Characterization of a Partitioned Section of the Höh Serh Fault System: Mongolian Altai

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Abstract  
Strike-slip faulting is often an integral component of strain accommodation in continental collisions. In the Himalayan orogenic belt, such faulting occurs up to 2000 km away from the area of primary deformation. This study characterizes the motion along two such faults, the dextral Höh Serh fault and a thrust splay, the Tsagaan Salaa fault, in the Mongolian Altai. Strike-slip motion is expressed in the field by drainage offsets, topographic depressions, and tension gashes in Quaternary alluvium. Reverse motion is observed geomorphically as offset alluvial fans, strath terraces, and a rare geologic exposure of a gouge zone. Differential GPS profiles of one alluvial fan offset by the Tsagaan Salaa fault show 5.5 ± 0.5 m of offset. Based on an estimated fan age of 7.5 ± 2.5 ka, this value gives a shortening rate of 1.5 ± 0.5 mm/yr across the Tsagaan Salaa Fault. Smaller offsets along the Tsagaan Salaa Fault on strath terraces suggest that the offset surveyed may record multiple ruptures.

Keywords: transpression, Mongolian Altai, Be-10, terraces, slip rates, neotectonics
INTRODUCTION
Intraplate strike-slip faulting is often an important component of both modern and ancient orogenic belts. Studying modern orogenies is often preferable; active faults allow easier measurement of current slip rates and characterization of the kinematics of deformation. The Himalaya is an excellent example of a modern orogenic belt that includes extensive intraplate strike-slip faulting (Molnar, 1975). Though most active strike-slip faults in the Himalaya are EW-striking left-lateral faults, faulting in far western Mongolia is unusual in that the faults are NNW-striking and have oblique dextral motion (Fig. 1,2; Cunningham et al., 2003). By constraining the movement along and structures associated with faulting in western Mongolia, it is possible to reach a better understanding of the anomalous kinematics of these far field Himalayan faults.

Previous studies have approached the problem of intraplate strike-slip faulting in Asia at a variety of scales. Some early work on strike-slip faulting in Central Asia, including Mongolia, suggested that strike-slip faulting accommodates shortening by extruding material away from the indenting Indian Plate (Cobbold and Davy, 1988; Tapponnier and Molnar, 1976; Tapponnier et al., 1982). Detailed characterization of the Red River fault in Southeast Asia, a large-scale extrusion structure suggests that escape tectonics can result in fault rotation and a reversal of fault motion (Leloup et al., 1995; Morley, 2002). At a more local scale, recent work involving detailed field observation has indicated that faulting in Mongolia is strongly influenced by local factors, such as crustal block geometry and Paleozoic metamorphic grain (Bayasgalan et al., 1999; Cunningham, 2005; Cunningham, 2007; Cunningham et al., 2003; Cunningham, 1998; Walker et al., 2006).
Figure 1. Simplified tectonic map of Asia showing a proposed sequence of deformation, adapted from Tapponnier et al. (1982). Each stage is identified by a number, 1 being the initial stage and 3 being the last stage. Major strike-slip structures (Altyn Tagh and Red River Faults) are labeled. Note presence of subduction zones to the southeast of Himalayan deformation. Box indicates location of Figure 2.
Figure 2. Simplified tectonic map of Mongolia showing general pattern of faulting in the Mongolian Altai and Gobi Altai. Arrows indicate direction of fault movement. Black box identifies location of Figure 3. Modified from Badarch et al. (2002).
This study considers a system of faults: a dextral strike-slip fault, the Höh Serh fault and the associated Tsagaan Salaa thrust fault in western Mongolia (Fig. 3). I used both field observation and analytical techniques such as differential GPS and Be-10 cosmogenic dating to characterize the motion along the fault system. From this data and previous work, I draw some preliminary conclusions about the relationship between faulting in Mongolia and the bulk deformation of the Himalayan orogeny.

TECTONIC BACKGROUND

The Himalayan orogeny began in the late Eocene with the closing of the Tethys Sea and docking of multiple terranes onto Eurasia (Molnar, 1975). As a result of the collision, the rate of convergence between the Indian Plate and the Eurasian Plate slowed from around 100 mm/yr to its present value of 58 ± 4 mm/yr (Bilham et al., 1997). Much of the horizontal shortening in the Himalayan orogeny is accommodated by crustal thickening along thrust belts, such as the Main Frontal Thrust near the Himalaya proper, as well as smaller and more distant fold and thrust belts such as the Tien Shan, the Pamir, and the Mongolian Altai (Fig. 1). However, the amount of shortening calculated from these geologic structures is less than the shortening implied by the present convergence rate (Johnson, 2002).

One way to account for the accommodation of N-S shortening is partial subduction of the continental Indian Plate beneath the Eurasian Plate (Johnson, 2002). Underplating plays a role in both the continued convergence of the two plates and the formation of the anomalously thick Tibetan Plateau (An and Harrison, 2000).
Figure 3. Aerial image of field area showing location of the dextral Höh Serh Fault and Tsagaan Salaa Saltn. a. Large-scale topographic expression of faulting. Trace of Höh Serh Fault is indicated by offset drainages. Tsagaan Salaa Thrust is defined by rangefront to the west. b. Figure 5a) with added fault traces. White boxes show approximate location of Figure 3, 4, f and Figure 6, a, c.
Calc-alkaline volcanism in Tibet is typically viewed as a record of partial melting of the Indian continental crust beneath the Himalaya (An and Harrison, 2000; Westaway, 1995).

An alternative explanation for the shortening deficit is escape tectonics, the theory that large-scale strike-slip faults, such as the Red River and Altyn Tagh faults (Fig. 1), extrude material from the main mountain belts towards the Sumatran subduction zone to the SE (Cobbold and Davy, 1988; Johnson, 2002). As extrusion continues, strain accommodation is transferred to new faults; inactive faults are rotated with crustal blocks and, in some cases, reactivated with opposite fault motion (Tapponnier et al., 1982). For example, though the dextral Red River fault currently strikes NW-SE, petrologic studies indicate that during the Tertiary there was as much as 700 km of left lateral offset along the fault. Experimental simulations in plasticine replicate the gross pattern of faulting in Asia, suggesting that the asymmetry of deformation in the Himalaya is related to the shape of the Indian subcontinent (Tapponnier et al., 1982). Alternatively, the lack of convergent margins like the Sumatran subduction zone to the west of the Himalaya may explain why deformation and escape structures are concentrated in the east (Tapponnier et al., 1982).

Active tectonics in Mongolia is dominated by transpression in the NNW-striking Mongolian Altai and EW-striking Gobi Altai, caused by NNE-directed shortening due to the Himalayan orogeny (Cunningham, 2005). In parts of Mongolia, this oblique motion is partitioned onto purely strike-slip and dip slip faults; in other areas the motion is accommodated on a single fault strand. In the Mongolian Altai, faults tend to strike NNW and have both dextral and thrust offsets; in the Gobi Altai, faults strike EW with both sinistral and thrust offsets (Fig. 2).
This study focuses on a section of the Höh Serh fault and a small thrust fault splay to the west called the Tsagaan Salaa fault, which are located in the Mongolian Altai near the village of Delüün (Fig. 3). The Höh Serh fault bounds the SW side of the Höh Serh Range, while the NE side is bounded by the dextral Ar Hötöl fault. South of the field area, the Höh Serh fault system accommodates both strike-slip and thrust motion on a single network of oblique faults. Within the field area, strain is partitioned, with dextral motion along the Höh Serh fault and thrust motion along the Tsagaan Salaa fault (Cunningham et al., 2003).

FIELD EXPRESSION

The surface geology of the study area is dominated by Quaternary alluvium and colluvium, though there are some bedrock exposures. The bedrock consists of NNW-striking foliated Paleozoic metasediments intruded by mostly Paleozoic granitic plutons and dikes (Badarch, 2002). Because the bedrock is poorly exposed, making direct field observation of regional faults is difficult. Instead, I used geomorphic and physiographic features to find the surface trace of the strike-slip Höh Serh fault and Tsagaan Salaa thrust. The exact location of the features discussed below can be found in Appendix A.

Höh Serh Fault

The Höh Serh fault strikes NNW and dips steeply to the NE. Figure 4 shows the typical field expression of the fault. Along the strike of the Höh Serh fault, NW-striking valleys alternate with high mountain passes (elev. >3000m). The fault is most visible at the passes as a topographic depression with as much as a meter of relief (Fig. 4a). In the valleys, the fault is often more difficult to locate, but is inferred to be along or near the
Figure 4. Field expression of Höh Serh Fault. 

a. Topographic saddle showing location of Höh Serh Fault. Boulders in foreground are ~.5m in circumference. 

b. Expression of Höh Serh Fault as a contact between metasediments and granite. Note exposure of parallel plane in metasediments. 

c. Windgap showing location of previous offset. The current drainage is NW of its previous location. Small white dots in background are yurts approximately 4 m tall and 10 m in diameter. 

d. Line drawing of c. Grey line is course of current drainage. 

e. Tension gashes in alluvium along the strike of Höh Serh Fault. The gashes are expressed as left-stepping topographic depressions. 

f. Line drawing of e. θ is less than 60°.
drainages. Because fault movement often decreases the competency of faulted rocks, such topographic expression is expected along the surface trace.

The surface trace is suggested in one exposure by a sharp vertical contact between metasediments and a granite intrusion (Fig. 4b). A vertical plane in the metasediments near this contact serves as further evidence of the fault’s orientation in this locality.

Mole tracks (small push-up ridges) and tension gashes are present along the trace of the strike-slip fault (Fig. 4c,d). This pattern of alternating small-scale (< 5 x 5 m) depressions and topographic highs is a typical expression of strike-slip faulting (Sylvester, 1988; Walker et al., 2006). The left-stepping orientation of these features is consistent with the dextral motion along the fault (Sylvester, 1988). The long axis of the tension gashes forms an acute angle (<60°) with the strike of the fault. In pure strike-slip motion, the expected angle between the long axis of the tension gashes and the trace of the fault is 60° (Davis and Reynolds, 1996). The deviation from this ideal orientation is possibly due to a small component of dip-slip motion and/or the unconsolidated nature of the colluvium.

The most obvious expression of the Höh Serh fault is the dextral offset of three rivers by as much as 2 km (Fig. 3). To the south of the field area, a streambed surveyed by another student was offset by ~50 m, suggesting that the larger 2 km offsets are the result of multiple fault ruptures (Sprajcar, pers. comm.). Further, a dry drainage in one of the northern valleys indicates the location of a previous offset (Fig. 4e,f). The offset suggested by this “windgap” is about a third of the offset indicated by the current course of the drainage.
**Tsagaan Salaa Fault**

The Tsagaan Salaa fault is subparallel to the Höh Serh fault and dips shallowly to the NE. The fault is expressed in the field by vertically offset alluvial fans at the base of the rangefront (Fig. 5a,b). In addition, there are several drainages running between the Höh Serh fault and the Tsagaan Salaa fault. The course of these drainages passes through very narrow, steep canyons, suggesting rapid rock uplift and contemporaneous river incision (Vassallo et al., 2007).

A rare exposure of the Tsagaan Salaa fault in cross-section is observed in Big Gorge, a deeply incised drainage (Fig. 5c; Cunningham et al., 2003). A zone of fault gouge about 20 m wide is visible along the south side of the streambed. There is a distinct color change in the gouge between white and ochre indicating the location of the fault. Using this exposure, we measured the dip of the thrust fault to be 22-30 NE.

Upstream from the fault exposure, Big Gorge contains several fluvial strath terraces where the alluvium above the bedrock is < 3 m thick (Fig. 5d; Wegmann and Pazzaglia, 2002). In this area, the Tsagaan Salaa fault is perpendicular to the course of the drainage. Strath terraces form in response to local or regional base-level fall, usually the result of climate change or tectonics (Burbank, 2001). The base-level fall results in rapid incision; the thin alluvial terrace is deposited by the upstream migration of the knickpoint (Burbank, 2001). Hence, the upstream section of each terrace is younger than the downstream section. Strath terraces are useful for estimating the rate of tectonic uplift, using incision rate as a proxy value (Vassallo et al., 2007; Wegmann and Pazzaglia, 2002).
Figure 5. Field expression of Tsagaan Salaa Thrust. 

**a.** Offset alluvial fan. White line is approximate trace of fault. The circle encloses another student (for scale) 

**b.** Line drawing of a. Dashed area shows increased slope of fault scarp. 

**c.** Exposure of fault along Big Gorge. Gouge zone is around 50 m long. The circle highlights another student. 

**d.** Youngest strath terrace in Big Gorge. Strath is approximately 3 m high.
TOPOGRAPHIC SURVEYING

To find precise offsets on geomorphic features, I used differential GPS. I surveyed the strath terraces in Big Gorge, as well as an offset alluvial fan along the Tsagaan Salaa fault. Because drainage offsets along the Höh Serh fault in the field area are so large, it was more efficient to measure these offsets using aerial photography.

Methodology

Differential GPS is a method of surveying that reduces the error inherent in using simple GPS receivers. GPS receivers operating in the same area experience the same magnitude and direction of error due to atmospheric effects (Kennedy, 1996). Differential GPS reduces systematic error to the sub-centimeter scale by using a receiver that has been in the same location for an extended period of time. The longer the unit remains stationary, the more exactly the receiver “knows” its location. Measurements of geomorphic features are taken with a roving unit. The pattern of error at the base station is used to reduce error in the roving measurements.

Results

The bedrock strath terraces in Big Gorge are a record of vertical offset along the Tsagaan Salaa fault. At the range front, there are three terraces that successively increase in height above the modern channel by ~2.5 m. The GPS survey shows that each terrace terminates in an abrupt convexity in the channel longitudinal profile (knickpoint), with the lowest terrace terminating at the down-stream most knickpoint, and the highest
Strath terraces along "Big Gorge"

Distance from Mountain Front / Fault trace (m)

Elevation of channel bed.

Figure 6. GPS profile of strath terraces in Big Gorge projected onto a single profile parallel to stream channel. Red points show elevation of channel bed.

Key (old to young)
- Terrace 1
- Terrace 2
- Terrace 3
- Stream channel

Terrace 1
terrace at the upstream-most one (Fig. 6). Because of this pattern of termination, it is clear that the strath terraces were formed as a result of local base-level fall due to tectonic uplift (Wegmann, pers. comm.). We interpret each terrace as the record of a single rupture of the fault, suggesting an average rupture of 2.5 m.

I also used differential GPS to survey profiles of a thrust scarp along the Tsagaan Salaa fault. I walked three SW-NE profiles (perpendicular to the strike of the scarp plane). Each profile was separated by about 20 m. I calculated the offset for each scarp profile by averaging the hillslope above and below the scarp. The vertical distance between the lines of best fit for each group of data corresponds to the vertical offset of the alluvial fan (Fig. 7). The scarp surveyed shows 5.5 ± 0.5 m of vertical displacement.

COSMOGENIC DATING

I used Be-10 cosmogenic dating to determine the exposure ages of alluvial fans offset by the Tsagaan Salaa fault. Cosmogenic nuclides, like Be-10, are trace elements in rocks that are created by the interaction of cosmic radiation with terrestrial materials. Cosmogenic dating measures the length of surface exposure, rather than the age of the rock, making it an ideal tool for dating erosional features.

Theory

Be-10 is produced by the interaction of cosmogenic radiation with the nuclei of Si-28 and O-16 in terrestrial olivine and quartz. Cosmogenic radiation is thought to originate primarily outside of our solar system, though within the Milky Way (Gosse, 2001). The radiation reacts with molecules in the Earth’s atmosphere; some primary radiation is deflected by this interaction and never reaches Earth’s surface. However, most of these
Figure 7. Three cross-sectional differential GPS profiles of a single offset alluvial fan along the Tsagaan Salaa fault. The thick grey line is a smoothed curve of GPS data. The black lines are linear regressions of the downslope data and translated upslope data.
inelastic reactions produce secondary radiation. The radiation that interacts with terrestrial material is composed almost entirely of neutrons because Earth’s dipole field deflects charged particles (Gosse, 2001).

The primary reaction that produces Be-10 in terrestrial material is called spallation. This reaction occurs when a high-energy neutron collides with a nucleus and shatters it. Lighter particles, such as Be-10, are produced from this collision. To calculate the production of Be-10, I used the following equation,

\[ P_{s,m}(Z) = \Psi_{m,k}(0) C e^{-\frac{Z}{\Lambda_f}}, \]

where \( P_{s,m} \) is spallation rate, \( \Psi_{m,k}(0) \) is the production rate of species \( m \) by spallation of element \( k \), \( Z \) is the units of cumulative mass traversed, and \( \Lambda_f \) is the apparent attenuation length of the energetic cosmic-ray particles for the integrated flux. This calculation assumes a reference condition of a flat plane at sea level and high latitude. The variables are determined empirically and must be corrected for spatial and temporal factors, described below.

The production rate of terrestrial cosmogenic nuclides varies spatially on several scales of observation (Fig. 8). At the largest scale, production rate increases as a function of latitude due to the reduced effect of the Earth’s magnetic field (Lal, 1991). Increasing altitude reduces the effect of atmospheric deflection, which also increases the production rate (Gosse, 2001). Shielding due to local topography is another factor that affects the rate of terrestrial cosmogenic nuclide production. Given a sufficiently high horizon angle, a significant portion of incident radiation will be blocked (Dunne et al., 1999).

However, since most radiation particles have an incident angle near 90°, it is not necessary
Figure 8. Spatial variation of terrestrial cosmogenic nuclide production. 

to consider the effect of topography unless the horizon angle is >20° (Frankel, pers. comm.) At the scale of sample collection, the production rate within Earth materials decreases with distance from the exposed side of the sample (Gosse, 2001). Seasonal cover (generally snow) also has an impact on production rates; snow-covered materials have lower production rates, since they do not experience direct exposure to cosmogenic radiation during part of the year (Gosse, 2001).

The production rate of terrestrial cosmogenic nuclides is also variable over the time-scale of many geologic processes. The intensity of cosmic radiation is fairly constant over periods of 10 million years or less (Vogt et al., 1990, Caffee 1988, Lavielle 1999 in Gosse 2001). The only exception to this observation is the occurrence of supernovae, which can cause significant variations in primary radiation over very short (< 1 Myr) periods of time (Gosse, 2001). The interplanetary magnetic field, generated by the sun, deflects a significant portion of primary radiation (Gosse, 2001). The magnitude of this deflection changes with solar variations such as sunspots and solar flares (Beer et al., 1991). The temporal variation of the Earth’s dipole field impacts the level of radiation. For sites above 30° latitude, no correction is necessary because the variation due to the magnetic field is less than the calculated empirical error (Gosse, 2001). Climate can also influence the production of terrestrial cosmogenic nuclides. For example, a change in atmospheric composition or thickness may affect the amount of incident radiation and, by extension, nuclide production (Gosse, 2001). Topographic shifts resulting from long-term climate variation may impact the shielding of a given site.
Data Collection and Analysis

I collected samples from six quartz-rich boulders in a single alluvial fan that is offset by the Tsagaan Salaa fault. Boulders are ideal sampling targets because their size increases the probability of a constant exposure history and decreases the likelihood of movement or cover by wind, water, or gravity. For the same reason, I attempted to sample boulders that showed signs of low erosion rates such as glacial polish or a high amount of lichen growth. In my calculations I corrected for five factors, as recommended by Gosse et al. (2001). I carried out spatial corrections for altitude, latitude, and topographic shielding, using the model of Lal (1991). To determine whether topographic shielding corrections were necessary, I took sightings of the horizon at each sample location using a handheld altimeter. Due to the lack of reliable weather data for my field site, I did not correct for snow cover. Furthermore, the exposure age of this alluvial fan (>1,000 years) is large enough to trivialize the effect of seasonal cover (Frankel, pers.comm.).

Results

Samples were prepared in Dr. Kurt Frankel’s lab at Georgia Tech University; mass spectrometry analysis was carried out at the Lawrence Livermore National Laboratory. Results were graphed on a probability density plot, yielding an average age of $35 \pm 5$ ka (Fig. 9). This value is much older than expected. Based on quantitative geomorphologic factors such as stream dissection, the weathering of cobbles, and the relative surface roughness of the fan, I estimated the age of the fan to be $7.5 \pm 2.5$ ka (Bull, 1991; Frankel and Dolan, 2007; Ritter et al., 1993). The discrepancy between these ages may be due to the low rate of erosion in Mongolia’s arid climate.
Figure 9. Probability density plot of cosmogenic dates from the alluvial fan offset by the Tsagaan Salaa thrust fault. Peak corresponds to a mean age of 35 ka.
DISCUSSION

Local slip rates

Based on the cosmogenic age of 35 ± 5 ka, my data yields an uplift rate of 0.1 ± 0.05 mm/yr on the Tsagaan Salaa fault. Using the measured dip of 22°-30° this translates to a shortening rate across the fault of 0.3 ± 0.05 mm/yr, directed NE-SW (Fig. 10).

This rate is two orders of magnitude slower than the shortening rates across major thrust faults in the Himalaya, such as the estimated 22 ± 7 mm/yr rate across the Main Central Thrust in Nepal (Kohn, 2004). The Mongolian Altai are about 2,000 km away from the Himalaya proper. Thus, it is not surprising that the shortening rate on this structure is less than the shortening rate across the major structures of the Himalayan orogenic belt. Despite this slow slip rate, the shortening across the Höh Serh fault system directly accommodates deformation caused by the Himalayan orogeny; the NW-striking Tsagaan Salaa thrust is similar in orientation to many of the major thrusts in the Himalaya proper.

The Tsagaan Salaa fault and the Höh Serh fault are most likely a single structure at depth. South of the field area, a single structure commonly accommodates both strike-slip and dip-slip motion, while within the field area, strain is partitioned. Strain partitioning is fairly common in large-scale transpressional and transtensional settings (Sylvester, 1988). This distribution of strain often takes the form of a flower structure or palm tree structure, where a single subvertical feature at depth is expressed at the surface as a subvertical strike-slip fault and several subparallel shallow thrust faults (Sylvester, 1988; Bayasgalan et al., 1999). Such structures are generally symmetric or close to symmetric in cross-section (Sylvester, 1988). In this particular case, however, it appears
Figure 10. Diagram showing the calculation of shortening rate across the Höh Serh fault system. Dip is from Cunningham (2003). The shortening rate can be calculated using the dip and the uplift rate.
that the structure is asymmetric, with only the Tsagaan Salaa fault branching off of the main Höh Serh fault (Fig. 11). Based on aerial photography, there is no obvious geometric reason for the transition from oblique faulting to partitioned motion along the Höh Serh fault system.

Though the offset of the alluvial fan on the Tsagaan Salaa fault appears continuous, the scarp may actually be the result of multiple ruptures. Another alluvial fan surveyed south of the field area (on the unpartitioned section of the Höh Serh fault) is vertically offset by $2.75 \pm 0.5$ m, about half the offset measured on the Tsagaan Salaa fault (Sprajcar, pers. comm.). Similarly, the strath terraces in Big Gorge are separated by ~2.5 m. Assuming that the Höh Serh fault and the Tsagaan Salaa fault are a single structure at depth, these offsets suggest that the scarp surveyed in this study records at least two rupture events.

**Regional context**

The cause of large-scale faulting in Mongolia is the subject of great debate. As noted, left-lateral faulting in the Gobi Altai is oriented E-W, while dextral faults in the Mongolian Altai strike NW-SE. This fault pattern has been interpreted in two ways: as conjugate faults related to regional escape tectonics and as features controlled primarily by local anisotropy and crustal block geometry.

At a regional scale, these faults are consistent with the pattern expected from Himalayan tectonics (Molnar, 1975). The EW-striking sinistral faults in the Gobi Altai are similar to large escape structures in China, such as the Altyn Tagh fault, that allow movement of crustal material to the east (Fig. 1). Early authors struggled to explain the relationship between faulting in the Gobi Altai and the NNW-striking dextral faulting in
Figure 11. Flower structures a. Typical flower structure, adapted from Sylvester (1988). b. Hypothetical subsurface structure of Höh Serh fault system.
the Mongolian Altai (Molnar, 1975). Despite the apparent kinematic similarities between the Mongolian Altai and the Red River fault, faults in the Mongolian Altai lack geologic evidence of the offset and rotation expected from extrusion tectonics. Given the relative geometry of the Mongolian Altai and the Gobi Altai, previous authors have been tempted to interpret them as a large-scale system of conjugate faults. However, given the direction of shortening, the expected strike of left-lateral faulting is NE-SW, not EW, as seen in the Gobi Altai (Fig. 12).

The alternative explanation suggests that the orientation of faulting in Mongolia is due to anisotropy in the Paleozoic metasediments of the Mongolian Altai and Gobi Altai and to the geometry of local crustal blocks (Cunningham, 2005) (Cunningham, 2005; Cunningham et al., 2003; Walker et al., 2006). The metamorphic grain of the basement rocks in the Mongolian Altai and the Gobi Altai is subparallel to the orientation of Cenozoic faults, suggesting that active faulting exploits existing planes of weakness (Cunningham et al., 2003; Walker et al., 2006). The work of Cunningham (2005) indicates that the geometry of the Hangay Dome and the Junggar Block, two relatively strong crustal blocks underlain by Precambrian crust, also influence the pattern of faulting in Mongolia (Fig. 13). Younger terranes appear to arc around the Hangay Dome (Fig. 2; Badarch et al., 2002), suggesting that the competent block caused the terranes to bend as they were accreted. Thus, the Mongolian Altai are oriented NNW while the Gobi Altai strike EW around two sides of the Hangay Dome (Cunningham, 2005; van Hinsbergen et al., 2008).

These two theories are not entirely inconsistent. Donath (1961) showed that shear fractures tend to form subparallel to planes of anisotropy, given that these planes are
Figure 12. Application of conjugate faulting to Mongolian tectonics a. Orientation of faulting in Mongolian Altai and Gobi Altai b. Expected orientation of faulting for NNE-directed SHmax. Dotted lines show strike of faults in Mongolia. Note that the variation is within the angular range (60° from $\text{SH}_{\text{max}}$) given by Donath (1961).
Figure 13. Schematic of Mongolian transpression controlled by crustal blocks, adapted from Cunningham et al. (2003). NNE-directed $S_{Hmax}$ is result of Himalayan orogeny.
within 60° of the direction of maximum compression. Faults in the Mongolian Altai are 45° from the direction of shortening; faults in the Gobi Altai are 60° from the direction of shortening (Fig. 12). Thus, given the orientation of the metamorphic grain and the influence of rigid crustal blocks, the pattern of faulting in Mongolia is an expected result of NNE-directed shortening due to the Himalayan orogeny.

CONCLUSIONS

Understanding intraplate strike-slip faults is crucial in characterizing the deformation associated with continental collisions. This study considers the Höh Serh fault system in the Mongolian Altai, an intraplate strike-slip fault resulting from broad distribution of deformation related to the Himalayan orogeny. Through field observations and differential GPS surveying along the main strike-slip fault and the Tsagaan Salaa thrust splay, I characterize the reverse component of motion along the faults. Offset of alluvial fans and drainages may record multiple ruptures of the fault. Based on cosmogenic dating and topographic surveying, the estimated shortening rate across the fault is 0.3 ± 0.05 mm/yr. This low value is consistent with the great distance between Mongolia and the main zone of Himalayan deformation. Though the pattern of faulting in Mongolia may seem anomalous, it can be explained by the interaction of NNE-directed shortening, crustal anisotropy, and the geometry of local crustal blocks.

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APPENDIX A: GPS COORDINATES OF FAULT FIELD EXPRESSION

<table>
<thead>
<tr>
<th>Fault</th>
<th>Feature</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
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<tbody>
<tr>
<td>Höh Serh</td>
<td>Figure 4a: saddle</td>
<td>48.06367N</td>
<td>90.80079E</td>
</tr>
<tr>
<td></td>
<td>Figure 4b: contact between granite and phyllite</td>
<td>48.11131N</td>
<td>90.76793E</td>
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<tr>
<td></td>
<td>Figure 4c: tension gashes</td>
<td>48.18982N</td>
<td>90.71160E</td>
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<tr>
<td></td>
<td>Figure 4e: wind gap</td>
<td>48.12179N</td>
<td>90.76332E</td>
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<tr>
<td>Tsagaan Salaa</td>
<td>Figure 5a: fault scarp</td>
<td>48.09798N</td>
<td>90.71220E</td>
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<tr>
<td></td>
<td>Figure 5c: gouge zone</td>
<td>48.05398N</td>
<td>90.76556E</td>
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<tr>
<td></td>
<td>Figure 5d: strath terraces</td>
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<td>&quot;</td>
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