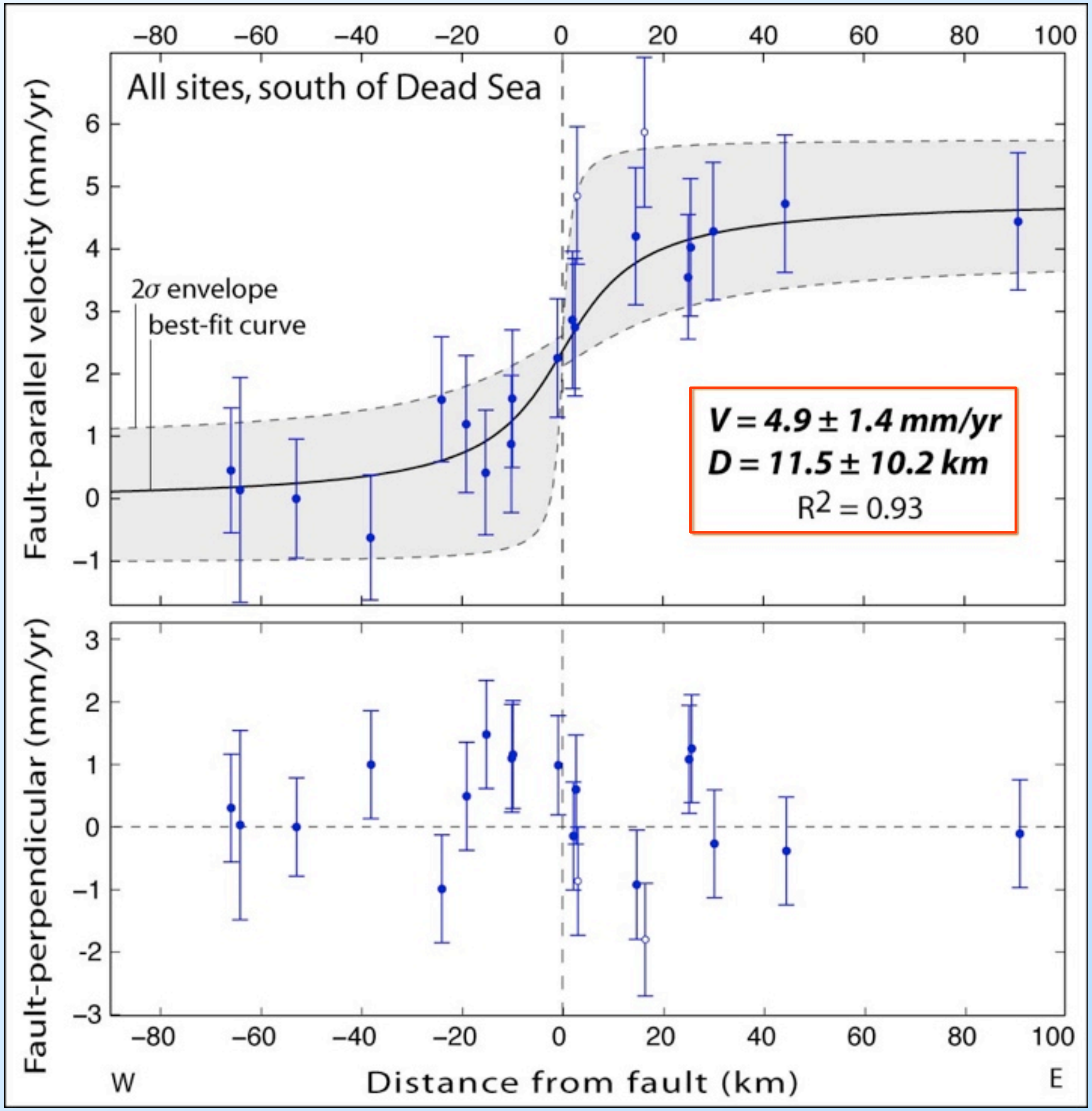
Result confirmed by a **3rd campaign in 2012:**

4.9 ± 0.5 mm/a [Masson et al, 2015]

Present-day fault slip rate

Le Béon et al, 2008, JGR





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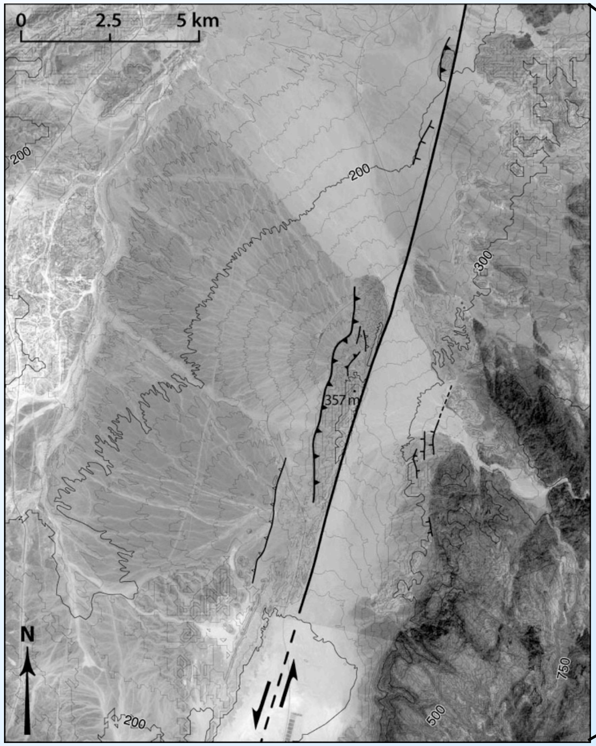
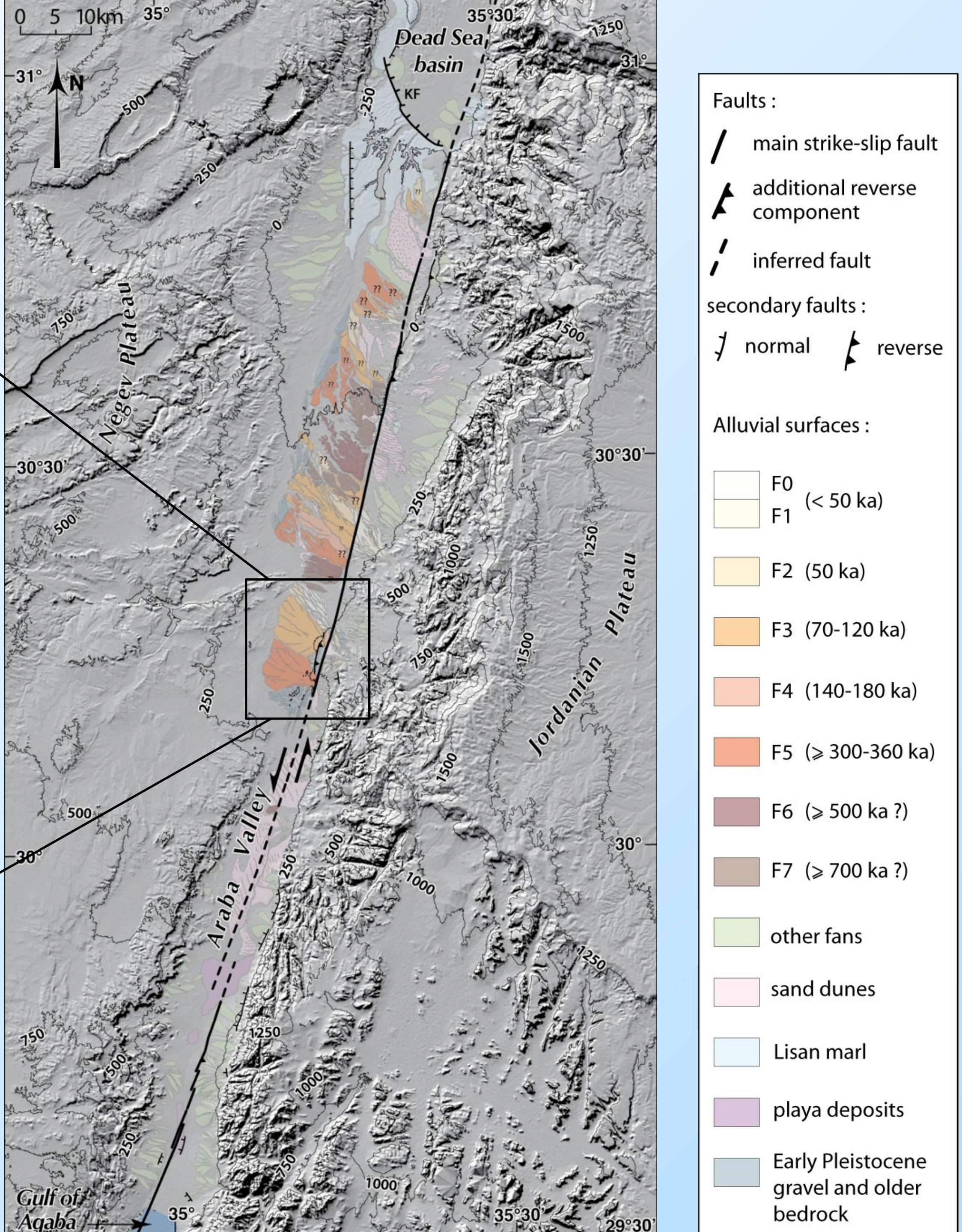
Morpho-tectonic map of the Wadi Araba



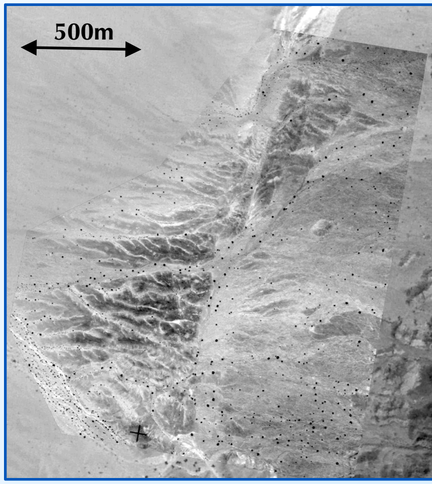
Topographic contour lines superimposed on SPOT5 image (pixel=2.5m)

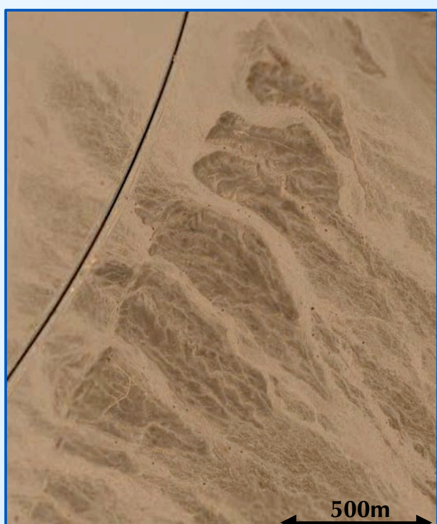


Le Béon et al, 2012, Tectonics

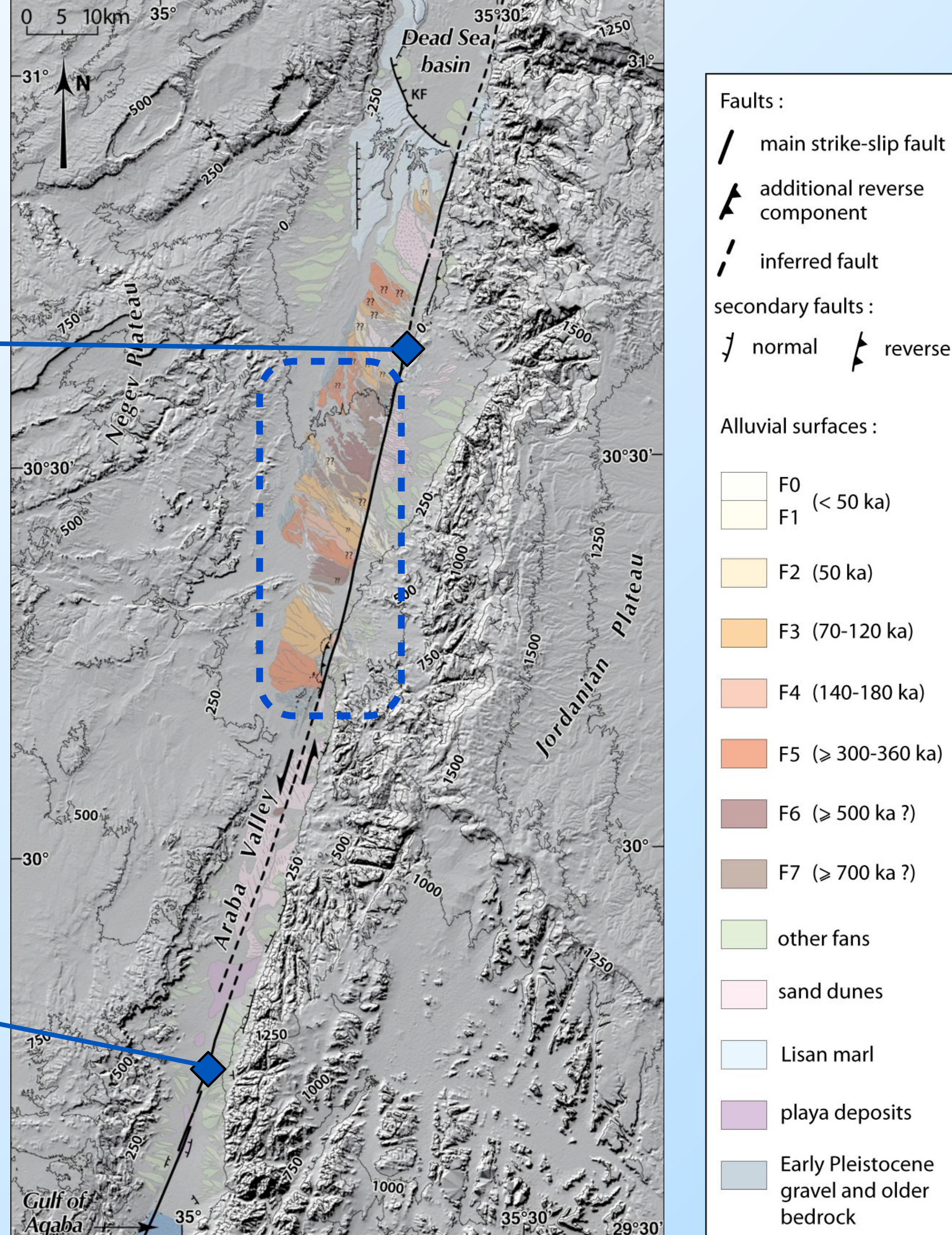
- **Geomorphology and cosmogenic isotopes dating (^{10}Be) over different time scales**

Hamra al-Fidan : ~100 ka

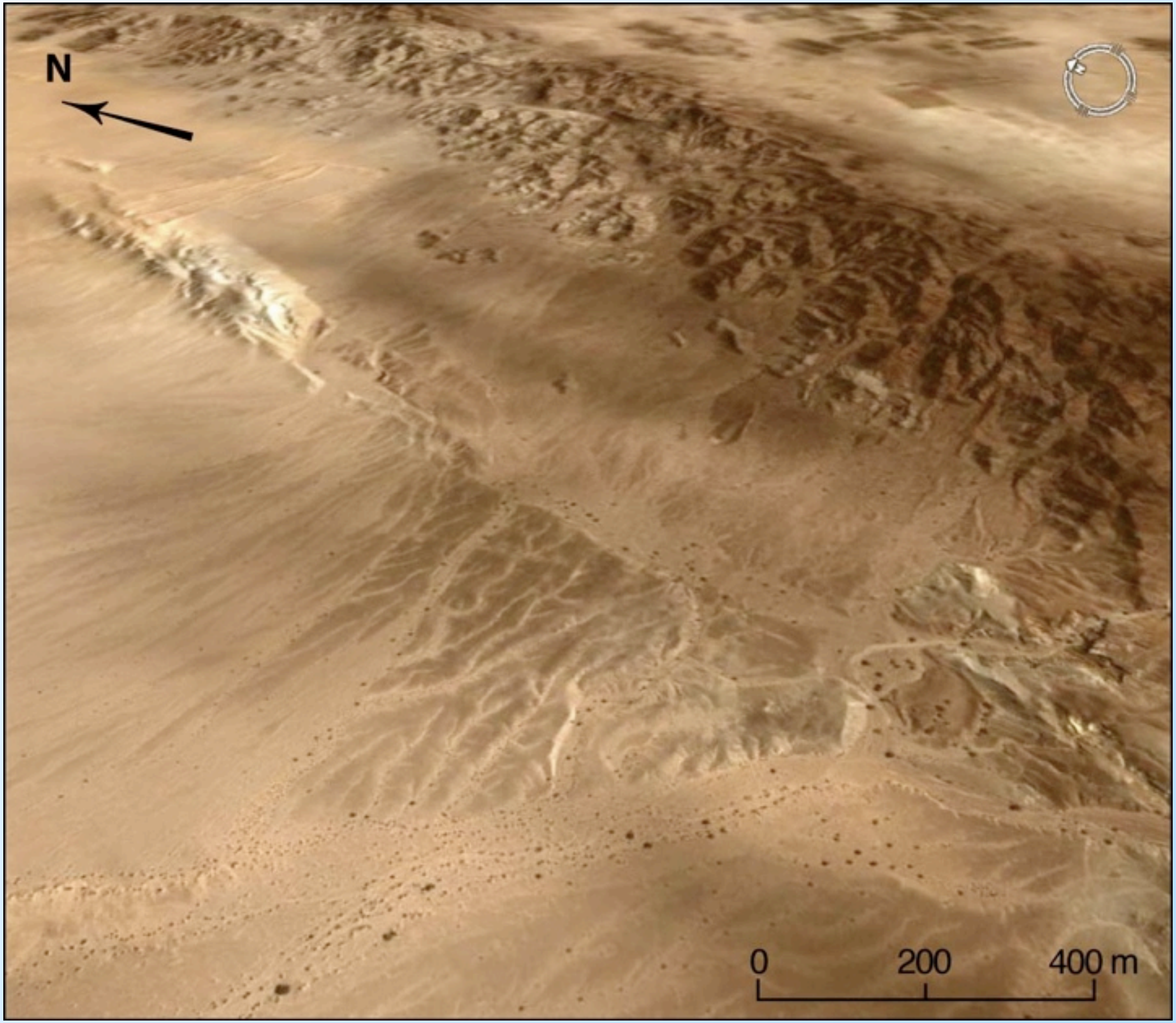




Jabal al-Muhtadi : ~10 ka

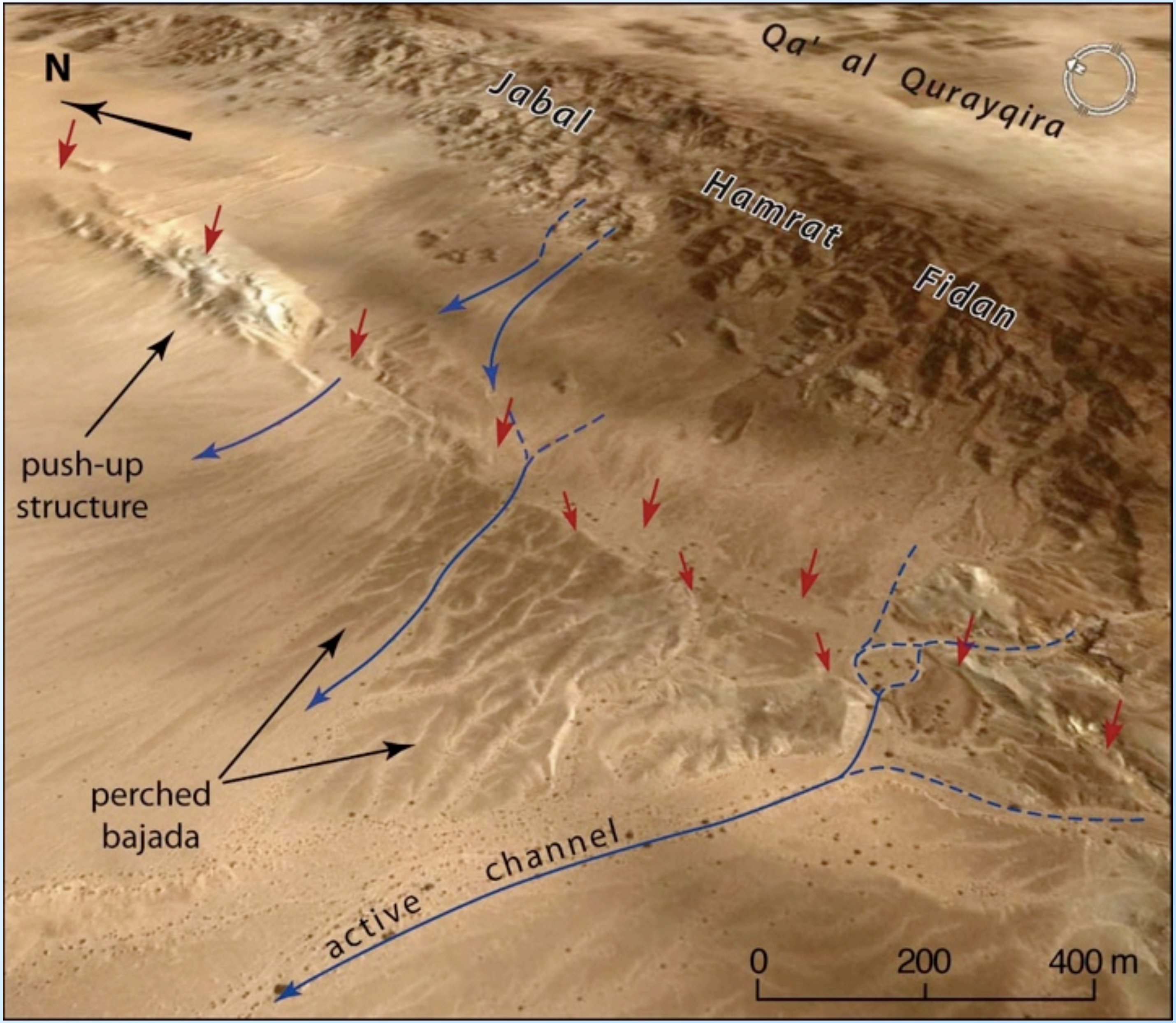


Overview of the Fidan site



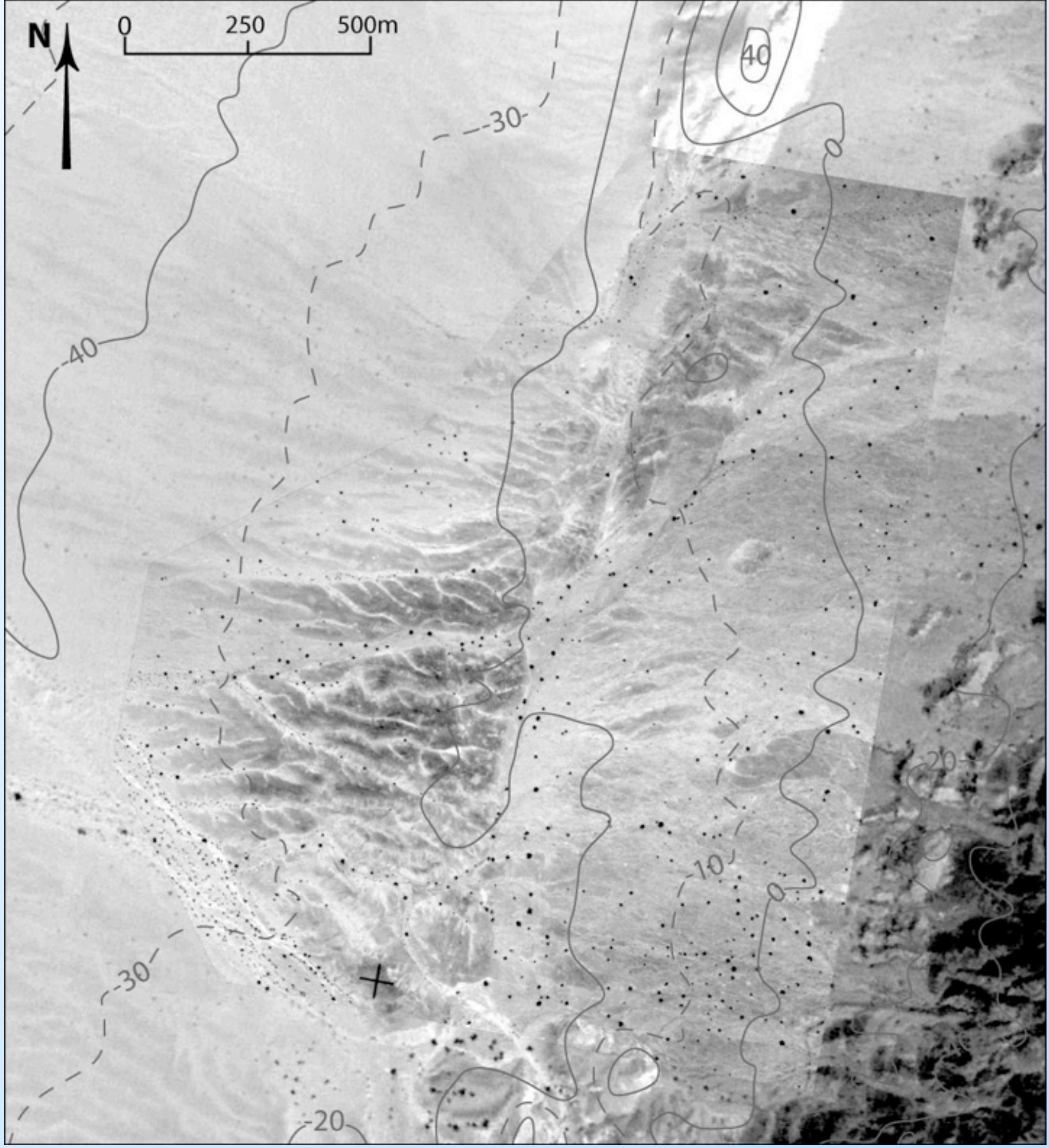
Google Earth overview

Overview of the Fidan site



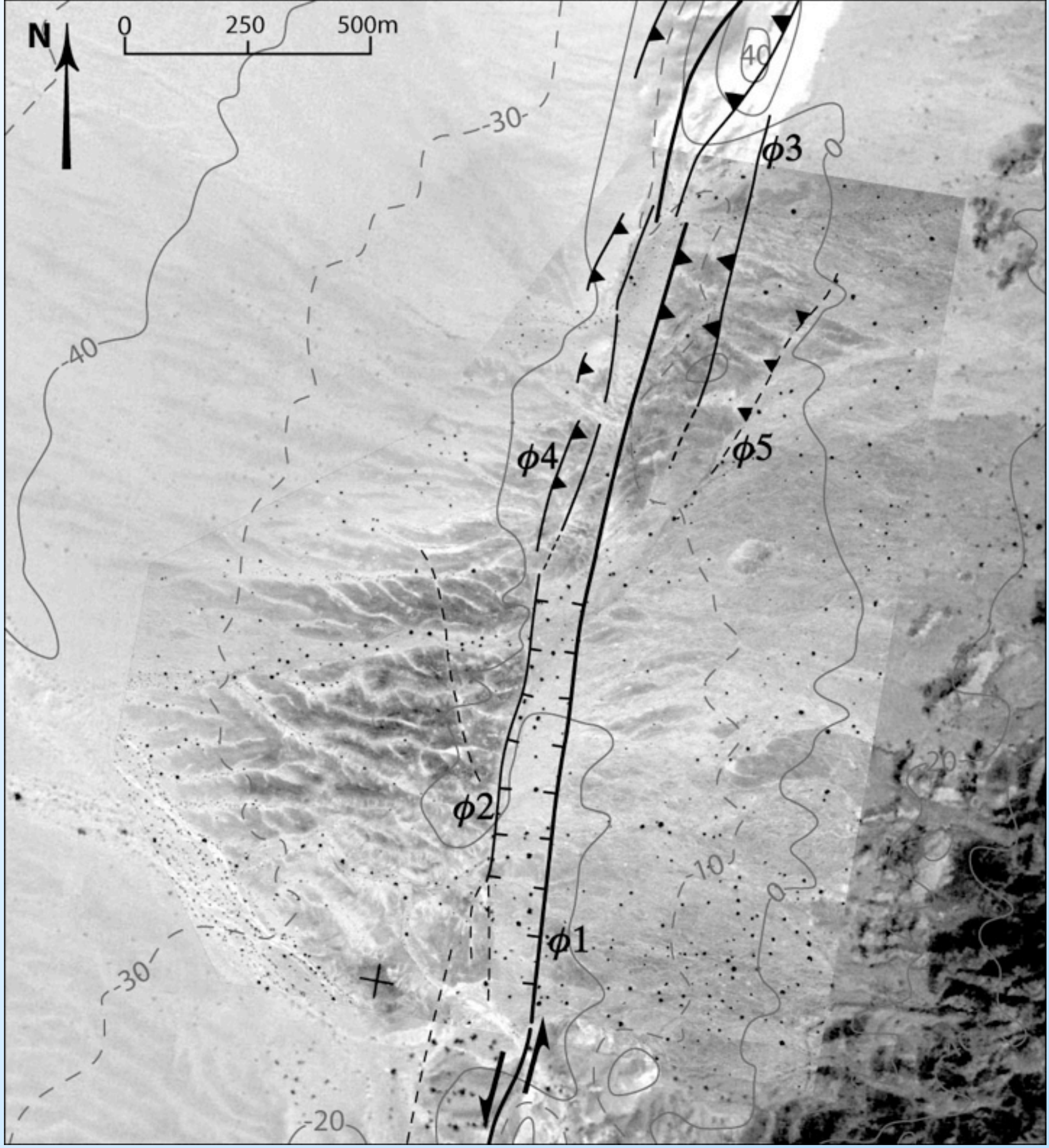
Google Earth overview

The Fidan site



Aerial view superimposed
on SPOT5 image

The Fidan site



Aerial view superimposed on SPOT5 image

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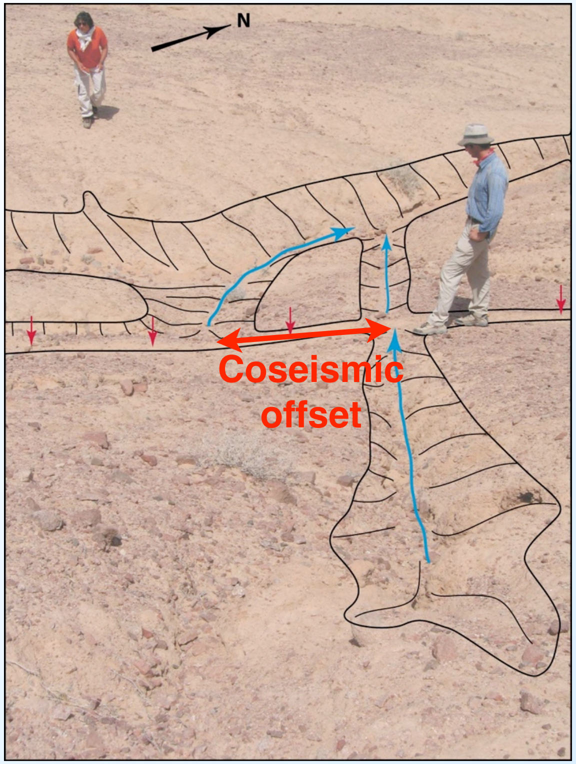

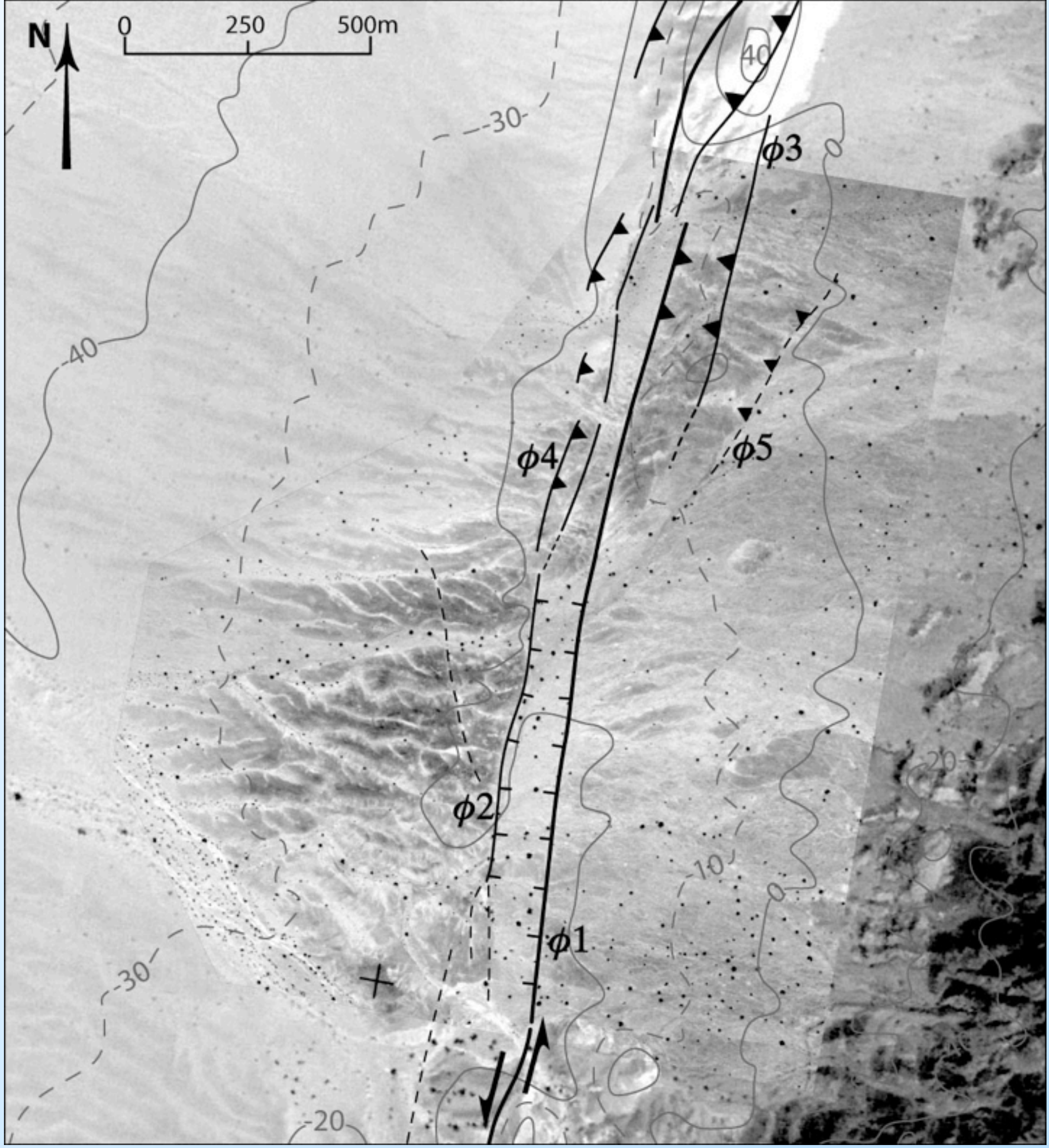

Aerial view superimposed
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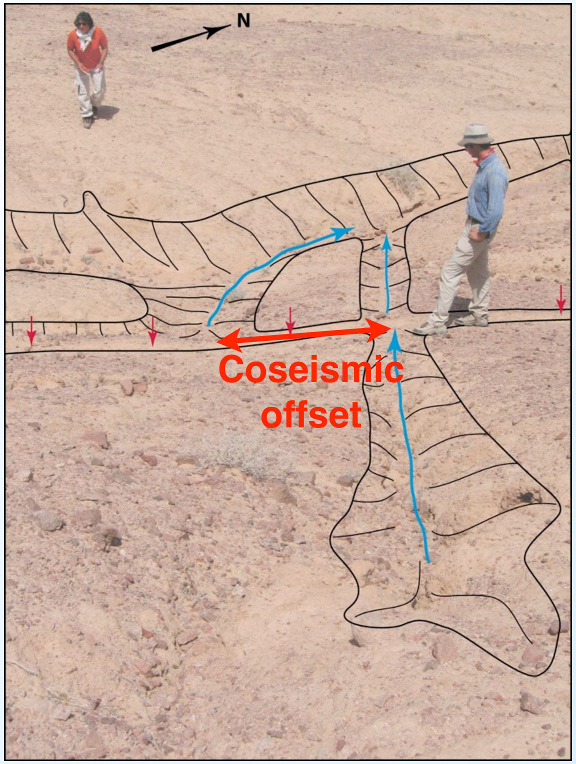
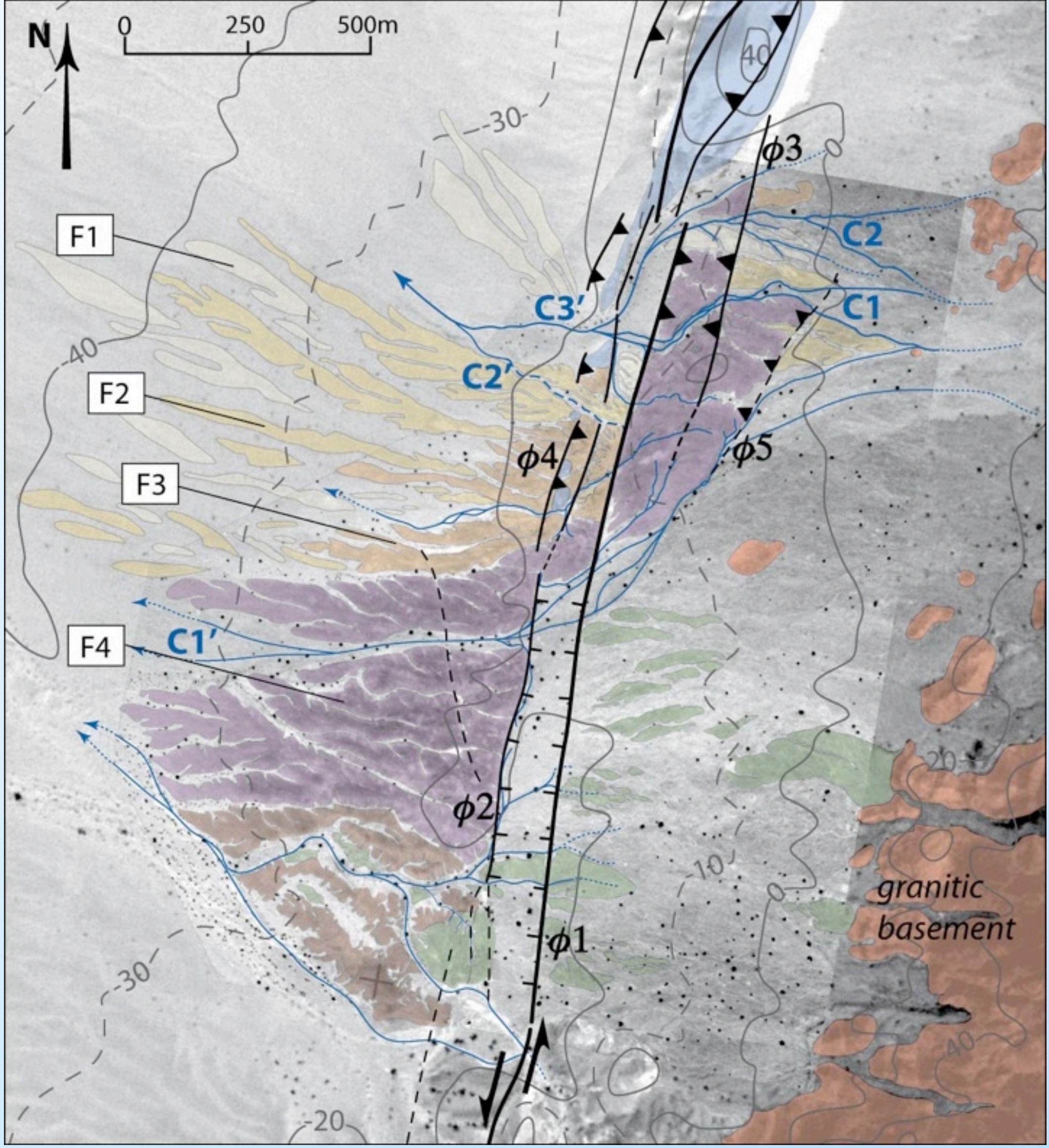
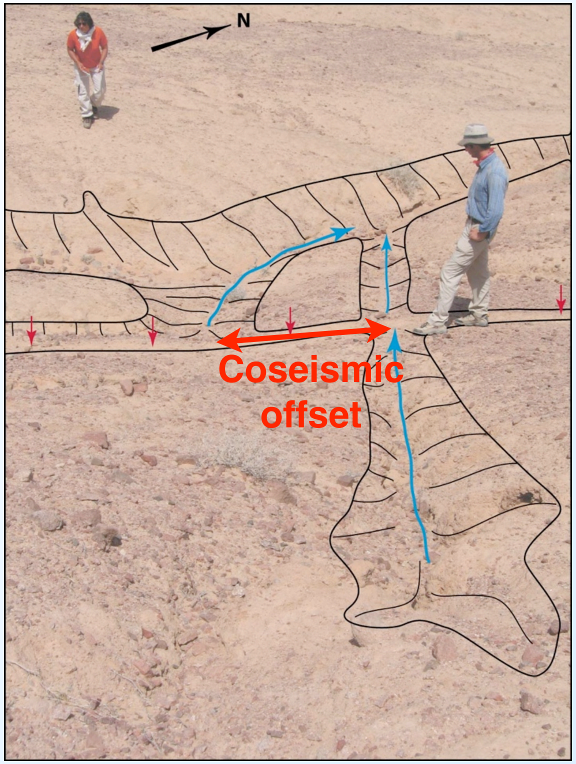
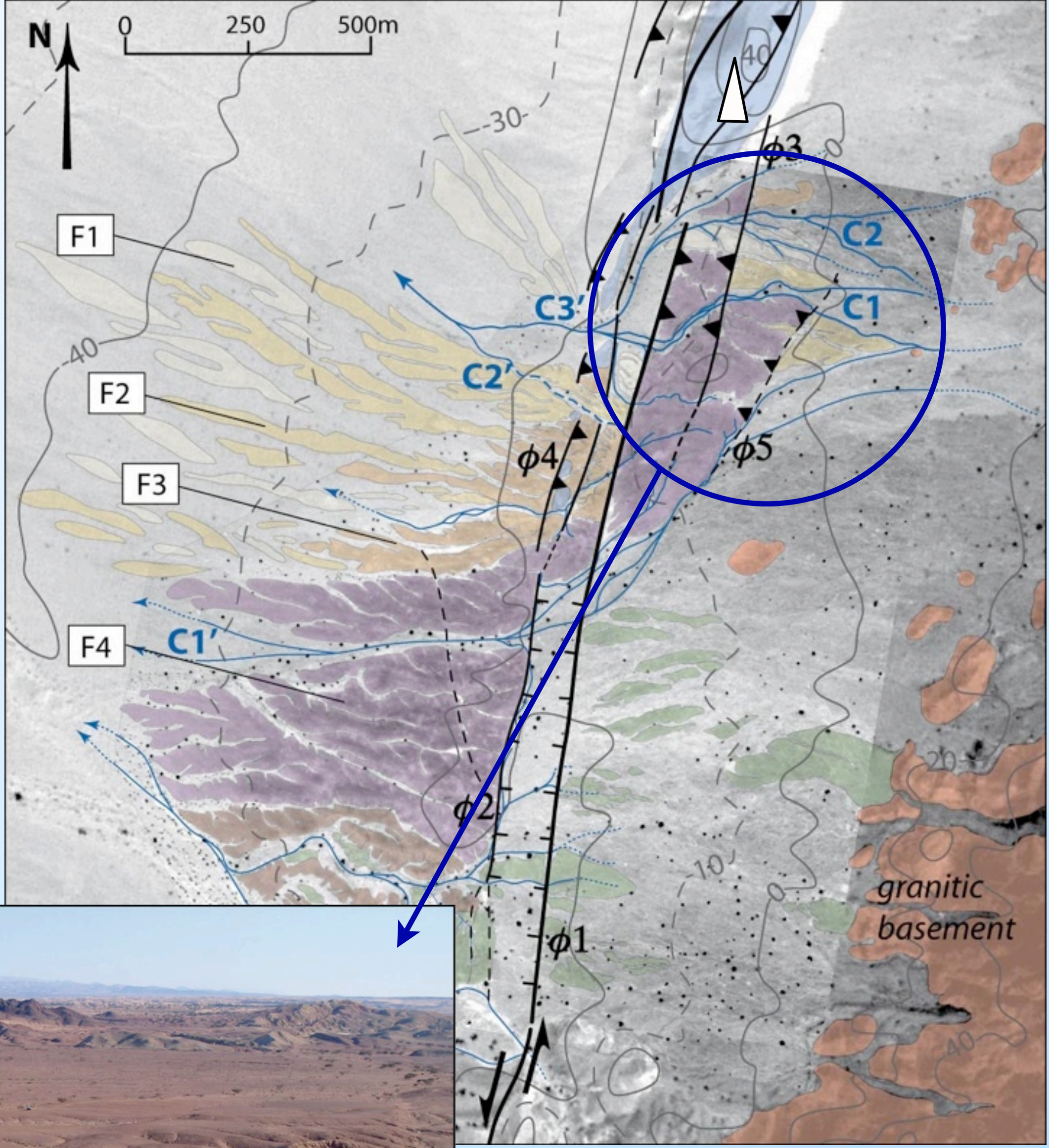




Aerial view superimposed on SPOT5 image

The Fidan site





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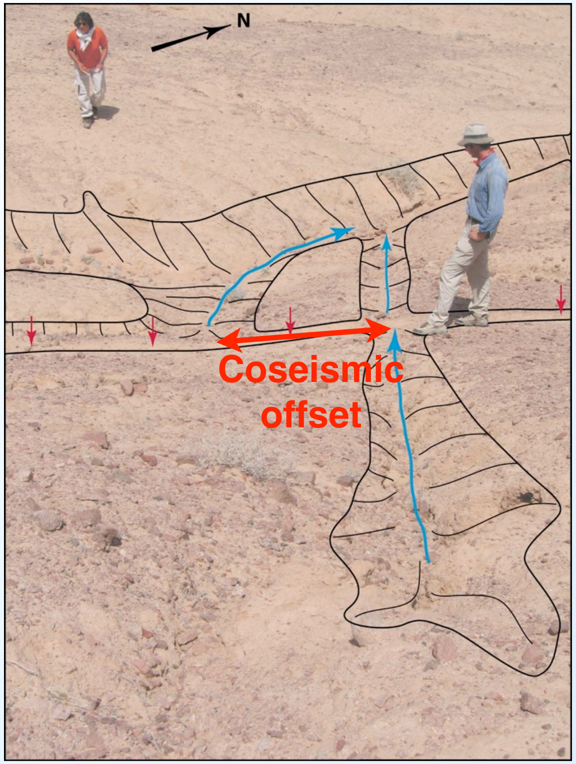
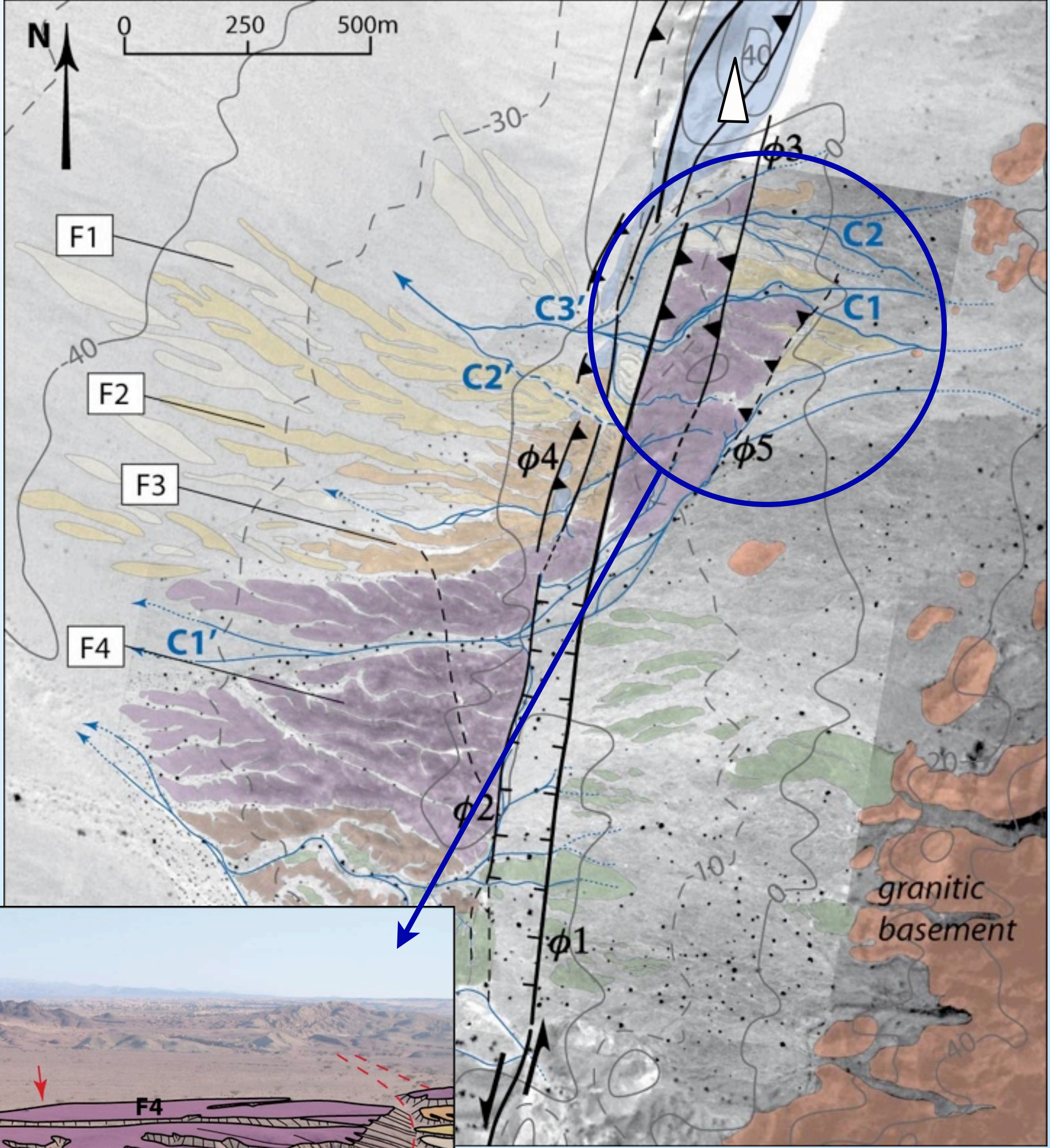
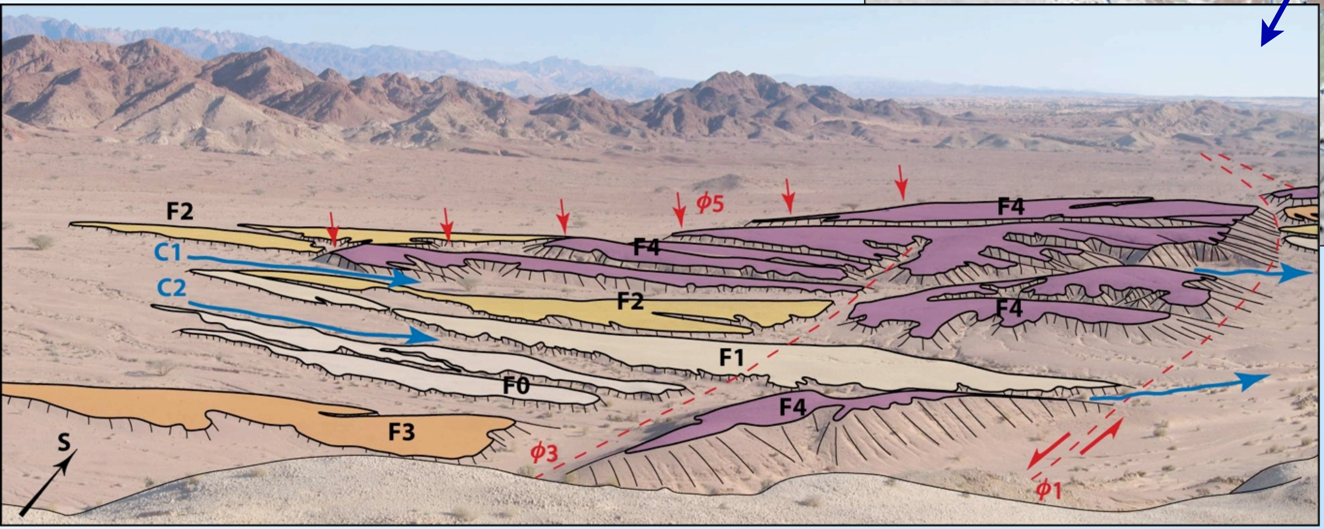
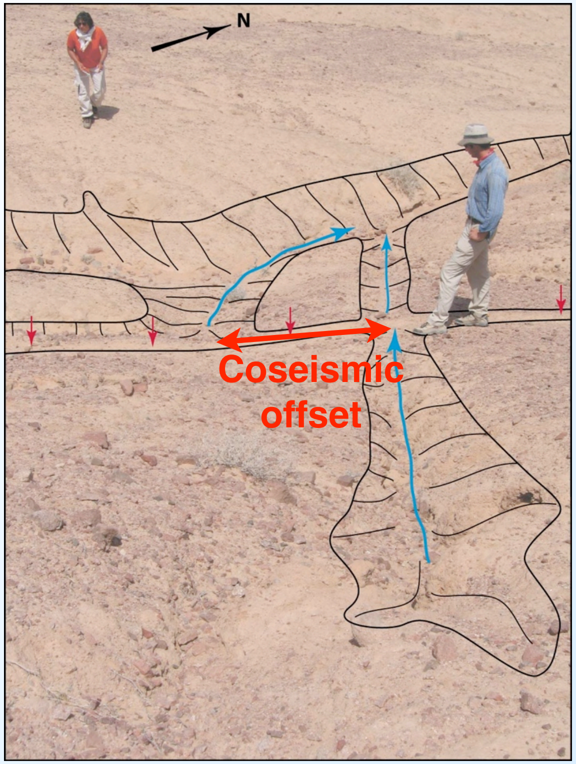


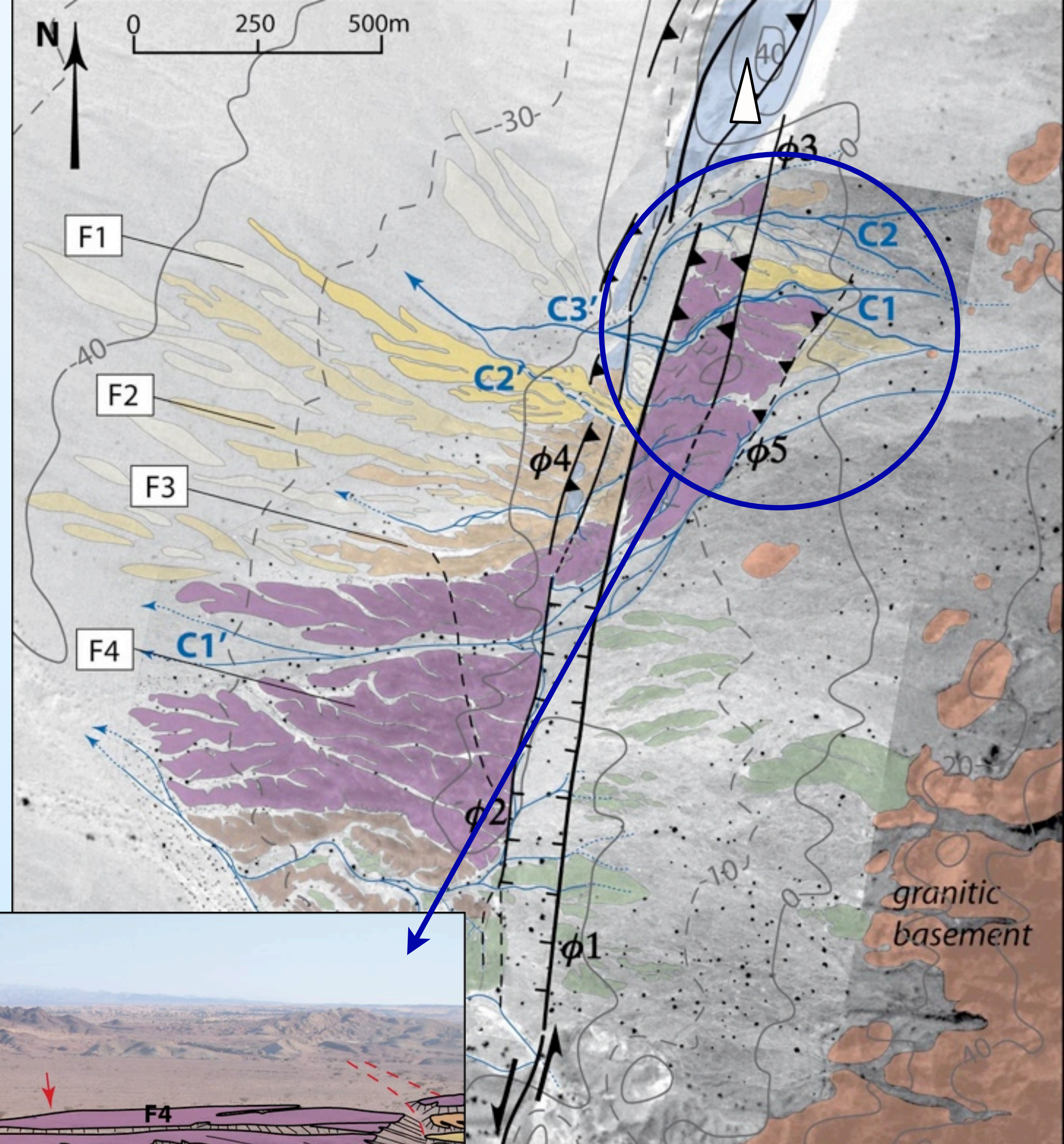


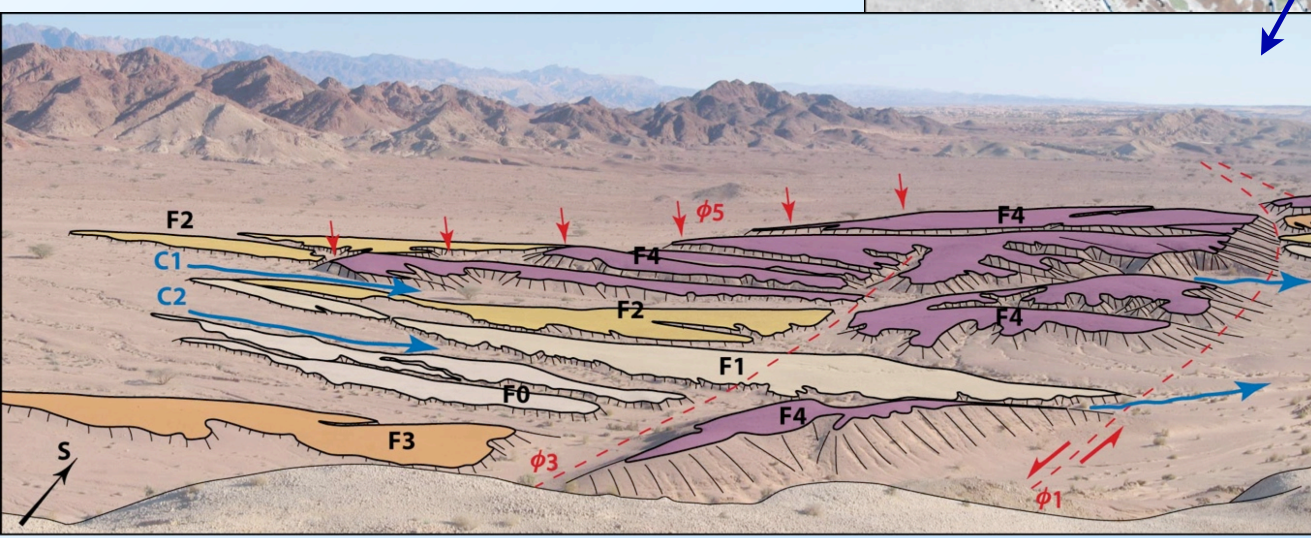


Aerial view superimposed on SPOT5 image

The Fidan site

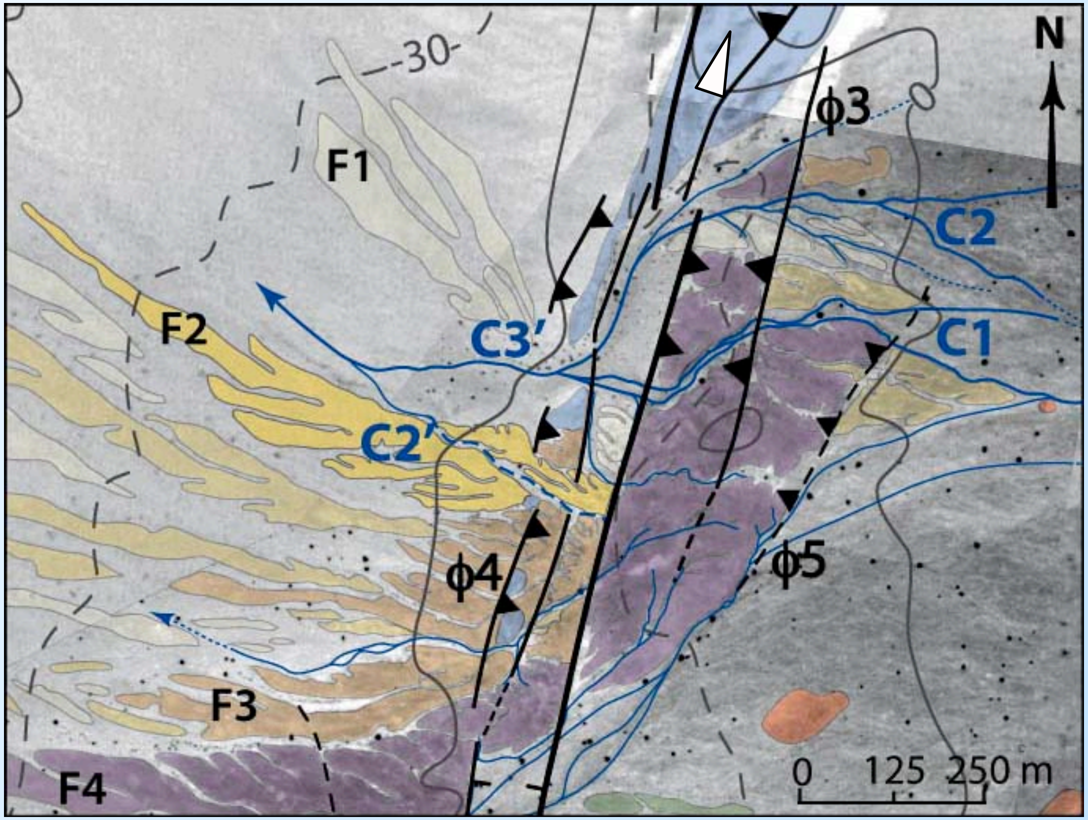


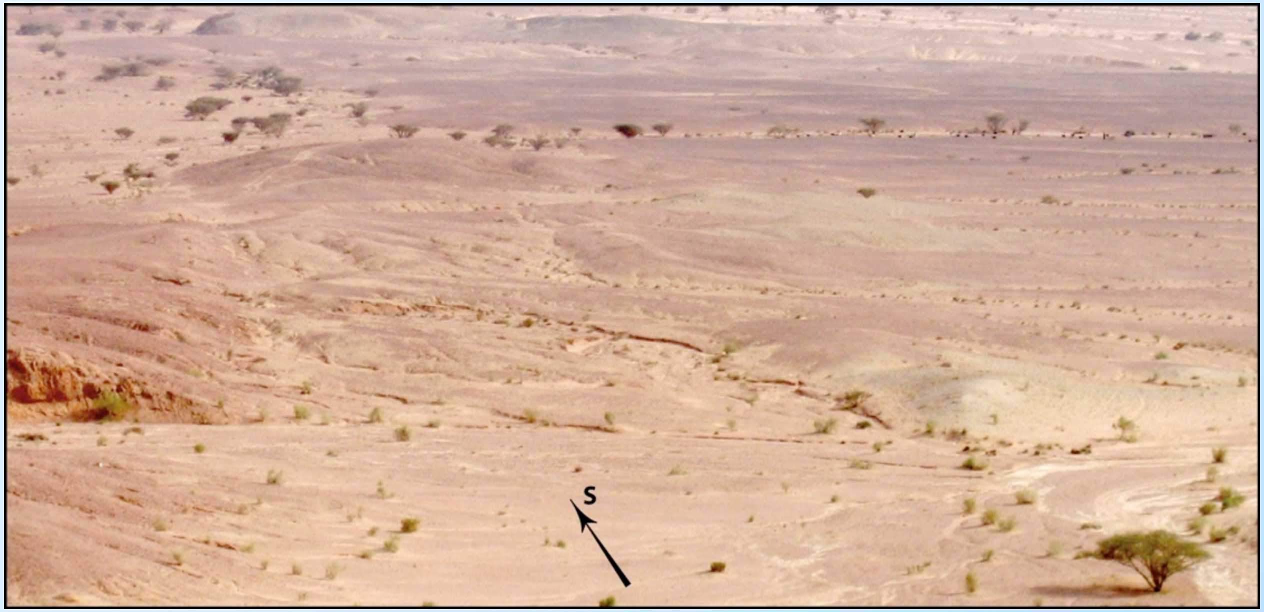




Aerial view superimposed
on SPOT5 image

Offset at Fidan: fan F2





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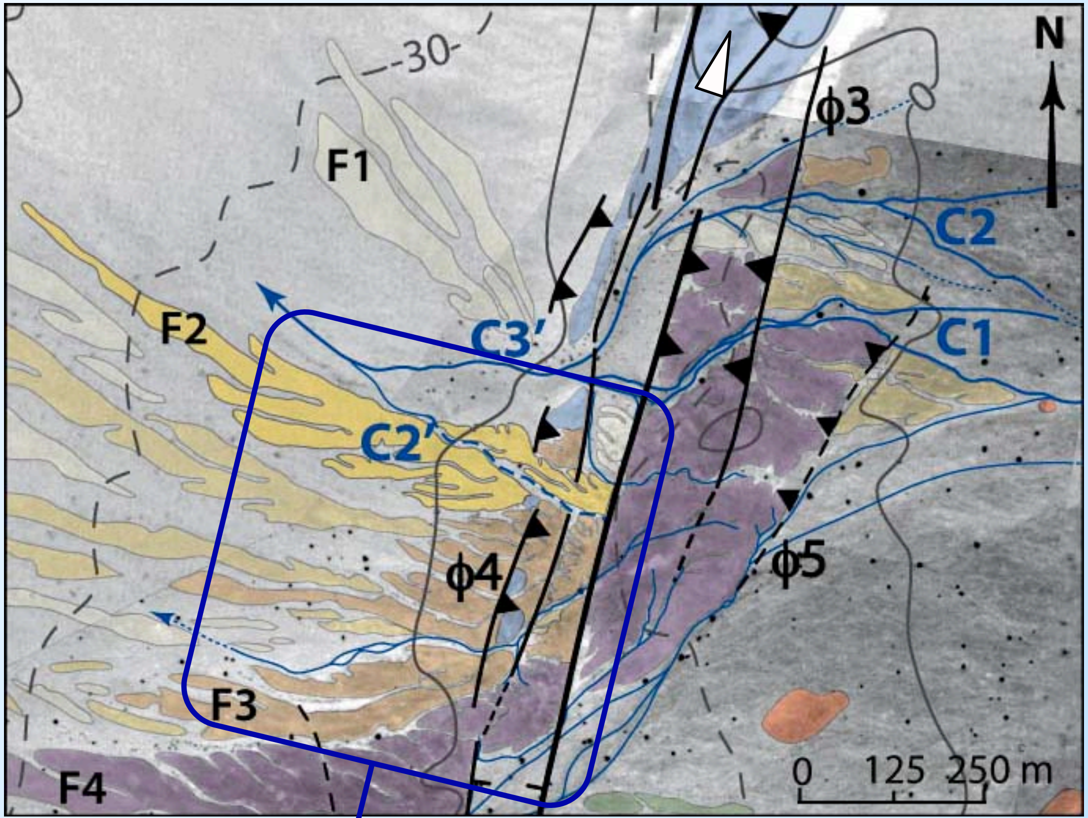

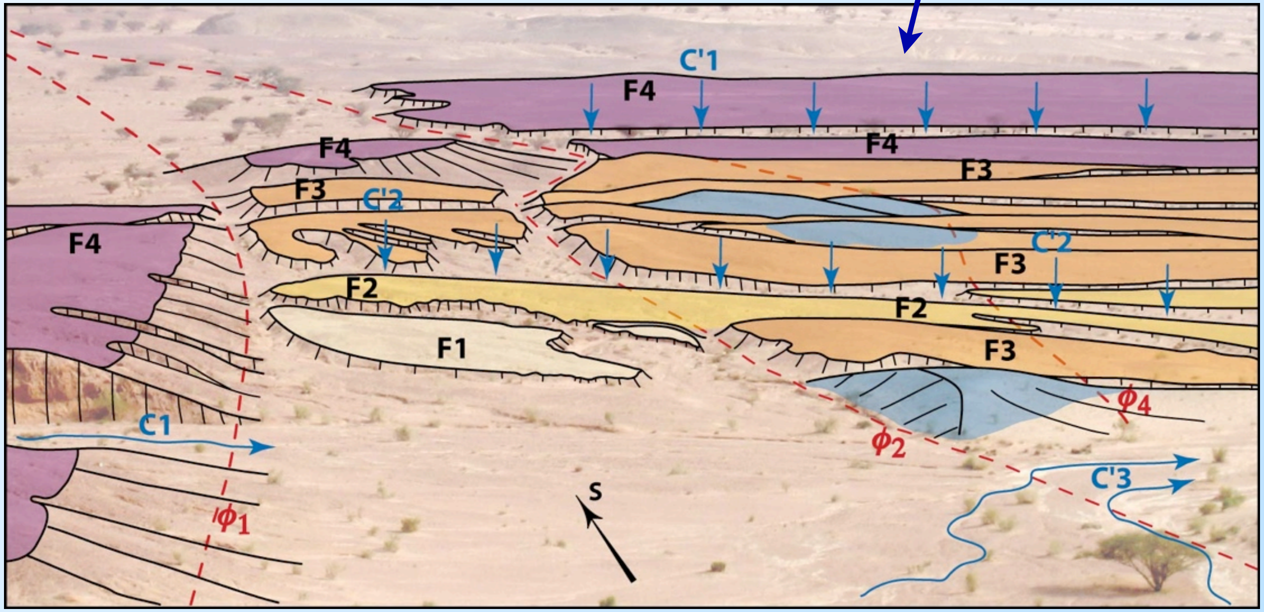

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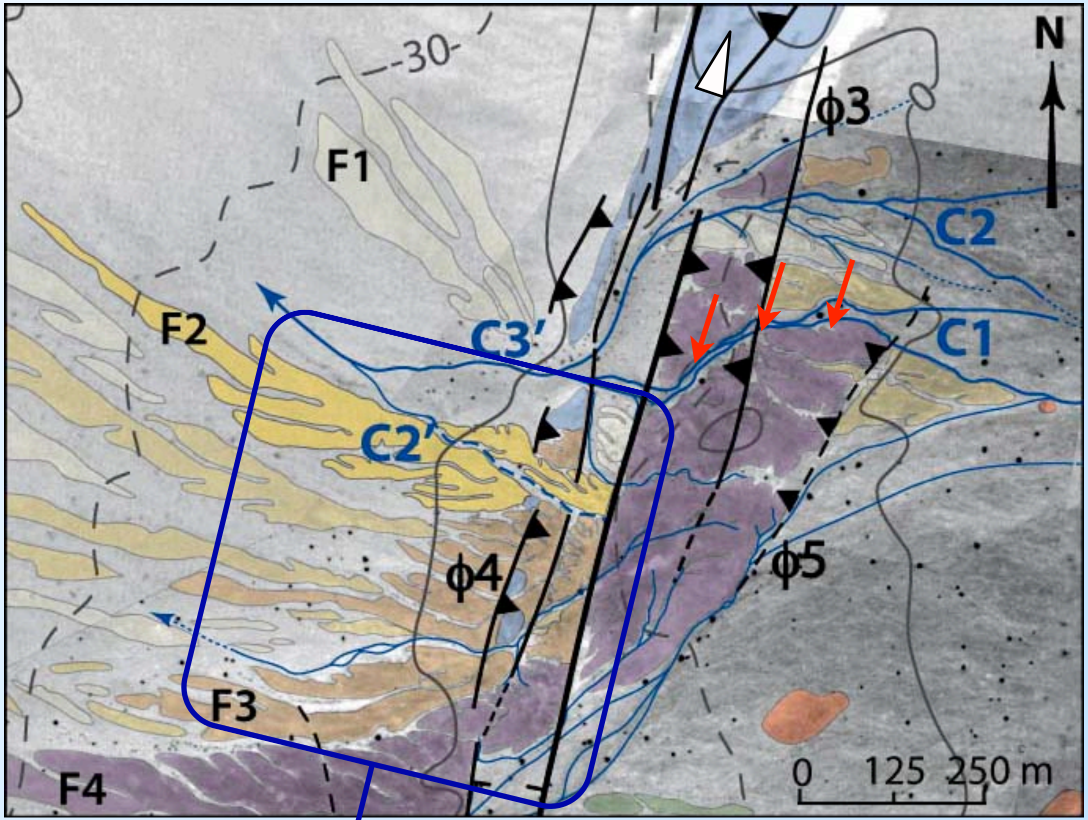

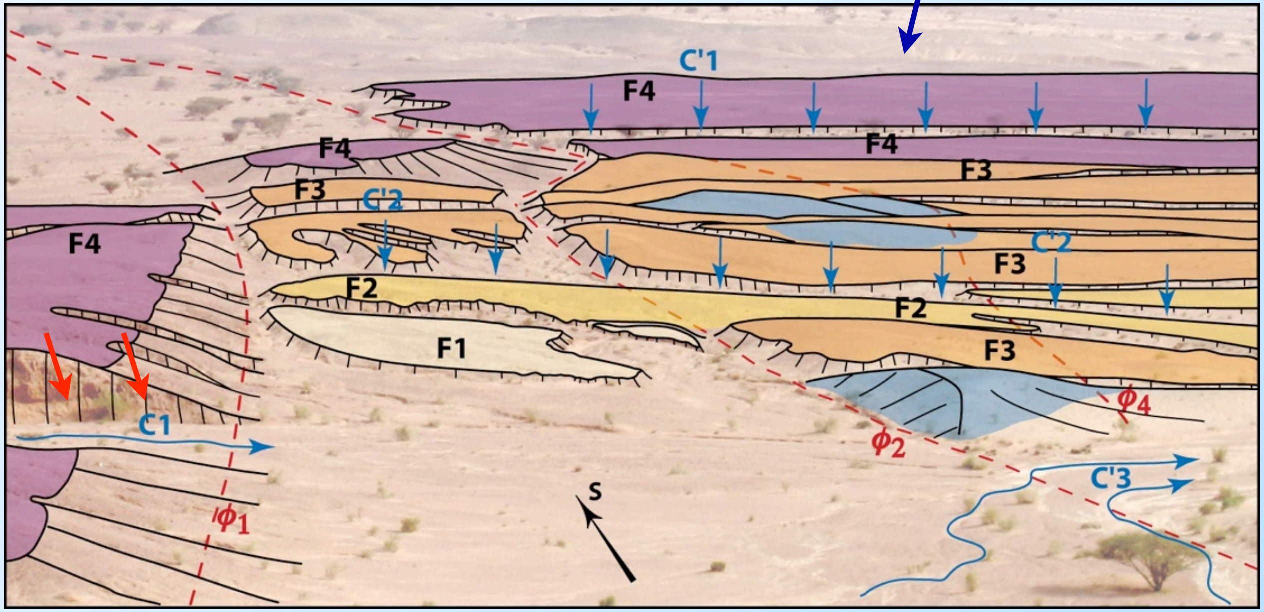

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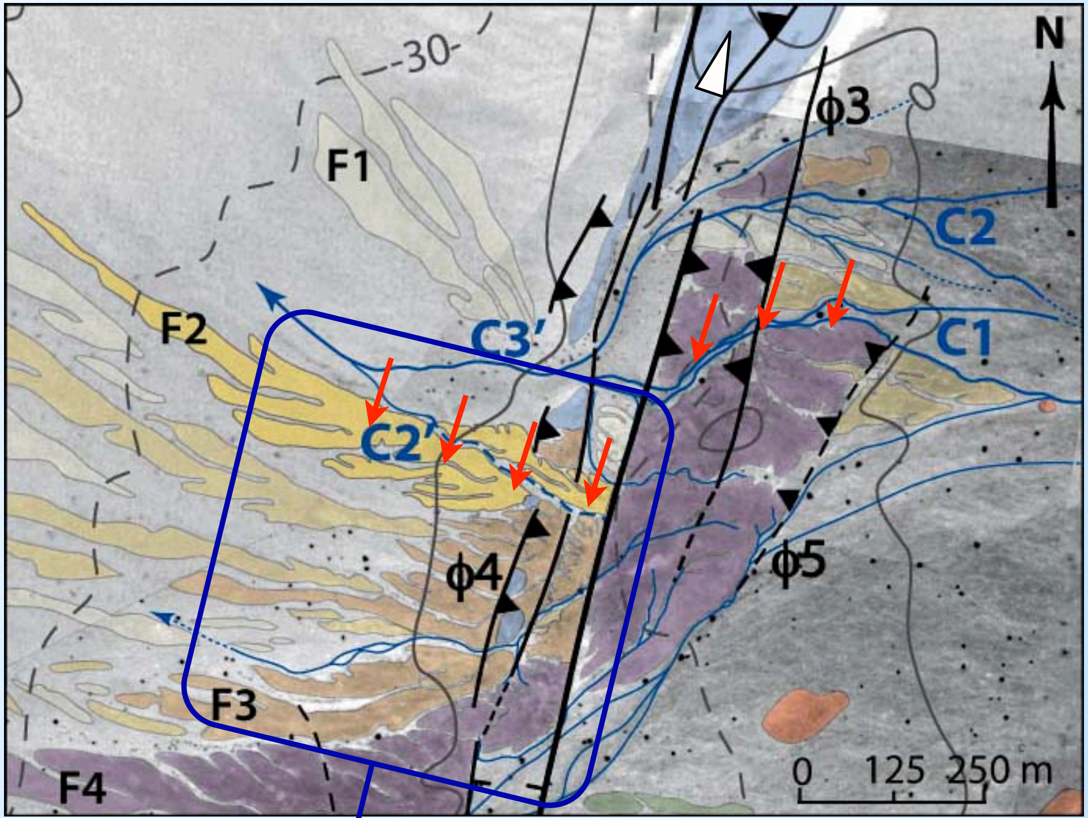
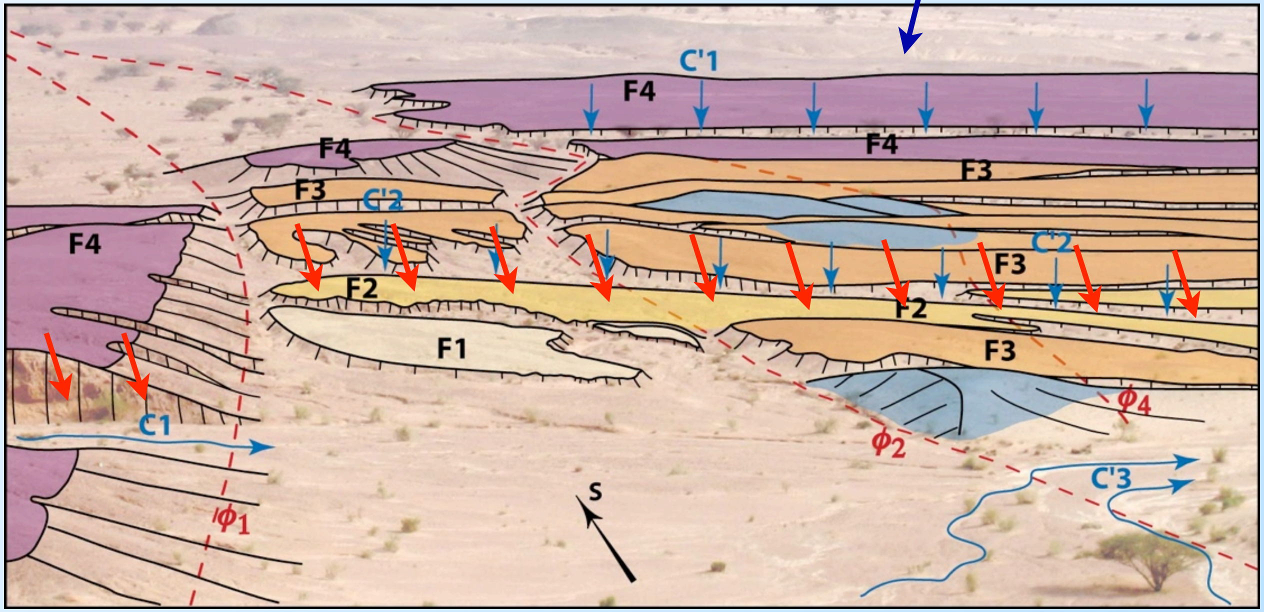
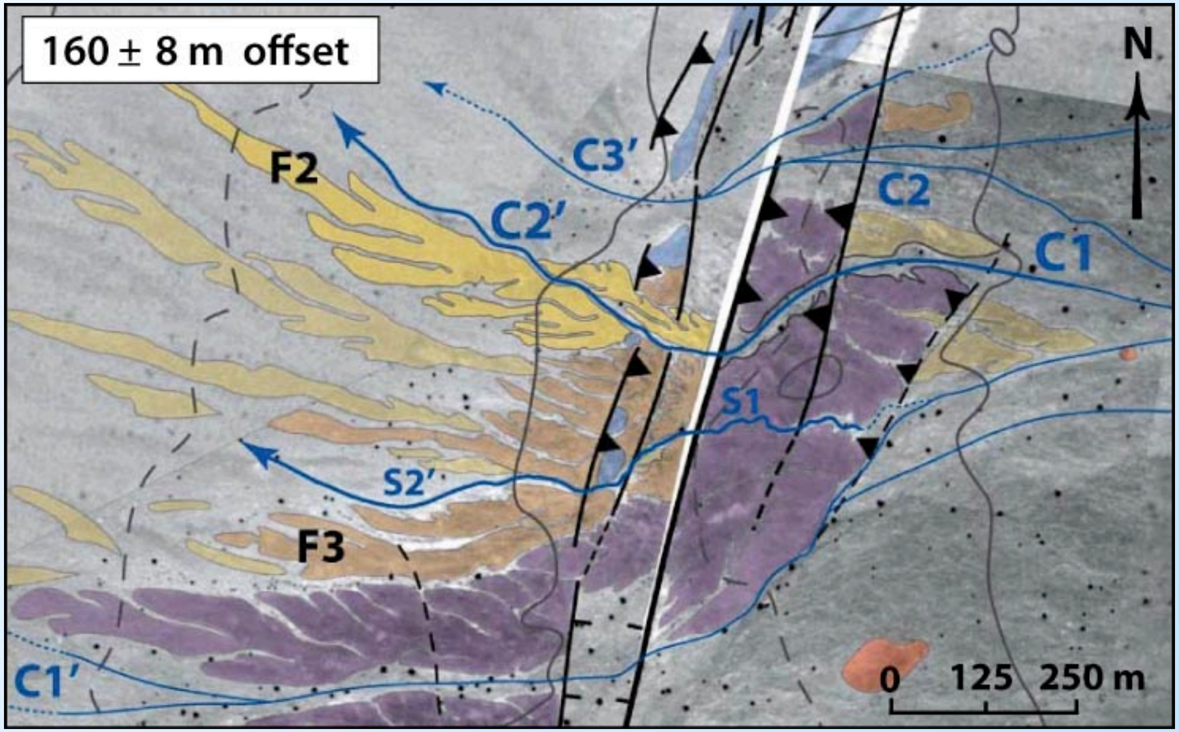
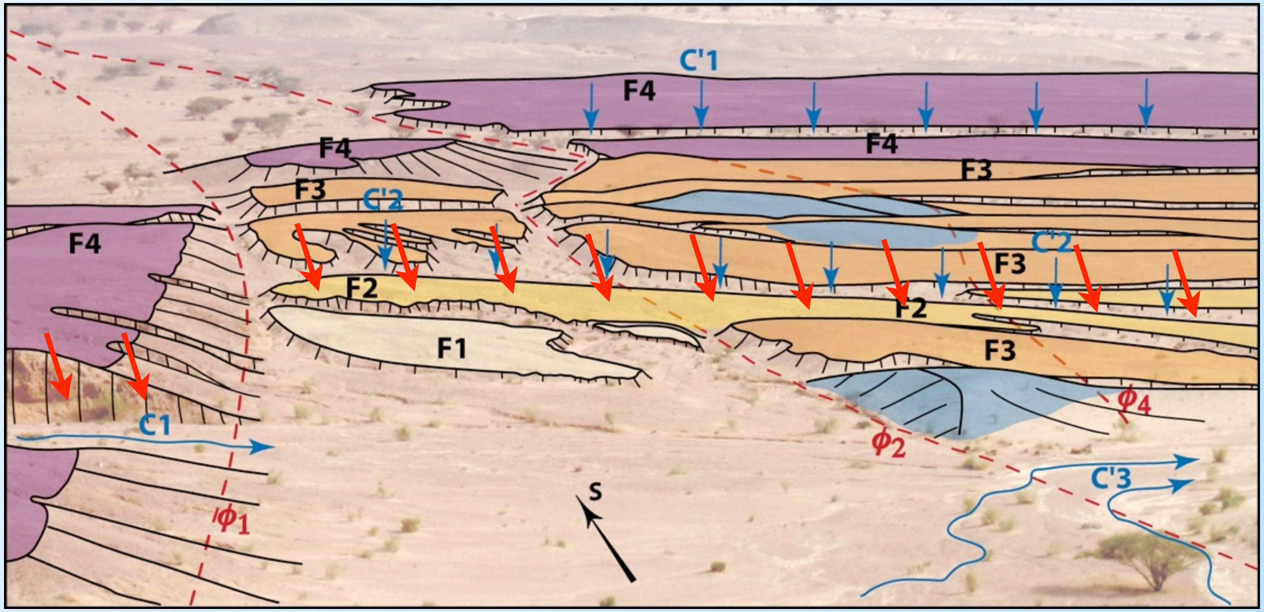


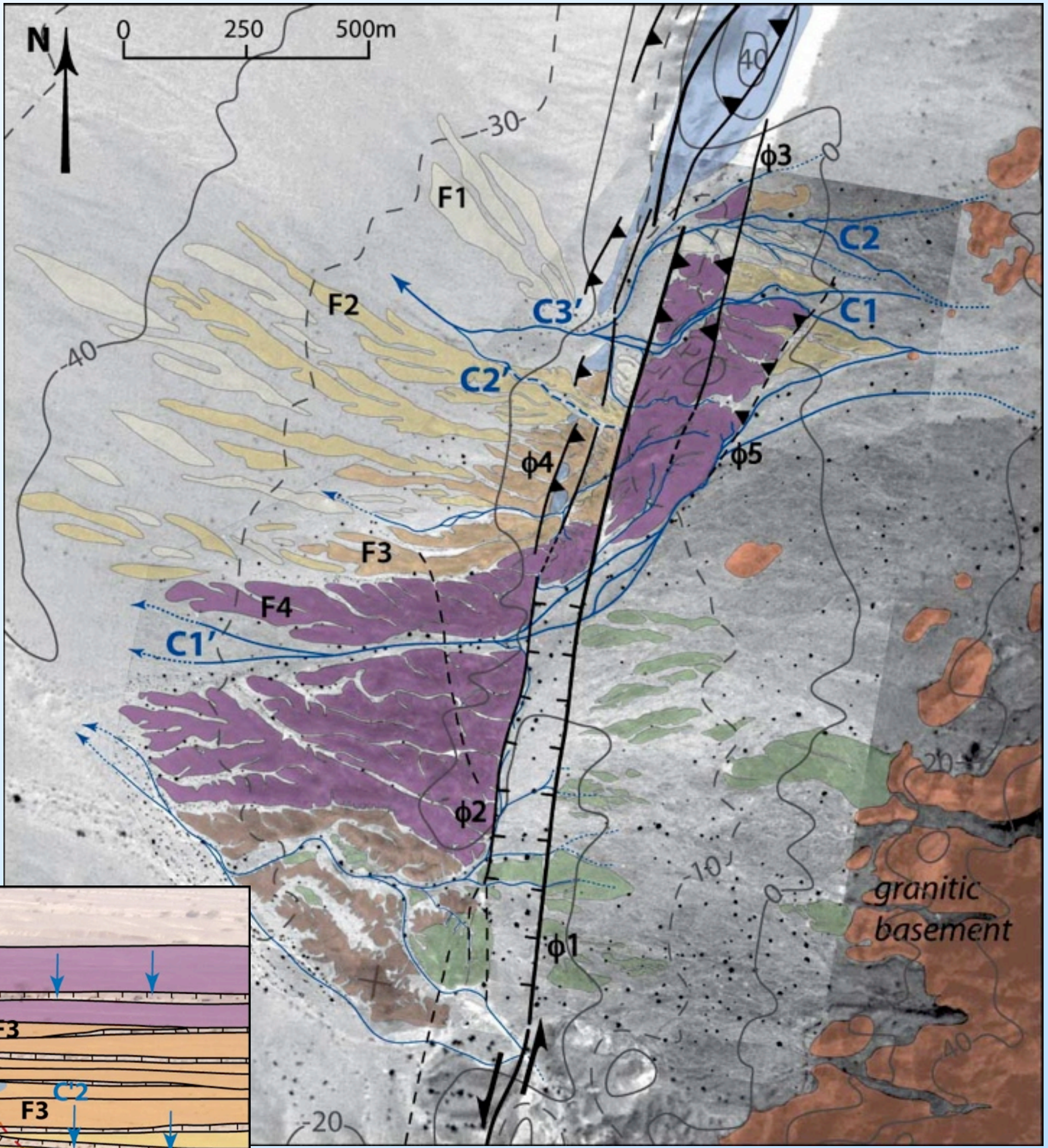


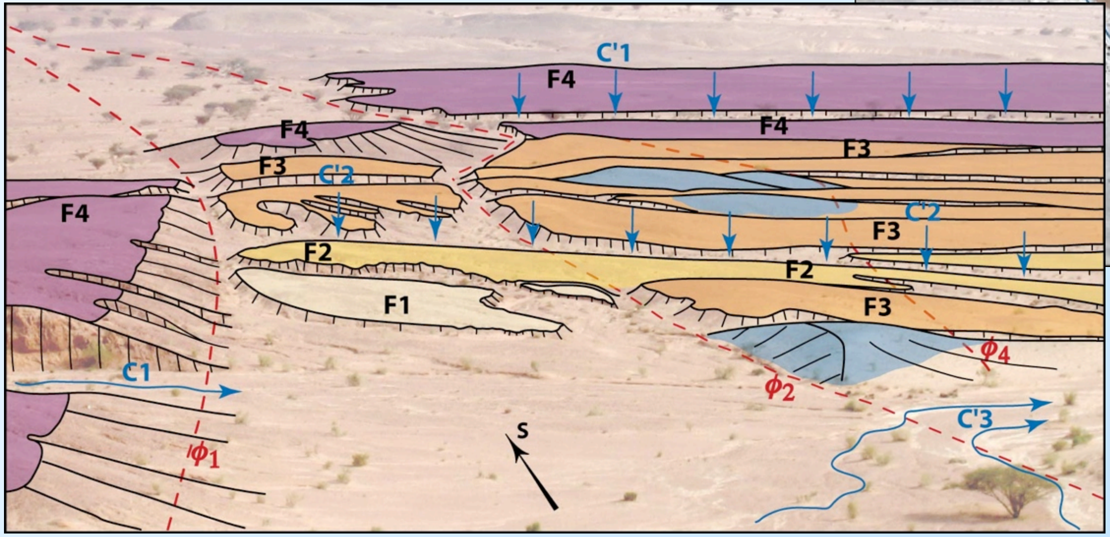
Offset at Fidan: fan F2



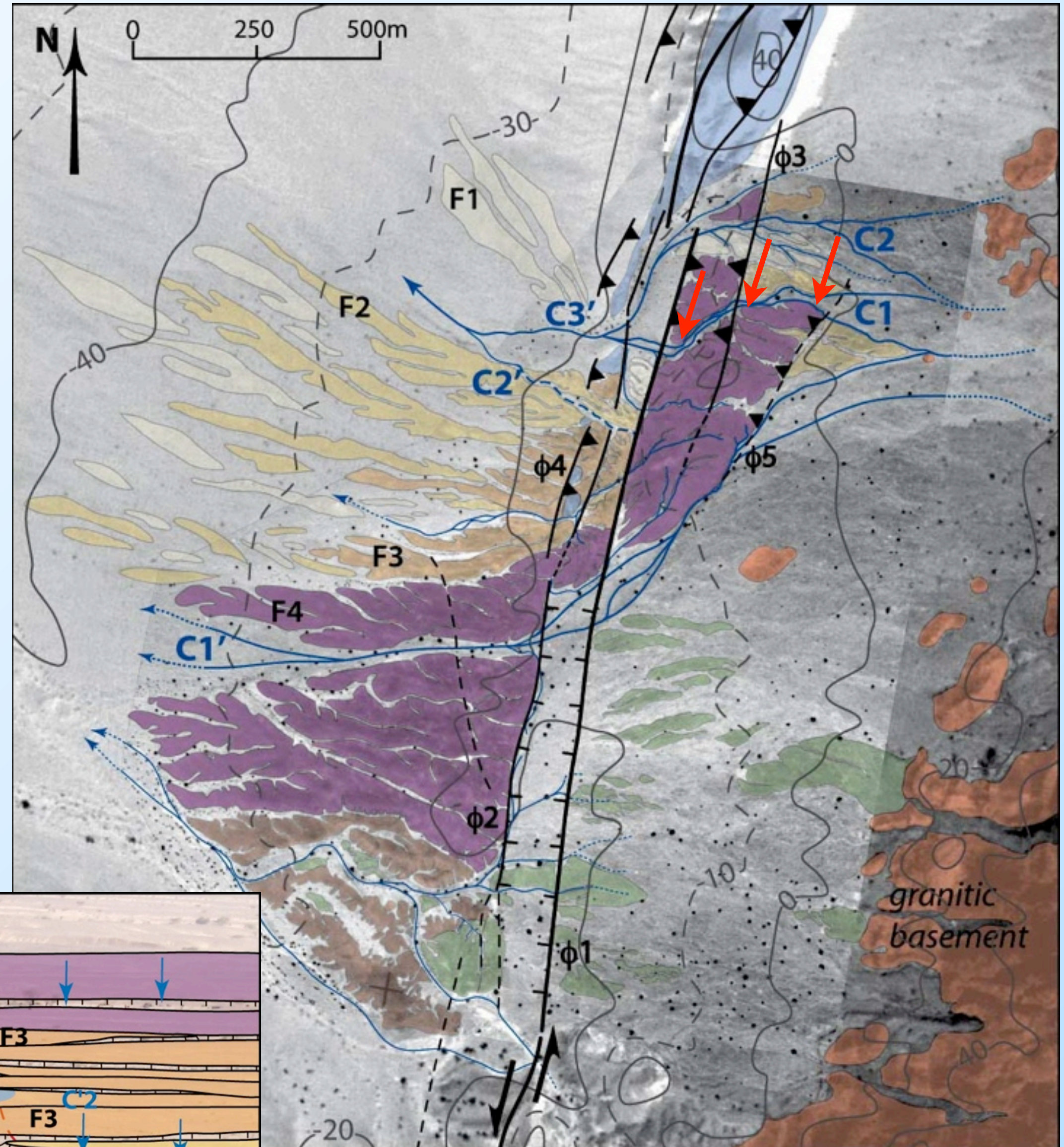


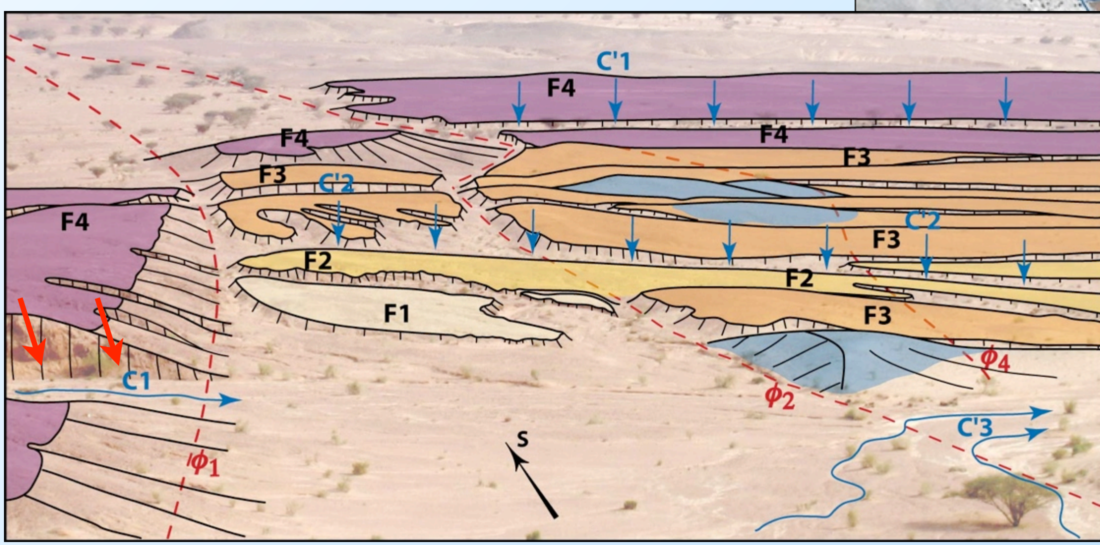
Offset at Fidan: fan F4



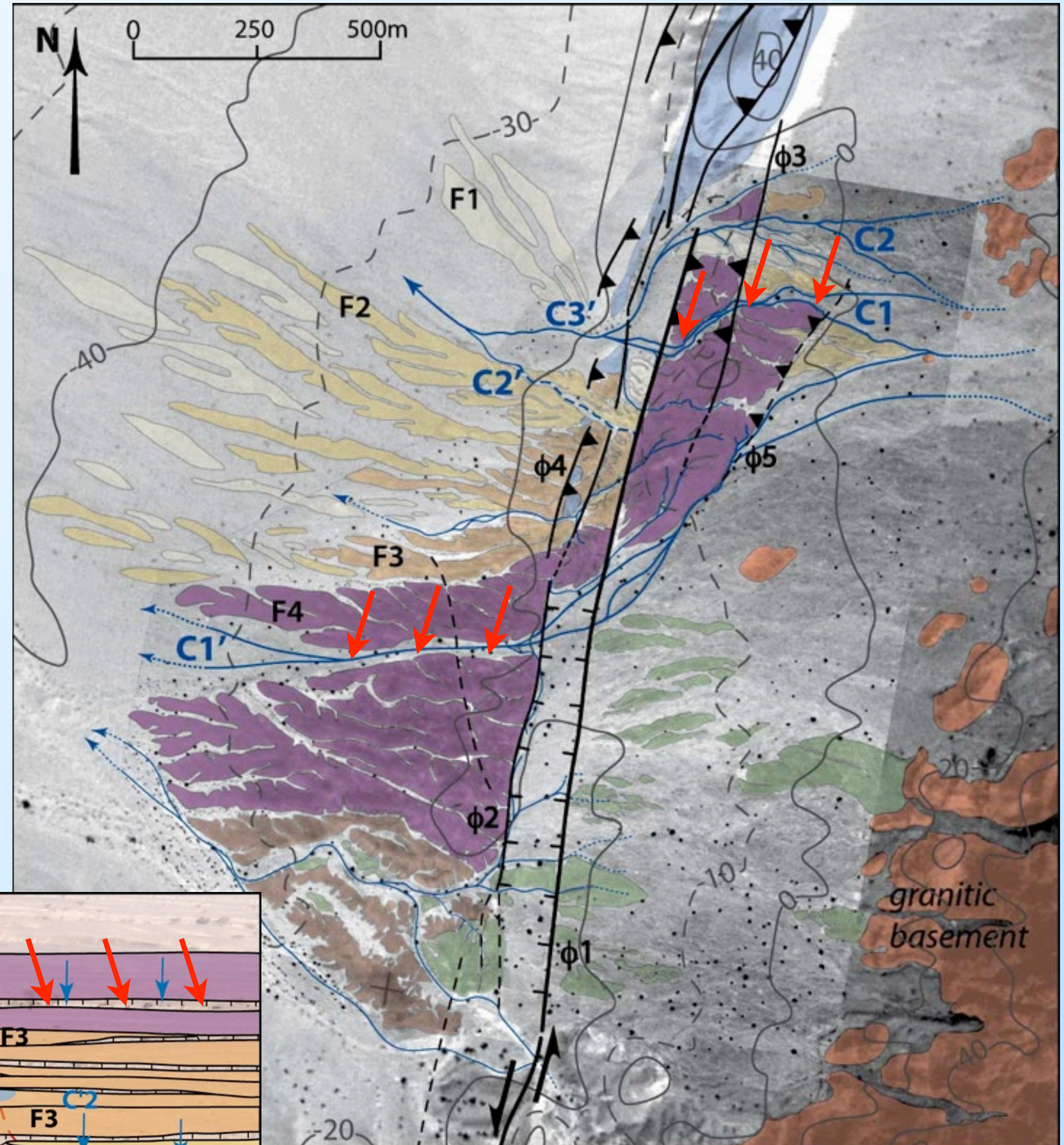


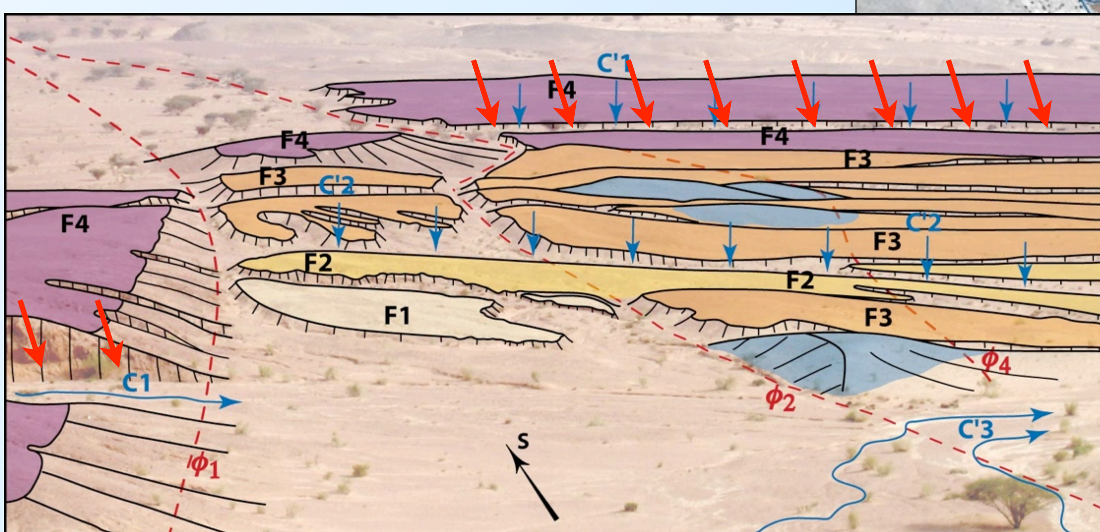
Offset at Fidan: fan F4





Offset at Fidan: fan F4





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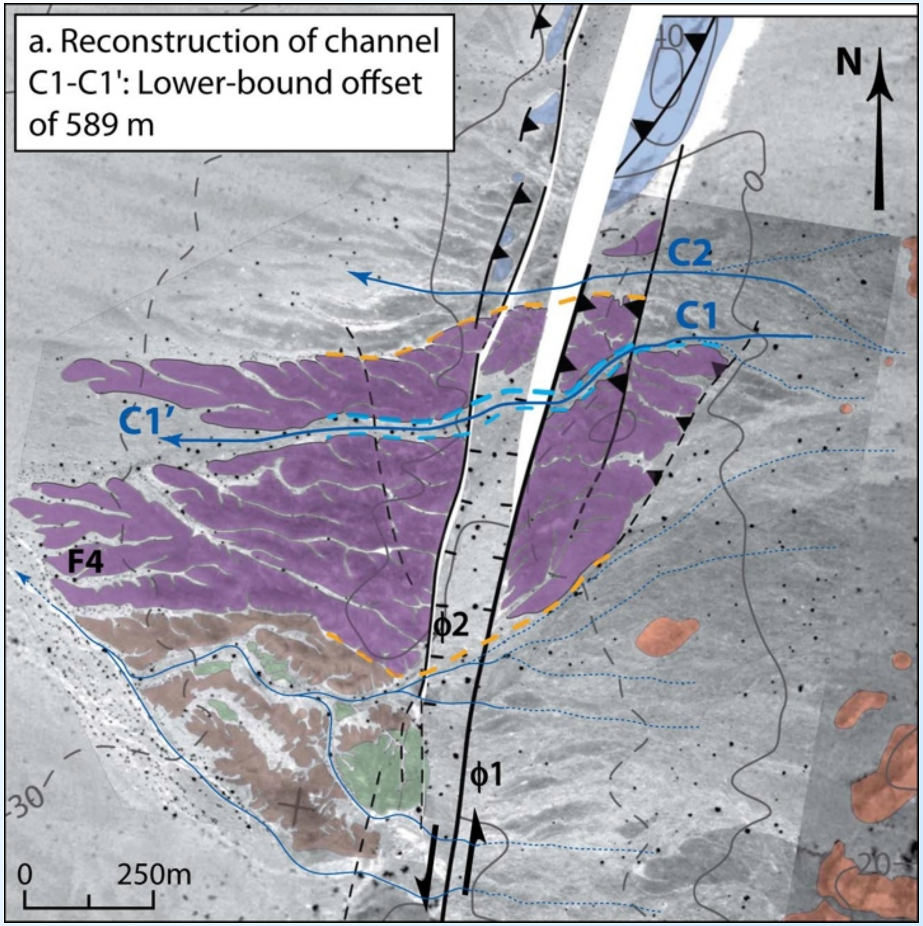
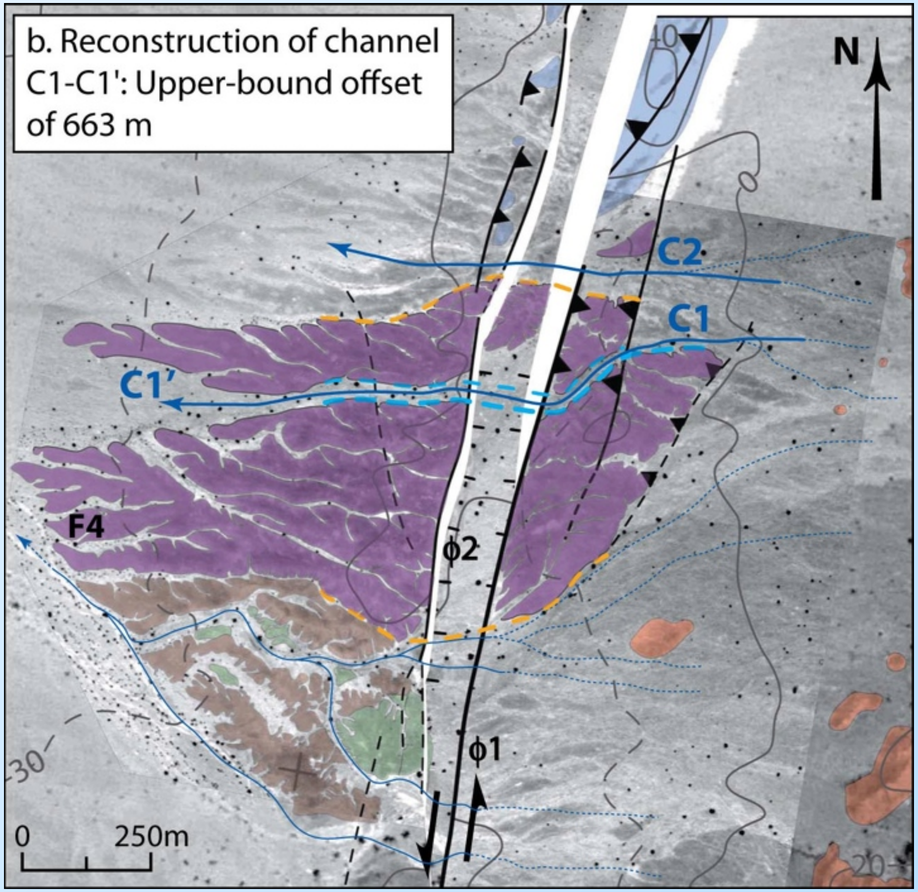
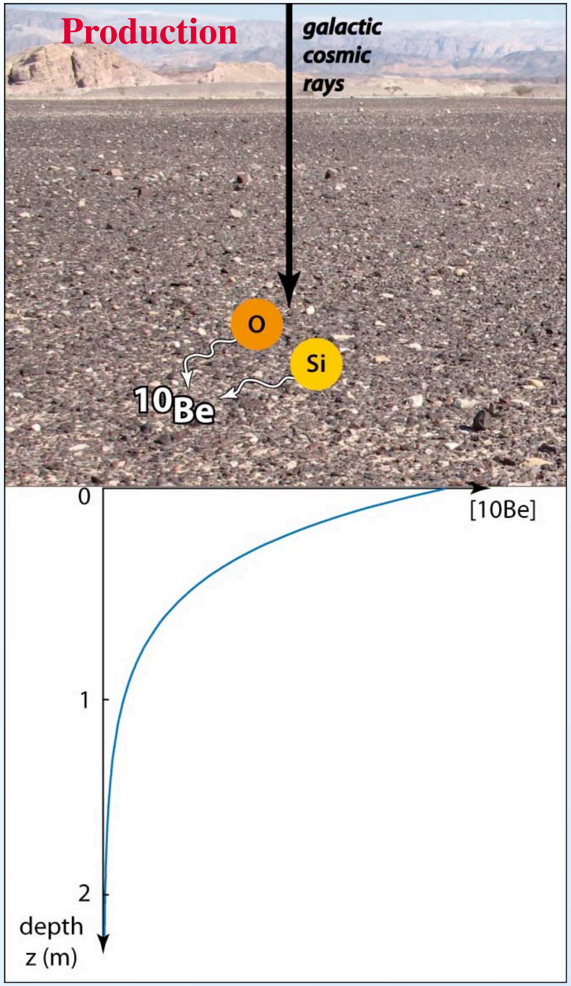




Offset of **626 ± 37 m**

About cosmogenic dating



Ages calculated with G. Balco's program

using Lal (1991) production rate

and Stone (2000) scaling factors.

(http://hess.ess.washington.edu/math/)

Pre-exposure **Production** **Decay**

$$\mathcal{N}_{10Be}(z,t) = \boxed{\mathcal{N}_{10Be,t_0}} + \boxed{\frac{\mathcal{P}\exp(-\mu z)}{\lambda+\mu\varepsilon}\Big(1} \boxed{-\exp(-(\lambda+\mu\varepsilon)t)}\Big)$$

$\mathcal{N}_{10Be}$: number of atoms $\mathcal{N}_{10Be,t_0}$: pre-exposure

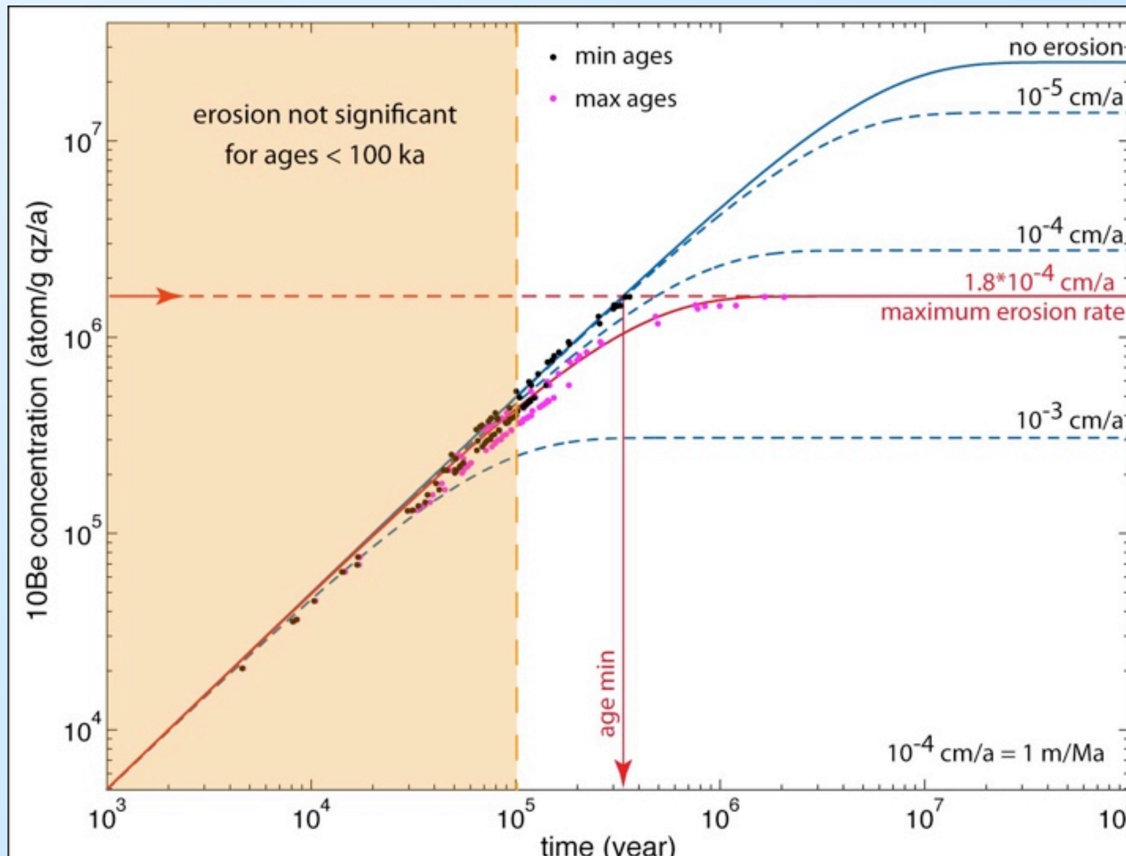
$\mathcal{P}$: production rate in at / g (qz) / yr

λ : half-life $\mu = \rho/\Lambda$

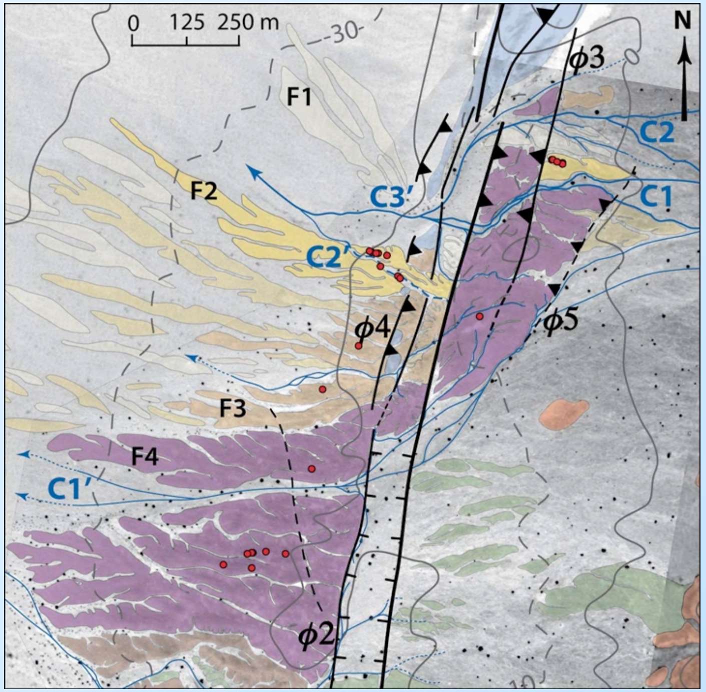
ε : erosion rate

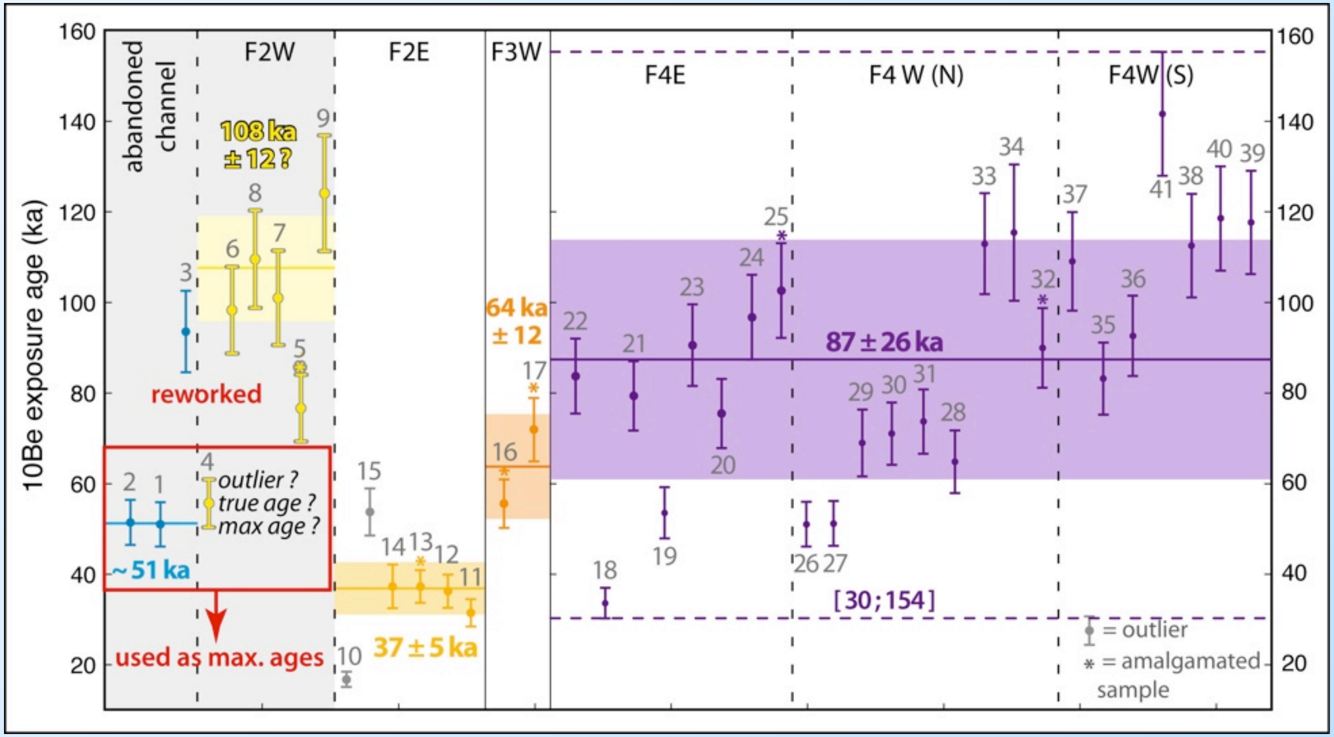
Lal (1991)

Assuming no erosion and no pre-exposure : $\mathcal{N}_{10Be}(z,t) = \frac{\mathcal{P}\exp(-\mu z)}{\lambda}\left(1 - \exp(-\lambda t)\right)$

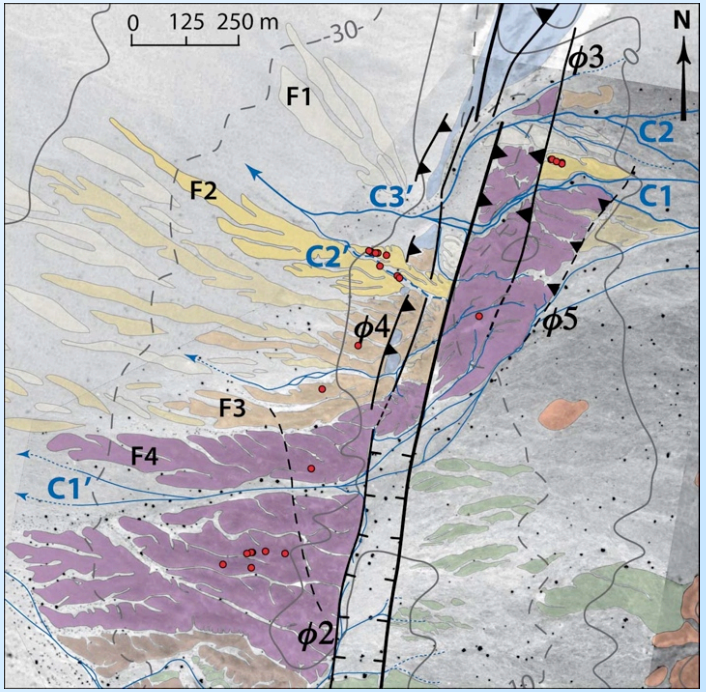


^{10}Be exposure ages

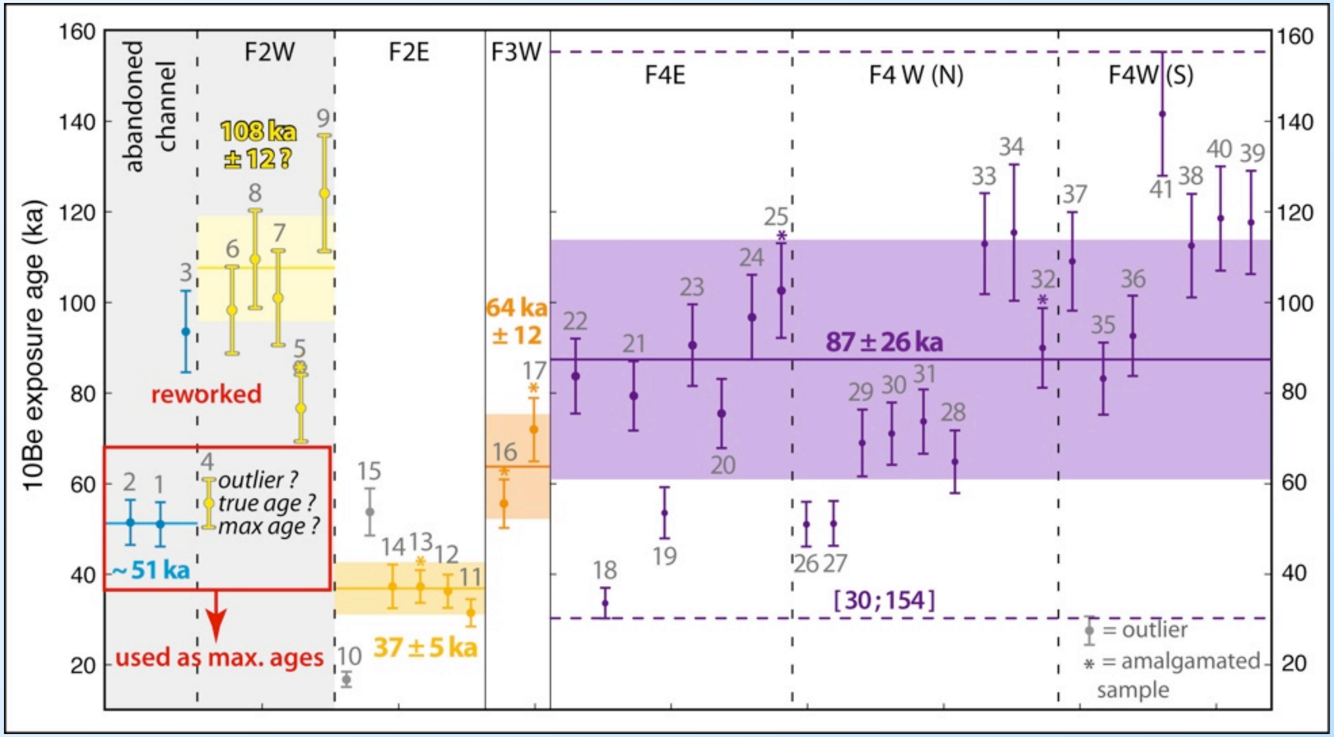




Long-term fault slip rates at Fidan



Le Béon et al, 2010, JGR



Long-term fault slip rates at Fidan

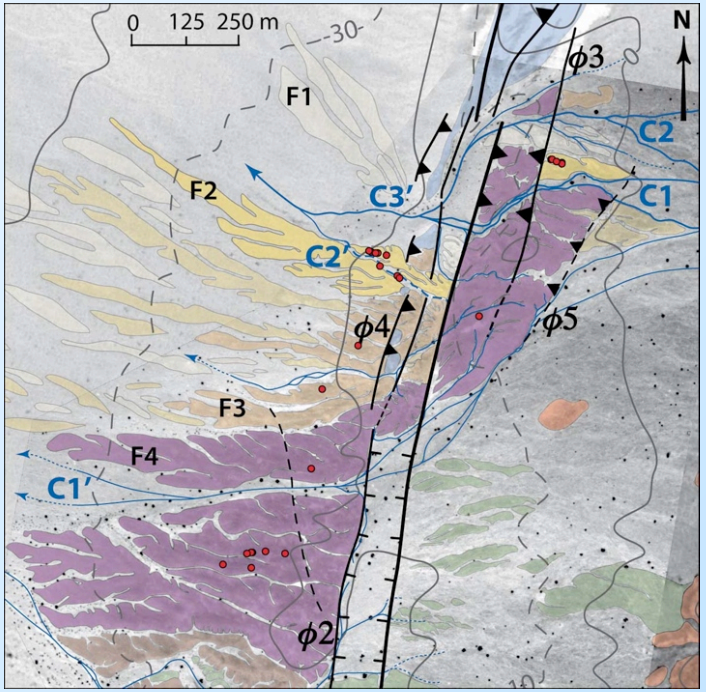
- Fan F2 :

Minimum slip rate of 3.2 ± 0.5 mm/a since 51 ka

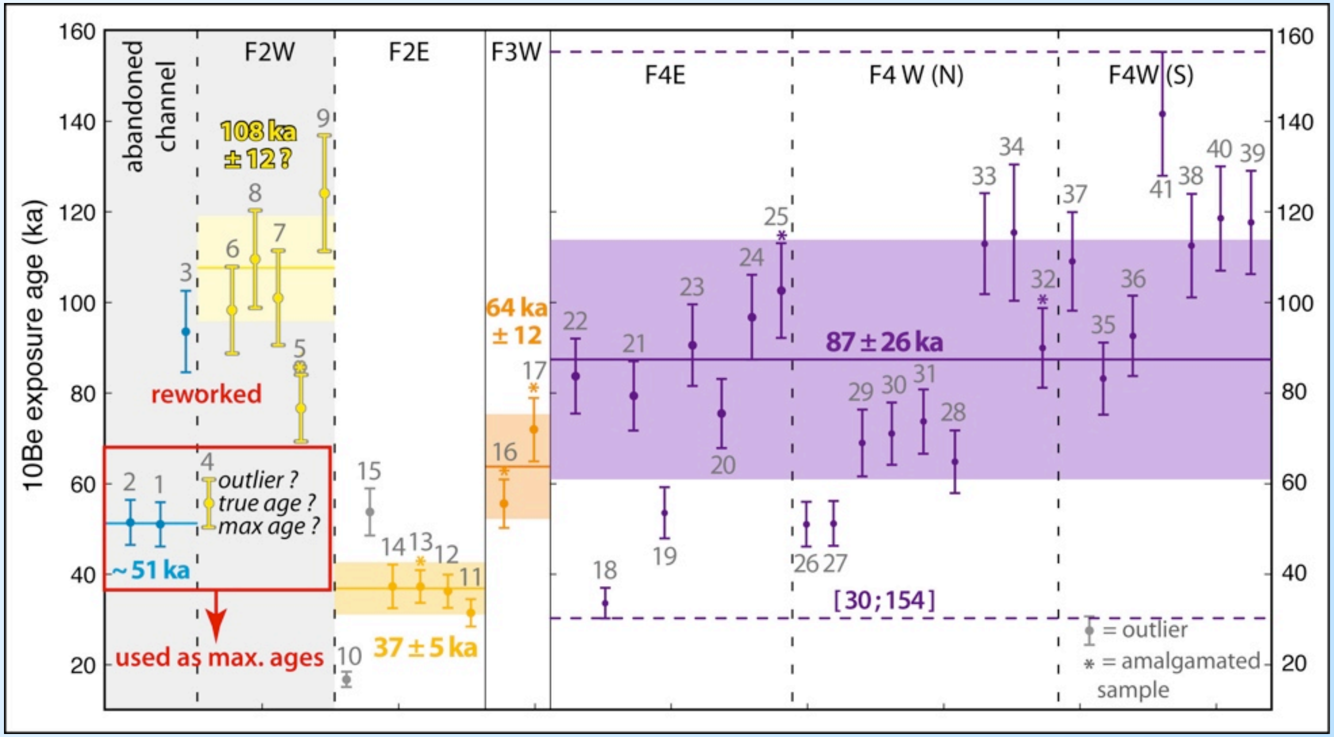
(minimum) slip rate of **4.5 ± 0.9 mm/a since 37 ka**

- Fan F4 :

(minimum) slip rate of **8.1 ± 2.9 mm/a since 87 ka,** with a full range of 3.8-22.1 mm/a



Le Béon et al, 2010, JGR



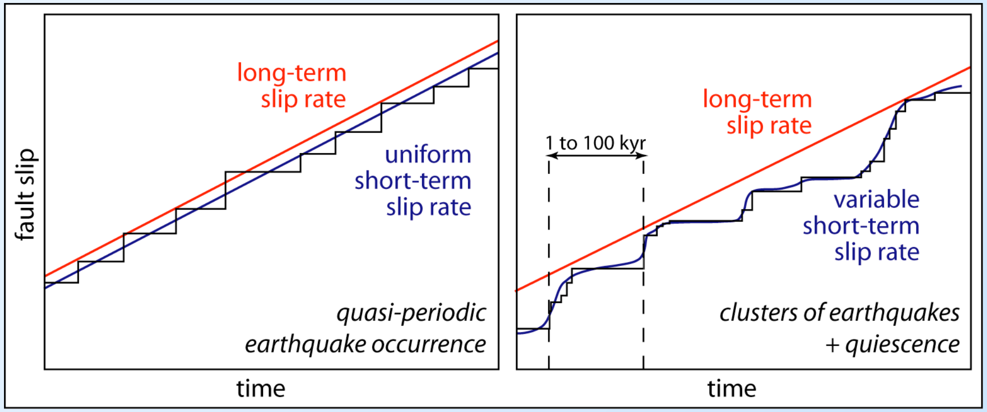
Fault slip rate results: conclusions and perspectives

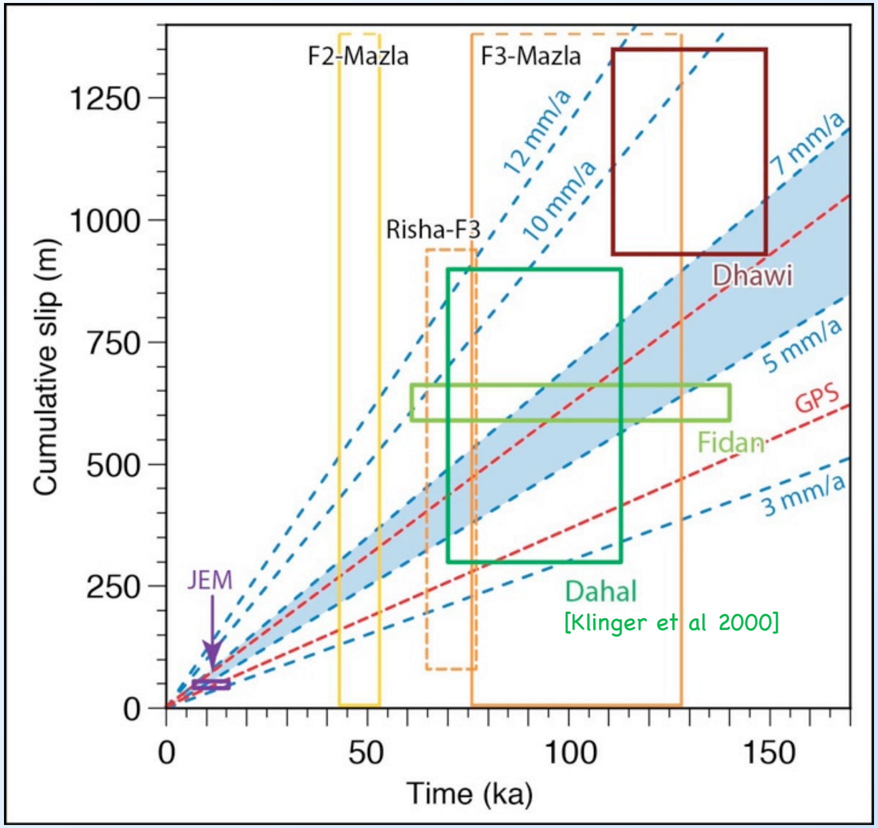
Conclusions:

- Present-day GPS = Late Quaternary

  slip rate   slip rates

- Constant slip rate of 5-7 mm/a
- Possible temporal variations





Perspectives:

- How to **improve dating** of alluvial deposits?
- How does the fault behave at the **10-ka time scale**?
- Implication regarding seismic hazard :

5 mm/an <=> **M~7 every ~300 years**

or **M~8 every ~1000 years ?**

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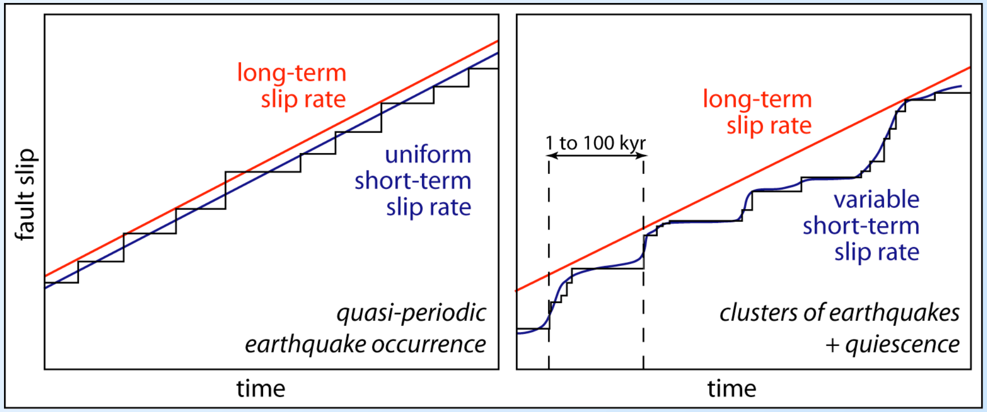

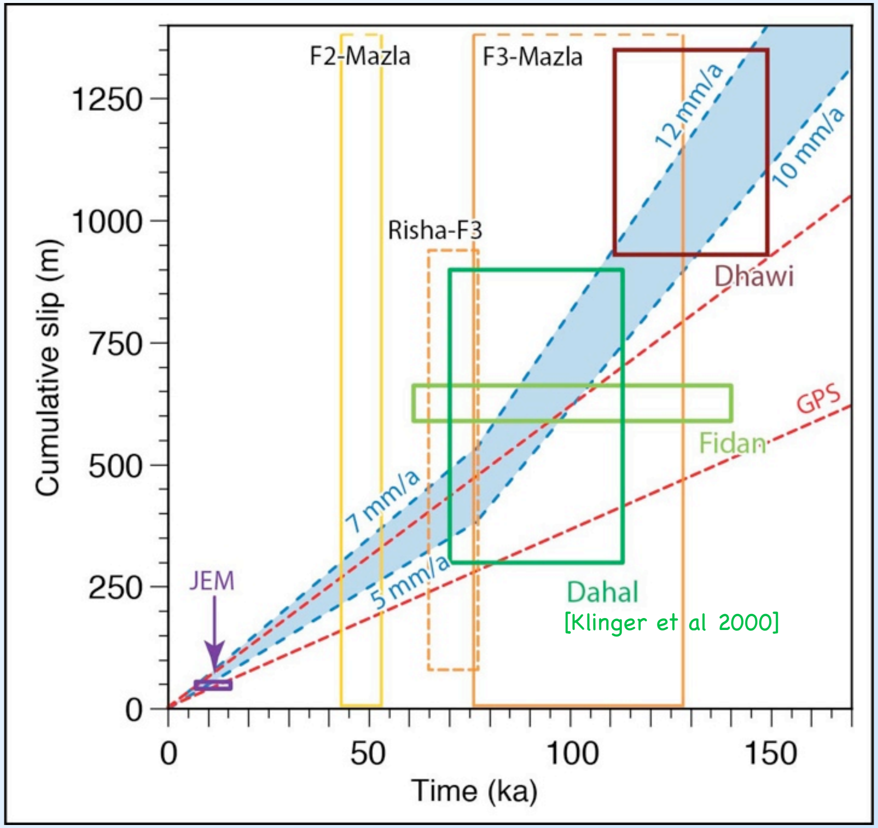

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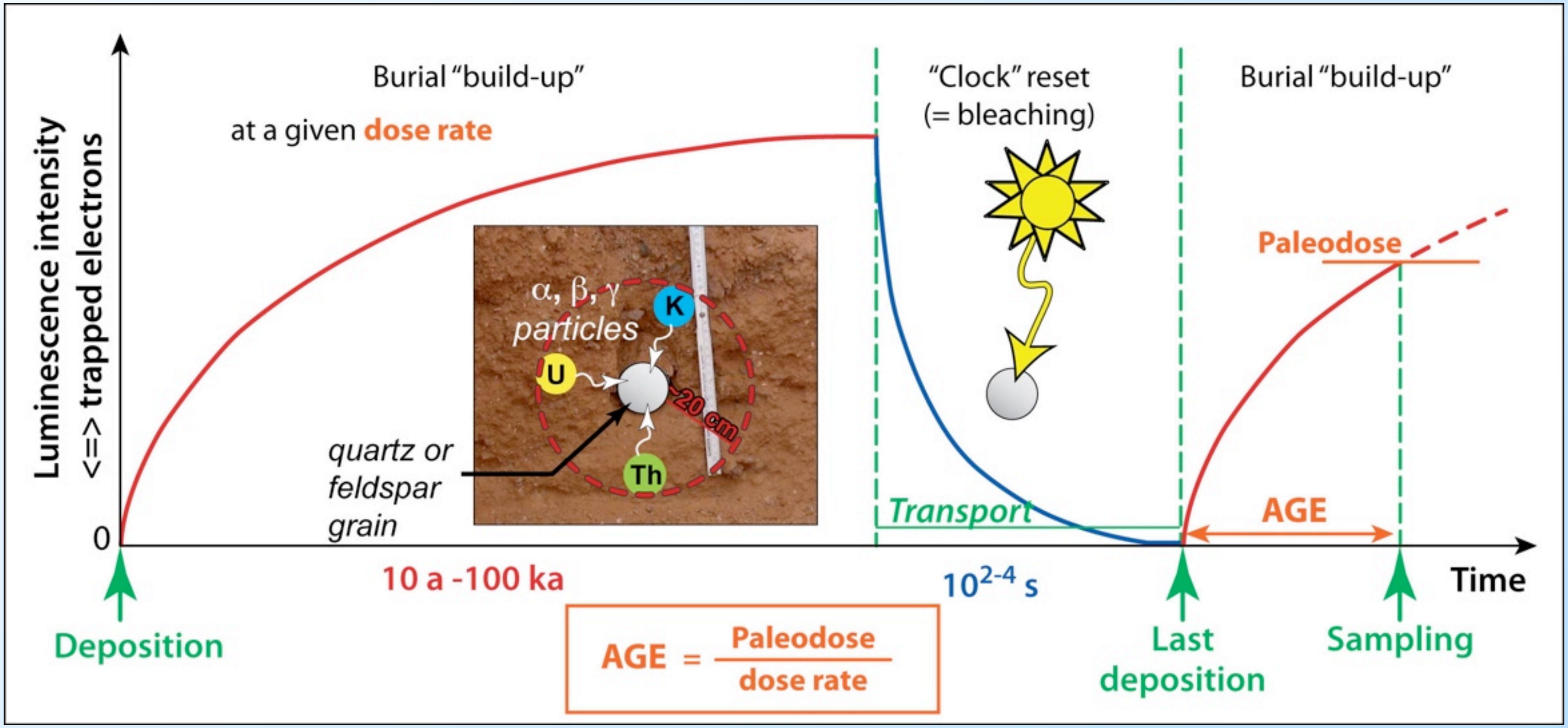
Cross-dating ^{10}Be - Luminescence (OSL)

	10Be	OSL
Target	Quartz-rich **cobbles**	**Sand** (quartz & feldspar)
Event dated	**Exposure**	**Burial**
Error sources	Pre-exposure, erosion	Incomplete bleaching before burial

Principle of **luminescence dating** :



Cross-dating ^{10}Be - Luminescence (OSL)

Sampling in PVC tube

or in light-proof bag

under black cover

Sampling strategy :

- Different fan lobes

  => duration of surface activity

- Upstream terraces

  => transit time across the bajada

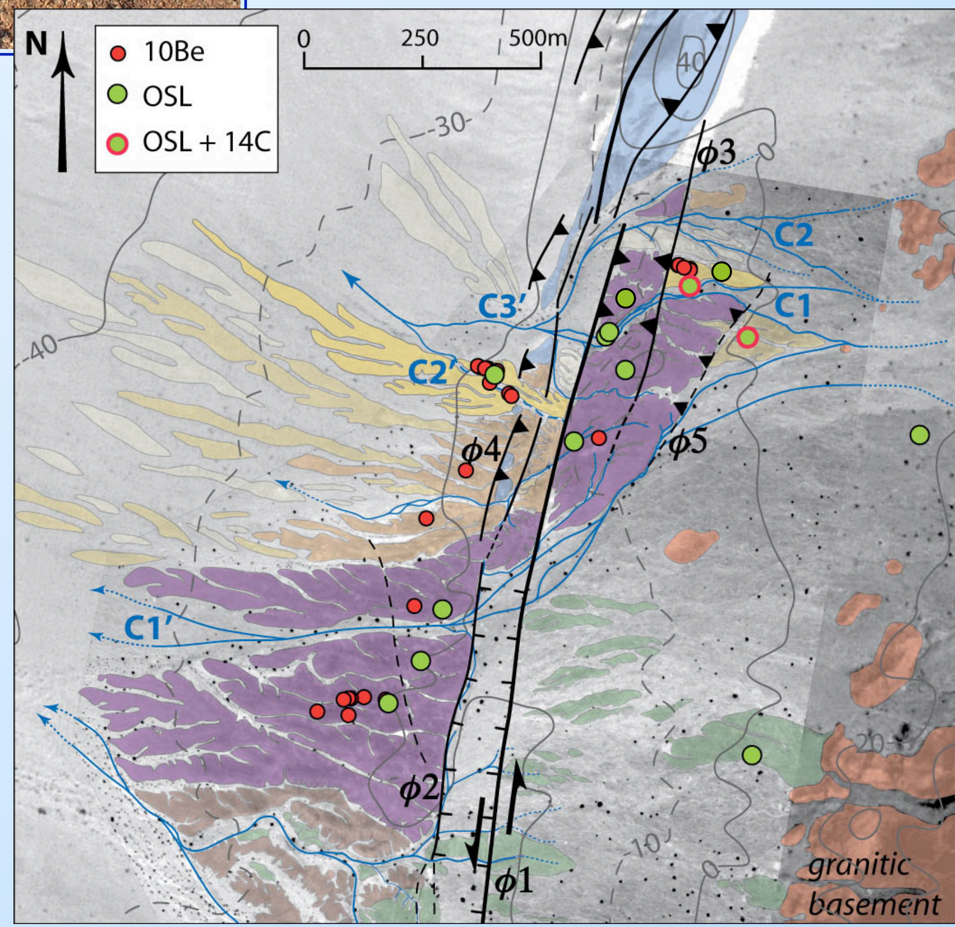
- Modern sand

  => bleaching

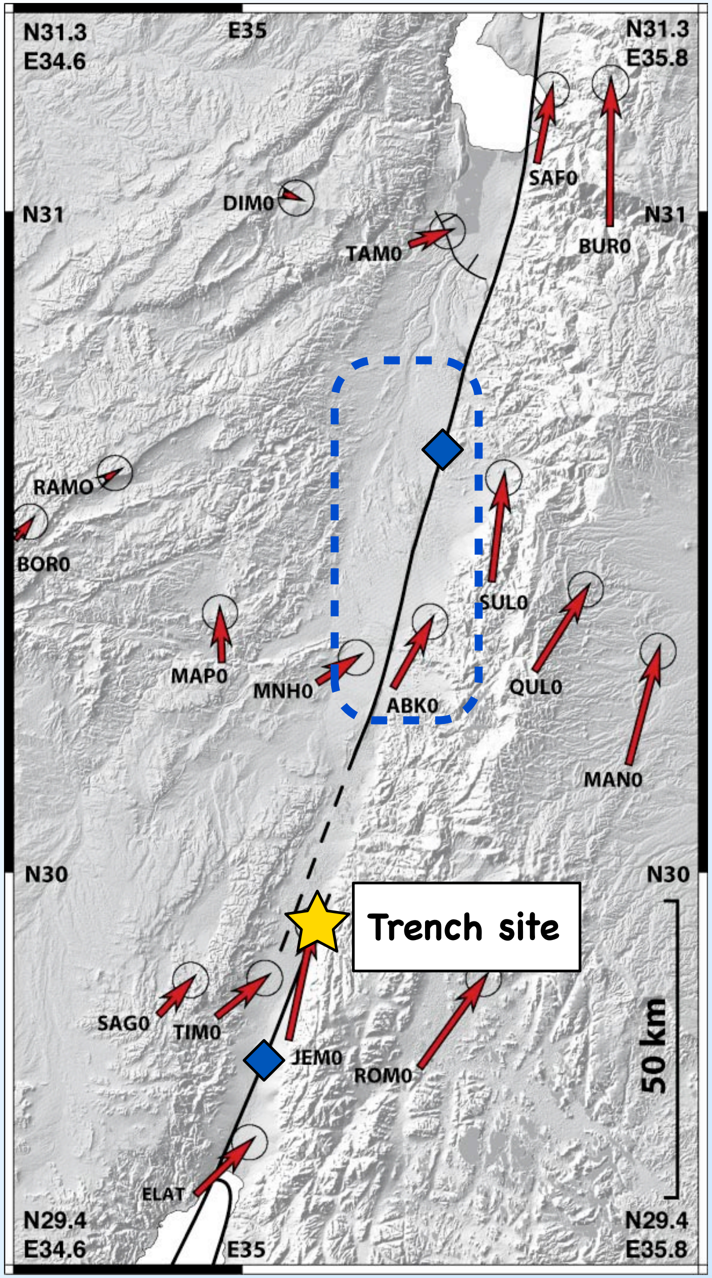
Traditional techniques failed

=> New technique MET-pIRIR on K Feldspar

[Buylaert et el 2012]

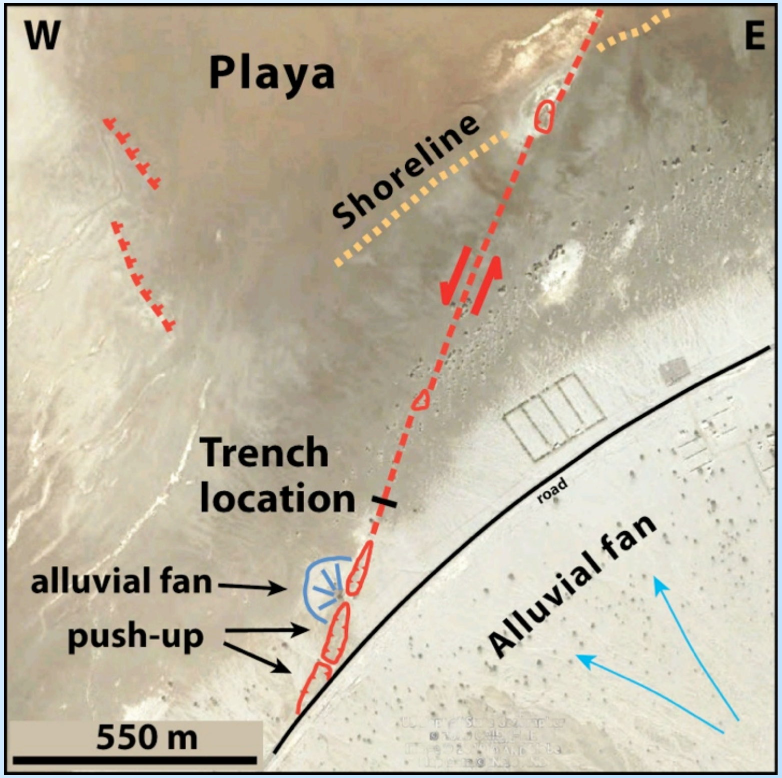


Occurrence of large earthquakes during the Holocene



Excavation of a paleo-seismologic trench

across the active fault trace



Paleo-seismology: principle

Co-seismic surface rupture :

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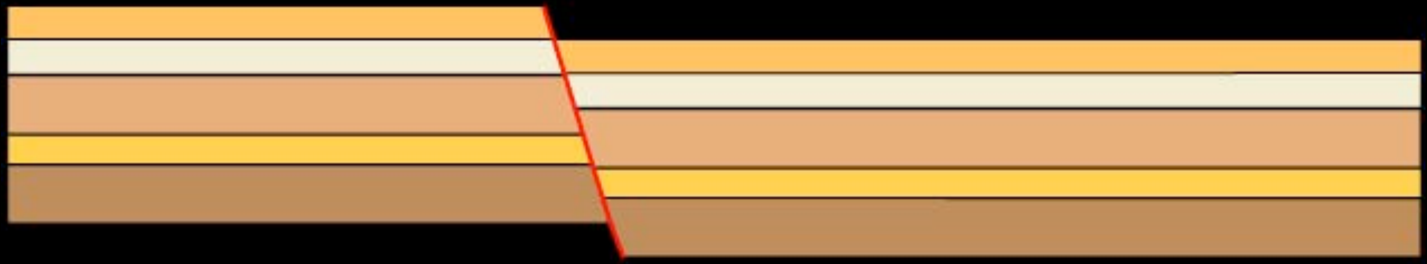
Co-seismic surface rupture :



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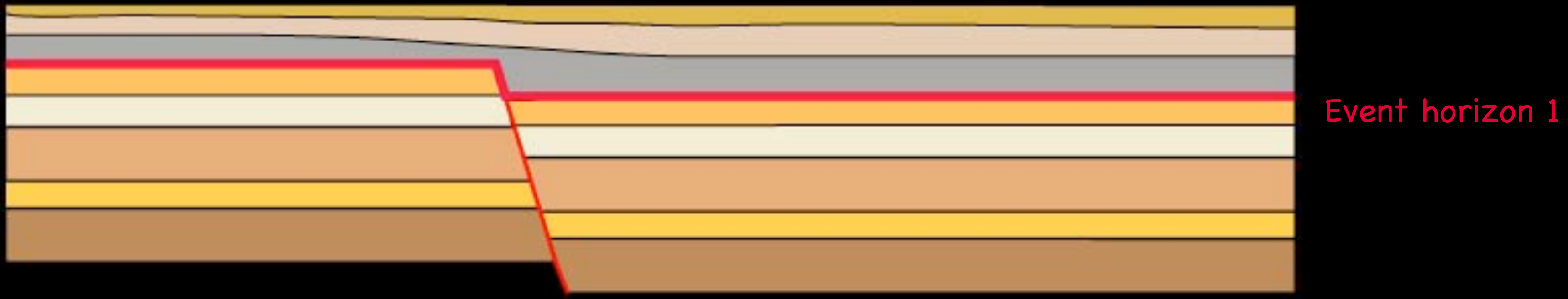

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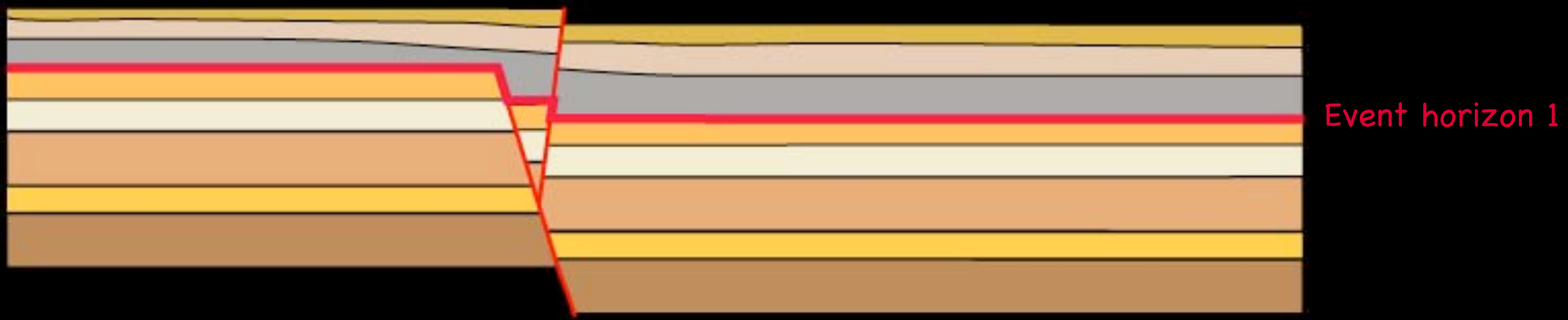

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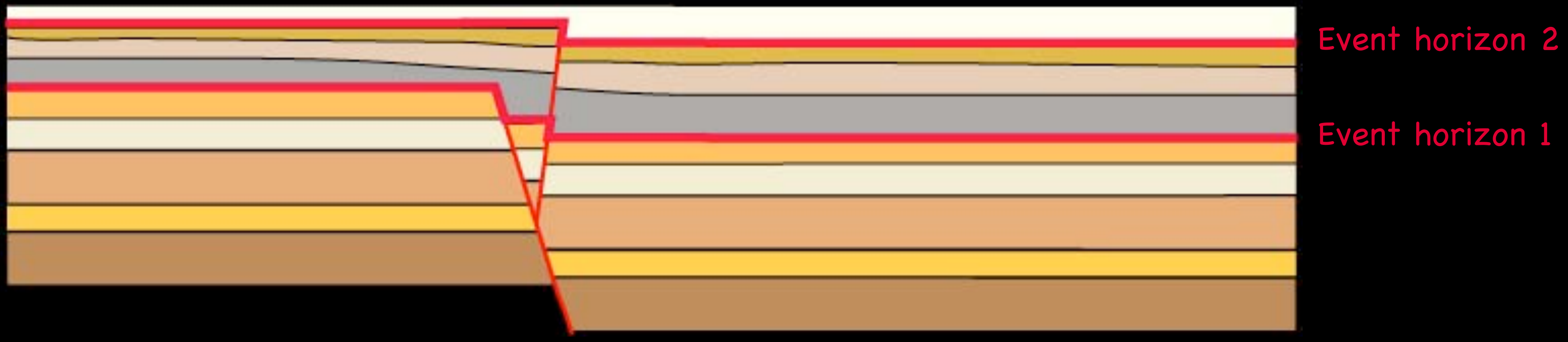

Mapping the trench walls

1 m

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1 m

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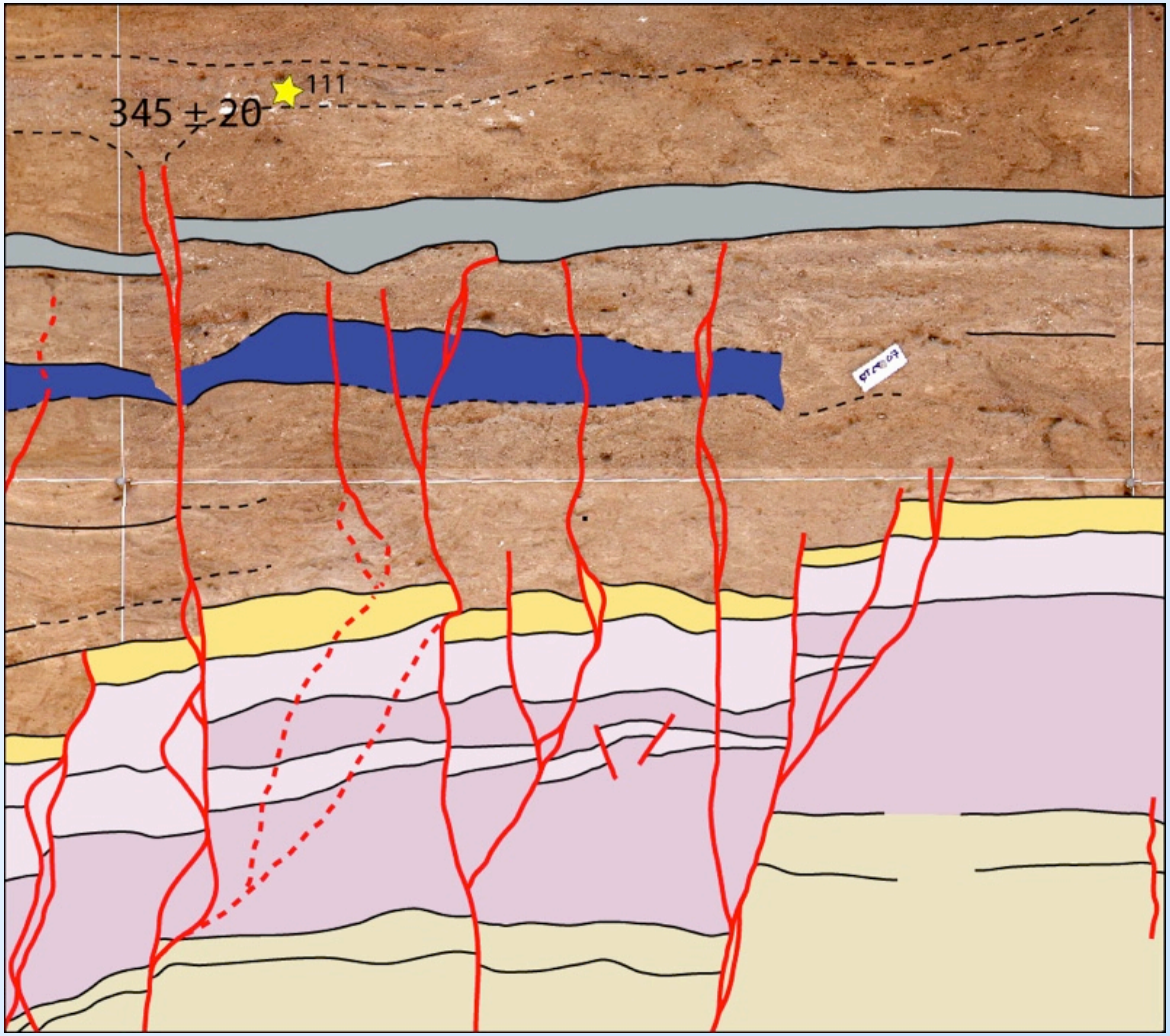

1 m

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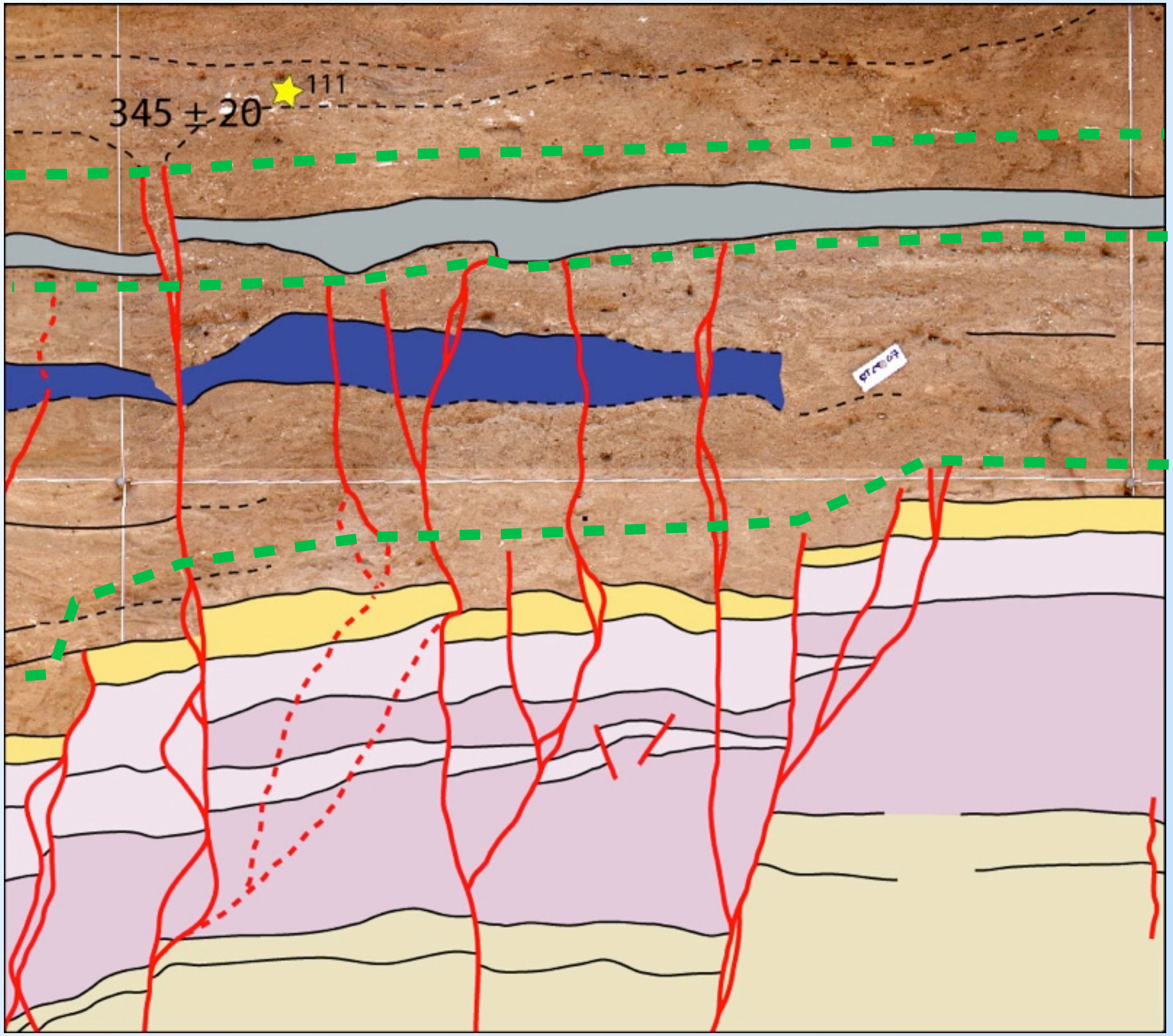
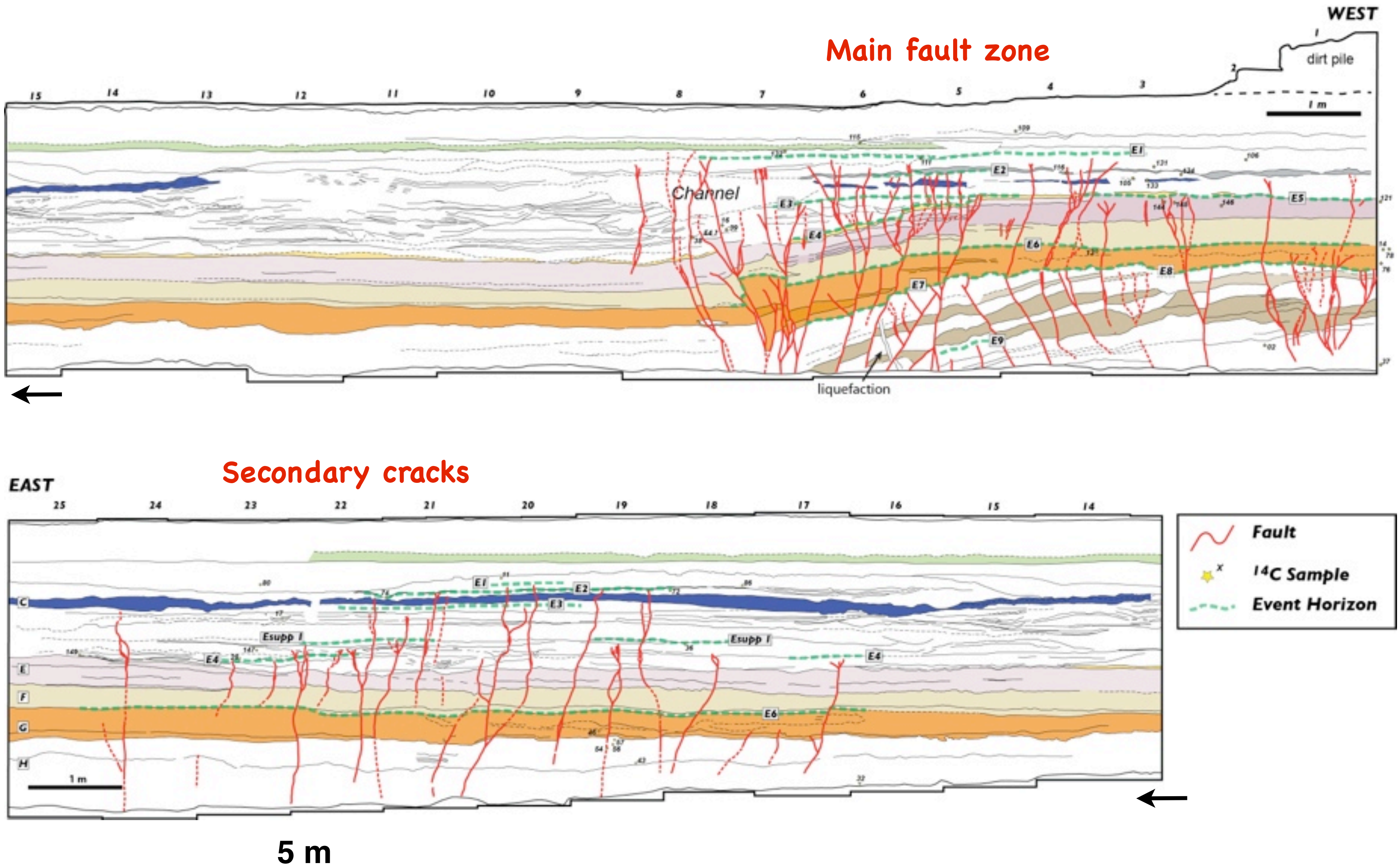


1 m

Overview of the trench



Klinger et al, in revision, GJI

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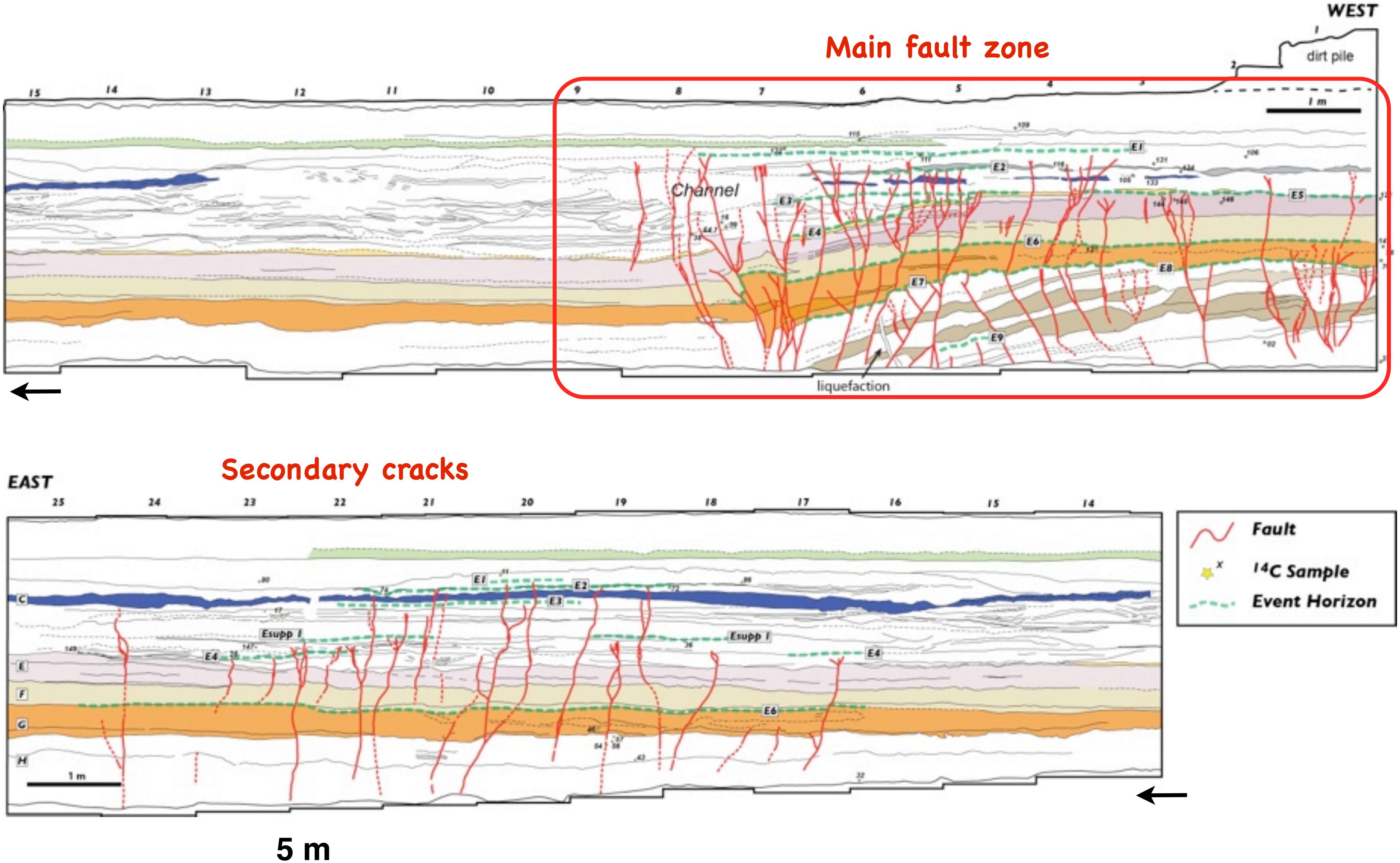
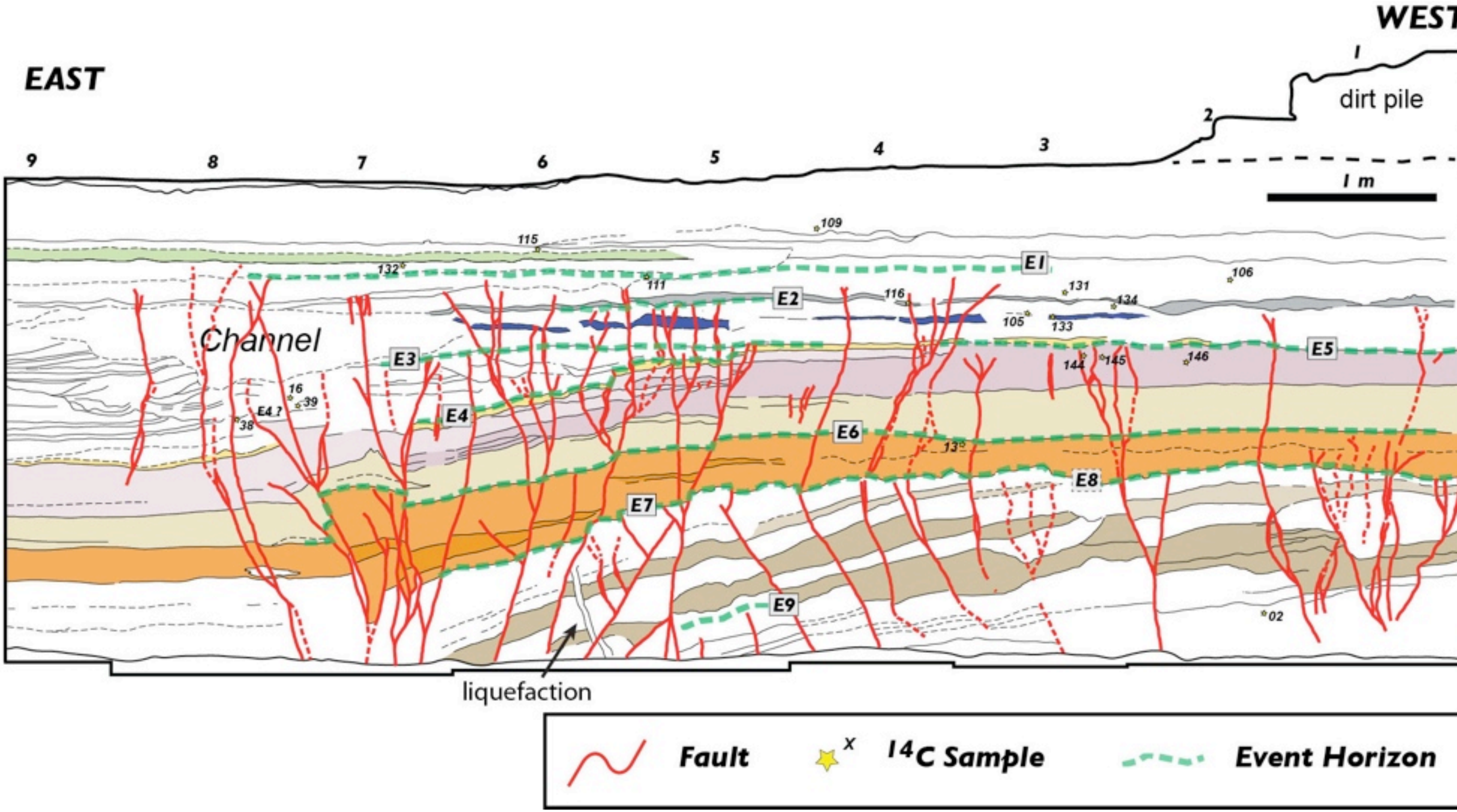


Klinger et al, in revision, GJI

Identification of paleo-earthquakes



9 paleo-earthquakes identified,

2 of them associated with **significant vertical offset**

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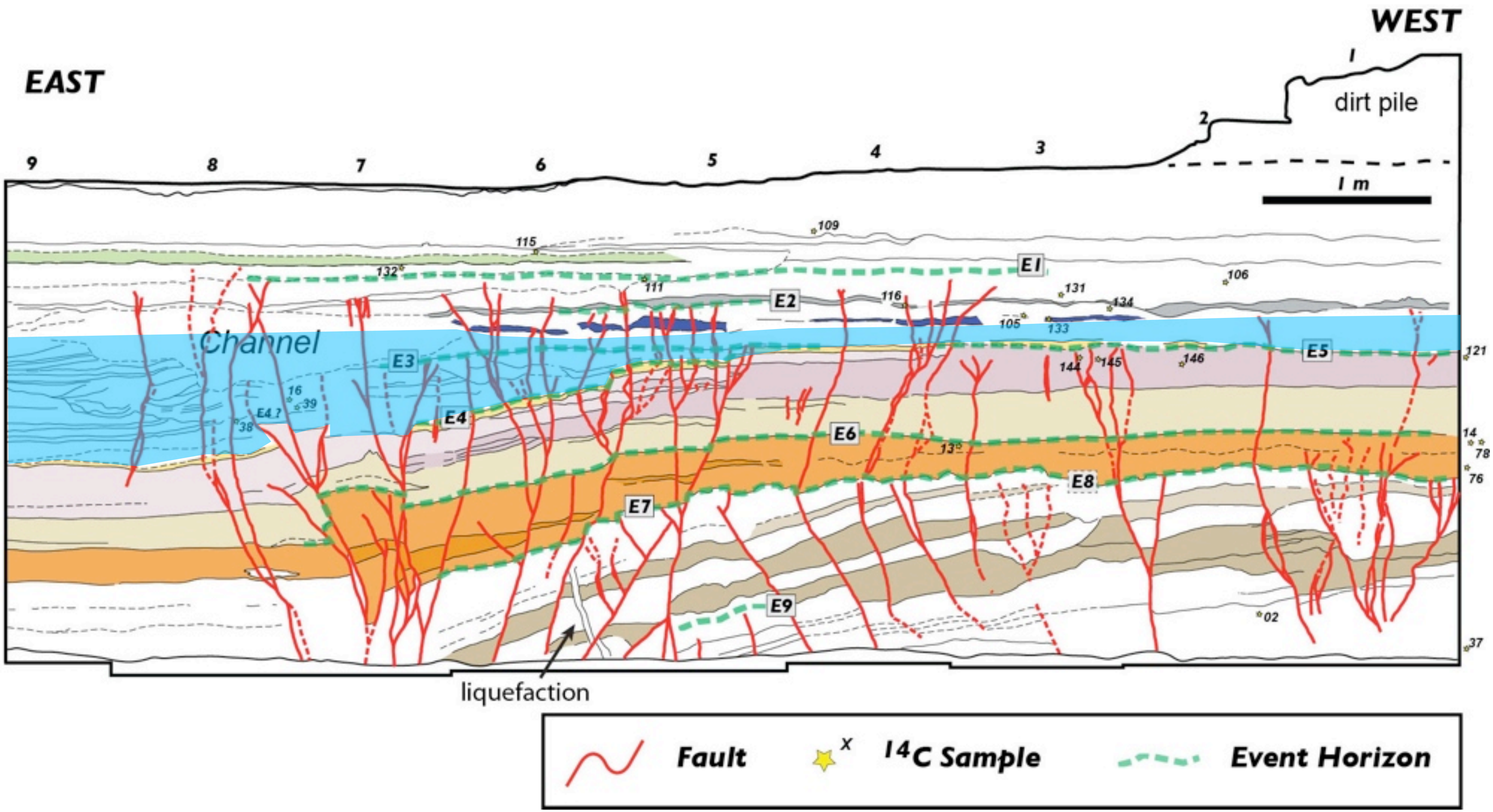

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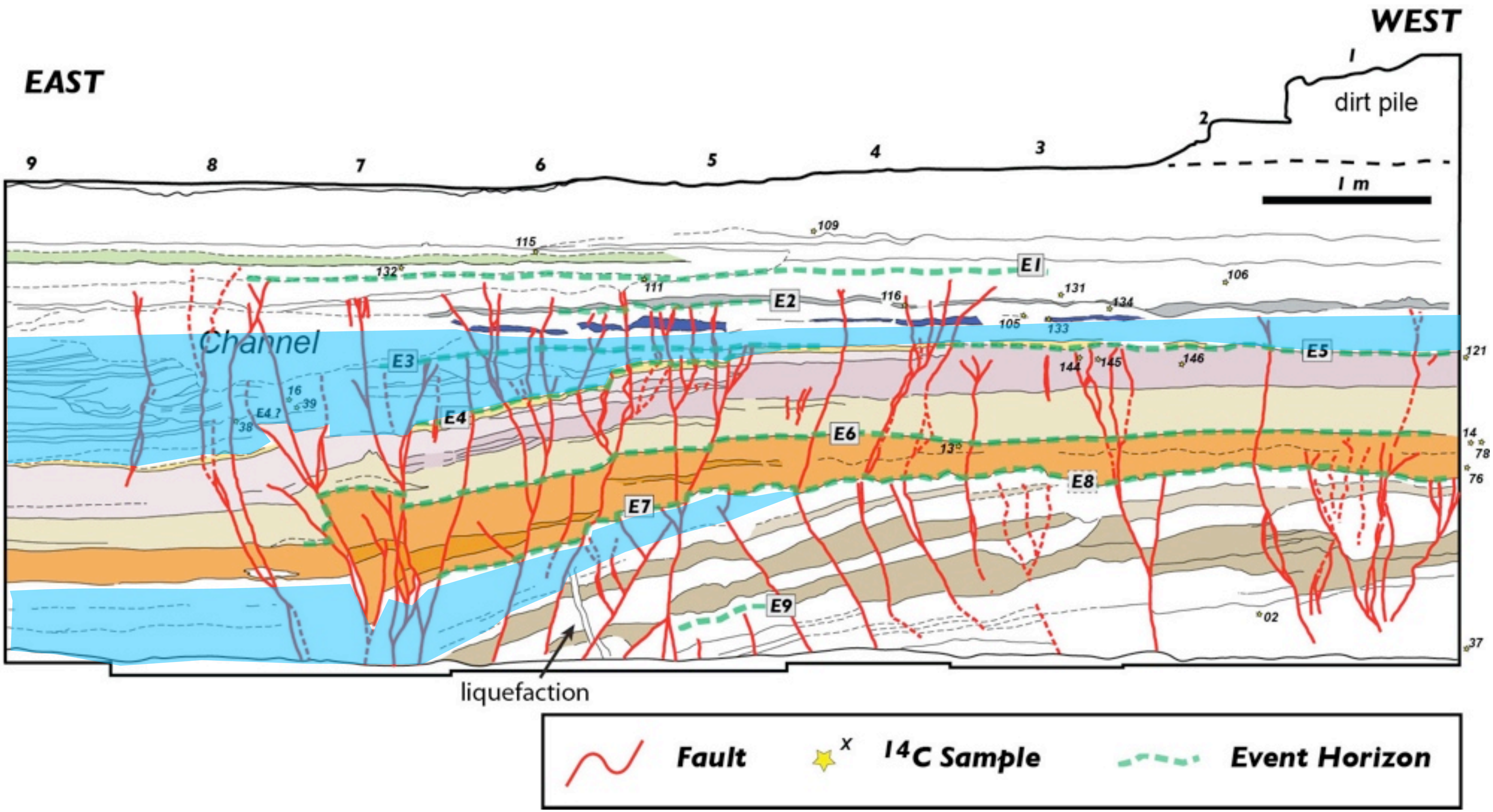

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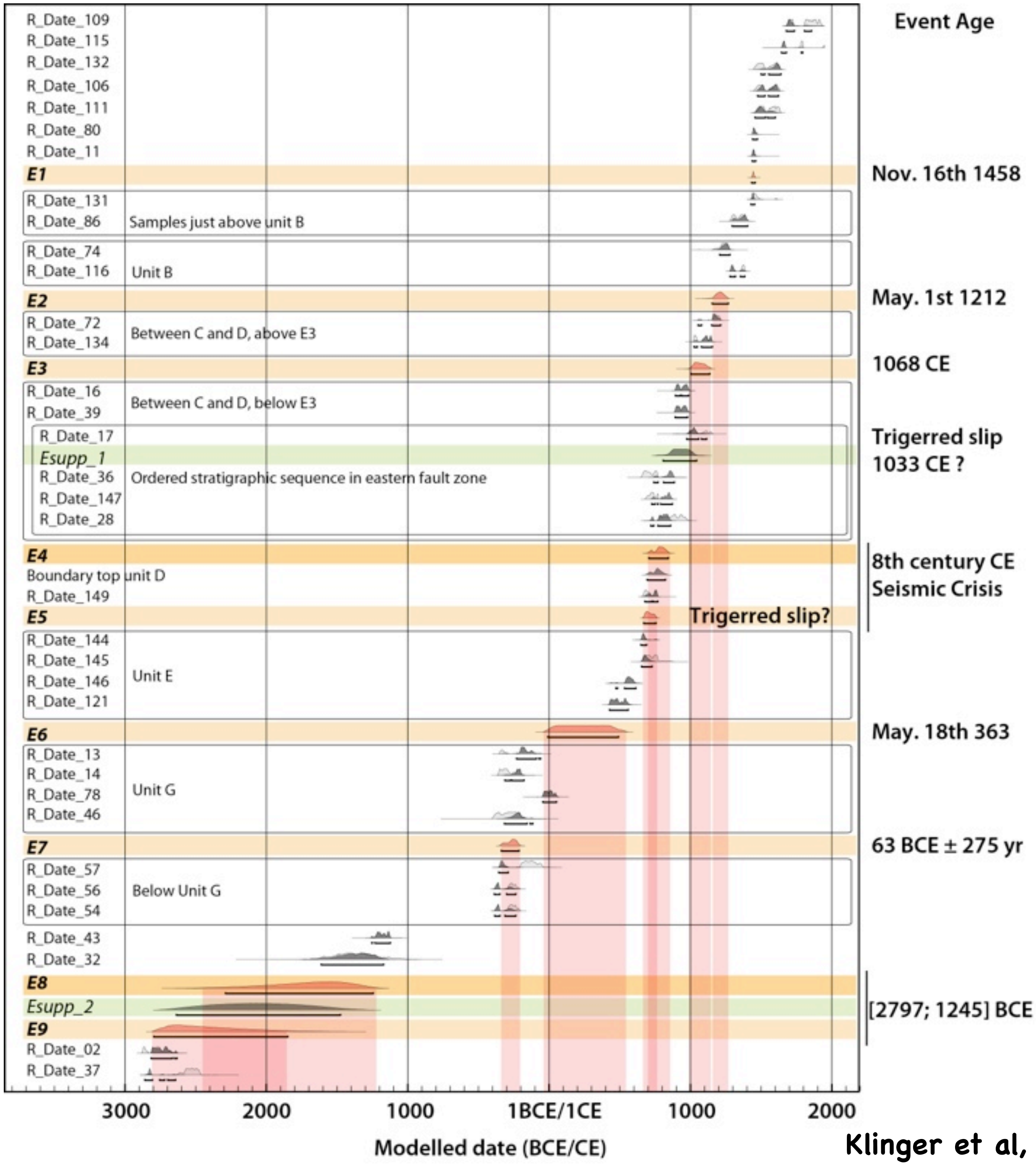
Timing of the paleo-earthquakes

Age model based on **32 ${}^{14}C$ dates** using Oxcal

+ a **2000-year long historical catalog** [Ambraseys et al, 1994]



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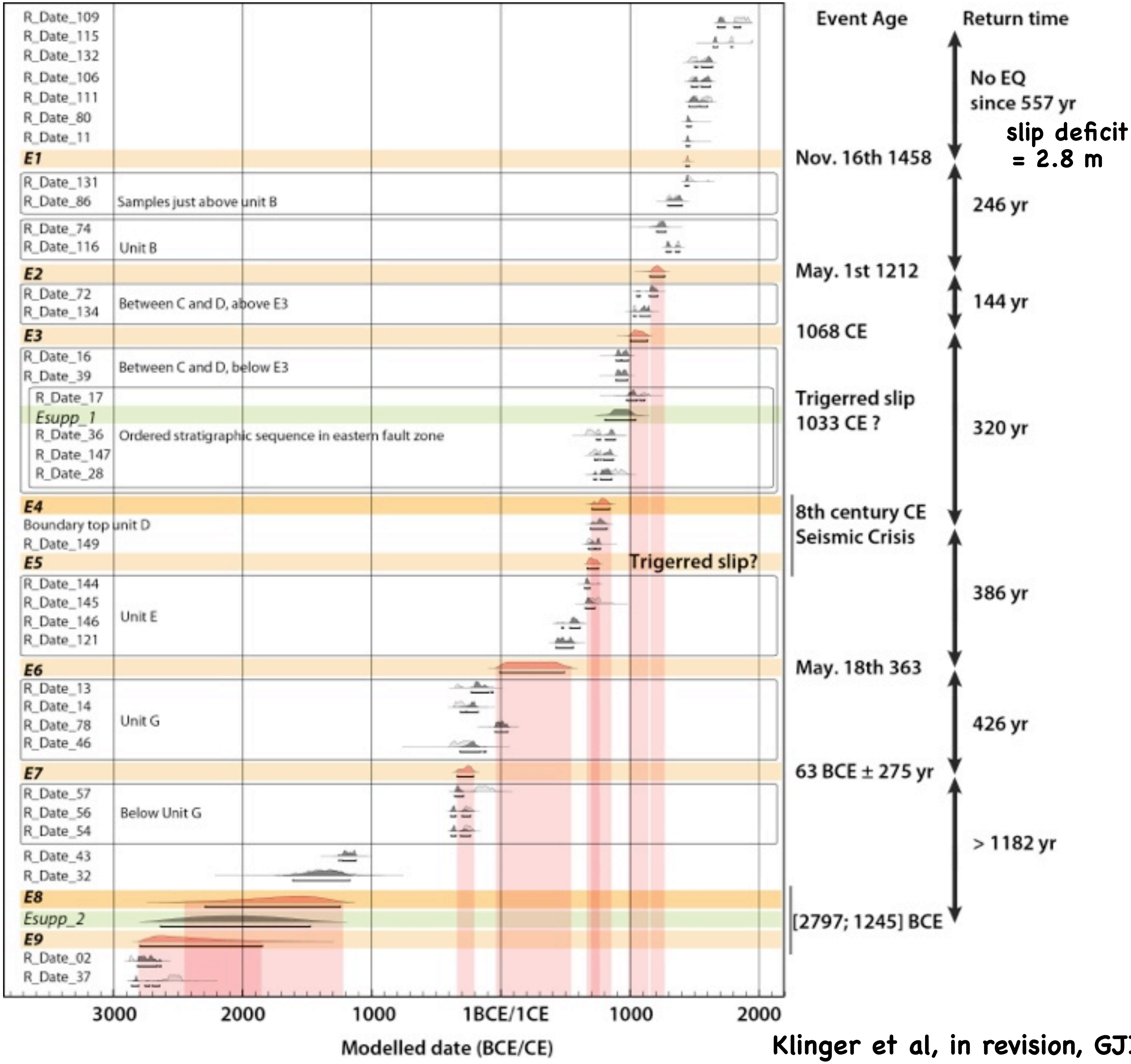

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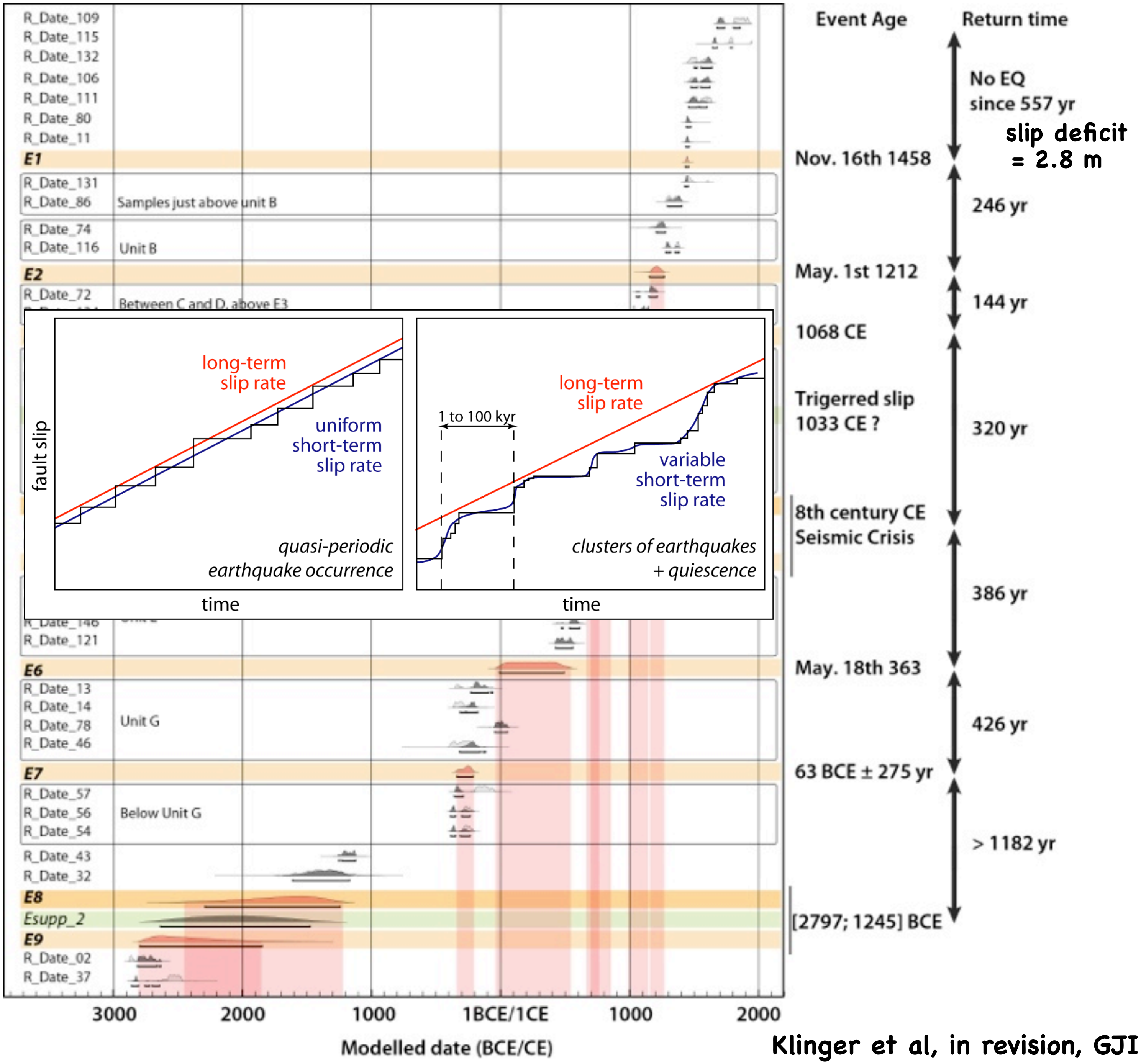


Klinger et al, in revision, GJI

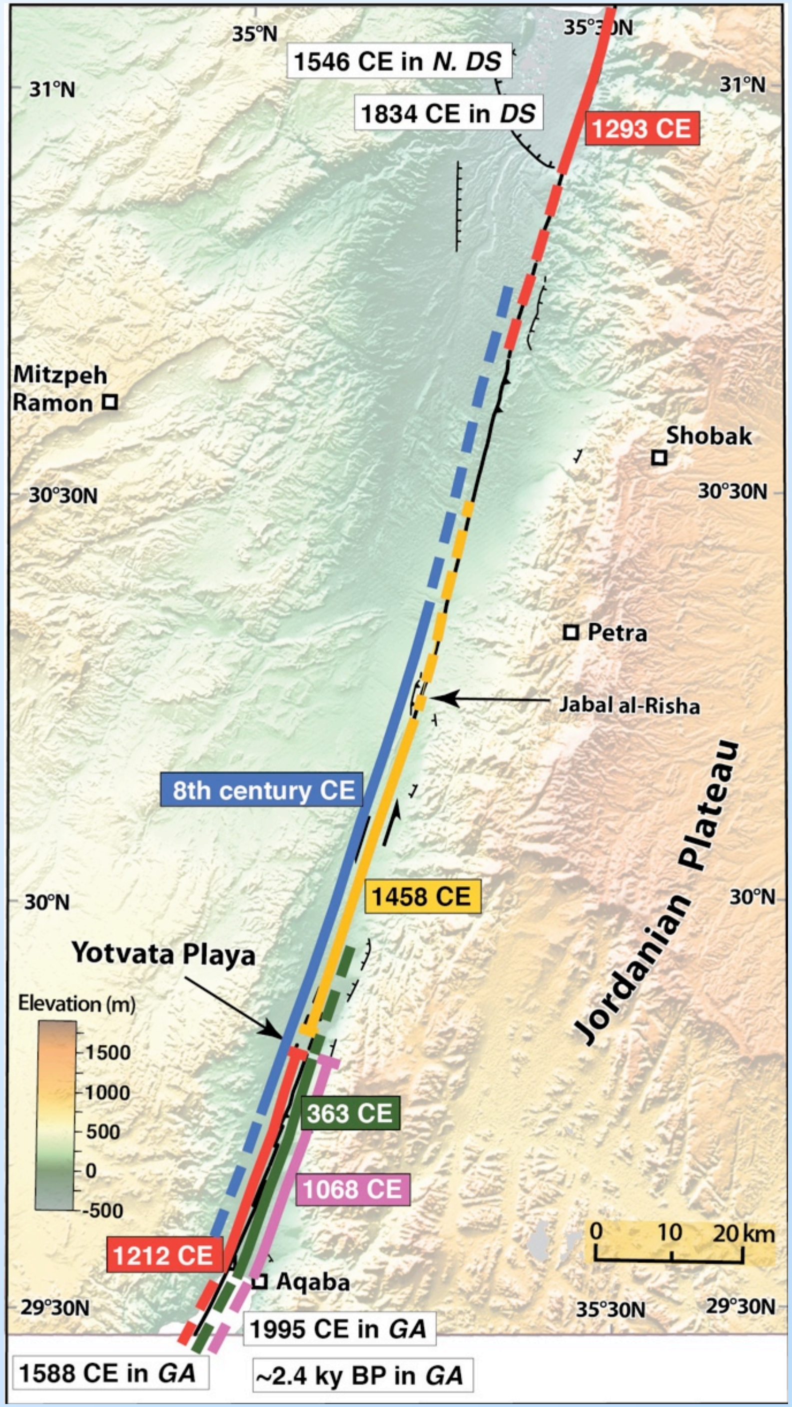
Rupture scenario

- 2 different types of events:

* Earthquake ruptures dying at the fault jog

* Larger earthquakes, less frequent, rupturing across the fault jog

- Proposed location of other reported historical earthquakes that we did not observe in the trench



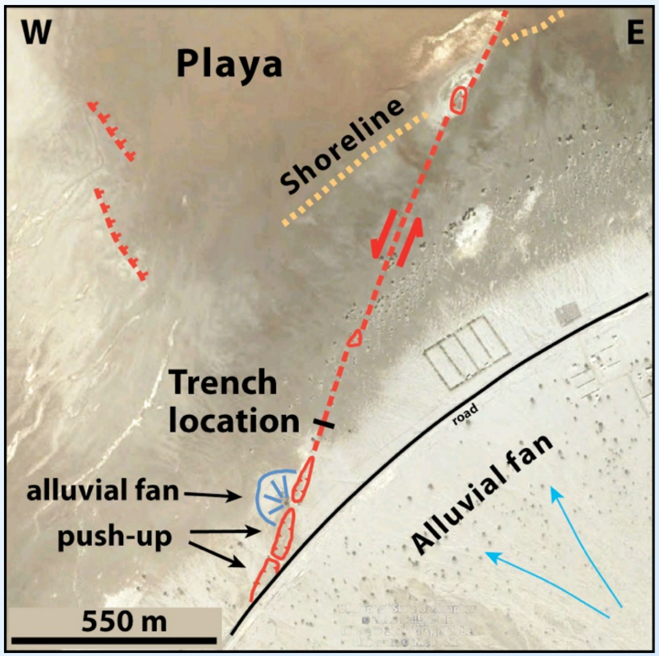
Klinger et al, in revision, GJI

Perspectives

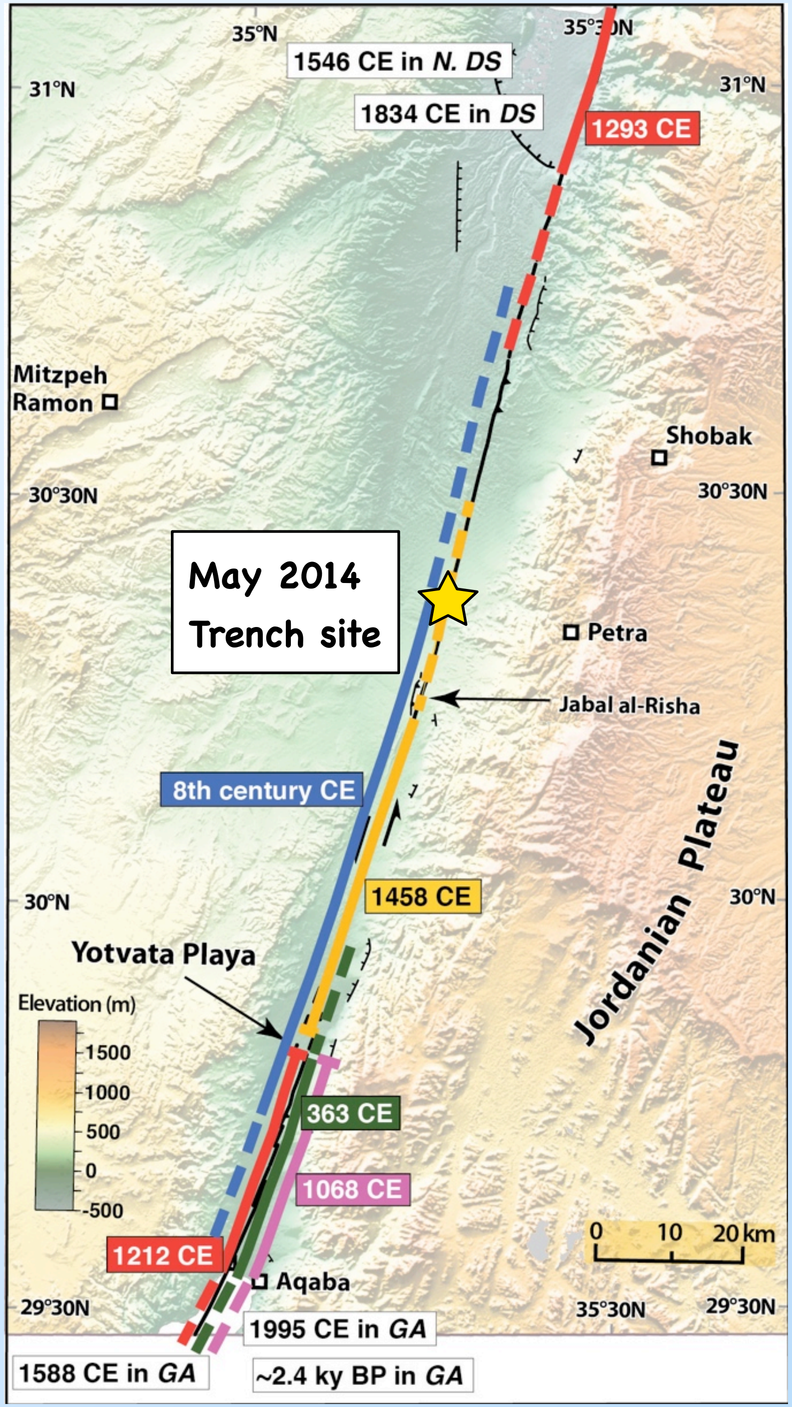
1/ **At the same site**:

* A deeper trench for a **longer record**

* Fault-parallel trenching to access **slip per event** (channels identified)



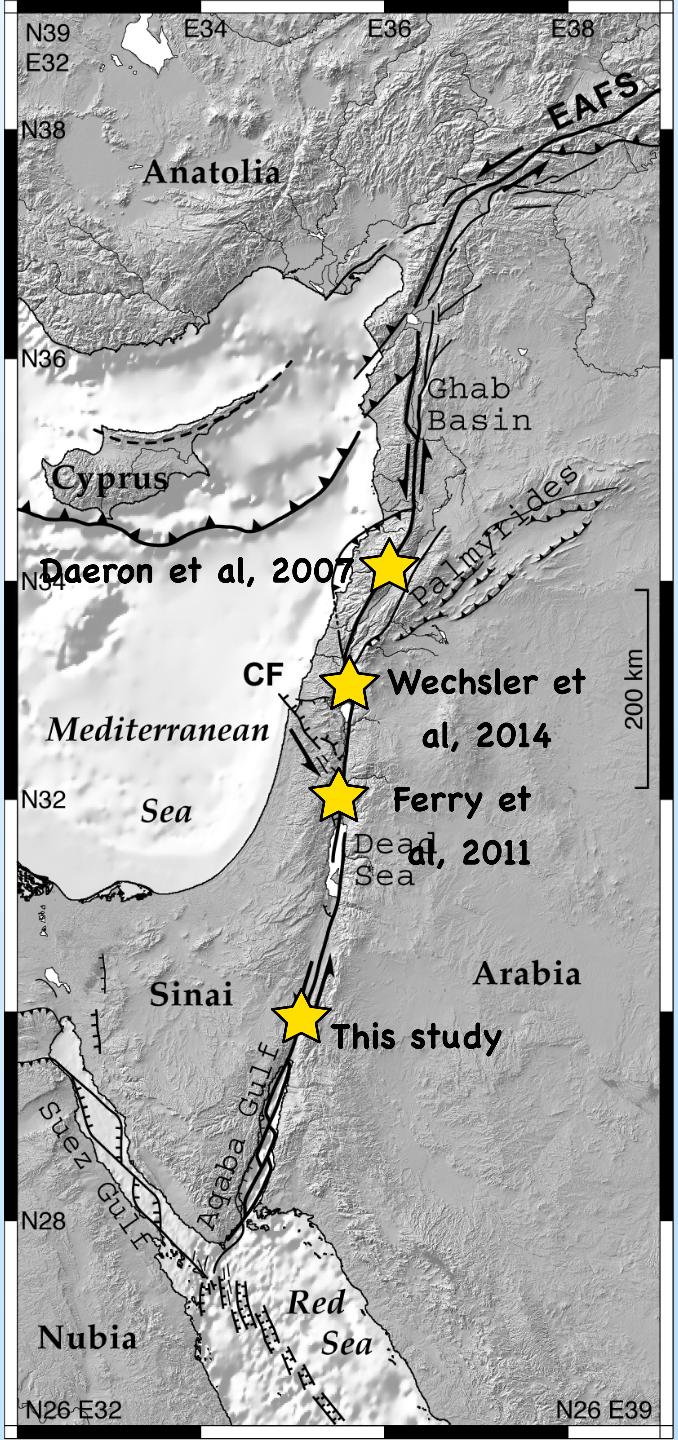
2/ **Excavation at another trench site** in May 2014 to **compare earthquake sequences** in order to test and complement our scenario



Perspectives

3/ **At the regional scale** :

Chief goal is to point out the source of all historical earthquakes along the Dead Sea fault and see how fault segments interact with each other.



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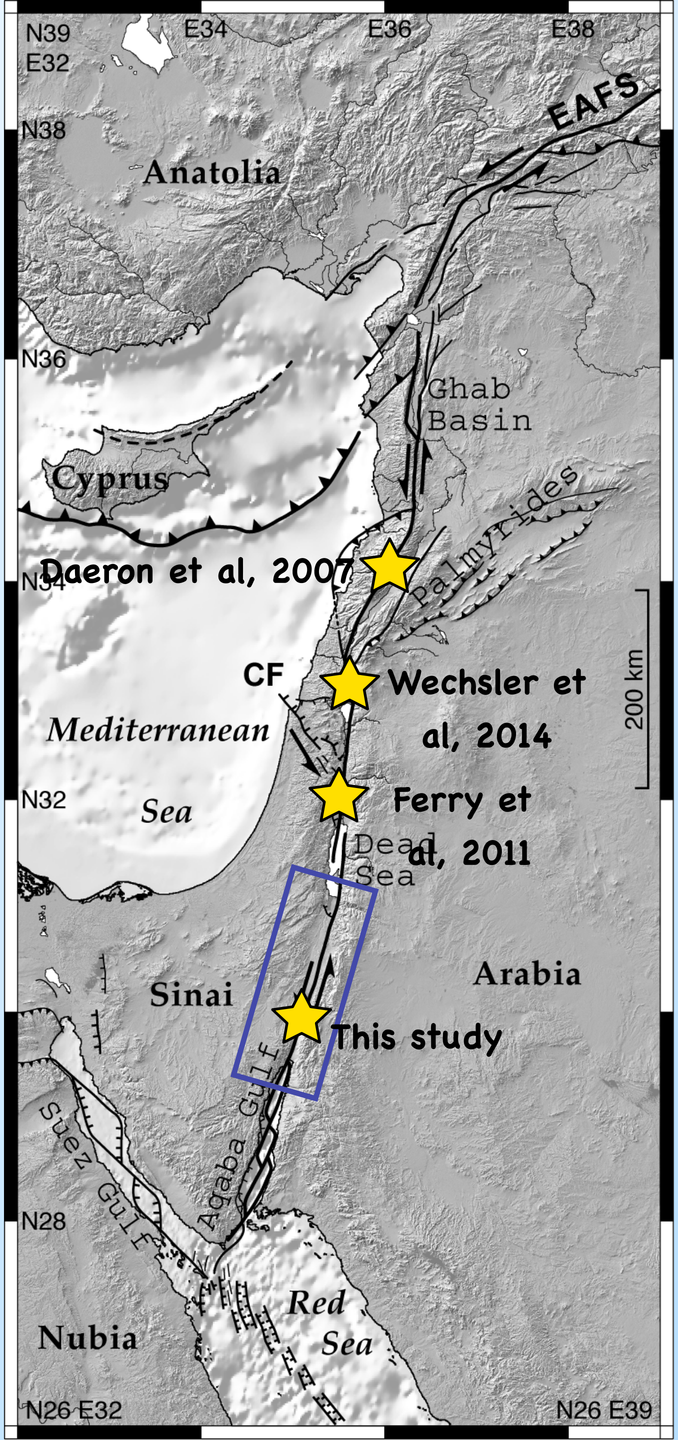
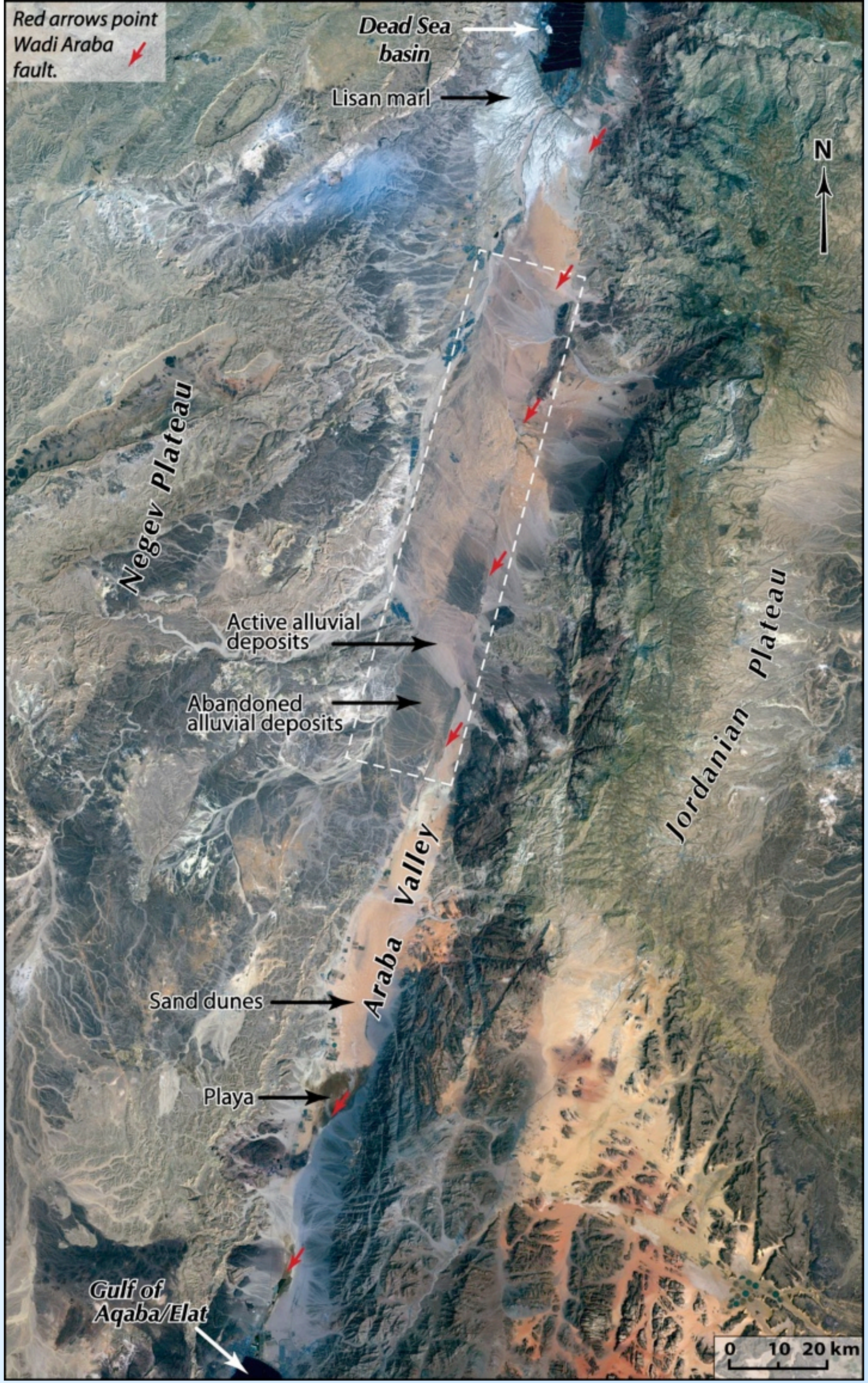
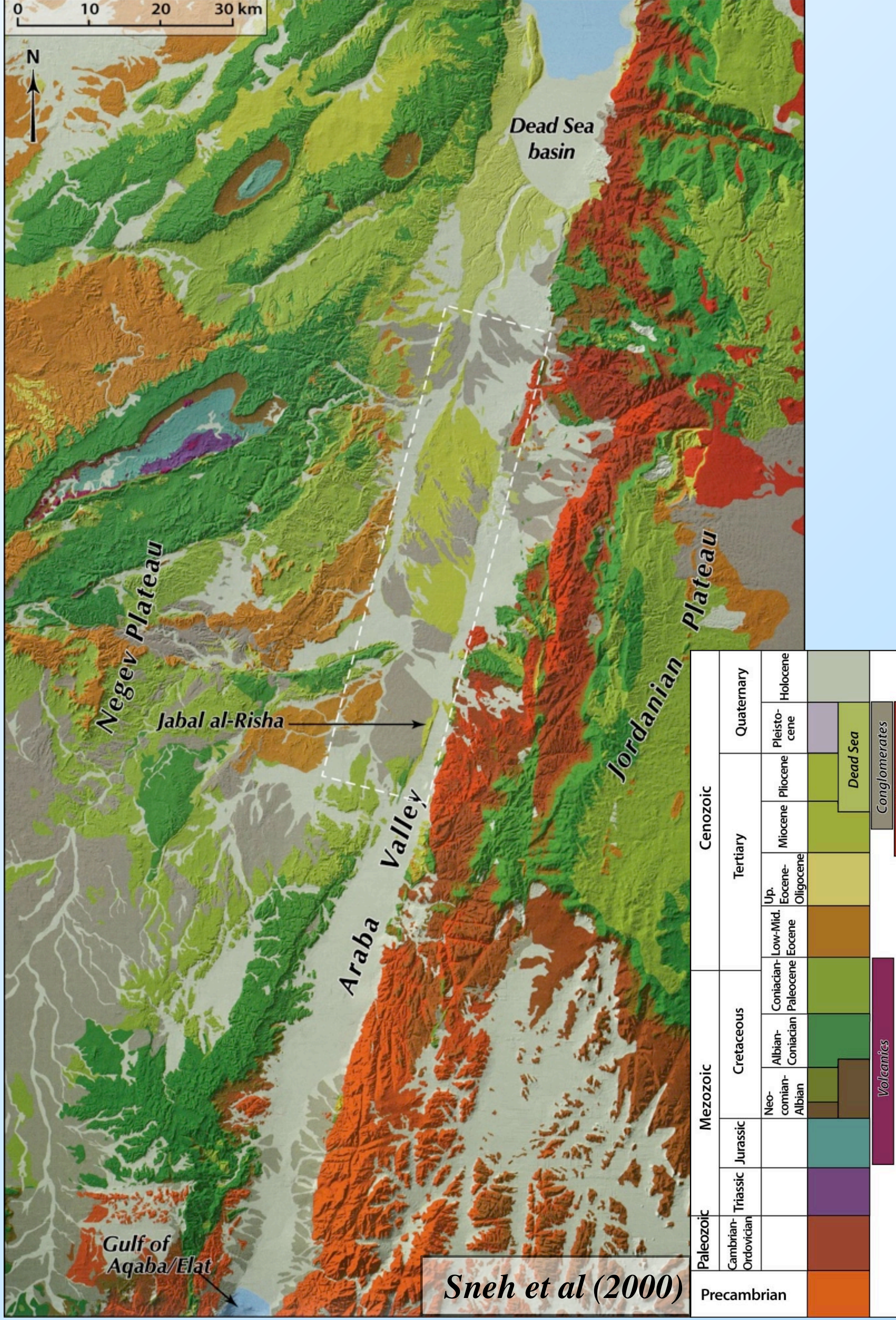



Thanks for your attention !

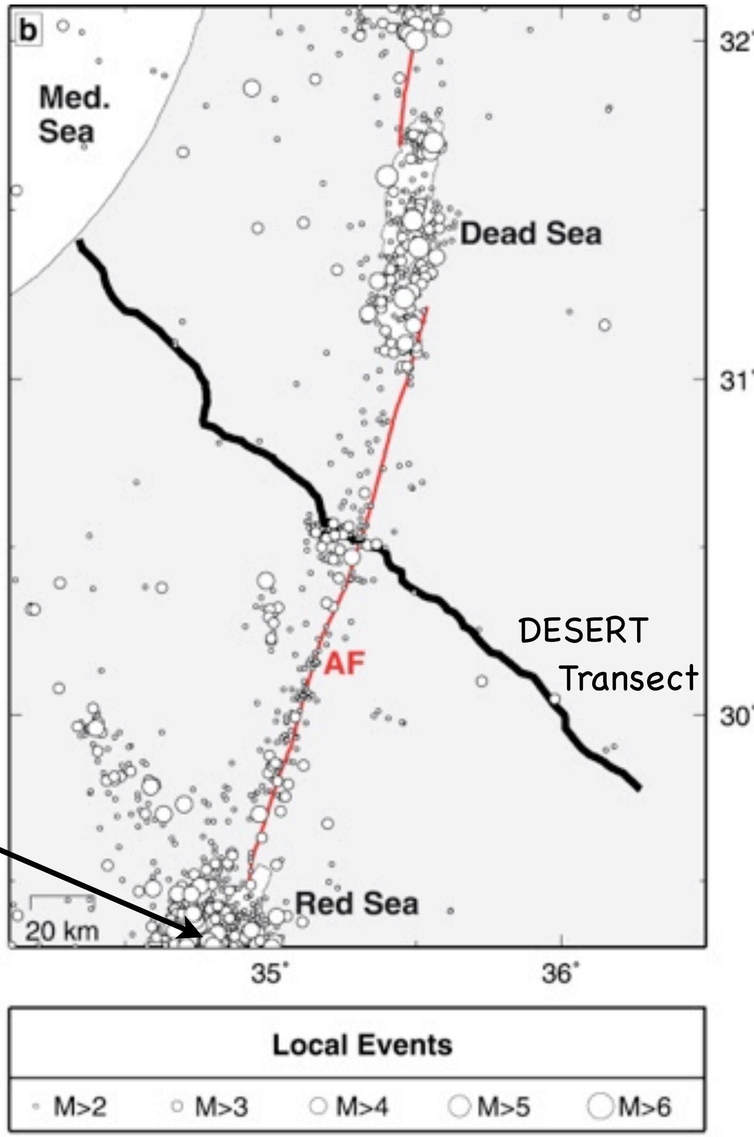

Red arrows point
Wadi Araba
fault.
Dead Sea
basin
Lisan marl
N
Negev Plateau
Active alluvial
deposits
Abandoned
alluvial deposits
Jordanian Plateau
Araba Valley
Sand dunes
Playa
Gulf of
Aqaba/Elat
0 10 20 km


0 10 20 30 km
N
Dead Sea
basin
Negev Plateau
Jabal al-Risha
Araba Valley
Jordanian Plateau
Gulf of
Aqaba/Elat
Sneh et al (2000)
Cenozoic
Quaternary
Holocene
Pleisto-
cene
Tertiary
Pliocene
Miocene
Up. Eocene-
Oligocene
Low-Mid. Eocene
Coniacian-
Paleocene
Mezozoic
Cretaceous
Albian-
Coniacian
Neo-
comian-
Albian
Jurassic
Triassic
Paleozoic
Cambrian-
Ordovician
Precambrian
Dead Sea
Conglomerates
Volcanics
Volcanics

Instrumental seismicity

Period
1983-2008

1995 Mw=7.3
Nuweiba
Earthquake
and aftershocks

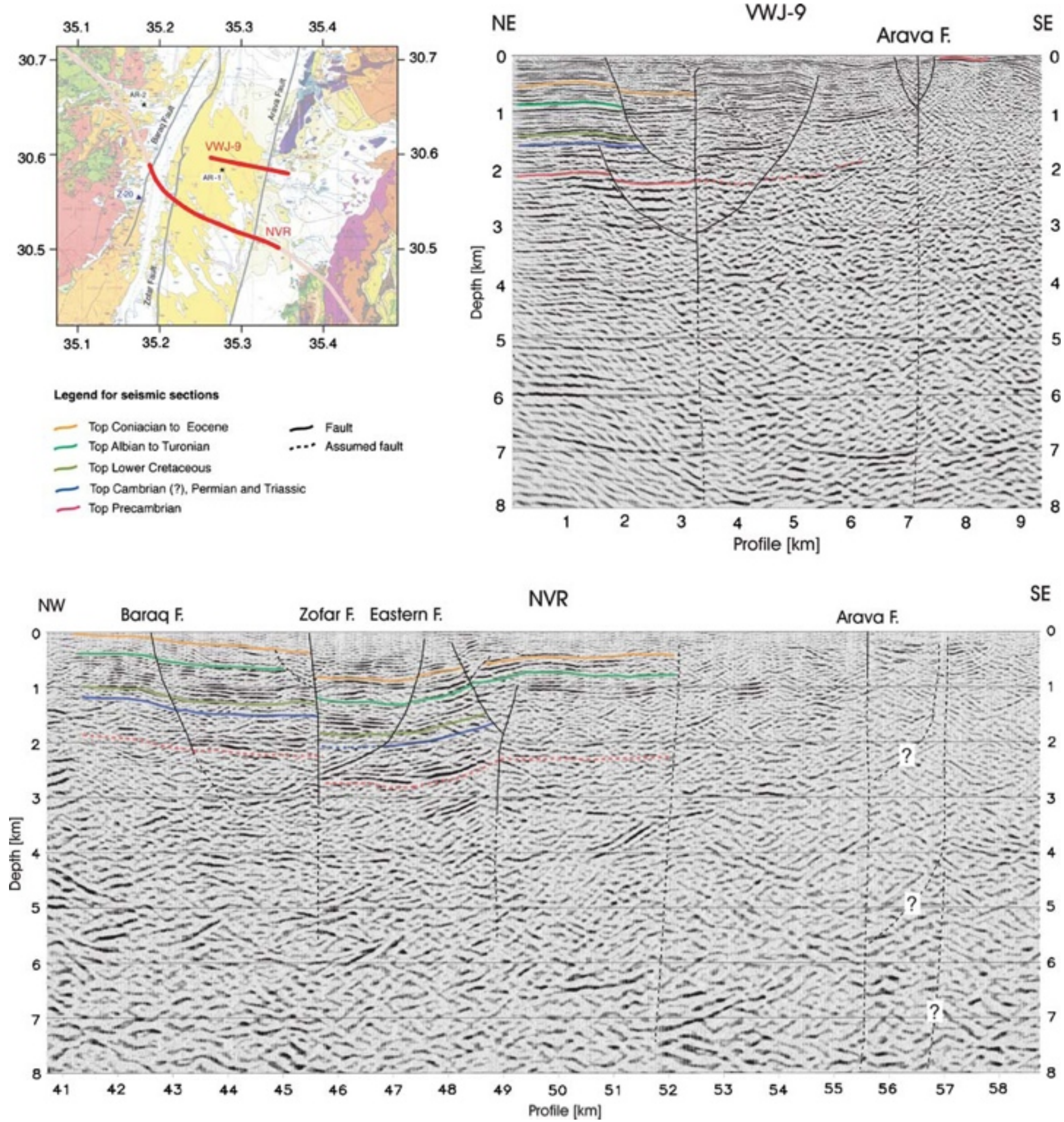


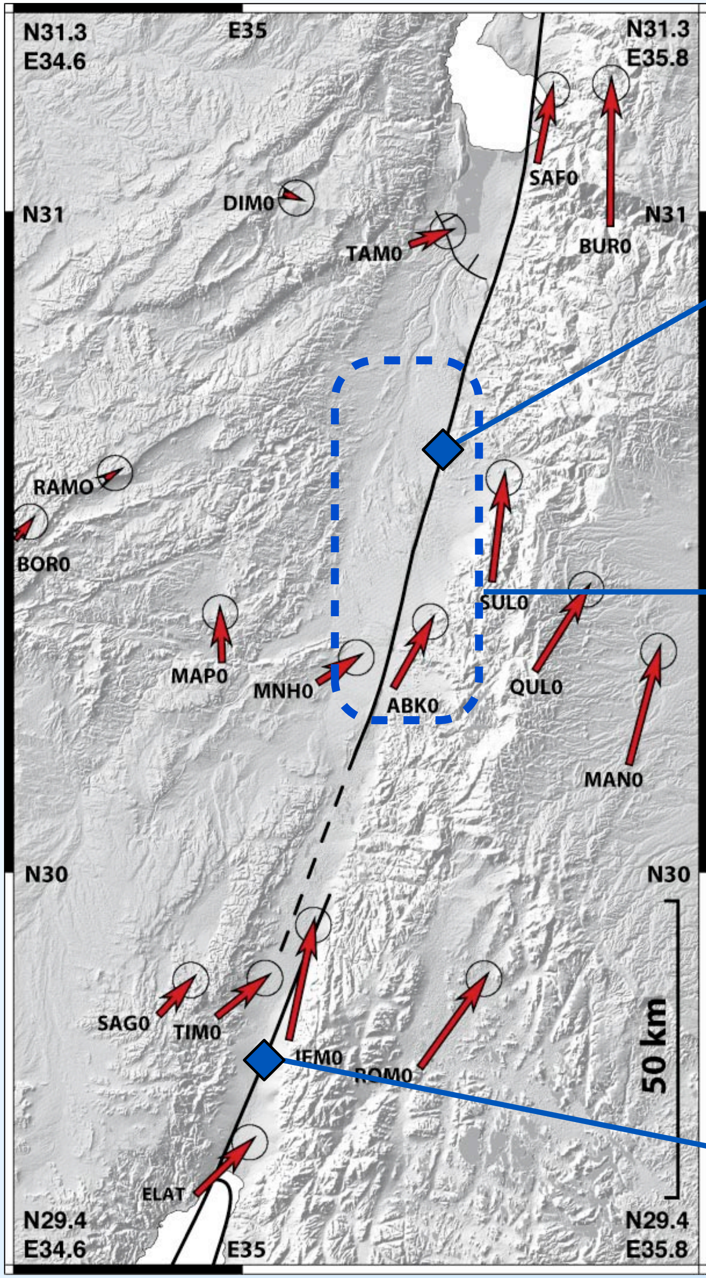
[Weber et al, 2009]

Sub-surface structure

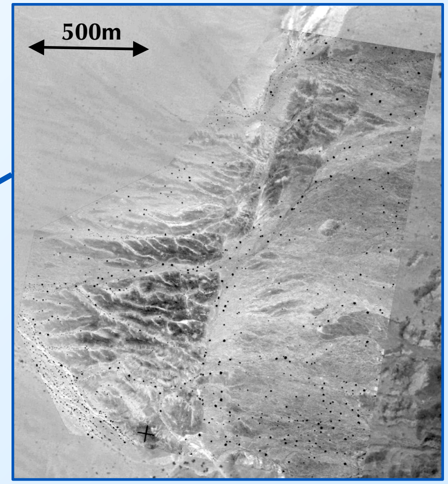
Near-surface structure as seen in seismic reflection data

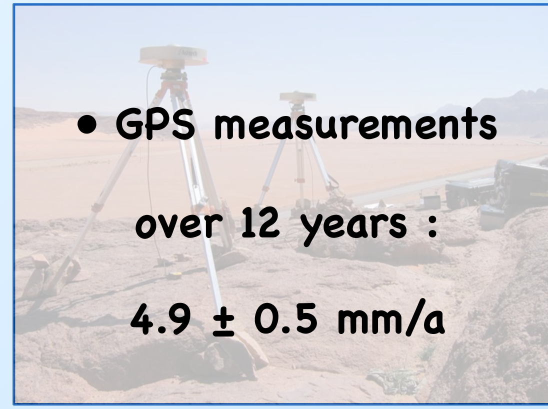
[Kesten et al, 2007]





Hamra al-Fidan : ~100 ka





• Geomorphology and cosmogenic isotopes dating (^{10}Be) over different time scales

Large fans : up to 300 ka

Jabal al-Muhtadi : ~10 ka

Le Béon et al, 2010, 2012