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Supplemental Material

Supplementary Methods 1. Structure and Shortening. Cross-section development description and shortening methods

Supplementary Methods 2. Trishear modeling.

Supplementary Data 1. References for compiled thermochronology (AFT) data.

Table S1. Carbonate $\delta^{13}C$ (‰ VPDB) and $\delta^{18}O$ (‰ VPDB) isotopic results and mean values; descriptions of samples and outcrops; interpretations of depositional environments.

Table S2. Descriptions, interpreted paleoenvironments and references for locations in the paleoenvironmental reconstruction figure.

Table S3. U-Pb data unknowns.

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Table S5. Statistical analysis of detrital zircon data.

Table S6. Location of detrital zircon samples.

1. SUPPLEMENTARY METHODS 1. STRUCTURE AND SHORTENING

1.1. Structural Analysis

Structural analysis included collecting strike and dip measurements on sedimentary bedding features and fault zones, as well as trend and plunge of slickenlines. Each field measurement was carefully labeled on Google Earth imagery. These data were incorporated into the geologic map (Fig. 2) and cross-sections completed in the program "Fault-bend Fold" from Dr. R. Allmendinger at Cornell University. This program creates balanced cross-sections based on dip data of the fault plane, or dip data of strata above the fault plane. The comprehensive balanced cross section through the field area allowed interpretation of total shortening magnitude across each structure by using the slip on the fault planes in conjunction with an area balanced and restored cross-section. This method appears similar to the line-length method in that it follows both a pre- and post-deformation horizon. It compares the pre- and post-deformation length from just above the décollement horizon across the section. It differs in that each successively higher stratigraphic layer will produce less shortening magnitudes due to thickening and thinning of strata during deformation. In shear deformation, the difference in shortening between the uppermost-deformed strata and the lowermost-deformed strata can vary significantly (e.g., Marshak and Nicholas, 1998; Suppe et al., 2004). Therefore, only the strata just above the décollement horizon can be used to estimate shortening magnitudes. Length of shortening is determined by the equation:

$$\Delta l = |l_{\text{final}} - l_{\text{initial}}|$$

where Δl is the change in length, l_{final} is post-deformation length, and l_{initial} is pre-deformation length

Shortening percentage (e) is determined by the equation:

$$e = ((l_{\text{final}} - l_{\text{initial}}) / l_{\text{initial}}) \times 100$$

where e is the percent change in length (a negative number indicates shortening, while a positive number would indicate extension)

The line length method requires a pin line on either side of the structure, ideally with strata at a pin line horizontal, or undeformed. Conventionally, a pin-line is drawn straight and perpendicular to bedding in a deformed cross section (Marshak and Nicholas, 1998). This pin-line must be either straight and perpendicular to strata, or a loose line that smoothly varies in the restored cross-section (Marshak and Nicholas, 1998). The value for l_{initial} is determined by using a marker bed; the length of the marker bed is measured through the deformed strata between the two pin lines. Pin-lines on either side of the deformed cross section must adhere to specific rules that are dictated by conservation of mass and geometric relationships. A restored cross section can then be drawn to provide support that the deformed cross-section is balanced, as well as visually illustrate the amount of shortening. The value for l_{final} is determined by measuring the linear distance between the two pin lines. The assumption is made that a negligible amount of material moves in or out of the cross-section line parallel to thrust motion. Four stratigraphic layers were used to determine the shortening. As stated above, only the layer immediately above the décollement horizon provides reliable shortening magnitudes.

1.2. Rates of Shortening

Shortening magnitude was combined with the youngest ages of deformed strata in order to quantify shortening rates across the foreland. The shortening rates of the Southern Tashenkou structure can be determined by using the following equation:

$$\text{Rate} = \Delta l/\text{Time}$$

Shortening rates determined herein are all geologic rates and can be compared to previously published geodetic rates in the table below.

Table 1. Previously published geodetic rates.

Region	Rate	Reference
India into Asia	40–50 mm/yr; 45 mm/yr	Reigber et al. (2001); Yang et al. (2008).
Across the Tian Shan	20 mm/yr; 20 +/−2 mm/yr	Abdrakhmatov et al. (1996); Yang et al. (2008); Zubovich et al. (2010).
Across the Himalaya	20 mm/yr	Reigber et al. (2001).
Across the Kunlun	10 mm/yr	Reigber et al. (2001).
Across the Kashi-Aksu Thrust Belt Tarim Basin beneath the Tian Shan (foreland)	8 +/−3 mm/yr; 4–7 mm/yr	Reigber et al. (2001); Zubovich et al. (2010)

2. SUPPLEMENTARY METHODS 2. TRISHEAR MODELING

Trishear modeling is a somewhat unexploited approach to cross-section modeling, as it requires numeric modeling and the use of programs and cannot be modeled by hand as can kink-band modeling. Before discussing the actual structures of the western Kepintagh, here we describe trishear modeling and how it is applied to fault studies.

Trishear was first introduced by Erslev in 1991 to more accurately describe fold geometries observed in nature that cannot be explained with typical kink-band models (Erslev, 1991; Hardy and Ford, 1997; Allmendinger, 1998). Kink-band modeling cannot be used to explain changes in bedding thickness in the backlimb or forelimb of a structure, and often fails to explain curved fold hinges (e.g.: Erslev, 1991, and Cristallini and Allmendinger, 2002). Moreover, kink-band models produce uniform dips of limbs and cannot allow for changes in dip often observed in nature (Erslev, 1991). Trishear modeling can account for variable dips of bedding in the hanging wall and bedding thickness changes often observed in fold geometries. In the trishear model, the forelimb of a fault-propagation fold tightens and converges downward toward the fault tip in a triangular zone (in cross-section) (Fig. 7). This zone is what is referred to as the trishear zone (Erslev, 1991). Erslev (1991) explains the trishear zone as a zone that accommodates "strain-compatible shear in a triangular zone". If the shear zone in a thrust fault were restricted to the hanging-wall or footwall, volume would either be lost or gained, respectively (Fig. 7). However, if the shear zone is evenly split between the hanging wall and footwall, no volume is gained or lost (Erslev, 1991). To maintain equal area pre- and post-deformation, material must be moved from the hanging-wall to the footwall in a direction oblique to the fault (Erslev, 1991). Fundamentally, trishear modeling allows for shear deformation, or an anisotropic component, in a traditionally wholly isotropically modeled structure.

The modeling program used for this study is FaultFoldForward (FFF), one of the few trishear programs available (Allmendinger, 2012). To construct a trishear model on FFF the following criteria must be entered into the modeling program:

Ramp angle – This is the dip of the fault; it can be determined by the dip of the strata exposed above the fault surface. No actual bedding dip data are input into the program.

Trishear angle – To determine trishear angle, the triangular zone of shear needs to be identified. This can be accomplished iteratively by superimposing different models over a true cross sectional view (based on field observations such as photo, sketch, or seismic imagery) of the structure.

Total slip – This is the net displacement on the fault surface. Note that with a fault-propagation fold, slip on a fault surface will decrease up dip; therefore, this does not refer to the amount of displacement that can be seen on the surface, rather the maximum displacement that is revealed at depth on the fault plane. If actual displacement on the fault is unknown, this is determined iteratively.

Propagation/Slip (P/S) ratio – This is the ratio of how far the structure has propagated, or moved, relative to how much slip has occurred on the fault surface. According to Hardy and Ford (1997) low P/S ratios ($P/S<1$) will result in thickening of the forelimb and tight folding within the trishear zone, while high P/S ratios ($P/S>1$) will exhibit less thickening and more open folding within the trishear zone. This ratio can have considerable effect on the appearance of the structure, and is determined iteratively.

Additional information is needed to complete the modeling including, but not limited to, unit thickness, fault type (thrust or normal), and point of initiation of faulting on an XY axis. This information, along with other modeling data, is not discussed herein since the modeling program itself is not part of the objective of this study. The values that created the best fit for the structures identified as T3, T4 and T5 in Figure 6 are shown in the table below.

Table 2. Values used for fault dip, trishear angle, and P/S ratio of faults T3, T4 and T5.

Data	T3	T4	T5
Ramp angle	30°	30°	20°
Trishear angle	0°	60°	60°
P/S ratio:	1	1.2	0.8

SUPPLEMENTARY DATA 1. References for compiled thermochronology (AFT) data. This compilation was recently published in Jepson et al. (2021).

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