Reinterpretation of the active faulting in central Mongolia

R.T. Walker
E. Nissen
Centre for the Observation and Modelling of Earthquakes and Tectonics (COMET),
Department of Earth Science, University of Oxford, Parks Road, Oxford OX1 3PR, UK
E. Molor
A. Bayasgalan
Mongolian University of Science and Technology, Ulaanbaatar, Mongolia

ABSTRACT

We present remote-sensing and field observations of an ~350-km-long east-west left-lateral strike-slip fault (the South Hangay fault) in the Hangay Mountains of central Mongolia, an area previously believed to be deforming solely by slip on scattered, and randomly oriented, normal faults. The known dip-slip faults are shown to be short segments introduced at bends in the much longer strike-slip fault. Our observations show that the active faulting in the Hangay Mountains is consistent with the regional strain field of Mongolia and does not require, as suggested in other studies, that the faults result from stresses introduced by the locally elevated topography. Our observations help to define the active tectonics of this important part of the India-Eurasia collision. The South Hangay strike-slip fault is a potential source of large-magnitude earthquakes and constitutes a previously unrecognized hazard in this part of Mongolia.

Keywords: Mongolia, Hangay, active faulting, strike slip, continental deformation.

INTRODUCTION

Western Mongolia and adjacent parts of China, Kazakhstan, and Siberia accommodate ~10 mm/yr of the shortening between India and Eurasia (Fig. 1; Calais et al., 2003). Although the onset of shortening in Mongolia is thought to date from the Oligocene, many of the ranges are younger than 10 Ma (Vassallo et al., 2006). The India-Eurasia collision appears to have propagated northward through time (Baljinnyam et al., 1993; Vassallo et al., 2006), and offers the chance to study both the temporal and spatial evolution of a continental collision. We focus on the active faulting within the central Mongolia Hangay Mountains, an enigmatic dome-shaped range often thought to result from dynamic uplift above a hot upwelling mantle. As well as helping to define the active tectonics of this important part of the India-Eurasia collision, we investigate whether active faulting in the Hangay region is consistent with the regional strain field of Mongolia or whether the faults result from stresses introduced by the locally elevated topography.

North-south shortening in western Mongolia is accommodated by a combination of right-lateral strike-slip and counterclockwise vertical axis rotation of crustal blocks within the Altay Mountains (Baljinnyam et al., 1993; Calais et al., 2003; Bayasgalan et al., 2005). Global positioning system (GPS) measurements show central Mongolia to be moving eastward with respect to Siberia (stable Eurasia). The resulting E-W left-lateral shear is manifested in the Bulnay strike-slip fault in the north of the country and faults of the Gobi-Altay in the south (Fig. 1A). The Hangay Mountains occupy the region between these two fault systems. The origin and late Cenozoic tectonics of the Hangay region are not well understood at present.

The dome-shaped Hangay Mountains reach elevations up to 4000 m and are capped by a regionally extensive Late Cretaceous erosion surface. Correlation of this erosion surface with counterparts in the basins south and west of the Hangay Mountains suggests ~2000 m of surface uplift. At present, there are no firm data on the duration and timing of this uplift, though an increase in clastic sedimentation in surrounding basins in the mid-Oligocene (ca. 25–30 Ma) is inferred to mark the onset of the Hangay Mountains as a sediment source (Yanshin, 1975). The origin of the elevated topography of the Hangay is not clear. The presence of a hot upwelling mantle is suggested on the basis of widespread Pliocene–Quaternary basaltic volcanism (e.g., Windley and Allen, 1993). However, there is no indication of the corresponding gravity anomaly that would result from dynamic support from an upwelling mantle (Bayasgalan et al., 2005). An alternative explanation for the elevated topography of the Hangay Mountains is the presence of underplated magmatic rocks (e.g., Petit et al., 2002; Bayasgalan et al., 2005), though this hypothesis has yet to be tested.

Active normal faults were mapped within the Hangay region (e.g., Zorin et al., 1982; Baljinnyam et al., 1993; Cunningham, 2001). Most of the mapped normal faults are oriented NE-SW. The NW-SE extension on these faults is compatible with the regional strain field. However, some of the mapped normal faults trend E-W or NW-SE, implying a NE-SW extension direction that is incompatible with the regional strain. The active faulting is thus interpreted as a result of localized stresses introduced from surface uplift (Baljinnyam et al., 1993; Cunningham, 2001). We present new field and remote-sensing observations that allow a reinterpretation of the active faulting.

SOUTH HANGAY STRIKE-SLIP FAULT

In the following section, we describe the evidence for a previously unidentified left-lateral strike-slip fault in the Hangay region (Fig. 1B). The strike-slip fault forms a continuous system extending for ~350 km between long 95.5°E and 100.5°E and shows clear evidence for movement in the late Quaternary.

Perhaps the clearest evidence for active left-lateral faulting is seen near the village of Bayan Bulag, where Cunningham (2001) identified several short faults. These faults have clear scarps in bedrock and alluvium with striations showing almost pure normal faulting. However, detailed analysis of advanced spaceborne thermal emission and reflection radiometer (ASTER) satellite imagery reveals that these short normal faults are actually part of a much larger fault system (Fig. 2A). A south-facing normal fault scarp is visible 1.5 km north of Bayan Bulag. The topographic expression of this fault ends at ~98º6' E. However, the fault continues farther east as a series of right-stepping depressions aligned obliquely to the local 80º trend of the fault (Fig. 2A). Figure 2C is a close-up of the

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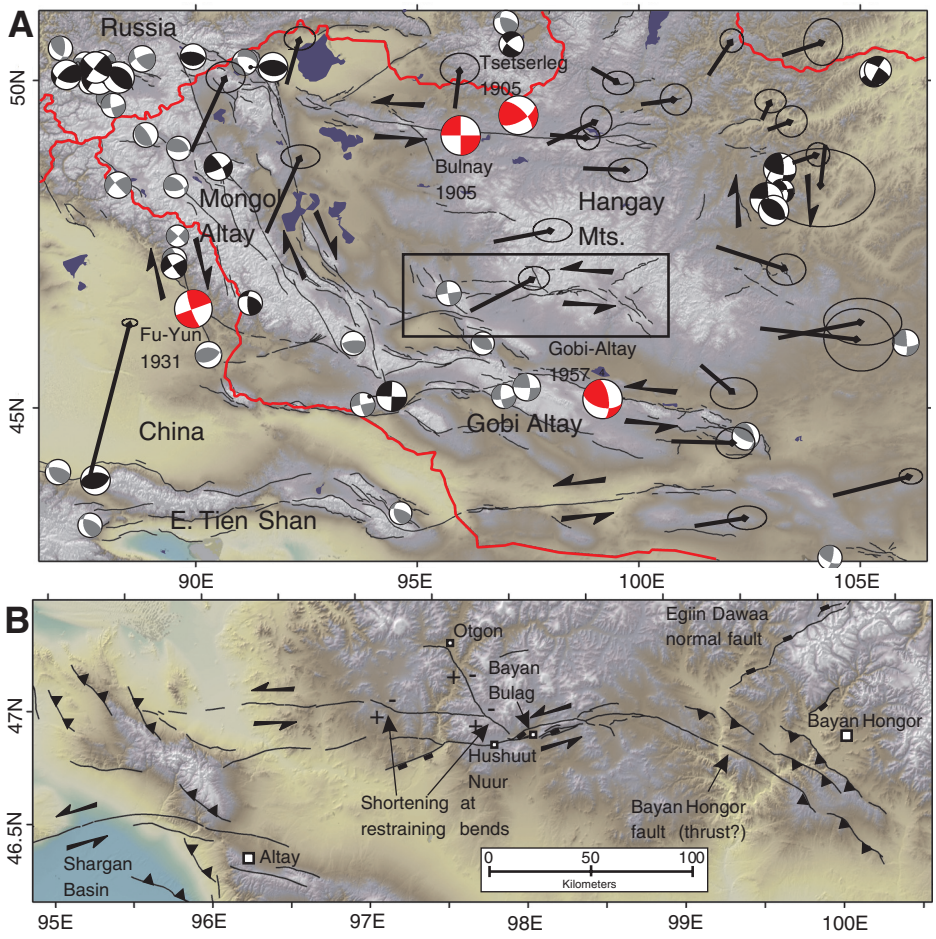


Figure 1. A: Shaded relief Shuttle Radar Topography Mission (SRTM) topography (Farr and Kobrick, 2000) of western Mongolia and surrounding parts of China and Russia. Black lines—active faults. Black arrows—global positioning system velocities of points measured relative to Irkutsk in Siberia. Fault-plane solutions of earthquakes are from Bayasgalan et al. (2005, and references therein). Gray solutions represent those from Harvard CMT (centroid moment tensor) catalog. Black solutions represent those where source parameters are delimited by P and SH body-waveform modeling. Four red solutions represent the four M >8 earthquakes that have occurred in Mongolia and its immediate surroundings in the twentieth century. Box represents the region shown in B. B: Shaded relief SRTM topography of South Hangay strike-slip fault. White rectangles—major towns and locations referred to in text.

ASTER image showing the fault trace. Figure 2B shows a field photograph of the right-stepping depressions where they cross the Bayan Bulag River. We interpret these depressions as the preserved remains of tensional fissures generated by slip on the fault. The nearest fissure in the photograph is 15–20 m long, 2–3 m wide, and is oriented at an azimuth of 65°. It is almost completely infilled and identified only by the relatively lush green vegetation within it. The orientation of the right-stepping fissures with respect to the local trend of the fault is indicative of left-lateral slip. These fissures are similar in appearance and scale to paleo-earthquake ruptures observed in many places around Mongolia (Baljinnyam et al., 1993; Walker et al., 2006).

A second strand of the fault passes just to the south of Bayan Bulag, and is clearly visible on ASTER satellite imagery (Fig. 2A). Series of small ponds and springs, along with the lack of topography across the fault, suggest strike-slip motion. This southern strike-slip fault traces eastward toward the Bayanbulak Valley scarps, which were identified as normal faults by Cunningham (2001) on the basis of downdip striations preserved on granites exposed in the scarp. The normal faults are clearly visible in ASTER imagery. The ASTER satellite imagery also reveals more details of the active faulting. The southwest of the two Bayanbulak Valley fault segments trends ~ENE. However, a low scarp, with a trend of ~100°, can be seen continuing eastward from the end of the previously mapped fault (Fig. 2D). Alluvial fans have been uplifted and incised on the north side of the scarp (Figs. 2A, 2D). Farther east, the fault, which is visible as a discontinuous dark line on the imagery, continues ~2 km to the south of, and parallel to, the main Bayanbulak normal fault. There is very little topography across this previously unidentified strand of the Bayanbulak Valley fault, which therefore appears to have a main strike-slip component. It is likely that normal and strike-slip components of slip are spatially separated (partitioned) onto separate surface structures that meet at depth. A similar spatial separation is likely to occur along the normal fault identified directly north of Bayan Bulag, though in this case the parallel normal and strike-slip strands are separated by only ~10 m at the surface. Partitioning of dip-slip and strike-slip components onto separate structures at the surface has been noted in other localities, such as the 2001 Kokoxili earthquake in Tibet (King et al., 2005; Klinger et al., 2005).

Spectacular evidence of left-lateral faulting is also preserved ~10 km west of Bayan Bulag at Hushuut Nuur (Fig. 3A). Alternating sag ponds and pressure ridges track across an otherwise featureless plain. The sag ponds are typically 10–20 m in diameter, though some are larger (Fig. 3B). Most are almost circular in shape, though a slight elongation at an azimuth of 80° was seen in some cases, which is roughly parallel to the trend of the fault as a whole. Hushuut Nuur, which translates as Monument Lake, is a large, ~500-m-diameter sag pond formed at a left step in the fault trace (Fig. 3A). Pressure ridges are between some, though not all, of the sag ponds. We visited one of the ridges (visible in the background of Fig. 3B). The ridge is <10 m high and is elongated along an azimuth of 100°–110°, slightly oblique to the local 80° trend of the fault. In contrast to the infilled fissures identified at Bayan Bulag, the size of the geomorphic features identified at Hushuut Nuur suggests that they are composite features resulting from more than one earthquake.

East of Bayan Bulag, the faulting continues as E-W–striking parallel scarps that eventually bend NW-SE and join the Bayan Hongor fault zone (Fig. 1B). The active faults can be traced easily on satellite imagery and in the field, and are manifest either as continuous scarps or as a series of alternating sag ponds and pressure ridges. Our field investigation did not extend west of long 97°E. However, indications of active left-lateral strike-slip faulting visible in satellite imagery continue for a further ~100 km to long 95.5°E, where the faults join with a system of NW-SE thrust faults (Fig. 1B).

BAYAN HONGOR AND OTGON FAULTS

We have shown that many of the known normal faults of the southern Hangay region are, in fact, only small parts of a large left-lateral strike-slip fault. The NE-SW trend of these normal faults is consistent with their situation at

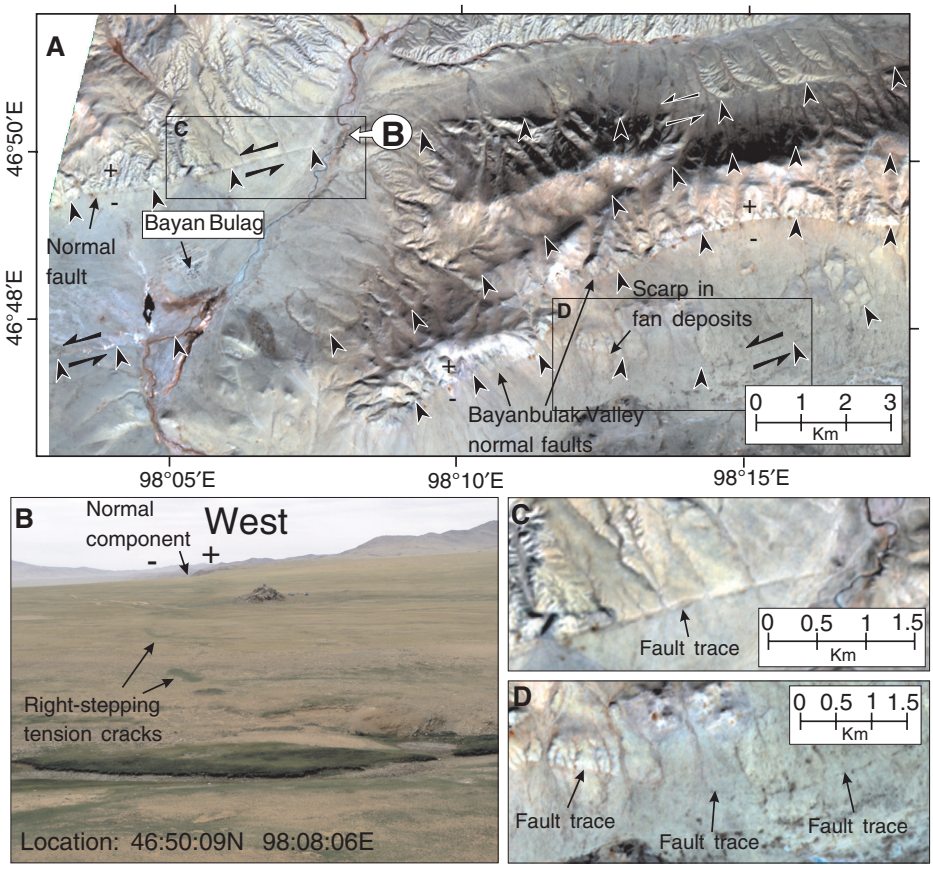


Figure 2. A: Advanced spaceborne thermal emission and reflection radiometer (ASTER) image (acquisition date 2003:09:25, band 3n,2,1) of South Hangay fault at Bayan Bulag (see Fig. 1B for location). Active faults are marked by black arrows. B: Field photograph looking west along the fault north of Bayan Bulag (see Fig. 1A for location). Right-stepping tension cracks show left-lateral slip. Larger version of photograph is included as Figure DR1A (see footnote 1). C: Close-up ASTER image of the fault north of Bayan Bulag (see A for location). D: Close-up ASTER image of the fault east of Bayan Bulag (see A for location).

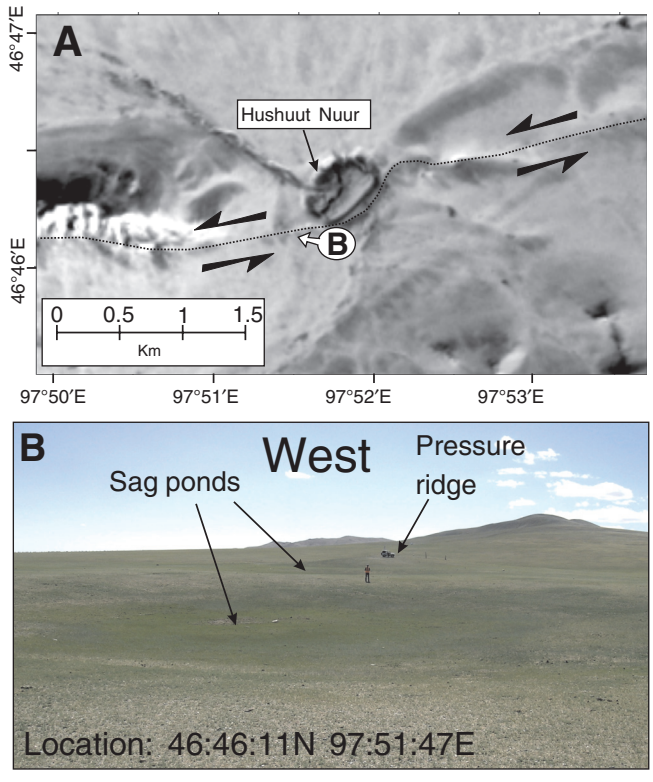


Figure 3. A: Close-up advanced spaceborne thermal emission and reflection radiometer (ASTER) imagery (acquisition date 2006:02:21, bands 3n,2,1) of faulting at the Hushuut Nuur releasing bend (see Fig. 1B for location). B: Field photograph looking west of sag ponds aligned along the fault trace. Car in distance is parked on a low-pressure ridge. Larger version of photograph is included as Figure DR1B (see footnote 1).

releasing bends along the strike-slip fault. Two other fault systems within the southern Hangay region are described in further detail, including detailed images and field photos, in the GSA Data Repository.[1]

The sense of slip on the Bayan Hongor and Otgon faults has major implications for the interpretation of active faulting in the Hangay. These faults are two of the few known faults in the Hangay region with a NW-SE trend. The Bayan Hongor fault has been interpreted either as a thrust (Baljinnyam et al., 1993) or a normal fault (Cunningham, 2001). If it is a normal fault, its NW-SE trend is not compatible with a regional E-W left-lateral shear.

From analysis of satellite imagery, and brief field investigation (see footnote 1), we are confident that the Bayan Hongor fault is a thrust fault forming at a restraining bend at the eastern end of the South Hangay strike-slip system. The sense of slip on the NW-SE Otgon fault is less clear. The fault appears to have components of both dip slip and right-lateral strike slip. From our field observations, we could not distinguish whether the dip slip results from a normal or reverse component. However, the southern part of the fault is located at a restraining bend on the left-lateral E-W South Hangay system (Fig. 1B), and it presumably accommodates shortening within this restraining bend. The orientation and suggested sense of slip on the Otgon fault are somewhat similar to the Teregtiyn (reverse and right lateral) and Dungen (right lateral) ruptures branching from the main E-W left-lateral surface breaks of the 1905 Bulnay earthquake (e.g., Balyinnjam et al., 1993). Presumably the Otgon fault is related to the South Hangay fault in a similar way that the Dungen and Teregtiyn segments are related to the Bulnay fault.

[1]GSA Data Repository item 2007191, description of the Bayan Hongor and Otgon faults, and supporting maps and field photographs (Figs DR1–DR4), is available online at www.geosociety.org/pubs/ft2007.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

DISCUSSION

We have shown that the previously identified normal faults of the south Hangay Mountains are connected by an ~350 km strike-slip fault system. That the South Hangay strike-slip fault has not previously been described is perhaps no surprise; strike-slip faults are, by their very nature, more difficult than dip-slip faults to identify because they produce less topography. The presence of the South Hangay fault has two major implications.

First, the realization that active faults of the Hangay accommodate E-W left-lateral shear is important for descriptions of the active tectonics. The previous interpretation of scattered, randomly oriented, normal faulting cannot accommodate the pattern of distributed E-W left-lateral shear in central Mongolia shown by GPS measurements (Calais et al., 2003; see Fig. 1A). The inconsistency between the observed pattern of faulting and the regional strain field was thought to arise from stresses local to the Hangay Mountains, the obvious candidate for these stresses being the elevated topography (Baljinnyam et al., 1993; Cunningham, 2001). The presence of scattered normal faulting has hence strongly suggested that doming of the Hangay region is ongoing (Cunningham, 2001). Our new results show the faults are entirely consistent with the regional strain field. The faulting in the Hangay area is still noticeably different from that observed within the Gobi-Altay to the south, where mountains have formed along prominent restraining bends (e.g., Ritz et al., 1995; Cunningham et al., 1997; Bayasgalan et al., 1999). The South Hangay fault and to a lesser extent the Bulnay fault in the northern Hangay region are typified more by releasing bends (Fig. 1A). It is possible that releasing bends along the South Hangay strike-slip fault, and additional NE-SW–trending normal faults, such as the Egiin Dawaa fault (Fig. 1B), within the interior of the mountains form as a result of localized stresses within the Hangay Mountains. However, we have shown that they are capable of accommodating the regional strain field, so there is no requirement for the NE-SW normal faults to result from localized stresses, and it is just as likely that the pattern of faulting is controlled by some other process, such as the presence of preexisting NE-SW weaknesses. There is, therefore, no real evidence from the active faulting that doming of the Hangay Mountains is active.

The South Hangay fault presents a newly identified hazard in a part of Mongolia that was, until now, thought to contain only scattered and relatively short faults. Strike-slip faults of a similar length to the South Hangay fault have generated four great (>M 8) earthquakes in the twentieth century in Mongolia and its surroundings (Fig. 1A; Baljinnyam et.al. 1993; Kurushin et al., 1997). The south Hangay region is relatively densely populated for Mongolia; there are several towns and villages situated along the fault. Further investigation of the record of past earthquakes is required to fully estimate the hazard posed by the South Hangay fault.

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