The Abdus Salam
International Centre
for Theoretical Physics

2464-16

Earthquake Tectonics and Hazards on the Continents

17 - 28 June 2013

Recognizing and characterizing strike-slip faults and earthquakes in Iran, Mongolia and Kazakhstan

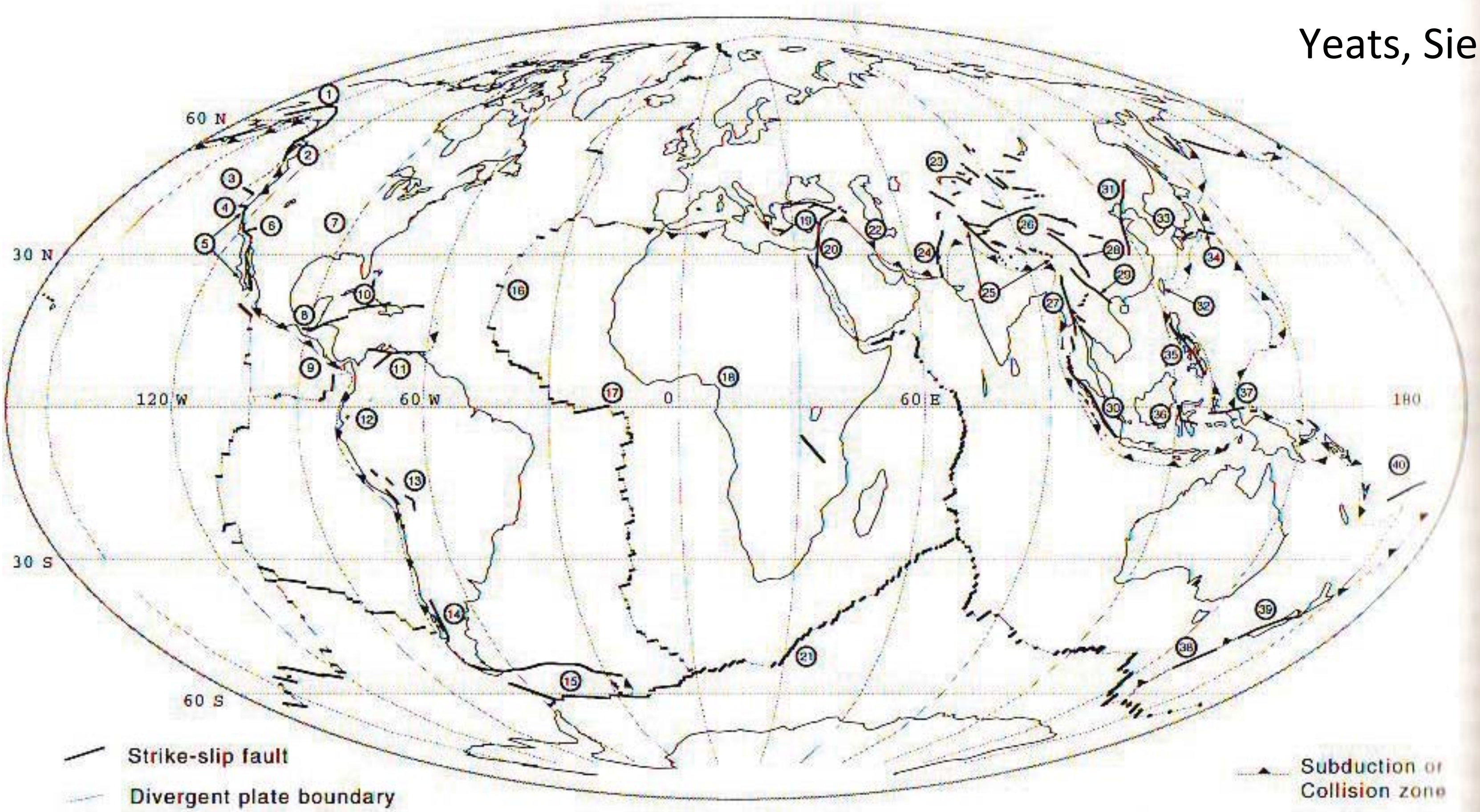
R. Walker
University of Oxford, UK

Recognizing and characterizing strike-slip faults and earthquakes

Richard Walker

N. Ambraseys

Yeats, Sieh and Allen

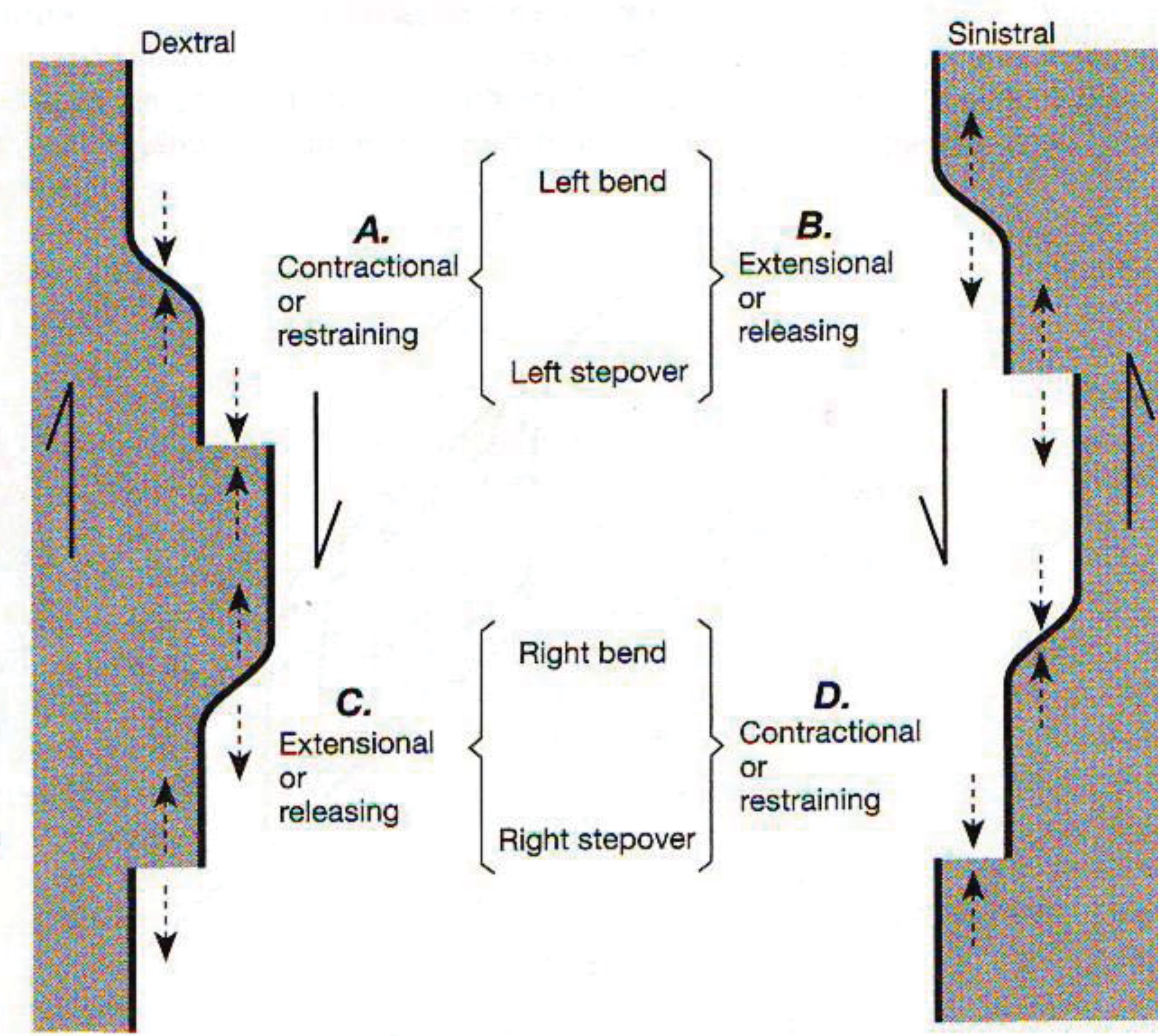


'igure 8–1. Worldwide distribution of major active strike-slip faults. Those mentioned in the text and se ected others are numbered: **Ridge-ridge transform faults:** Blanco, 3; Kane, 16; Romanche, 17; Andrew Bain, 21. **Trench-trench transform faults:** Chaman, 24; Macquarie Ridge, 38; Alpine, 39; Fiji, 40; Northern bound ary of Caribbean plate (Swan, Oriente, Motagua and Chixoy-Polochic faults, 8; and Septentrional fault, 10) and outhern boundary of Caribbean plate (El Pilar and Boconó faults), 11; Northern and southern boundary of the Scotia plate, 15. **Ridge-trench transform faults:** Mendocino, 4; Fairweather and Queen Charlotte Islands, 2; Dead Sea, 20; Sagaing, 27. **Other transform faults:** San Andreas-Gulf of California, 5. **Trench-parallel faults:** Denali, 1; Pallatanga, 12; Atacama and El Tigre, 13; Liquine-Ofqui, 14; Great Sumatran, 30; Median Tectonic Line, 33; Philippine, 35; Sorong, 37. **Indent-linked faults:** North and East Anatolian and Pliny Trough, 19; Dasht e-Bayaz, Rudbar-Tarom, and others, 22; Fuyun, Talas-Fergana, Kopet-Dagh, and others, 23; Altyn Tagh, Haiyuan and Kunlun, 26; Karakorum-Jiali, 25; Xianshuihe and Xiaojiang, 28; Honghe, 29; Tan-lu, 31. **Other:** conjugate faults of central Honshu, Japan, 33; Gorda Deformation Zone, between 3 and 4; Basin Ranges, 6; New Madrid and Meers, 7; Managua, 9.

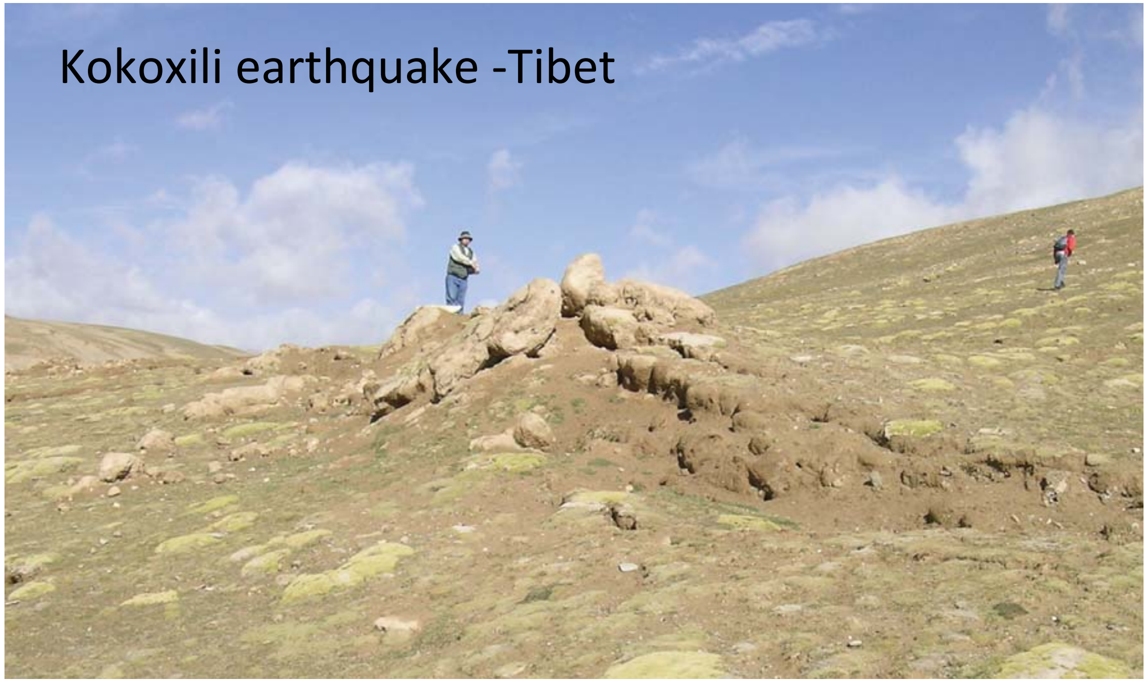
Strike-slip faults are not always linear

Sometimes restraining bends are called 'transpressional bends'

and releasing bends 'transtensional'

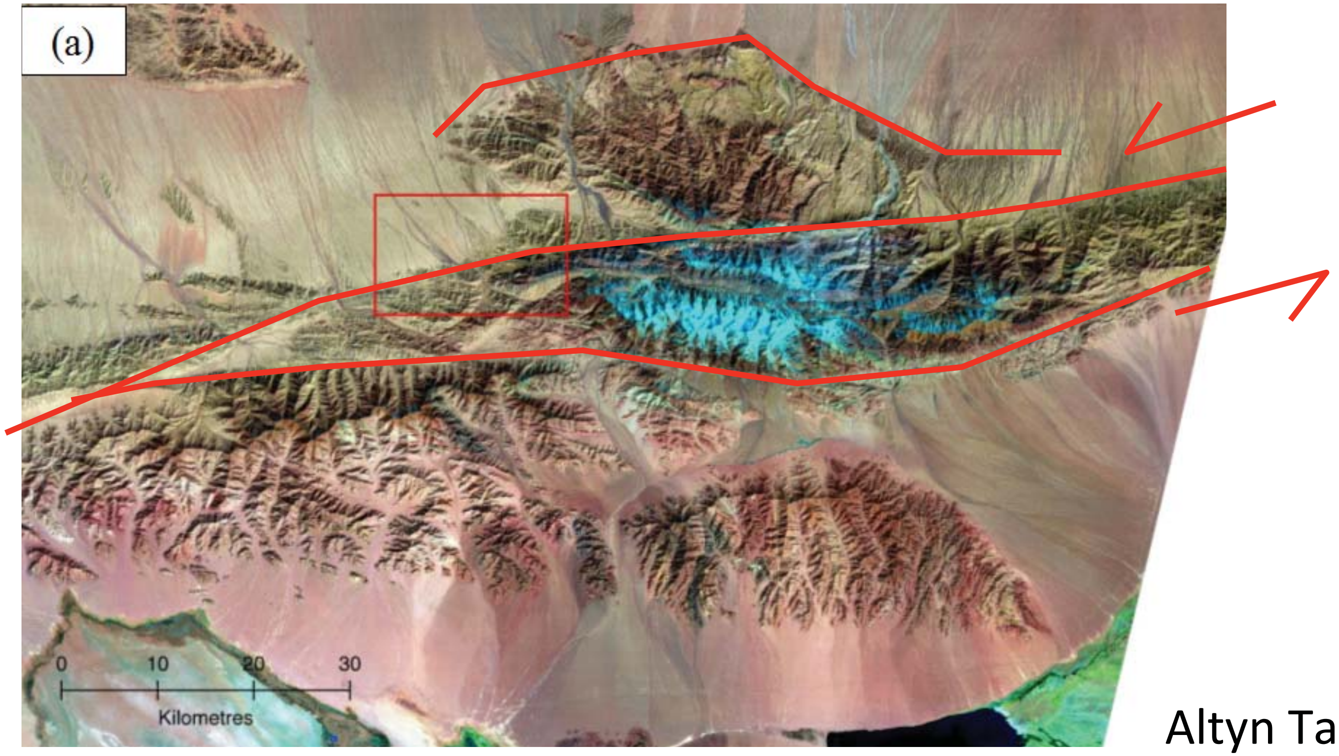


These features can occur at a range of scales – from earthquake rupture to mountain range!

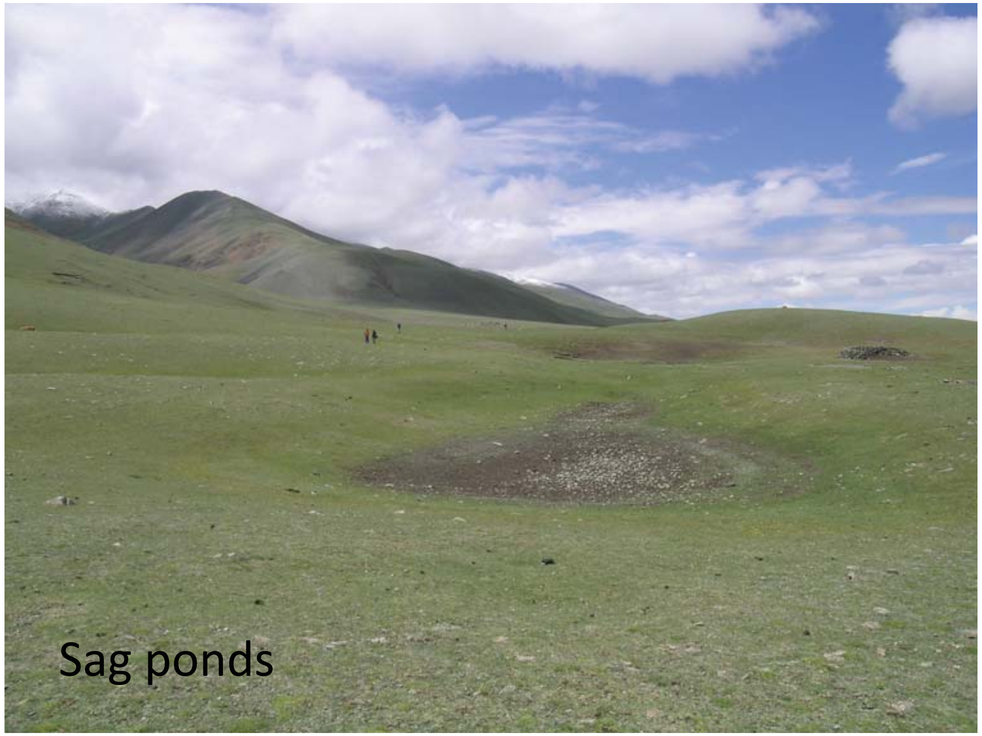


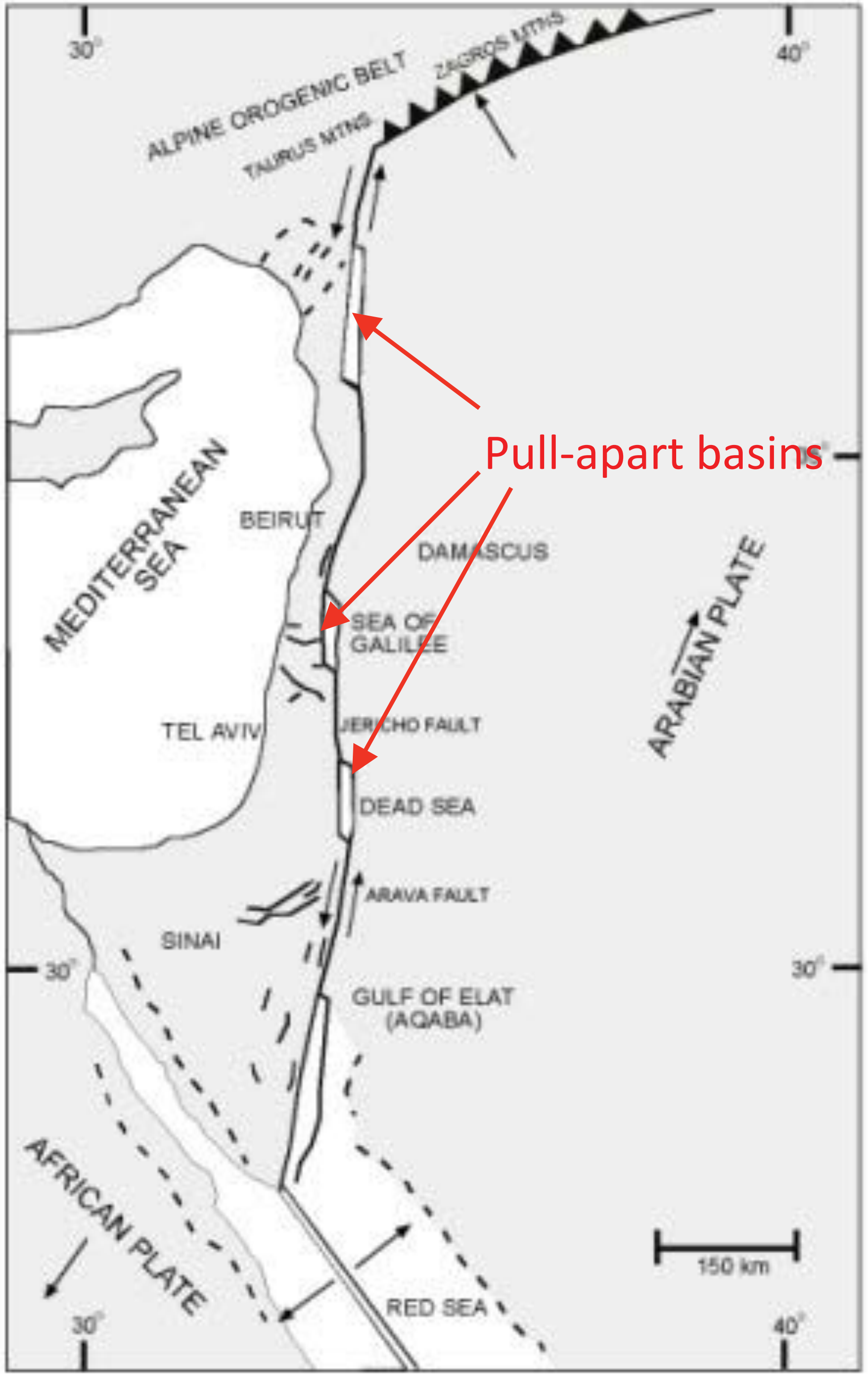
Miracle hill, on the San Andreas fault (photo D. Lynch)

http://epod.usra.edu/archive/epodviewer.php3?oid=298368



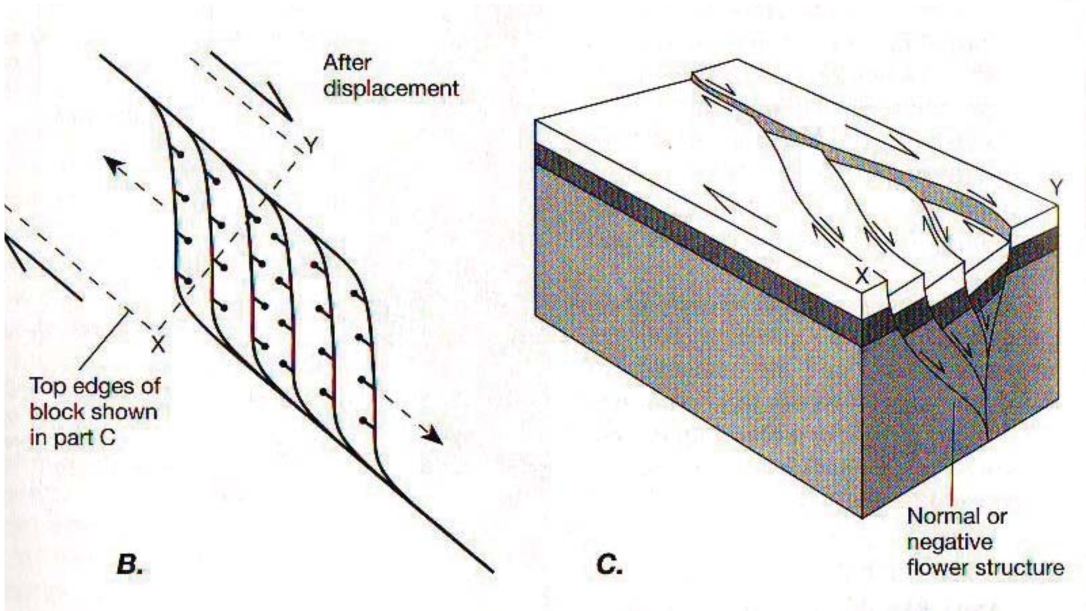
Altyn Tagh fault, Tibet

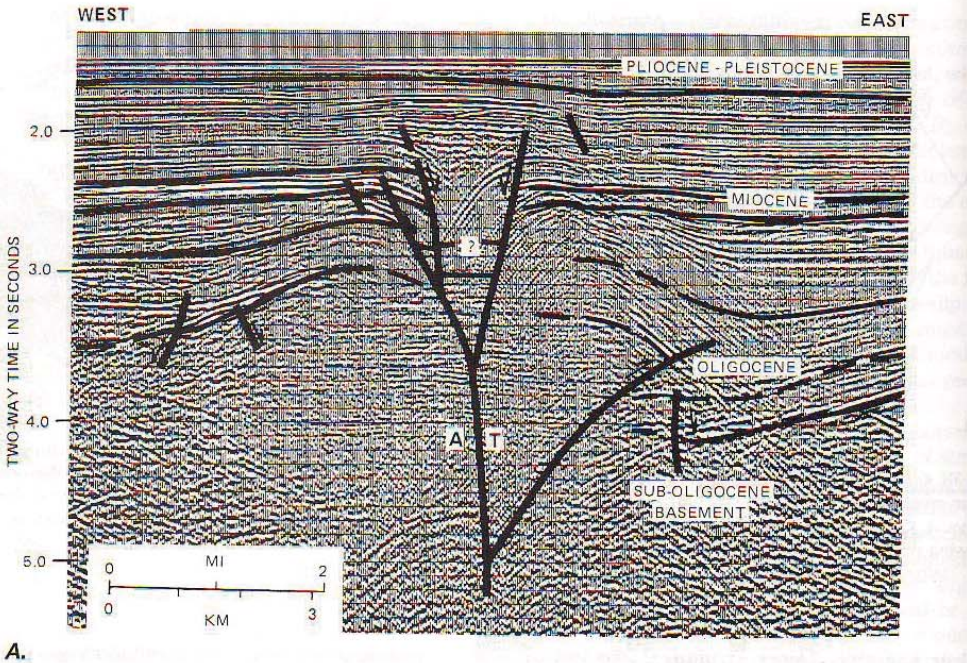


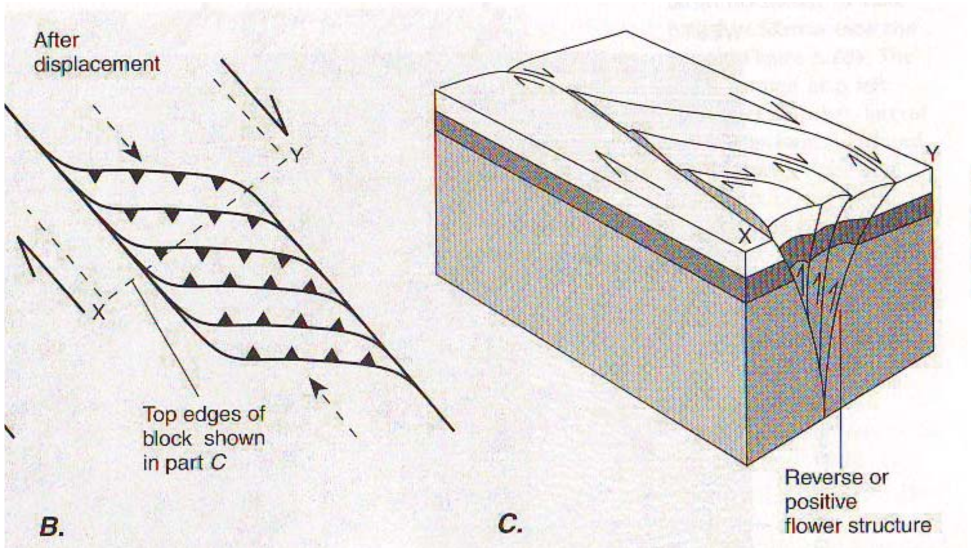


http://www.tau.ac.il/~zviba/intro.html

Flower structures







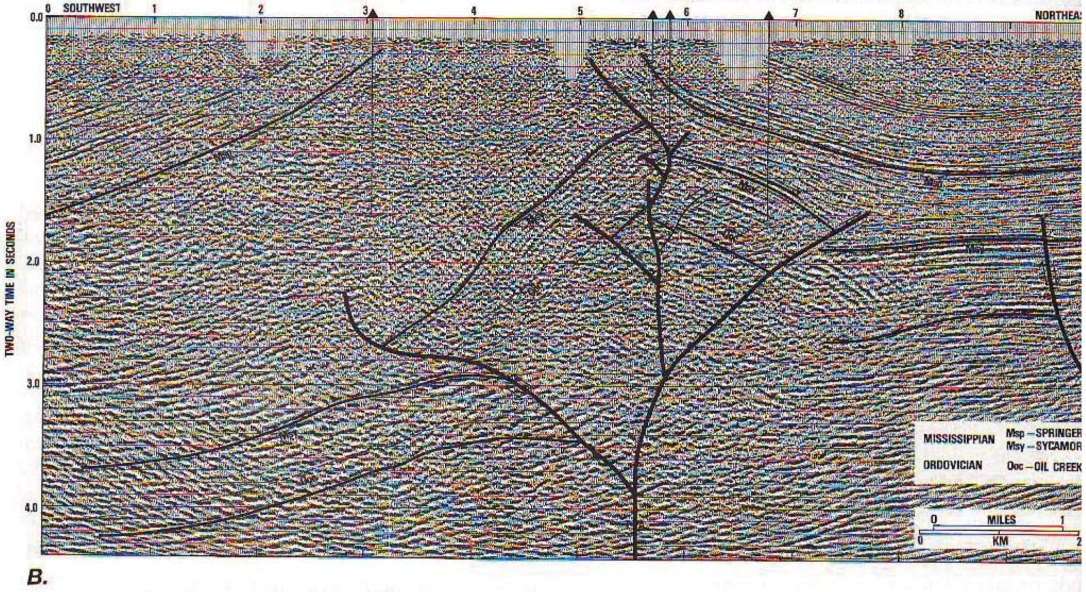
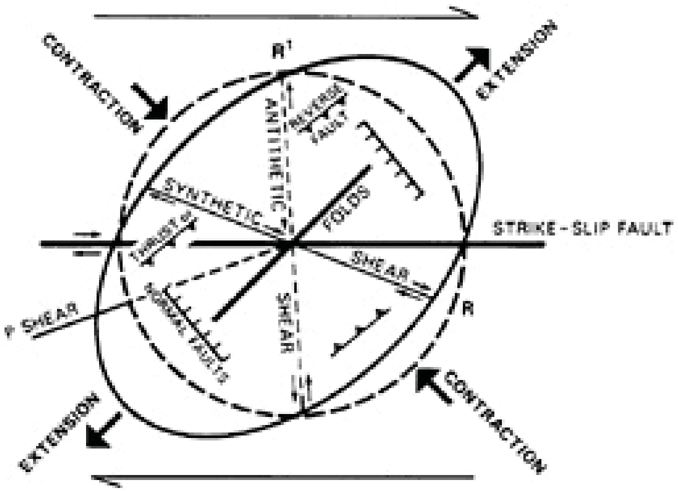
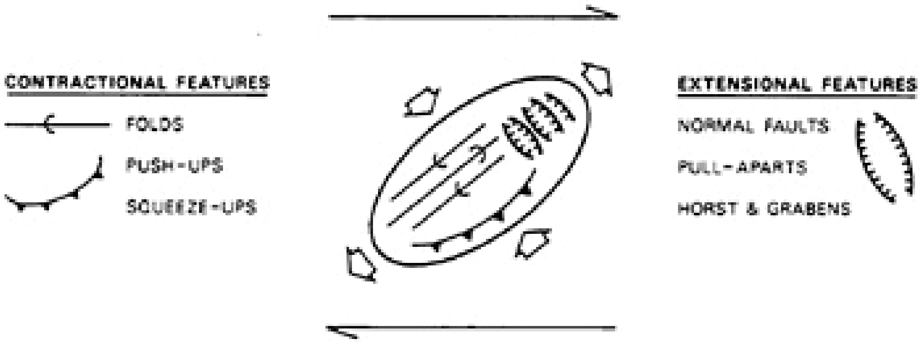


FIGURE 6.8 Seismic profiles of flower structures. *A.* Example of a negative flower structure from an extensional duplex on a dextral strike-slip fault from the Andaman Sea between India and the Malay Peninsula. Unmigrated seismic reflection profile. *B.* Example of positive flower structure from a contractional duplex on a sinistral strike-slip fault in the Ardmore Basin, Oklahoma. Migrated seismic profile. (After Harding 1985)

Strike-slip earthquake ruptures

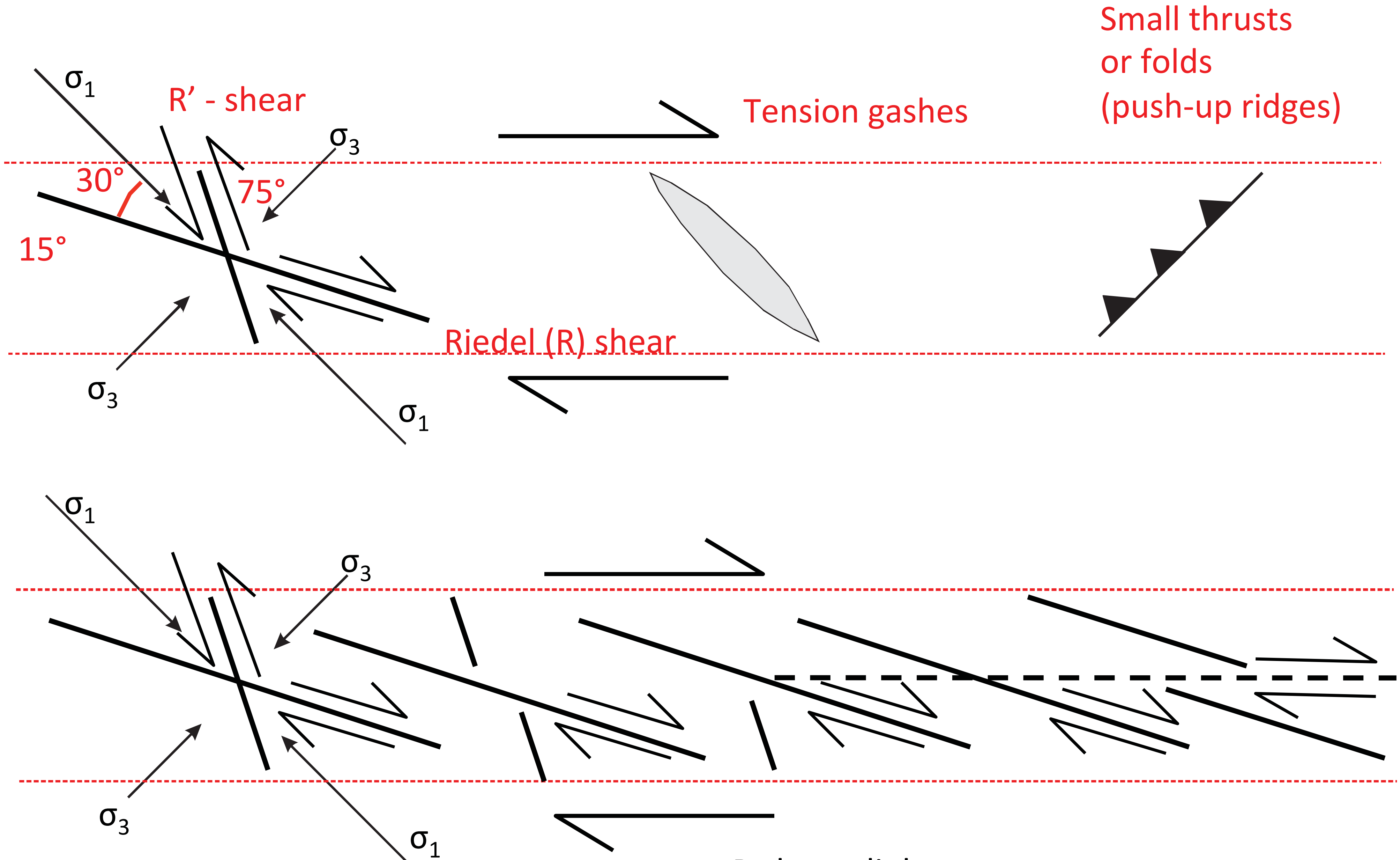


A



B

http://www.ipgp.jussieu.fr/~lacassin/Kunlun/kunlun.html



Riedel shears (R) often better developed than conjugate Riedel (R')

P-shears link Riedel shears together

Through-going fault formed

Ruptures of the 1968 Dasht-e Bayaz left-lateral earthquake (Iran)

Nick Ambraseys

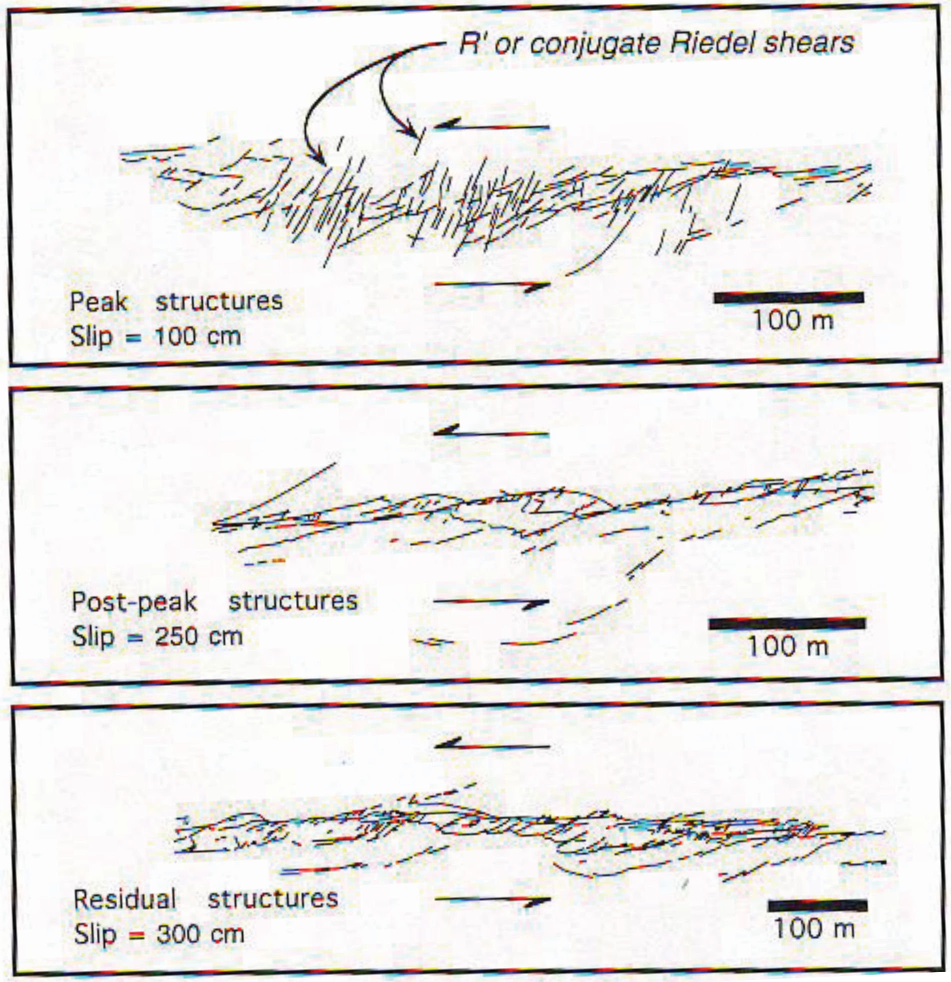


Figure 8–20. Patterns of rupture along strike-slip faults are very similar to those created in the laboratory. These patterns from three localities along the Dasht-e-Bayaz fault rupture correspond structurally to the patterns associated with laboratory peak, post-peak and residual phases. Redrawn from Tschalenko (1970).

Palaeoseismology of strike-slip faults

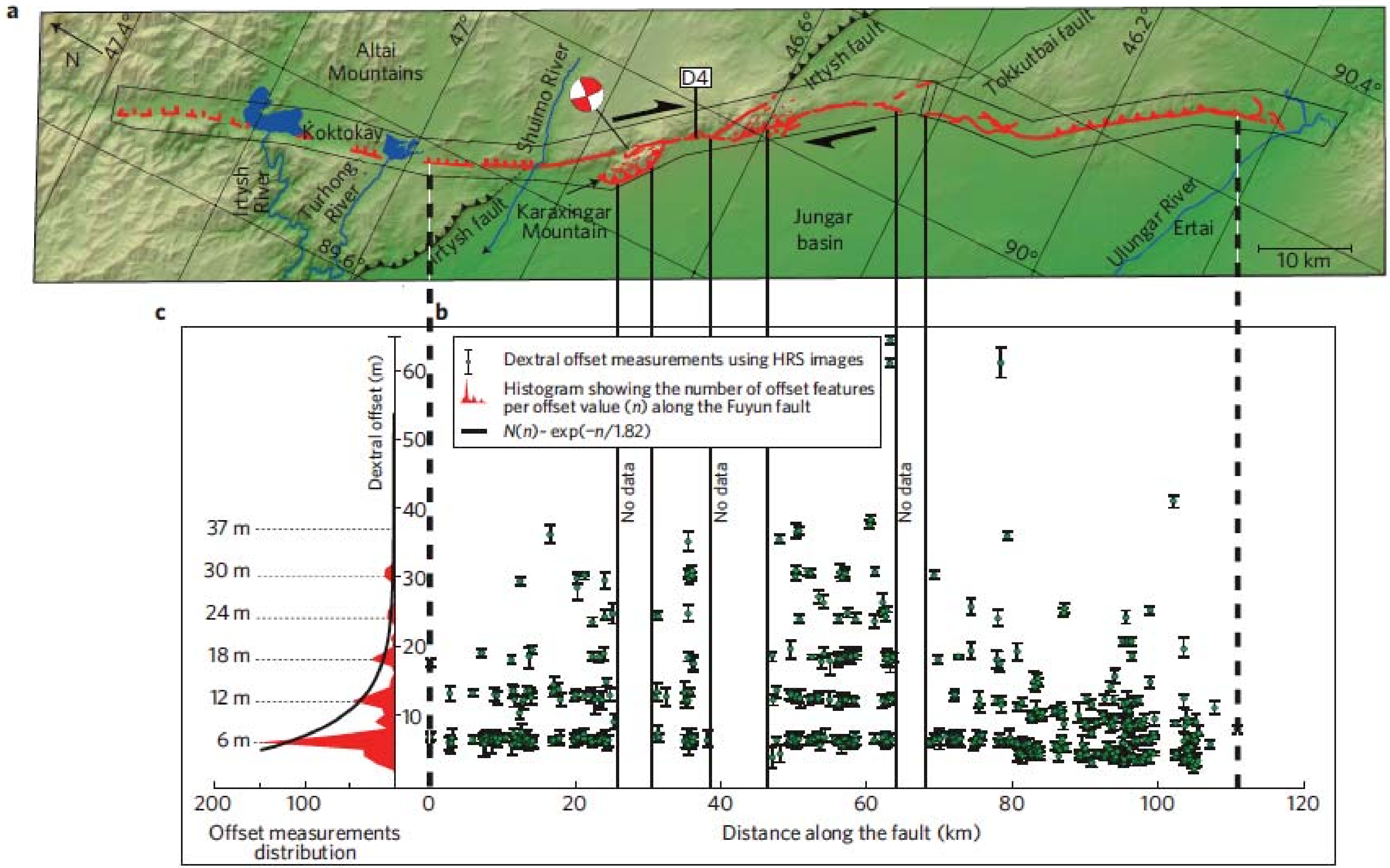


Figure 1 | Rupture map and offset measurements. a, 1931 rupture trace (red), mapped from Quickbird satellite image swath (swath limits indicated by thin lines). **b**, 569 horizontal offset measurements along the south-central part of the rupture from retrofitting of geomorphic markers into initial alignment. Error bars depend on the quality of measurements (see text and Supplementary Material for discussion). **c**, Horizontal offset distribution. Note the number of measurements decreasing exponentially with increasing offset size.

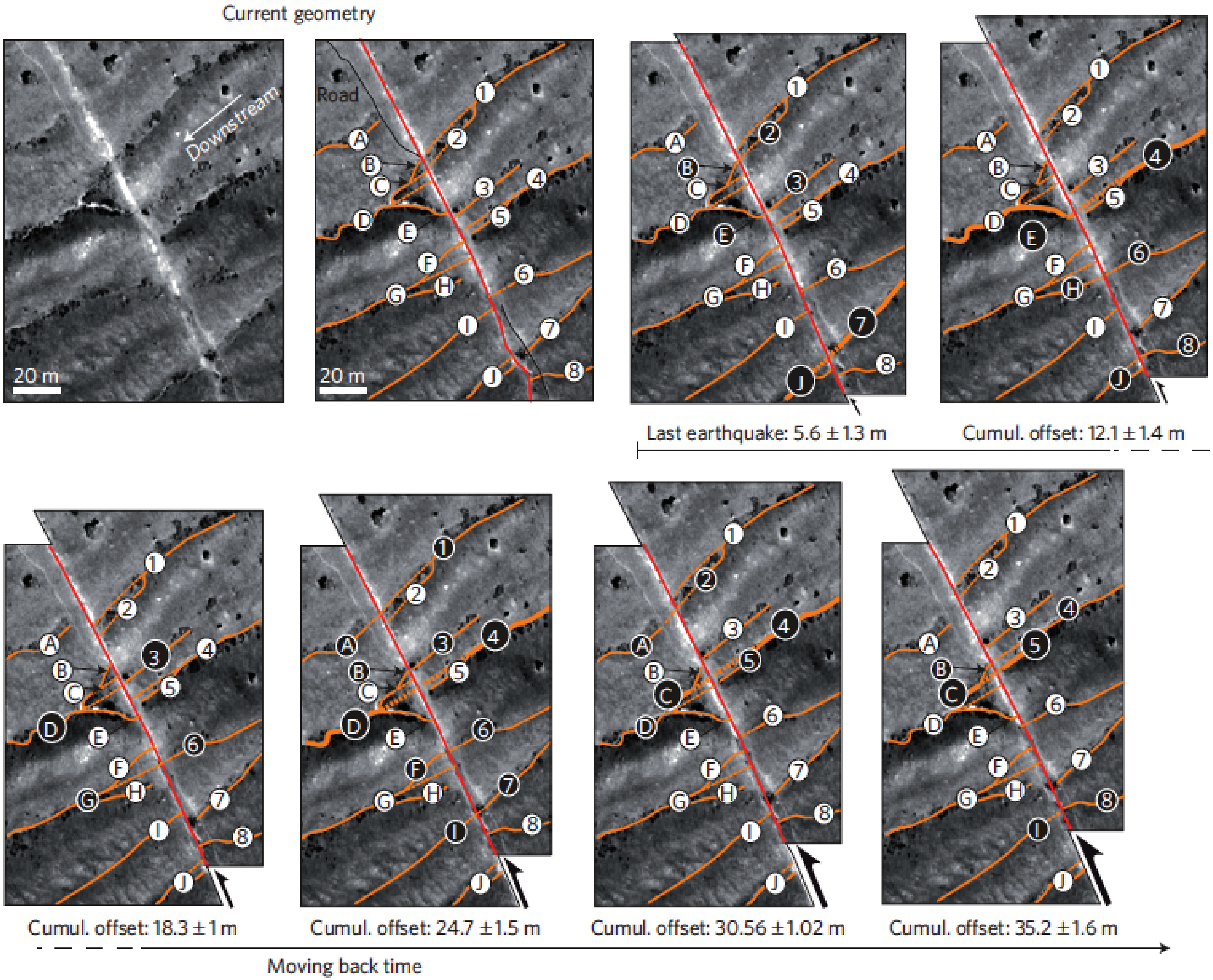
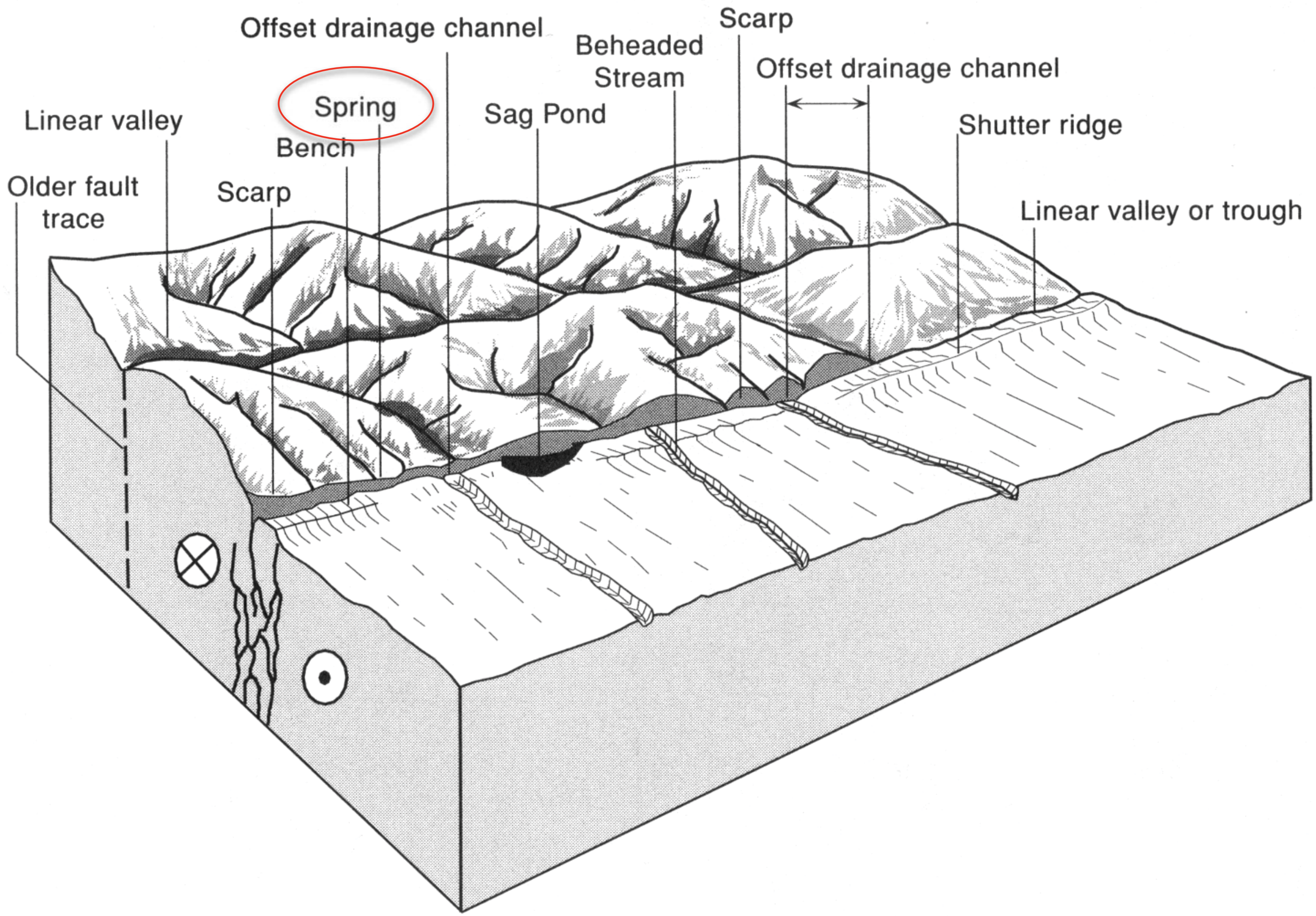


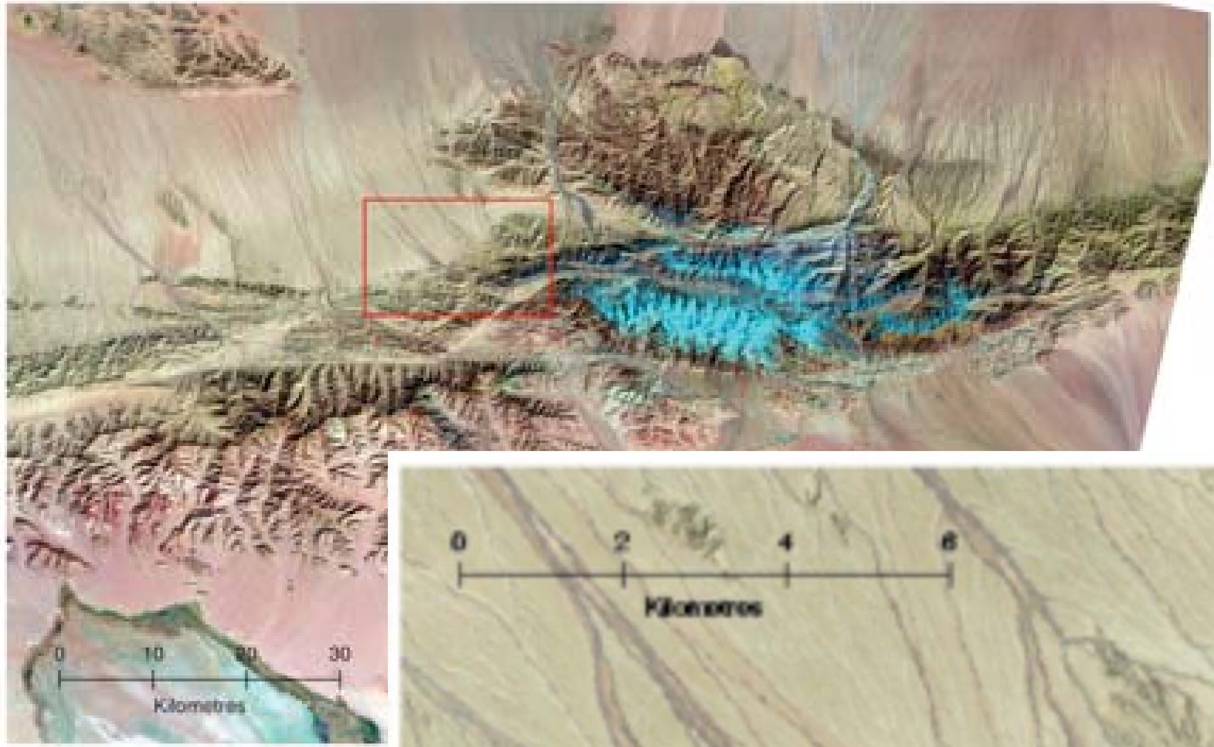
Figure 2 | Successive reconstructions of offset channels at site 4D (location on Fig. 1). Channels are labelled alphabetically and numerically on the west and east sides of fault, respectively. Starting from the present geometry, the east side is moved to realign channels truncated or disconnected as the result of successive earthquakes. Each offset is determined by restoring continuity of one main channel (large black circle) and other secondary channels (small black circles). Successive offsets of 5.6, 12.1, 18.3, 24.7, 30.56 and 35.2 m are identified.

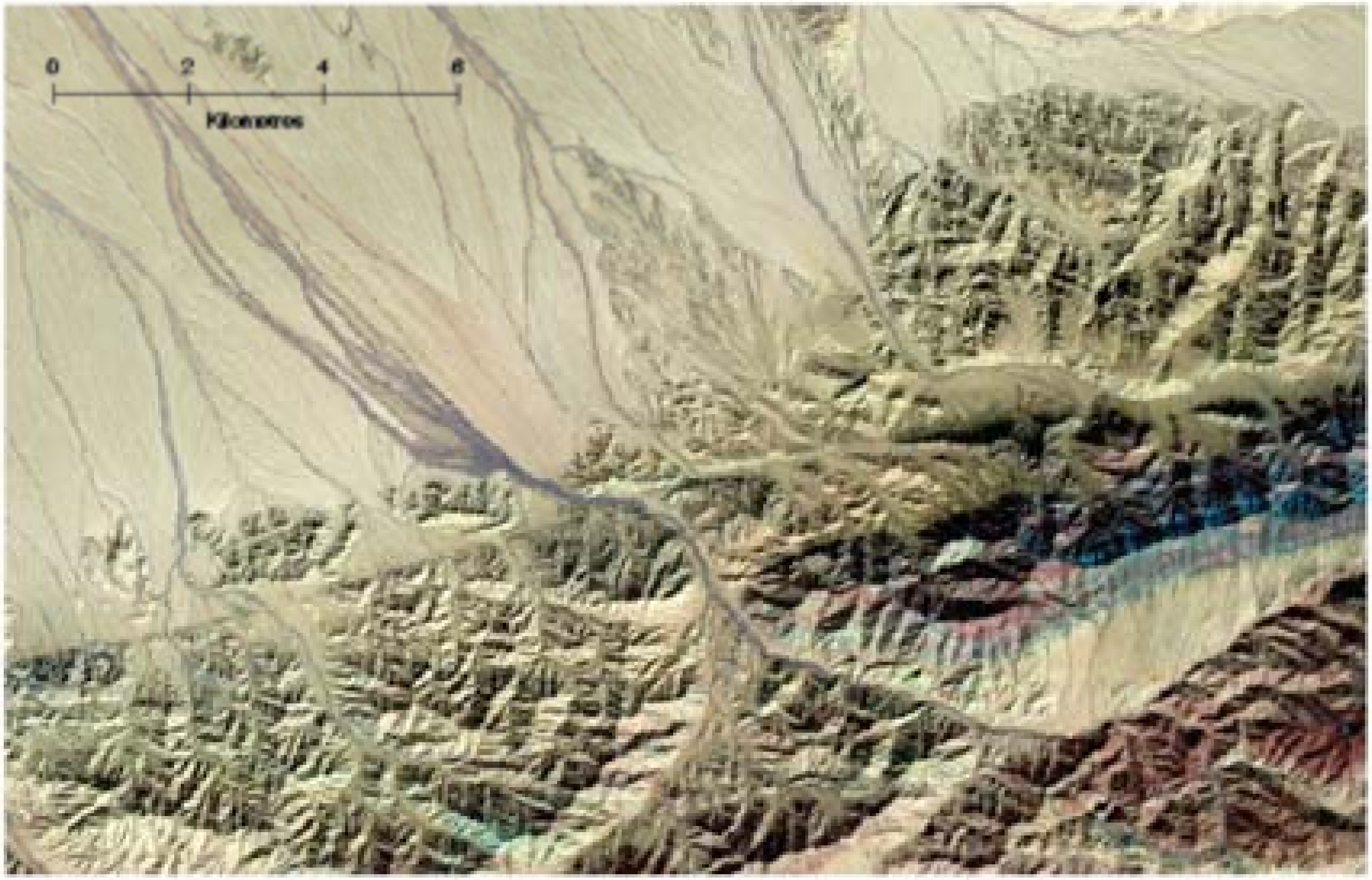
The Geomorphology of Strike-Slip Faults



Displaced drainage and shutter ridges

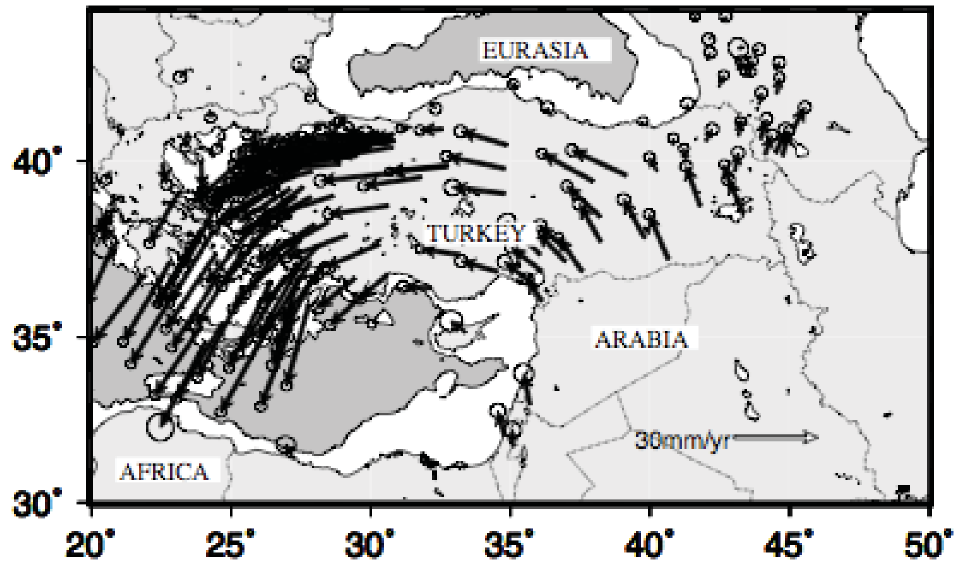
Example from the Altyn Tagh Fault
Northern Tibet



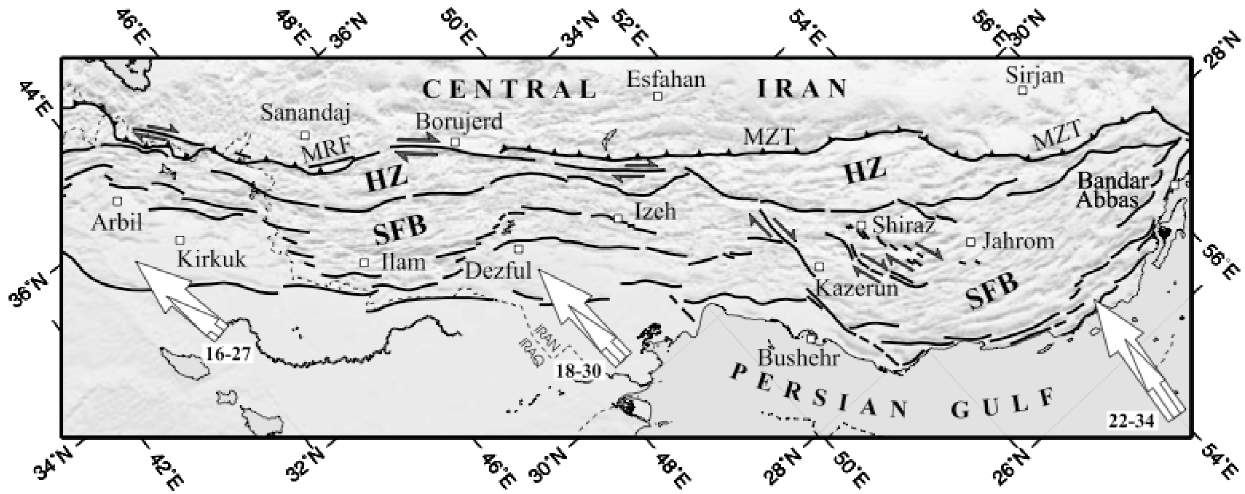


The tectonic roles of strike-slip faulting

Lateral transport (e.g. Turkey)

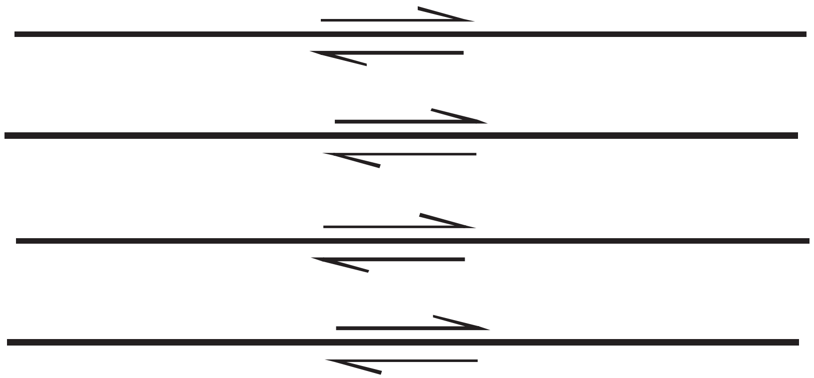


Partitioning (e.g. the western Zagros in Iran)



Rotation about vertical axis …

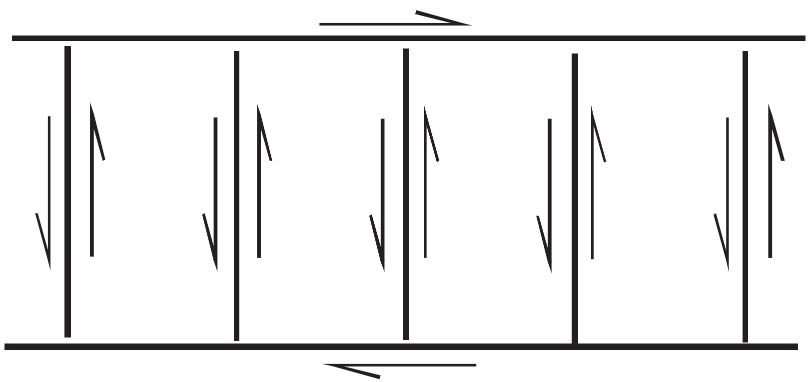
Vertical axis rotation associated with strike-slip faults

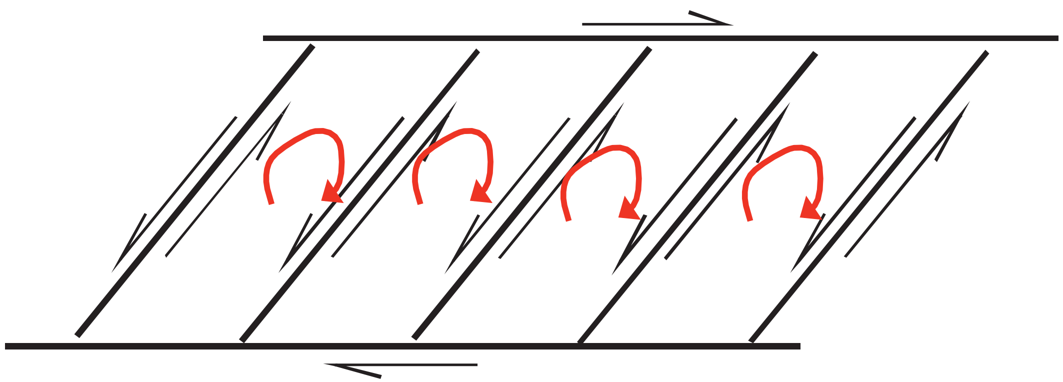


A zone of dextral strike-slip faulting

The faults that bound the rotating blocks are left-lateral!

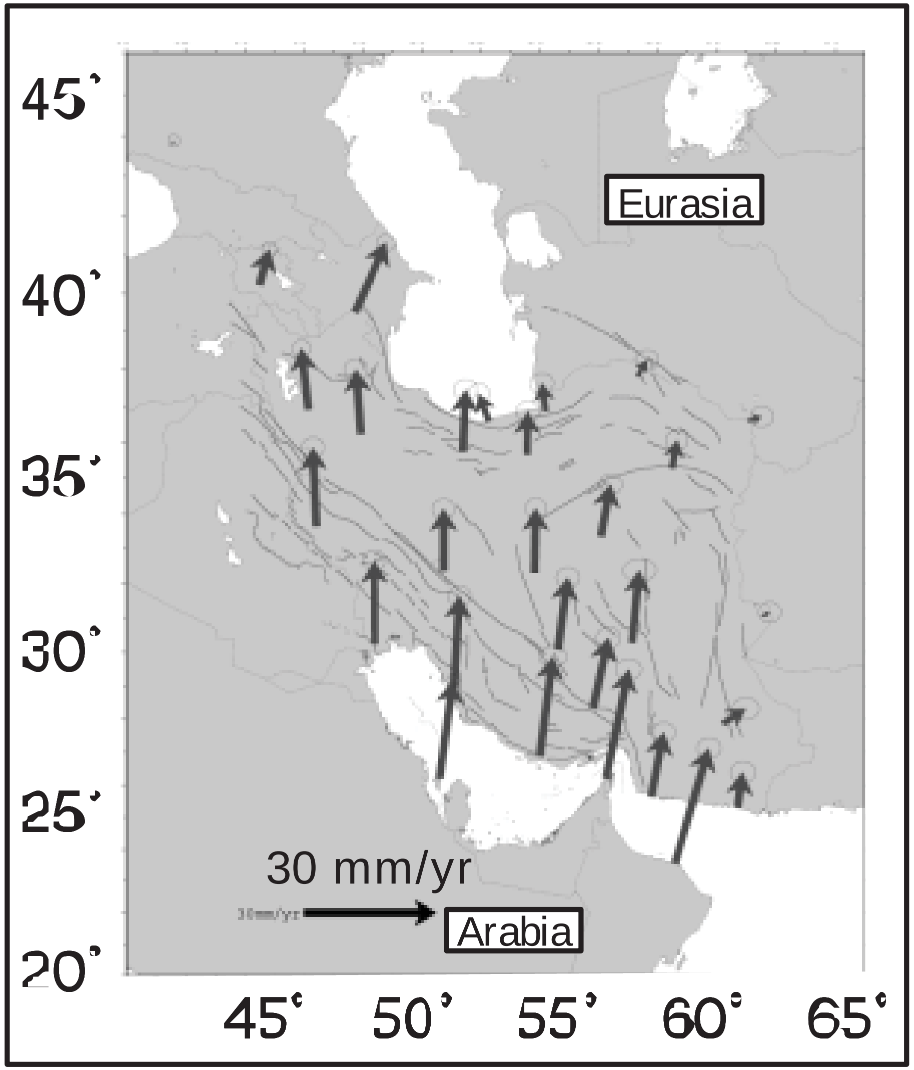
Or …



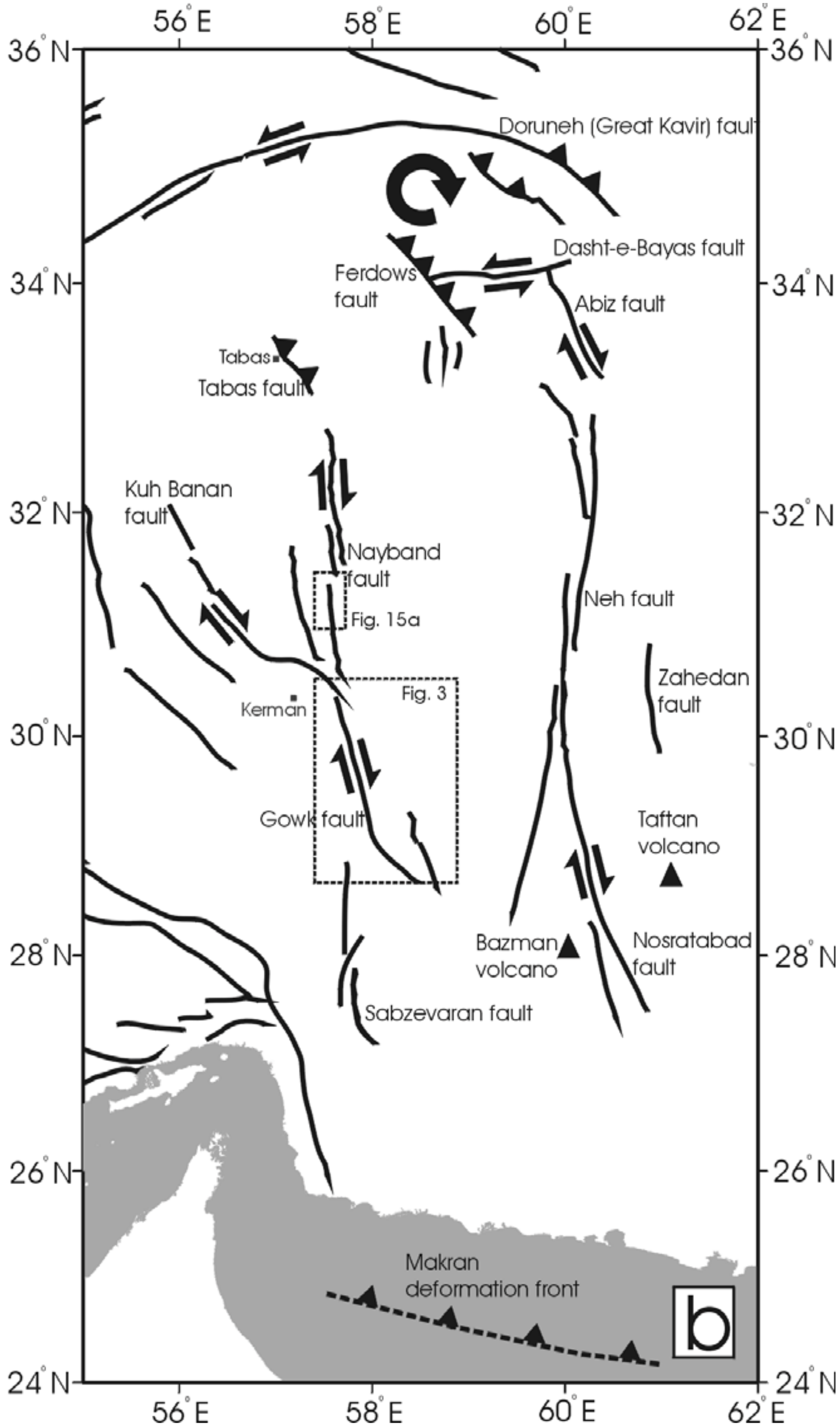


Rotations can be measured using palaeomagnetism (declination changes)

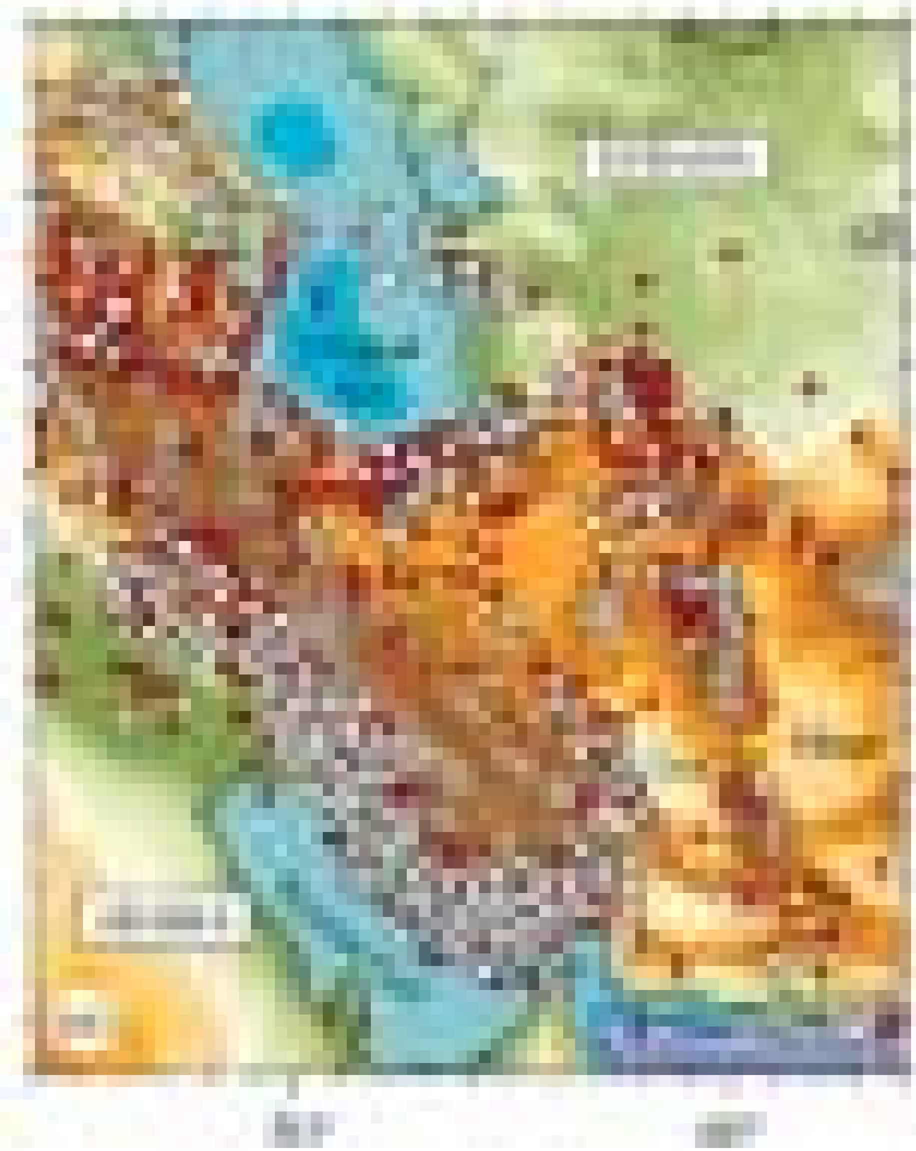
An example … eastern Iran



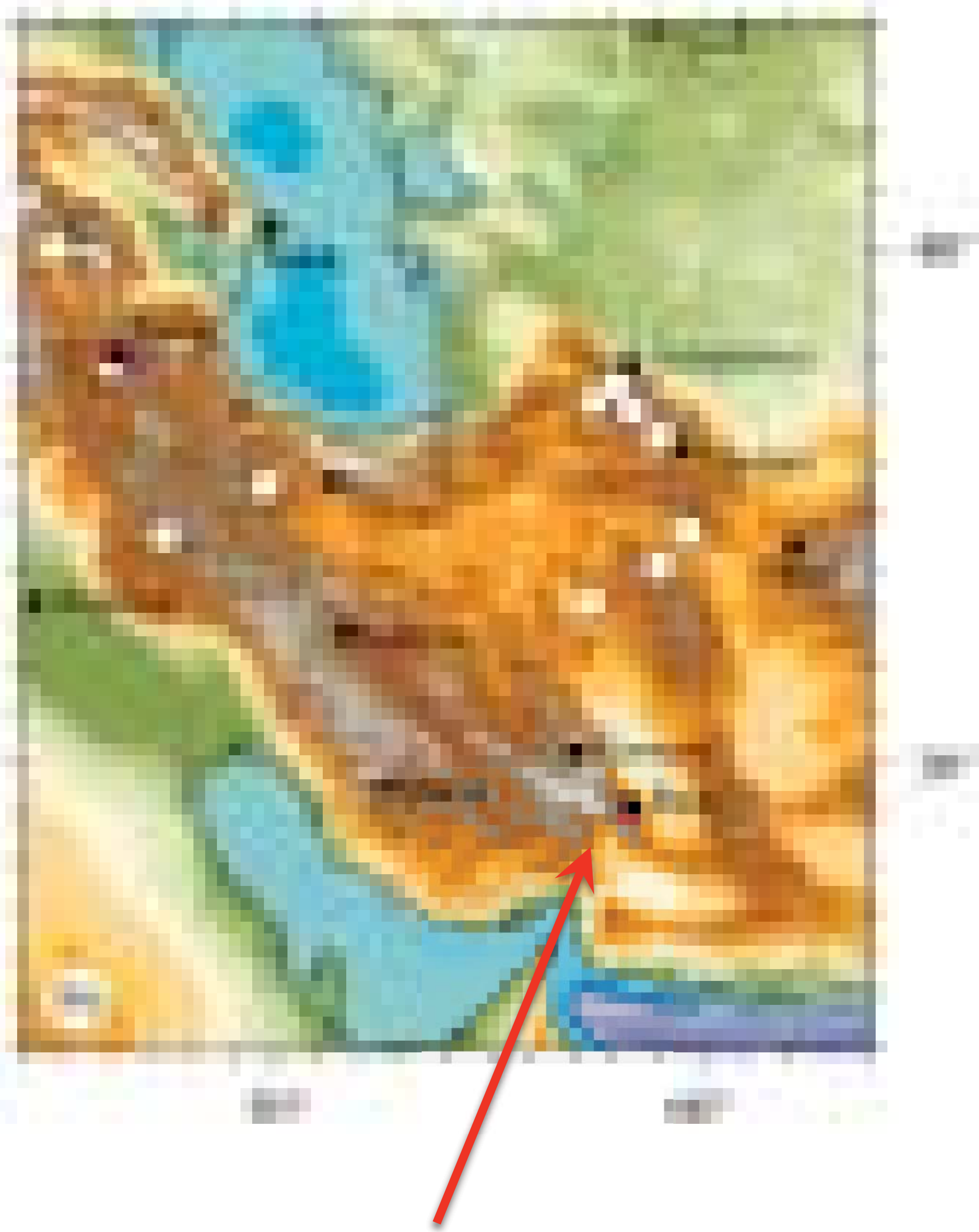
GPS velocity field
(Vernant et. al. 2004)



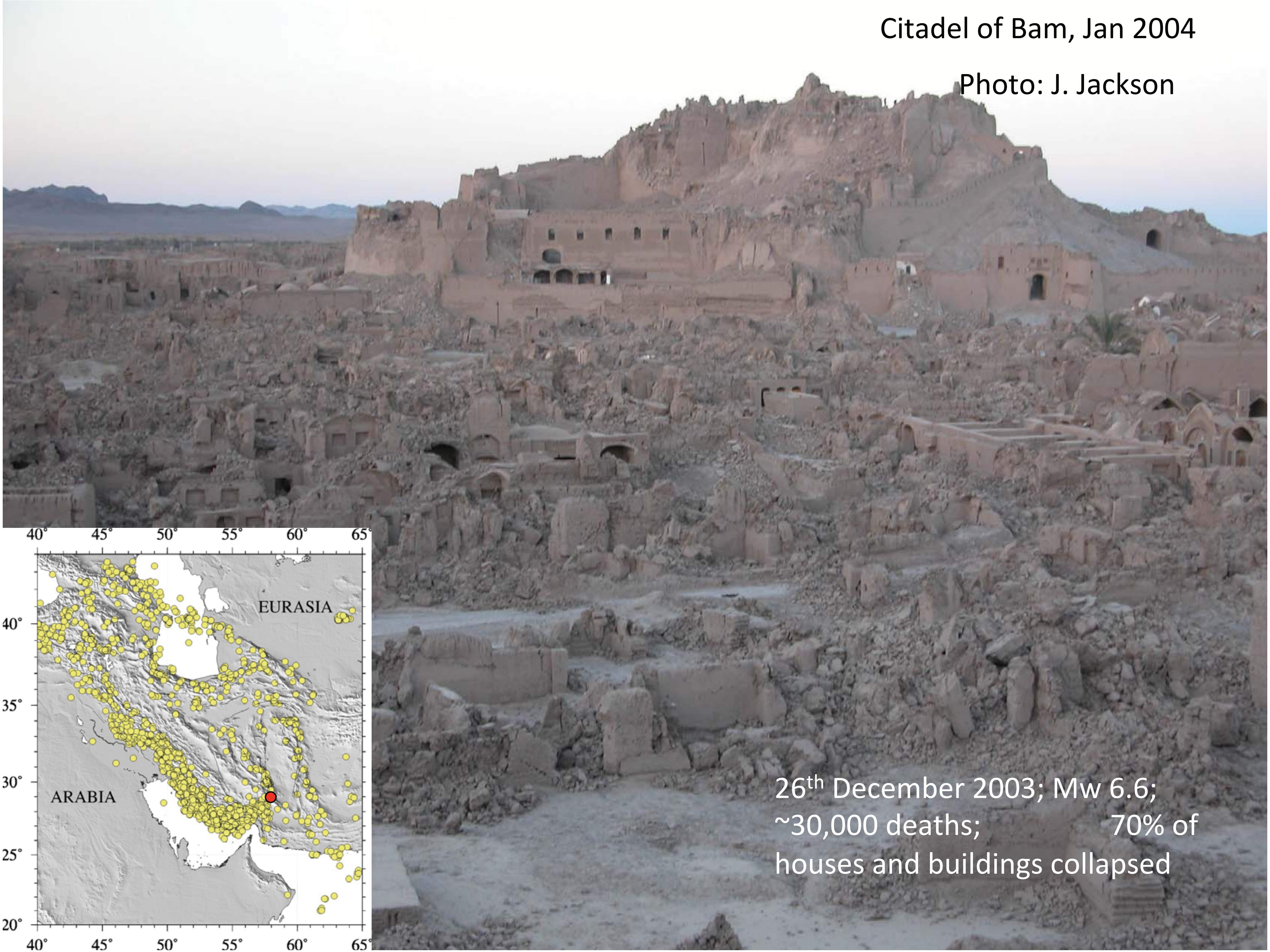
Walker and Jackson, 2002



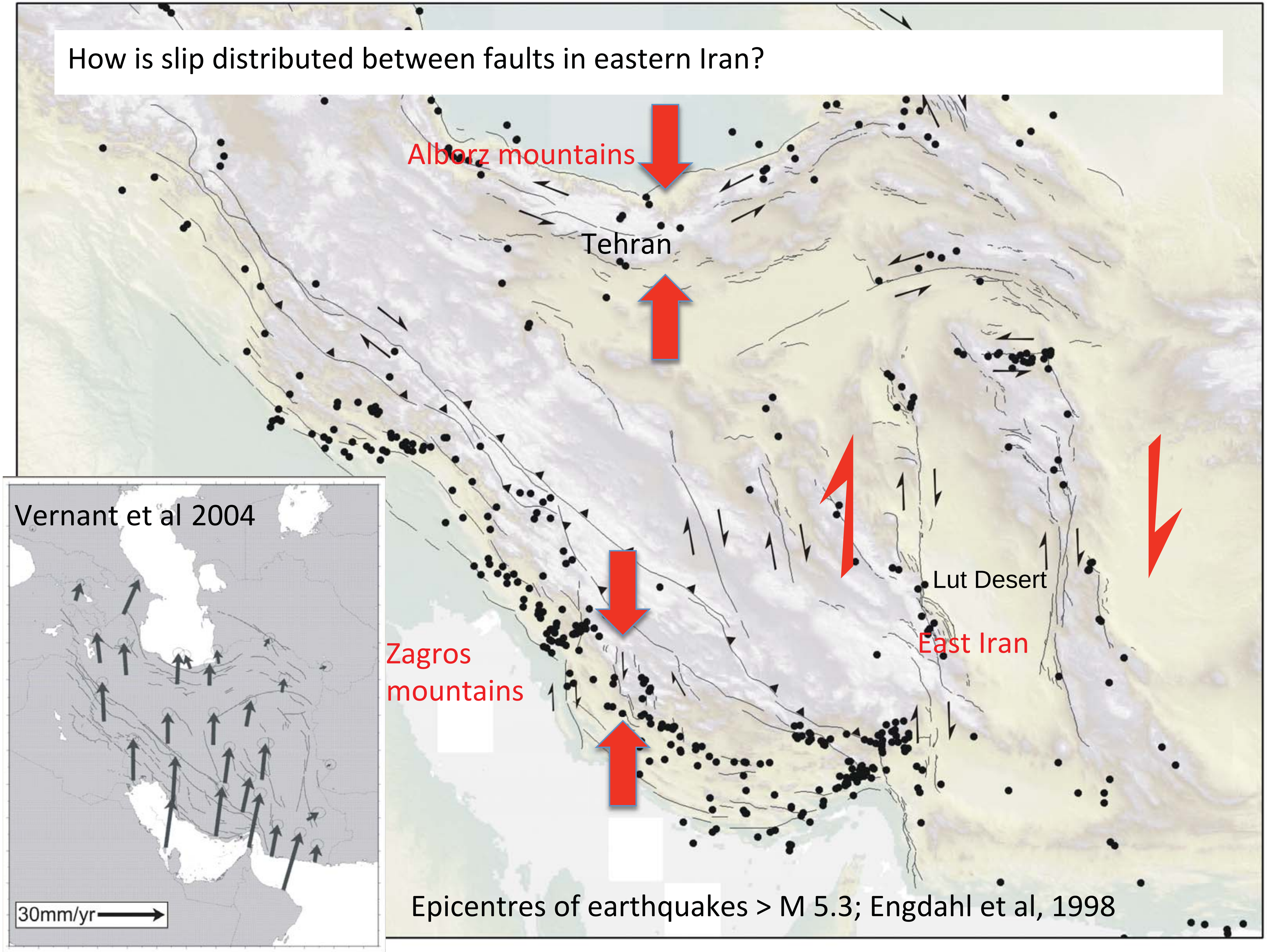
Jackson (2007)

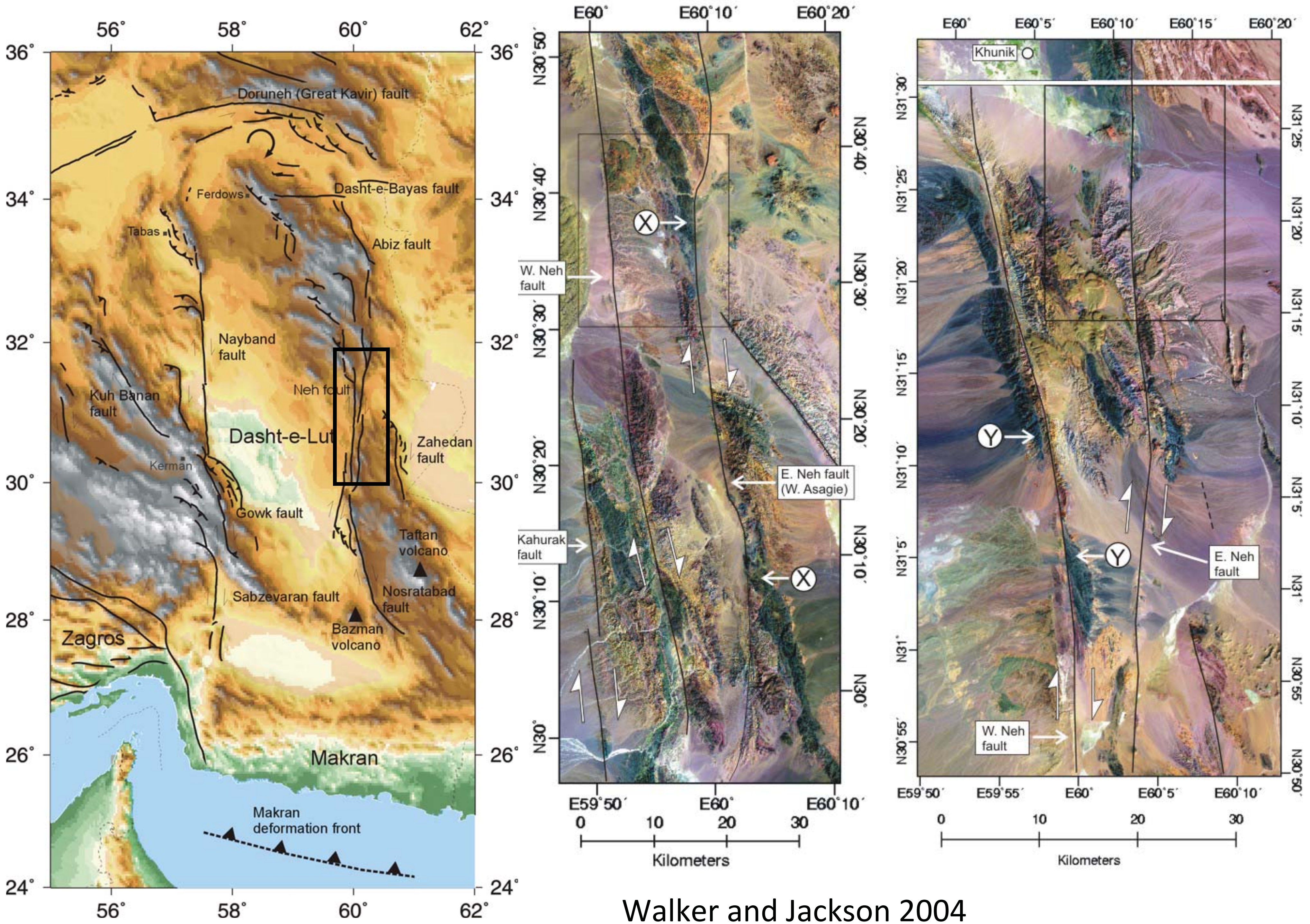


Citadel of Bam, May 2000


Citadel of Bam, Jan 2004
Photo: J. Jackson
26th December 2003; Mw 6.6; ~30,000 deaths; 70% of houses and buildings collapsed
EURASIA
ARABIA
40° 45° 50° 55° 60° 65°
40° 35° 30° 25° 20°

How is slip distributed between faults in eastern Iran?

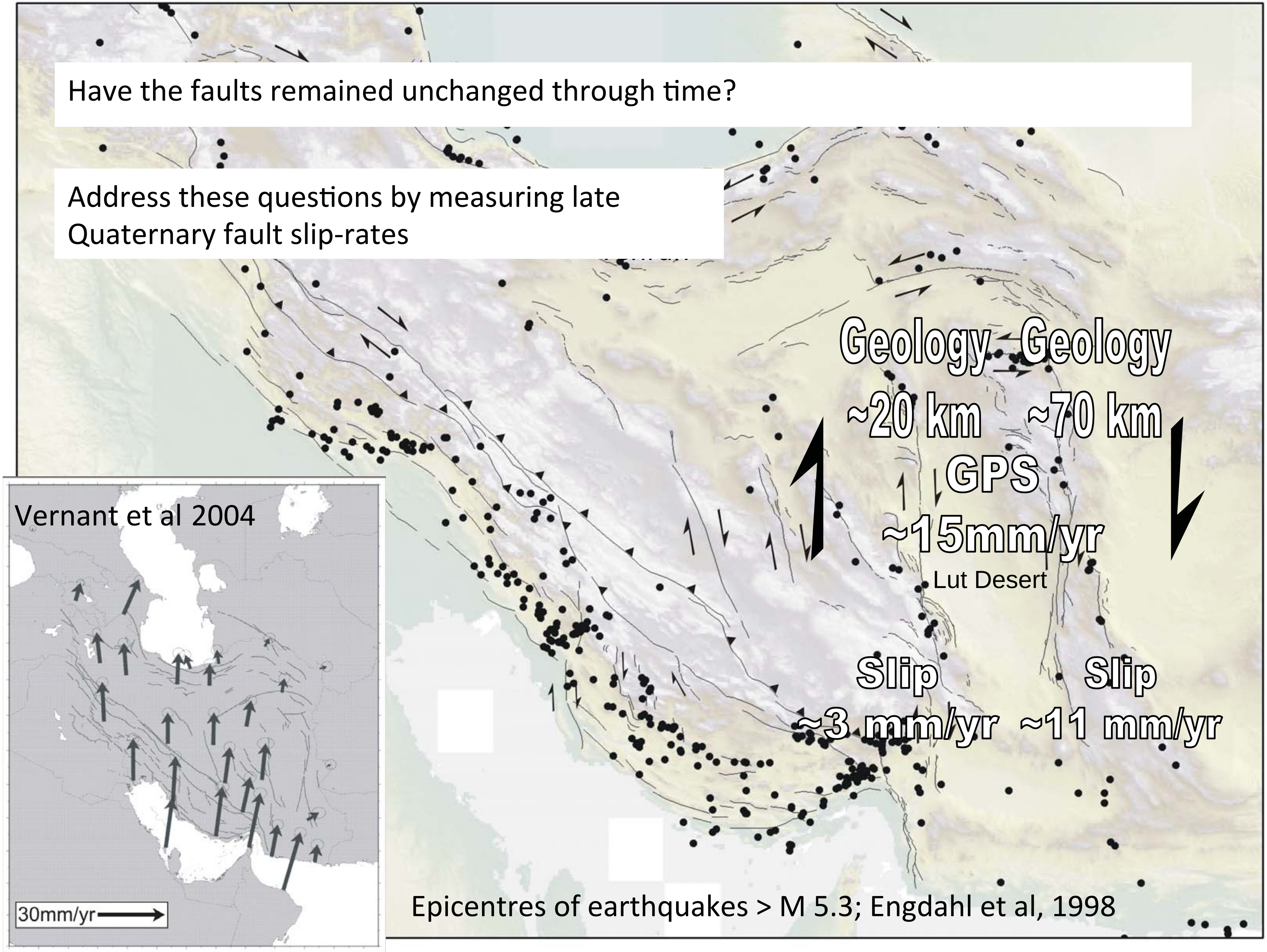




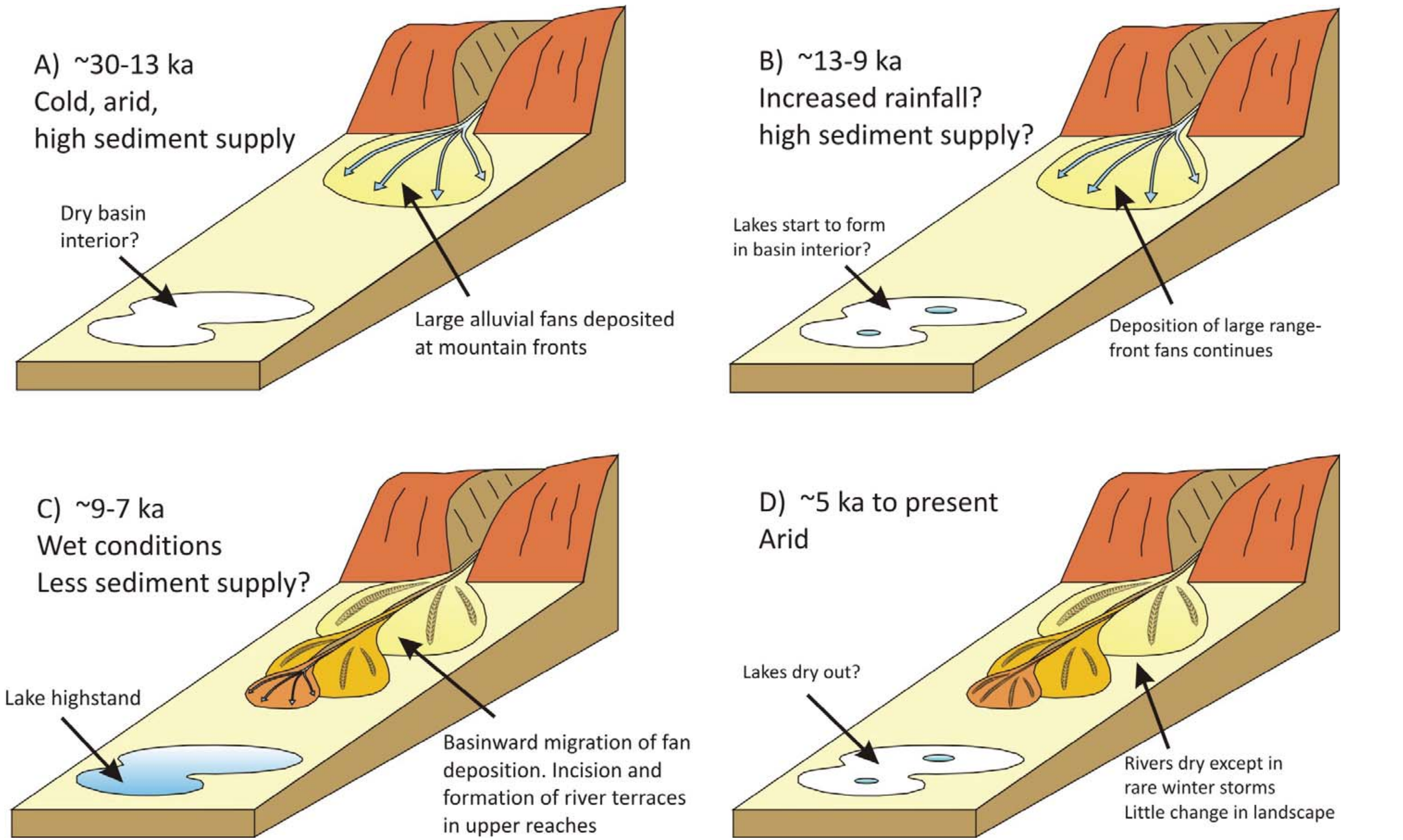
Walker and Jackson 2004

Have the faults remained unchanged through time?

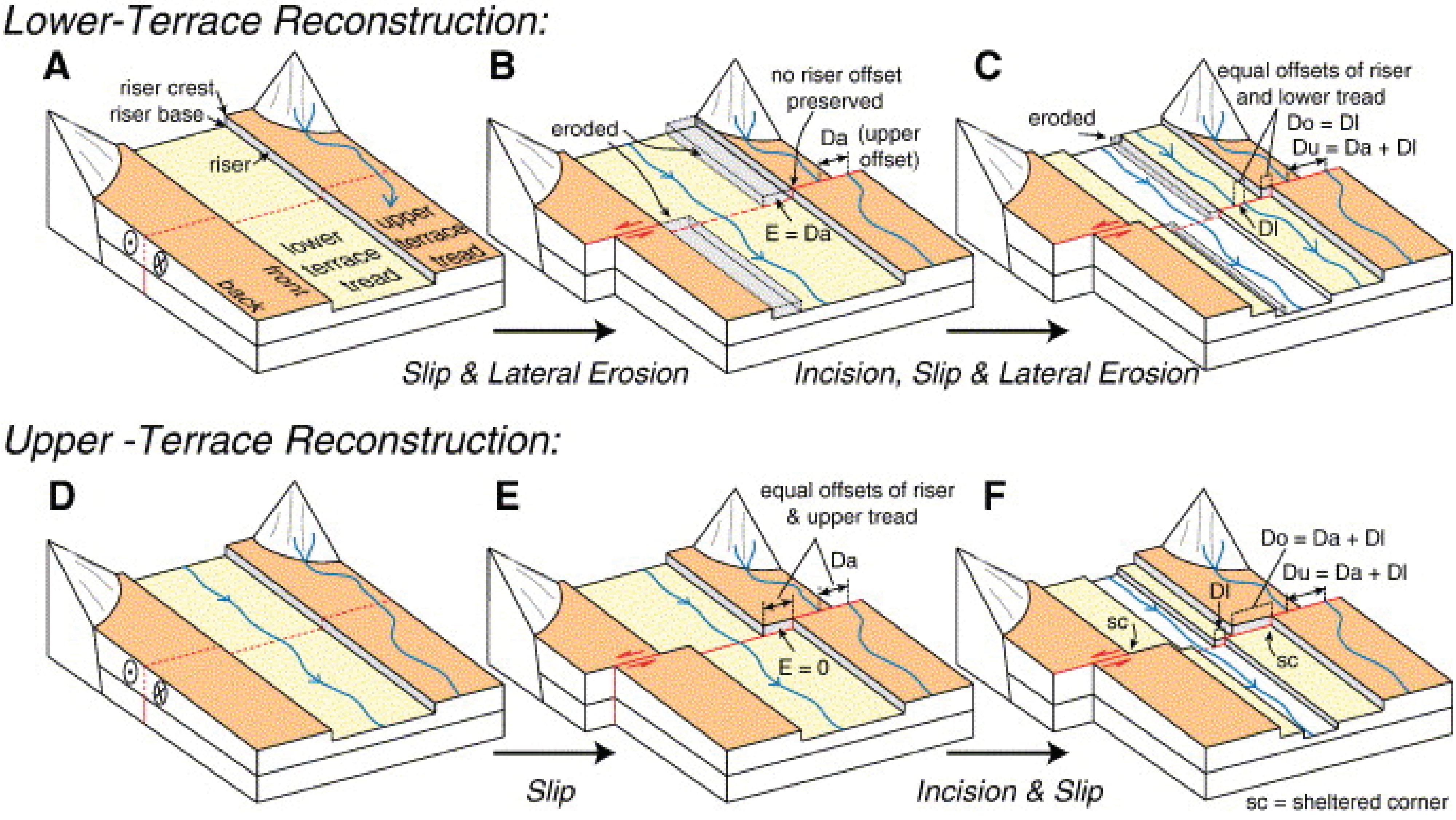
Address these questions by measuring late Quaternary fault slip-rates



Timing of landscape development in eastern Iran



Walker and Fattahi, 2011. A framework of Holocene and Late Pleistocene environmental change in eastern Iran inferred from the dating of periods of alluvial fan abandonment, river terracing, and lake deposition Quaternary Science Reviews



Do = total observed riser displacement

Du = total displacement of the upper tread after its abandonment

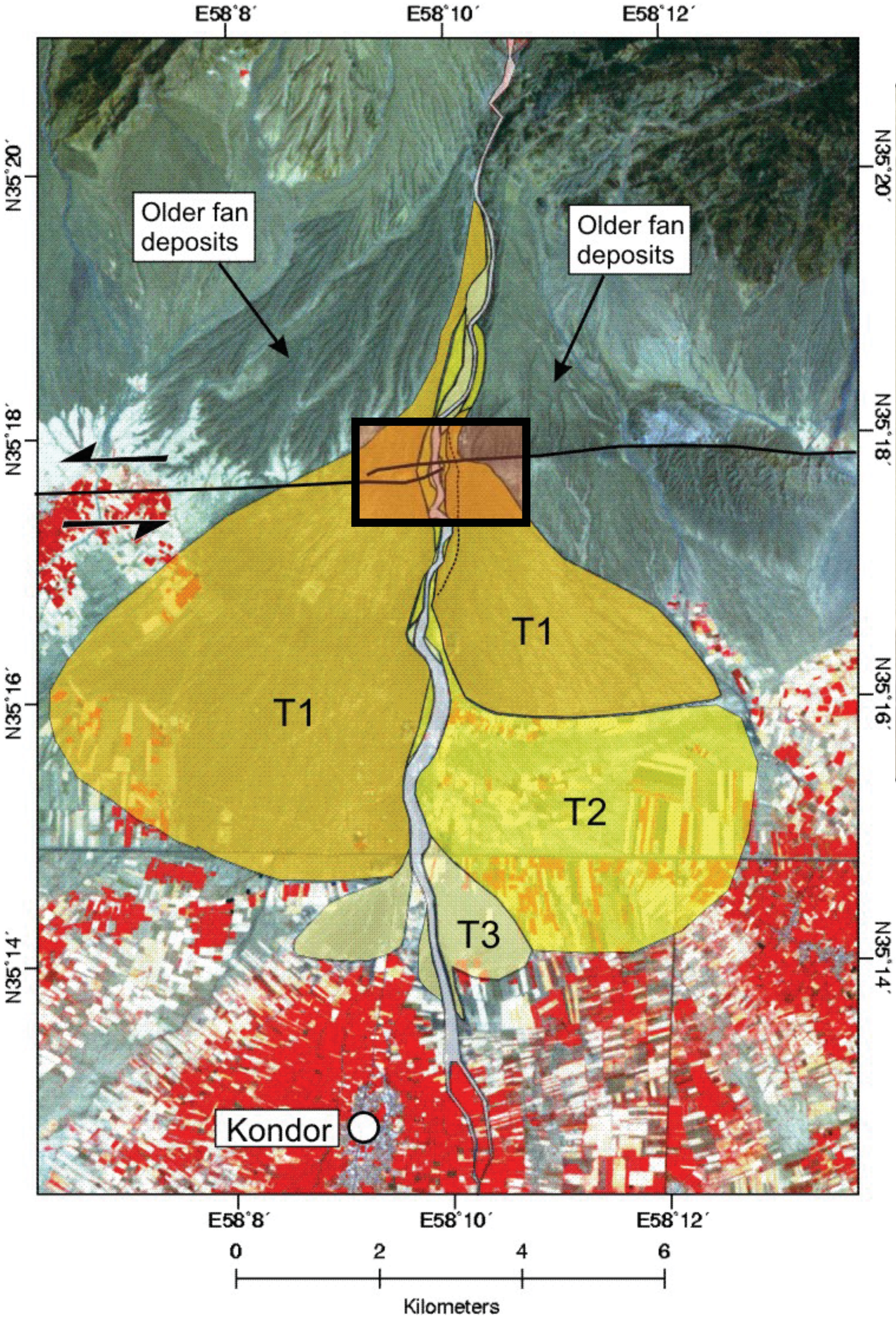
Dl = total displacement of the lower tread after its abandonment

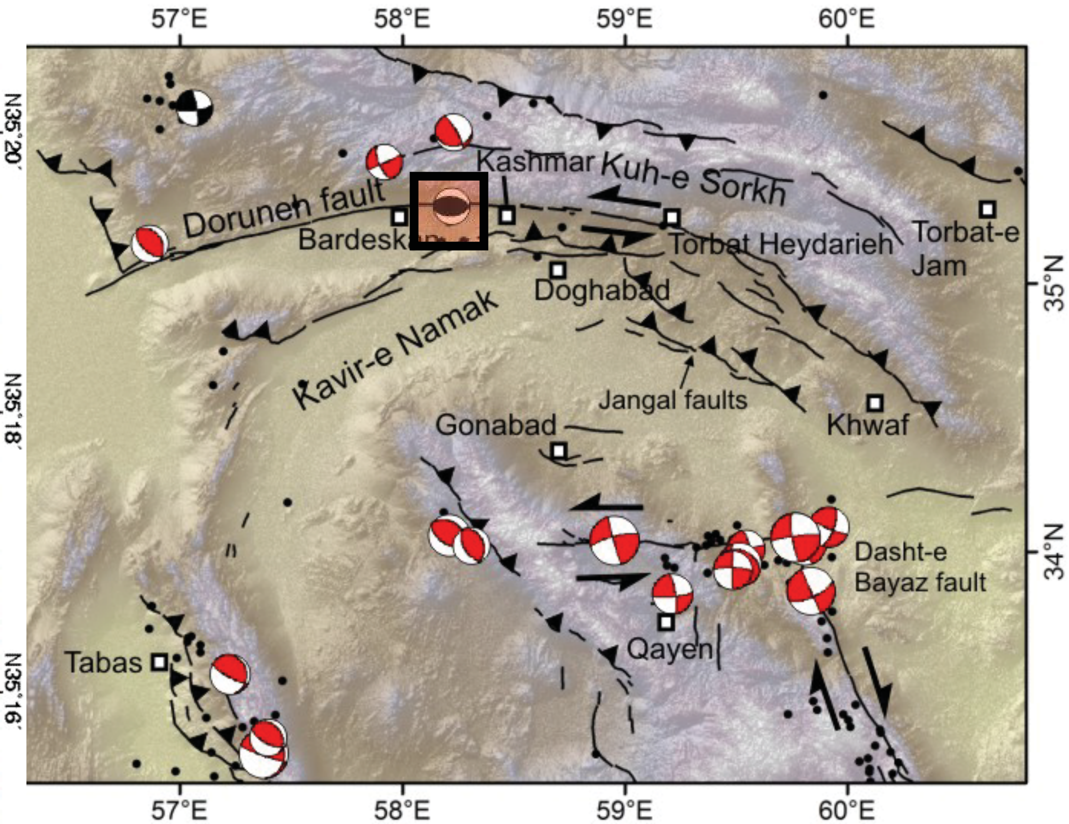
Da = displacement of the upper tread after its abandonment but before incision of the lower tread

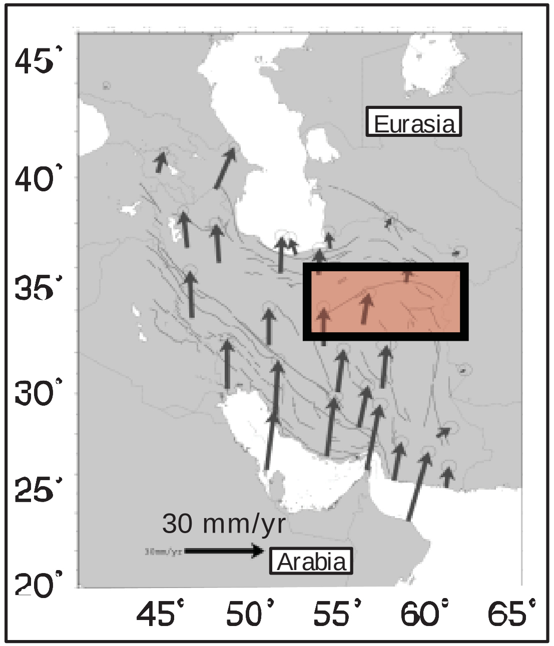
E = lateral erosion of the displaced riser after abandonment of upper tread but prior to incision of the lower tread

Eric Cowgill

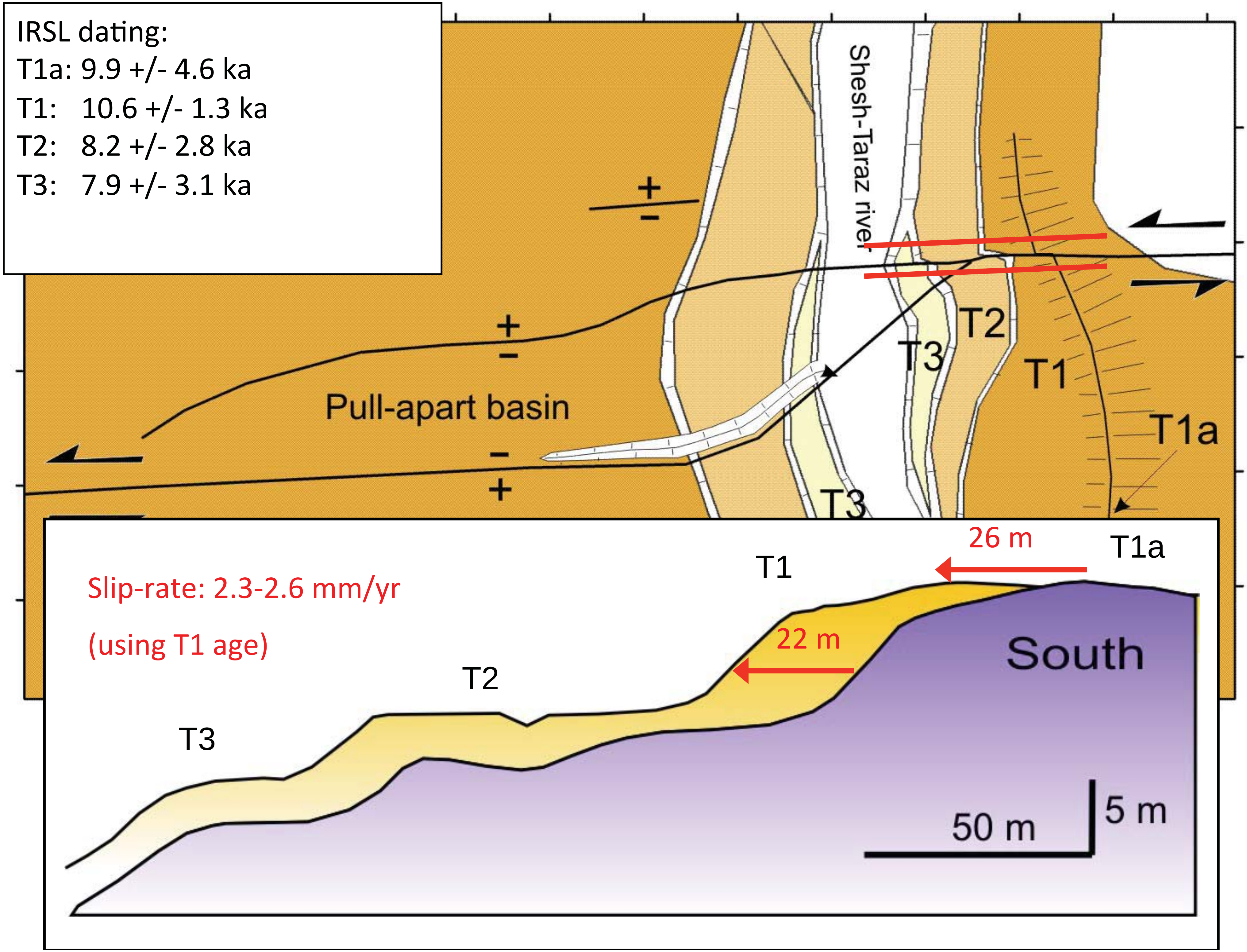

Image © 2011 DigitalG
389 m
© 2011 Cnes/Spot Im



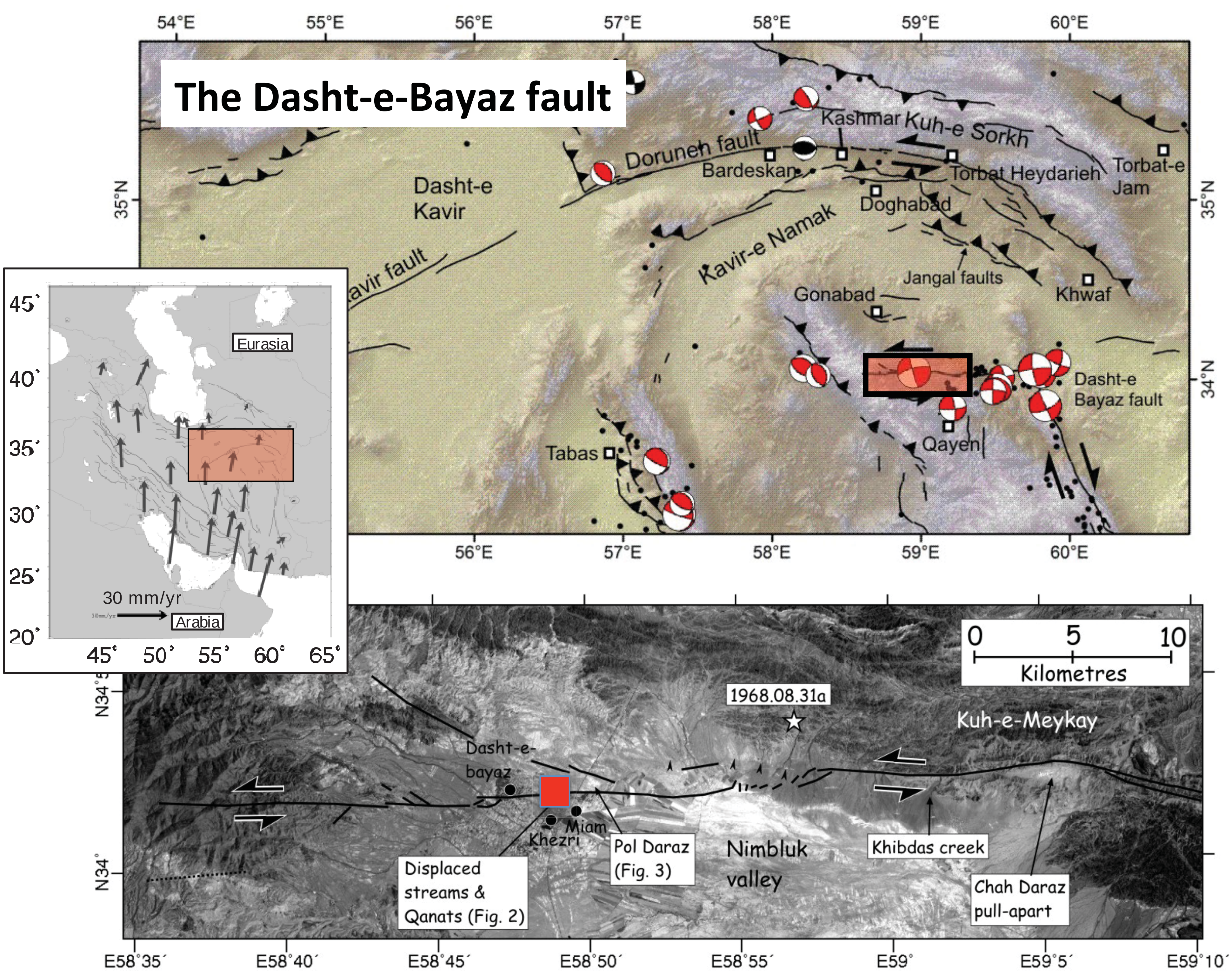


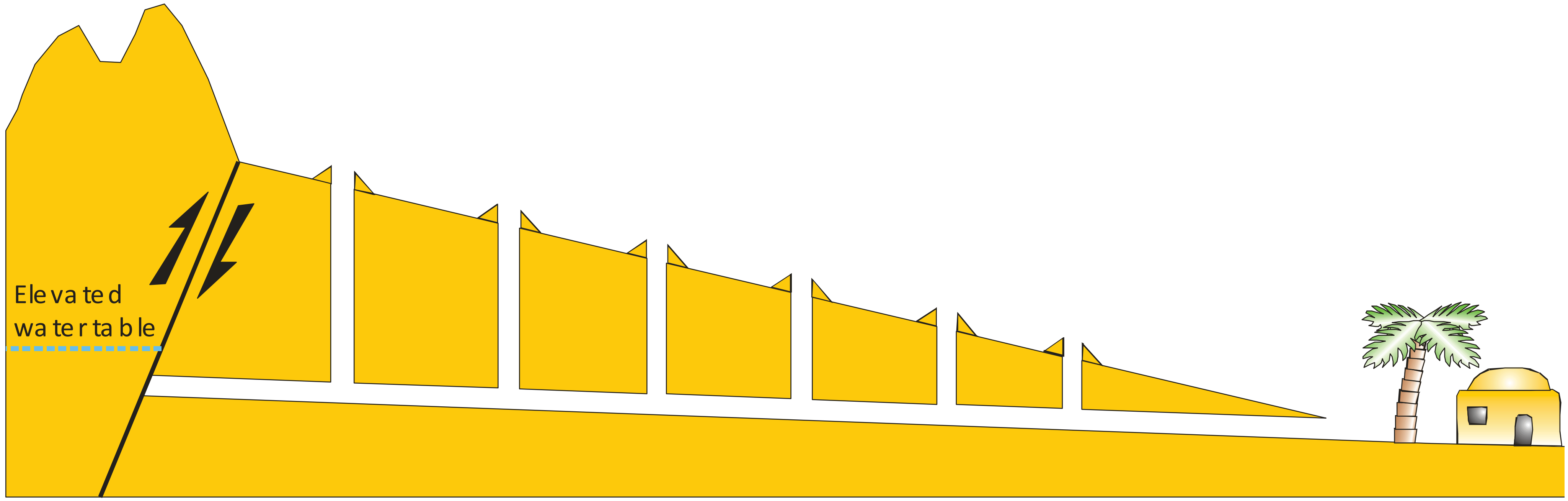


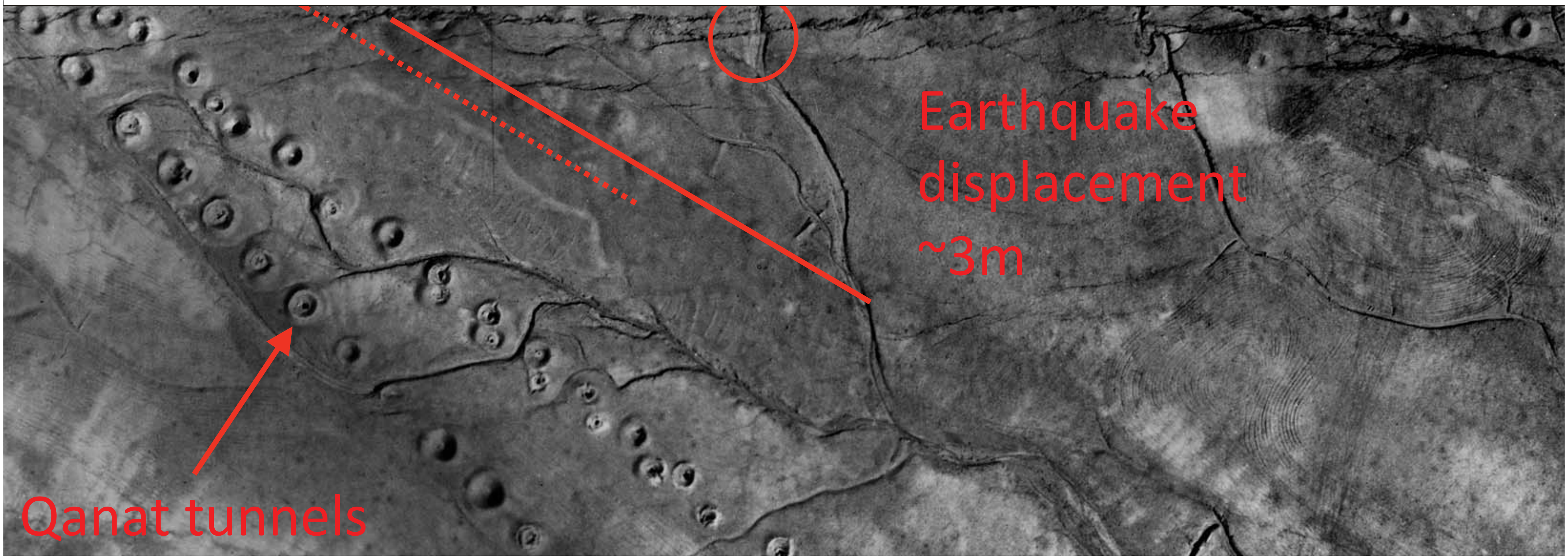
Doruneh fault (Fattahi et.al., 2007, GJI)

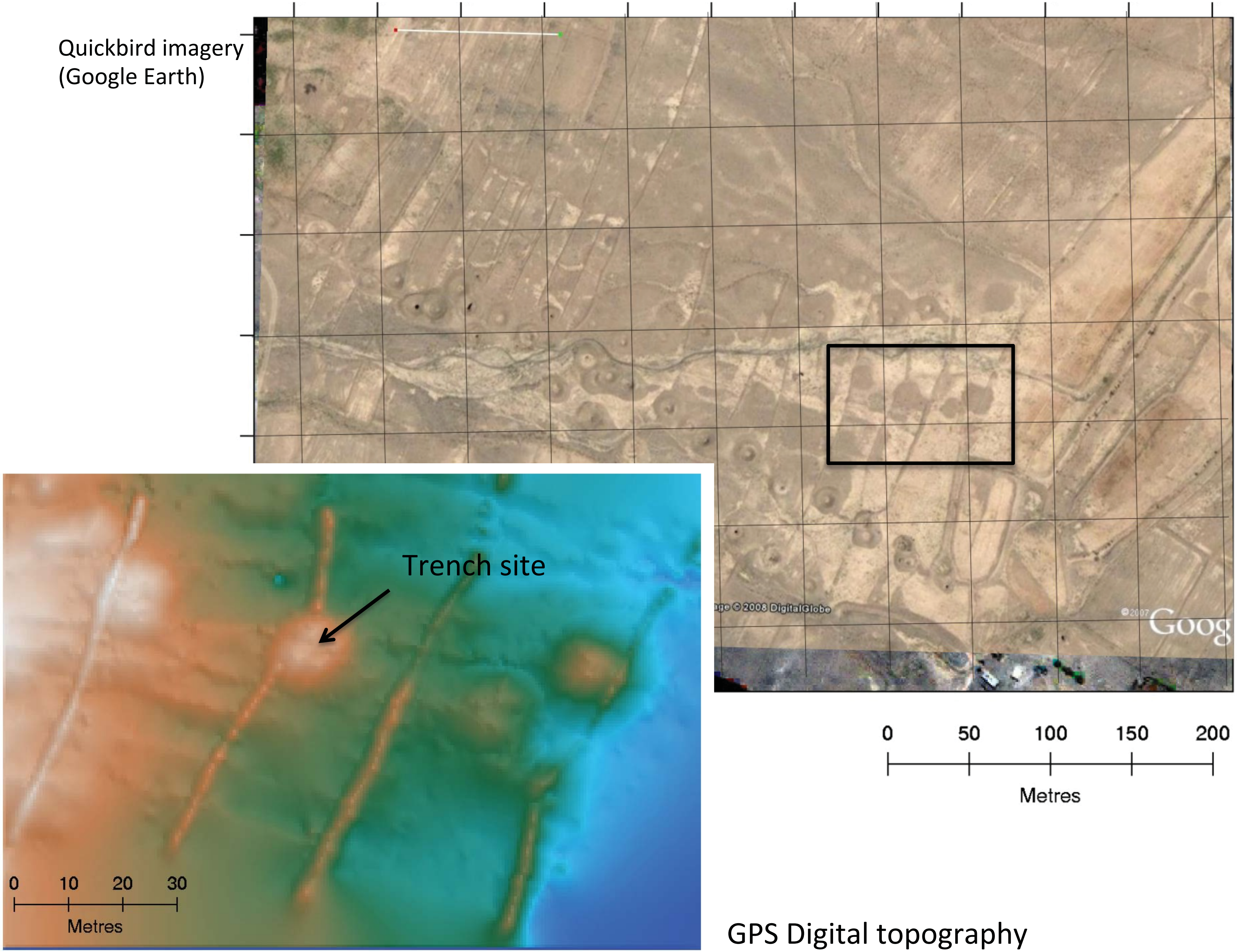

IRSL dating:
T1a: 9.9 +/- 4.6 ka
T1: 10.6 +/- 1.3 ka
T2: 8.2 +/- 2.8 ka
T3: 7.9 +/- 3.1 ka
Shesh-Taraz river
Pull-apart basin
T2
T3
T1
T1a
T3
26 m
T1a
T1
Slip-rate: 2.3-2.6 mm/yr
(using T1 age)
22 m
South
T2
T3
5 m
50 m

The Dasht-e-Bayaz fault

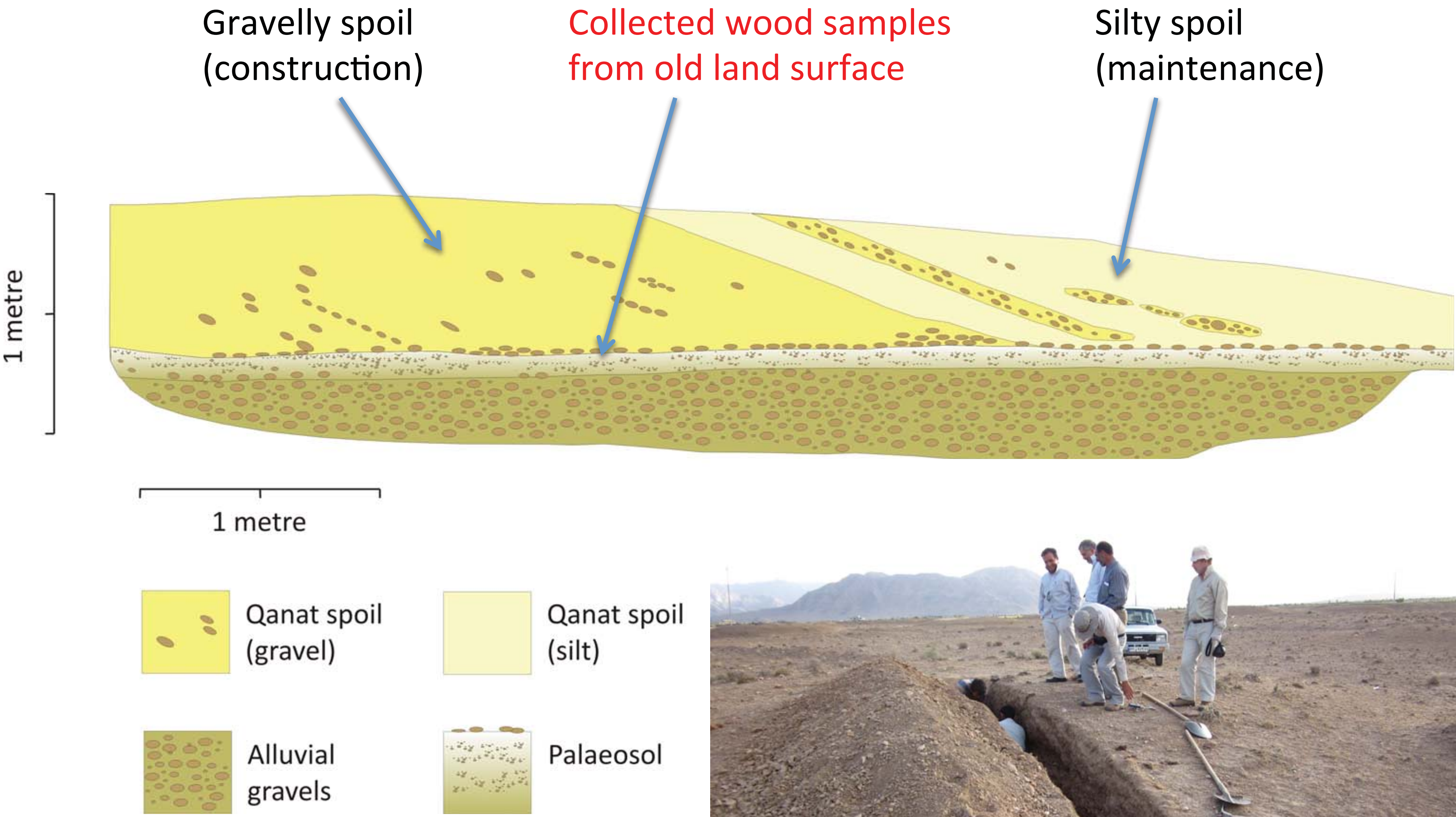



Elevated
water table


Earthquake
displacement
~3m
Qanat tunnels

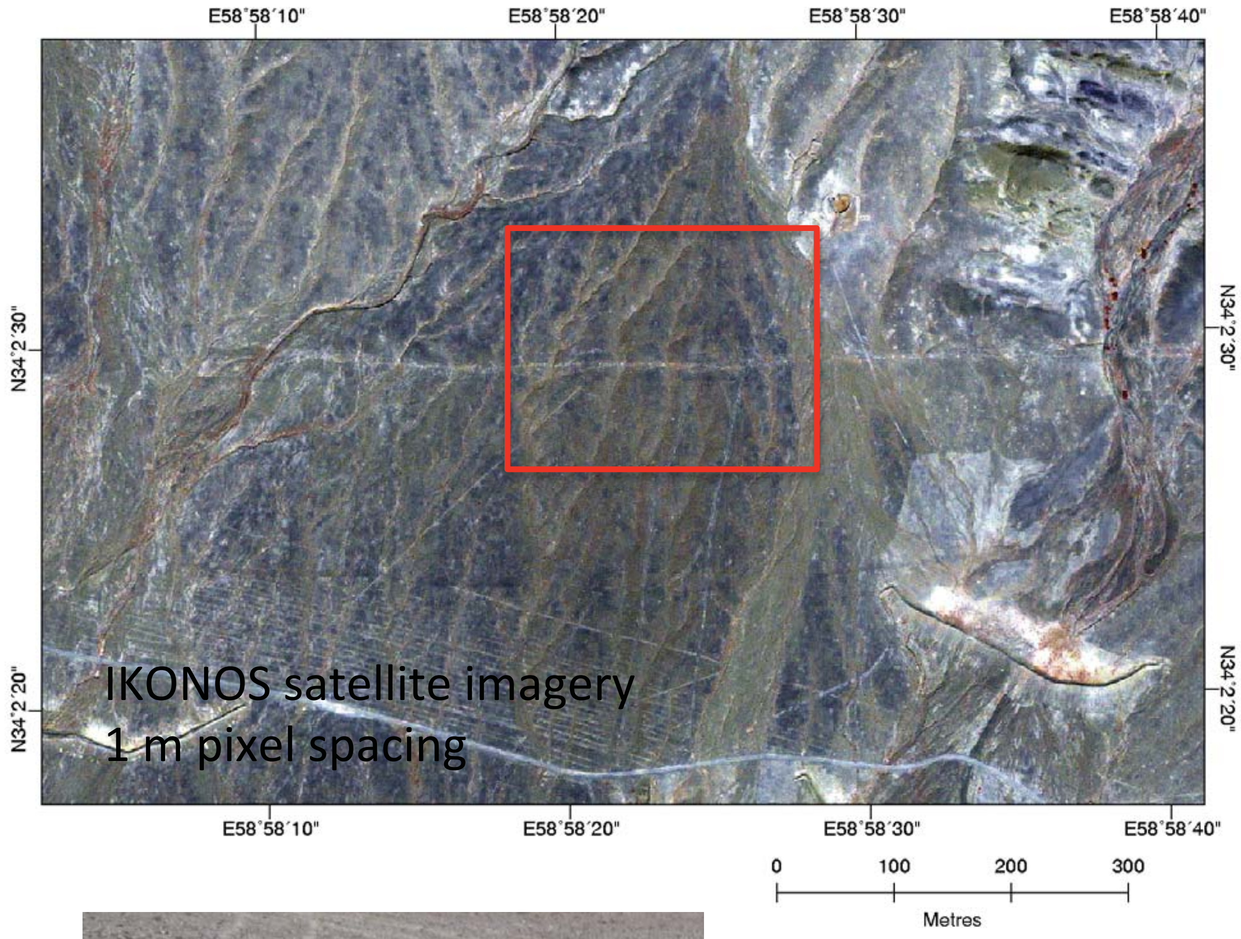


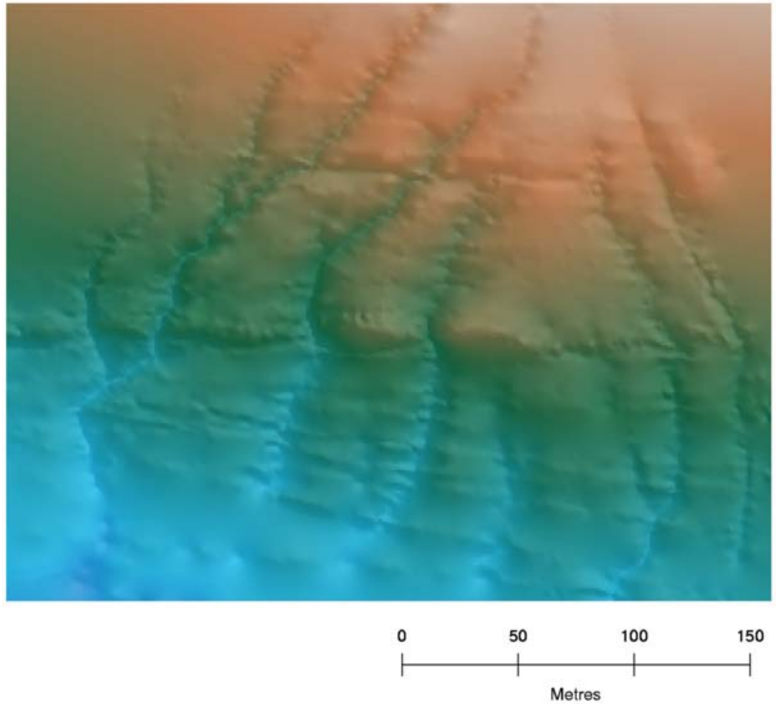
Quickbird imagery (Google Earth)
Image © 2008 DigitalGlobe
©2007 Goog
0 50 100 150 200
Metres
Trench site
0 10 20 30
Metres
GPS Digital topography

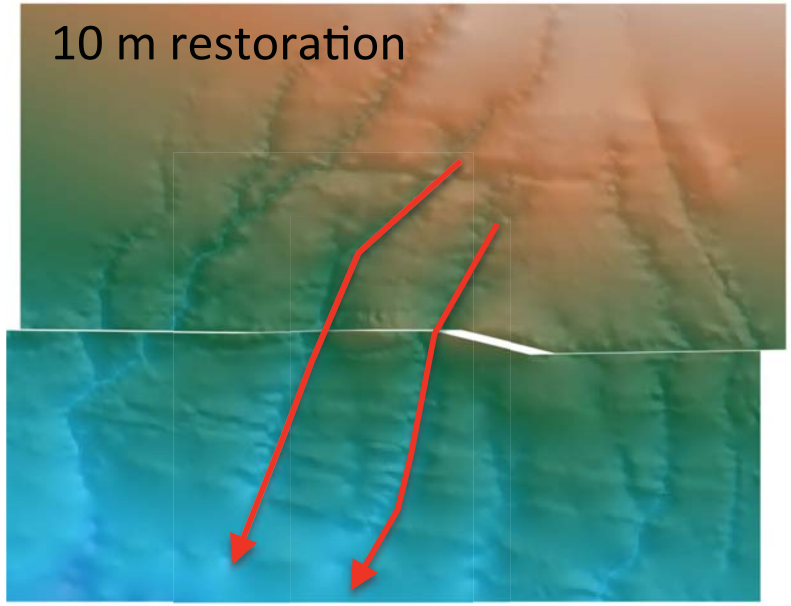


Initial dating > 5 ka. Indicates a slip-rate of < 2 mm/yr

Difficult to find clearly displaced alluvial fans
Why? Because of lack of relief within the basin

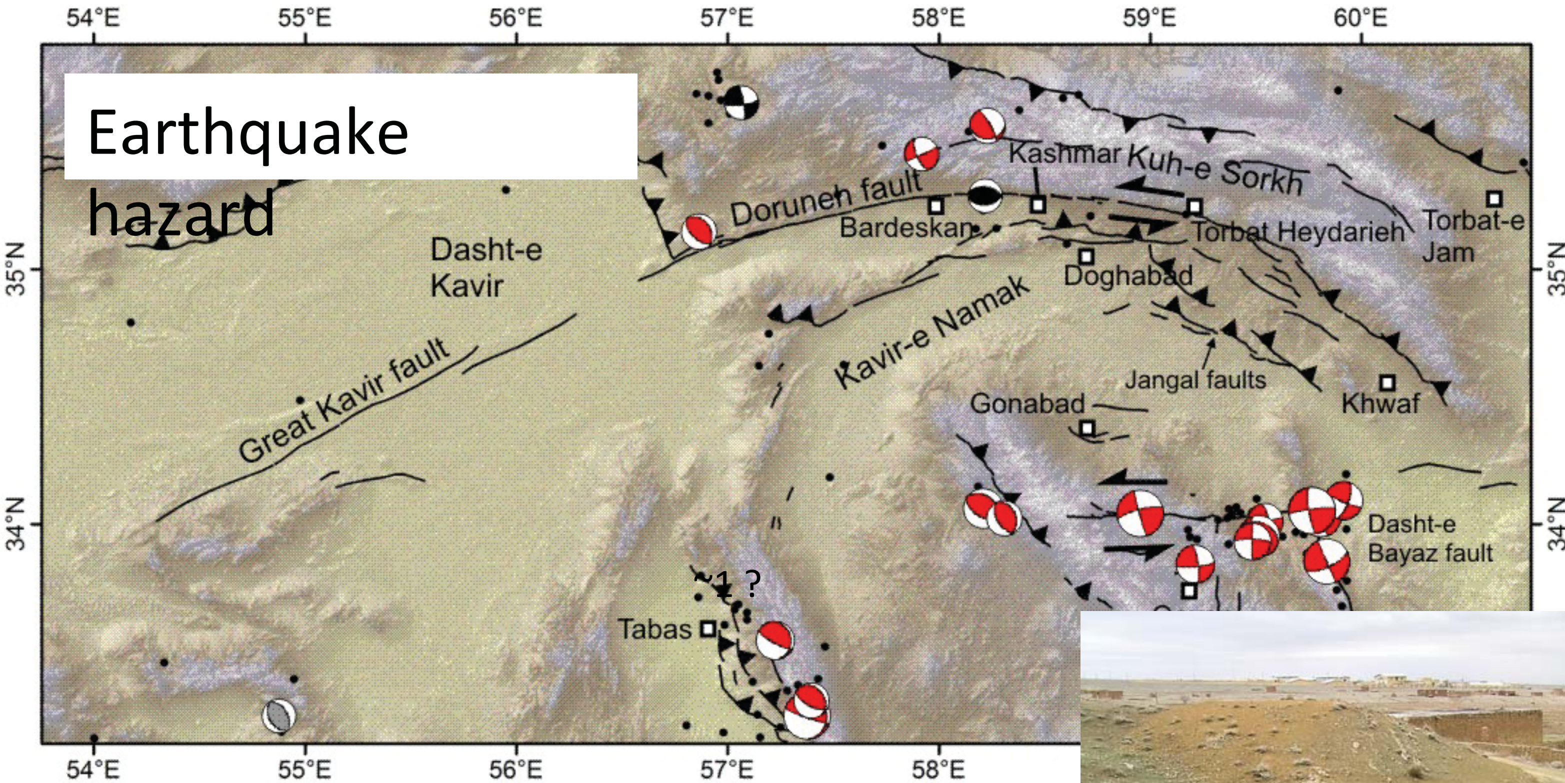






Fan abandonment at >10 ka …
Slip rate <1 mm/yr?

Earthquake hazard

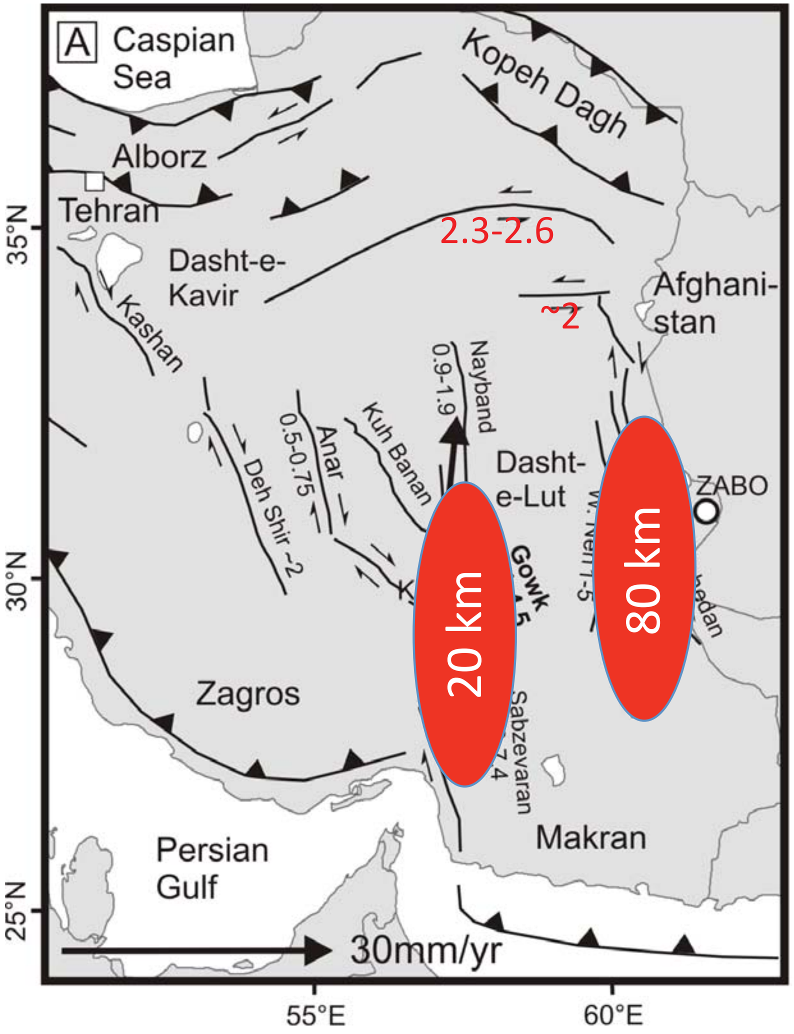


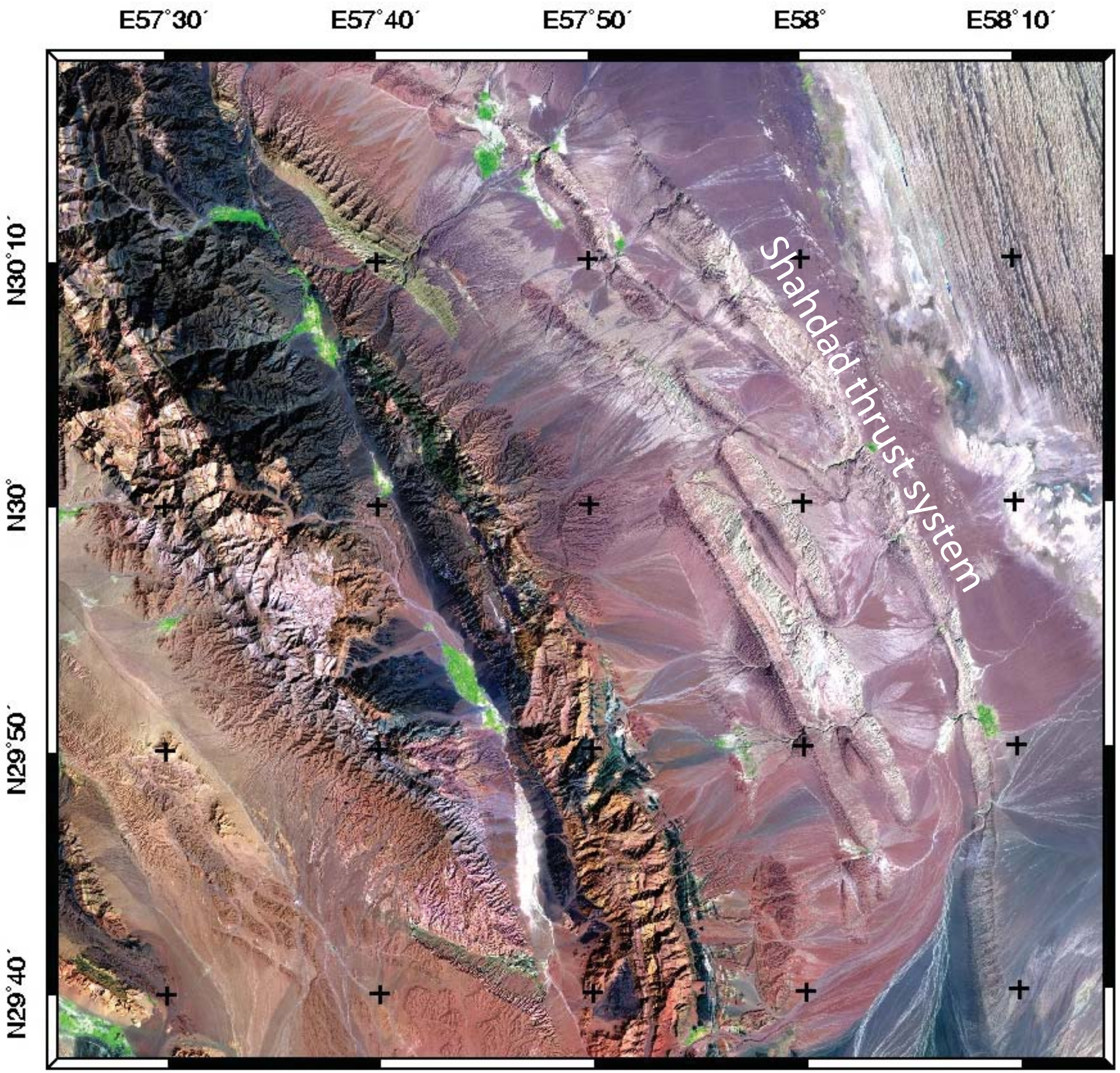
N. Ambraseys

Slip-rate < 2 mm/yr
Average slip in earthquake ~2.5 m
Average interval between events >1000 years

Slip-rate ~2.5 mm/yr
Slip in earthquake ~5 m
Average interval between events ~2000 years

The right-lateral faults of eastern Iran

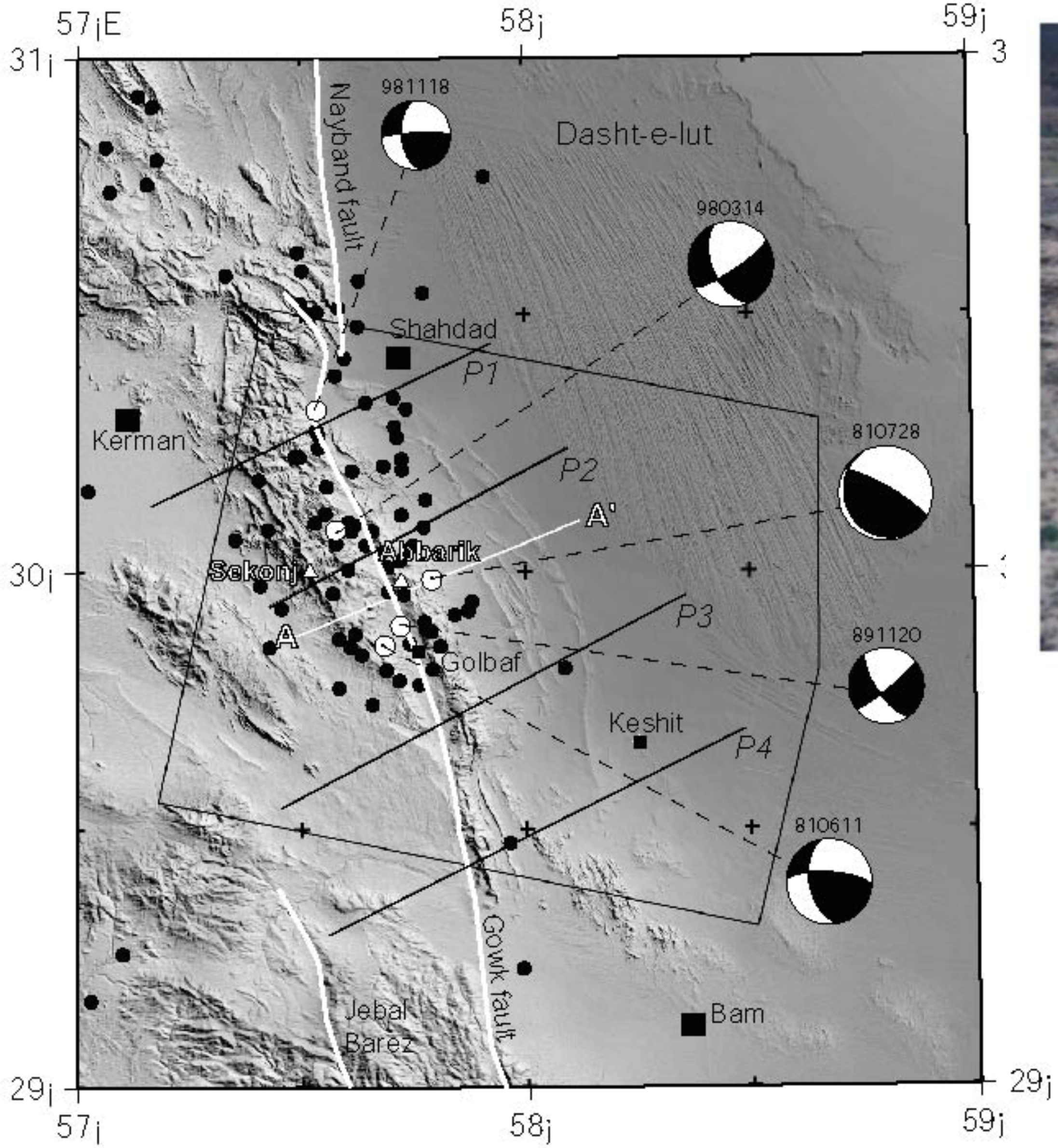




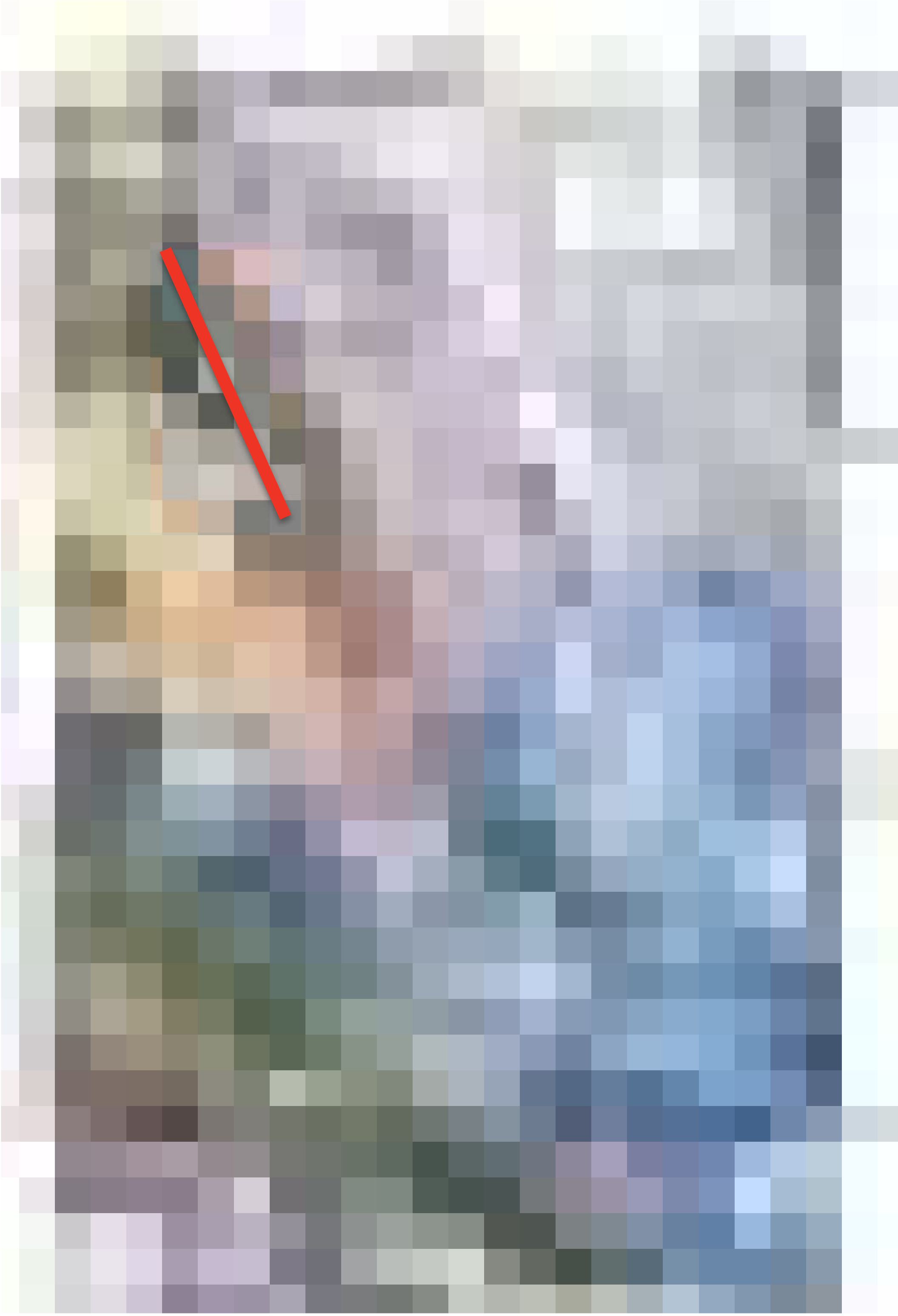
RGB 542

Walker et. al. (2009, 2010); Regard et. al. (2005); Meyer & Le Dortz (2007)

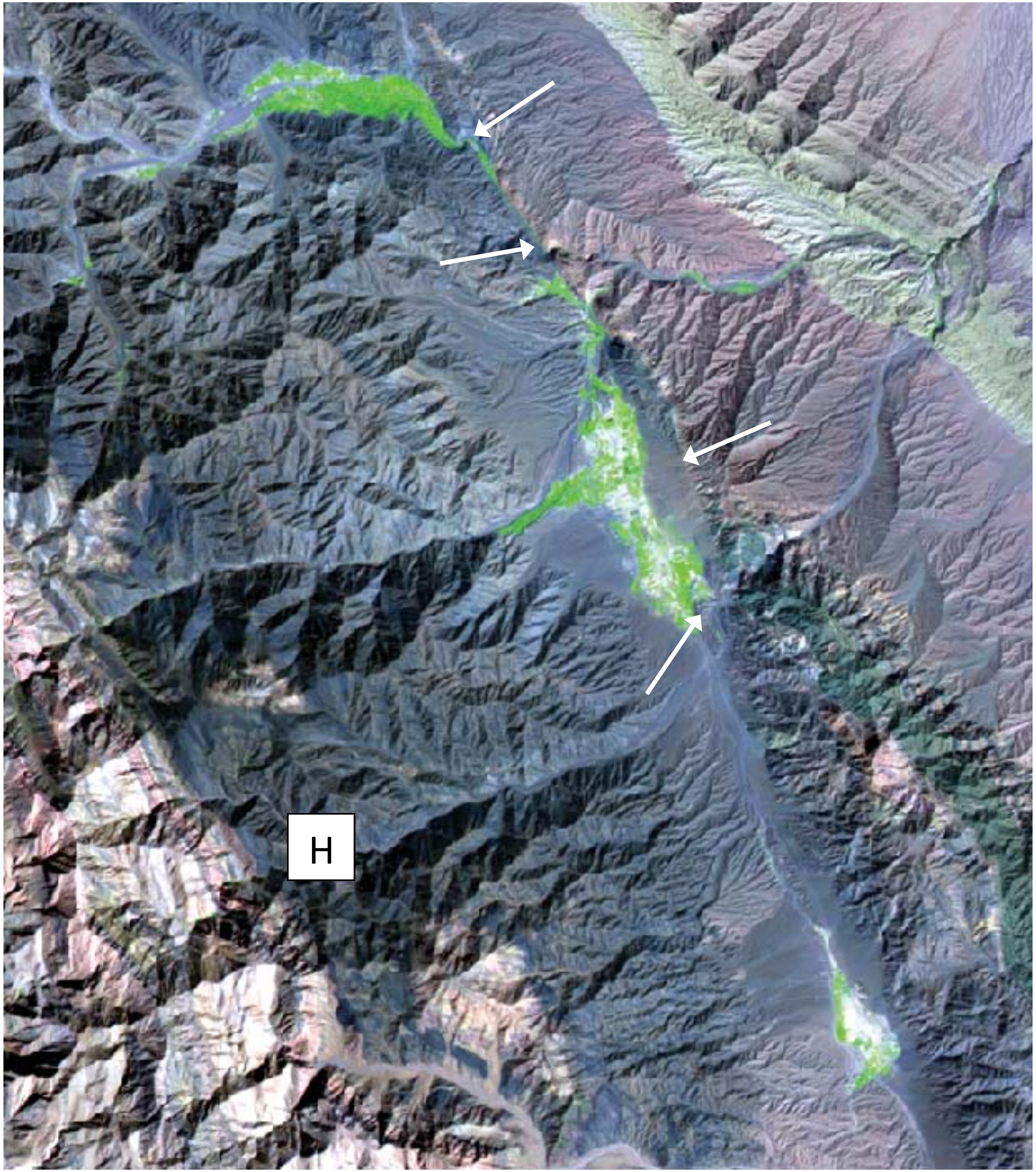
Earthquakes on the Gowk Fault



3 m of slip during the 1998 Fandoqa earthquake on the Gowk fault

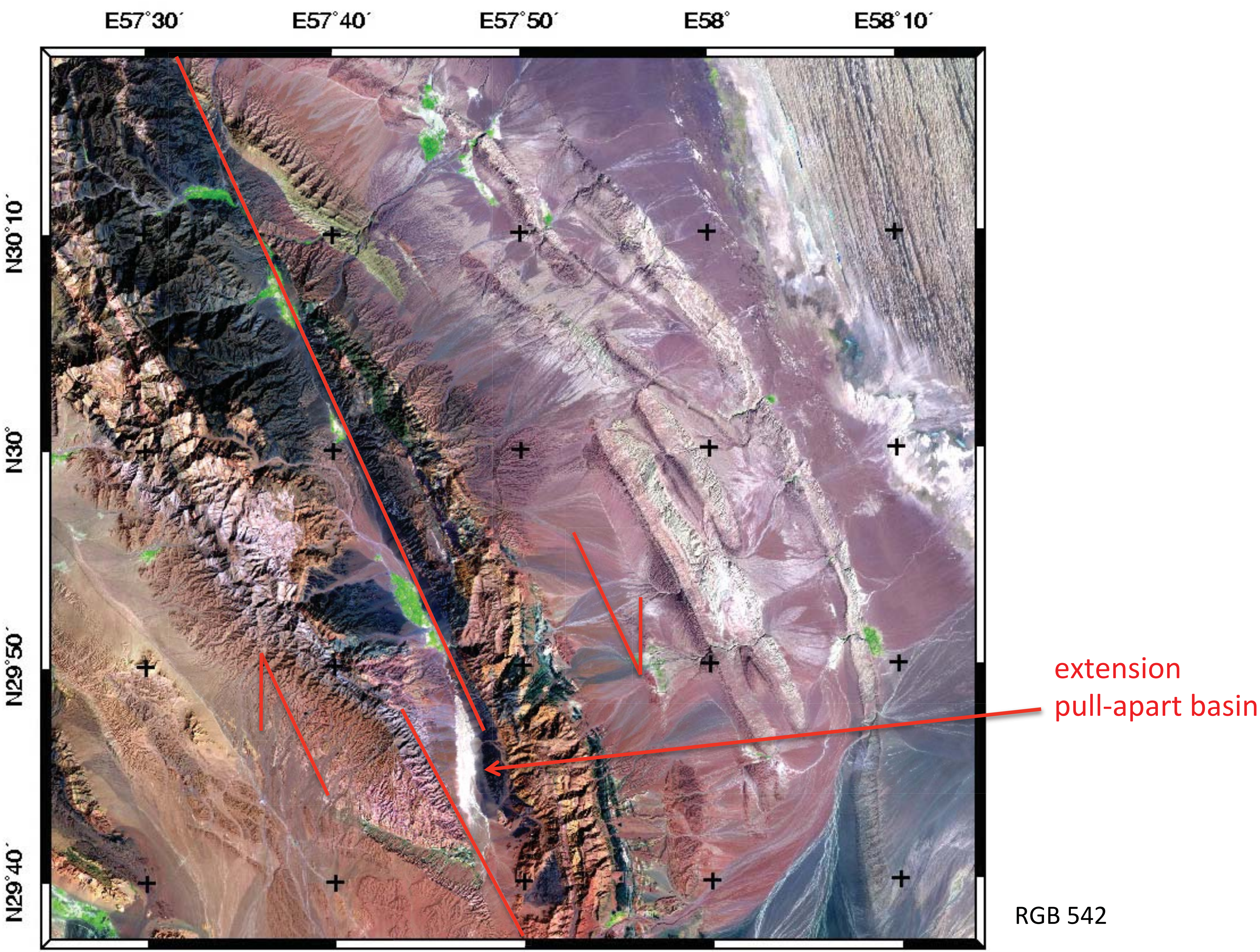



(c)



Offset Drainage across the Gowk Fault

Both Sirch (S) and Joshan (J) rivers drain into the Sirch gorge at present. Shifting the east side of fault by 3 km left-laterally restores alignment of rivers and gorges, with the Joshan river originally flowing in the Hashtadan gorge. This gorge remained open because of capture of the Hashtadan (H) river


E57°30´
E57°40´
E57°50´
E58°
E58°10´
N30°10´
N30°
N29°50´
N29°40´
extension
pull-apart basin
RGB 542

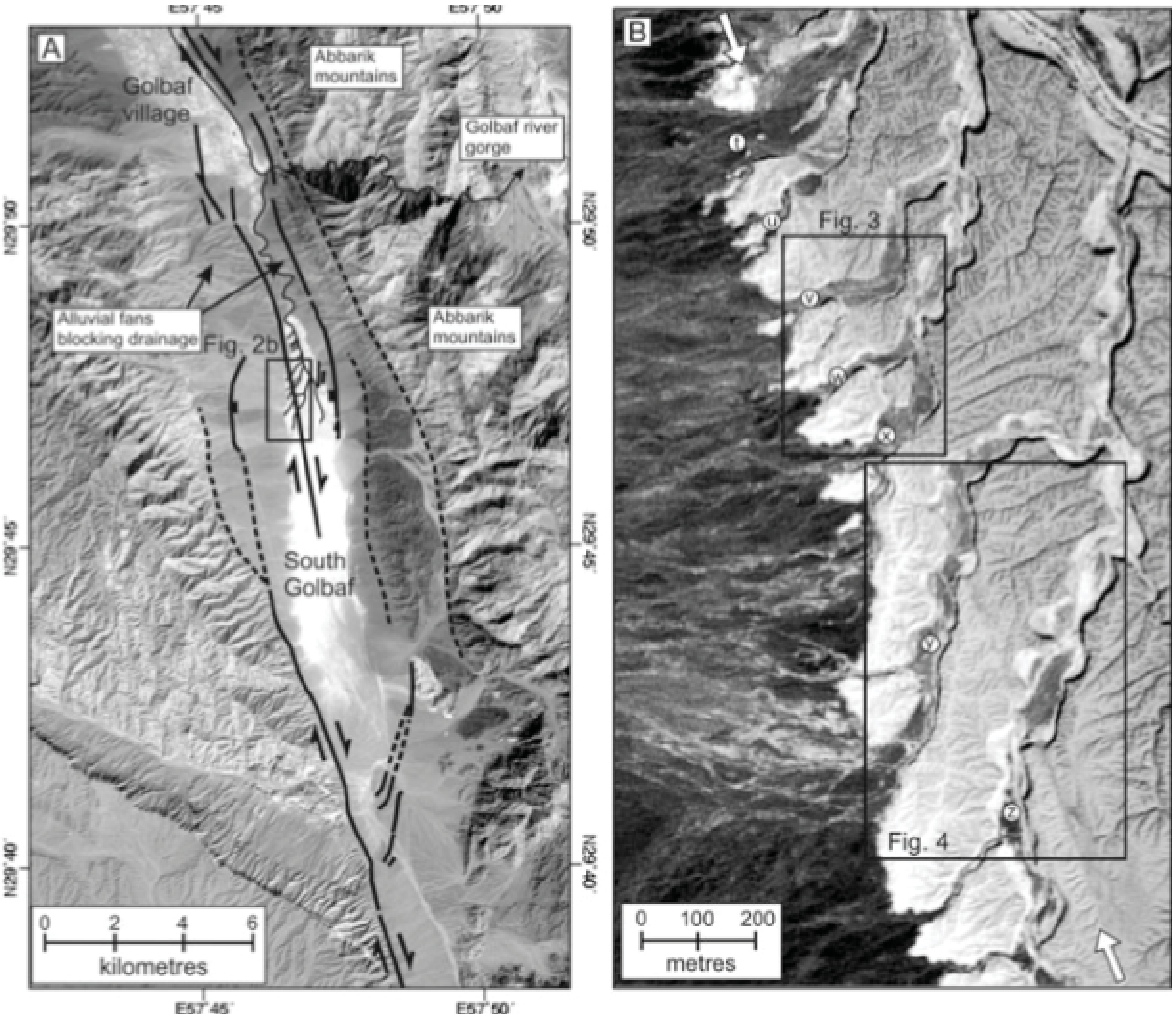
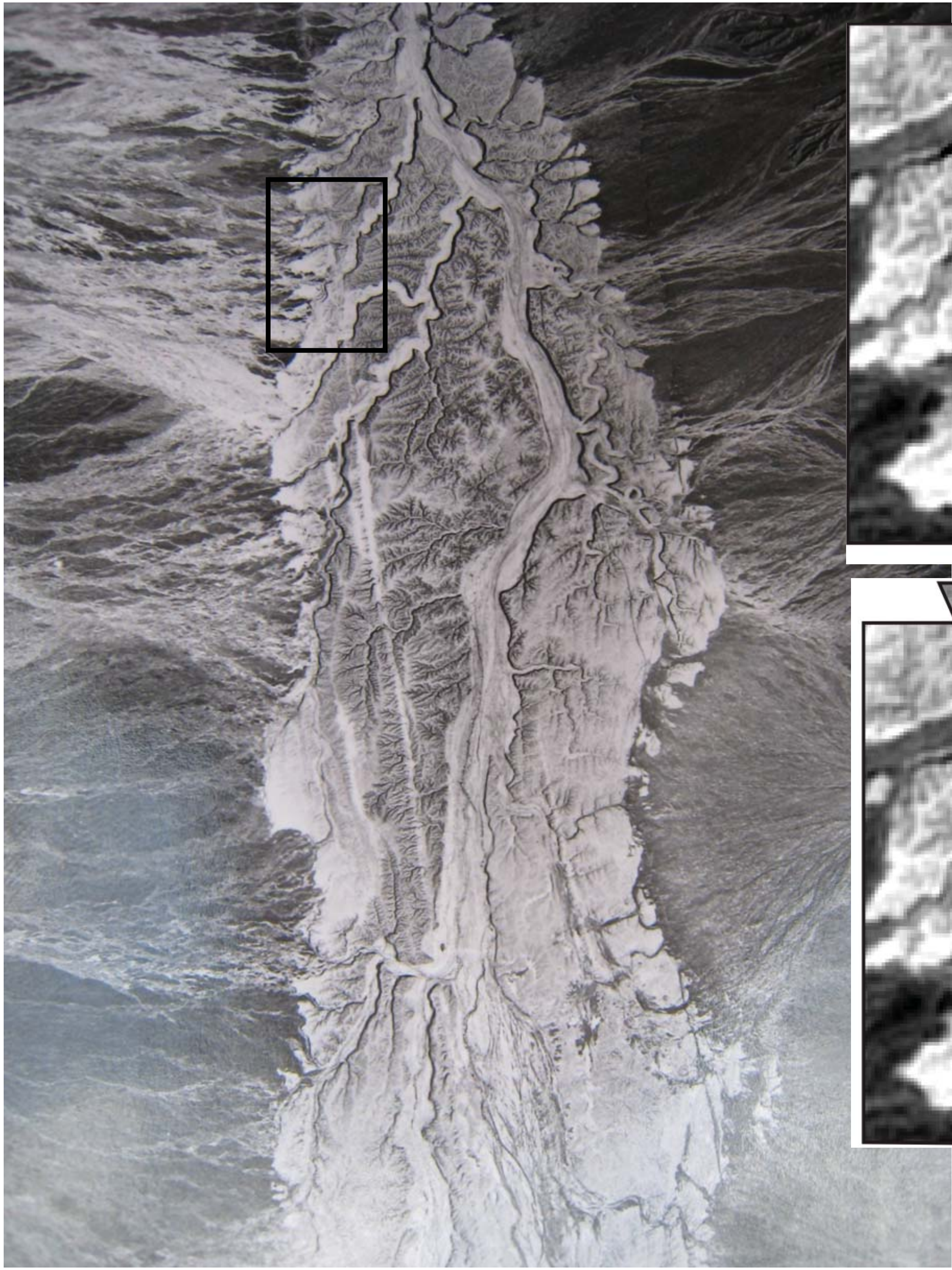
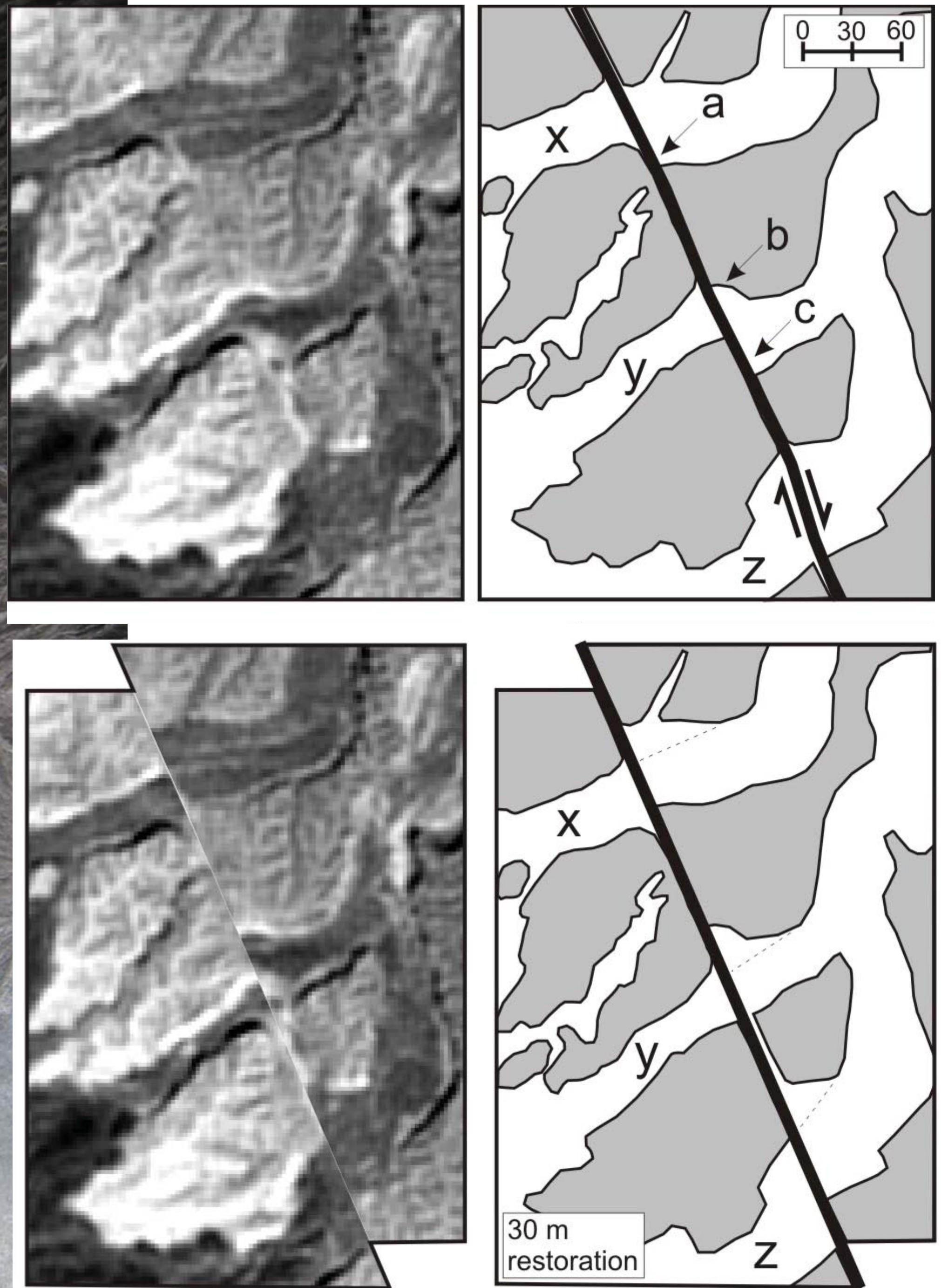
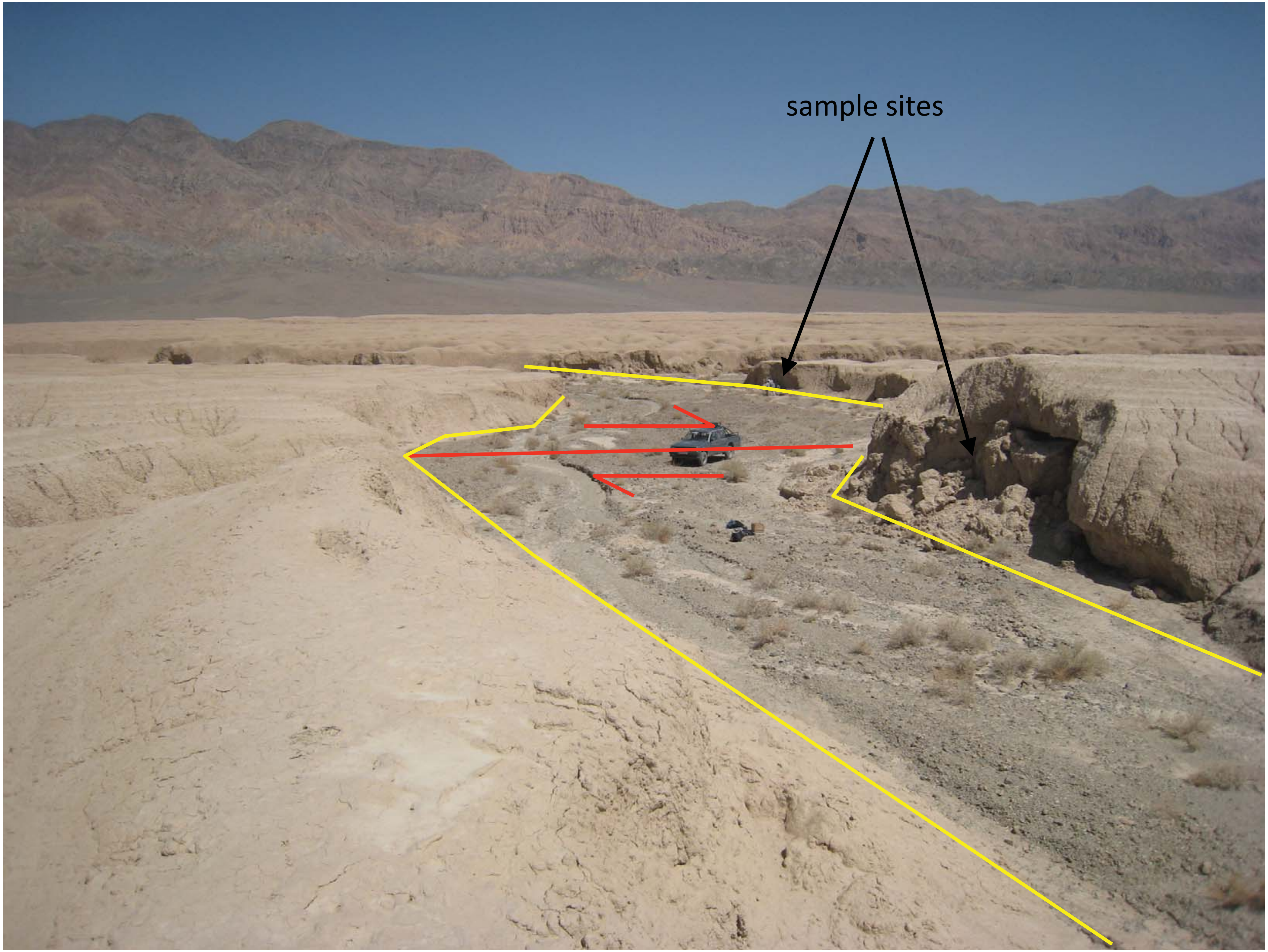


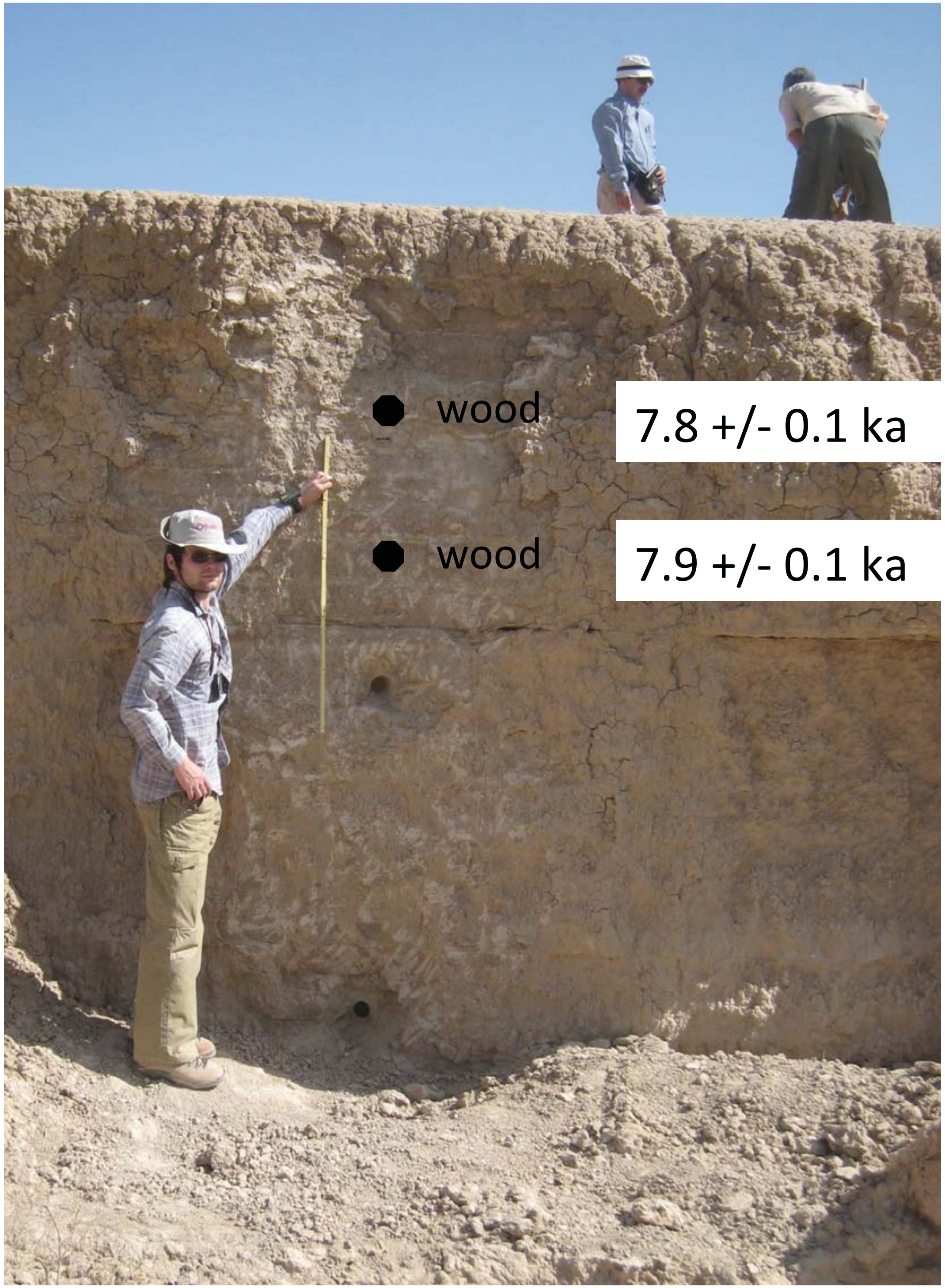
Figure 2. (a) ASTER satellite image of the South Golbaf Depression showing the active faults (thick black lines—dotted where inferred) and the main streams (thin black lines). Faults to the east and west of the South Golbaf basin appear to be mainly dip-slip with the main strike-slip trace running through the centre of the basin. Holocene lakebed deposits occupy the centre of the basin (light-coloured regions). Numerous eastward-flowing streams, which are incised into the lakebed deposits, cross the trace of the fault and are displaced right-laterally. (b) SPOT5 satellite image (2.5 m pixel spacing) of eastward-flowing streams (labelled t–z) that are incised into lakebed deposits and displaced right-laterally across the Gowk fault (the fault runs between the white arrows).





~30 +/- 5 m lateral disp.


sample sites

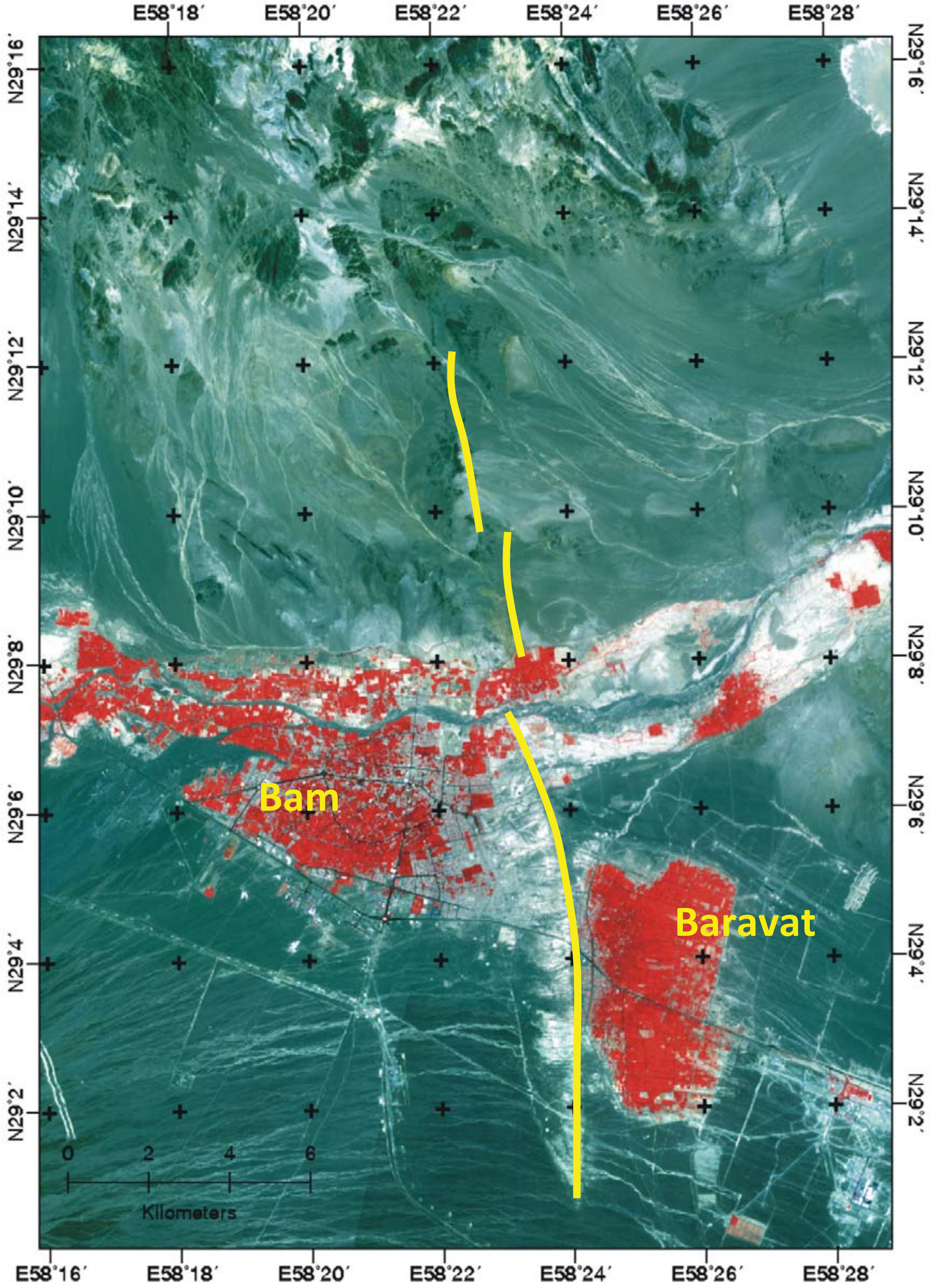


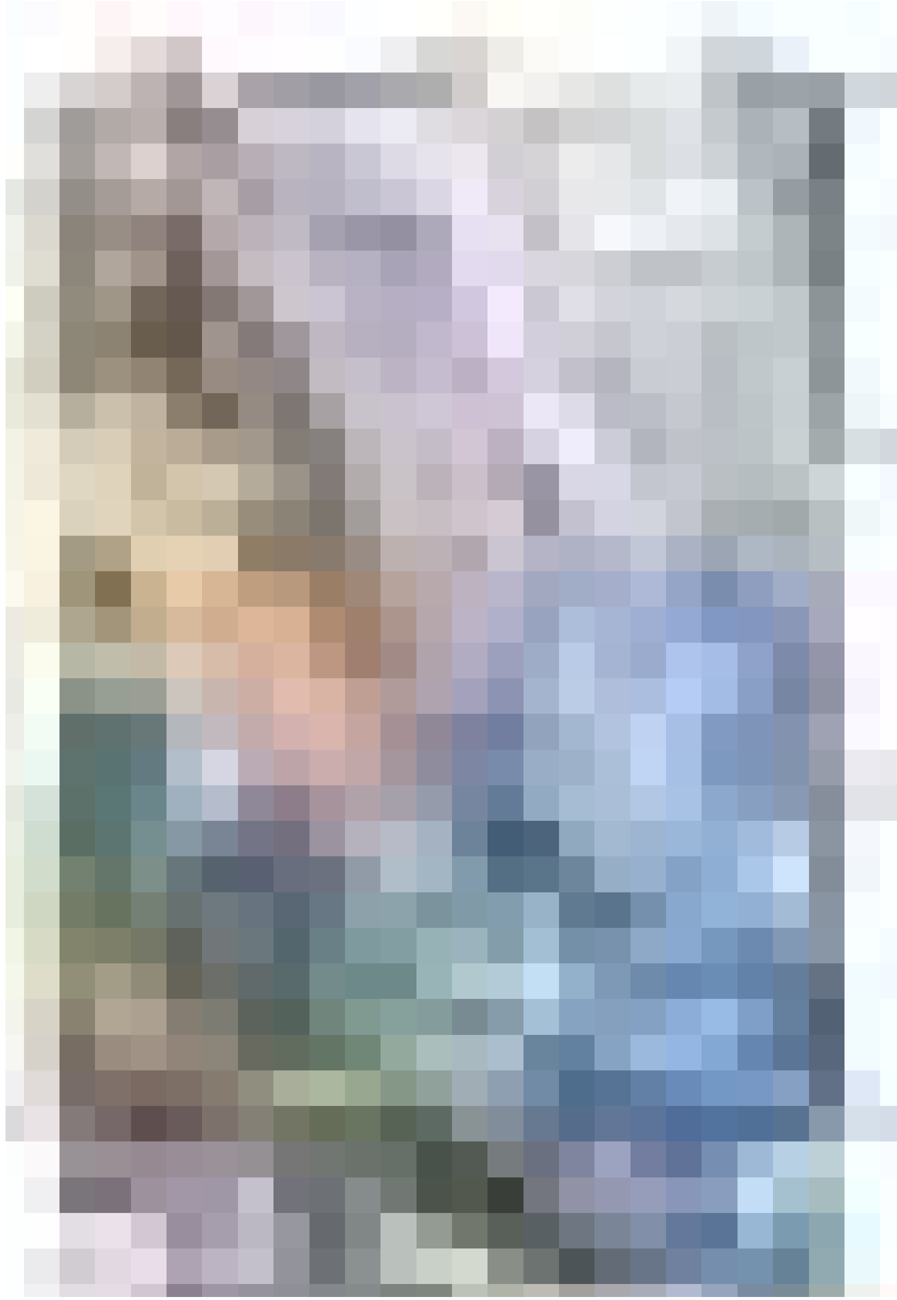
Age at surface ~7,800 years or less
Average slip-rate ~3.1-4.5 mm/yr
(Walker et.al. 2010)

Earthquakes involving 3 metres of slip every 660-960 years (on average)

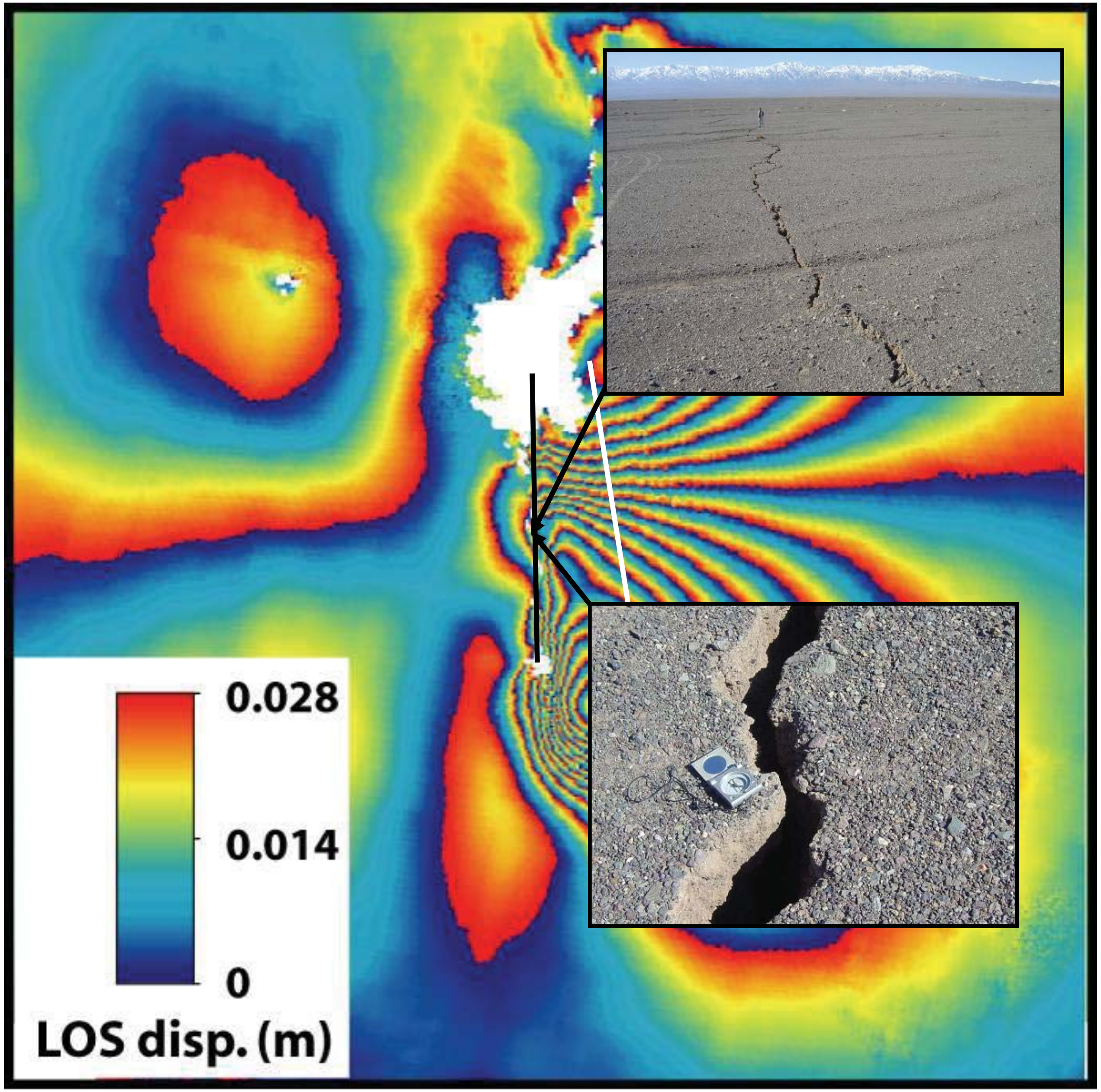

Usually we aren’t so lucky ….

Are all the earthquakes on the major faults?





Envisat Interferogram for the Bam Earthquake



COMET+

There are many many faults, most of which are moving very slowly, and might have intervals of thousands of years between earthquakes

So how can we find them?

Learn from the places that have recently had earthquakes … export the knowledge