Reminder of some of the later stage exhumation of rocks—these are found in ranges termed core complexes.
Buck, Tectonics, 1988

(a) Harcuvar Mountains

WSW

Miocene Sedimentary
& Volcanic Rocks

pC Gneiss
& Granite

Mylonitic
Foliation

"Detachment"

(b) Whipple Mountains

SW

Older Tertiary Sedimentary
& Volcanic Rocks

Younger Tertiary Sedimentary
& Volcanic Rocks

Metamorphic
Foliation

Breccia

Mylonitic
Foliation

"Detachment"

Fig. 1. Interpretative cross sections of two metamorphic core complexes showing features common to many core complexes: (a) the Harcuvar Mountains in Arizona (after Rehrig and Reynolds, 1980) and (b) the Whipple Mountains in California with inferred doming removed (after Davis, 1980).

Upper plate rocks, those above the detachment, have typically undergone only brittle deformation while lower plate rocks have experienced considerable ductile deformation [e.g., Miller et al. 1983; Dokka et al., 1986]. The lower plate rocks frequently show mylonitization, indicating that they were deformed in a temperature range where quartz flowed but where feldspars fractured. High-temperature rock mechanics experiments show that this could occur between about 400 and 500 °C [Caristan, 1982]. The lower plate mylonites often show overprinting of brittle deformation on the ductile fabric [e.g., Crittenden et al., 1980]. Geochronologic studies of lower plate rocks from several core complexes indicate rapid uplift of midcrustal rocks [Davis, 1988]. Dallmeyer et al. [1986] use 40Ar/39Ar dating of lower plate rocks from the Ruby Mountain metamorphic core complex in eastern Buck, Tectonics, 1988
Generic core complex

- Breakaway detachment
- Cataclasite
- Mylonite and ultramylonite
- Thinned, extended, and disrupted upper plate
- High strain rocks
- High-grade core with pre-MCC structures

Plast. J. Geol. Soc., 2015
These structures also vary in map view, making doubly-plunging antiforms. Look at one of these (Buckskin) in more detail.
Blue in upper right upper plate. Orange is lower plate T pluton, purple at bottom lower plate pC.
Rawhide Mtns from Swansea site
Red vs green, Buckskin CC
Looking into the fault
Mylonite, Buckskin Mtns
Catalina Mtns, So. AZ
Cataclasite?
Ultramylonite, Catalina core complex (Rincon Mtns)
So how are these things created? Simple cartoons of some ideas. Look at what the observations were that led to these.
First up, recognition of very variable amounts of extension but flat Moho.
You push things back assuming vertically uniform deformation and you get craziness.
Fig. 3. A highly generalized present-day cross section of the eastern Great Basin that illustrates the two-layer, open-system model for crustal stretching. See text for discussion.
Fig. 1. Total horizontal stresses measured in southern Africa [McGarr and Gay, 1978]. The vertical total stress gradient (26.5 MPa/km) is shown along with Byerlee's law (BY) for hydrostatic pore pressure (HYD) and zero pore pressure (DRY).

Fig. 3. Total horizontal stresses measured in Canada [McGarr and Gay, 1978]. Symbols as in Figure 1.
Fig. 4. Limiting values of total horizontal stress as a function of depth, based on Byerlee's law with hydrostatic pore pressure (BY-HYD) and the quartz (QTZ) and olivine (OL) flow laws adjusted to a strain rate of $10^{-15}$ s$^{-1}$. The temperature profile $T(^{\circ}K) = 350 + 15z$ (km).
\[ \sigma = 7 \times 10^3 (n_e - n_i) \exp \left( \frac{-0.52 \text{ MPa/m}}{RT} \right) \]

\[ \sigma = 5.7 \times 10^6 \exp \left( \frac{-0.54 \text{ MPa/m}}{RT} \right) \]

where \( \sigma \) is in MPa and \( n_e - n_i \) is in megapascals. The plastic deformation behavior of quartz appears to depend markedly on OH⁻ content. We consider here experimental results on dry samples which should provide an upper limit to the strength of quartz. Recent experiments of Christie et al. (1979) on dry quartz at 800° and 900°C, combined with the data of Brace and Kohlstedt (1980) yield the flow law

\[ \sigma = 5 \times 10^3 (n_e - n_i) \exp \left( \frac{-0.19 \text{ MPa/m}}{RT} \right) \]

where \( \sigma \) is in MPa and \( n_e - n_i \) is in megapascals.

Fig. 4. Limiting values of total horizontal stress as a function of depth, based on Brace's law with hydrostatic pore pressure (HYD) and the quartz (Q2) and olivine (OL) flow laws adjusted to a strain rate of 10⁻¹⁰ s⁻¹. The temperature profile \( T(K) = 700 + 150z(\text{km}) \).

Fig. 5. Difference between maximum or minimum horizontal stress and the vertical stress as a function of depth. Values of \( \lambda \) give pore pressure level. See also Figure 4.
Compression, strain rate $10^{-15}$ s$^{-1}$, quartzite over olivene

- 25°/km, total strength $0.55 \times 10^{13}$ N/m
- 20°/km, total strength $0.89 \times 10^{13}$ N/m
- 15°/km, total strength $3.6 \times 10^{13}$ N/m

σ$_1$ - σ$_2$, MPa
Fig. 3. Pre- and post-contraction back-geometry and topography for the Snake Range and Wind River Mountain systems, with thickening due to back-arc (shortening due to back-arc) thinning as a result of stress relaxation (Figure 2a). Dashed and dotted topography (initial) are shown in dark color, and the final topography in Figure 3b. The post-contraction thickening due to back-arc (shortening due to back-arc) thinning is shown in black. The topography is used to determine the final depth of the crust. The back-arc (shortening due to back-arc) thinning is shown in black. The topography is used to determine the final depth of the crust. The back-arc (shortening due to back-arc) thinning is shown in black. The topography is used to determine the final depth of the crust.

Table 3a-3d

<table>
<thead>
<tr>
<th>Location</th>
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<th>Mean</th>
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Block and Royden, Tectonics, 1990
Fig. 3. Pre- and post-seismic back geometry and topography for the Snake Range and Willingham Basins depression fault systems along the back-arc margin. (A) Topo map of the back-arc margin with the back-arc basin, Willingham Basin, Snake Range, and adjacent geology. (B) History of fault displacement in the back-arc basin showing before and after seismic activity. The diagrams illustrate the movement of the faults and the changes in topography. Block and Royden, Tectonics, 1990.
Fig. 4. Schematic of a normal fault cutting the entire upper crust. The base of the upper crust is always at a fixed depth, as shown by the dashed line.
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Fig. 6. Model formulation. (a) shows offset along a high-angle normal fault; (b) shows flexural response to the topographic load caused by the offset. The flexure causes rotation of the high angle normal fault over a flexural wavelength. In (c) the rotated fault is abandoned and a new extension of the fault, which is rooted in the lower crust, is cut through the top of the upper crust. Buck, Tectonics, 1988
Fig. 4. Schematic of a normal fault cutting the entire upper crust. The base of the upper crust is always at a fixed depth, as shown by the dashed line.

Fig. 6. Model formulation, (a) shows offset along a high-angle normal fault; (b) shows flexural response to the topographic load caused by the offset. The flexural response results in the high-angle normal fault over a flexural wavelength. In (c) the created fault is abandoned and a new extension of the fault, which is rooted in the lower crust, is cut through the top of the upper crust.

Fig. 7. Topography and positions of active and abandoned faults resulting from a calculation with a fault angle $\theta$ of 60$^\circ$, an effective flexural rigidity of 0.5 km, and a rotation angle $\phi$ of 5$^\circ$. A line at 2 km depth is also plotted. Horizontal offsets of approximately (a) 15 km, (b) 30 km, and (c) 60 km are shown. There is no vertical exaggeration.

Buck, Tectonics, 1988
Fig. 4. Schematic of a normal fault cutting the entire upper crust. The base of the upper crust is always at a fixed depth, as shown by the dashed line.

Fig. 7. Topography and provinces of active and abandoned faults resulting from a calculation involving fault orientation. The fault orientation is a horizontal dip of 60°, a fault plane dip of 5°, and a fault plane dip angle of 3°. The base of the upper crust is shown. There is no vertical exaggeration.

Fig. 12. Results of variable rigidity calculations in which sediment has been added to fill in all levels below 1000 m depth. Two cases of assumed angle of fault rotation before fault abandonment are shown: 80° = 5° and 80° = 10°.

Buck, Tectonics, 1988
Fig. 2. Schematic cross section perpendicular to strike of transition zone at the latitude of Lake Mead showing inferred uplift of Gold Butte block. Location of profile shown in Figure 1. Modified from Wernicke and Axen [1988].

Kruse et al., JGR, 1991
I think they assumed a Moho contrast of 600 kg m⁻³
The channels strongly ductile viscous regions. Example, = average crustal dimensional and same thinning). 1020 x 1020 km, Vx - • transition -- • Element - • \[ V_x = \text{Vext} \]

\[ \sigma_y = \rho g \Delta h \]

\[ v_x = 0 \]

\[ \sigma_y = 0 \]

\[ v_x = 0 \]

\[ \sigma_y = 0 \]

\[ v_x = 0 \]

\[ v_y = 0 \]

\[ v_x = 0 \]

\[ v_y = 0 \]

Fig. 7. (a) Schematic representation of ductile flow in response to upper crustal thinning. (b) Boundary conditions on finite element models for ductile channel with a fixed lower boundary.

Kruse et al., JGR, 1991
The required variations for viscosities and thickness for flow in a channel initially 25 km thick with a fixed lower boundary. The upper crust has zero flexural rigidity and thins over the left side of the mesh at a rate of 1 km/m.y.

Kruse et al., JGR, 1991
Figure 2. Schematic diagram of warping and uplift of detachment fault. A: Inception of master detachment fault and subsidiary normal faults within upper plate. B: After 20 km of extension an antiformal warp has developed. Shape of warp and amount of uplift are depicted in listric model of Figure 1 (solid line). Antiform is becoming barrier to movement of upper plate from left, upper plate in area of synformal warping is becoming inactive, and one-sided denudation of antiform is about to begin. C: 20 km of one-sided denudation has resulted in further uplift and initial exposure of lower plate to subaerial erosion. Shape of basal detachment fault and distribution of extension during one-sided denudation resemble planar detachment of Figure 1 and skewed distribution of extension (dashed line, Fig. 1), resulting in subdued arching of fault surface and amplified uplift in breakaway area.

Spencer, Geology, 1984
increasingly higher peak deformation temperatures in the continuation of a detachment fault, mylonites should record patterns. If a lower plate shear zone initiated as the down-dip complexes can be tested with detailed studies of mylonitization domino-style fault-block rotation (e.g., Proffett, 1977), suggesting some lower plate shear zones may initiate as isostatically-driven warping of the footwall faults and ductile shear zones to shallow angles is generally attributed to either isostatically-driven warping of the footwall or suggests some lower plate shear zones may initiate as isostatically-driven warping of the footwall or be captured by master detachment fault and isostatically bowed upwards; B) shear zone; shear zone is captured by master detachment fault and isostatically bowed to subhorizontal; C) detachment fault and mylonitic shear zone initiate at a high angle and isostatically rotate to subhorizontal along a “rolling hinge” without a core complex development with detailed microstructural analysis of mylonitized early tectonic events. This study tests geometric models of metamorphic core complexes. A) Detachment faults splay from a subhorizontal mylonitic shear zone and master detachment fault initiate at a shallow dip. C) or D) Detachment faults and mylonitic shear zones initiate at moderate to steep angles (40-60°) and rotate to sub-horizontal via domino-style extension.

A) Low-angle normal faults splay from a subhorizontal mylonitic shear zone. B) Mylonitic shear zone and master detachment fault initiate at a shallow dip. C) Detachment fault and mylonitic shear zone initiate at a high angle and isostatically rotate to subhorizontal along a "rolling hinge." D) Detachment faults and mylonitic shear zones initiate at moderate to steep angles (40-60°) and rotate to sub-horizontal via domino-style extension.
Based on temp est from quartz deformation in mylonites, argue shear zone initiated as a very flat feature but think that the upper plate faults were much steeper.