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

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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 Altais 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 seismicity (Fig. 1A). To assess and quantify the tectonic activity along these *Valley of Lakes faults,* we evaluated the regional tectonic geomorphology. We analysed fault kinematics, quantified vertical offsets and estimated slip rates from ages of associated fan levels determined by Be^{10} cosmogenic nuclide dating. Additionally, we combined tectonic and geomorphological mapping to reconstruct landscape changes of the Tuyn Gol Valley since Middle Pleistocene times.

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.

Results

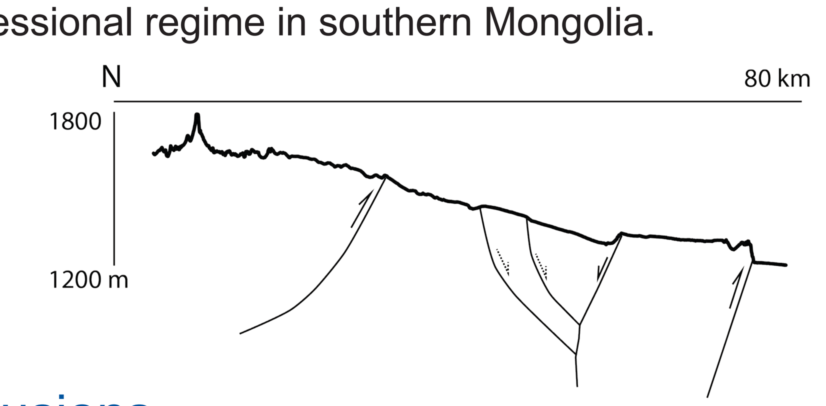
Characterisation of fault activity

The Valley of Lakes faults (Fig. 1B) can each accommodate M~7 earthquakes with up to ~1.7 m offset per earthquake (Wells & Coppersmith, 1994). Vertical offsets measured across the T3 surface east 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.

Fault	Fault length (km)	Moment magnitude	Measured offset (m)	Recurrence interval (kyr)	Slip rates (mm/yr)
F1	62.12	7.19	52.2±22.37	5.68±2.67	0.15±0.06
F2	67.19	7.27	31.70±7.97	16.80±4.36	0.09±0.03
F3	41.08	6.95	4.87±2.45	*~76.77*	0.01±0.005
F4	85.08	7.32	20.36±10.5	40.82±24.11	0.06±0.02

Structural setting

The kinematics of the Valley of Lakes faults (Fig. 1B) fit well with the NW-SE direction of maximum principal stress. Although lateral offsets cannot be quantified from morphotectonic observations, we interpret the faults to reflect a strike-slip regime (see figure below) similar to, however more widespread, than in the Gobi Altai. The regional spread of deformation is likely related to differential subsurface structures that are overprinted by the Cenozoic to modern transpressional regime in southern Mongolia.



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 Vassallo 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 confined by F2, implying prior or coeval fault activity, relative to deposition.
- Paleochannel activity likely started during the following glacial-interglacial transition. The preservation of T2 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 paleochannel interfere with beach ridges associated with the lake level highstand.
- Deflection from the paleochannel (PC) to the active Tuyn Gol channel (TG), with subsequent formation of Holboliin Nuur by activity along F2 followed.
- Deposition of T0 must have occurred prior to the mid-Holocene lake level highstand (~7 ka; Nottebaum et al., in review).

Conclusions

- Kinematics of the Valley of Lakes faults fit within the regional tectonic left-lateral strike-slip regime.
- All faults in the Valley of Lakes can accommodate M~7 earthquakes, and have been active since 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 Altiai, Valley of Lakes and Hangay connect at depth. Likely, the surface expression of active faulting is related to the overprinting of preexisting crustal structures.
- Middle Pleistocene to modern drainage network evolution of the Tuyn Gol Valley reflects tectonic activity as well as lake level variations in the Orog Nuur Basin.
- The strong tectonic imprint on the Tuyn Gol deposits and drainage reorganisations highlights the importance of regional, long-term studies to assess the seismic hazard in areas of low instrumental seismicity.

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References

Heidbach, O., Rajabi, M., Reiter, K., Ziegler, M., WSM Team (2016). World Stress Map Database Release 2016, V. 1.1. GFZ Data Services

Nottebaum, V., Stauch, G., van der Wal, J.L.N., Zander, A., Reicherter, K., Batkhishig, O., Lehmkuhl, F. (in review). Sedimentary system interaction in endorheic basins during the late Quaternary: the Orog Nuur Basin in southern Mongolia, submitted to Earth Surface Processes and Landforms, 2020

Rizza, M., Ritz, J. F., Braucher, R., Vassallo, R., Prentice, C., et al. (2011). Slip rate and slip magnitudes of past earthquakes along the Bogd left-lateral strike-slip fault (Mongolia). Geophysical Journal International, 186(3), 897–927

Vassallo, J.F. Ritz, R. Braucher, M. Jolivet, S. Carretier, et al., 2007; Trans- pressional tectonics and stream terraces of the Gobi-Altay, Mongolia. Tectonics, American Geophysical Union (AGU), 2007, 26 (5), pp.TC5013

Wells, D. L., & Coppersmith, K. J. (1994). New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. Bulletin of the Seismological Society of America, 84(4), 974–1002

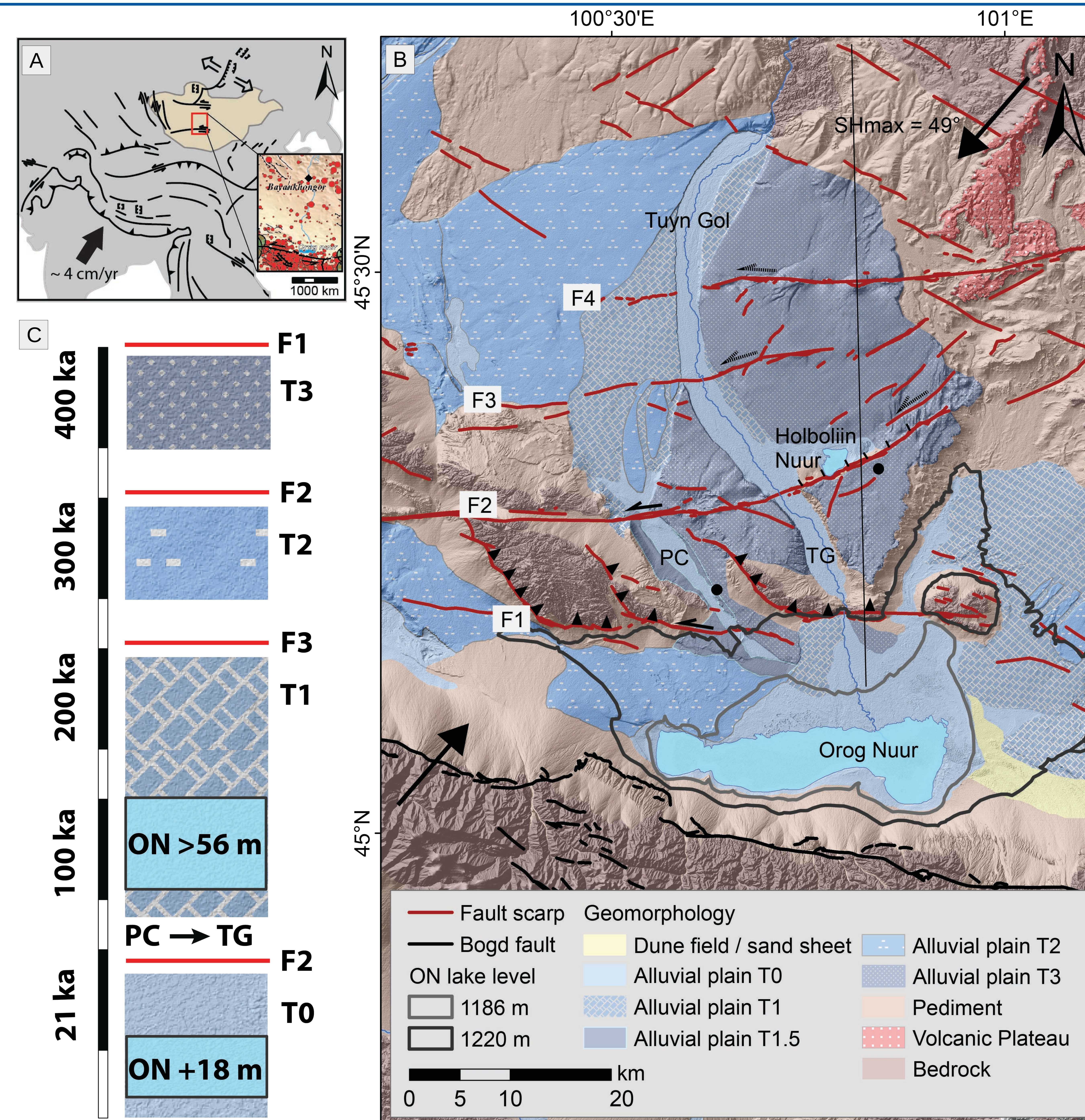

Fig. 1 A) Tectonic setting of Mongolia in relation to structures within the Asian continent and the India-Eurasia collision; cut-out of regional historic and instrumental seismicity of Mongolia (1900-2000; adapted from Dugarmaa and Schlupp, 2003); B) Morphotectonic map of the Tuyn Gol Valley highlighting multiple previously unmapped faults (kinematics in black: triangles indicate thrusting, arrows indicate strike-slip movement, lines indicate normal faulting), and alluvial plains associated with the Tuyn Gol (TG), including a paleochannel (PC). Grey outlines indicate Orog Nuur (ON) lake level highstands dated by Nottebaum et al (in review). Black N-S line indicates the location of the cross section discussed in ‚Structural setting'; SHmax is inferred from the World Stress Map (Heidbach 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.