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Is the North Altyn fault part of a strike-slip duplex along the Altyn Tagh fault system?

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Notes

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ABSTRACT

Although the Altyn Tagh fault system has played an important role in the Indo-Asian collision, its geometry and tectonic evolution remain poorly known. Between 86° and 92°E, this system is at least 100 km wide and is bounded to the north and south by the North Altyn and Altyn Tagh faults, respectively. Mapping along the Jianglisai reach of the North Altyn fault indicates that Miocene(?) to Pliocene(?) motion was predominantly left to left-reverse slip, with transport vectors trending N45°–60°E. Map relationships suggest that total offset on the fault is >120 km. These results are inconsistent with previous models of the Altyn Tagh fault system in which oblique convergence along the northern margin of the Tibetan Plateau is partitioned into thrusting on the North Altyn fault and left slip on the Altyn Tagh fault. An alternative hypothesis is that the North Altyn fault is the northern boundary of a transpressional strike-slip duplex within which the structurally elevated Altyn Mountains were created. Our model suggests that transpressional deformation may be restricted to this strike-slip duplex and need not characterize the entire margin.

Keywords: Altyn Tagh, Tibetan plateau, strike slip, transpression.

INTRODUCTION

Although the Altyn Tagh fault system is thought to have played an important role in accommodating Indo-Siberian convergence (Avouac and Tapponnier, 1993; Peltzer and Tapponnier, 1988; Tapponnier et al., 1986; Burchfiel et al., 1989) its tectonic evolution remains poorly known. Locally, the Altyn Tagh fault coincides with the northern edge of the Tibetan Plateau and separates it from the Tarim basin to the north (Fig. 1). Between 86° and 92°E, however, the 600-km-long by 90-km-wide Altyn Mountains are north of the fault. This range, after which the Altyn Tagh fault is named, is bounded to the north by the North Altyn fault system.

It was suggested that deformation along the northern margin of the plateau is partitioned into thrusting on the North Altyn fault system and left slip on the Altyn Tagh fault to the south (Avouac and Tapponnier, 1993; Burchfiel et al., 1989; Molnar et al., 1987a; Peltzer and Saucier, 1996; Wittlinger et al., 1998). To test this interpretation, we investigated the westernmost 120 km of the North Altyn fault, herein referred to as the Jianglisai reach. In contrast to the expected northwest-directed thrusting, we found that slip occurred as east-northeast–directed left-reverse motion. To explain these kinematics we suggest that the North Altyn fault system is the northern bounding fault of a rhomb-shaped transpressional strike-slip duplex along the Altyn Tagh fault system (Fig. 1).

JIANGLISAI REACH OF THE NORTH ALTYN FAULT

The Jianglisai reach extends from the old Qiemo coal mine in the west to Unusai in the east, and comprises the Jianglisai, Luojianglisai, and Unusai faults (Fig. 2). Along most of this reach, the system strikes ~N60°E and dips 60°–70°S. South of the fault, hanging-wall rocks are predominantly quartzofeldspathic gneiss, schist, and marble, cut by nonfoliated granitic dikes. Northwest of the system are folded Mesozoic and Cenozoic strata in addition to Proterozoic(?) schist, amphibolite, and limestone intruded by tonalite plutons. Steeply northwest dipping Tertiary deposits between Tatulekisu and Unusai are separated from Mesozoic strata to the south by the vertical to steeply south dipping Luojianglisai fault (Fig. 2). The Tertiary section coarsens upward from upper Oligocene fluvial and lacustrine redbeds (Rumelhart, 1998) to Pliocene-Pleistocene(?) (Xinjiang Bureau of Geology and Mineral Resources, 1993) alluvial-fan facies boulder conglomerate.

West of Luojianglisai, the trace of the Jianglisai fault coincides with the topographic front of the Altyn Mountains. East of Unusai, however, this front steps right ~35 km and becomes significantly less linear. We suspect that in this area the main fault diverges from the range front and continues to the east either in the subsurface of the Tarim basin along the Luojianglisai fault or inside the Altyn Mountains along the Jianglisai fault. Quaternary fault scarps with 80–90 m of vertical separation have been observed along the range front ~200 km east of Unusai (Molnar et al., 1987a, 1987b; Wittlinger et al., 1998), and these structures may be equivalent to faults within the Jianglisai reach.

Kinematics

Three aspects of the deformational style in the area suggest strike-slip faulting. (1) The trace of the Jianglisai fault is straight for more than 75 km (Fig. 2). (2) Near the old Qiemo coal mine subparallel fault strands separate ridges of crystalline basement from intervening panels of Jurassic strata (Fig. 2). The along-strike variability in the dip direction and magnitude of these faults is

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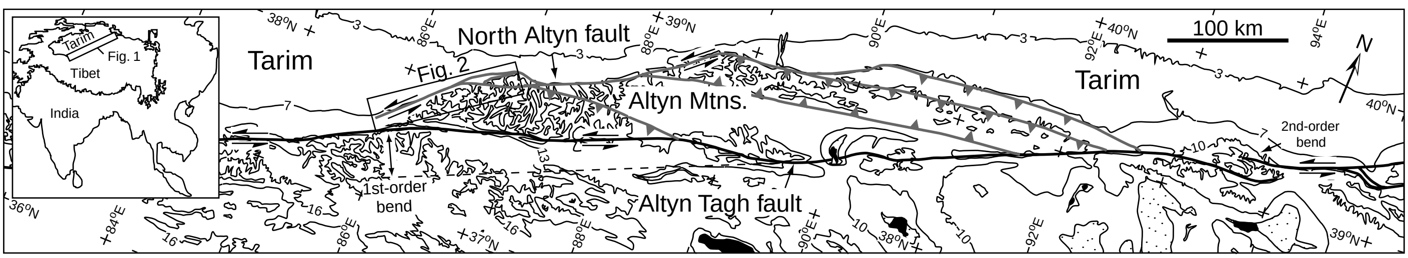


Figure 1. A: Simplified map of northwest Tibet showing positions of North Altyn and Altyn Tagh faults relative to Altyn Mountains. First-order bend in Altyn Tagh fault is south of Altyn Mountains. Topographic contours shown at 3000 ft intervals; numbers give elevations in thousands of feet. Compiled from Anonymous (1989, 1990); Chinese State Bureau of Seismology (1992), Wang (1997), and our mapping.

Data Repository item 200030 contains additional material related to this article.

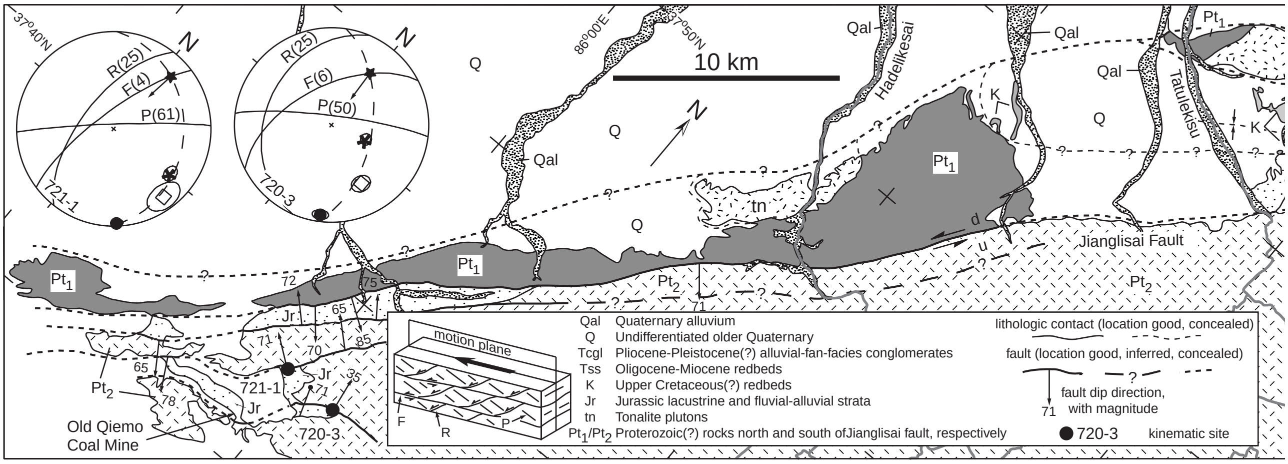


Figure 2. Simplified geologic map of Jianglisai reach based on 1:100 000-scale mapping. Equal-area, lower hemisphere stereograms summarize fault-zone composite fabrics, and inset block diagram (after Cowan and Brandon, 1994) shows kinematic interpretation of Riedel composite structures. Note that both map and stereograms have been rotated. Only mean poles (with α_{95} confidence cones) and corresponding planes are shown (see text footnote 1). Filled circles, open squares, and asterisks correspond to mean P, F, and R poles, respectively; number of measured planes is shown in parentheses. Best-fit great circle to mean poles corresponds to motion plane and is shown dashed. Derived slip directions are shown as arrows and indicate motion of hanging-wall block relative to footwall.

characteristic of strike-slip structures (Sylvester, 1988). (3) South of the Luojianglisai strand Upper Cretaceous(?) and Jurassic strata are deformed into a northeast-trending syncline (Fig. 2). The oblique orientation of this fold axis with respect to the bounding faults that truncate it is consistent with its formation in a zone of sinistral shear. In addition to the style of deformation that is suggestive of strike-slip kinematics, left- to left-reverse slip directions are indicated by kinematic data.

Riedel Composite Fabrics. The Jianglisai, Luojianglisai, and Unusai faults typically occur as ≥2 m thick gouge and cataclasite zones in which composite fabrics are locally well developed. These fabrics consist of a penetrative scaly cleavage (P-foliation) that is inclined to the margins of the shear zone (F-plane) and that is typically dissected by millimeter- to centimeter-spaced Riedel shears (R-planes). We follow Chester and Logan (1987), Platt et al. (1988), and Cowan and Brandon (1994) in our kinematic interpretation of these fabrics (e.g., see block diagram in Fig. 2). The stereograms in Figure 2 summarize composite fabrics measured at six sites.[1] Mean fault planes are labeled F, and the arrows indicate the motion of the hanging-wall block relative to the footwall. Fault surfaces at sites 702-1, 704-4, and 705-3 are northeast striking and southeast dipping with shallowly southwest-plunging slip vectors that indicate sinistral motion. Site 701-1 is located on a northwest-dipping section of the Unusai fault that has a releasing geometry (Fig. 2), and slip at this station was directed downdip. Sites 721-1 and 720-3 indicate left to left-reverse motion on northwest-dipping fault surfaces.

[1]GSA Data Repository item 200030, Unsimplified plots of kinematic data, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/drpint.htm.

Fault-Slip Directions. Slip vector azimuths were also measured on striated surfaces within the gouge and adjacent rocks. Fault-parallel surfaces both bound and occur within the gouge zones and preserve two sets of striae (Fig. 3A): a southwest-trending set that indicates left-reverse motion, and a northeast-trending population with a sinistral slip vector azimuth. Only at 831-1 (Fig. 2) do both sets occur on the same surface. At this site the northeast-trending set is younger. Also plotted in Figure 3A are density-contoured quartz-rod stretching lineations measured in the basement south of the fault system. Although scattered, these data show a southwest-plunging maximum that generally is on the fault surfaces and is subparallel to the southwest-plunging brittle striae. Fault-slip data from microfaults measured outside of the fault zone are shown in Figure 3 (B–D). Surfaces with left to left-oblique slip azimuths are plotted in Figure 3B and are subparallel to the main fault in Figure 3A. Microfaults with normal (Fig. 3C) and reverse (Fig. 3D) slip directions both occur as two sets of surfaces, one of which is approximately parallel to the Jianglisai reach.

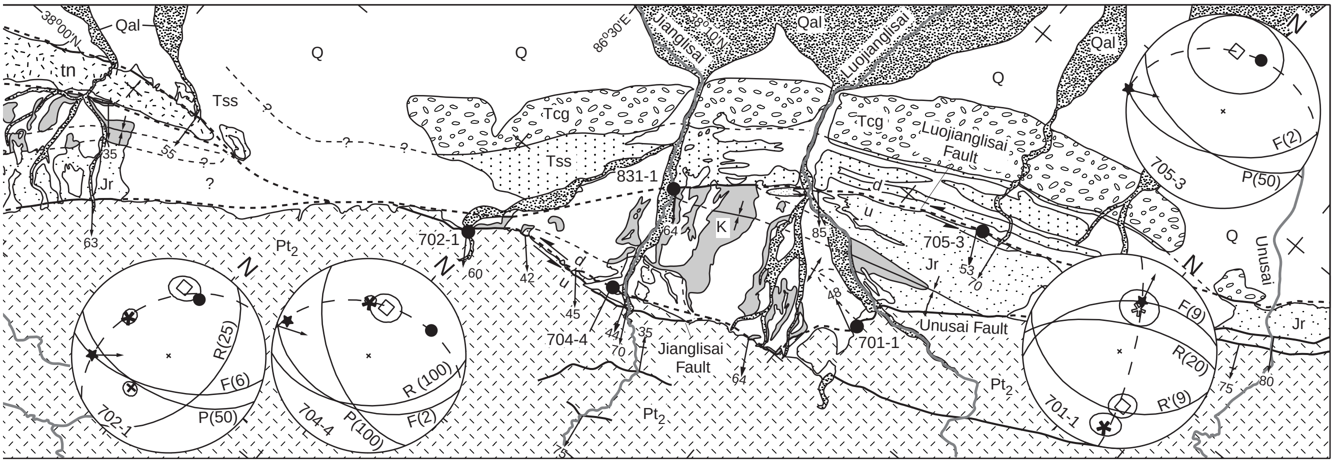
Although it is possible that the dip-slip microfaults record a phase of dip-slip displacement along the Jianglisai reach, other compelling evidence for such motion is lacking. An alternative explanation is that the microfaults formed within restraining and/or releasing bends or by the "porpoising" of blocks during strike slip. Because the dip-slip striae approximately coincide with the line of intersection between the two microfault sets, another hypothesis is that the striae formed during simultaneous slip on preexisting, intersecting planes (Marrett and Allmendinger, 1990). Unfortunately, the age relations needed to distinguish between these hypotheses are not clear.

Timing of Slip

Although the timing of slip along the Jianglisai reach is not well known, it is the subject of ongoing work. Magnetostratigraphic analyses by Rumelhart (1998) indicate that the Tertiary coarse-clastic transition at Jianglisai occurred prior to ca. 26.5 Ma. If this transition was caused by uplift due to left-reverse motion on the Jianglisai and Unusai faults, then the system was active by late Oligocene time.

Additional timing relationships are provided by apatite fission-track analyses from opposite sides of the Unusai fault in the Unusai valley (Fig. 2). A Jurassic sample north of the fault has a mean track length of 12.16 ± 1.84 µm and a pooled age of 15.7 ± 1.2 Ma, whereas the basement to the south has a mean track length of 12.2 ± 2.05 µm and a pooled age of 17.2 ± 0.9 Ma (Rumelhart, 1998). Both the distribution of single-grain ages and the low mean track lengths indicate that these samples are partially annealed and thus probably do not reflect middle Miocene cooling. Nevertheless, the similarity of these two analyses suggests that rocks on opposite sides of the Unusai fault have similar low-temperature cooling histories. The simplest interpretation is that (1) slip on the Unusai strand juxtaposed these rocks either within or beneath the partial annealing zone, and (2) the fault was subsequently exhumed as a passive marker during left-oblique motion on the Luojianglisai strand to the north.

Uniform bedding attitudes in Tertiary strata north of the Luojianglisai indicate that these strata were not deformed until after the alluvial-fan facies boulder conglomerates were deposited. Although the age of this unit is poorly known, it is thought to be latest Neogene to early Quaternary (Xinjiang Bureau of Geology and Mineral Resources, 1993). East of Jianglisai valley there appears to be an ~35-km-wide restraining bend



(Figure 2, continued.)

in the Jianglisai fault (Fig. 1). If the Pliocene-Pleistocene age for the boulder conglomerates is correct, then it is a maximum age for the time at which these strata passed through this bend.

The straight, fault-bounded range front indicates that slip on the Jianglisai fault occurred recently. Both our field observations and examination of CORONA satellite imagery, however, indicate that all faults in the studied area are capped by Quaternary alluvial deposits that are ~40 m above the active drainage. Bedding north of the Luojianglisai fault crops out as smooth ridges that trend parallel to the fault and make identification of a scarp along this structure difficult. Nevertheless, an older Quaternary unit that is sparsely preserved ~140 ± 40 m above the active drainages appears to be cut by the Luojianglisai fault on the CORONA images.

Total Offset Estimates

Rocks do not match across the Jianglisai fault system for at least 120 km, suggesting that total offset is at least this much. This observation may not be conclusive, however, because the dip-slip component of motion on the system may have juxtaposed significantly different structural levels. If the syncline within Upper Cretaceous(?) strata at Tatulekisu (Fig. 2) initially formed within the restraining bend east of Unusai and was then transported along the fault, then slip is at least 80 km.

Estimates of shortening perpendicular to the North Altyn fault system are 1–8 mm/yr, based on reconnaissance observations of fault scarps (Molnar et al., 1987a) and velocity models of the Indo-Asian collision zone (Avouac and Tapponnier, 1993; Peltzer and Saucier, 1996). On average, faults within the Jianglisai reach are oriented ~N60°E, 60°S with a 20°W raking slip vector that is oriented S50°W, 20°. For slip along this vector to have a fault-normal rate of 1–8 mm/yr, it must also have a strike-slip component of 6–45 mm/yr. If the slip rate and direction have remained roughly constant since the late Miocene, then total strike-slip offset would range from 60 to 450 km. Although these numbers are obviously speculative, they provide an order-of-magnitude estimate of the total offset that is comparable to the >120 km offset derived from our field observations.

DISCUSSION

Tarim-Tibet relative motion is generally thought to be oblique to the Altyn Tagh system and partitioned into left slip on the Altyn Tagh fault and thrusting on the North Altyn fault (Avouac and Tapponnier, 1993; Burchfiel et al., 1989; Molnar et al., 1987a; Peltzer and Saucier, 1996; Wittlinger et al., 1998). However, slip directed N45°E to N60°E on the Jianglisai reach of the North Altyn fault system is not consistent with this model. In addition, this model does not readily explain why the Altyn Mountains are the only such structurally elevated region north of the Altyn Tagh fault. An alternative interpretation is that the North Altyn and Altyn Tagh faults form the north and south boundaries of a strike-slip duplex (Fig. 4) (Woodcock and Fischer, 1986) in which the Altyn Mountains are a rhomb horst (Aydin and Nur, 1982). Length-to-width ratios of strike-slip stepovers have been shown to be scale invariant, with a constant value between 2.4 and 4.3 (Aydin and Nur, 1982). The ratio of the Altyn Mountains is 3.6, consistent with its interpretation as a rhomb horst. Such an interpretation predicts that shortening has occurred in the east-northeast sector of the range along left-oblique slip faults within the Lapeiquan and Soukuli belts, adjacent to the Lapeiquan suture (Guo et al., 1999; Sobel and Arnaud, 1999). The North Altyn fault system has lower slip rates than the Altyn Tagh fault to the south (Bendick et al., 1998) and the Jianglisai reach is no longer aligned with the Altyn Tagh fault to the west. These observations indicate that slip on the Altyn Tagh fault has recently become dominant and that the Altyn mountains have been captured by the Tarim (Fig. 4B).

A recent tomographic profile across the Altyn Mountains indicates that they are underlain by thickened crust (Wittlinger et al., 1998). Although these authors argued that their results indicate that the Altyn Tagh fault system is a transpressional plate boundary, our strike-slip duplex model sug-

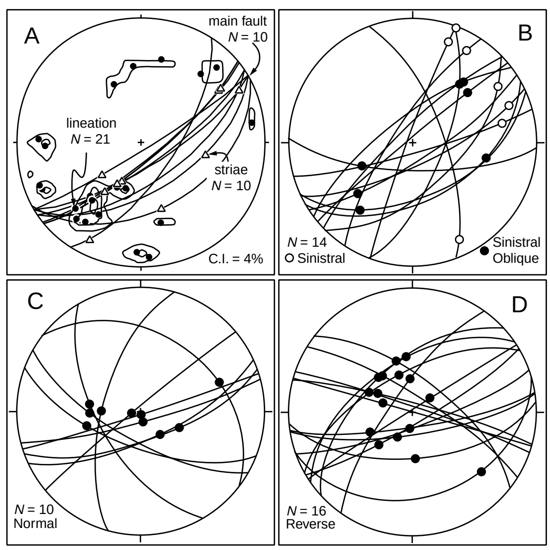


Figure 3. Equal-area, lower hemisphere stereograms of additional kinematic data. A: Jianglisai, Unusai, and Luojianglisai fault measurements. All striae indicate left-slip directions, and two populations are evident: southwest-trending set centered on 213, 53, and northeast-trending set centered on 055, 25. Also shown are 1% area contours of quartz-rod stretching lineations where dots are contoured data. Contour maximum is centered near southwest-plunging set of brittle striae. B–D: Microfaults adjacent to Jianglisai fault. B: Surfaces with left to left-oblique motion. Note that these surfaces form single population that parallels regional faults plotted in A. Slip directions cluster into southwest- and northeast-trending sets. C: Planes with striae raking 61°–90° and showing normal slip directions. D: Same as C, but for reverse slip directions. Shear sense on microfaults was determined using criteria discussed by Petit (1987).

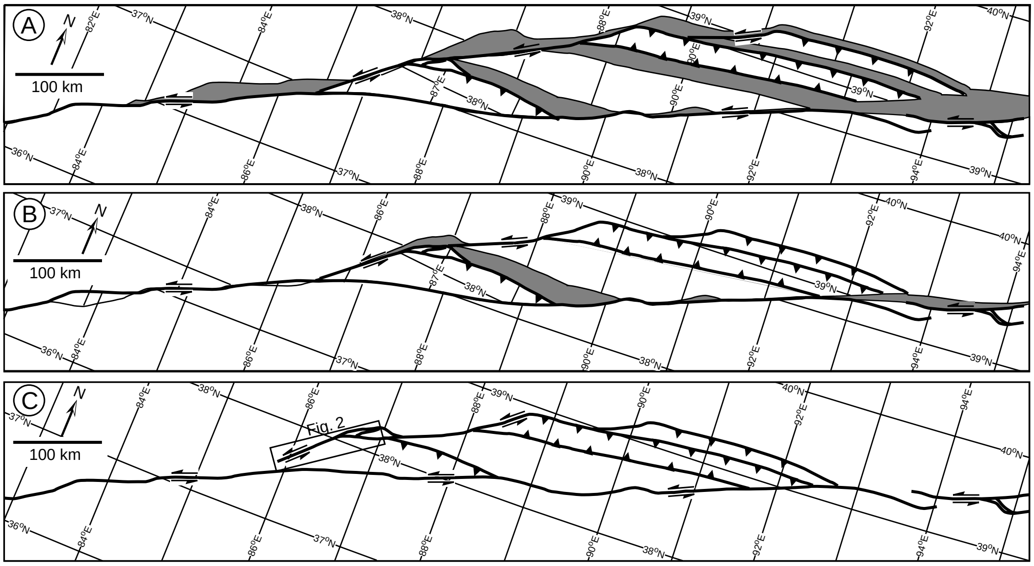


Figure 4. Diagrams illustrating possible tectonic evolution of Altyn Mountains as strike-slip duplex. Areas consumed by convergence shown in gray. A: Initial configuration. North Altyn fault was along strike from western Altyn Tagh fault, forming northern margin of transpressional stepover. B: Decrease in slip rate on North Altyn system resulted in capture of Altyn Mountains by Tarim block. Partial translation of duplex out of bend resulted in ~5° counterclockwise rotation of westernmost edge of duplex. C: Present configuration.

gests that thickening and transpressional deformation could be restricted to the strike-slip duplex and need not characterize the entire fault system.

CONCLUSIONS

1. Geologic mapping along the 120-km-long Jianglisai reach of the North Altyn fault system indicates that the range front is characterized by several subparallel, steeply dipping fault strands that juxtapose basement gneiss to the south against predominantly Mesozoic and Cenozoic strata to the north.

2. On average, this system strikes N60°E and dips 65°S with a 20°W raking slip vector that is oriented S50°W, 20°.

3. The timing of slip is poorly constrained, but the fault may have been active from the middle Miocene until the Pliocene-Pleistocene. Additional timing relationships are the subject of ongoing work.

4. The geology does not correlate across the fault for the entire ~120 km length of the reach we mapped, suggesting that total left slip is at least this great.

5. We suggest that the North Altyn fault system forms the northern boundary of a strike-slip duplex that coincides with the Altyn Mountains. This model suggests that transpressional deformation could be restricted to the duplex.

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