Geometry, kinematics and mechanics of foreland fold-thrust belts: insights from a multisource and multiscale study of the active Zagros fold-thrust belt (Iran).

Olivier LACOMBE

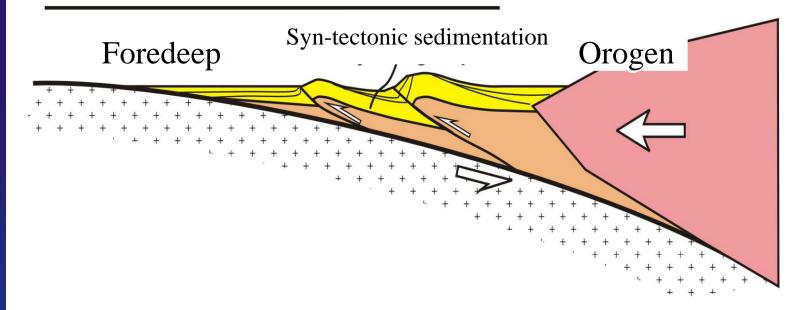


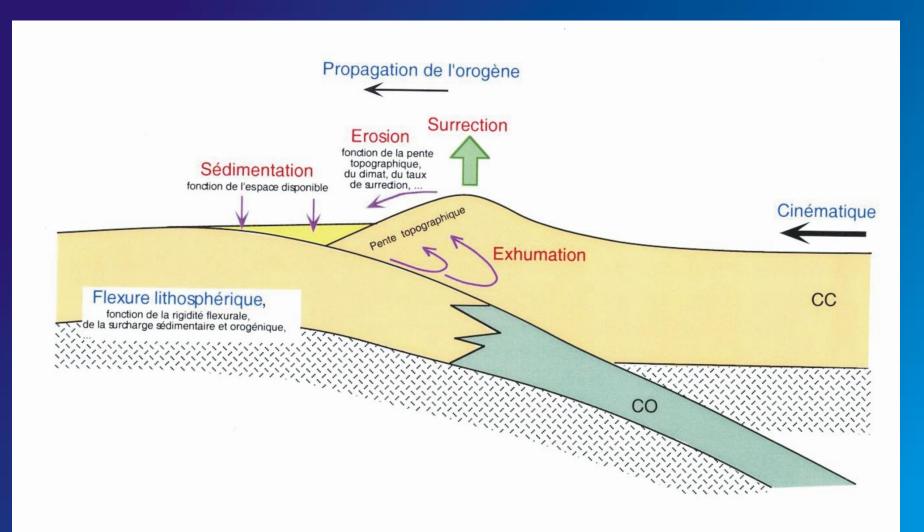


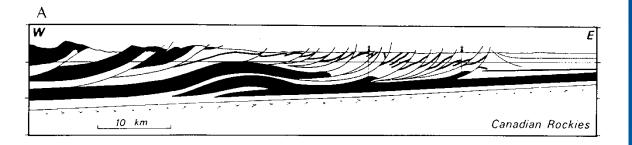


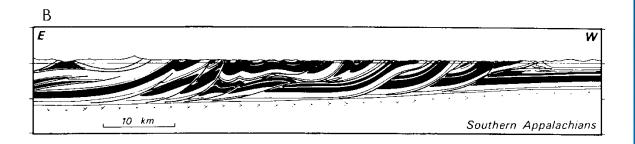
Orogenic wedge

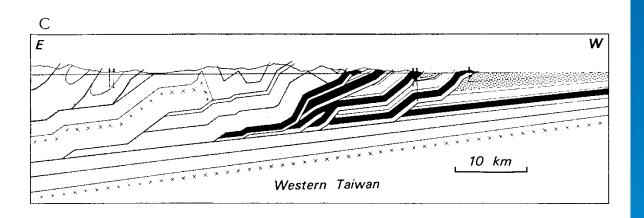
Foreland basin

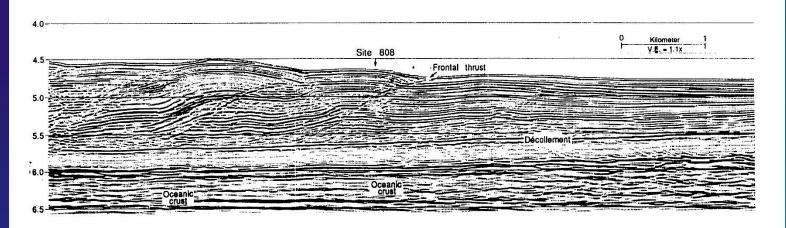


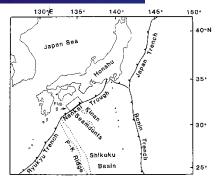


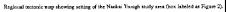


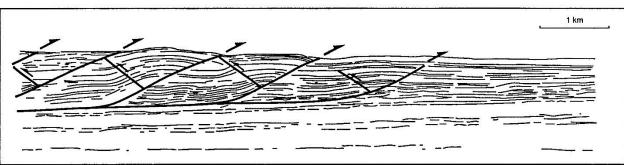


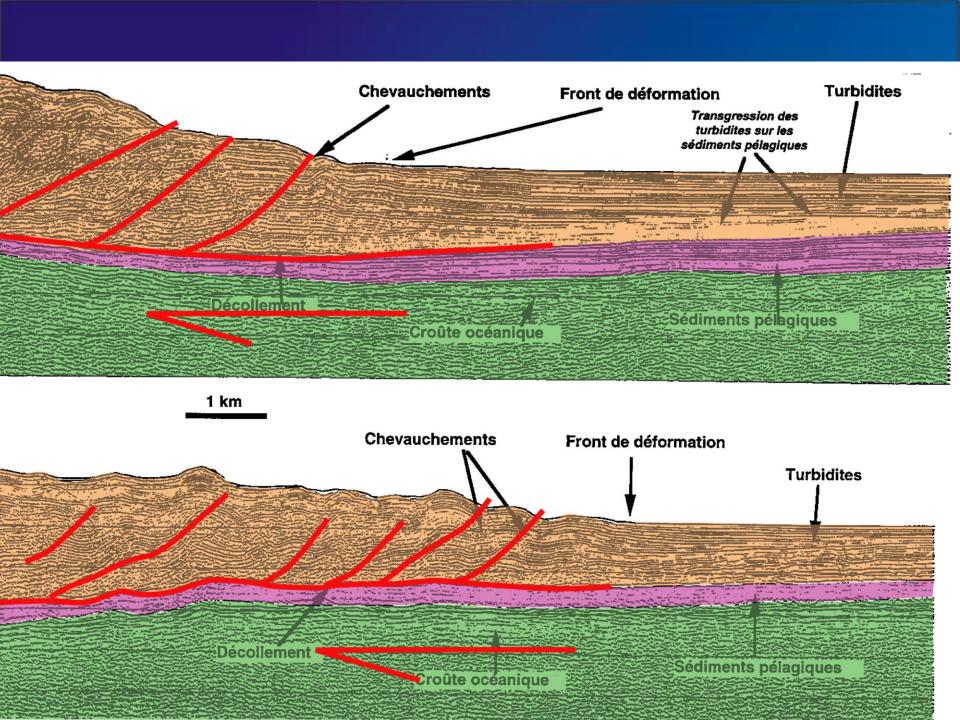


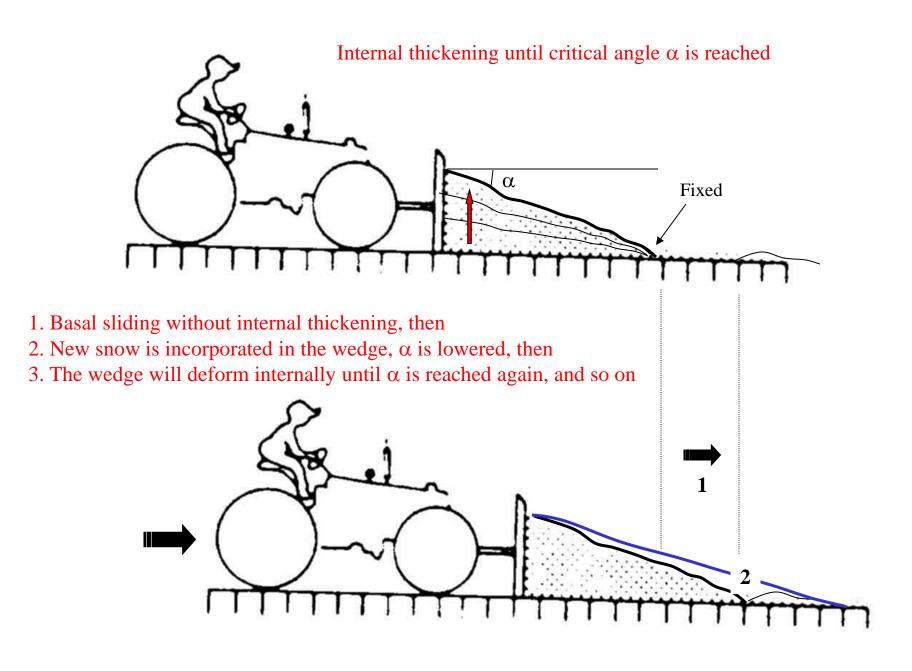


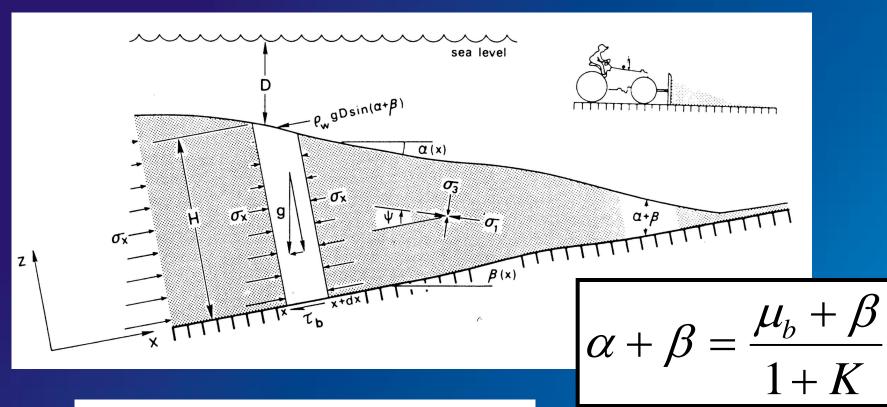












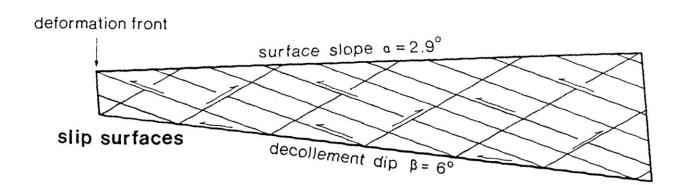
$$\rho g H \beta + \rho_w g D(\alpha + \beta) + \tau_b + \frac{d}{dx} \int_0^H \sigma_x dz = 0$$

Weight of overburden

Weight of water

Basal friction

Lateral forces



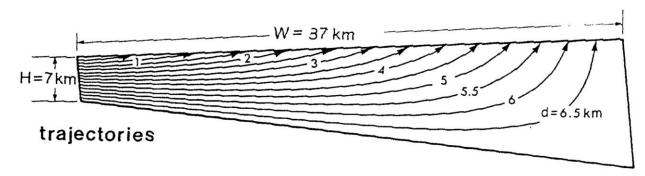
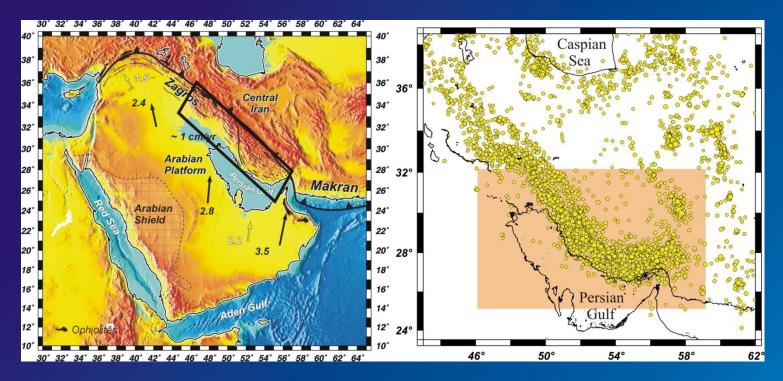


Figure 14. Theoretical slip surfaces and rock trajectories in the critically tapered Taiwan wedge, assuming $\mu = 0.85$.

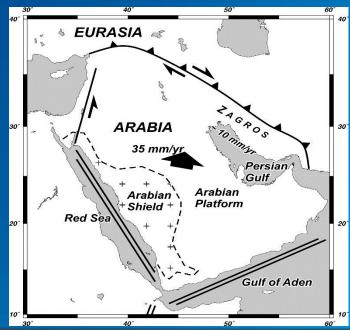
Dahlen et Suppe, 1988

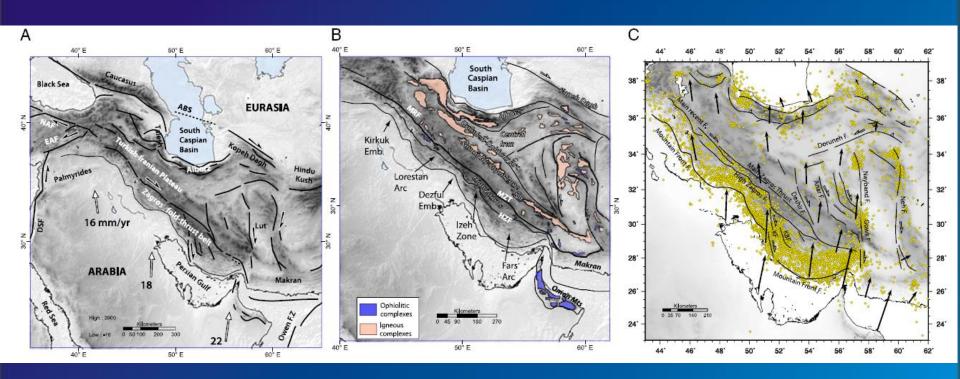
Geodynamic and kinematic setting of the Zagros fold-and-thrust belt



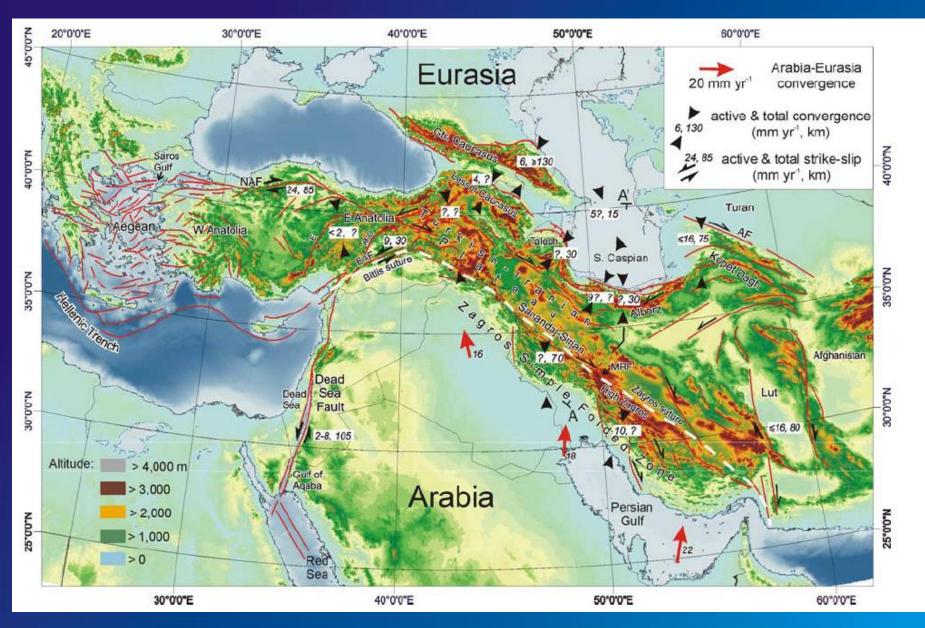
The Zagros belt results from the collision between Arabia and Central Iran, beginning in (Oligo ?)-Miocene times and continuing today.

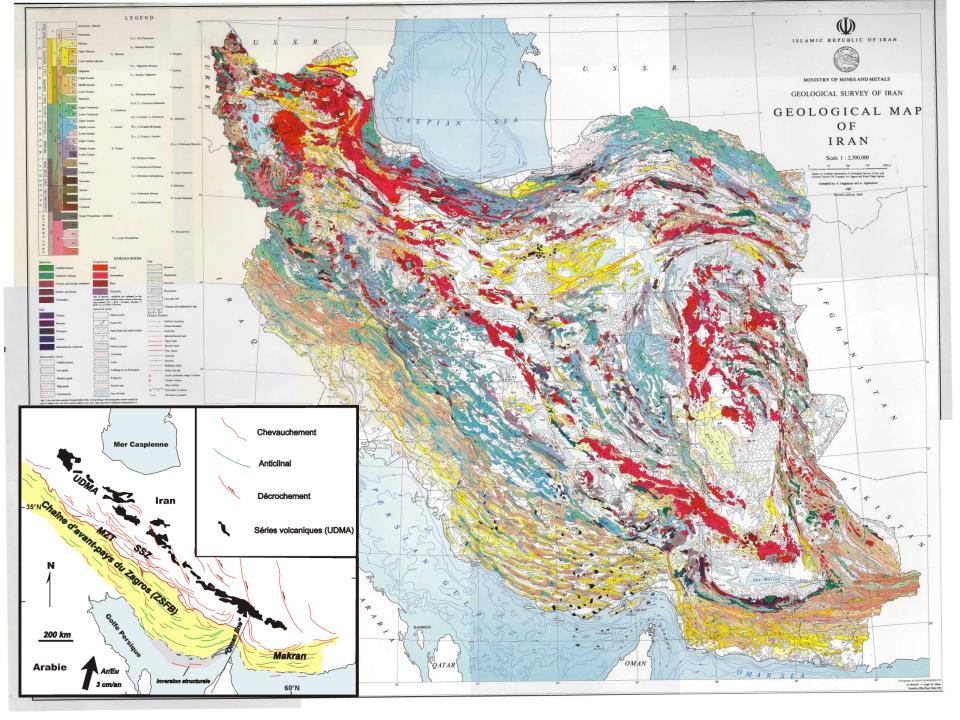
About one third of the 22-25 mm/yr Arabia-Eurasia convergence is currently accommodated in the Zagros (Vernant et al., 2004)



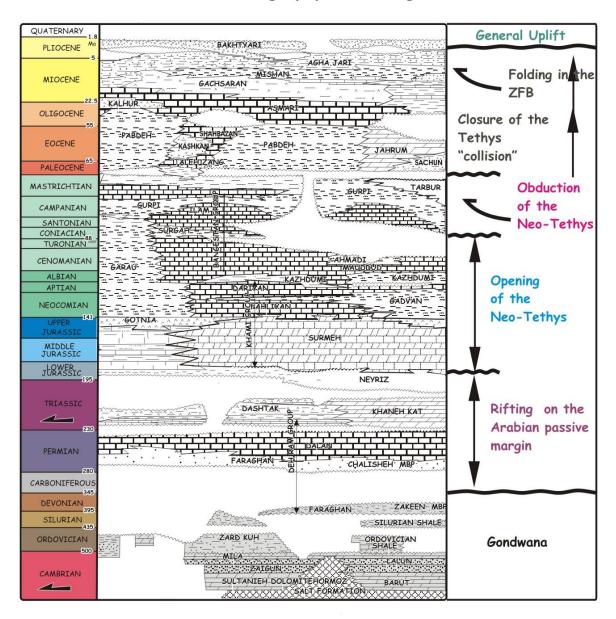


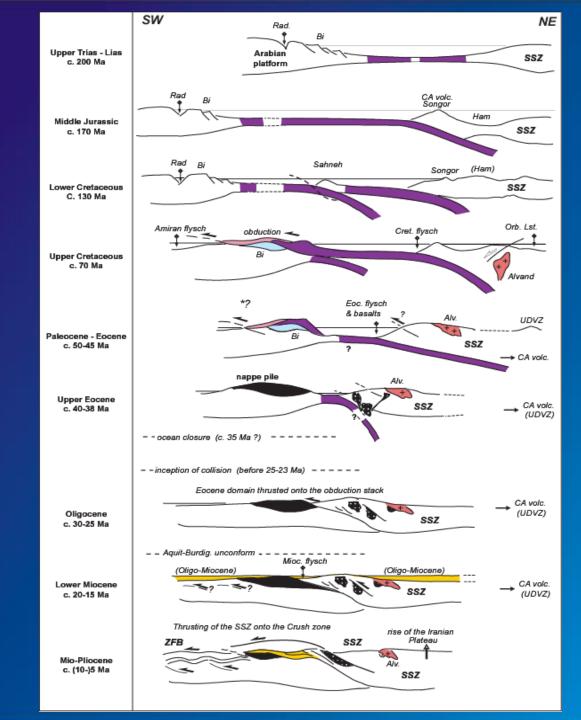
Mouthereau et al. 2012





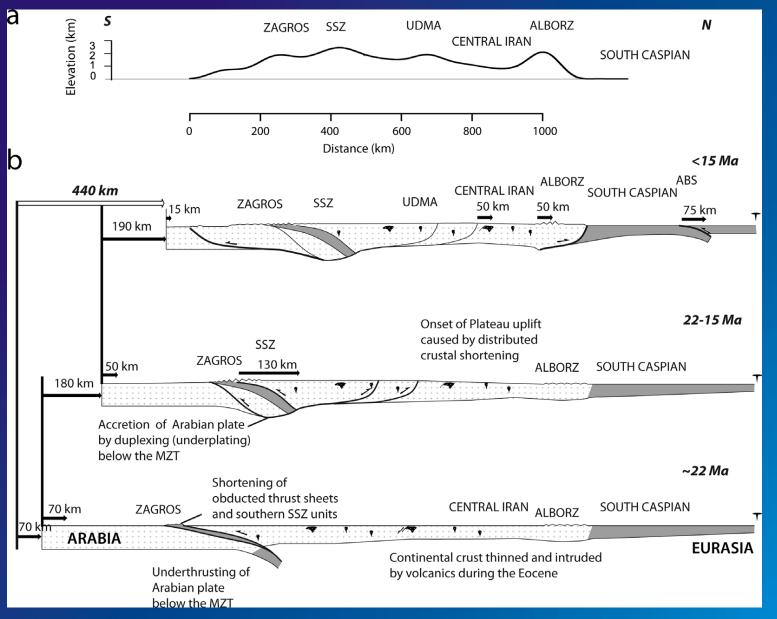
Lithofacies and stratigraphy in the Zagros basin

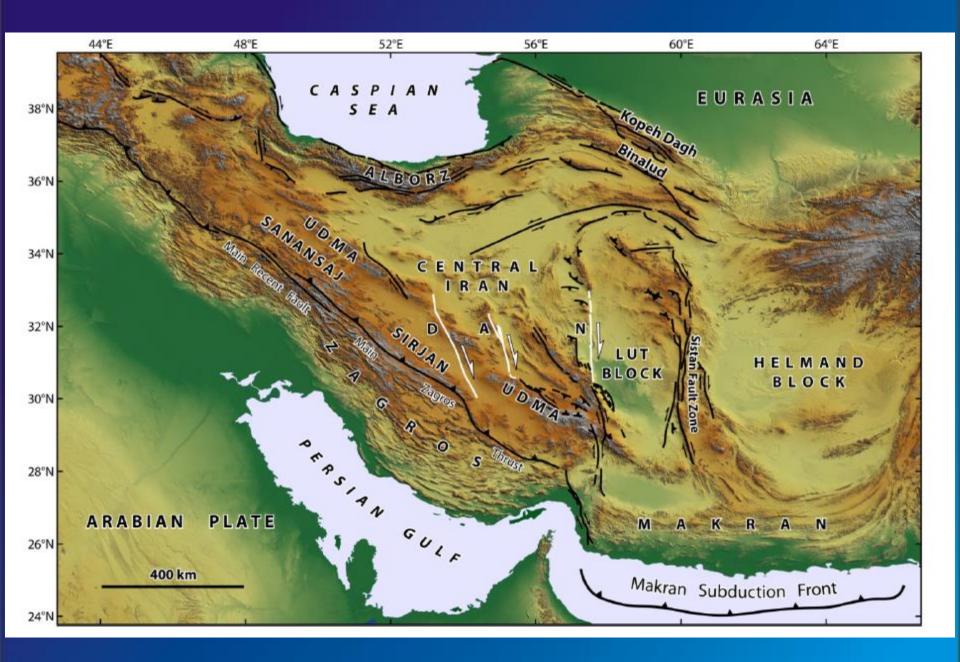




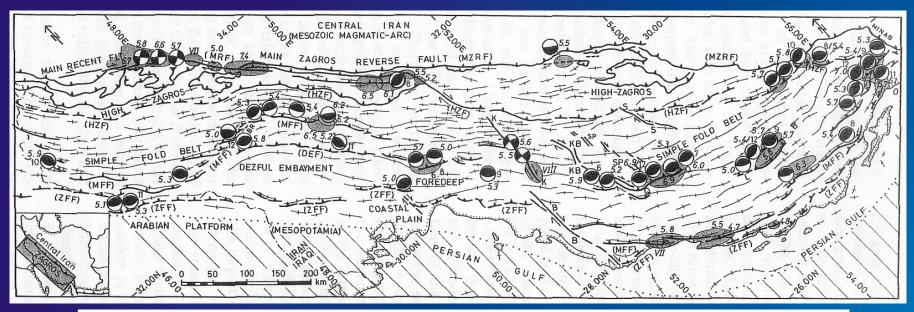
(Agard et al., 2005)

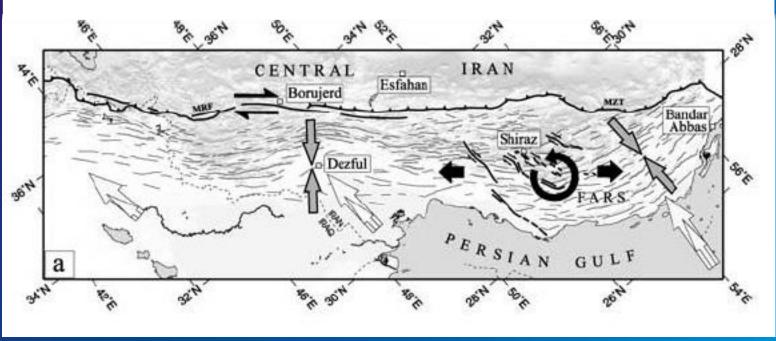
Fars



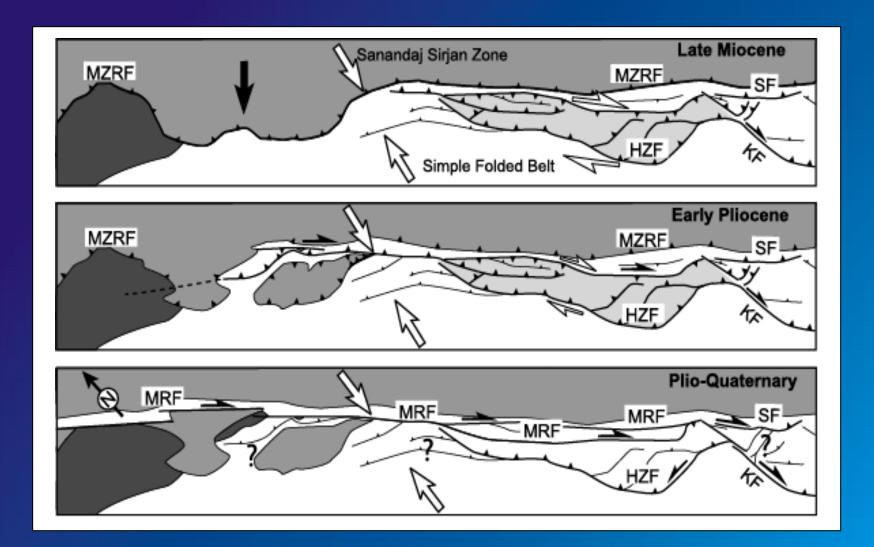


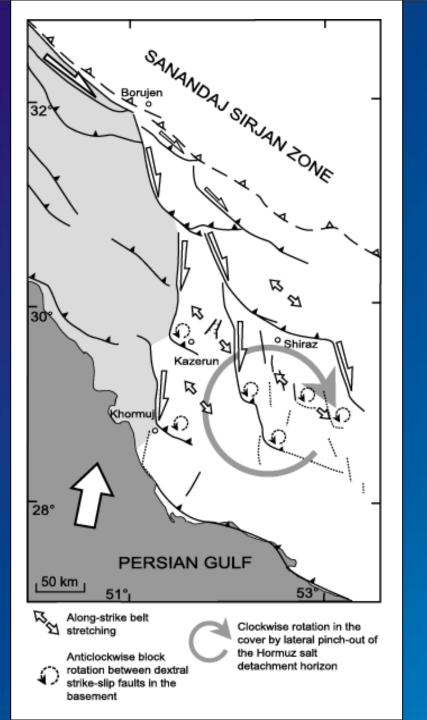






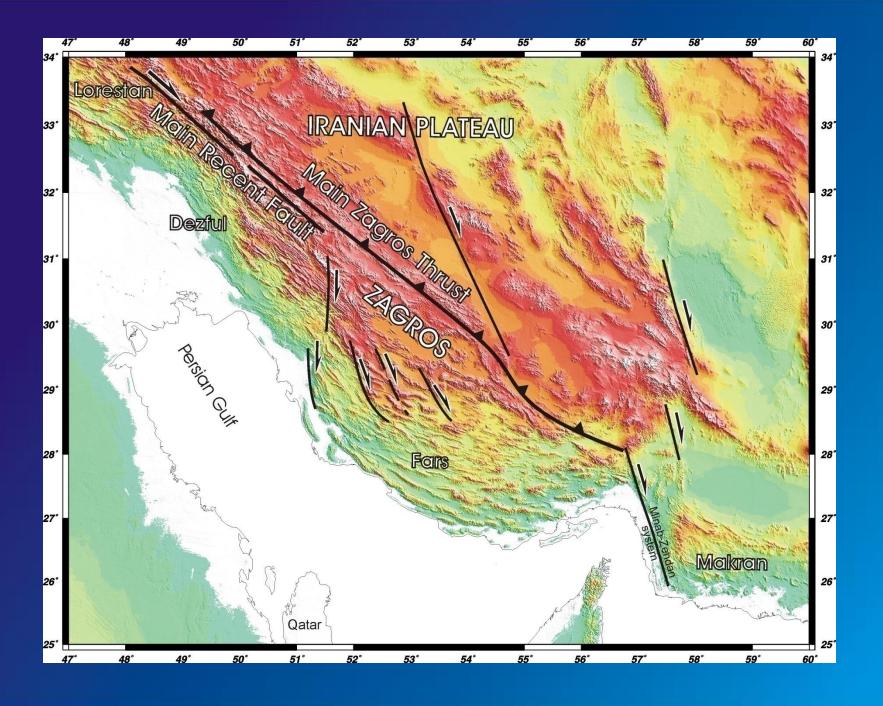
(Berberian, 1995; Talebian and Jackson, 2004)

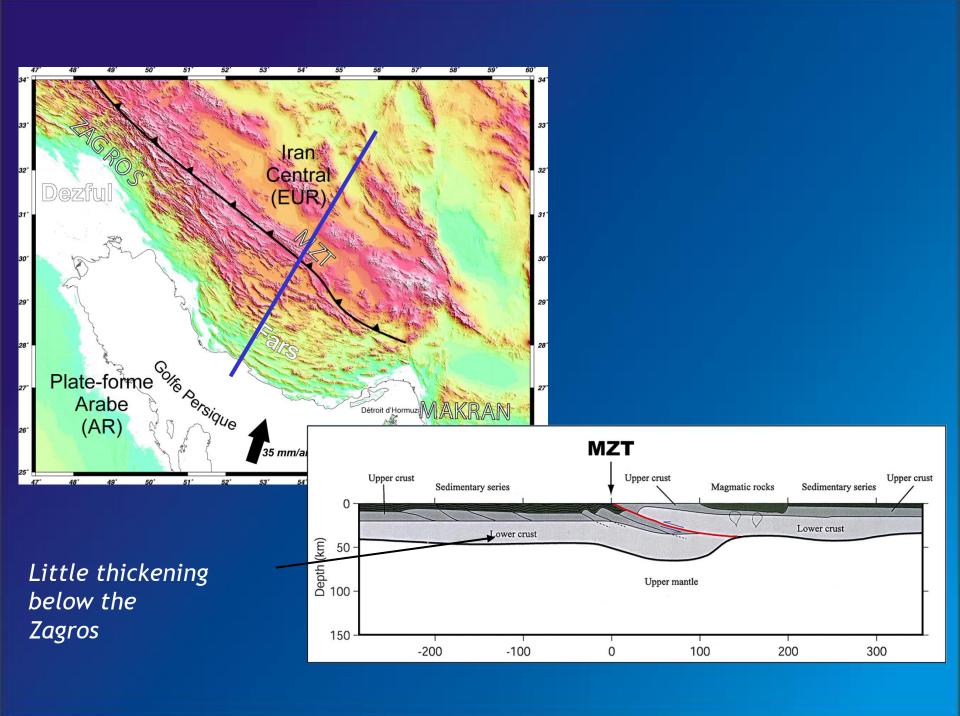




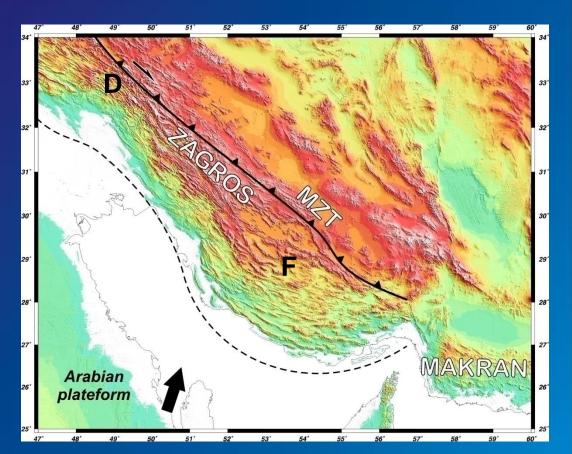
(Authemayou et al., 2006)

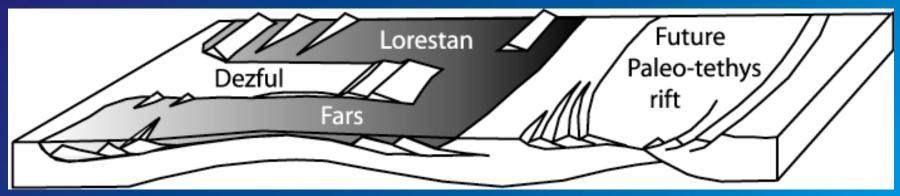
Geological setting of the Zagros fold-and-thrust belt





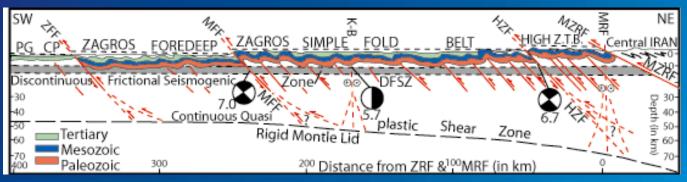
Along-strike segmentation is usually related either to variations in frictional properties of the basal décollement (Cambrian Salts) and/or to the distribution of pre-orogenic basins in the Arabian margin

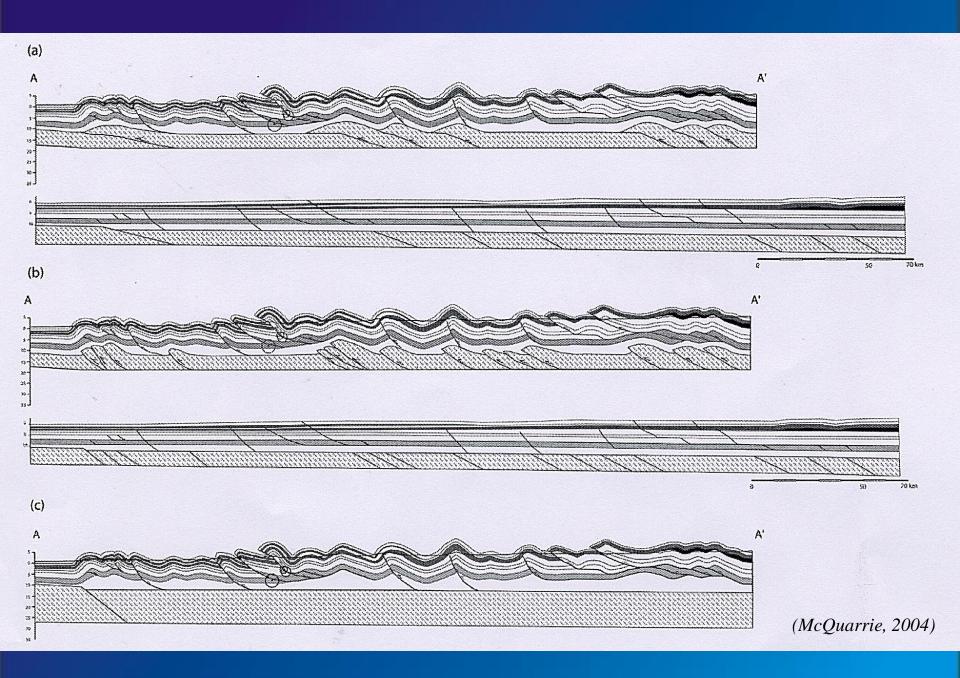


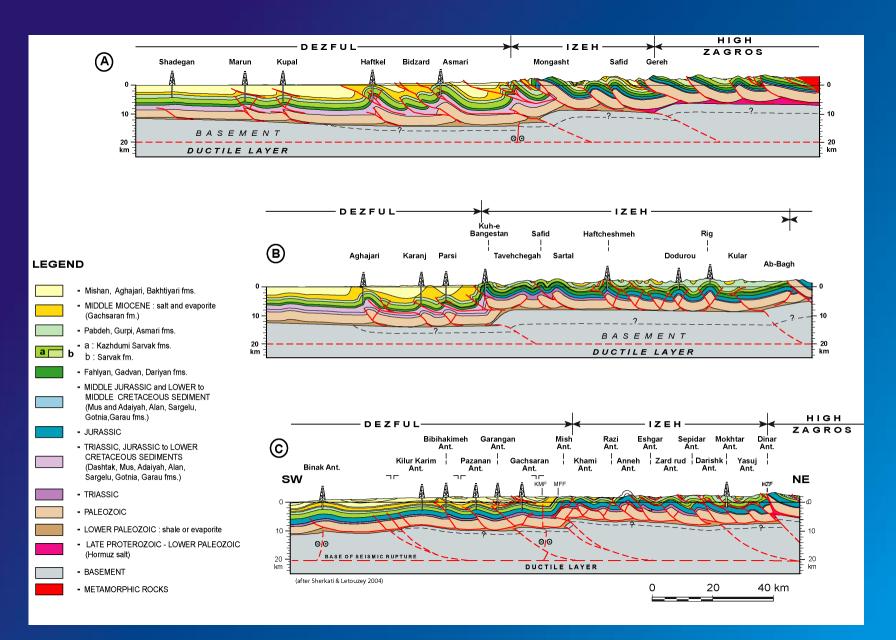


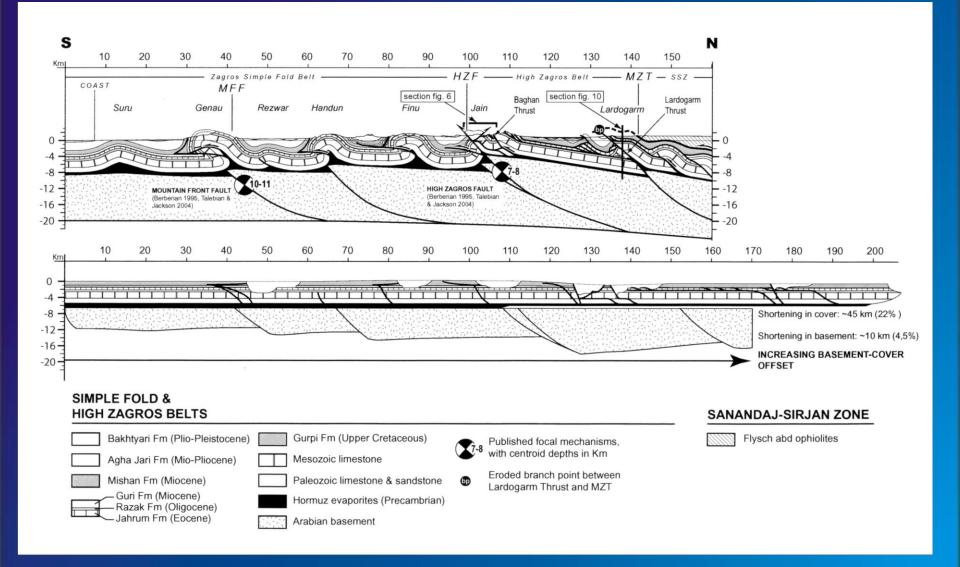


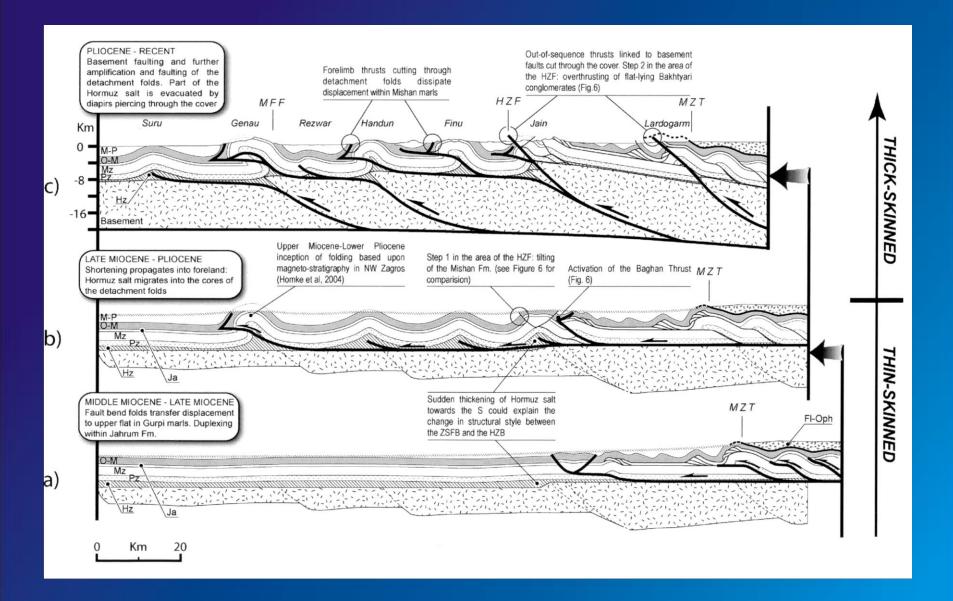
(Berberian, 1995)

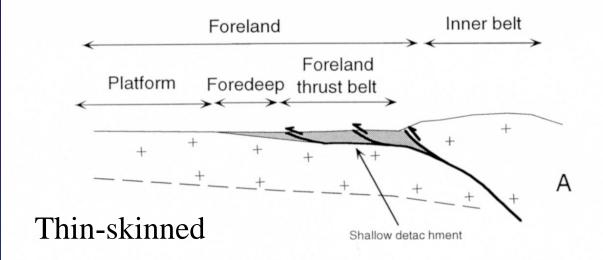




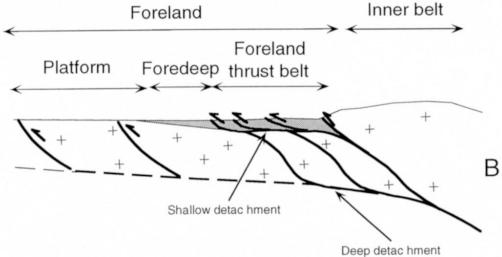




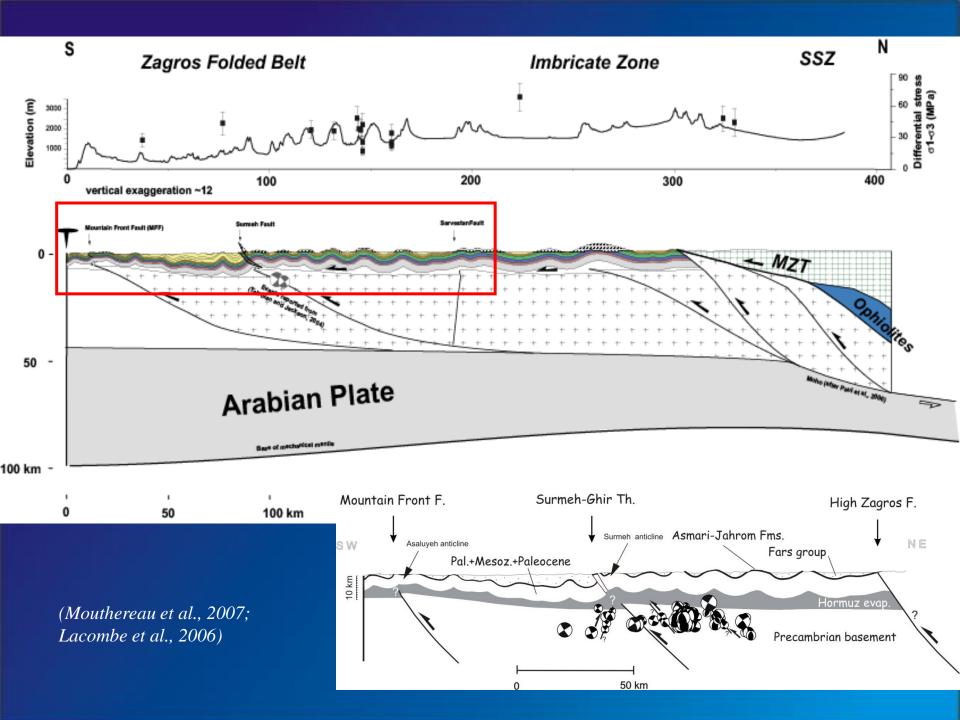


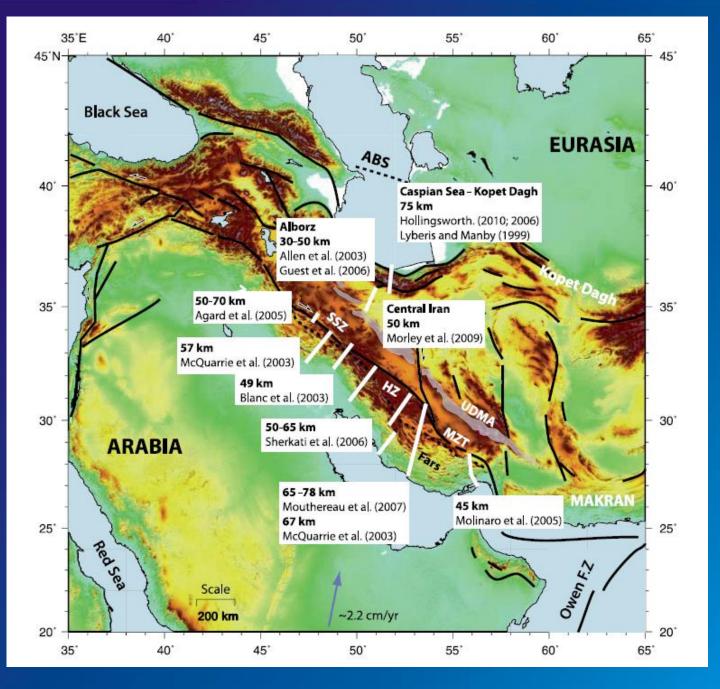


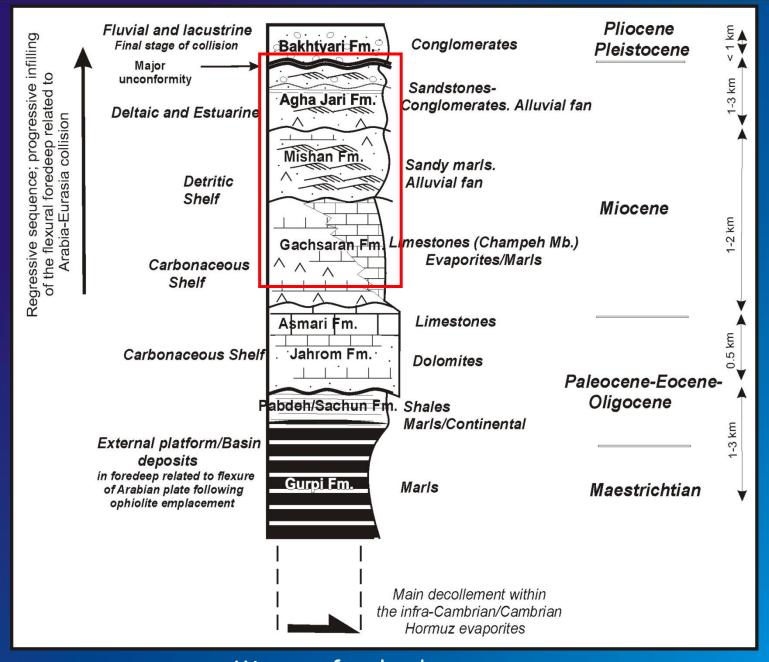
(Lacombe and Mouthereau, 2002)



Thick-skinned?
Thin-skinned + thick-skinned?





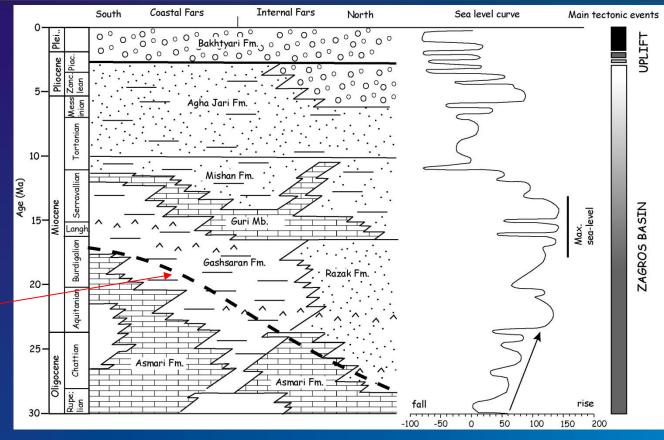


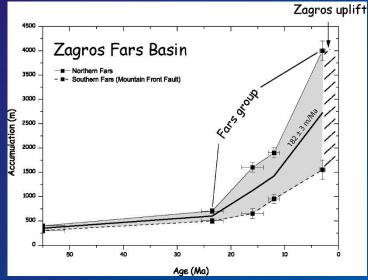
Miocene foreland sequences:
Thick regressive siliciclastic sequence of the Fars Group

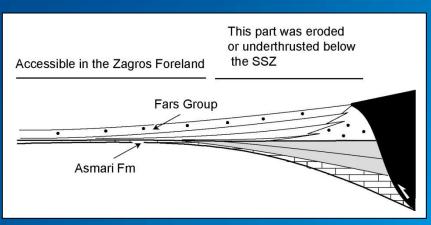
Progressive southward onlap through time

of the shallowingupward synorogenic deposits (Razak-Gashsaran Fm) onto the carbonates of the Asmari Fm

in the context of flexural basin development



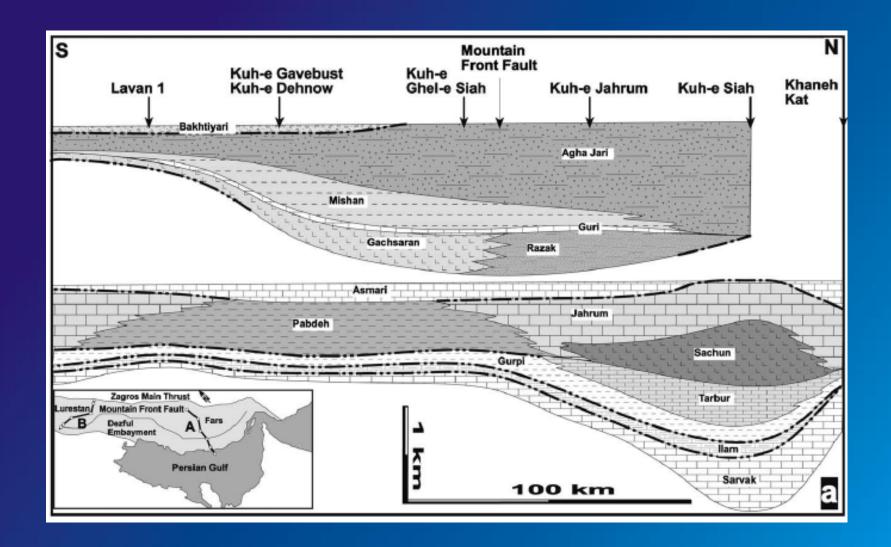




(Mouthereau et al., 2007)

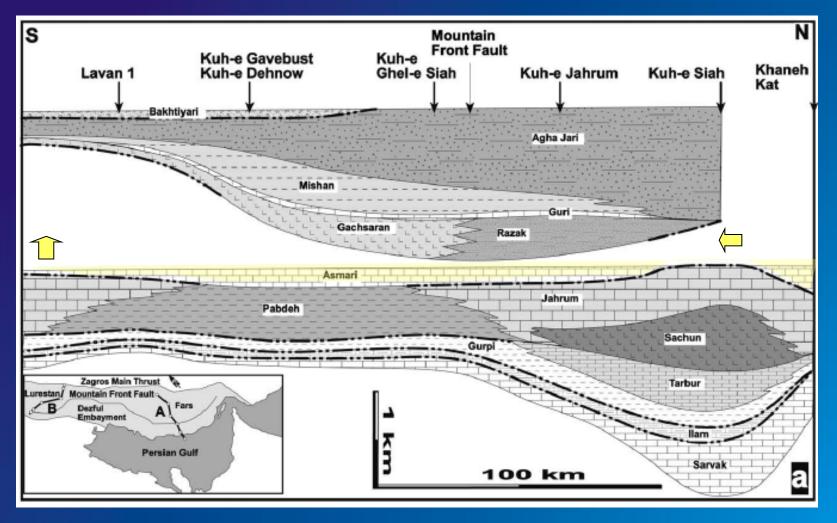
Infill of the foreland basin

Miocene foreland sequence: thick regressive siliciclastic sequence of the Fars Group



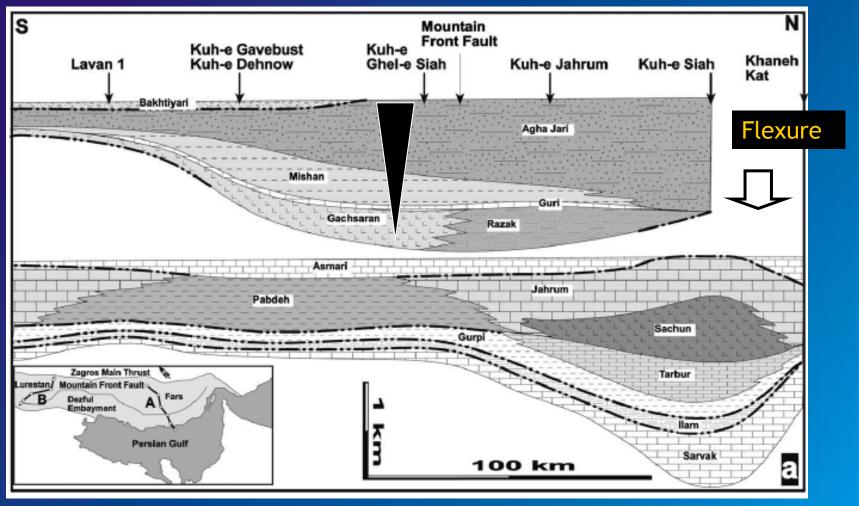
Oligocene- lower Miocene

- Major transgression on the Plateau and the northern Zagros: deposition of miocene flyschs to the north and carbonates to the south.
- No evidence of folding at that time

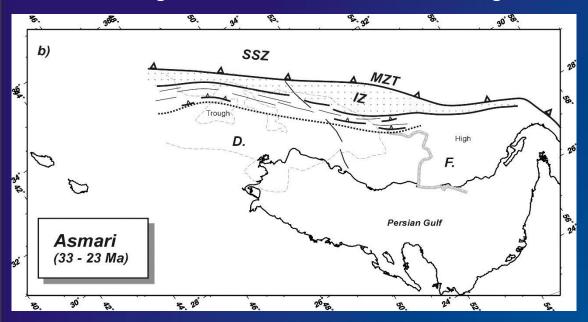


Miocene. Fars Group

- -Regression and filling of the foreland flexural basin; coarsening-upward sequence
- -Zagros: migration of the basin, strong subsidence, clasts



Oldest folding event recorded in the Fars - Oligocene

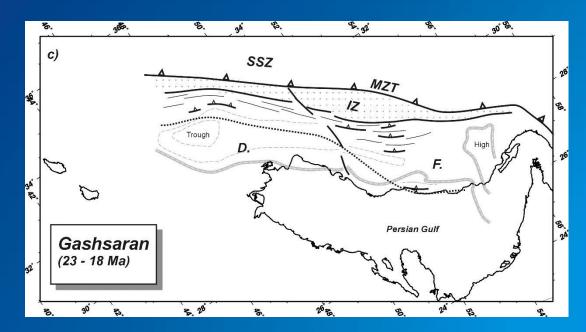


(adapted from Mottiei, 1993)

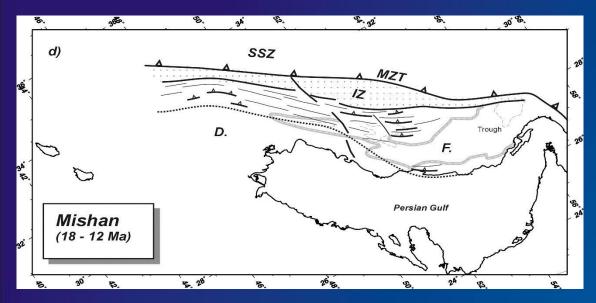
Migration of the collision southward
Maximum subsidence in the Dezful

Initiation of deformation in the southern Fars (Gulf Coast)

Migration of the collision southward
Maximum subsidence parallel to the MZT - the flexural basin was formed



Developement of the upper Fars and active folding near the Gulf Coast (formation of an intramountain trough)

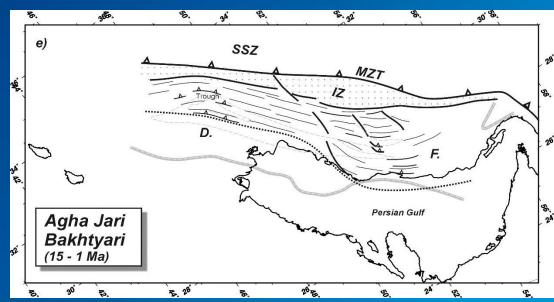


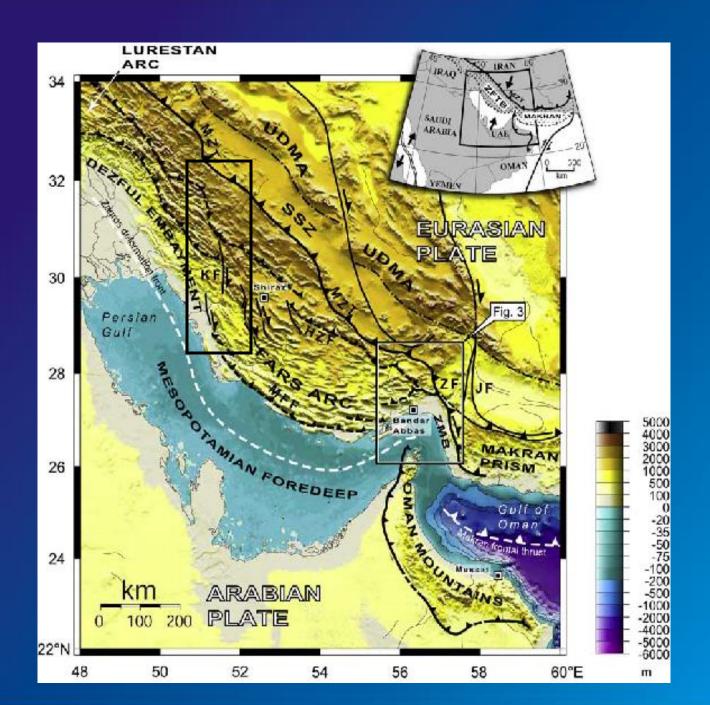
Migration of the collision southward
Maximum subsidence toward a southern trough

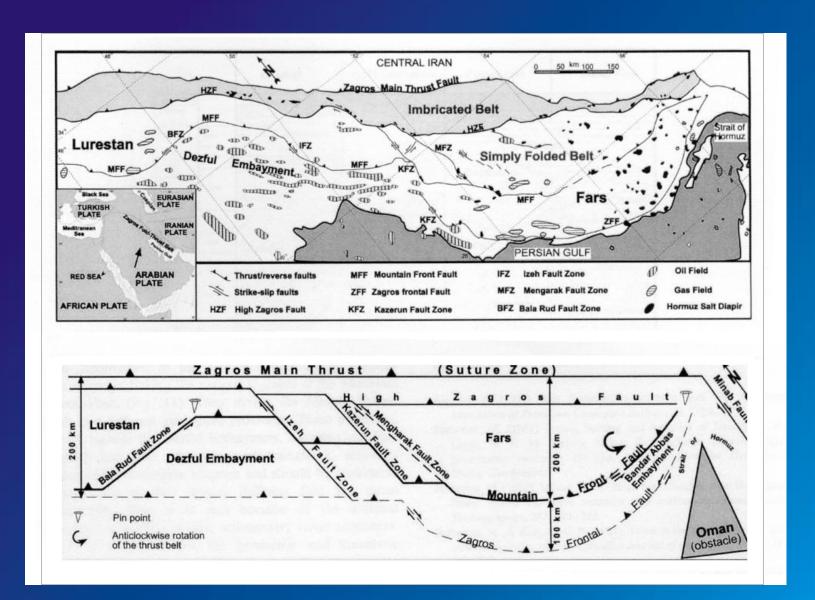
(adapted from Mottiei, 1993)

Renewed subsidence in the Dezful and achievement of the present structure of the ZSFB

Migration of the deformation front toward the Arabian shelf Maximum subsidence domain propagated into the Arabian shelf consistently

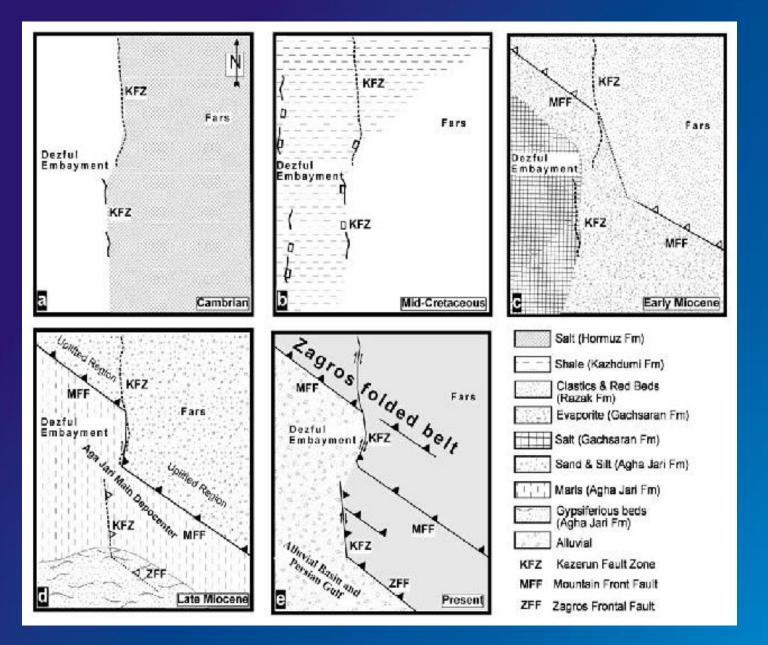






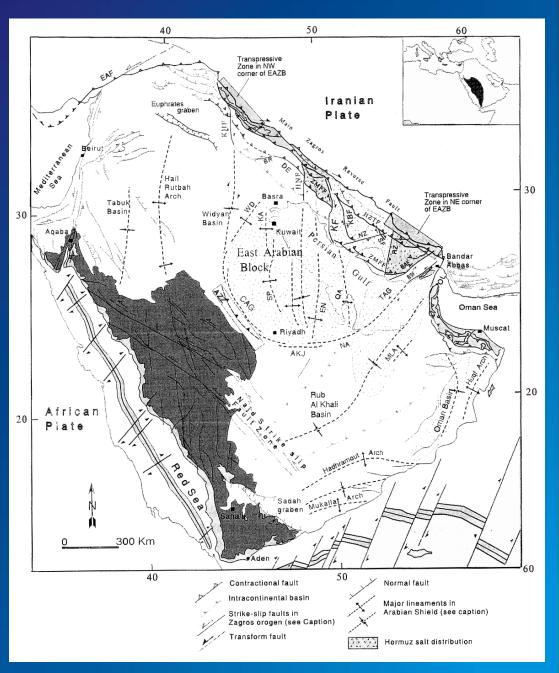


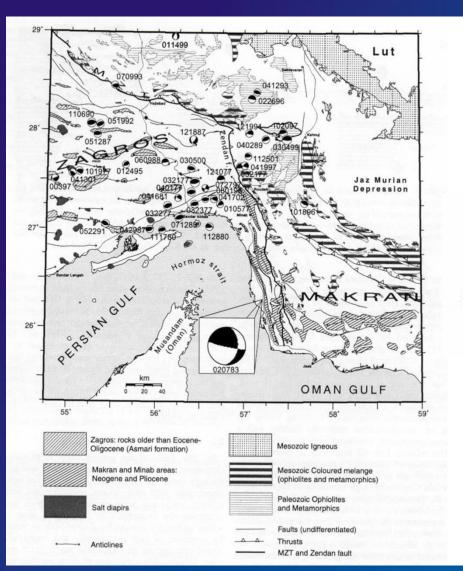
(Sepher and Cosgrove, 2005)

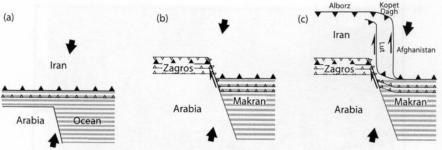


N-S basement faults
underlying the Zagros cover
inherited from
Panafrican orogeny

(Al Laboun, 1986; Beydoun, 1991; Berberian, 1995; Weijermars, 1998; Husseini, 2000; Bahroudi and Talbot, 2003)



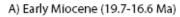


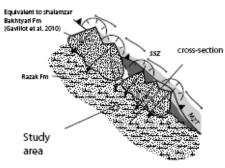


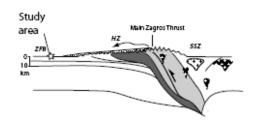
(Regard et al., 2004)

Fars

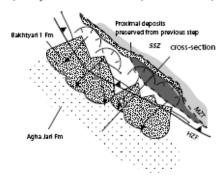
(Khadivi et al., 2012)

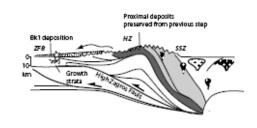




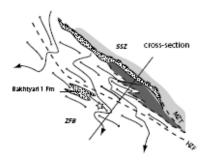


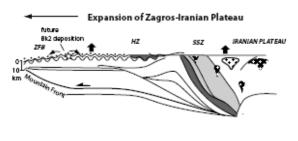
B) Early-Middle Miocene (16.6-13.8 Ma)





C) Late Miocene (<12.4 Ma)





Coastal sabkhas

Alluvial fans

Deltaic environments

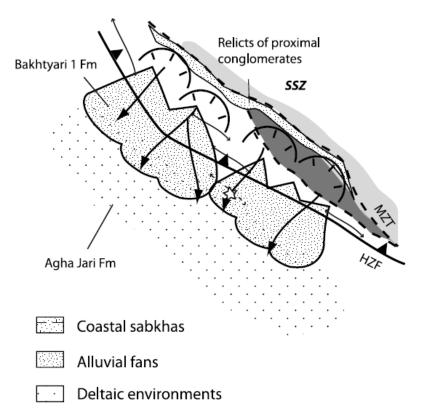
Metamorphic mélange + Sanandaj-Sirjan HP belt

Obducted complex

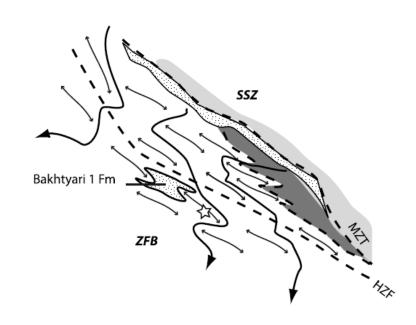
Granite Gabbroic intrusion

Drainage reorganisation from transverse to axial river network

Early-Middle Miocene (16.6-13.8 Ma)



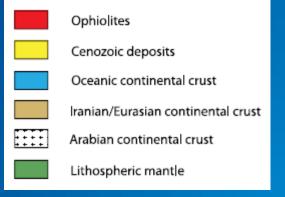
Late Miocene (<12.4 Ma)



- Metamorphic mélange + Sanandaj-Sirjan HP belt
- Obducted complex

Distal continental margin extensional magmatic flare-up Neyriz obducted accretionary prism + relict of upper cretaceous complex UDMA S mélange **EUR** higher density distal Asthenospheric margin upwelling AFRICA(ARABIA) 55-36 Ma Roll back OIB-like magmatism Zagros foreland UDMA KD **EUR** Subdcution velocity stable AFRICA(ARABIA) Underthrusting of distal margin 36-25 Ma Alkaline magmatism Razak Fm./Shahlamzar Qom limestones Bakhtvari congli **ARABIA** Accretion of normal thickness crust Shortening of the upper Iranian plate Mantle flow Decrease in subduction velocity 25-15 Ma Zagros and Iranian Plateau uplift MZT UDMA SSZ Asthenospheric ARABIA Subduction velocity decreasing Mantle flow Afar plume Slab sinking Slab sinking and retreat 15-5 Ma

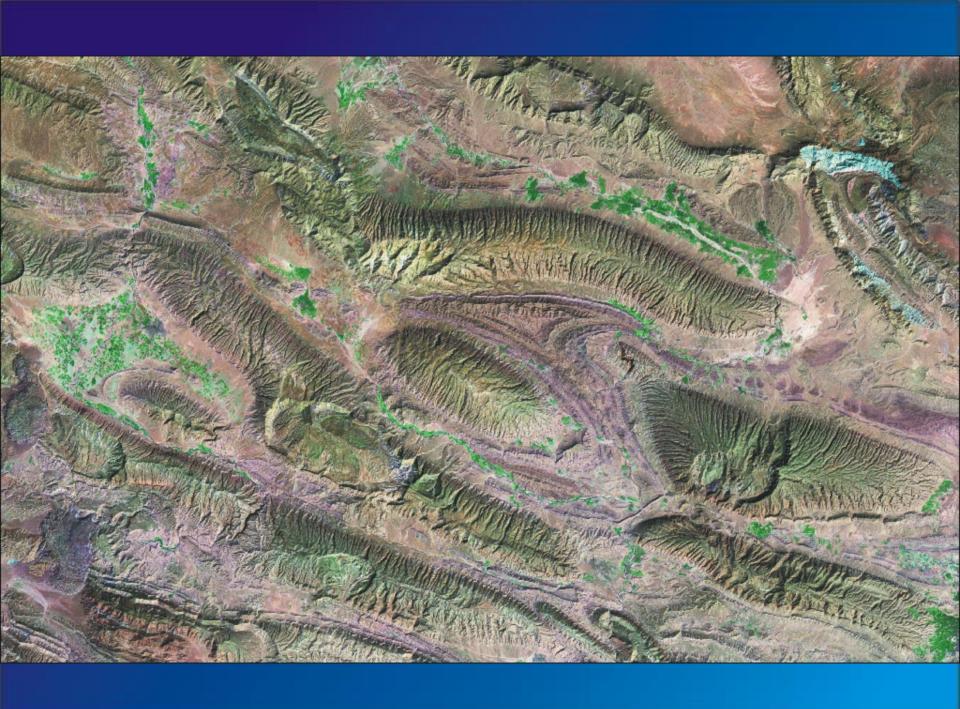
Central Zagros



(Mouthereau et al, 2012)

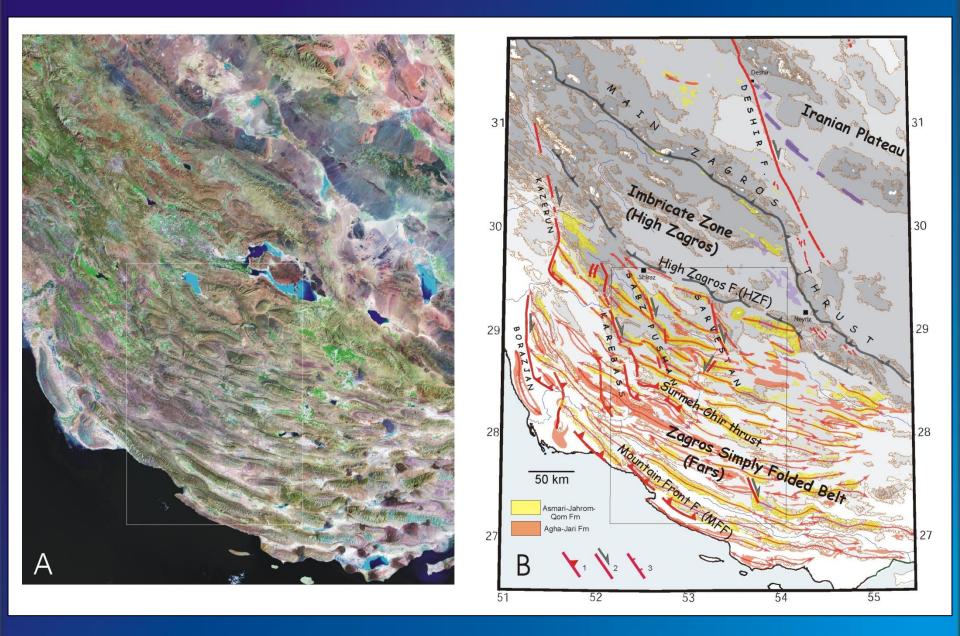
Deformation in the Zagros (1): folding

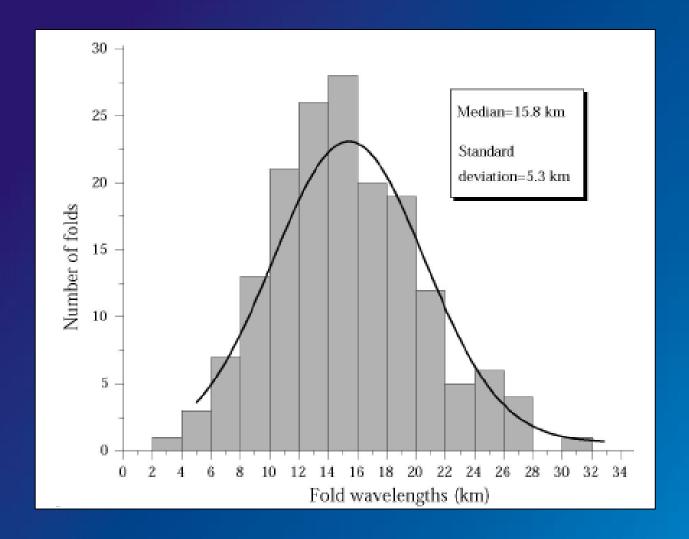






Fars









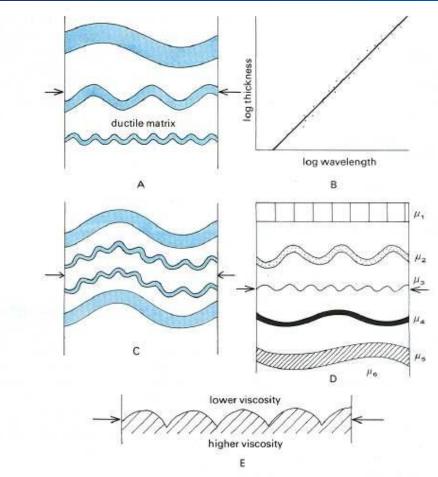




« buckle folds »

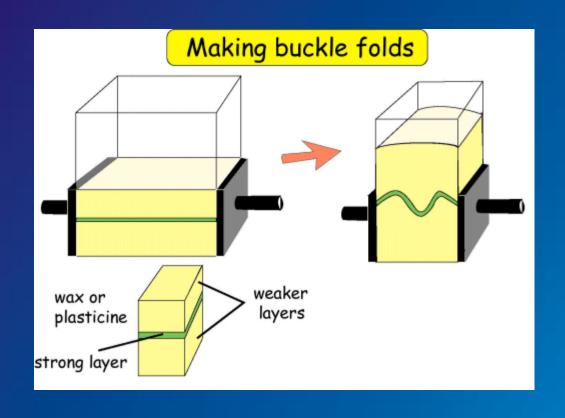
Development of this type of folds requires a significant contrast of competence between the folded strata (elastic or viscous) and the surrounding medium (viscous).

In this case, there is a direct relationship between the thickness of the competent strata and the wavelength of folding

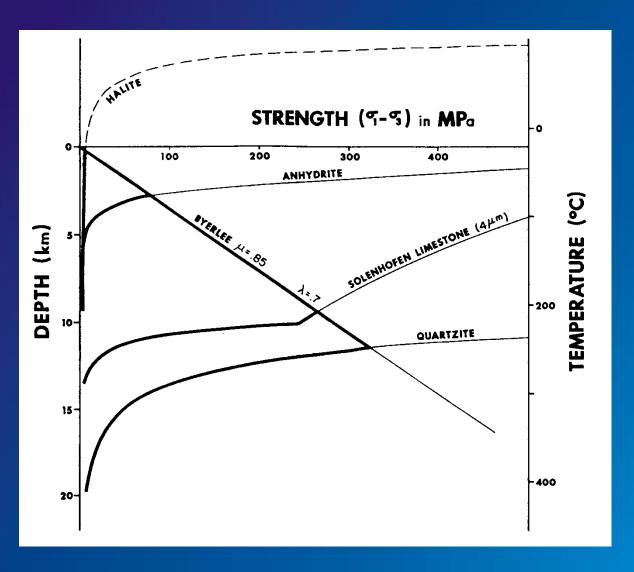


Influence of layer thickness and viscosity contrast on the wavelength of buckle folds. A, B. There is a linear relationship between log layer thickness and log buckle wavelength for widely separated layers of constant viscosity in a ductile matrix of much lower viscosity. C. Buckle folds of different wavelength may be superimposed if the layers are close enough to interfere. D. Buckle folding produced by a number of layers of different viscosity μ_1 - μ_5 and different thickness in a ductile matrix of much lower viscosity μ_6 . A, C and D are examples of disharmonic folding (see section 3.6). (After Ramberg, H. (1964) Tectonophysics, 1, 307–41.) E. Buckle folding of an interface between two thick layers of contrasting viscosity. The cusps point towards the material of higher viscosity (cf. mullion structure, see section 4.2 and Figure 4.8B).

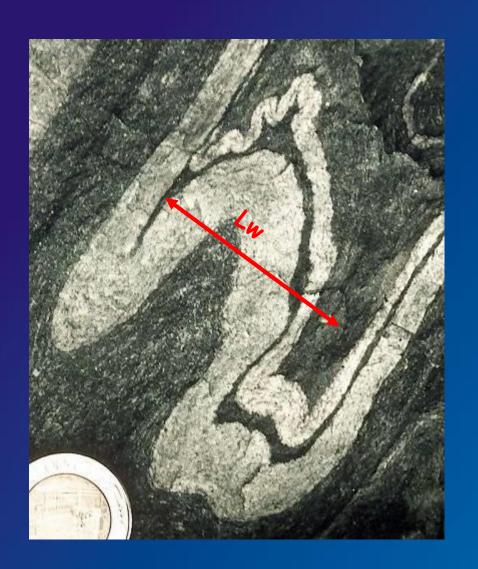
« buckle folds » Conditions : « pure shear »

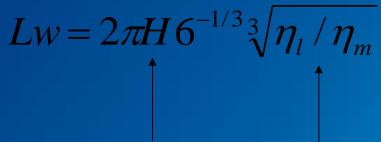


Mechanical behaviour of evaporites



Wavelength Lw for viscous buckling

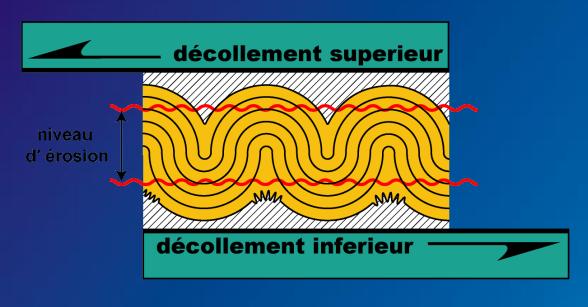




Initial thickness of competent strata

Viscosity contrast between strata and matrix

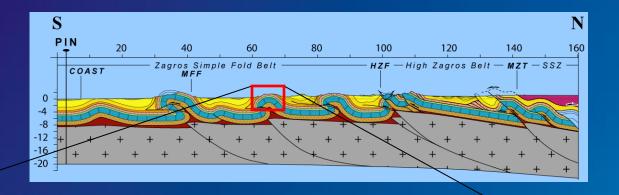
Outcrop scale



Dahlstrom (1969)

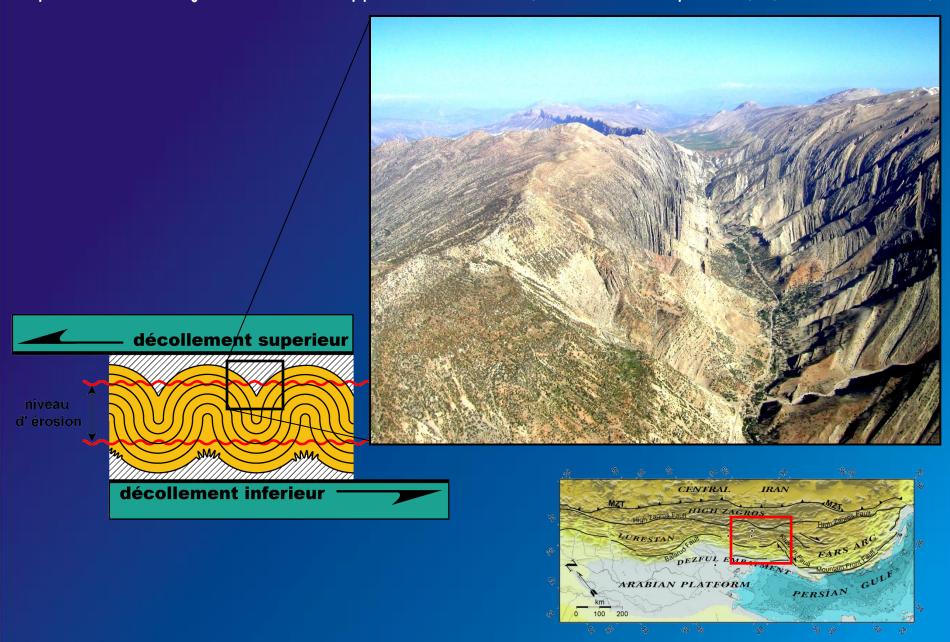
Concentric folding requires 2 décollement levels

Décollement fold with typical geometry (eastern Zagros) (Molinaro, 2004)

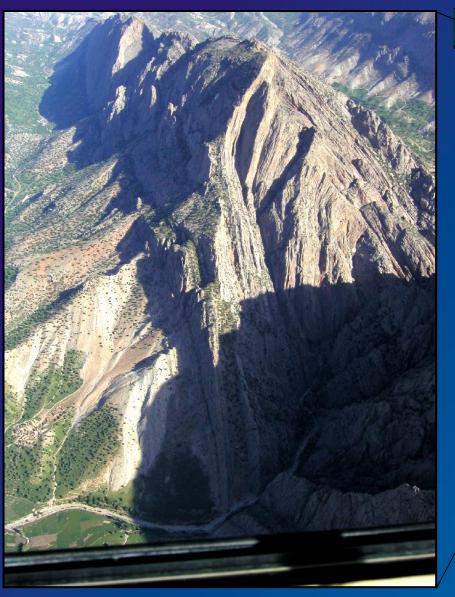


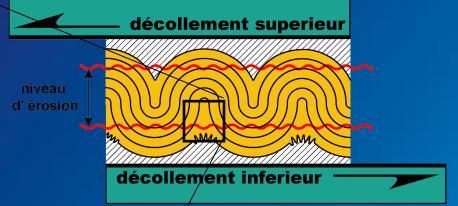


Syncline located just below the upper décollement (Gachsaran evaporites) (Sherkati, 2004)



Anticline located just above the lower décollement (Kadjumi Fm) (Sherkati, 2004)

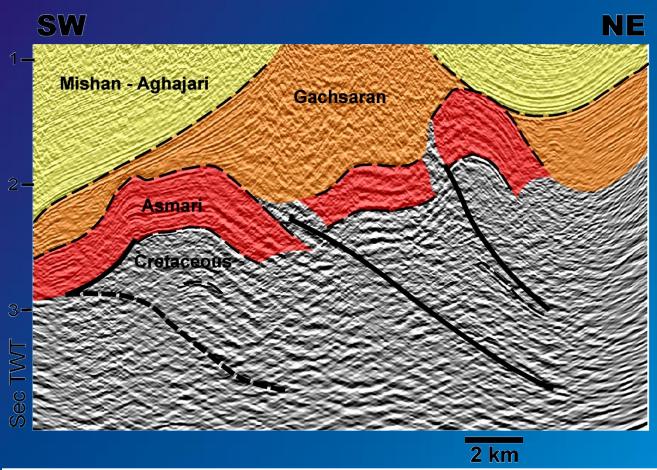


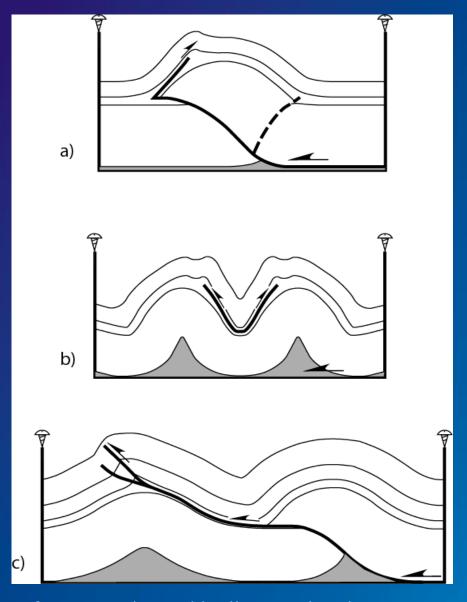




Complete decoupling across upper décollement (Gachsaran salt) (Sherkati, 2004)

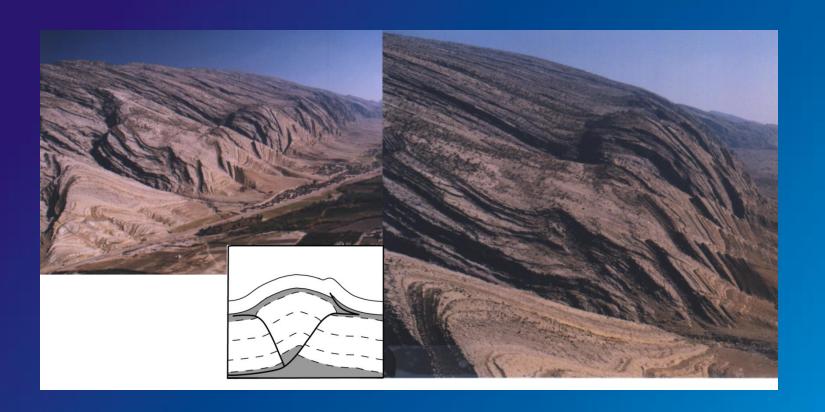






Role of intermediate décollement levels

- a) et b): « rabbit-ear » folds
- c): transmission of deformation from one fold to the other

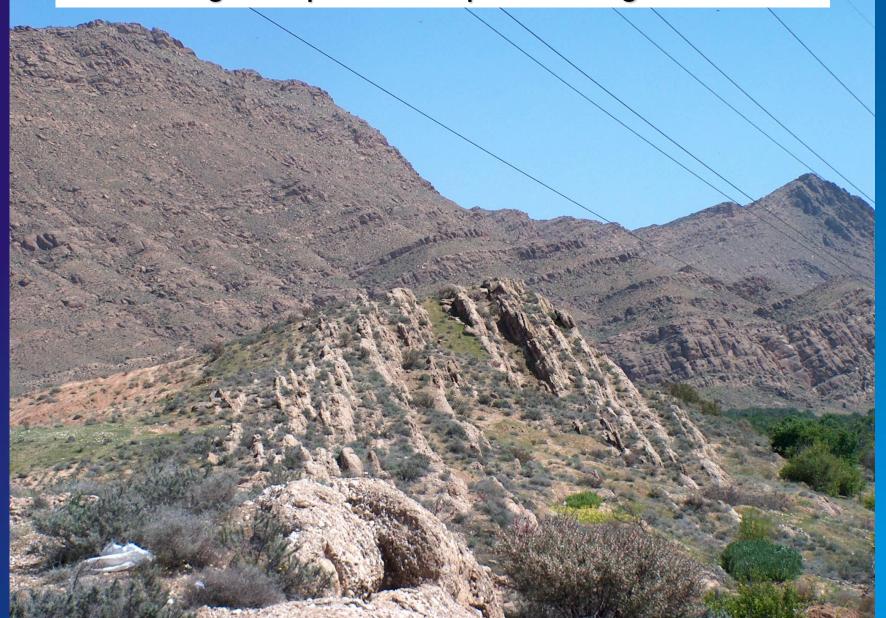


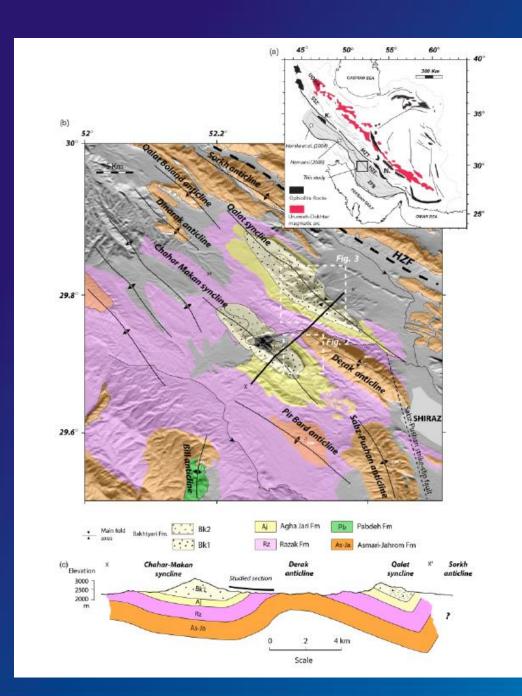
Example of « rabbit-ear » fold (central Zagros)

Upper Miocene: growth strata within upper Agha Jari Fm

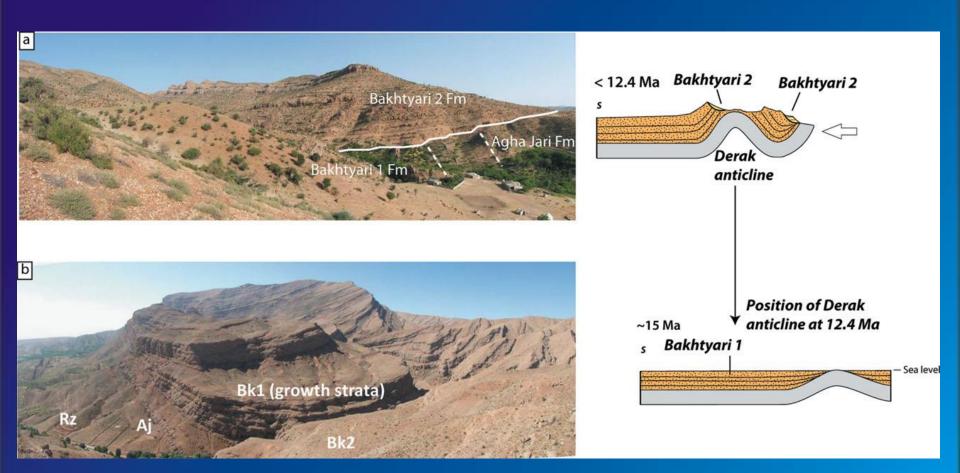


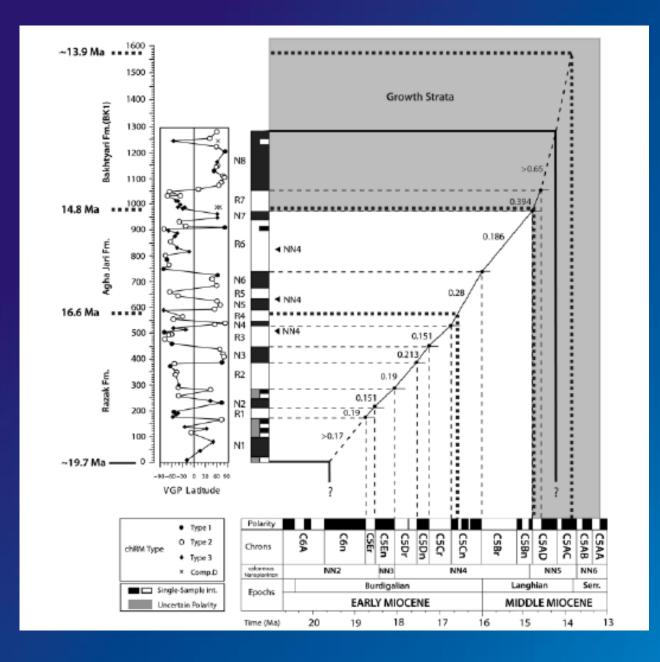
Plio-Pleistocene: Major post-folding unconformity Regional uplift after deposition of Agha Jari Fm.



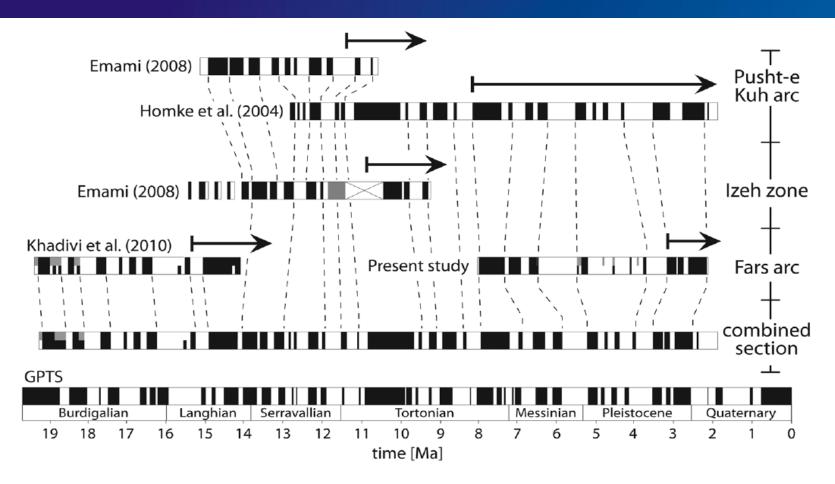


(Khadivi et al., 2010)

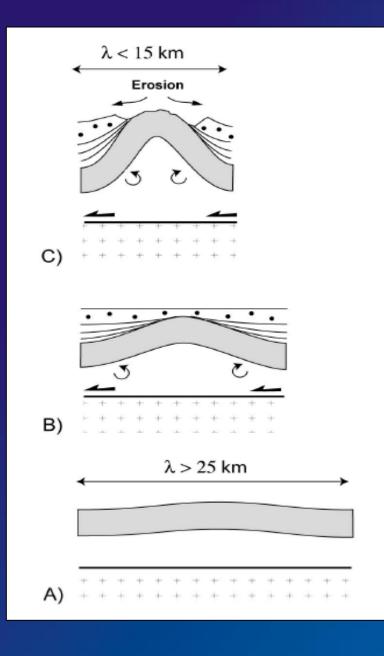




(Khadivi et al., 2010)

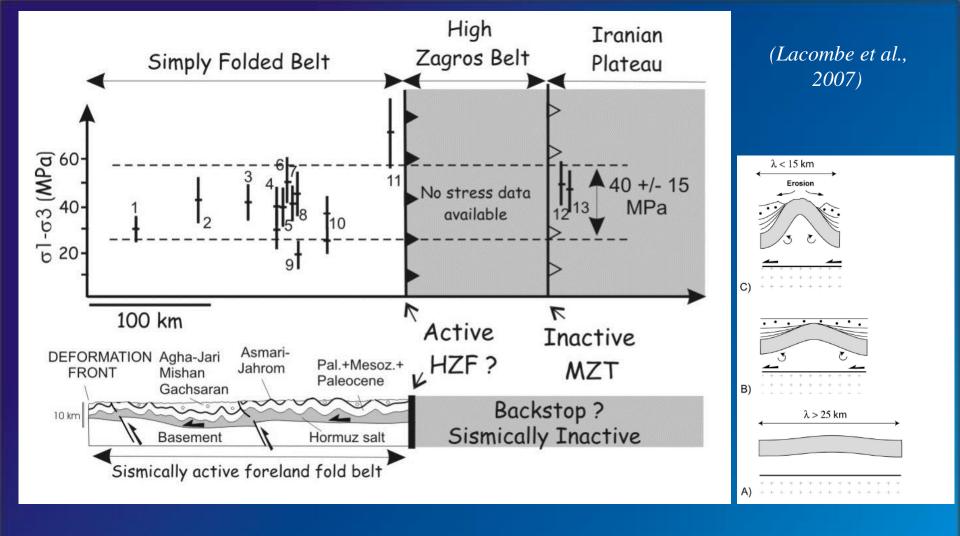


Combined magnetostratigraphic section of studies conducted in the Simply Folded Belt of the Zagros. Black arrows indicate onset of deformation inferred by progressive unconformities. Folding in the outer Pusht-e Kuh arc [Homke et al., 2004] is triggered by the Mountain Front Flexure.



- Overall homogeneous fold wavelength;
- Homogeneously distributed shortening across the Simply Folded Belt;
- Initial rapid fold growth rate, then decrease relative to foreland subsidence;
 - Folding under low differential stresses:

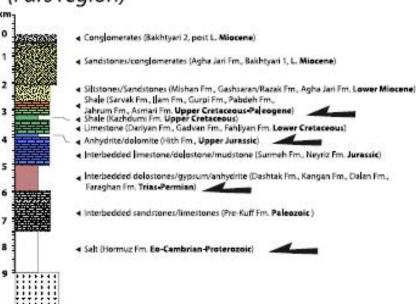
→ Buckling of the competent cover above the Hormuz salt



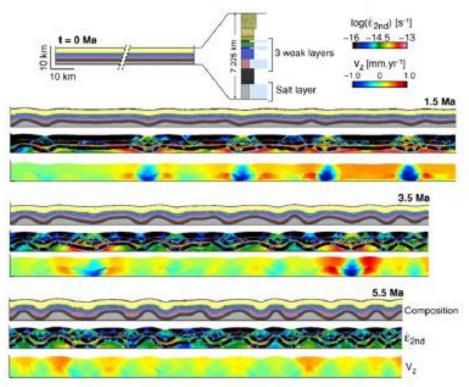
The relative homogeneity of differential stresses agrees with the homogeneously distributed shortening across the SFB, where no deformation gradient toward the backstop is observed in contrast to classical fold-thrust wedges

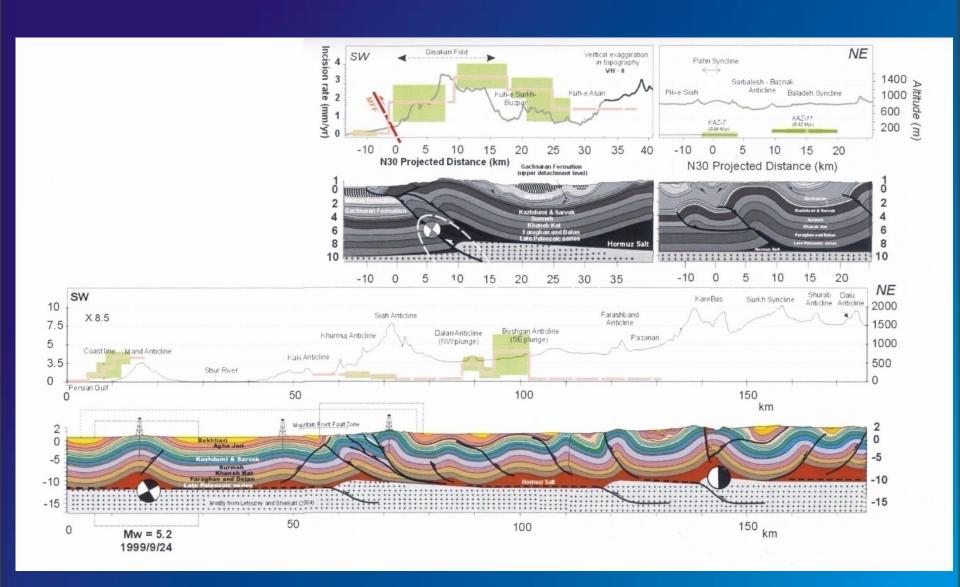
Both pre- and post-folding differential stresses are low --> folding likely occurred at low stresses; this favours pure-shear deformation and buckling of sedimentary rocks rather than brittle tectonic wedging.

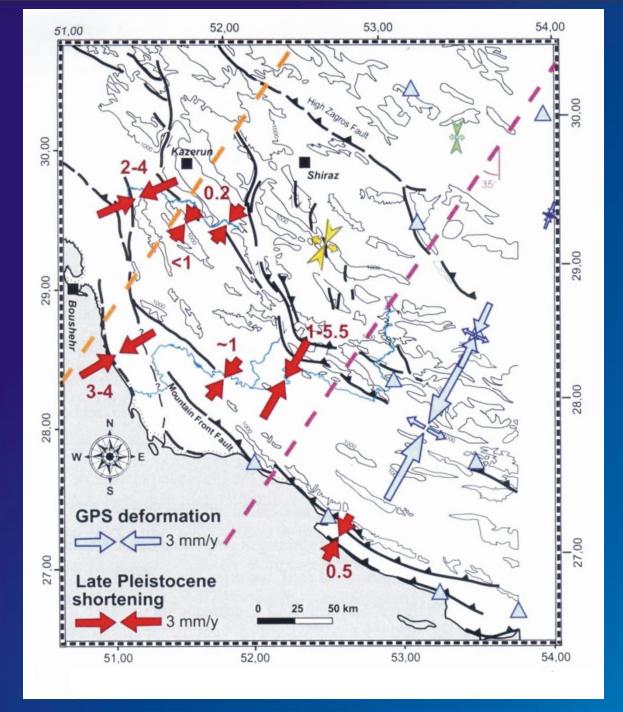
Mechanism of cover folding Stratigraphy and mechanical layering (Fars region)



Mechanical modelling of cover folding



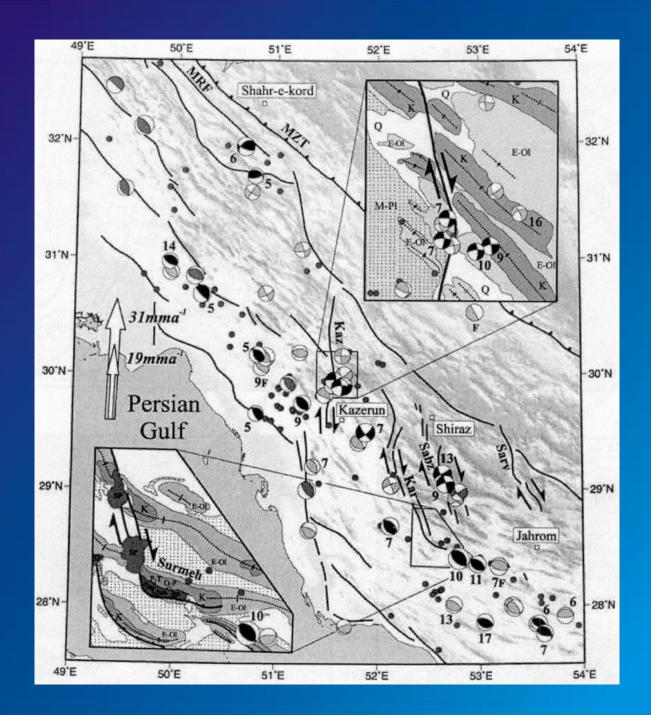




Outer folds accommodate most of current shortening in the Zagros. Their growth over the last My can be accounted for either by thin-skinned tectonics, or by the activity of underlying basement faults. Cover and basement are mostly decoupled: this is in agreement with superimposed thin- and thickskinned tectonics styles.

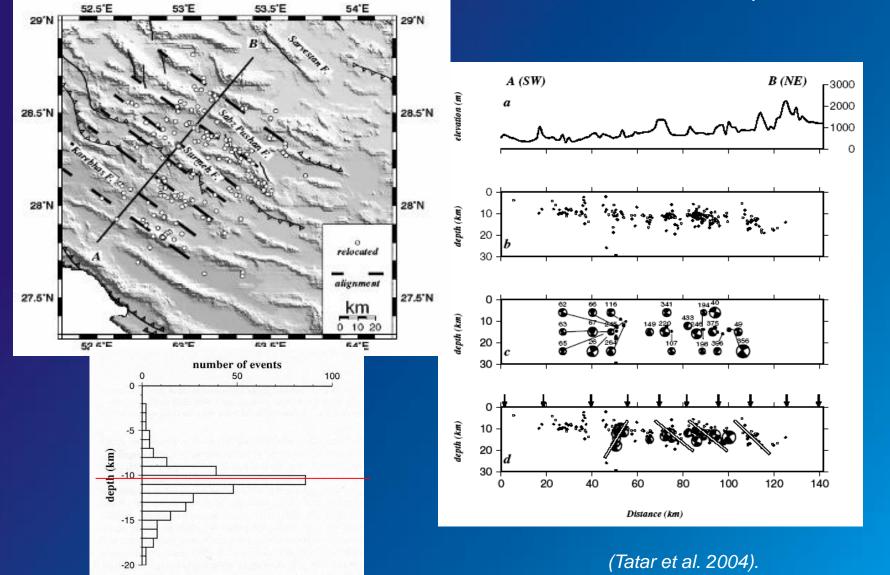
(Oveisi, PhD thesis, 2007)

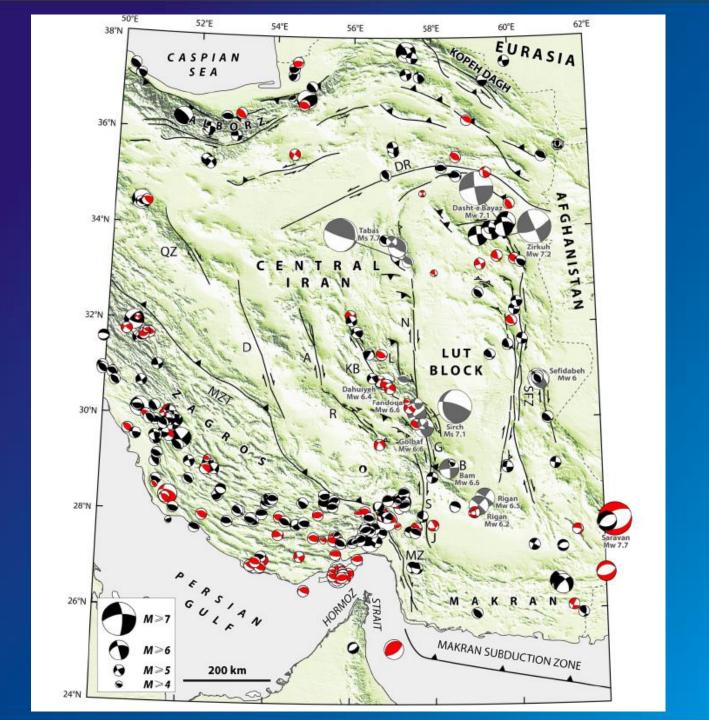
Deformation in the Zagros (2): earthquakes and seismic faulting

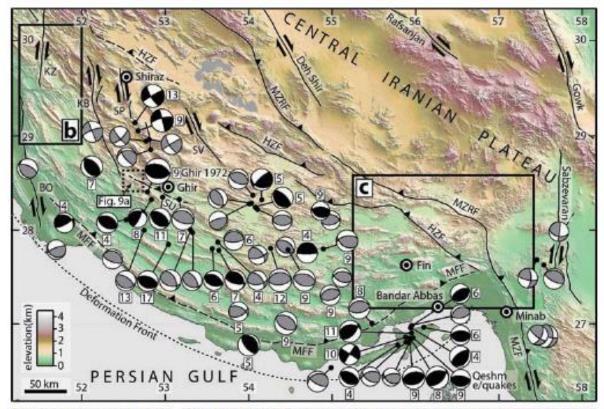


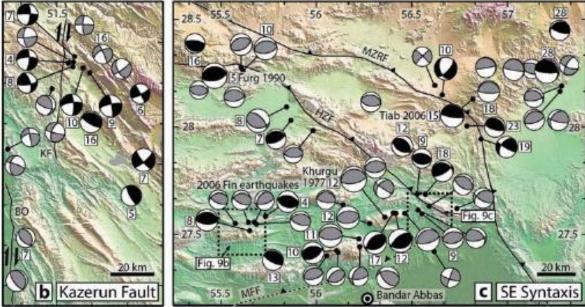
(Talebian and Jackson, 2004)

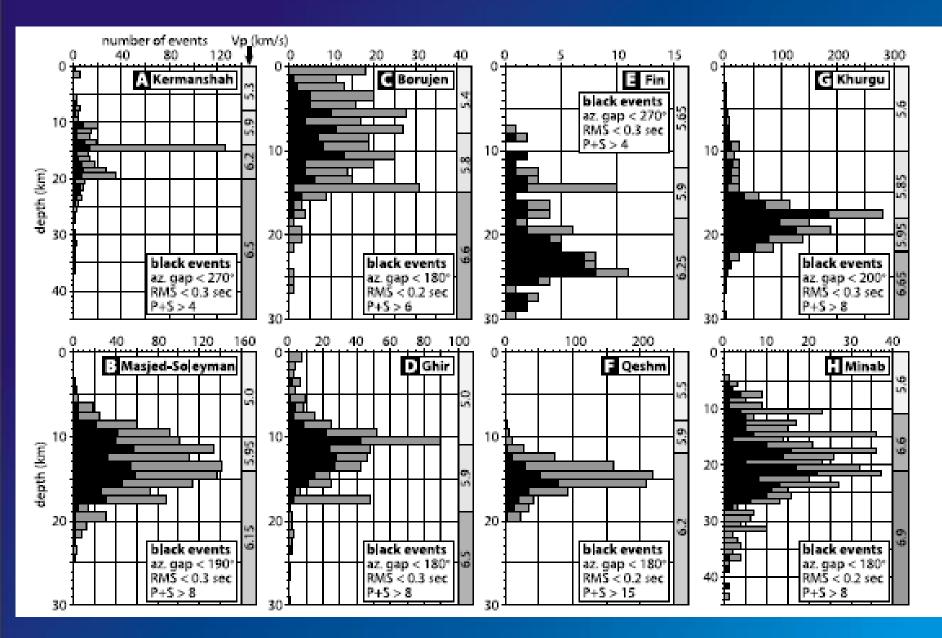
Localization of basement faults using microseismicity

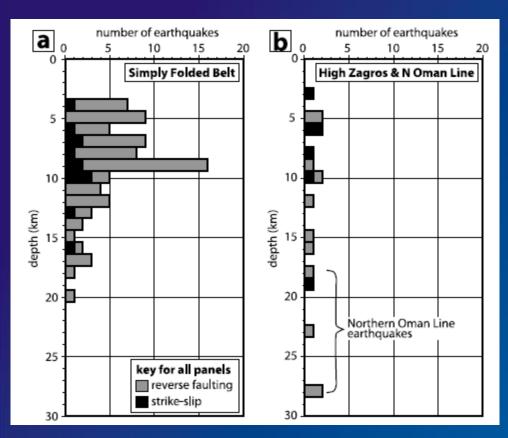


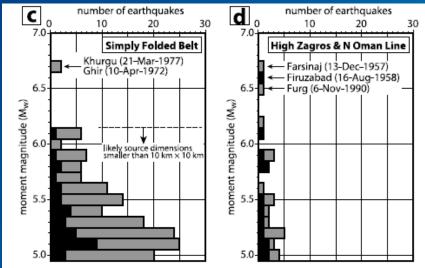




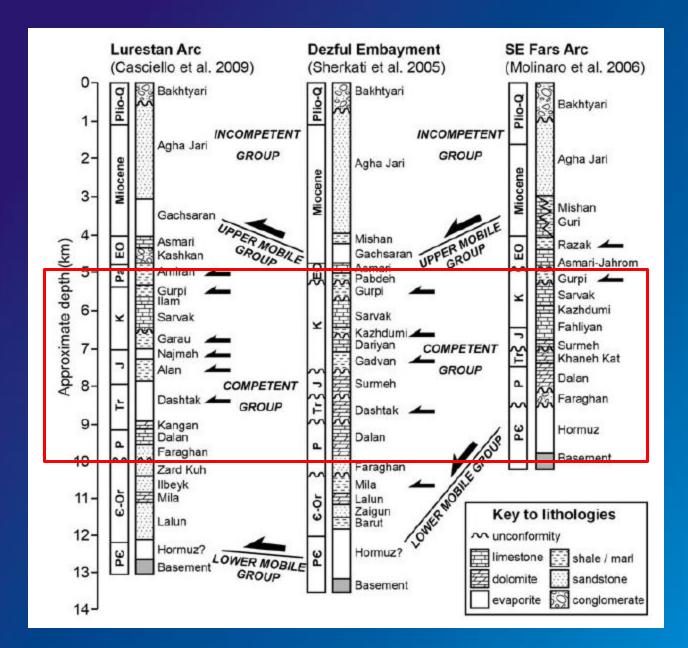


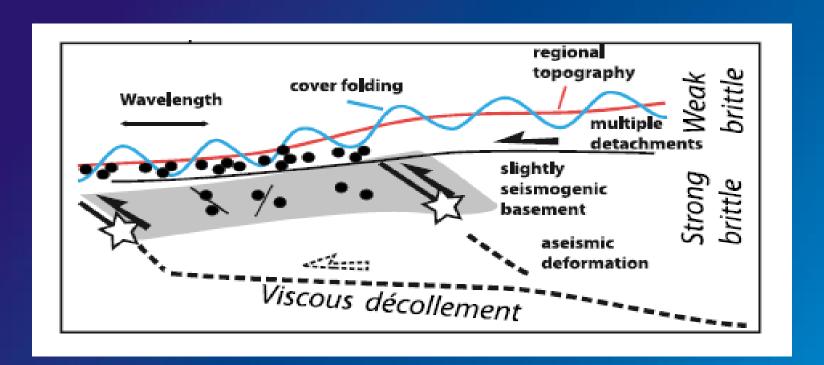


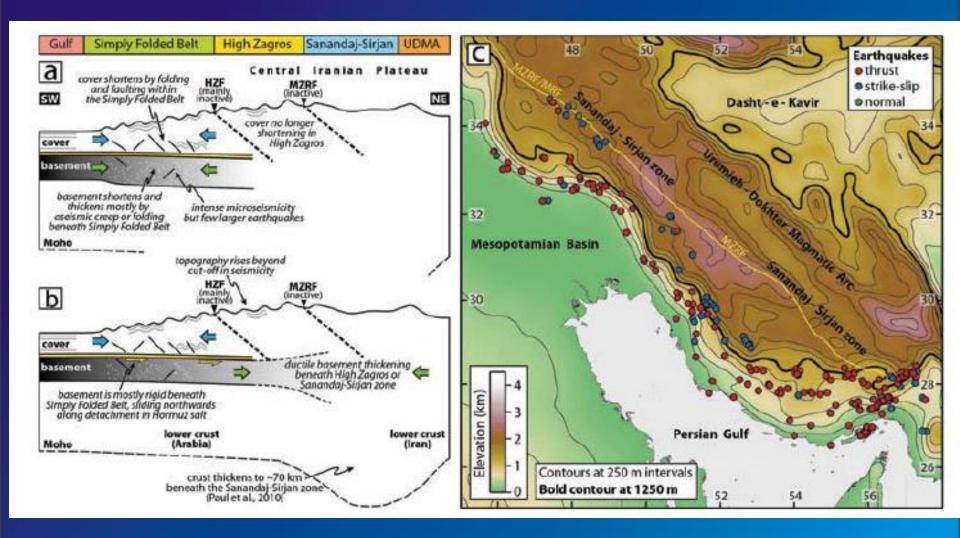




teleseismically recorded earthquakes







Deformation in the Zagros (3): meso-scale fracturing

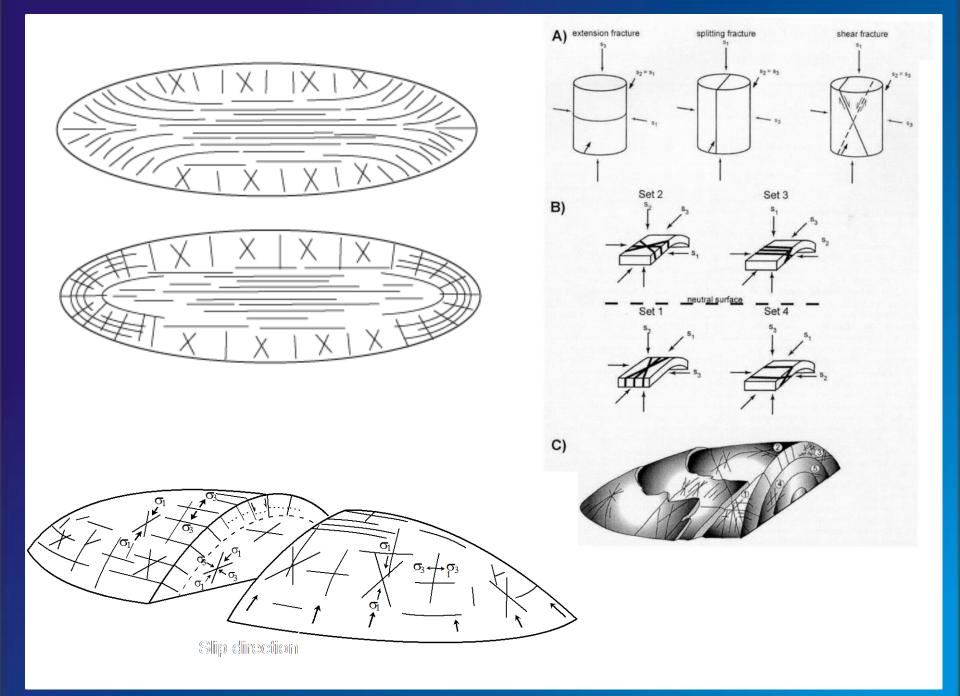
The study of fracture patterns and their possible genetic relationships to cover folding is of key importance in the Zagros.

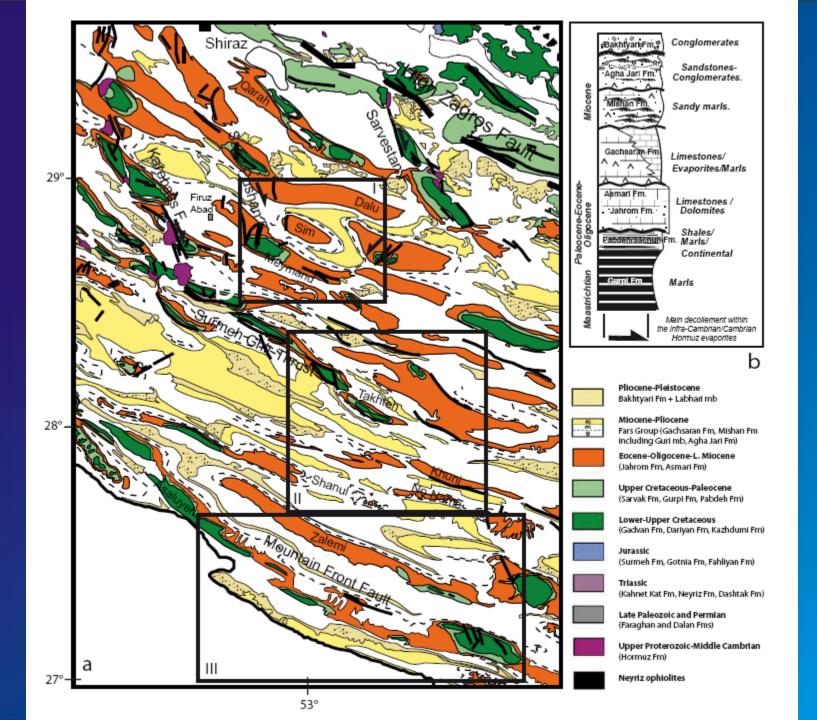
Several giant oil fields are found, especially in the Dezful Embayment

The Asmari Formation is an Oligocene-Early Miocene platform carbonate which is the most prolific oil reservoir in Iran, and it is commonly regarded as a classic fractured carbonate reservoir, with production properties that depend strongly on the existence of fracture networks

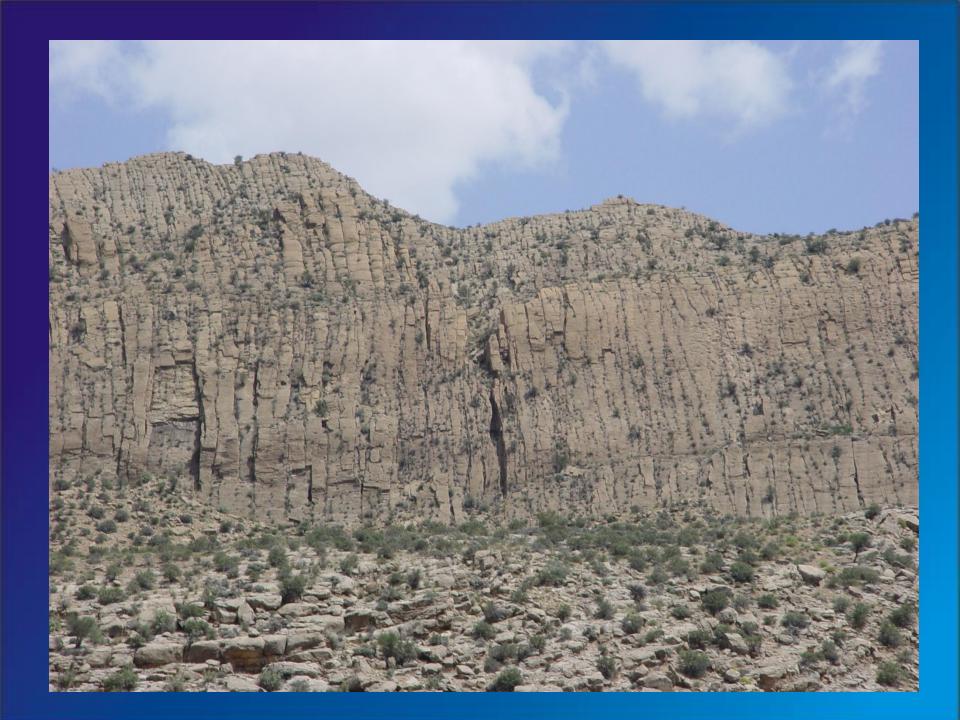
as the most important factors that control fracturing. Stearn & Friedman (1972) proposed a pioneering classification of fold-related fractures, including an axial extensional set running parallel to the fold axis, a cross-axial extensional set oriented perpendicular to the fold axis and two sets of conjugate shear fractures oblique to the fold axis with their obtuse angle intersecting the trend of the fold axis.

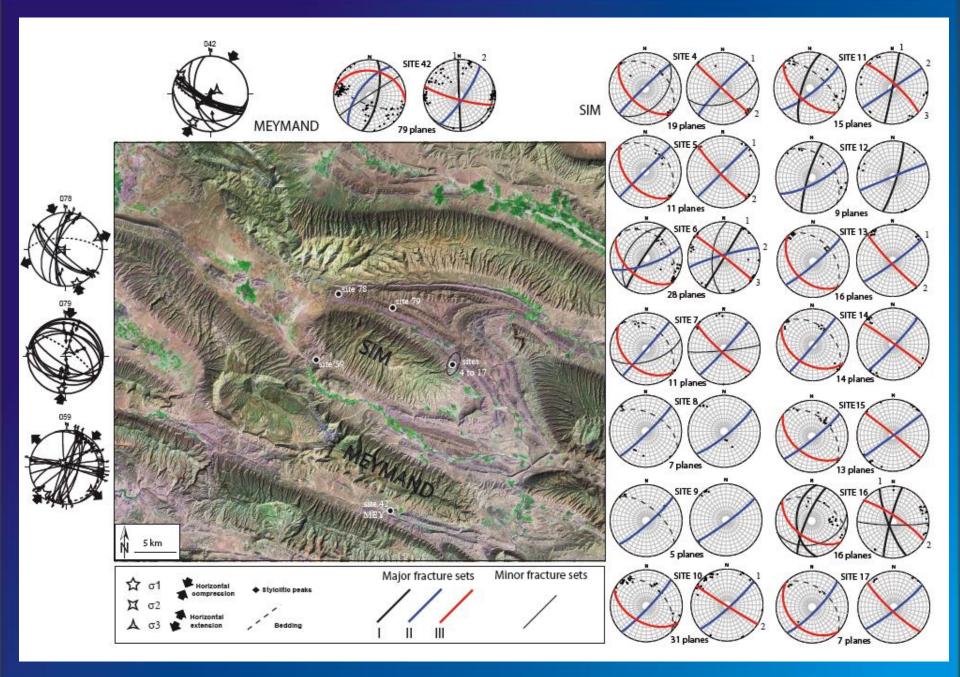
Since then, numerous studies have attempted to relate the development of meso-structures to either the structural domains of the fold or to quantitatively estimated curvature of strata

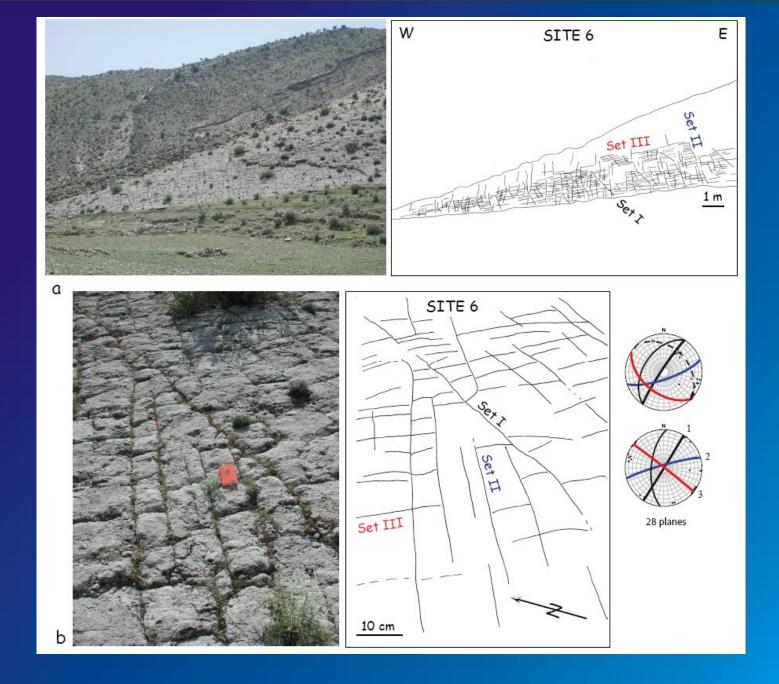


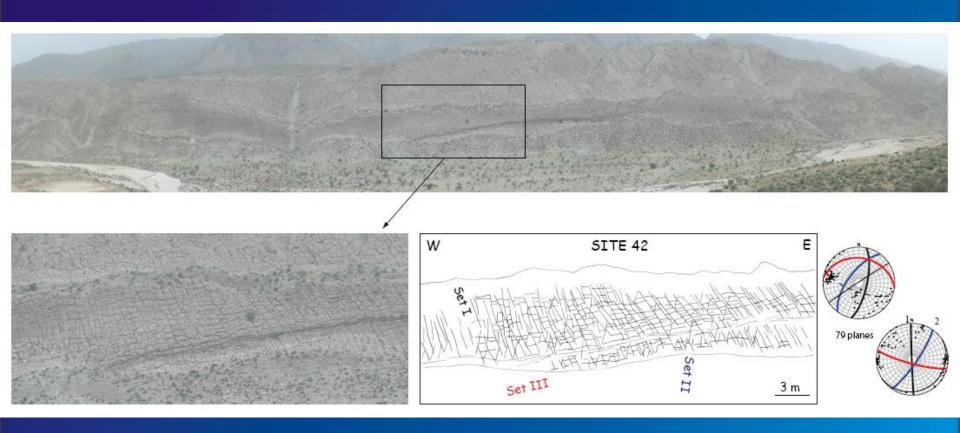


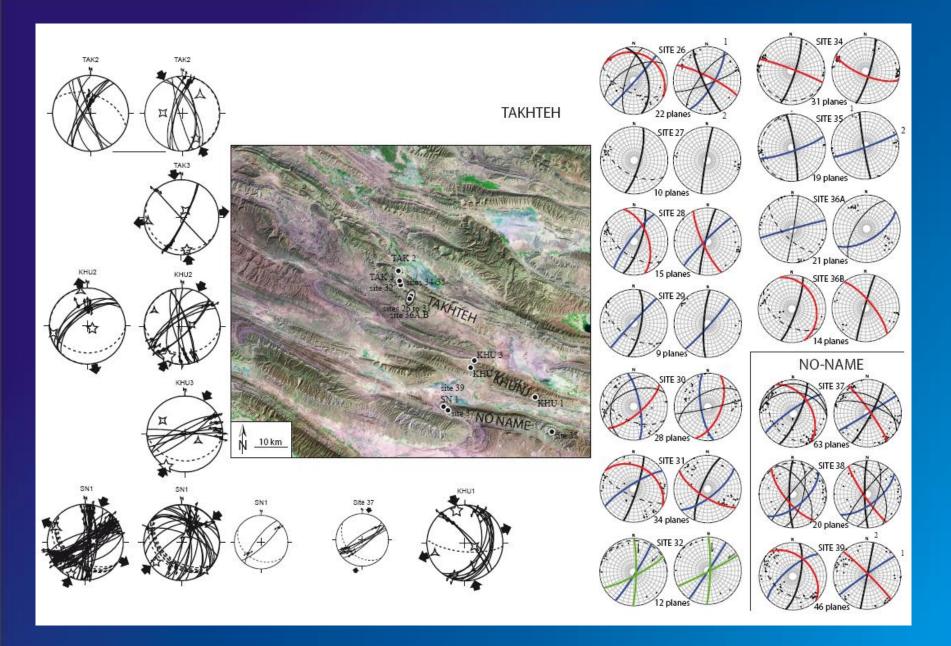








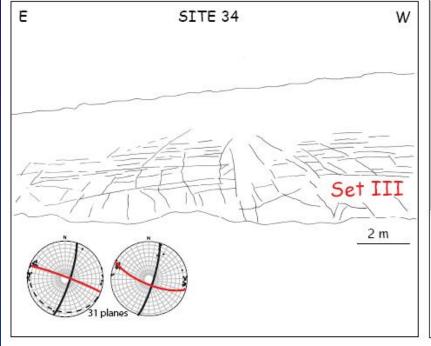


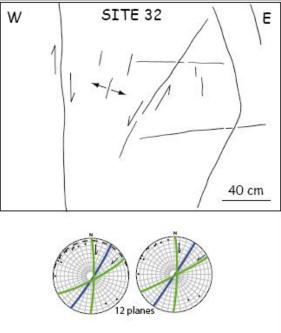






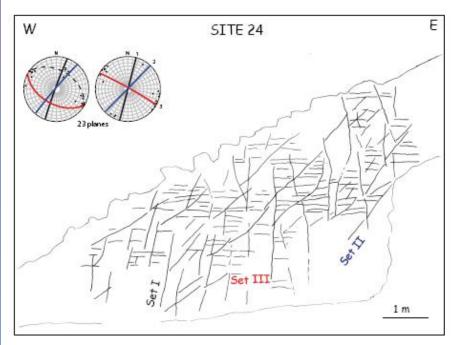






(Lacombe et al., 2011)





(Lacombe et al., 2011)

3 major sets in all the domains considered:

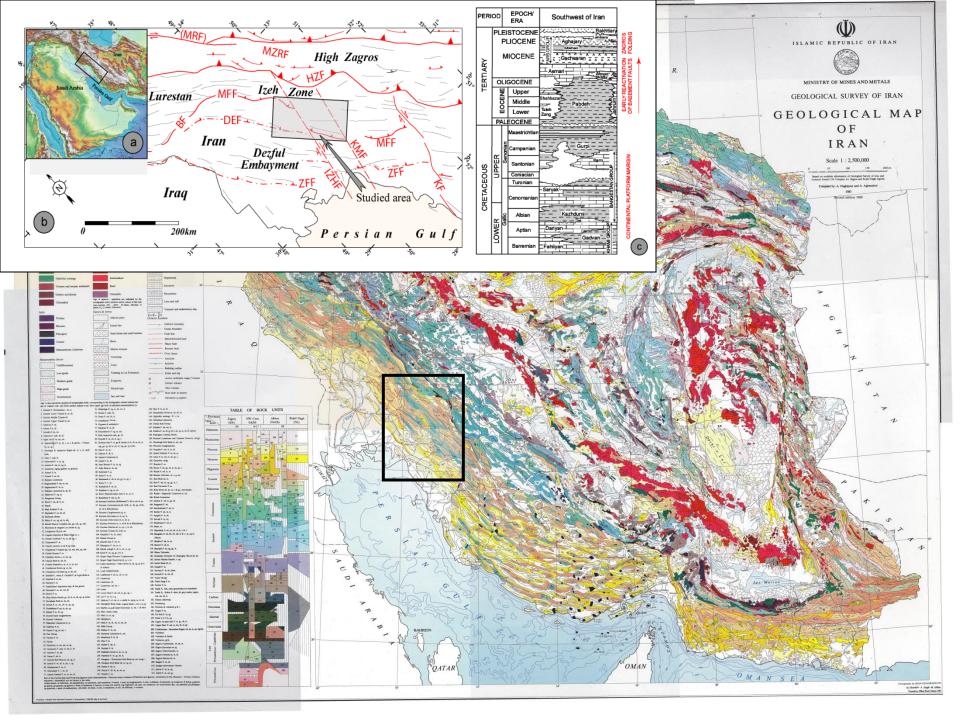
Set I is generally bed-perpendicular, and trends N-S to N020-030 after unfolding. Set II is also bed-perpendicular, and strikes NE to ENE (N040 to N070) after unfolding. Set III is bed-perpendicular and trends almost always parallel to the local fold axis (E-W to NNW-SSE, mainly WNW-ESE).

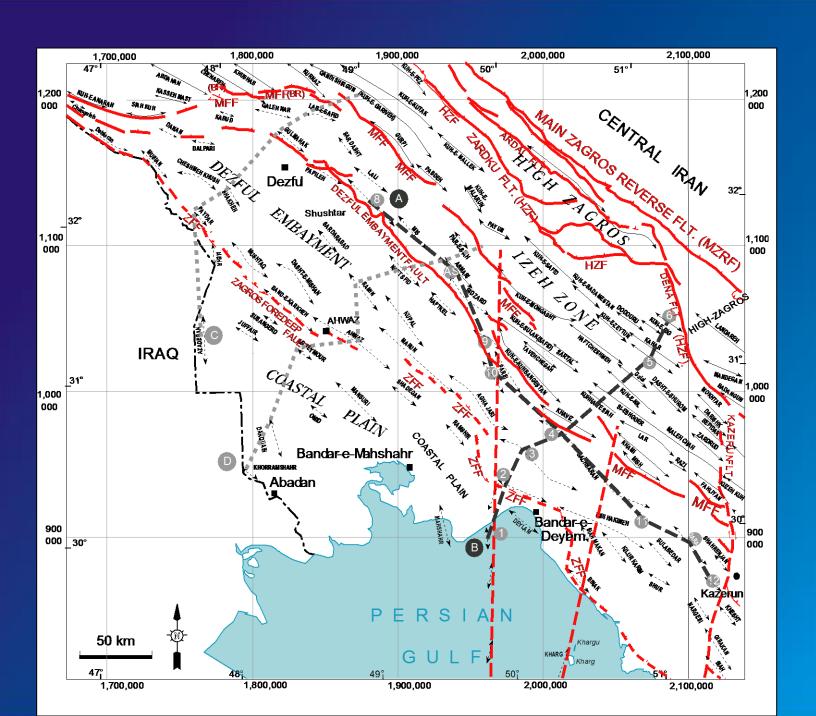
Set III fractures trending parallel to the fold axis and observed in most sites are interpreted as extensional axial fractures generated in response to the fold outer arc extension, hence typically fold-related.

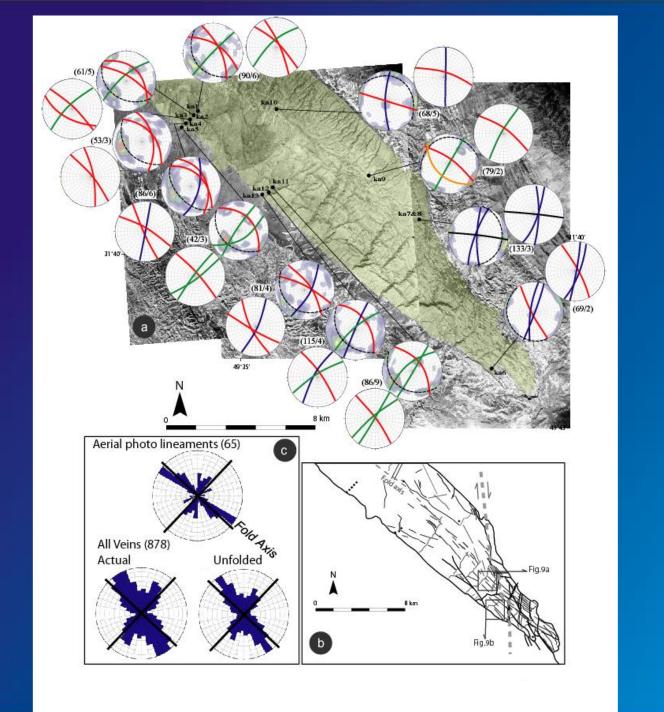
Fracture sets, either bed-perpendicular (in most cases) or not strictly perpendicular, against which fractures of set III abut, were considered pre-tilting (or possibly syn-tilting if perpendicular to the fold axis, i.e. cross-axial).

Among pre-tilting fractures, the distinction between pre-folding and early-folding fractures is based on the kinematic consistency with folding. While an early folding set formed during LPS in a consistent stress field (i.e. a fold-related extensional cross-axial set or oblique shear fracture set), a pre-folding set also predates bed tilting but may have originated in a differentstress field (unrelated to folding).

Post-folding fractures are theoretically observed in a sub-vertical attitude and they cut across the tilted strata irrespective of the geometry of the fold if they originated from a later, different stress field. In our study, post-folding fracture sets have in their present attitude a trend similar to that of the early-folding fractures of set I after unfolding. They possibly reflect a late (post-tilting) stage of fracture development during late fold tightening.



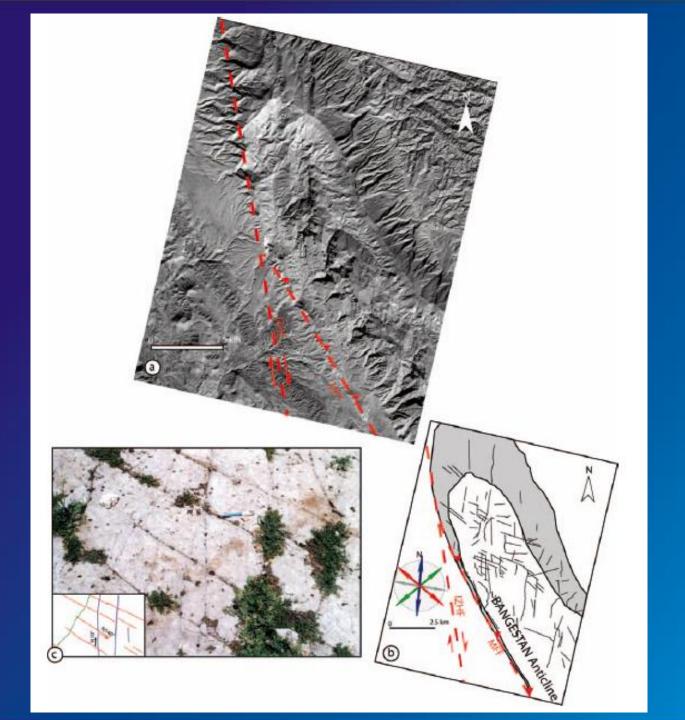




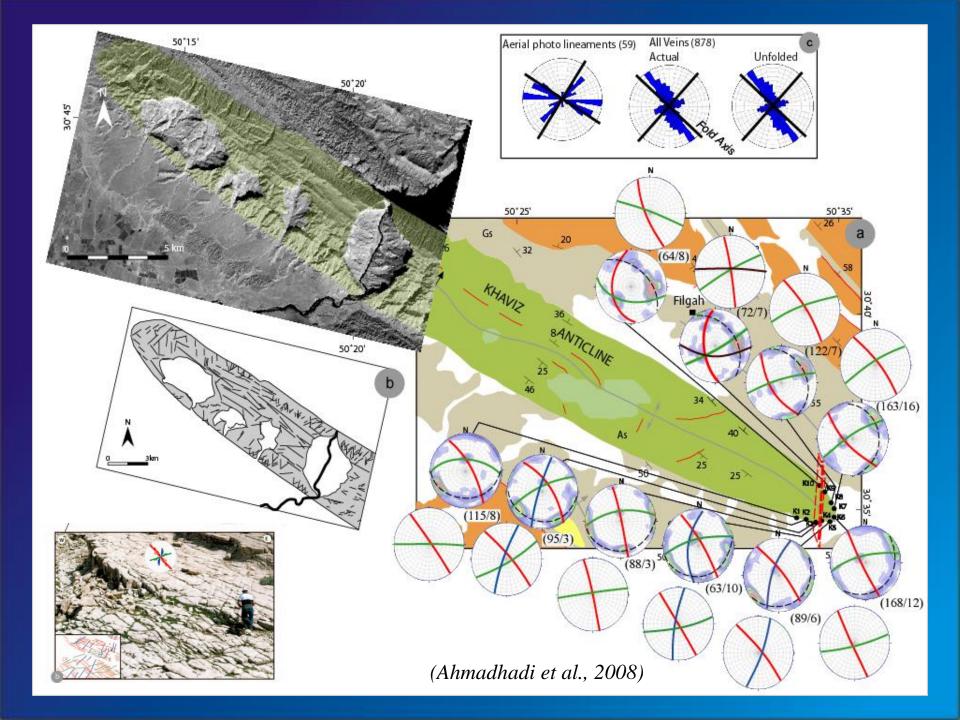
(Ahmadhadi et al., 2008)

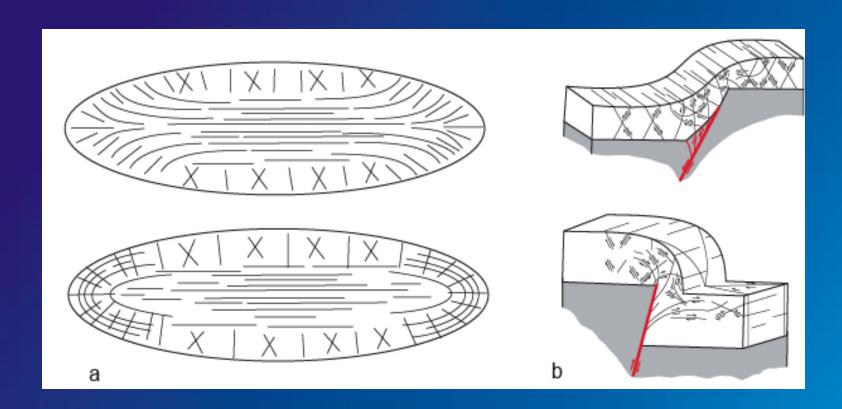


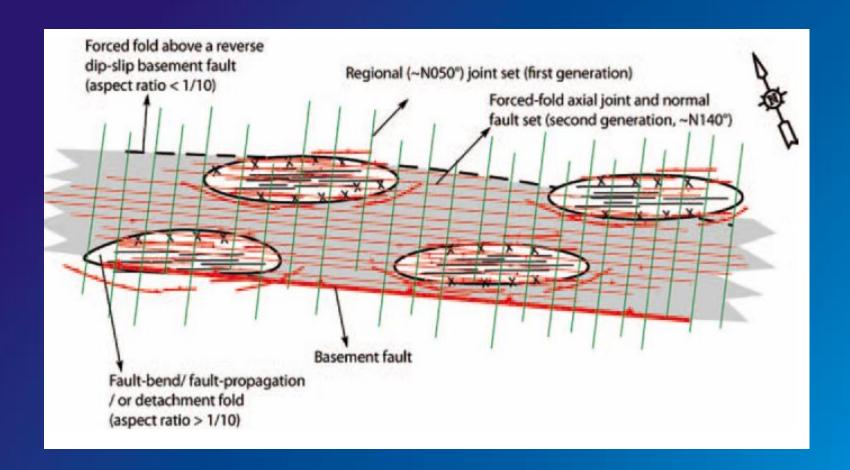
(Ahmadhadi et al., 2007)

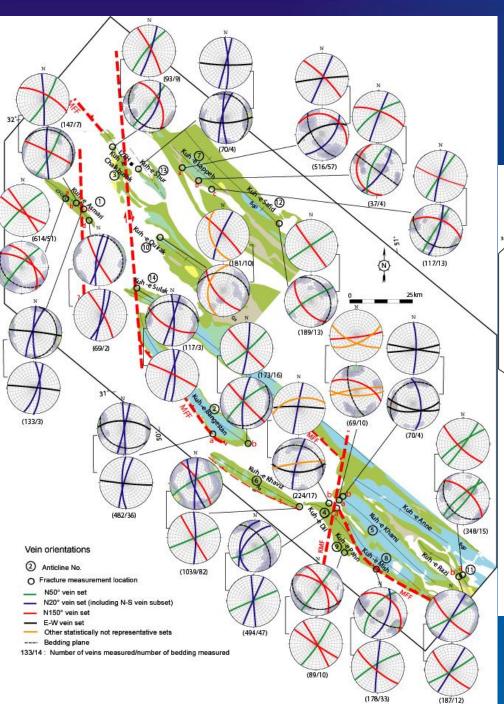


(Ahmadhadi et al., 2007)

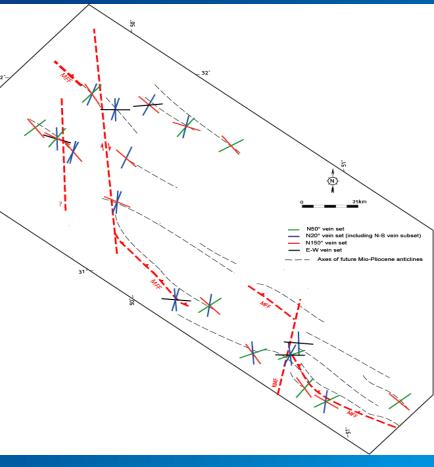








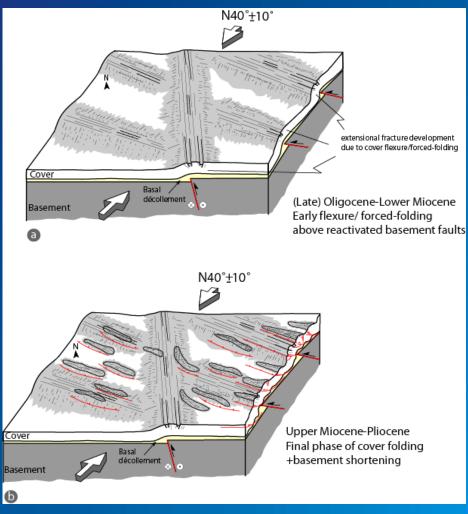
Specific occurrence of some prefolding vein sets in the vicinity of basement faults



(Ahmadhadi et al., 2008)

N40*±10° Early stress build-up in the Zagros cover sets N50° set Prefolding vein (Late) Oligocene-Lower Miocene early flexure/forced-folding N40°+10° above reactivated basement faults N20"subset N150"set, N-S subset Vein and normal fault developme due to large-scale flexure/ N20°, N150° and E-W sets N40°±10° Mio-Pliocene generalized cover folding and thrusting + reactivation of preexisting vein sets Fold-related fracture sets Layer parallel shortening shear fractures Syn-folding joint and normal faults due to outer-rim extension Syn-folding sinistral shearing along pre-folding N50° veins Re-opening of pre-folding N150° veins, with possible dextral shear component Syn-folding dextral shearing of pre-folding E-W veins due to outer-rim extension Syn- / post-folding low angle reverse faults Re-opening and/or dextral shearing of pre-folding N-S veins Cover

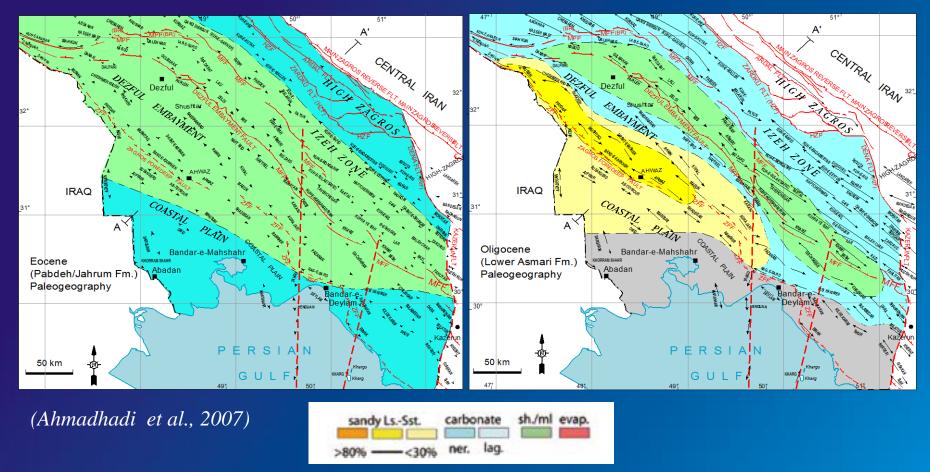
Onset of stress build-up



(Ahmadhadi et al., 2007; Ahmadhadi et al., 2008) Basement structures and early basement block movements may therefore have an impact on fracture development in the overlying cover rocks.

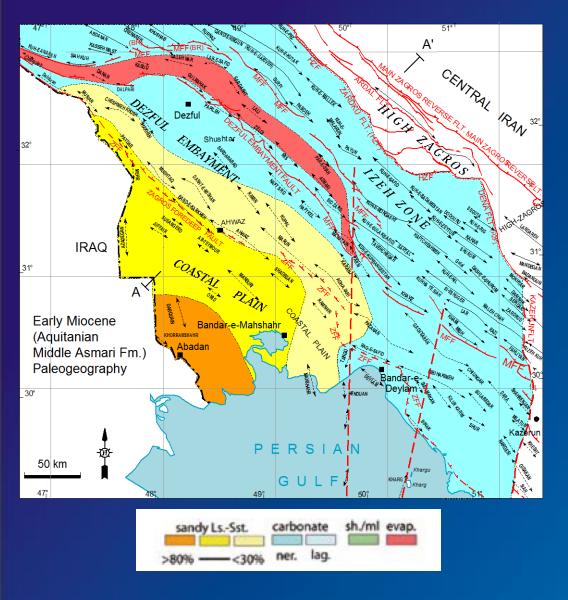
The occurrence of some local compressional trends and related fracture sets was partly controlled by underlying deep-seated basement faults in the Zagros region. The transmission of orogenic stress through the faulted crystalline basement of the Zagros was probably heterogeneous and complex; deformation propagated in an irregular fashion through the basement and the cover leading to local stress perturbations, hence to a complex directional distribution and chronology of fractures in the cover.

Such a complexity should be taken into account in further studies of folded and fractured reservoirs.



During Eocene times, the Pabdeh basin covered a wide area from the south of the High Zagros fault toward the Zagros Foredeep Fault.

During the Lower Oligocene, progressive basin restriction and sedimentary flux progradation toward the depocenter of the previous Pabdeh basin - between the MFF to the north and the ZFF to the south - following the progradation of the carbonate platform and clastic facies of the Lower Asmari Formation suggest that the NW-SE trending basement faults were presumably reactivated



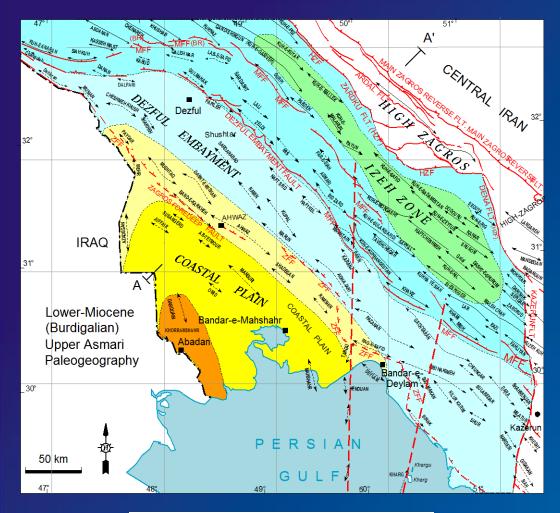
The development of a long narrow evaporitic intra-basin (Kalhur Member) during the latest Oligocene-early Lower Miocene likely indicate an abrupt facies change (both laterally and vertically)

→ difficult to interpret simply by eustasy or any sedimentological process alone, without any tectonic control.

Rather:

the localization of this intra-basin between the MFF to the north and the DEF to the south and the abrupt facies change from marls to evaporites suggests a direct relation between this restricted lagoon intrabasin and deep-seated basement faults.

(Ahmadhadi et al., 2007)

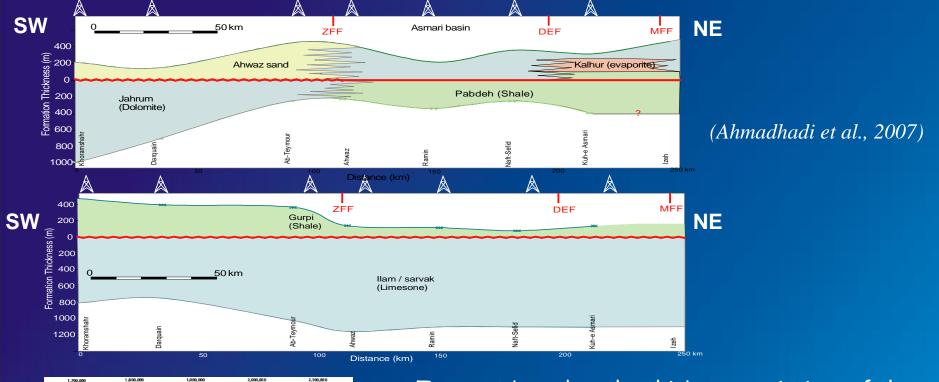


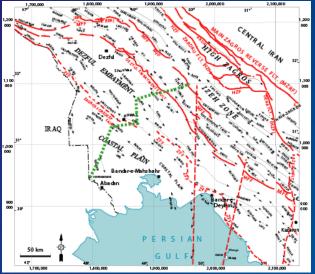
The Ahwaz/Ghar Member delta front, indicated by more than 30% of the sand content of the Asmari carbonate, formed just and parallel to the south of the ZFF.

During Burdigalian times, the
Upper Asmari carbonates covered
the entire basin with a
hemipelagic facies toward the
northern part of the Mountain
Front Fault



(Ahmadhadi et al., 2007)



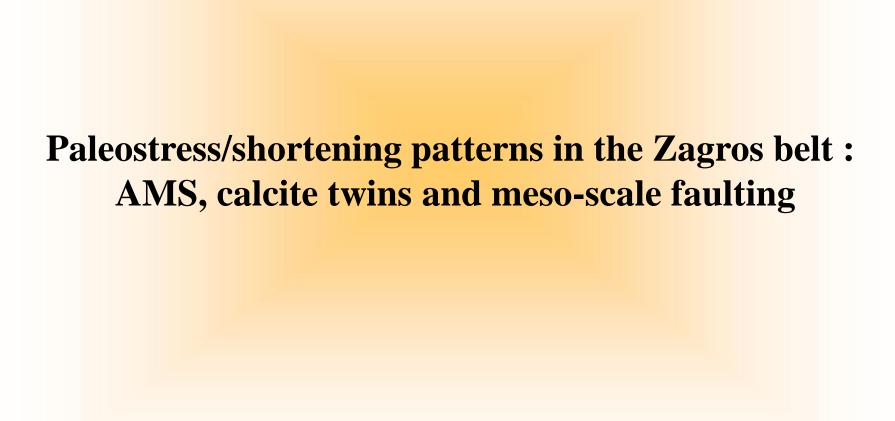


Transect based on the thickness variations of the main lithostratigraphical units (formations) with definite time lines (top and bottom):

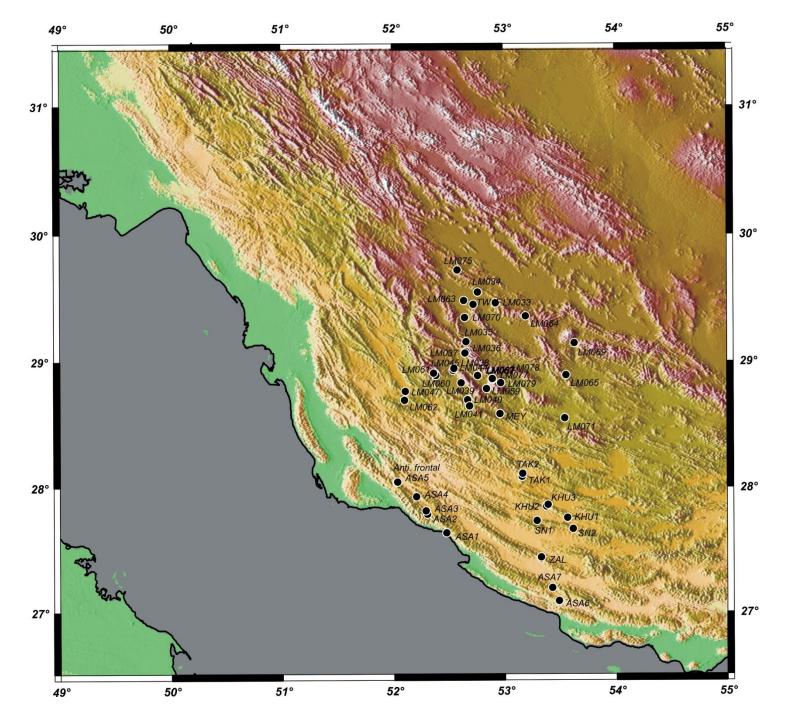
Both thickness and main facies variations within Pabdeh/Jahrum and Asmari formations coincide with the location of the main basement faults; this strongly suggests that these faults were reactivated during Pabdeh/Jahrum and Asmari deposition.

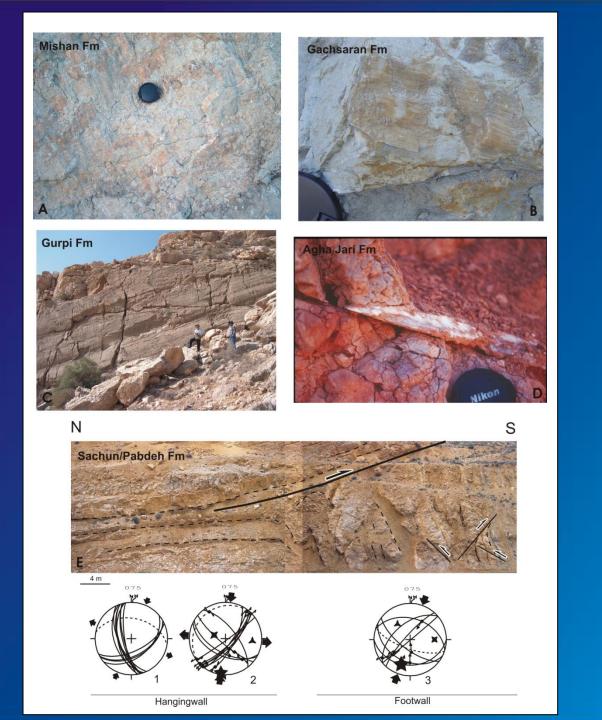
 Facies distribution and sub-basins development in the Central Zagros during Eo (?)-Oligocenelower Miocene were likely controlled by the compressional reactivation of deep-seated basement faults

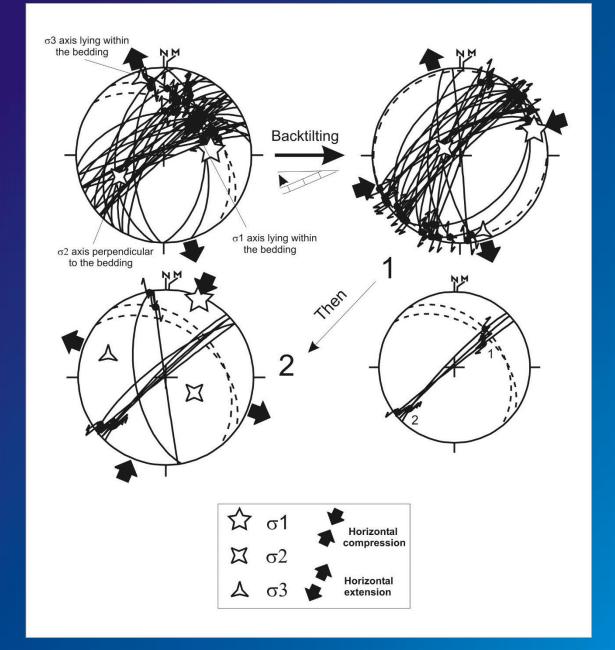
• Deformation in the region presumably started as soon as Eocene – Oligocene, with amplification of forced folding during Chattian/Aquitanian (~30 – 22 Ma) and initiation of early vein sets within Asmari Fm

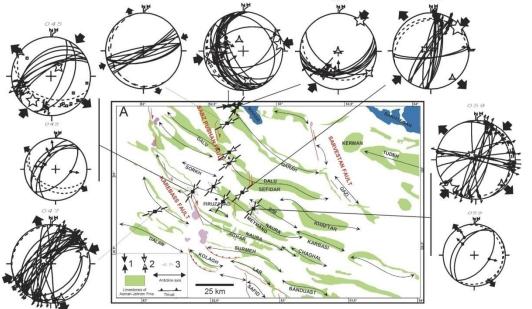


MINAB anticline MAND anticline AMS GC BSC BSC 9K 5 Km

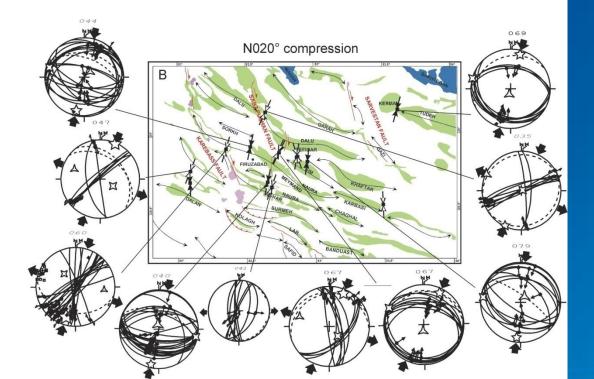




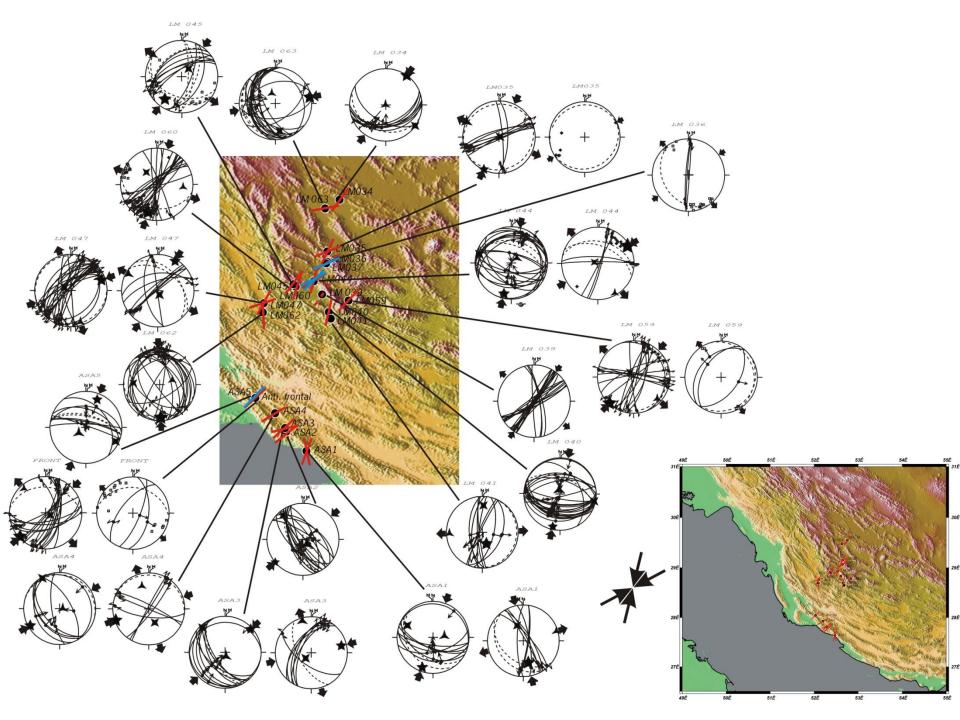


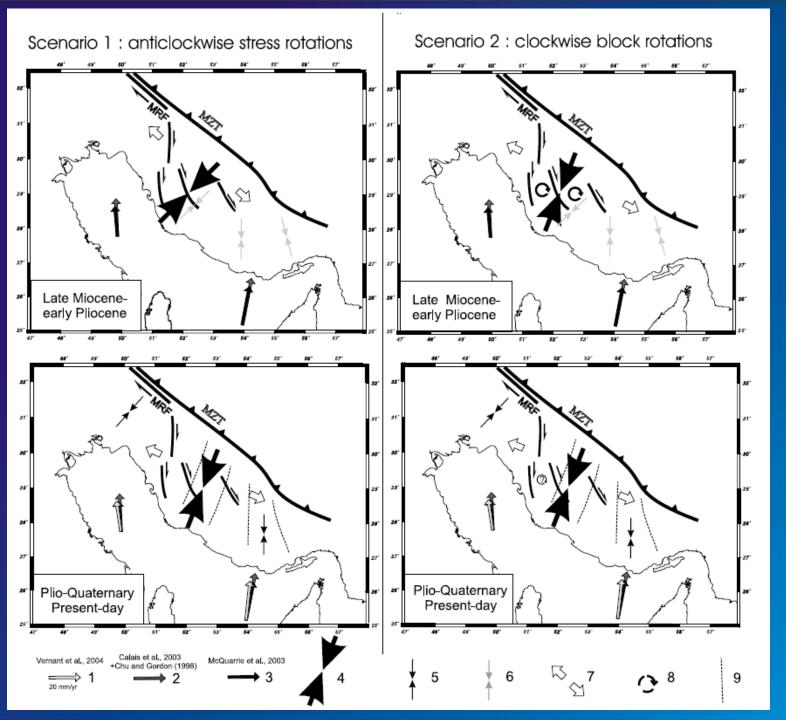


NE-SW compression

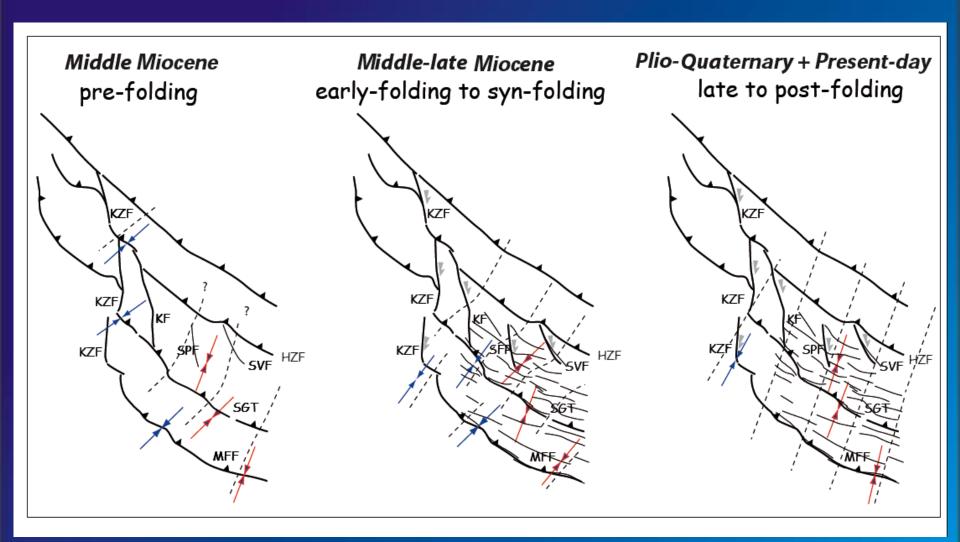


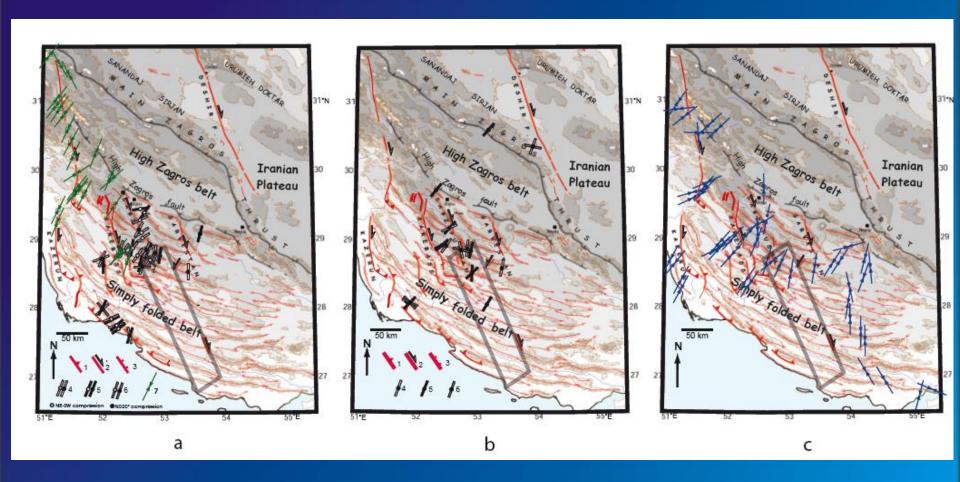
(Lacombe et al.,2006)

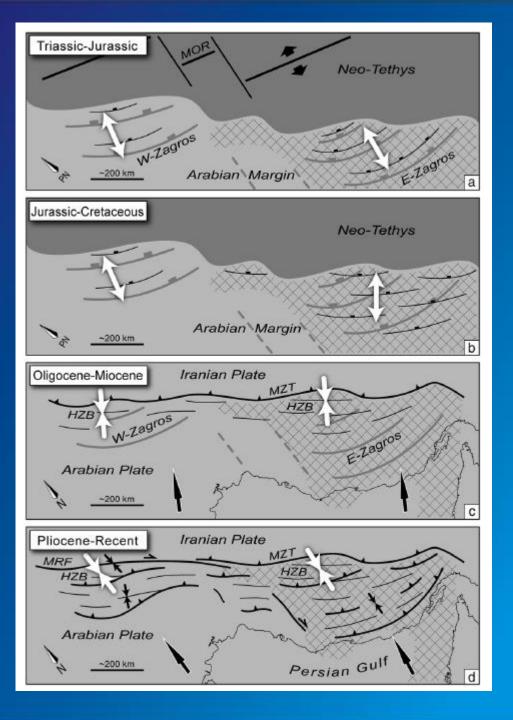


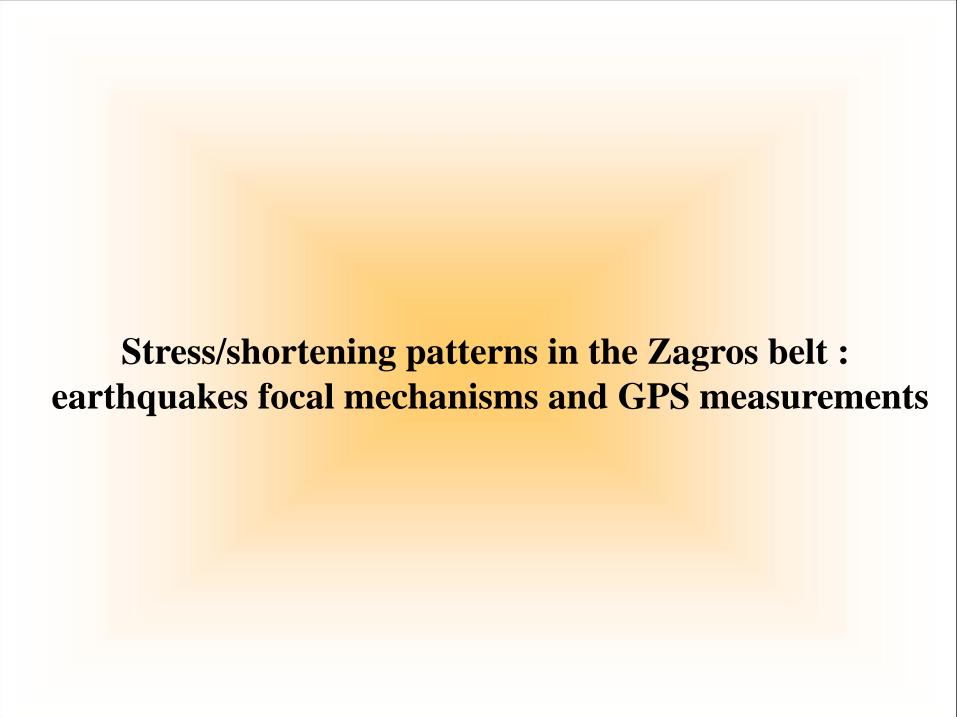


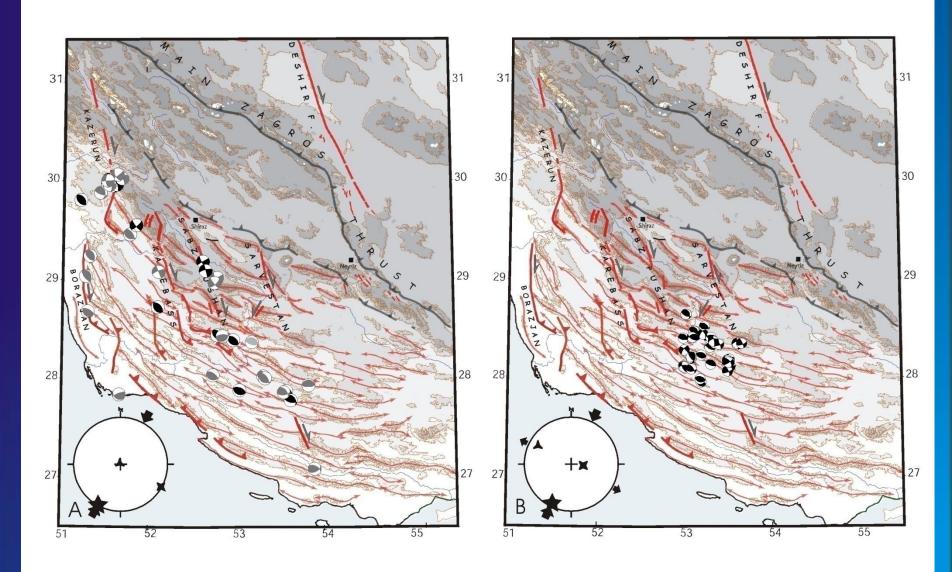
(Lacombe et al., 2006)

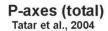


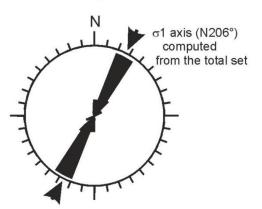




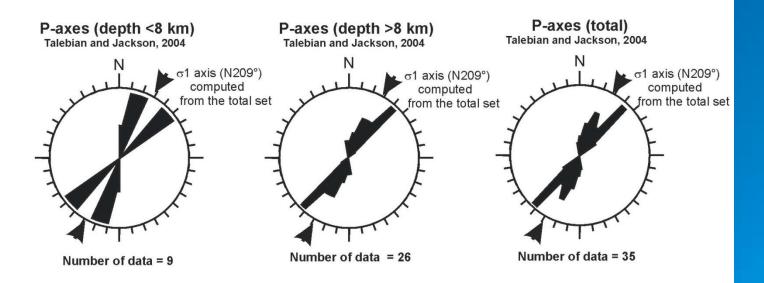


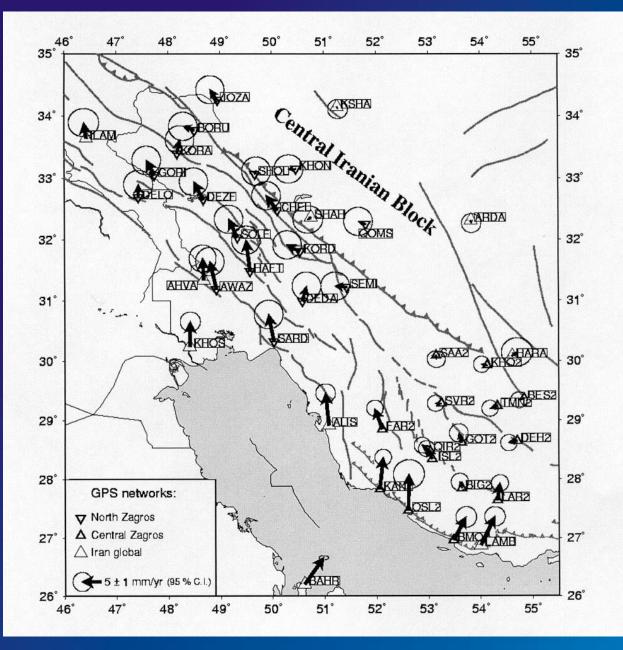




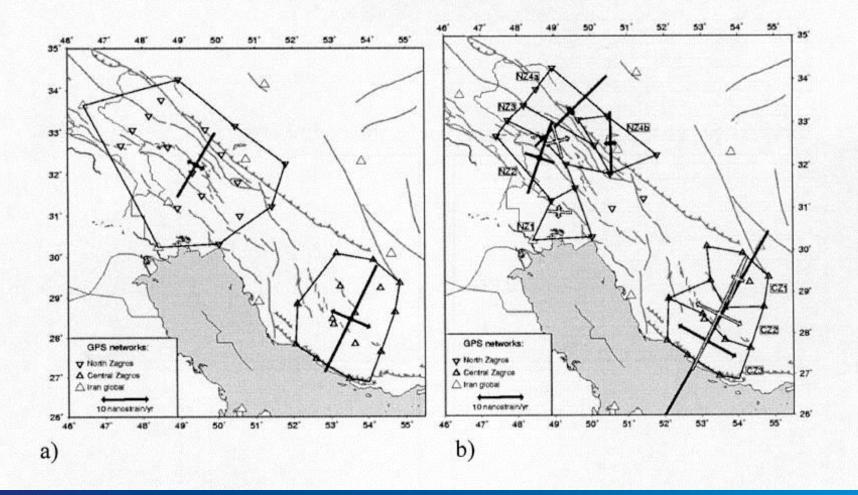


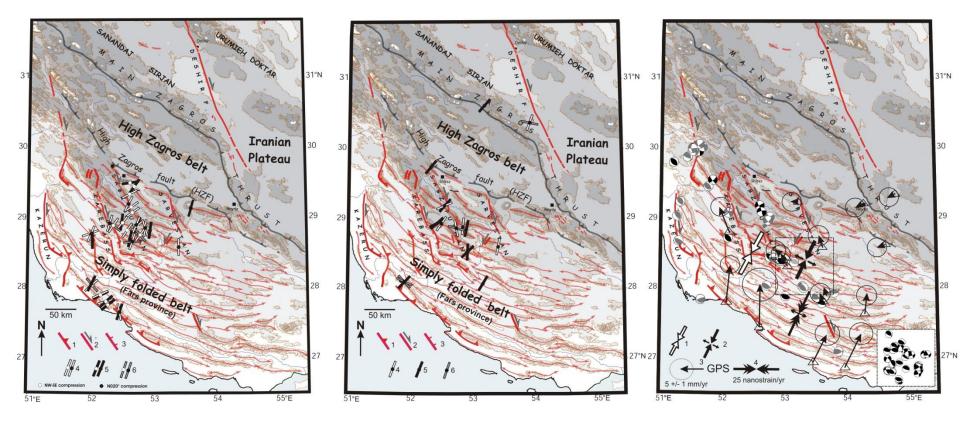
Number of data = 50





(Walpersdorf et al., 2006)





Neogene compressional trends from fault slip data in the cover (Lacombe et al., 2006)

Neogene compressional trends from calcite twin data in the cover (Lacombe et al., 2007)

Current compressional trends from earthquake focal mechanisms in the basement (Lacombe et al., 2006) and GPS shortening rates (Walpersdorf et al., 2006)

→ Neogene collisional stresses consistently recorded at all scales
 → The salt-bearing Hormuz master decollement poorly
 decouples basement and cover stress fields

- The early stage of reactivation of basement faults likely marks the onset of collisional deformation and intraplate stress build-up in the Zagros basin. Basement-involved deformation started 25-15 Ma and predated the initiation of cover folding.
- This indicates far-field stress transmission from the Arabia-Central Iran plate boundary since late Oligocene-early Miocene, and therefore efficient mechanical coupling between the Arabian and Eurasian plates since that time.

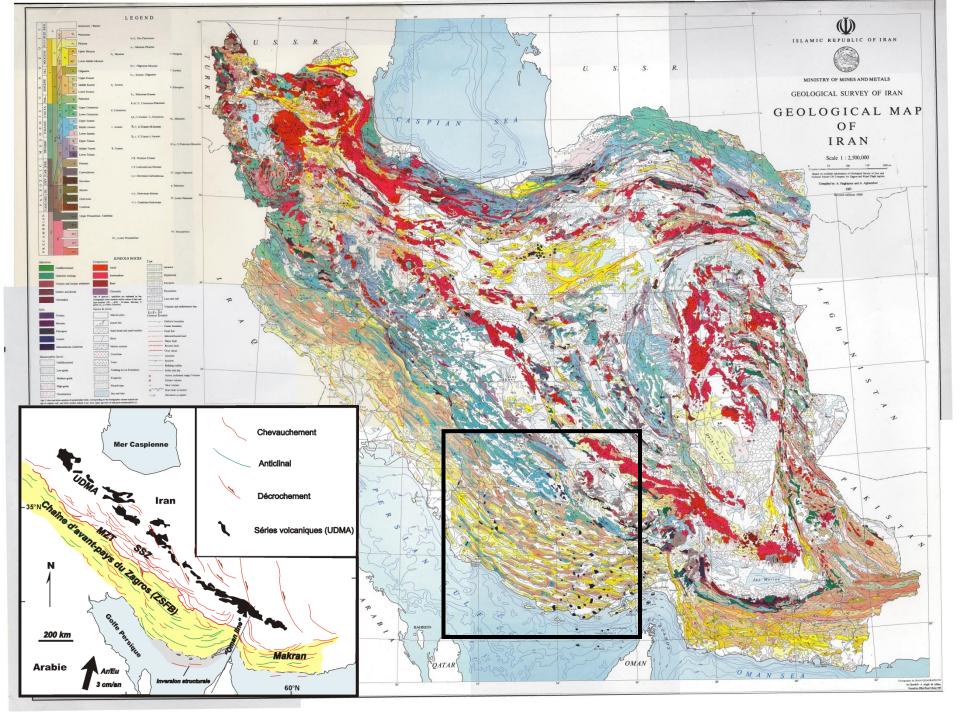
- The transmission of stress through the pre-fractured Arabian crystalline basement was however heterogeneous and complex, so the deformation front propagated in an irregular fashion through the basement and the cover.
- The sequence of deformation includes early inversion of basement faults, then more or less nearly coeval thin-skinned and thick-skinned tectonics.
- Beyond regional implications, this study also puts emphasis on the need of carefully considering pre-folding fracture development related to early reactivation of basement faults in models of folded-fractured hydrocarbon reservoirs.

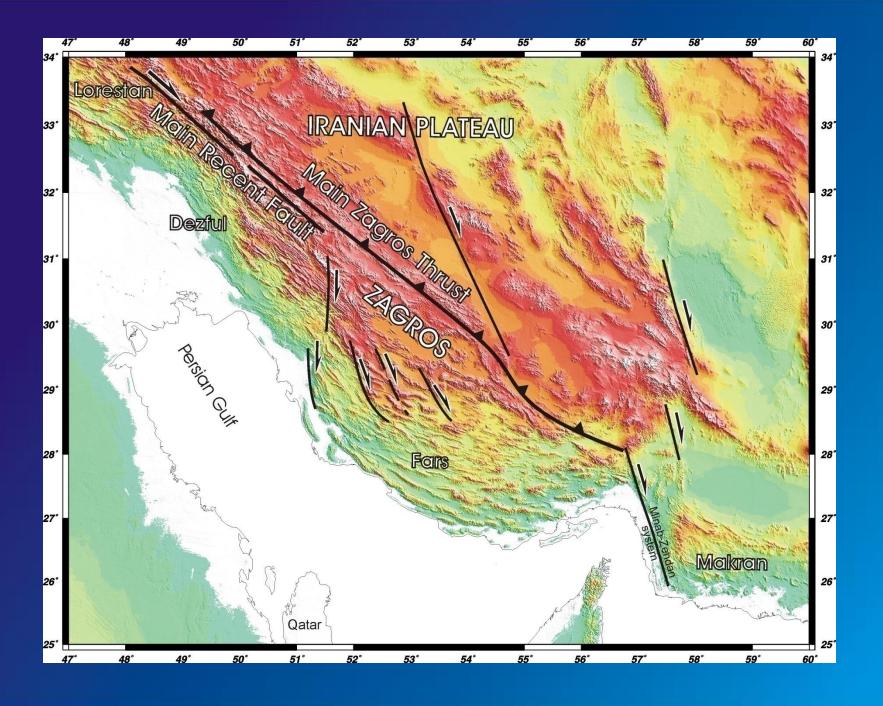
In contrast to other seismic regions of Iran (Alborz, Kopet Dagh), the seismicity in the Zagros is abundant but of low magnitude (only small to moderate earthquakes).

The comparison of seismic and geodetic strain rates indicates mainly aseismic deformation in the Zagros (Masson et al., 2005).

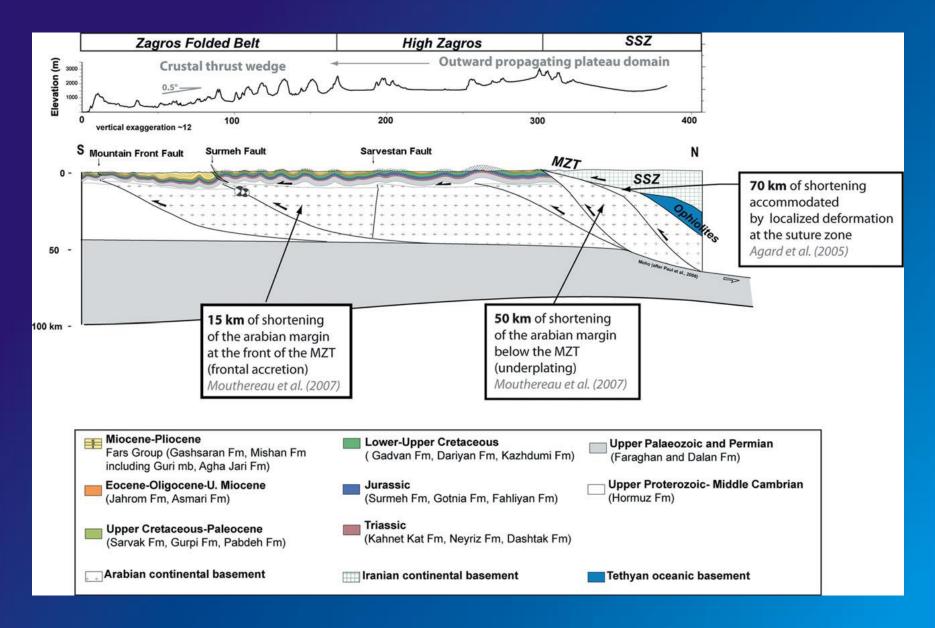
Cover is mainly decoupled from the basement (Hormuz salt); stress transfer from the basement to the cover may however occur during increasing strain rate (i.e., few large earthquakes).

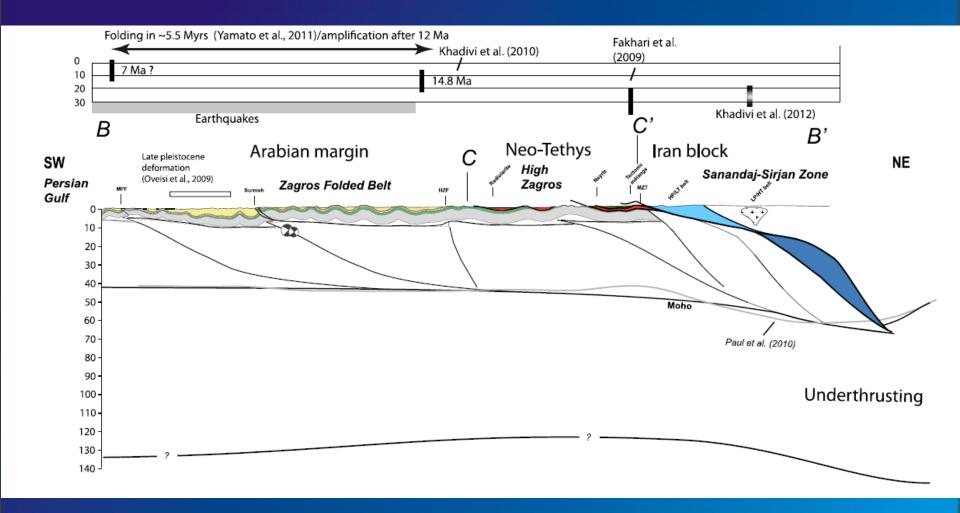
Crustal rheology, mechanics of folding and the building of topography in the Zagros

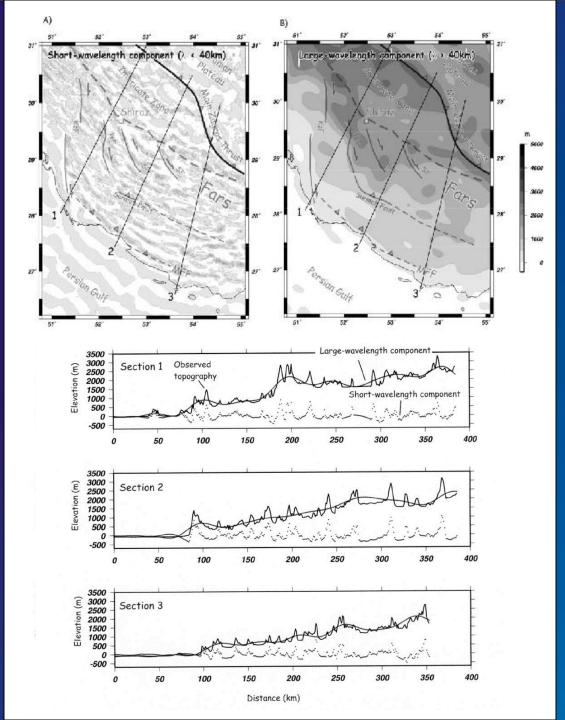




Fars

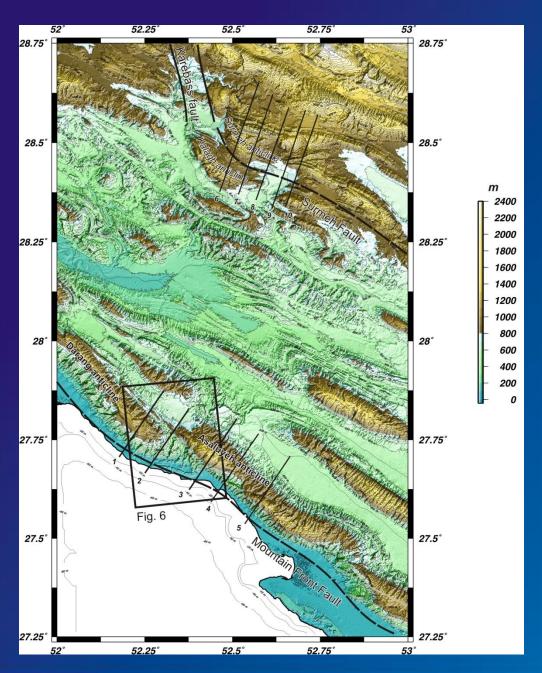




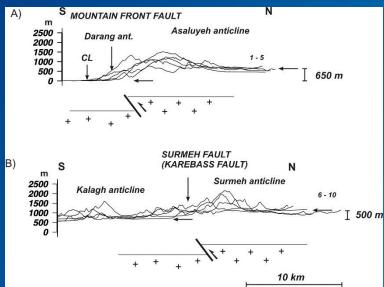


Analysis of topography

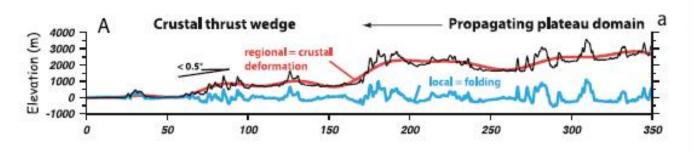
(Mouthereau et al., 2006)

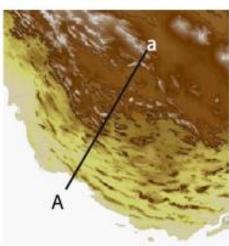


(Mouthereau et al.,2006)

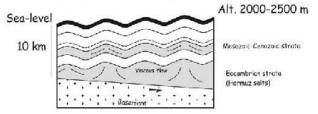


Wavelength components of the topography (Fars region, central Zagros)

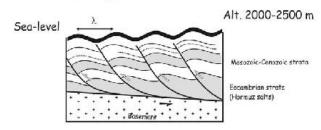


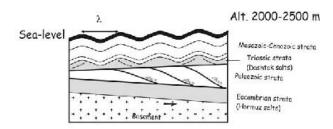


A) Wedge taper controlled by ductile thickening of salt

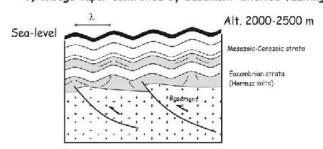


B) Wedge taper controlled by frictional behavior of sedimentary rocks

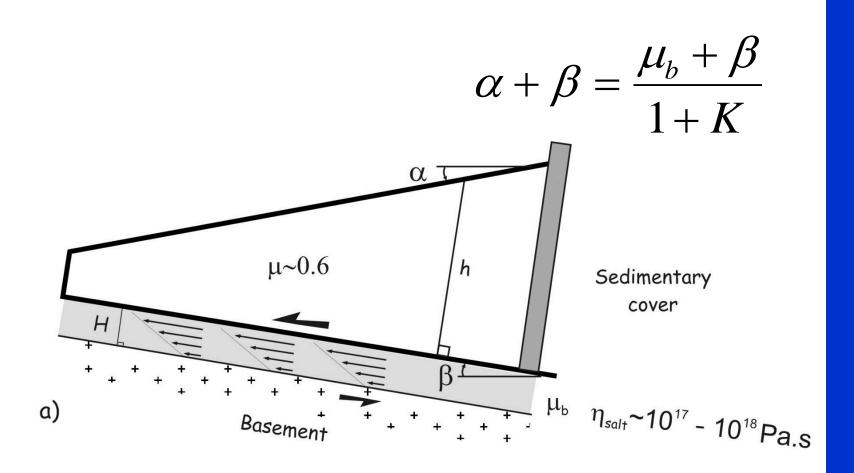




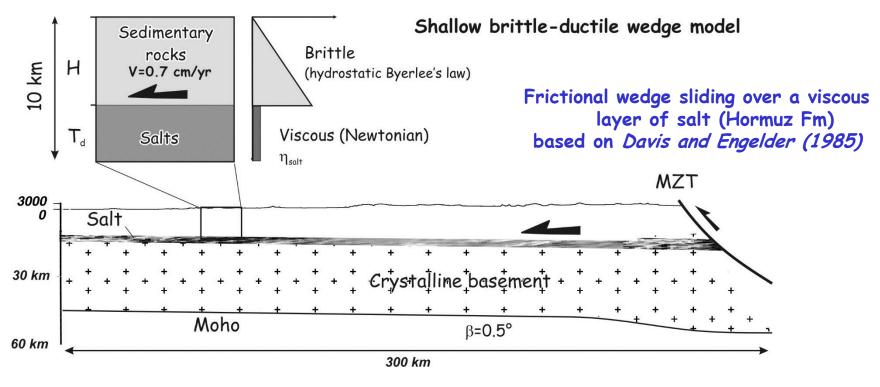
C) Wedge taper controlled by basement-involved faulting



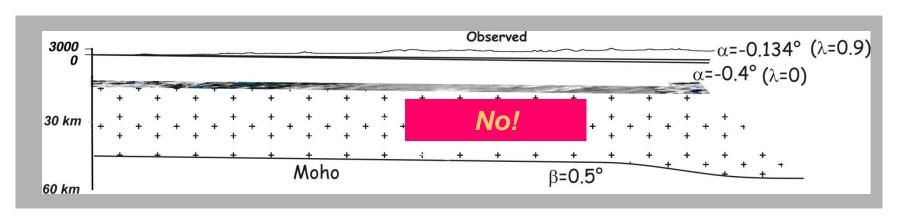
Wedge modelling



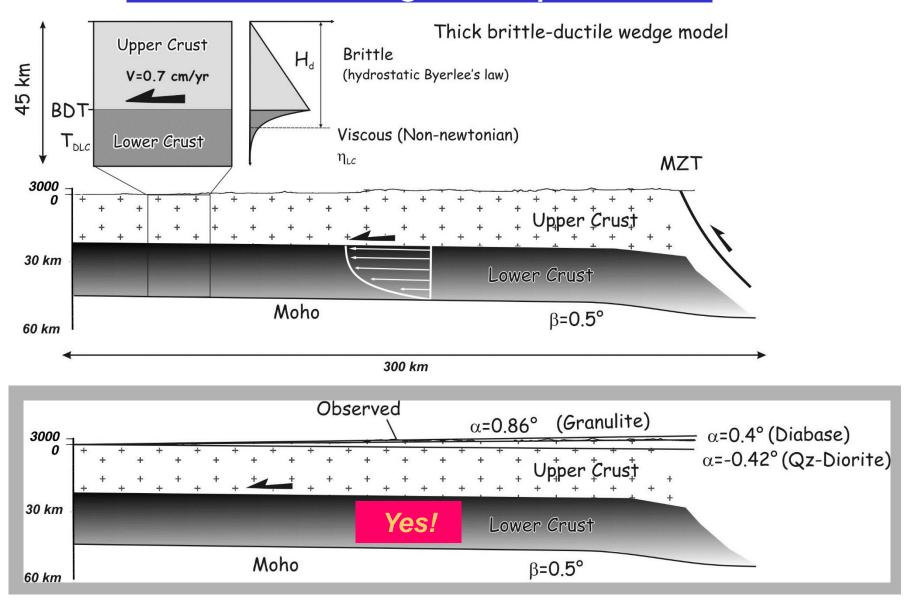
Salt/cover wedge assumption



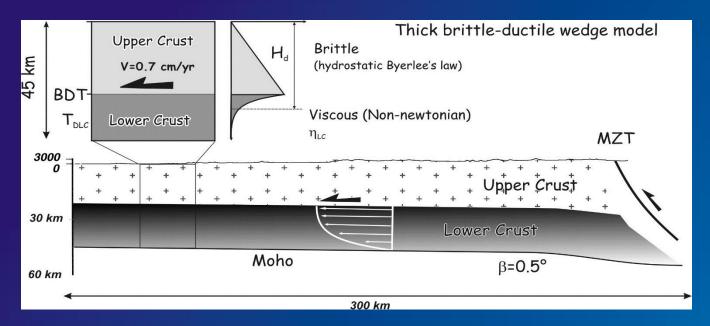
Viscosities 10^{17} to 10^{18} Pa.s (higher bounds) Internal friction angles $30\text{-}40^\circ$ Salt thickness 0.5-1-2 km Variable pore fluid ratio



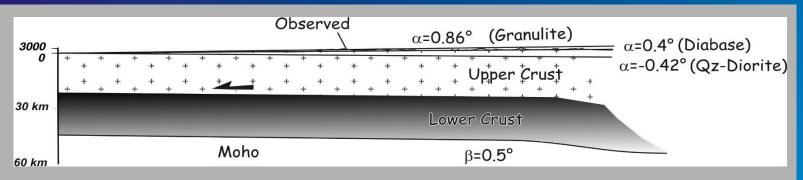
Crustal wedge assumption



Such a model involving a granulitic lower crust with sufficient viscosity is able to reproduce the observed topography

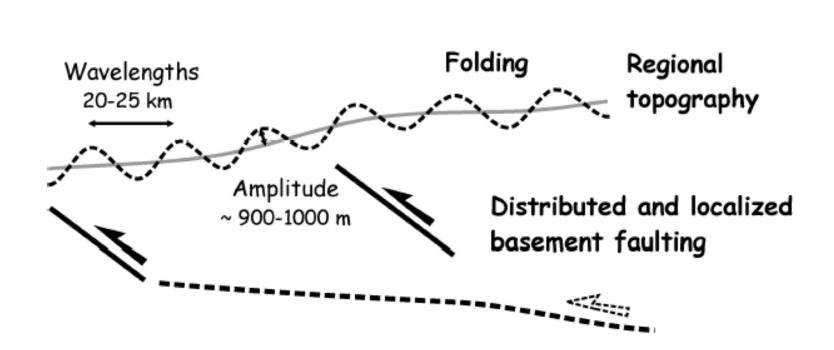


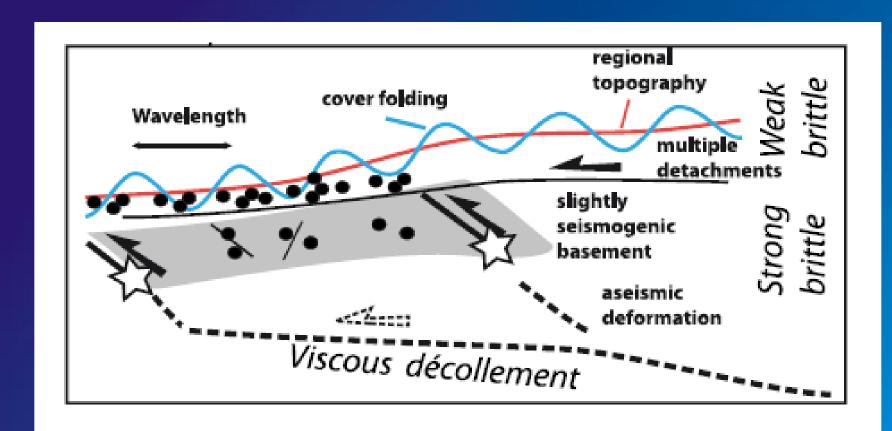
(Mouthereau et al., 2006)



Analytical modelling of the Zagros wedge

→ salt is unable to sustain topography; only a model of critically-tapered brittle-viscous wedge involving the crystalline basement reproduces the observed topographic slopes across the Fars



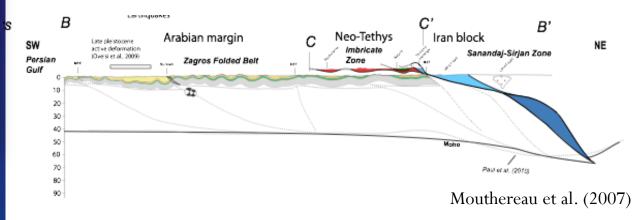


Zagros = superimposed thin-skinned and thickskinned tectonics



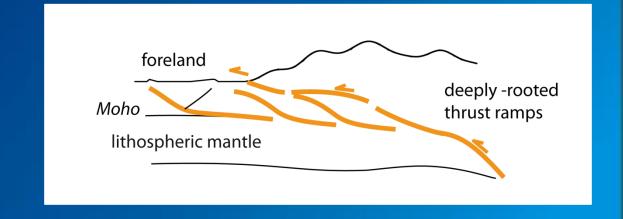
Convergence 7km/Ma Erosion rate <2 km/Ma

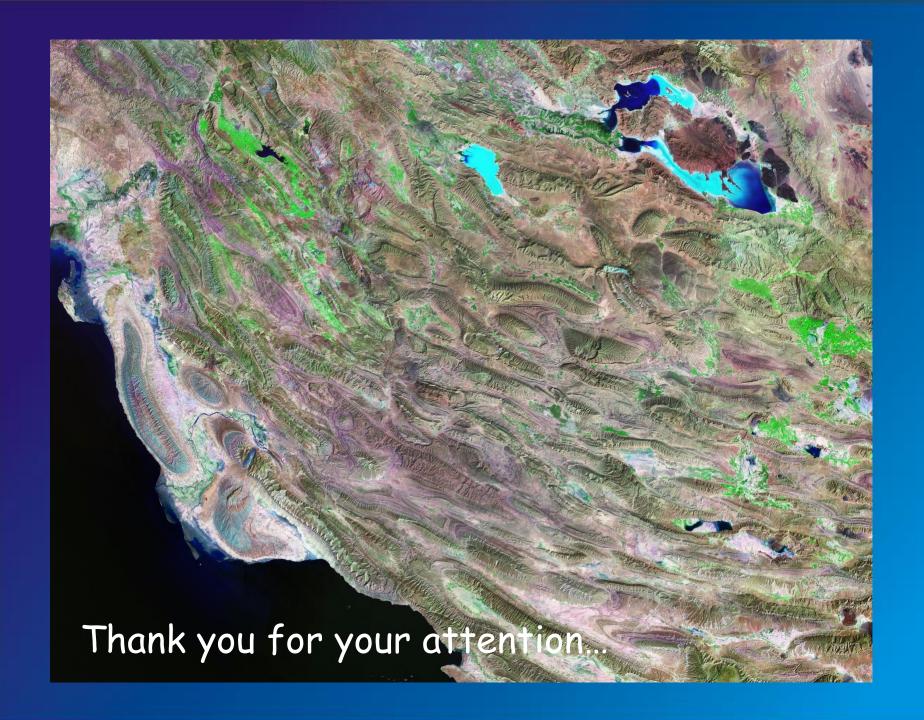
Zagros: inverted Mesozoic rifted margin Shortening: ~37 %



style thick-skinned "pure-shear"

Decoupling within middle-lower crust h ~ 15-20 km





Suggested readings:

Ahmadhadi F., Daniel J.M., Azzizadeh M. & Lacombe O., 2008, Evidence for pre-folding vein development in the Oligo-Miocene Asmari Formation in the Central Zagros Fold Belt, Iran. <u>Tectonics</u>, 27, TC1016

Lacombe O., Mouthereau F., Kargar S. & Meyer B., 2006, Late Cenozoic and modern stress fields in the western Fars (Iran): implications for the tectonic and kinematic evolution of Central Zagros. <u>Tectonics</u>, 25, TC1003

Lacombe O., Bellahsen N. & Mouthereau F., 2011, Fracture patterns in the Zagros Simply Folded Belt (Fars): New constraints on early collisional tectonic history and role of basement faults. In "Geodynamic evolution of the Zagros", O. Lacombe, B. Grasemann and G. Simpson eds, <u>Geological Magazine</u>, 148, 940-963

Mouthereau F., Lacombe O. & Meyer B., 2006, The Zagros Folded Belt (Fars, Iran): constraints from topography and critical wedge modelling, **Geophys. J. Int**., 165(1), 336-356

Mouthereau F., Tensi J., Bellahsen N., Lacombe O., Deboisgrollier T. & Kargar S., 2007, Tertiary sequence of deformation in a thin-skinned/thick-skinned collision belt: the Zagros Folded Belt (Fars, Iran). <u>Tectonics</u>, 26, TC5006

Mouthereau F., Lacombe O. & Verges J., 2012. Building the Zagros collisional orogen: timing, strain distribution and the dynamics of Arabia/Eurasia plate convergence. <u>Tectonophysics</u>, 532-535, 27-60

Talebian, M.& Jackson J.A., 2004. A reappraisal of earthquake focal mechanisms and active shortening in the Zagros mountains of Iran, <u>Geophys. J. Int.</u>, 156, 506 – 526.