Mongolian summits: An uplifted, flat, old but still preserved erosion surface

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ABSTRACT

In Gobi Altay and Altay, Mongolia, several flat surfaces, worn through basement rocks and uplifted during the ongoing tectonic episode to a similar altitude of 4000 m, suggests disruption of a single large-scale surface. New thermochronology and field data show that the plateau surfaces represent uplifted parts of an ancient peneplain that formed during Jurassic time. The Gobi Altay and Altay flat-topped massifs are tectonically and geomorphologically unique. Their preservation for ~150 m.y. implies that no further tectonic movements occurred before the onset of the last deformation episode, 5 ± 3 m.y. ago. It also suggests that very low erosion rates were maintained by a dry climate over millions of years.

Keywords: Mongolia, erosion surface, peneplain, uplift, thermochronology.

INTRODUCTION

The current relief of the Gobi Altay and Altay ranges in Mongolia started to grow ca. 5 ± 3 Ma as the result of the far-field effect of the India-Asia Cenozoic collision nearly 2000 km to the south (Molnar and Tapponnier, 1975; Cunningham, 1998; De Grave et al., 2007; Vassallo et al., 2007). Instead of sharp and steep peaks, as in numerous mountain belts, these ranges, ~4000 m high, are characterized by flat summit plateaus assumed to be erosion surfaces (e.g., Florensov and Solonenko, 1965; Cunningham et al., 2003; Ritz et al., 2003). Mongolian and Siberian summit plateaus are generally several tens of kilometers long and several kilometers wide. In Gobi Altay, the Ih Bogd massif (Figs. 1 and 2) developed in a restraining bend along the sinistral Bogd fault, which ruptured in A.D. 1957 during one of the strongest intracontinental earthquakes of the past century (Mw 8.1) (Florensov and Solonenko, 1965; Kurushin et al., 1997). The core of the Ih Bogd massif is formed by basement rocks (metasediments, granites, and volcanics) of Proterozoic to Paleozoic age. Cretaceous volcanic and volcano-sedimentary series are exposed on the southeast edge of the massif (Florensov and Solonenko, 1965; Bayasgalan et al., 1999). The highest point of the Ih Bogd summit surface (3957 m) corresponds to an outcrop of extrusive volcanics, a few hundred meters in diameter and ~10–30 m high, on top of the plateau surface (Fig. 2). In the Altay and West Sayan ranges, the Baatar and Bai Taiga massifs (Fig. 1) are not directly linked to major strike-slip faults; they form pop-up structures within the general compressive system. Those massifs are composed of Proterozoic to Paleozoic basement rocks (Windley et al., 2002). The Bai Taiga plateau is the northernmost such structure that we identified. The piedmont of the Mongolian massifs is formed by the Valley of Lakes, a several thousand kilometers long, ~1000-m-high flat plain extending from the Gobi Desert to the Siberian border (Fig. 1).

In the three examples we studied, the summit plateau surfaces are cut through basement rocks and do not represent stratigraphic surfaces. Polygonal and striped grounds have been observed on all plateaus (Fig. 2). The Baatar massif is locally covered by a thin (10–100 m) ice cap, but there is no indication of present-day or past ice on the Ih Bogd massif. The absence of large-scale glacial features and thus of significant erosion by ice makes the Ih Bogd massif a key area to reconstruct the history of formation and evolution of those flat summit surfaces.

GEOCHRONOLOGY

To understand the formation of these reliefs, apatite fission track (AFT) samples were taken from the summit surfaces of the Ih Bogd (two samples) and Baatar (one sample) massifs as well as from the surrounding basement of the Valley of Lakes (three samples) (Fig. 1; GSA Data Repository Table DR1[1]). Mean AFT ages represent a minimum age at which the sample cooled below ~110 °C ± 10 °C. That mean age can be rejuvenated, depending on the cooling path of the sample between ~110 °C and 60 °C, the limiting temperatures for the method (Green et al., 1986). Mean AFT ages from the plateaus are very consistent: 195 ± 21 Ma and 196 ± 7 Ma for Ih Bogd, and 192 ± 7 Ma for Baatar. Mean AFT lengths are slightly variable: 12.4 μm and 13.5 μm in the Ih Bogd massif, and 12.8 μm in the Baatar massif. Age data obtained from the Valley of Lakes samples are similar: 167 ± 16.6 Ma north of the Ih Bogd massif on the edge of the Hangay dome (Ushgug), and 199 ± 13 Ma (Hovd05–1) and 184 ± 12 Ma (IT-05–14) north of the Baatar massif, with mean AFT lengths between 12.6 and 13.6 μm.

AFT length modeling, which provides a statistical temperature-time path for the samples between ~110 ± 10 °C and 60 °C (Laslett et al., 1987), was performed on all samples except IT05–14, for which the small number of fission tracks did not allow a reliable model.

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[1] GSA Data Repository item 2007219, Figure DR1 (K-feldspar correlation plots for the IBTOP(A) and IBTOP(B) sample $^{40}Ar/^{39}Ar$ analysis), Table DR1 (Apatite fission track analysis data), and Table DR2 ($^{40}Ar/^{39}Ar$ analytical results), 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.

Geology, October 2007; v. 35; no. 10; p. 871–874; doi: 10.1130/G23758A.1; 3 figures; Data Repository item 2007219.

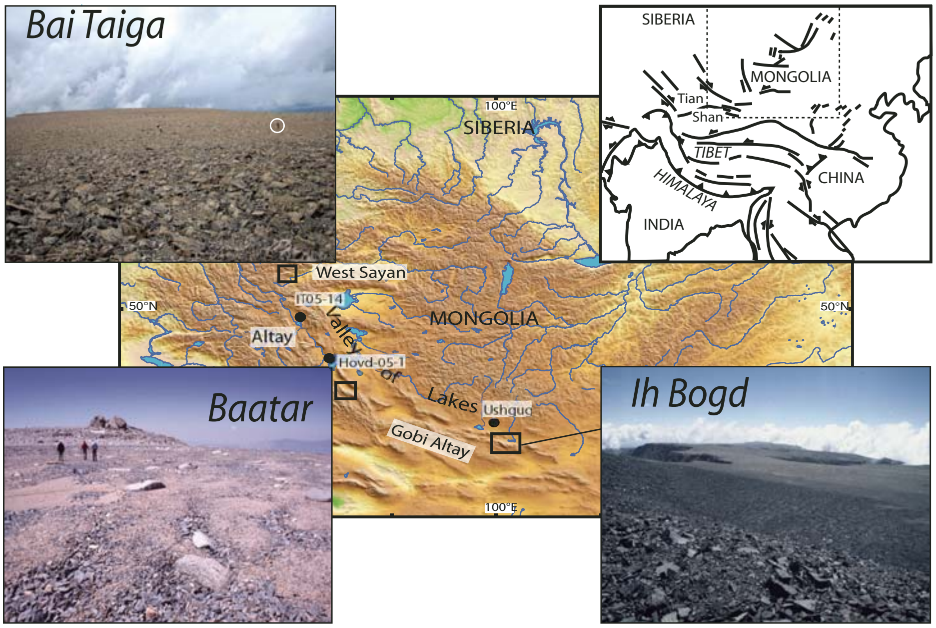

Figure 1. Center: General topographic map of Mongolia and its surroundings. Examples of summit plateaus are in the Gobi Altay (south Mongolia), Altay (western Mongolia), and Sayan (southern Siberia) ranges. The Bai Taiga massif is the northernmost summit surface that we identified (the character inside the small white circle gives the scale). Ushgug, Hovd05–1, and IT05–14 are the Valley of Lakes samples. Width of the Ih Bogd plateau in figure is ~8 km.

The modeled cooling histories show that in Gobi Altay (Fig. 3), the Ih Bogd massif samples cooled from ~110 °C down to 60 °C during a first Early Jurassic exhumation period. Sample IB-05–4 crossed the 60 °C isotherm ca. 200 Ma (Early Jurassic). AFT modeling is only valid between 110 ± 10 °C and 60 °C, and we have no data on the cooling path after 200 Ma. Nonetheless, given the mean AFT age of 196 ± 7 Ma and 195 ± 21 Ma obtained on these samples and the steep slope of the modeled cooling path, this first cooling event was certainly generated by rapid tectonic uplift and strong denudation, and the samples reached the near surface by that time (Fig. 3). This is confirmed by the 198 ± 8 Ma and 193 ± 7 Ma ^{40}Ar/^{39}Ar (K-feldspar) ages of the extrusive volcanics on the Ih Bogd summit surface. Given the saddle shape of both ^{40}Ar/^{39}Ar spectra, the age of the samples may be slightly younger, possibly ca. 180 Ma (Fig. 2; Fig. DR1 and Table DR2).

The Valley of Lakes samples also show a strong exhumation event during the Early Jurassic, very similar to the one observed for the summit plateaus (sample Hovd05–1 in Fig. 3). In places like Ushgug (Fig. 1), cooling rates are lower than for the Ih Bogd samples, and the cooling period only ends in the Late Jurassic, ca. 150 Ma (Fig. 3). By that time, the Ushgug sample was still at ~60 °C, and thus at depths of ~2 km, considering a mean 30 °C/km geothermal gradient. Cooling of the Valley of Lakes samples was then followed by the same protracted period of stability.

IMPLICATION FOR THE TOPOGRAPHY, CLIMATE, AND EROSION HISTORY

Topography

There is no indication of thick Jurassic volcanic series in the Gobi Altay, and the Ih Bogd summit lava probably represented a small volume. Preservation of these volcanic rocks on top of the plateau allows for only a few hundreds of meters of erosion since their emplacement. Consequently, abrasion and leveling of the surface preserved on top of the Ih Bogd massif happened near the end of the Early Jurassic.

Using similar AFT data from basement rocks, Vassallo et al. (2007) concluded that samples collected near the base of a 2-km-high vertical profile within the massif remained below 60 °C from the Early to Middle Jurassic. This is incompatible with a thick post-Jurassic sedimentary cover on top of the actual summit plateau.

The sediments derived from erosion of the Jurassic topographic highs must have been either exported or deposited within the lower Valley of Lakes axis, locally tapering the effect of tectonic exhumation in areas like Ushgug. In these places, samples brought toward the surface by Jurassic tectonic activity were still covered by ~2 km of sediments. By Late Jurassic time, complete leveling was accomplished over the entire area of the Gobi Altay and western Mongolia.

Mesozoic (Early Jurassic to Early-middle Cretaceous) vertical tectonic movements, basement cooling, and coarse basin sedimentation have been widely reported in the area from northern Tibet to southern Siberia. These movements are generally associated with distant effects of the Cimmerian orogeny in Tibet (collision of the Qiangtang and Lhasa blocks in the Late Triassic–Middle Jurassic and Late Jurassic–Early Cretaceous) (e.g., Hendrix et al., 1992, 1996; Sobel

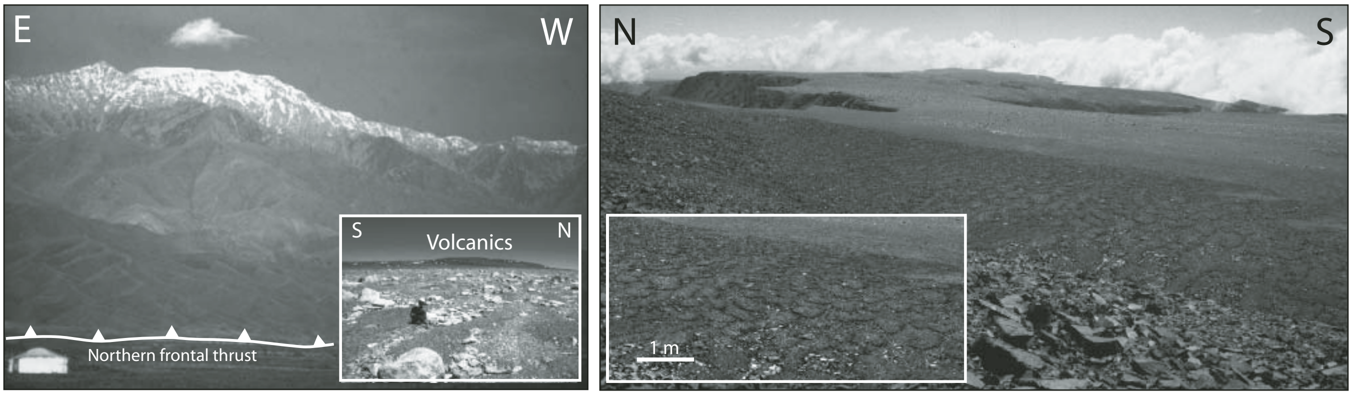

Figure 2. Left: Ih Bogd massif showing the frontal thrust fault that allows massif to grow both in width and height (far field is ~20 km wide). Extensive flat summit of massif is highlighted by snow. Inset shows volcanics on top of the erosion surface in the far field. Right: Ih Bogd summit plateau (the plateau is ~20 km long and a maximum of 8 km wide). Inset shows details of the surface characterized by striped polygonal ground (granite).

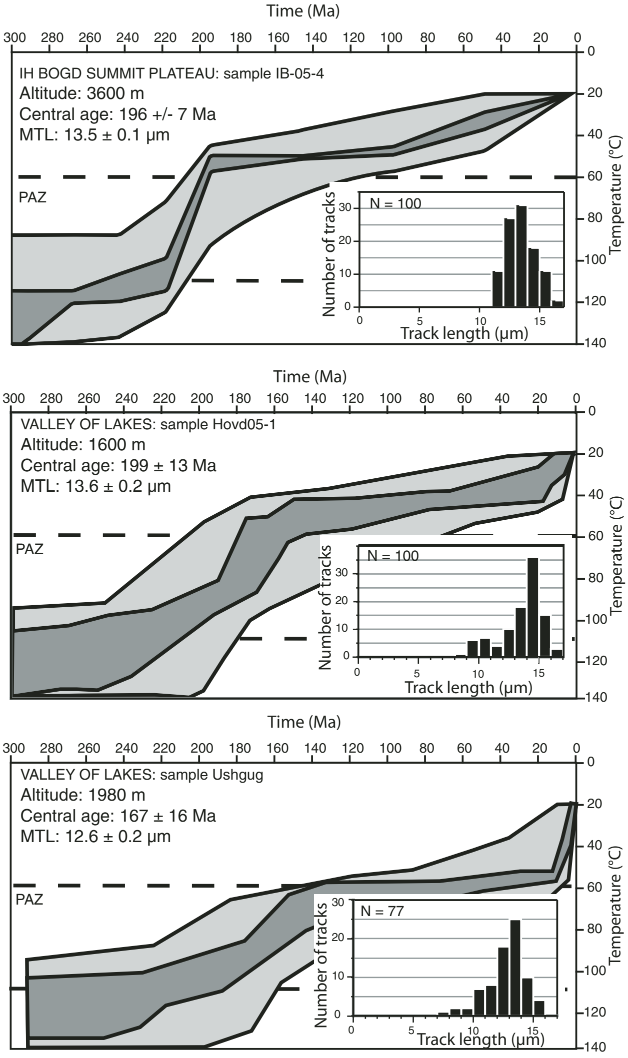

Figure 3. Apatite fission-track (AFT) modeling of sample IB-05–4 (top) from the Ih Bogd summit plateau, and Hovd-05–1 (middle) and Ushgug (bottom) from the Valley of Lakes. The AFTSolve software (Ketcham et al., 2000) was used to model the thermal histories, using the Ketcham et al. (1999) annealing model. Cooling paths are only defined within apatite partial annealing zone, between 110 ± 10 °C and 60 °C (dotted lines). The light gray and dark gray areas are the 2σ and 1σ confidence envelopes, respectively. Altitude—sampling altitude; Central age—AFT central age; MTL—measured mean track length (small inset histogram shows track length distribution).

and Dumitru, 1997; Zorin, 1999; Dumitru and Hendrix, 2001; Jolivet et al., 2001; De Grave and Van Den Haute, 2002). Recent geochronology and sedimentology work show that by Late Jurassic–Early Cretaceous time, most vertical tectonic movements and related active erosion in a huge area from southwest Mongolia to the northeast of the Tibetan plateau and west around the Tarim and Jungar basins had stopped. The early to middle Mesozoic building and consecutive erosion was followed by a long period of stability that ended in Eocene–Oligocene time (e.g., Hendrix et al., 1996; Dumitru and Hendrix, 2001; Bullen et al., 2001; Jolivet et al., 2001; De Grave and Van Den Haute, 2002, 2007).

The lack of vertical movement during this period led to the formation of a peneplain that probably extended toward the southwest in Tien Shan (Burbank et al., 1999; De Grave et al., 2007; Sobel et al., 2006) and northern Tibet (Jolivet et al., 2001) and toward the northwest in the Russian Altay (De Grave and Van Den Haute, 2002). Evidence of Cretaceous extension leading to the formation of intracontinental rift basins was reported from eastern Mongolia (Johnson et al., 2001; Wang et al., 2004), but this tectonic episode did not affect western Mongolia.

Climate and Erosion

Our data support the idea that, during the protracted period of nearly 150 m.y. during which no major exhumation event occurred in Gobi Altay and east Altay, there was very little erosion. In the areas like the present Ih Bogd massif plateau, erosion has been less than a few hundred meters. Sedimentation had to be very limited; this is consistent with the near absence of Cretaceous and Tertiary sedimentary series in western Mongolia. The Gobi Altay and Altay region has probably remained a continental area since the Late Jurassic, and erosion was only driven by factors such as rivers, ice, and wind. The ^{40}Ar/^{39}Ar dating of bulk dust brought from Central Asia by wind and deposited in the North Pacific Ocean during the past 8 m.y. shows uniform ages between 192 and 212 Ma (Pettke et al., 2000). These ages mainly indicate the ^{40}Ar/^{39}Ar age of the surface eroded in Central Asia over the past 8 m.y, and match the age of the Jurassic erosion surface now exposed in Gobi Altay and Altay.

Preservation of the flat summit surfaces during the last tectonic episode (which lifted the summit plateau more than 2000 m above the piedmont) implies very low erosion. Preliminary ^{10}Be analysis of a granite boulder from the Ih Bogd plateau provided a Holocene erosion rate of 28 m/m.y. for the surface, which is considered to be a maximum value because erosion probably increases with the increasing altitude of the growing massif (Ritz et al. [2006] calculated a 6 ± 1 m/m.y. erosion rate from the piedmont). If projected over 5 ± 3 m.y., the total uplift period of the massif (Vassallo et al., 2007), it would only account for between ~220 m and ~60 m of erosion.

Very low erosion in the studied area over the past ~150 m.y. also implies a dry climate. Paleoenvironment studies in southern Mongolia, Tien Shan, and northern Tibet have shown that since Late Jurassic–Early Cretaceous time climate in these regions has been marked by long periods of warm semiarid to arid conditions separated by shorter periods of cooler and more humid conditions (Hendrix et al., 1992; Wang et al., 1999; Tang et al., 2001; Li et al., 2004). Drying of Central Asia was further enhanced by global cooling and retreat of Paratethys to the west during Late Eocene–Early Oligocene time (Dupont-Nivet et al., 2007). Uplift of the Tibetan plateau by the Late Miocene intensified the drying (Ramstein et al., 1997; Wang et al., 1999).

The Ih Bogd and the Baatar massif summit plateaus are outstanding features that represent preserved relicts of a peneplain older than, or at least of the same age as, the well-known central Australian plains (Belton et al., 2004). This surface most certainly reached the Tien Shan, North Tibet, and West Sayan ranges. In Gobi Altay and east Altay, this peneplain was probably not covered by sediments or abraded by ice after its formation, unlike most known planation surfaces in Europe or South America (e.g., Hättestrand and Stroeven, 2002; Kirschbaum et al., 2005).

CONCLUSION

The Mongolian summit plateaus are the oldest known tectonically uplifted surfaces on Earth. This was mainly achieved by the combination of a generally dry climate and a protracted period of tectonic quiescence that lasted at least 150 m.y. The geometry and the kinematics of faults controlling the massifs during the Late Tertiary tectonic episode played an important role in the preservation of the summit plateaus. Thrust faults functioning at the same rate on both sides of the massifs allowed the summit surface to remain horizontal through time (Ritz et al., 2003). This prevented the formation of a drainage pattern that would have increased the surface incision and rapidly destroyed the surface. The large initial width of the massif between the two bounding faults may also be a key factor in the preservation of the uplifted surface.

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REFERENCES CITED

Bayasgalan, A., Jackson, J., Ritz, J.-F., and Carretier, S., 1999, “Forebergs”, flower structures, and the development of large intra-continental strike-slip faults: The Gurvan Bogd fault system in Mongolia: Journal of Structural Geology, v. 21, p. 1285–1302.

Belton, D.X., Brown, R.W., Kohn, B.P., Fink, D., and Farley, K.A., 2004, Quantitative resolution of the debate over antiquity of the central Australian landscape: Implications for the tectonic and geomorphic stability of cratonic interiors: Earth and Planetary Science Letters, v. 219, p. 21–34, doi: 10.1016/S0012–821X(03)00705–2.

Bullen, M.E., Burbank, D.W., Garver, J.I., and Abdrakhmatov, K.Y., 2001, Late Cenozoic tectonic evolution of the northwestern Tien Shan: New age estimate for the initiation of mountain building: Geological Society of America Bulletin, v. 113, p. 1544–1559.

Burbank, D.W., McLean, J.K., Bullen, M., Abdrakhmatov, K.Y., and Miller, M.M., 1999, Partitioning of intermontane basins by thrust-related folding, Tien Shan, Kyrgyzstan: Basin Research, v. 11, p. 75–92.

Cunningham, W.D., 1998, Lithospheric controls on late Cenozoic construction of the Mongolian Altai: Tectonics, v. 17, p. 891–902.

Cunningham, W.D., Dijkstra, A.H., Howard, J., Quarles, A., and Badarch, G., 2003, Active intraplate strike-slip faulting and transpression uplift in the Mongolian Altai, *in* Storti, F., et al., eds., Interplate strike-slip deformation belts: Geological Society [London] Special Publication 210, p. 65–87.

De Grave, J., and Van Den Haute, P., 2002, Denudation and cooling of the Lake Teletskoye region in the Altai Mountains (South Siberia) as revealed by apatite fission-track thermochronology: Tectonophysics, v. 349, p. 145–159, doi: 10.1016/S0040–1951(02)00051–3.

De Grave, J., Buslov, M.M., and Van Den Haute, P., 2007, Distant effects of India-Eurasia convergence and Mesozoic intracontinental deformation in Central Asia: Constraints from apatite fission-track thermochronology: Journal of Asian Earth Sciences, v. 29, p. 188–204, doi: 10.1016/j.jseaes.2006.03.001.

Dumitru, T.A., and Hendrix, M.S., 2001, Fission-track constraints on Jurassic folding and thrusting in southern Mongolia and their relationship to the Beishan thrust belt of northern China, *in* Hendrix, M., and Davis, G.A., eds., Paleozoic and Mesozoic tectonic evolution of Central and eastern Asia: From continental assembly to intracontinental deformation: Geological Society of America Memoir 194, p. 215–229.

Dupont-Nivet, G., Krijgsman, W., Langereis, C.G., Abels, H.A., Dai, S., and Fang, X., 2007, Tibetan plateau aridification linked to global cooling at the Eocene-Oligocene transition: Nature, v. 445, p. 635–638, doi: 10.1038/nature05516.

Florensov, N.A., and Solonenko, V.P., eds., 1965, The Gobi-Altay earthquake: Washington, D.C., U.S. Department of Commerce, 424 p.

Green, P.F., Duddy, I.R., Gleadow, A.J.W., Laslett, G.M., and Tingate, P.R., 1986, Thermal annealing of fission tracks in apatite, 1—A qualitative description: Chemical Geology, v. 59, p. 237–253, doi: 10.1016/0009–2541(86)90048–3.

Hättestrand, C., and Stroeven, A.P., 2002, A relict landscape in the centre of Fennoscandian glaciation: Geomorphological evidence of minimal Quaternary glacial erosion: Geomorphology, v. 44, p. 127–143.

Hendrix, M., Graham, S.A., Carroll, A., Sobel, E., McKnight, C., Schulein, B., and Wang, Z., 1992, Sedimentary record and climatic implications of recurrent deformation in the Tian Shan: Evidence from Mesozoic strata of the north Tarim, south Dzungar, and Turpan basin, northwest China: Geological Society of America Bulletin, v. 104, p. 53–79.

Hendrix, M., Graham, S.A., Armory, J.Y., and Badarch, G., 1996, Noyon Uul syncline, southern Mongolia: Lower Mesozoic sedimentary record of the tectonic amalgamation of Central Asia: Geological Society of America Bulletin, v. 108, p. 1256–1274.

Johnson, C.L., Webb, L.E., Graham, S.A., Hendrix, M.S., and Badarch, G., 2001, Sedimentary and structural records of late Mesozoic high-strain extension and strain partitioning, East Gobi basin, southern Mongolia, *in* Hendrix, M.S., and Davis, G.A., eds., Paleozoic and Mesozoic tectonic evolution of central Asia: From continental assembly to intracontinental deformation: Geological Society of America Memoir 194, p. 413–433.

Jolivet, M., Brunel, M., Seward, D., Xu, Z., Yang, J., Roger, F., Tapponnier, P., Malavieille, J., Arnaud, N., and Wu, C., 2001, Mesozoic and Cenozoic tectonics of the northern edge of the Tibetan plateau: Fission-track constraints: Tectonophysics, v. 343, p. 111–134, doi: 10.1016/S0040–1951(01)00196–2.

Ketcham, R.A., Donelick, R.A., and Carlson, W.D., 1999, Variability of apatite fission-track annealing kinetics: III. Extrapolation to geological time scales: American Mineralogist, v. 84, p. 1235–1255.

Ketcham, R.A., Donelick, R.A., and Donelick, M.B., 2000, AFTSolve: A program for multikinetic modelling of apatite fission-track data: Geological Materials Research, v. 2, p. 1–32.

Kirschbaum, A., Martinez, E., Pettinari, G., and Herrero, S., 2005, Weathering profiles in granites, Sierra Norte (Cordoba, Argentina): South American Earth Sciences, v. 19, p. 479–493.

Kurushin, R.A., Bayasgalan, A., Olziybat, M., Enkhtuvshin, B., Molnar, P., Bayarsayhan, C., Hudnut, K.W., and Lin, J., 1997, The surface rupture of the 1957 Gobi-Altay, Mongolia, earthquake: Geological Society of America Special Paper 320, 143 p.

Laslett, G.M., Green, P.F., Duddy, I.R., and Gleadow, A.J.W., 1987, Thermal annealing of fission tracks in apatite, 2. A quantitative analysis: Chemical Geology, v. 65, p. 1–13, doi: 10.1016/0009–2541(87)90189–6.

Li, Z., Song, W., Peng, S., Wang, D., and Zhang, Z., 2004, Mesozoic-Cenozoic tectonic relationships between the Kuqa subbasin and Tian Shan, northwest China: Constraints from depositional records: Sedimentary Geology, v. 172, p. 223–249, doi: 10.1016/j.sedgeo.2004.09.002.

Molnar, P., and Tapponnier, P., 1975, Cenozoic tectonics of Asia: Effects of a continental collision: Science, v. 189, p. 419–426, doi: 10.1126/science.189.4201.419.

Pettke, T., Halliday, A.N., Hall, C.M., and Rea, D.K., 2000, Dust production and deposition in Asia and the North Pacific Ocean over the past 12 Myr: Earth and Planetary Science Letters, v. 178, p. 397–413, doi: 10.1016/S0012–821X(00)00083–2.

Ramstein, G., Fluteau, F., Besse, J., and Joussaume, S., 1997, Effect of orogeny, plate motion and land-sea distribution on Eurasian climate change over the past 30 million years: Nature, v. 386, p. 788–795.

Ritz, J.-F., Bourles, D., Brown, E.T., Carretier, S., Chery, J., Enhtuvshin, B., Galsan, P., Finkel, R.C., Hanks, T.C., Kendrick, K.J., Philip, H., Raisbeck, G., Shlupp, A., Schwartz, D.P., and Yiou, F., 2003, Holocene to upper Pleistocene fault rates estimated with ^{10}Be dates: Examples of the Gurvan Bulag thrust fault (Gobi-Altay, Mongolia): Journal of Geophysical Research, v. 108, doi: 10.1029/2001JB000553.

Ritz, J.-F., Vassallo, R., Braucher, R., Brown, E.T., Carretier, S., and Bourlès, D., 2006, Using in situ-produced ^{10}Be to quantify active tectonics in the Gurvan Bogd mountain range (Gobi-Altay, Mongolia), *in* Siame, L.L., et al., eds., Application of cosmogenic nuclides to the study of Earth surface processes: The practice and the potential: Geological Society of America Special Paper 415, p. 87–110, doi: 10.1130/2006.2415(06).

Sobel, E.R., and Dumitru, T.A., 1997, Thrusting and exhumation around the margins of the western Tarim basin during the India-Asia collision: Journal of Geophysical Research, v. 102, p. 5043–5063.

Sobel, E.R., Oskin, M., Burbank, D., and Mikolaichuk, A., 2006, Exhumation of basement-cored uplifts: Example of the Kyrgyz Range quantified with apatite fission track thermochronology: Tectonics, v. 25, doi: 10.1029/2005TC001809.

Tang, F., Luo, Z.X., Zhou, Z.H., You, H.L., Georgi, J.A., Tang, Z.L., and Wang, X.Z., 2001, Biostratigraphy and palaeoenvironment of the dinosaur-bearing sediments in Lower Cretaceous of Mazongshan area, Gansu Province, China: Cretaceous Research, v. 22, p. 115–129, doi: 10.1006/cres.2000.0242.

Vassallo, R., Jolivet, M., Ritz, J.-F., Braucher, R., Larroque, C., Sue, C., Todbileg, M., and Javkhlanbold, D., 2007, Uplift age and rates of the Gurvan Bogd system (Gobi-Altay) by apatite fission track analysis: Earth and Planetary Science Letters (in press).

Wang, J., Wang, Y.J., Liu, Z.C., Li, J.Q., and Xi, P., 1999, Cenozoic environmental evolution of the Qaidam Basin and its implications for the uplift of the Tibetan Plateau and the drying of central Asia: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 152, p. 37–47, doi: 10.1016/S0031–0182(99)00038–3.

Wang, T., Zheng, Y., Li, T., and Gao, Y., 2004, Mesozoic granitic magmatism in extensional tectonics near the Mongolian border in China and its implications for crustal growth: Journal of Asian Earth Sciences, v. 23, p. 715–729, doi: 10.1016/S1367–9120(03)00133–0.

Windley, B.F., Kröner, A., Guo, J., Qu, G., Li, Y., and Zhang, C., 2002, Neoproterozoic to Paleozoic geology of the Alati orogen, NW China: New zircon age data and tectonic evolution: Journal of Geology, v. 110, p. 719–737.

Zorin, Y.A., 1999, Geodynamics of the western part of the Mongolia-Okhotsk collisional belt, Trans-Baikal region (Russia) and Mongolia: Tectonophysics, v. 306, p. 33–56, doi: 10.1016/S0040–1951(99)00042–6.

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