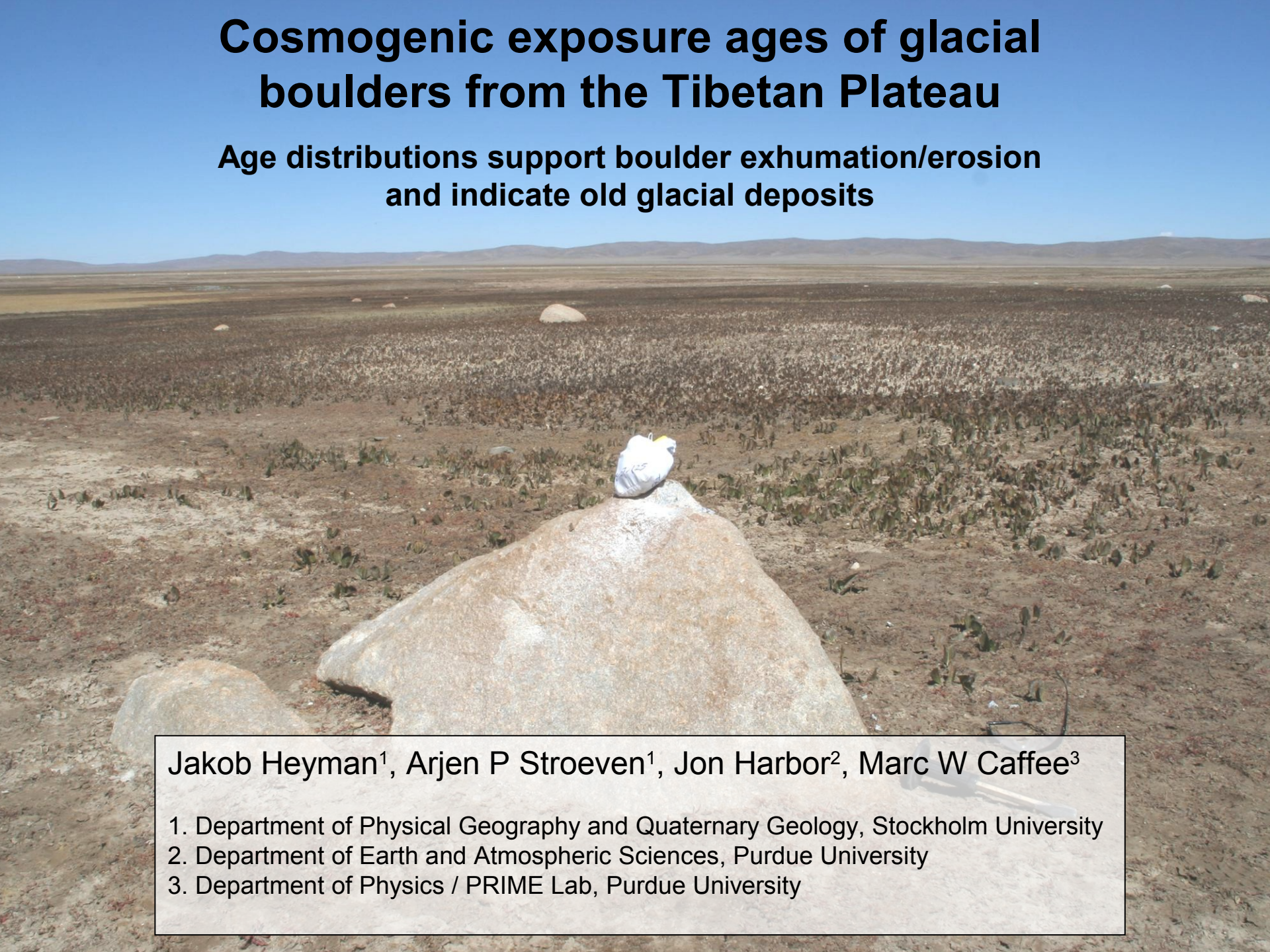
Cosmogenic exposure ages of glacial boulders from the Tibetan Plateau

Age distributions support boulder exhumation/erosion and indicate old glacial deposits



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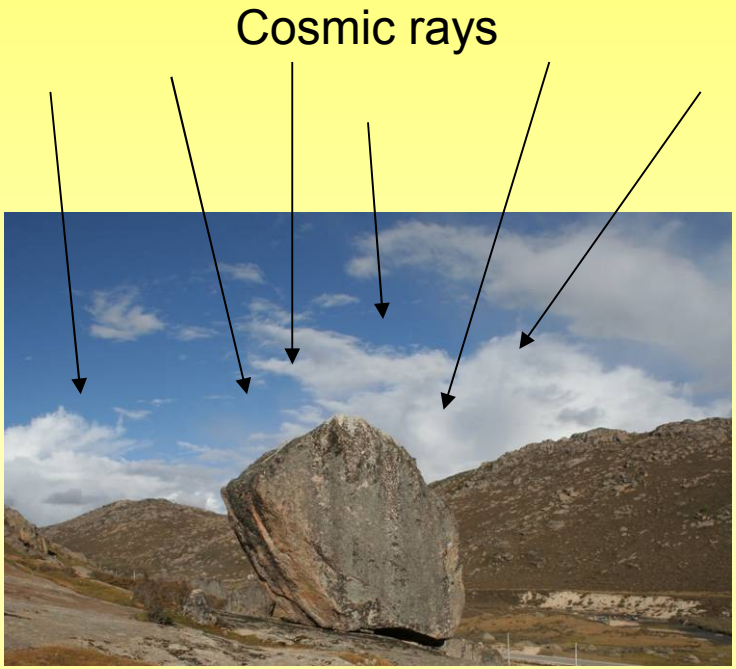
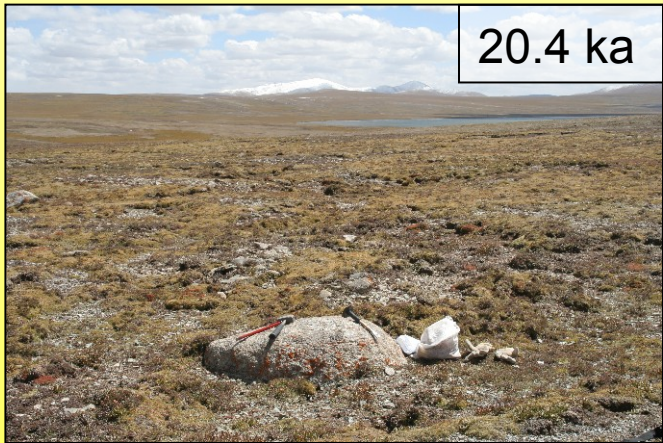
Presentation outline

- Cosmogenic exposure dating
  - Introduction
  - Geological sources of error
- Age distribution investigation – aim and strategy
- Tibetan TCN age distributions – results
- Explaining the TCN age distributions
  - Inheritance
  - Exhumation/erosion
- Conclusions

Cosmogenic exposure dating



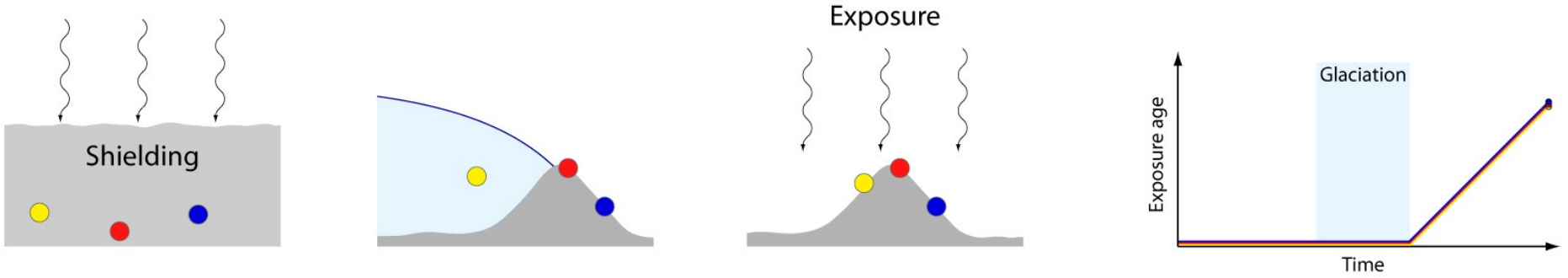


Production of cosmogenic nuclides (^{10}Be) in quartz when exposed to cosmic radiation

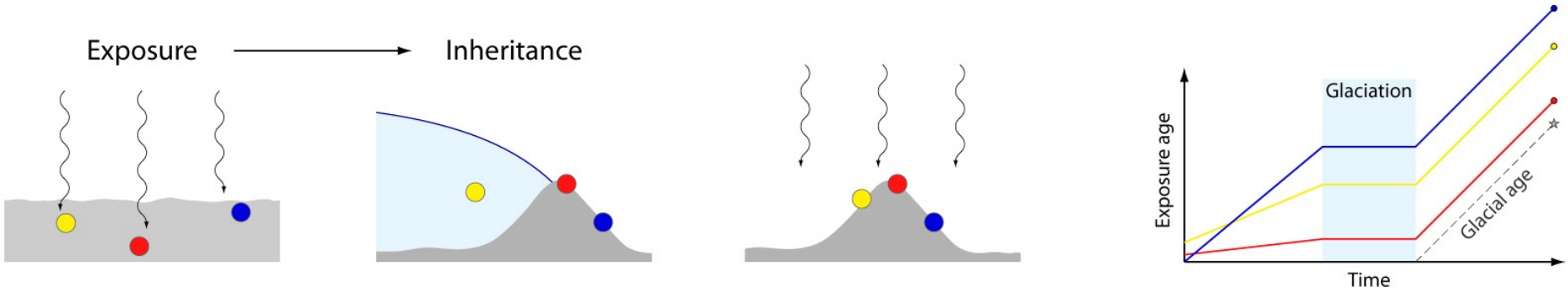
Absolute measurement of **<u>exposure age</u>**

Geological sources of error

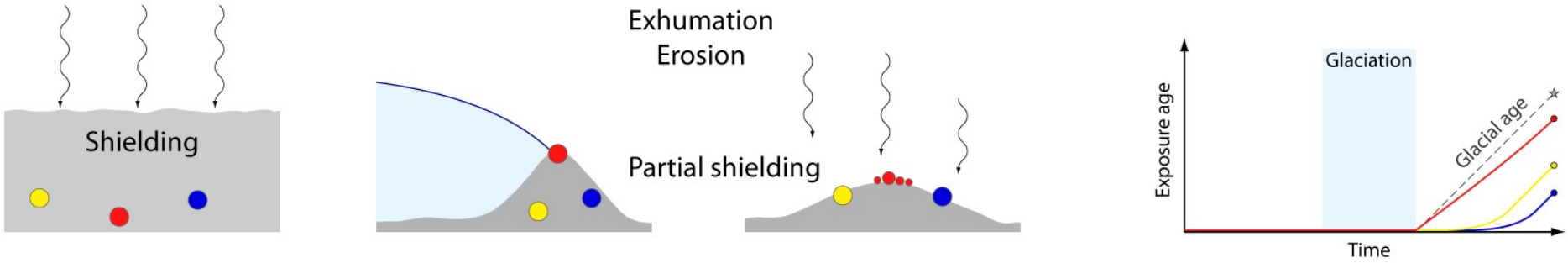
IDEAL CASE



PRE-GLACIAL EXPOSURE



POST-GLACIAL SHIELDING



Aim and strategy

Reseach question:

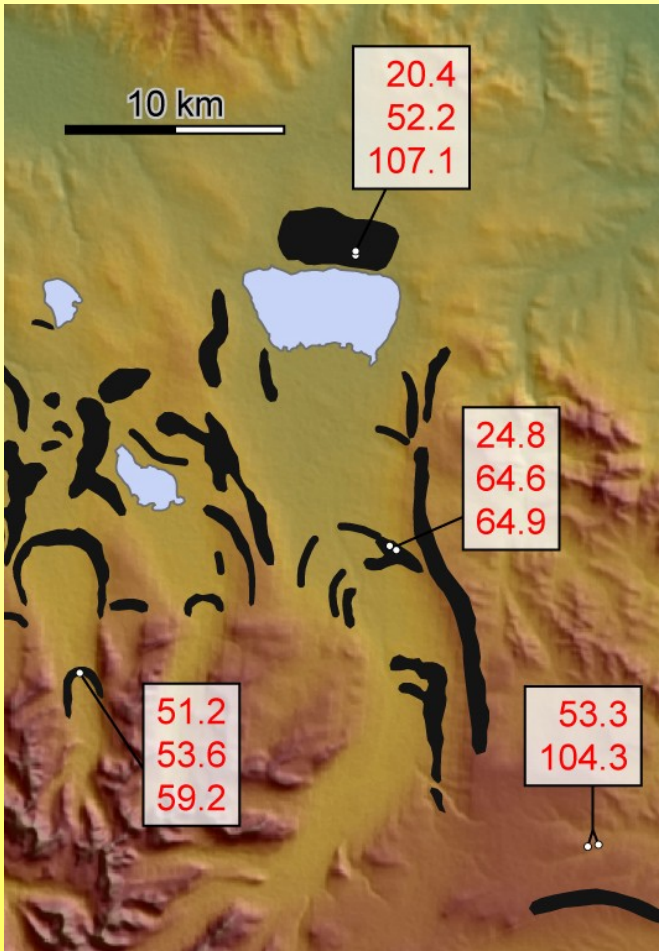
How to interpret wide TCN age spreads of multiple glacial boulders?

Strategy:

Investigation of large set of glacial boulders from the Tibetan Plateau:

• Glacial boulders included: All ^{10}Be measurements from locations where at least two samples have been dated with reasonable uncertainties

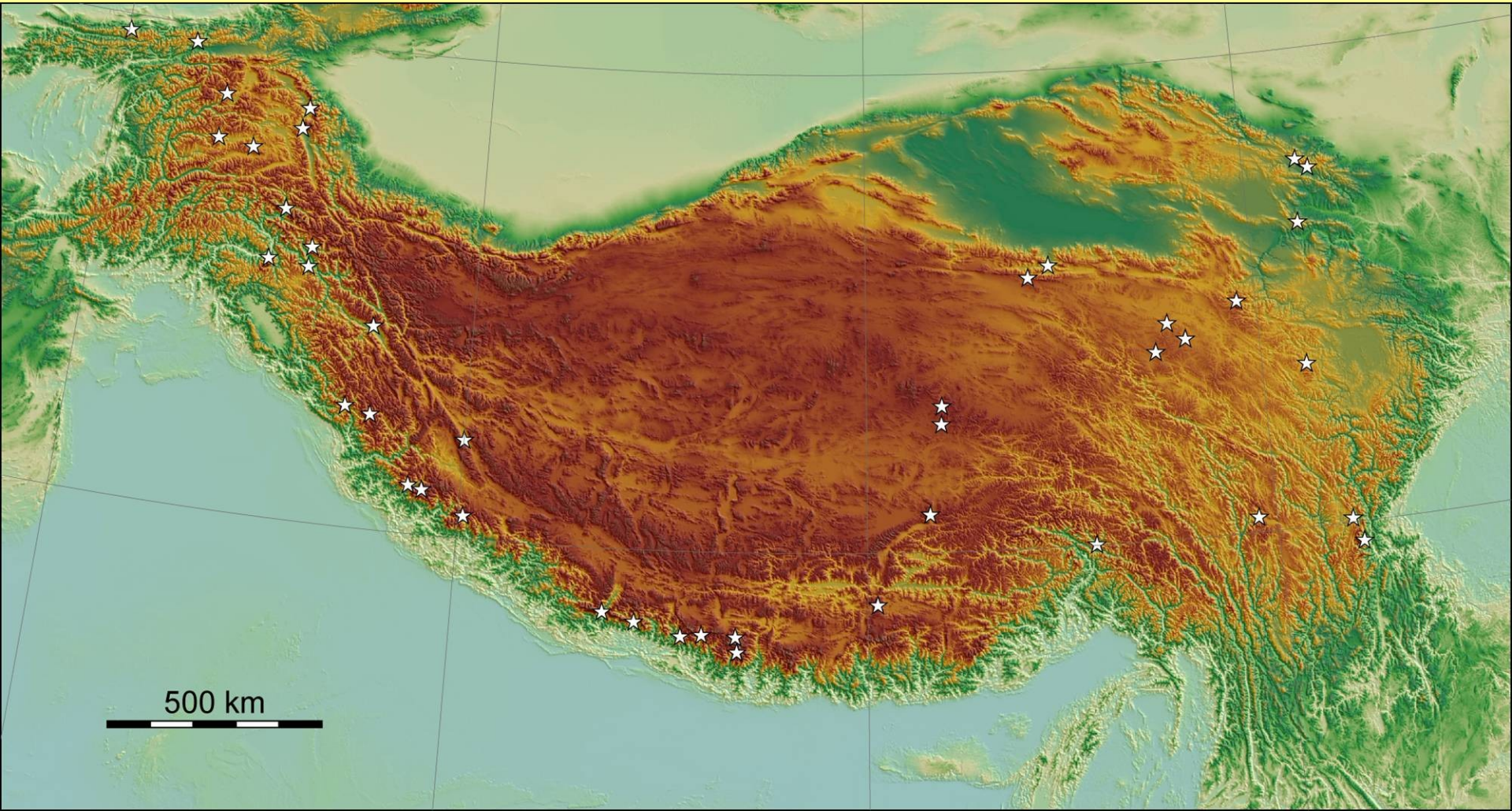
• Exposure ages (re)calculated with the CRONUS web calculator (Balco et al. 2008) using the Lal (1991) / Stone (2000) scaling scheme



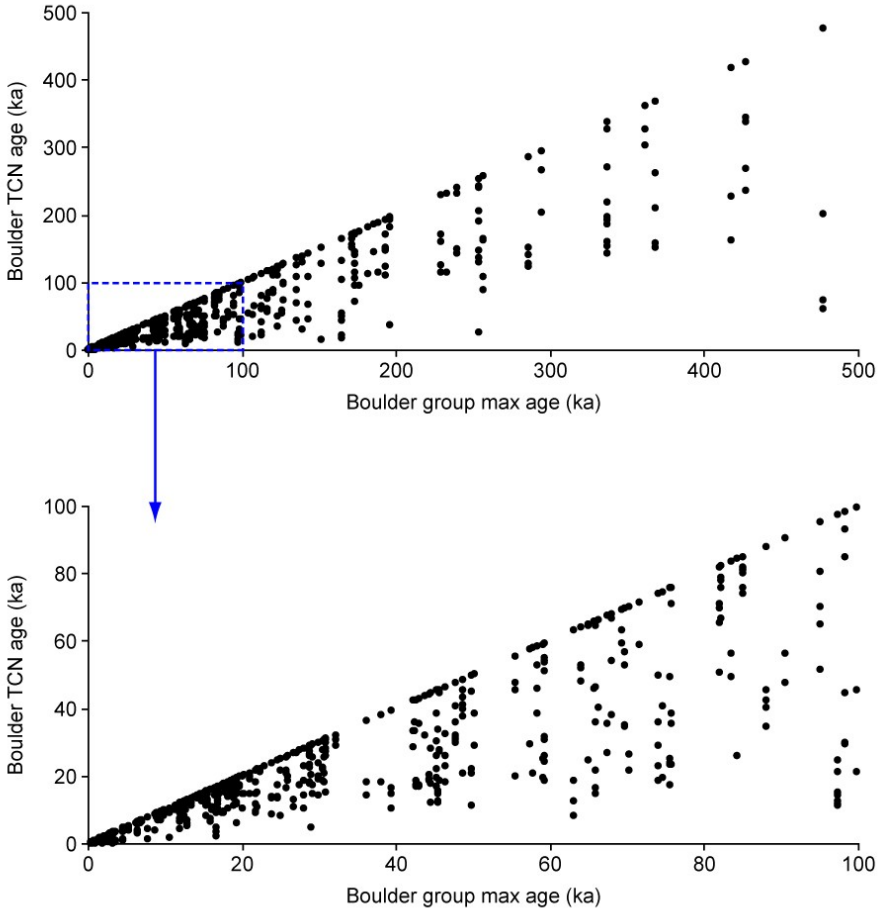
Glacial boulder TCN ages from the Tibetan Plateau

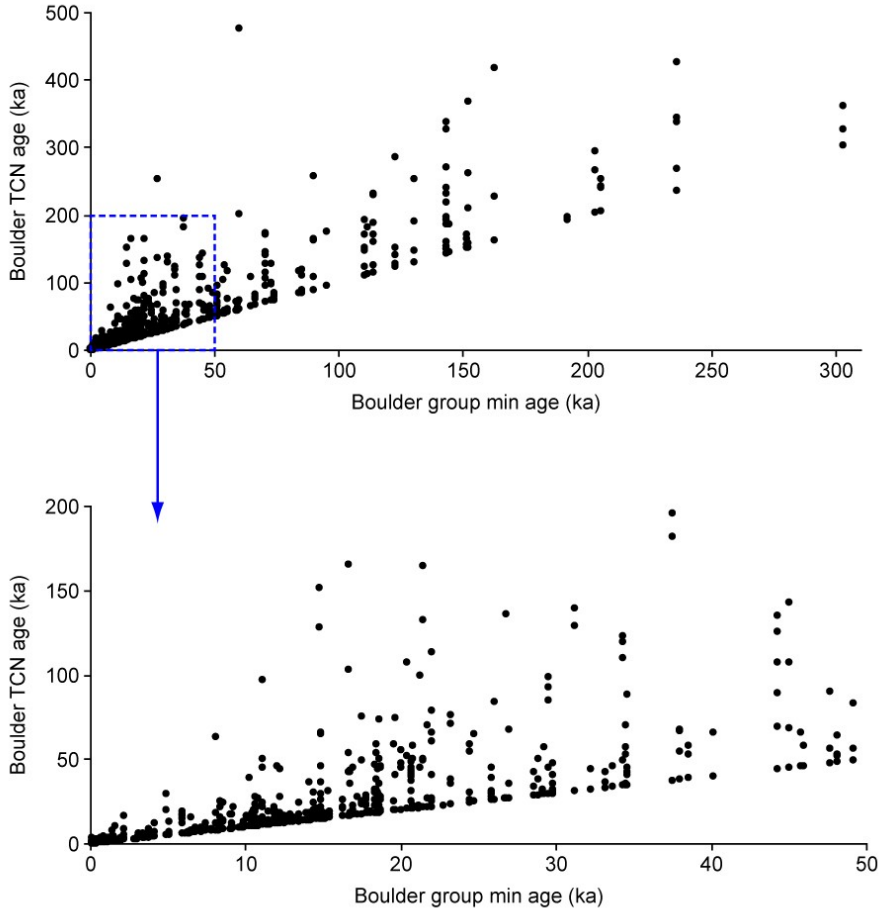
869 boulders from 227 boulder groups and 31 locations

Abramowski et al. (2006), Aoki and Imamura (1999), Barnard et al. (2004a, 2004b, 2006), Brown et al. (2002), Chevalier et al. (2005), Finkel et al. (2003), Heyman et al. (in prep), Owen et al. (2001, 2002, 2003a, 2003b, 2003c, 2005, 2006a, 2006b, in press), Phillips et al. (2000), Schaefer et al. (2008), Schäfer et al. (2002), Seong et al. (2007, 2009), Strasky et al. (2009), Tschudi et al. (2003), Zech et al. (2005, in press), Zhou et al. (2007)

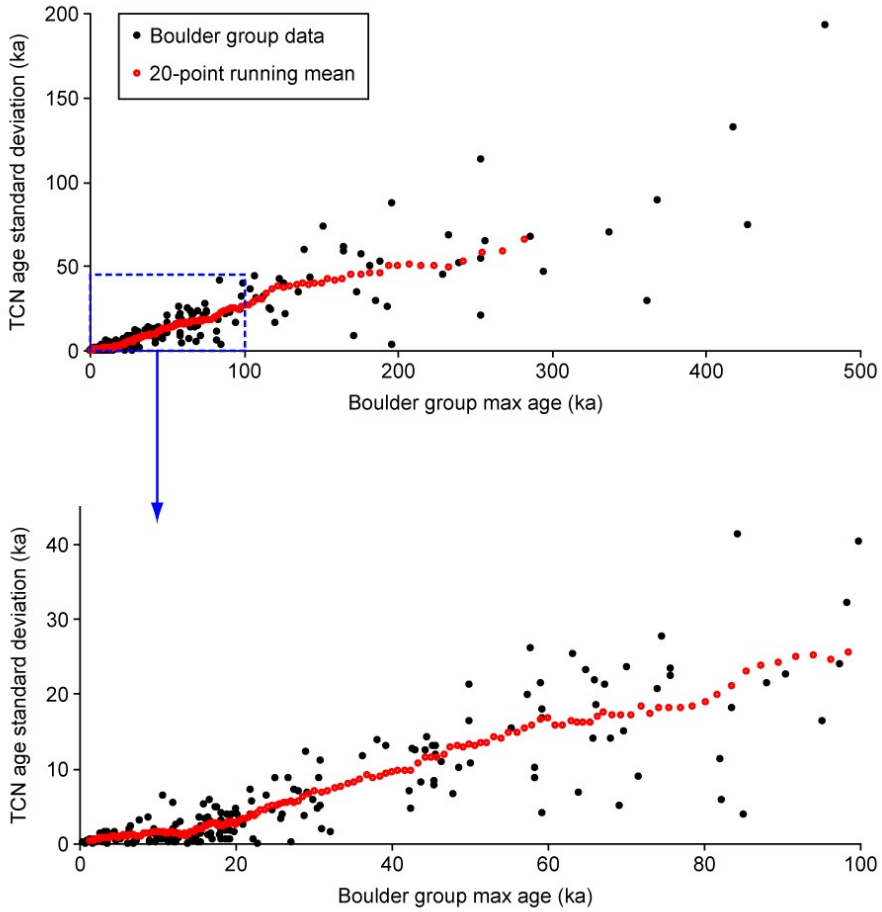


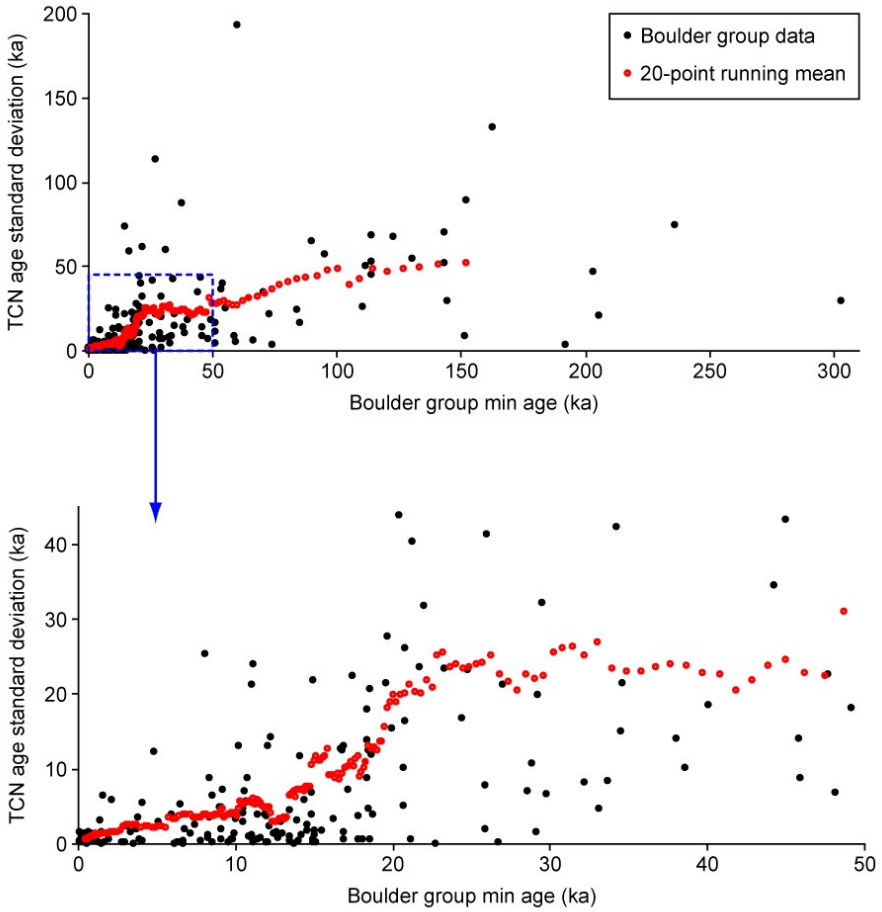
Individual boulder ages plotted against boulder group max/min age





Standard deviation of boulder groups plotted against max/min age



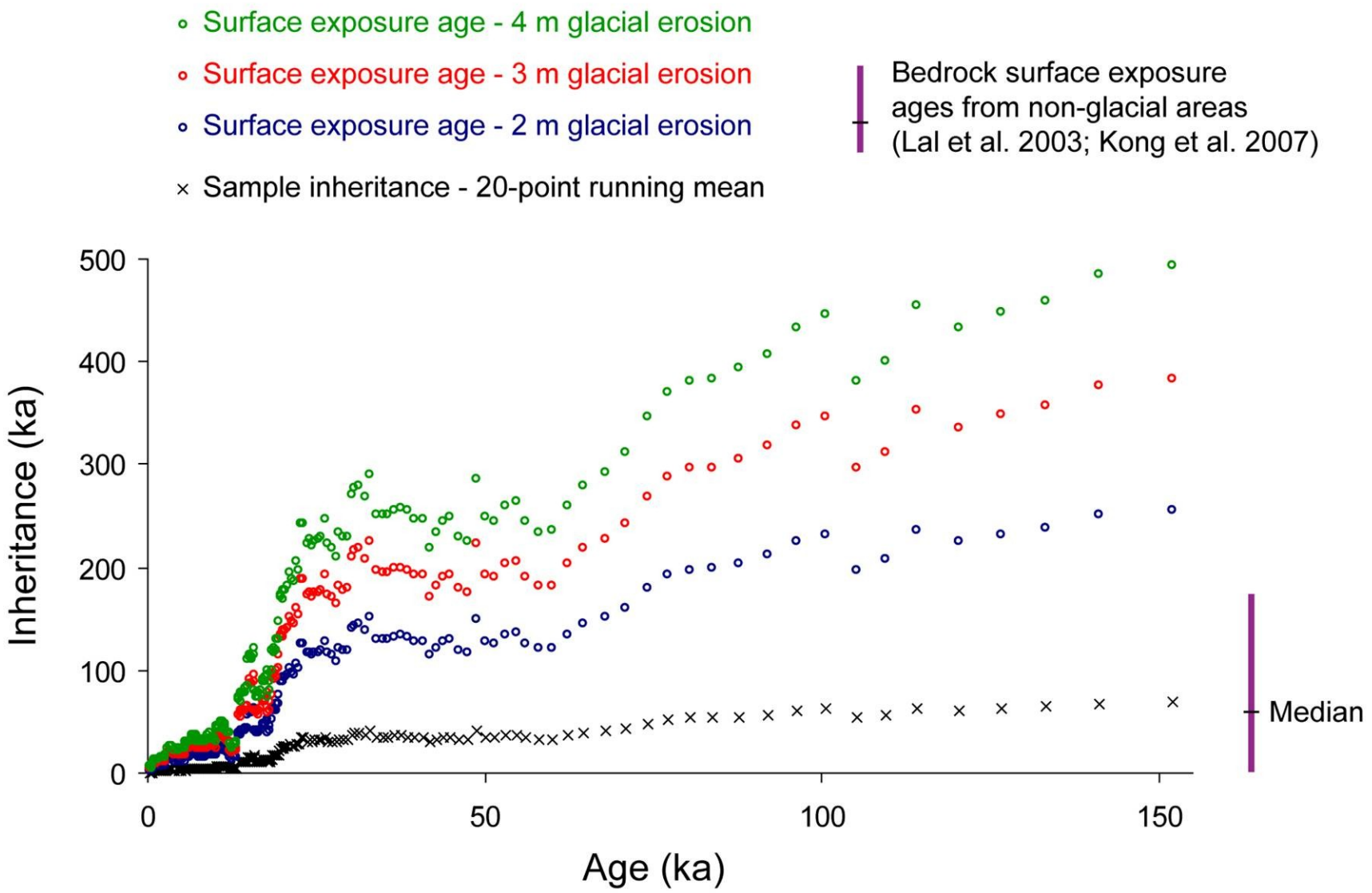


Older samples → wider age spread

Significant step in age spread from c. 13 ka

Explaing the age spread by inheritance

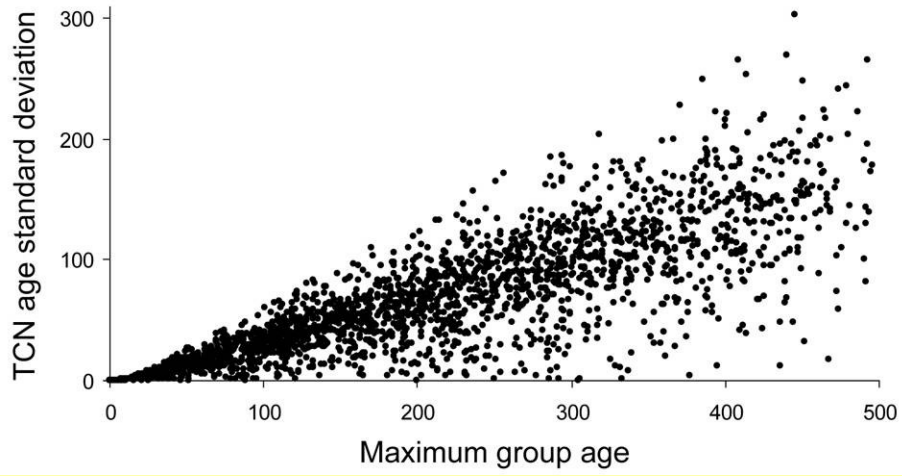
Extreme inheritance and limited glacial erosion required

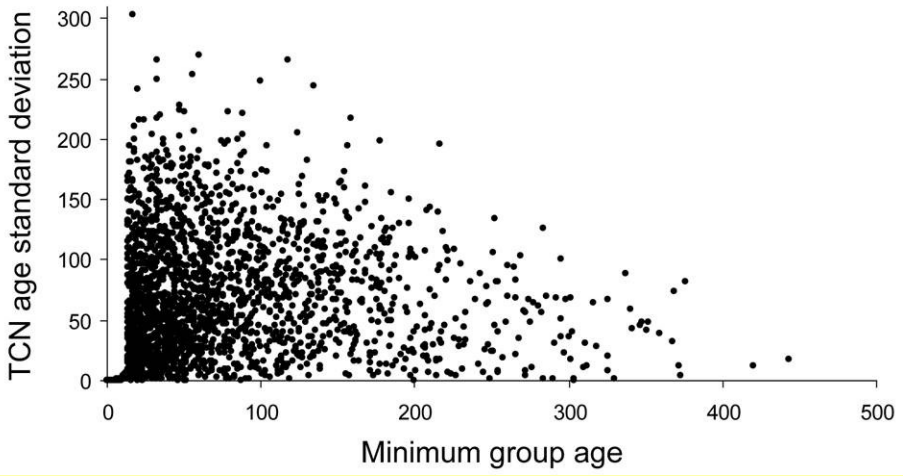


Poor explanatory power!

Explaing the age spread by exhumation/erosion

Assuming constant exhumation (6.2 cm/ka) through till (2.0 g/cm^3)





Older samples → wider age spread

Extreme step in age spread from c. 13 ka

Captures both main characteristics of the TCN age distribution well!

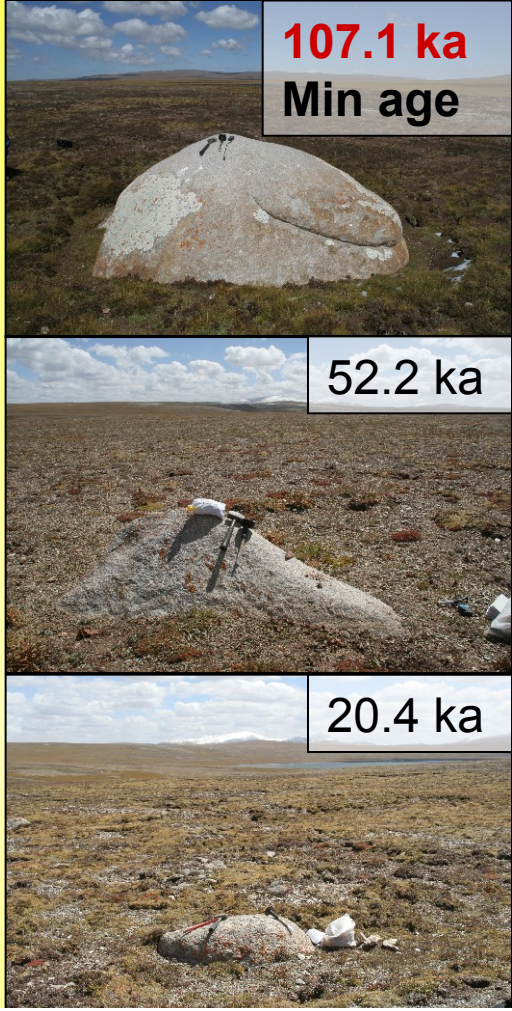
Conclusions

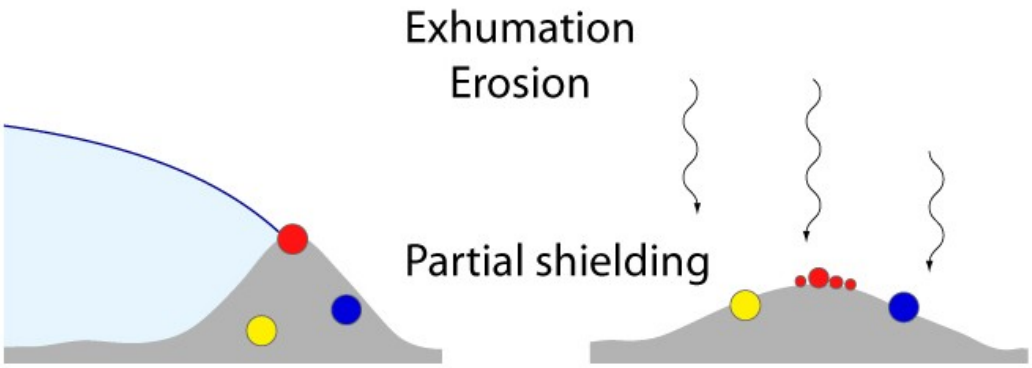
• Exhumation/erosion can explain the 10Be TCN age distribution of the entire set of glacial boulder groups from the Tibetan Plateau

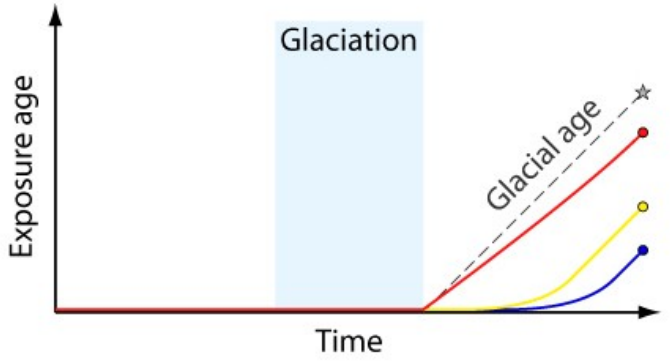
• Inheritance cannot explain the TCN age distribution set without extreme and unrealistic assumptions

• If there are no special circumstances indicating inheritance, the oldest sample of a group of boulders should be interpreted as a minimum age

(cf. Putkonen and Swanson 2003)





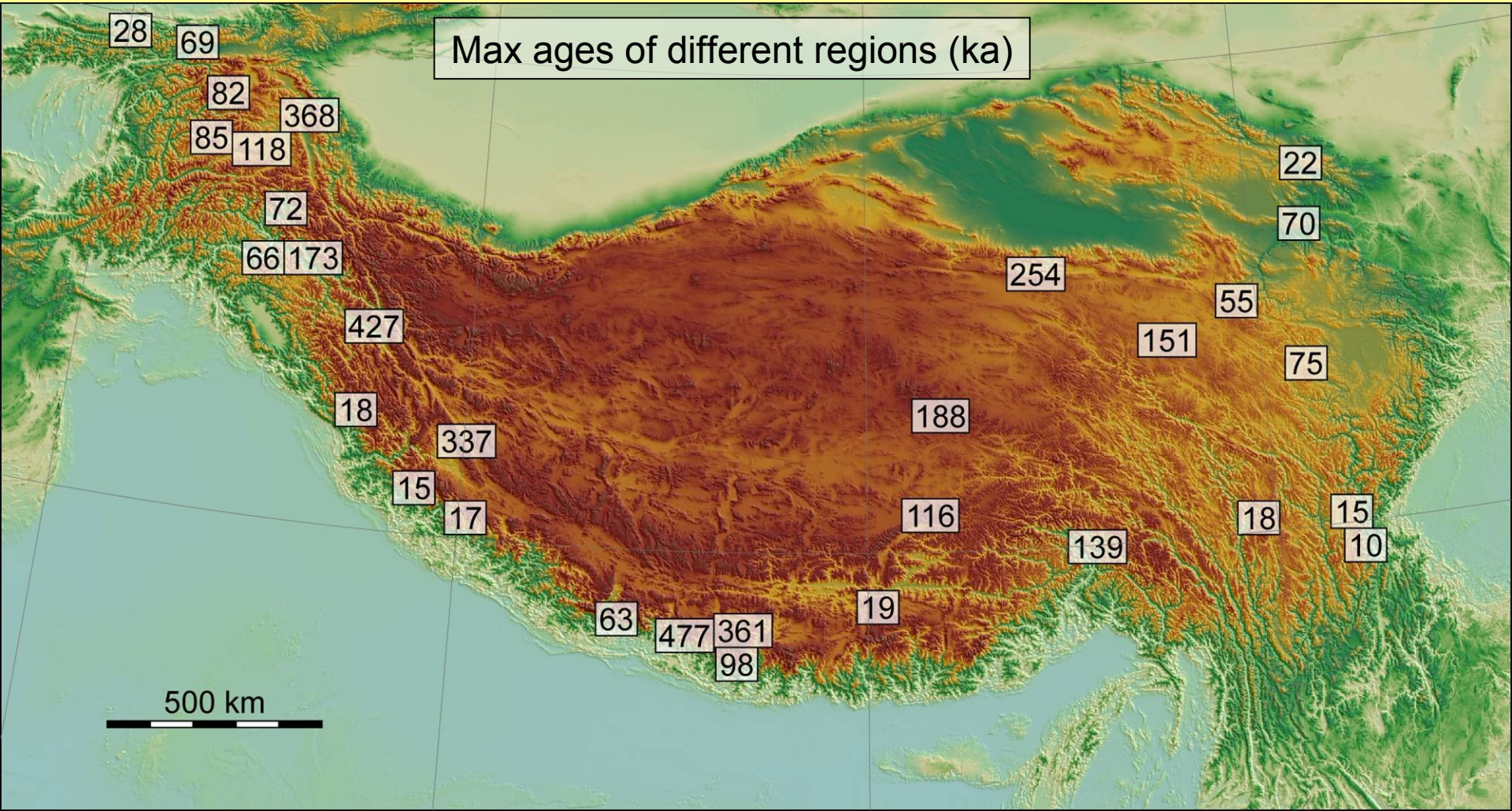


Implications for Tibetan paleoglaciology

The Tibetan Plateau holds a glacial geological record that is significantly older than what is normally found in the northern hemisphere

Average max age: 60.4 ka

Median max age: 24.6 ka




Thank you!

References

Abramowski U, Bergau A, Seebach D, Zech R, Glaser B, Sosin P, Kubik PW, Zech W. 2006: Pleistocene glaciations of Central Asia: results from ^{10}Be surface exposure ages of erratic boulders from the Pamir (Tajikistan), and the Alay–Turkestan range (Kyrgyzstan). *Quaternary Science Reviews*, 25, 1080–1096.

Aoki T, Imamura M. 1999: Reconstructing the glacial chronology based on the ^{10}Be exposure age in the Khumbu Glacier, Eastern Nepal Himalaya. *Proceedings of the Korea-Japan/Japan-Korea Geomorphological Conference*, 134-135.

Balco G, Stone JO, Lifton NA, Dunai TJ. 2008: A complete and easily accessible means of calculating surface exposure ages or erosion rates from 10Be and 26Al measurements. *Quaternary Geochronology*, 3, 174-195.

Barnard PL, Owen LA, Sharma MC, Finkel RC. 2004a: Late Quaternary (Holocene) landscape evolution of a monsoon-influenced high Himalayan valley, Gori Ganga, Nanda Devi, NE Garhwal. *Geomorphology*, 61, 91–110.

Barnard PL, Owen LA, Finkel RC. 2004b: Style and timing of glacial and paraglacial sedimentation in a monsoon-influenced high Himalayan environment, the upper Bhagirathi Valley, Garhwal Himalaya. *Sedimentary Geology*, 165, 199–221.

Barnard PL, Owen LA, Finkel RC, Asahi K. 2006: Landscape response to deglaciation in a high relief, monsoon-influenced alpine environment, Langtang Himal, Nepal. *Quaternary Science Reviews*, 25, 2162–2176.

Brown ET, Bendick R, Bourlès DL, Gaur V, Molnar P, Raisbeck GM, Yiou F. 2002: Slip rates of the Karakorum fault, Ladakh, India, determined using cosmic ray exposure dating of debris flows and moraines. *Journal of Geophysical Research*, 107, B9, 2192.

Chevalier ML, Ryerson FJ, Tapponnier P, Finkel RC, Van Der Woerd J, Li HB, Liu Q. 2005: Slip-Rate Measurements on the Karakorum Fault May Imply Secular Variations in Fault Motion. *Science*, 307, 411-414.

Finkel RC, Owen LA, Barnard PL, Caffee MW. 2003: Beryllium-10 dating of Mount Everest moraines indicates a strong monsoon influence and glacial synchroneity throughout the Himalaya. *Geology*, 31, 561-564.

Heyman J, Alexanderson H, Caffee MW, Harbor J, Hättestrand C, Li YK, Stroeven A, Zhou LP. In prep: Cosmogenic exposure ages of Bayan Har Shan, NE Tibetan Plateau.

Owen LA, Gualtieri L, Finkel RC, Caffee MW, Benn DI, Sharma MC. 2001: Cosmogenic radionuclide dating of glacial landforms in the Lahul Himalaya, northern India: defining the timing of Late Quaternary glaciation. *Journal of Quaternary Science*, 16, 555-563.

Owen LA, Finkel RC, Caffee MW, Gualtieri L. 2002: Timing of multiple late Quaternary glaciations in the Hunza Valley, Karakoram Mountains, northern Pakistan: Defined by cosmogenic radionuclide dating of moraines. *Geological Society of America Bulletin*, 114, 593-604.

Owen LA, Finkel RC, Ma HZ, Spencer JQ, Derbyshire E, Barnard PL, Caffee MW. 2003a: Timing and style of Late Quaternary glaciation in northeastern Tibet. *Geological Society of America Bulletin*, 115, 1356-1364.

Owen LA, Spencer JQ, Ma HZ, Barnard PL, Derbyshire E, Finkel RC, Caffee MW, Nian ZY. 2003b: Timing of Late Quaternary glaciation along the southwestern slopes of the Qilian Shan, Tibet. *Boreas*, 32, 281-291.

Owen LA, Ma HZ, Derbyshire E, Spencer JQ, Barnard PL, Nian ZY, Finkel RC, Caffee MW. 2003c: The timing and style of Late Quaternary in the La Ji Mountains, NE Tibet: evidence for restricted glaciation during the latter part of the Last Glacial. *Zeitschrift für Geomorphologie Supplementband*, 130, 263-276.

Owen LA, Finkel RC, Barnard PL, Ma HZ, Asahi K, Caffee MW, Derbyshire E. 2005: Climatic and topographic controls on the style and timing of Late Quaternary glaciation throughout Tibet and the Himalaya defined by ^{10}Be cosmogenic radionuclide surface exposure dating. *Quaternary Science Reviews*, 24, 1391-1411.

Owen LA, Caffee MW, Bovard KR, Finkel RC, Sharma MC. 2006a: Terrestrial cosmogenic nuclide surface exposure dating of the oldest glacial successions in the Himalayan orogen: Ladakh Range, northern India. *Geological Society of America Bulletin*, 118, 383-392.

Owen LA, Finkel RC, Ma HZ, Barnard PL. 2006b: Late Quaternary landscape evolution in the Kunlun Mountains and Qaidam Basin, Northern Tibet: A framework for examining the links between glaciation, lake level changes and alluvial fan formation. *Quaternary International*, 154-155, 73-86.

Owen LA, Robinson R, Benn DI, Finkel RC, Davis NK, Yi CL, Putkonen J, Li DW, Murray AS. In press: Quaternary glaciation of Mount Everest. *Quaternary Science Reviews*.

Phillips WM, Sloan VF, Shroder JF, Sharma P, Clarke ML, Rendell HM. 2000: Asynchronous glaciation at Nanga Parbat, northwestern Himalaya Mountains, Pakistan. *Geology*, 28, 431-434.

Putkonen J, Swanson T. 2003: Accuracy of cosmogenic ages for moraines. *Quaternary Research*, 59, 255-261.

Schaefer JM, Oberholzer P, Zhao ZZ, Ivy-Ochs S, Wieler R, Baur H, Kubik PW, Schlüchter C. 2008: Cosmogenic beryllium-10 and neon-21 dating of late Pleistocene glaciations in Nyalam, monsoonal Himalayas. *Quaternary Science Reviews*, 27, 295-311.

Schäfer JM, Tschudi S, Zhao ZZ, Wu XH, Ivy-Ochs S, Wieler R, Baur H, Kubik PW, Schlüchter C. 2002: The limited in£uence of glaciations in Tibet on global climate over the past 170 000 yr. *Earth and Planetary Science Letters*, 194, 287-297.

Seong YB, Owen LA, Bishop MP, Bush A, Clendon P, Copland L, Finkel R, Kamp U, Shroder JF. 2007: Quaternary glacial history of the Central Karakoram. *Quaternary Science Reviews*, 26, 3384-3405.

Seong YB, Owen LA, Yi CL, Finkel RC. 2009: Quaternary glaciation of Muztag Ata and Kongur Shan: Evidence for glacier response to rapid climate changes throughout the Late Glacial and Holocene in westernmost Tibet. *Geological Society of America Bulletin*, 121, 348-365.

Strasky S, Graf AA, Zhao ZZ, Kubik PW, Baur H, Schlüchter C, Wieler R. 2009: Late Glacial ice advances in southeast Tibet. *Journal of Asian Earth Sciences*, 34, 458-465.

Tschudi S, Schäfer JM, Zhao ZZ, Wu XH, Ivi-Ochs S, Kubik PW, Schlüchter C. 2003: Glacial advances in Tibet during the Younger Dryas? Evidence from cosmogenic ^{10}Be, ^{26}Al, and ^{21}Ne. *Journal of Asian Earth Sciences*, 22, 301-306.

Zech R, Abramowski U, Glaser B, Sosin P, Kubik PW, Zech W. 2005: Late Quaternary glacial and climate history of the Pamir Mountains derived from cosmogenic ^{10}Be exposure ages. *Quaternary Research*, 64, 212-220.

Zech R, Zech M, Kubik PW, Kharki K, Zech W. In press: Deglaciation and landscape history around Annapurna, Nepal, based on ^{10}Be surface exposure dating. *Quaternary Science Reviews*.

Zhou SZ, Xu LB, Colgan PM, Mickelson DM, Wang XL, Wang J, Zhong W. 2007: Cosmogenic ^{10}Be dating of Guxiang and Baiyu Glaciations. *Chinese Science Bulletin*, 52, 1387-1393.