Geomorphological evidence of active faulting in low seismicity regions—examples from the Valley of Lakes, southern Mongolia

Jorien L.N. van der Wal¹, V. Nottebaum², G. Stau², F. Lehmkhul³, K. Reichert³

Background & Methods
As a result of far-field stresses related to the India-Eurasia collision, active faulting in southern Mongolia localizes on the margins of the rigid Hangay dome, in the transpressional Altai and Gobi Altai ranges. The Altai and the Hangay accommodated four M=8+ earthquakes in the last century however they are separated by the seismically quiescent Valley of Lakes. Quaternary deposits of the Tuyn Gol river, that flows into the endorheic Orog Nuur in the Valley of Lakes, are crosscut by E-W striking fault scarps that could not have formed only by the minor M=4 earthquakes recorded by instrumental seismology (Fig. 1A). To assess and quantify the tectonic activity along these Valley of Lakes faults, we evaluated the regional seismic hazard of the Valley of Lakes and the Hangay and used cosmogenic nuclides sampling to determine theurred and estimated slip rates from ages of associated fan levels determined by Be⁹⁰ cosmogenic nuclides dating. Additionally, we combined tectonic and geomorphological mapping to reconstruct landscape changes of the Tuyn Gol Valley since Middle Pleistocene times.

Results
Characterisation of fault activity
The Valley of Lakes faults (Fig. 1B) can each accommodate M=7+ earthquakes with up to ~17 m offset per earthquake (Wells & Coppersmith, 1994). Vertical offsets measured across the two surface areas of the Tuyn Gol river (see table) reflect cumulative deformation along the fault scarps. We dated this surface to be ~400 ka (black circles in Fig. 1B), and determined associated slip rates and recurrence intervals.

Landscape evolution
Assuming that alluvial fan abandonment and incision occurs at glacial-interglacial transitions that occur every ~100 kyr climate cycle (suggested for the Gobi Altai by Vassal et al., 2007 and Rizza et al., 2011), we can combine our geomorphological mapping, tectonic interpretations and cosmogenic nuclide dating (Fig. 1B) to determine a time line for landscape evolution in the Valley of Lakes (see Fig. 1C).

- No remnants of T3 are found south of F1, so F1 must have been active prior or coeval to T3 deposition.
- T2 deposition is conflated by F2, implying prior or coeval fault activity, relative to deposition.
- Palaeochannel activity likely started during the following glacial-interglacial transition. The preservation of two terrace remnants within T1 implies that F3 was active during this time. Activity of the channel lasted until after the MIS 5 (130-80 ka) lake level highstand of Orog Nuur (ON; Nottebaum et al., in review: fluvial sediments at the outlet of the palaeochannel interfere with beach ridges associated with the lake level highstand.
- Deflection from the palaeochannel (PC) to the active Tuyn Gol channel (TG), is suggested suggesting deflection of the channel by the rapidly rising lake level.
- Deposition of T0 must have occurred prior to the mid-Holocene lake level highstand (~7 ka; Nottebaum et al., in review).

Main conclusions
Faults in the Valley of Lakes are tectonically active at rates similar to surrounding systems in the Gobi Altai and Hangay, and they have played a major role in drainage network evolution since Middle Pleistocene times.

Regional tectonic geomorphology studies that span time scales longer than the paleoseismological record are essential for seismic hazard assessment in slow-slip regions with little instrumental seismicity.

Conclusions
- Kinematics of the Valley of Lakes faults fit within the regional tectonic framework.
- All faults in the Valley of Lakes can accommodate M=7+ earthquakes and have active since Middle Pleistocene times. Vertical slip rates accumulate to 0.31±0.12 mm/yr, which is of the same order as uplift along the Bogd fault; however, recurrence intervals are slow in comparison to the 3-5 kyr estimated in the Gobi Altai.
- It remains unclear how the strike slip systems of the Gobi Altai, Valley of Lakes and Hangay connect at depth. Likely, the surface expression of active faulting is related to the pre-drainage structural setting of the Altai region.
- Middle Pleistocene to modern drainage network evolution of the Tuyn Gol Valley reflects tectonic activity as well as lake level variations,
- The strong tectonic imprint on the Tuyn Gol deposits and drainage reorganisation highlights the importance of regional, long-term studies to assess the strong seismic hazard in areas of low instrumental seismicity.

Fig. 1A Tectonic setting of Mongolia in relation to structures within the Asian continent and the India-Eurasia collision; cut-out of regional historic and instrumental seismicity of Mongolia (1900-2000; adapted from Dugmansa and Schurp, 2003); b Morphological map of the Tuyn Gol Valley outlining multiple previously ungauged faults (kinematics in black; triangles indicate thrusting, arrows indicate strike-slip movement, lines indicate normal faulting), and alluvial plains associated with the Tuyn Gol fault (TG, including a paleo-channel (PC) Grey outlines indicate Orog Nuur (ON) (lake level) highstands dated by Nottebaum et al. 2016); Black N-S line indicates the location of the cross section discussed in Structural setting; SHmax is inferred from the World Stress Map (Heidbach el et al., 2016). C Time line of landscape evolution suggesting the timing of terrace and fault activity, and including lake level highstands; see Landscape evolution for further explanation of our interpretations.