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A transect of quaternary geological slip rates in the Kazakh Tien Shan


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Abstract: Large faults in the Tien Shan give rise to significant seismic hazard for cities in Kazakhstan, Kyrgyzstan and China, but as yet little is known about fault slip rates and the relative importance of the various structures in the region, so seismic hazard is poorly constrained. We present here a systematic approach to constrain fault slip rates throughout the region through dating of quaternary geomorphic features offset by fault motion. We apply this to a N-S transect of seven faults in eastern Kazakhstan, linking in several places to the most recent surface-ruptures on the faults also. These slip rates provide an estimate of the distribution of tectonic shortening across the region beyond the resolution limit of geodetic methods.

Key words: Kazakhstan, Tien Shan, Slip rate, Shortening.

INTRODUCTION

The mountain ranges of central Asia (Pamir, Tien Shan, Borohoro Shan, Dzungarian Alatau, and the Kazakh and Mongolian Altai) represent the northermmost expression of the India-Eurasia collision zone (Molnar and Tapponnier, 1975; Tapponnier and Molnar, 1979; Bullen and Burbank, 2001). The intense deformation in the Himalaya has concealed or destroyed much of the evidence from the early stages of continental collision. Mountain building in the far-field regime (with less cumulative deformation) can however provide a sensitive measure of processes going on at the collision front.

Central Asia is also an under-studied area of potentially high seismic risk, with low strain rates, poor historical records and rare but damaging high magnitude earthquakes. In the past couple of centuries there have been a number of large (Mw >7) destructive earthquakes in the region (Bagdanovich et al., 1914; Ghose and Mellors, 1997) but only a small fraction of the known active faults have failed in recorded history. Few mapped faults have known slip-rates and many more faults are still unmapped. Due to a lack of slip-rate data and incomplete mapping, current seismic hazard assessments are based entirely on instrumental seismicity and geodetic observations. However, with earthquake recurrence intervals of typically several thousand years and fault strain rates below the geodetic resolution limit, the instrumental record only samples a very small fraction of the seismic cycle.

In Kazakhstan, the compressional mountain building is separated into two discrete bands, the high Tien Shan and the Dzungarian Alatau, between them accommodating a significant fraction (around one quarter) of the ~35 mm/yr India-Eurasia convergence (Abdrakhmatov et al., 1996). This tectonic shortening is accommodated by a series of E-W oriented thrust faults and conjugate strike slip faulting. Identifying the fastest moving and most important faults can give us an insight into seismic hazard assessment and, in combination with thermochronology data, the initiation, growth and propagation of mountain building.

Here we construct a transect of geological shortening rates across the Kazakh and Kyrgyz Tien Shan and the Dzungarian Alatau (shown by the line A-A’ in figure 1). In this slowly deforming region (< 8 mm/yr across at least 8-10 faults), we aim to compare the rates of geological shortening with those indicated by geodetic data through the region. This will also allow us to determine which faults are likely to be the most seismically active and, in combination with palaeoseismology, estimate possible earthquake magnitudes and recurrence intervals on the faults.

Two similar studies have previously been carried out further to the west, in Kyrgyzstan, by Thompson (2002) and in an unpublished thesis (Ray Weldon, pers. comms.). Older studies completed before modern dating techniques were available were based on estimated alluvial fan ages from climate records – these include Avouac and Tapponnier (1993), further east in the Borohoro Shan, China.

METHODS

The main aim of this work is to constrain a series of slip rates and shortening rates on the E-W striking thrust faults in a N-S profile. Initial reconnaissance by remote sensing is used to map the active faults and identify well situated sites for field studies. To that end we choose sites on each fault which display clearly displaced geomorphological markers in Quaternary material.
Figure 1: An overview of the Kazakh Tien Shan and Dzungarian Alatau in shaded relief from SRTM elevation data. Faults shown in bold are those we have performed slip-rate studies on, with the individual field sites shown in yellow. Other known active faults are also marked, with inferred faults shown as dotted lines. The Zubovich et al. (2010) regional GPS vectors (relative to fixed Eurasia) are shown with 95% confidence ellipses and the line A-A’ is the profile onto which the GPS is projected in figure 2. Labels: KK-Karkara Fault, CH-Chilik Fault, BG-Bartogay Fault, KY-Konyrolen Fault, AE-Altyrn Emel, UT-Usek Thrust, DZ-Dzungarian southern rangefront fault, SK-Sarkand Fault, LP-Lepsy Fault.
These include displaced alluvial fans, fluvial river terraces and archaeological features etc. In order to accurately quantify the morphological offsets, we use aerial photos acquired from a helium balloon to reconstruct a digital elevation model (DEM) by structure from motion (SfM) based photogrammetry (Johnson et al., 2014). We further use these DEMs to quantify earthquake surface slip distributions along strike. For the majority of our sites, we date the displaced markers by a combination of radiocarbon dating and quartz/feldspar optically/infrared stimulated luminescence (OSL/IRSL). For surfaces beyond the limit for radiocarbon, or without material for radiocarbon/OSL dating, we turn to cosmogenic dating. In some limited locations, we can also perform Uranium-Thorium dating on well stratified carbonate cements on the undersides of pebbles within the surface to be dated. Wherever possible, we use a combination of these methods.

**FAULTS**

We select 8 faults of interest in the region of this transect, as shown in figure 1, of which two have slip-rates published already (the Lepsy fault, (Campbell et al. In Rev.) and the Usek Thrust, (Cording et al., 2014), LP and UT in grey in figure 1). At each of these faults, we have 1-3 field sites. Below are described a selection of these faults:

**Karkara Rangefront (KK)**
This fault is the only one resolvable in the GPS (figure 2), which suggests that is likely to be a significant fault. Our study site here focuses on a flight of fluvial river terraces progressively offset by fault motion, by up to 60 m. Through radiocarbon dating, we find a preliminary slip rate of 1.6-3.5mm/yr, though further dating is in progress (see Mackenzie et al. this Volume for more details).

**Bartogay Fault (BG)**
At this fault a large offset of ~12m in an alluvial fan surface provides a linear marker. With a granitic catchment, this fan is a good target for dating with a cosmogenic beryllium-10 depth profile, and OSL. We have also performed trenching at this site, on a lower section of scarp to study the most recent earthquake(s) on the fault. This fault therefore provides us with an important link between the long term fault behaviour in the region and the behaviour in individual earthquakes (see Carson et al, this volume for more details).

**Dzungarian Southern Rangefront (DZ)**
One of two significant faults on the southern rangefront of the Dzungarian Alatau, this fault has in most places broken the surface in two parallel strands. Thus we choose to date a large fan surface in which we can clearly measure a total offset of ~30 m. With such large

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Figure 2: Regional GPS data from Zubovich et al. (2010) projected onto the line A-A", resolved into profile-parallel (red) and profile-perpendicular components. Stations from within 40 km either side of the profile are shown. Faults mapped in figure 1 are shown as dashed lines (see figure 1 caption for fault labels). Shown as a shaded region is the approximate projection of the subperpendicular Altyn Emel (AE) strike slip fault. We see a significant drop of ~3-4 mm/yr in the northwards (parallel) velocity across the Karkara rangefront, but the majority of the faults are unresolved. The Altyn Emel fault (AE in figure 1) may be responsible for the change in perpendicular velocity at 250-300 km. The dotted line represents a prominent fault (marked in figure 1), on which we were unable to measure a slip-rate due to poor expression in Quaternary materials – geomorphic expression does however suggest that the fault is active.
offsets it is likely that the fans are beyond the range of radiocarbon dating, but we find well-developed U-Th rinds on the undersides of boulders embedded at depths of ~0.6 m within the fan. In conjunction with an OSL sample this should give us a reliable age for the fan deposits, and hence slip-rate on the fault.

Sarkand Fault (SK)
The major northern rangefront of the Dzungarian Alatau (with exception of the Dzungarian Fault to the NE, (Campbell et al., 2013)), this fault appears to be moving more slowly than those further south. In the few locations that scarsps are visible, they are heavily degraded. Again we date a fan surface displaced by the fault, and perform an aerial survey to study the slip distribution along strike. However, the smaller scarp of ~6 m, suggests that this represents only a 2-3 earthquakes, so any slip rate estimate here will be poorly constrained. We have also sampled from several fans which are undisturbed by the fault in attempt to constrain the minimum age of the most recent event on the fault.

CONCLUSIONS

We have identified and mapped numerous faults which displace quaternary deposits across the region of SE Kazakhstan, showing that active deformation is clearly distributed across the whole region. We have also demonstrated the utility of structure-from-motion photogrammetry both in measuring individual geomorphic marker offsets and in assessing the distribution of slip along strike. Much of the dating work is still in progress, but we aim to form a relatively comprehensive study across the majority of the identifiably active structures in the region.

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