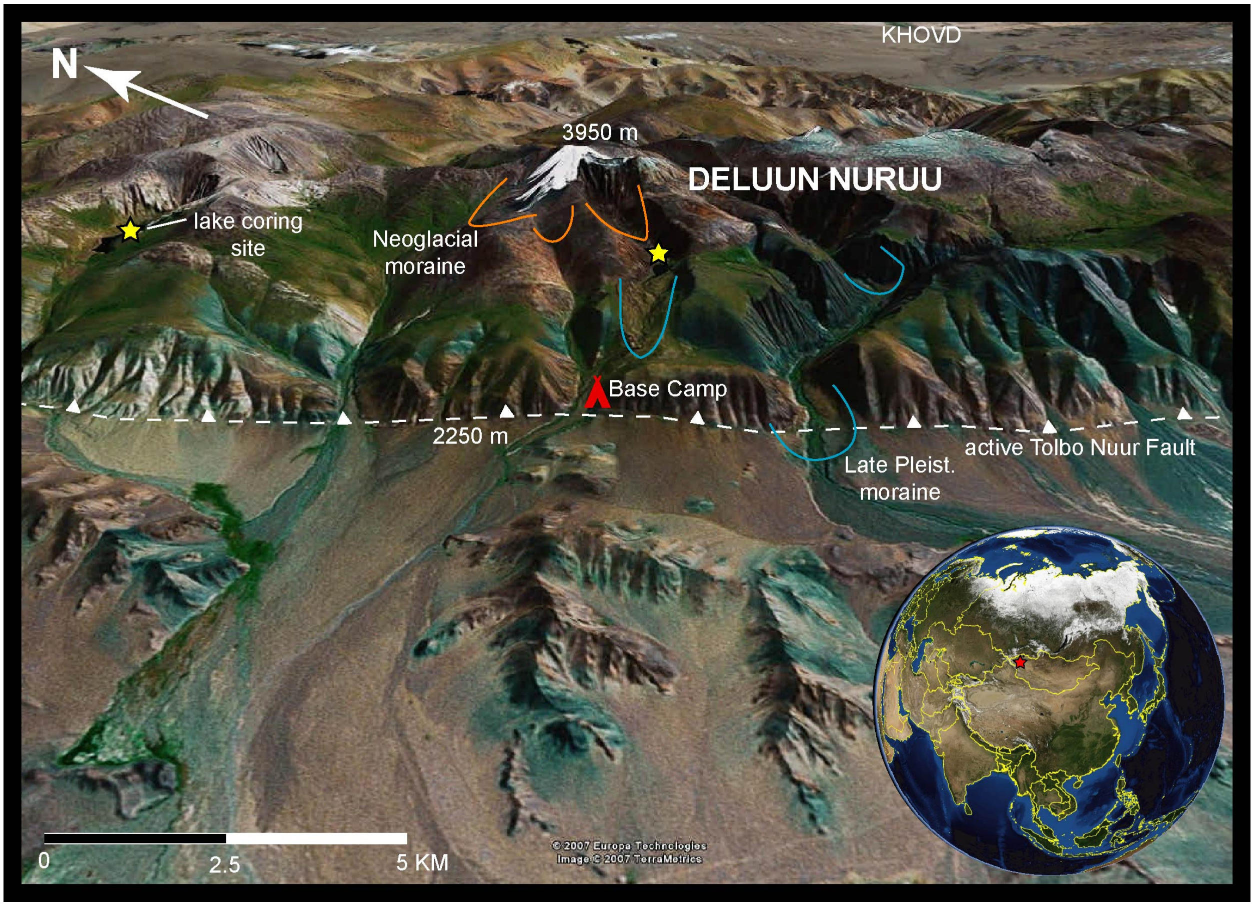
2008 Keck Geology Consortium Research Proposal

Quaternary Tectonic and Geomorphic Evolution of the Deluun Nuruu, Mongolian Altai, Western Mongolia



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2008 Keck Geology Consortium Research Proposal

Title: QUATERNARY TECTONIC AND GEOMORPHIC EVOLUTION OF THE DELUUN NURUU, MONGOLIAN ALTAI, WESTERN MONGOLIA

Co-directors: Amgalan ("Bayasaa") Byasgalan — Mongolian University of Science and Technology (Central Asian geology, structural geology, paleoseismology); Bob Carson — Whitman College (geomorphology, glacial geology); Karl Wegmann — Lehigh University (tectonic geomorphology; paleoecology). Bayasaa Bayasgalan has done considerable active tectonic and paleoseismology research in western Mongolia, including in the Altai Mountains (Bayasgalan et al., 1999; 2005). He co-directed Keck projects in the Gobi (2003), Kharkhiraa Nuruu (2004) and Hangay Nuruu (2006). Bob Carson did research in northern Mongolia and the Khangay Nuruu (Carson and Carson, 2004) in 2000, and co-directed Keck projects in Mongolia in 2003–2004 and 2006. Karl Wegmann has extensive experience in tectonic geomorphology (Wegmann and Pazzaglia, 2002; Wegmann et al., in revision). He was an adjunct faculty member on the 2003 and 2006 Mongolia Keck projects and is an alumnus of the 1994 Quetico and 1995 Montana Keck projects.

Number of students: 8 American students, 8 Mongolian students

Approximate date: July/August 2008 (4 weeks)

Why Western Mongolia?

Our motivations for the proposed research in western Mongolia are threefold: first, to provide constraints for models of active intracontinental faulting and orogenesis; second, to provide Late Quaternary paleoenvironmental proxy records of environmental change in this understudied portion of Central Asia; and third, to promote cross-cultural scientific exchange between U.S. and Mongolian geoscience students. In Central Asia, 2,500 km north of the India–Eurasia collision zone, a vast array of active intracontinental mountain belts are present. The Deluun Nuruu, a sub-range of the greater Mongolian Altai, is one of these. Paleozoic to Cenozoic sedimentary rocks crop out in the range and flanking hills, with minor amounts of late Paleozoic to Mesozoic intrusive rocks attesting to subduction, terrane collision and orogenesis during the Mesozoic when the Siberian and North China cratons collided (Tomurtogoo, 2003). Western Mongolia is host to many large active faults, including the Bulnay, Fu-yun, and Gobi Altai, which released three of the largest recorded intracontinental earthquakes in 1905 (Mw 8.1), 1931 (Mw 8), and 1957 (Mw 8.3), respectively (Baljinnyam et al., 1993). The Deluun Range is flanked on its western side by the Tolbo Nuur Fault, which exhibits evidence for both recent right-lateral strike-slip and thrust rupture, but has never been studied beyond a reconnaissance level (Baljinnyam et al., 1993). The Mongolian Altai is the largest glaciated area in Mongolia (Lehmkuhl, 1998), and the Deluun range supports retreating glaciers that provide runoff critical to local peoples and endemic species.

Geologic Setting:

Major mountain ranges on the continents can be grossly subdivided into plate boundary and intraplate orogens. A number of active intraplate orogenic belts exist in Central Asia around the perimeter of the Indo-Eurasian deformation field, including the Mongolian and Gobi Altai

(Fig. 1). The Mongolian Altai represents one of the best examples of an active intraplate intracontinental transpressional orogen (Cunningham, 2005). The Mongolian Altai is a far-field deformational response to the Indo-Eurasia collision occurring 2500 km to the south (Tapponnier and Molnar, 1979; Balijinnyam et al., 1993; Cunningham, 1998). The mountains are a northwest-trending belt composed mostly of amalgamated island-arc terranes, dating from the Paleozoic (Sengör et al., 1993) that were tectonically reactivated in the late Cenozoic. A rapid increase in coarse clastic sedimentation in the Miocene may date the onset of mountain building (e.g. Cunningham et al., 2003).The topography is characterized by a series of parallel NNW-SSE trending fault-bounded ranges, which reach elevations of over 4000 m in places.

Modern tectonic activity in the Mongolian Altai is provided by historical seismicity (e.g. Balijinnyam et al., 1993; Bayasgalan, 1999), Quaternary surface fault ruptures, linear mountain fronts bordered by active alluvial fans, and other geomorphic indices of active tectonism (Balijinnyam et al., 1993; Cunningham et al., 2003) (Fig. 1). Recently published GPS results indicate that ~15% (~7 mm/yr) of the total India-Eurasia convergence is accommodated by N-S shortening combined with dextral shear in the Mongolia Altai (Calais et al., 2003; 2006) (Fig. 2). The angular relationship between the present-day stress field (NNE) (revealed by GPS studies) and the major terrane boundaries along with the prevailing basement structural grain in the Altai (NW) (Xiao et al., 2004) promote dextral transpressional deformation on the NW-trending strike-slip faults and linked oblique–slip and thrust faults (Cunningham, 2005) (Fig. 1).

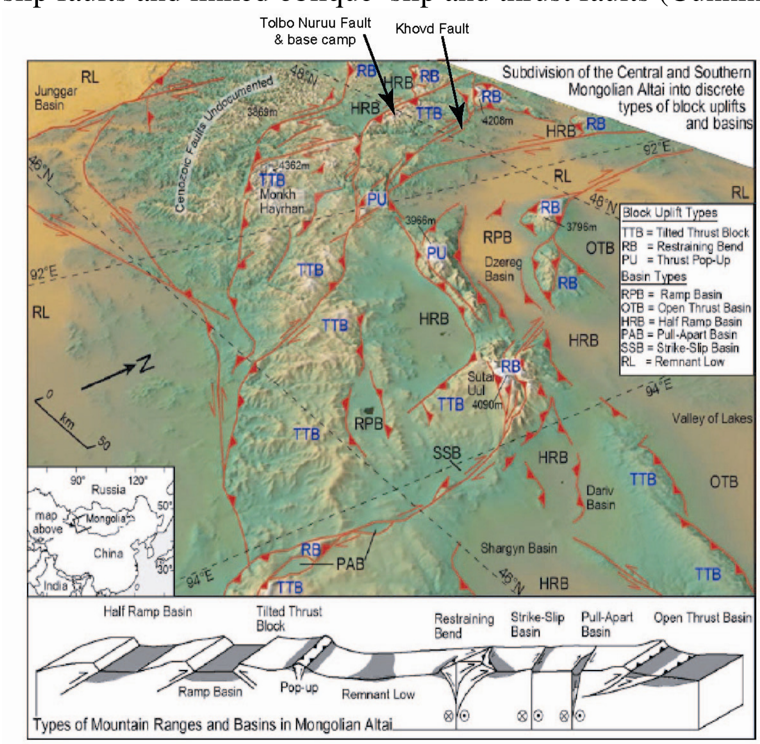

Figure 1. Oblique DEM perspective of the central Mongolian Altai, showing major fault systems believed to be active during the Quaternary. According to Cunningham (2005) the Mongolian Altai range can be subdivided into distinct mountain and basin types controlled by the style of localized faulting, as shown in the lower block diagram. The Deluun Nuruu is a tilted-thrust block formed by movement on the Tolbo Nuruu Fault (Balijinnyam et al., 1993). Uplift of the Deluun Nuruu may be quite recent (hypothesized to be ~ 1 Ma).

<u>Deluun Nuruu:</u>

The Deluun Nuruu, a largely unstudied fault-bounded range, is approximately 100 km north-to-south and 40 km west-to-east, centered on 47.95º N, 90.95º E (Figs. 1, 3). The Deluun, a subrange of the Mongolian Altai, reach a maximum elevation of 3950 m, with total relief in excess of 1700 m (Fig. 4). The range separates the internally-drained Mongolian Valley of Lakes to the east, which represents local base level, from interior ranges of the Mongolian Altai to the west-northwest. The Buyant Gol (river) drains the western flank of the Deluun, cutting a 1500-m-deep transverse gorge across the southern end of the range (Fig 4). Higher elevations are glaciated and periglacial landforms are present above ~2200 m. Vegetation includes small larch forests on intermediate-elevation north-facing slopes, shrubs, and grasses. August is the wettest month in Mongolia, so a little rain or snow is expected. Daily summer temperatures range between 0 to 25º C. The only major town in the vicinity is Khovd, on the east flank of the range, at an elevation of 1425 m.

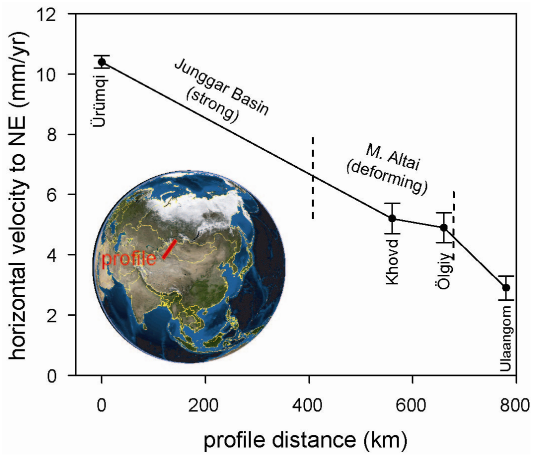

Figure 2. Horizontal GPS velocities for selected stations along an 800-km NE-oriented transect from Ürümqi, China, at the southern end of the Junggar Basin to Ulaangom, Mongolia, on the NE flank of the Mongolian Altai (Calais et al., 2003). Approximately 7 mm/yr of compression is accommodated across the Mongolian Altai, resulting in dextral strike-slip and thrust faulting. The Deluun Nuruu, located along the Tolbo Nuur Fault, provides the opportunity to study linkages between strike-slip and thrust motion along a single fault and the partitioning of time-transgressive compression into surface uplift and landscape evolution.

The Deluun Nuruu is a down-to-the east tilted thrust block bounded by the active Tolbo Nuur Fault (TNF) along its western flank. The range is actively overriding the Buyant Gol half-ramp basin to the west (Baljinnyam et al., 1993; Cunningham, 2005) (Figs 1, 3). Geologic mapping suggests that the range consists predominantly of fossiliferous Cambrian-to-Ordovician marine forearc and/or backarc sedimentary sequences, with younger Devonian strata preserved within the half-ramp basin and on footwalls of local faults within the range (Tomurtogoo, 1998). These rocks have experienced localized low-grade metamorphism.

Evidence for active faulting:

The Deluun Nuruu is a seismically active part of Mongolia for which very few historical records are available. The TNF was distinguished by Tikhonov (1974) and Khil'ko and others (1985) as one of several major dextral strike-slip faults to partition strain across the Mongolian Altai; however, the style and amount of offset has never been studied in detail. The main strand of the fault trends NNW for about 450 km, 100 km of which bounds the western flank of the Deluun Nuruu. Based upon the 90-m SRTM DEM and available space-imagery, it appears that the TNF displays predominantly dextral strike-slip motion at the northern and southern ends of the range, as revealed by offset valleys (Fig. 5), versus a larger component of thrust-to-oblique thrust adjacent to the central portion of the range and corresponding to the highest topography (Figs. 3 & 5). This type of behavior of paired strike-slip and thrust components is similar to that documented during the 2004 Keck Mongolia expedition for the Jid dextral strike-slip fault (Walker et al., 2006). It is in this central sector where the mountain front contains faceted spurs, and alluvial fans are disrupted and show a component of vertical displacement (Baljinnyam et al., 1993), consistent with active thrusting and the building of topography.

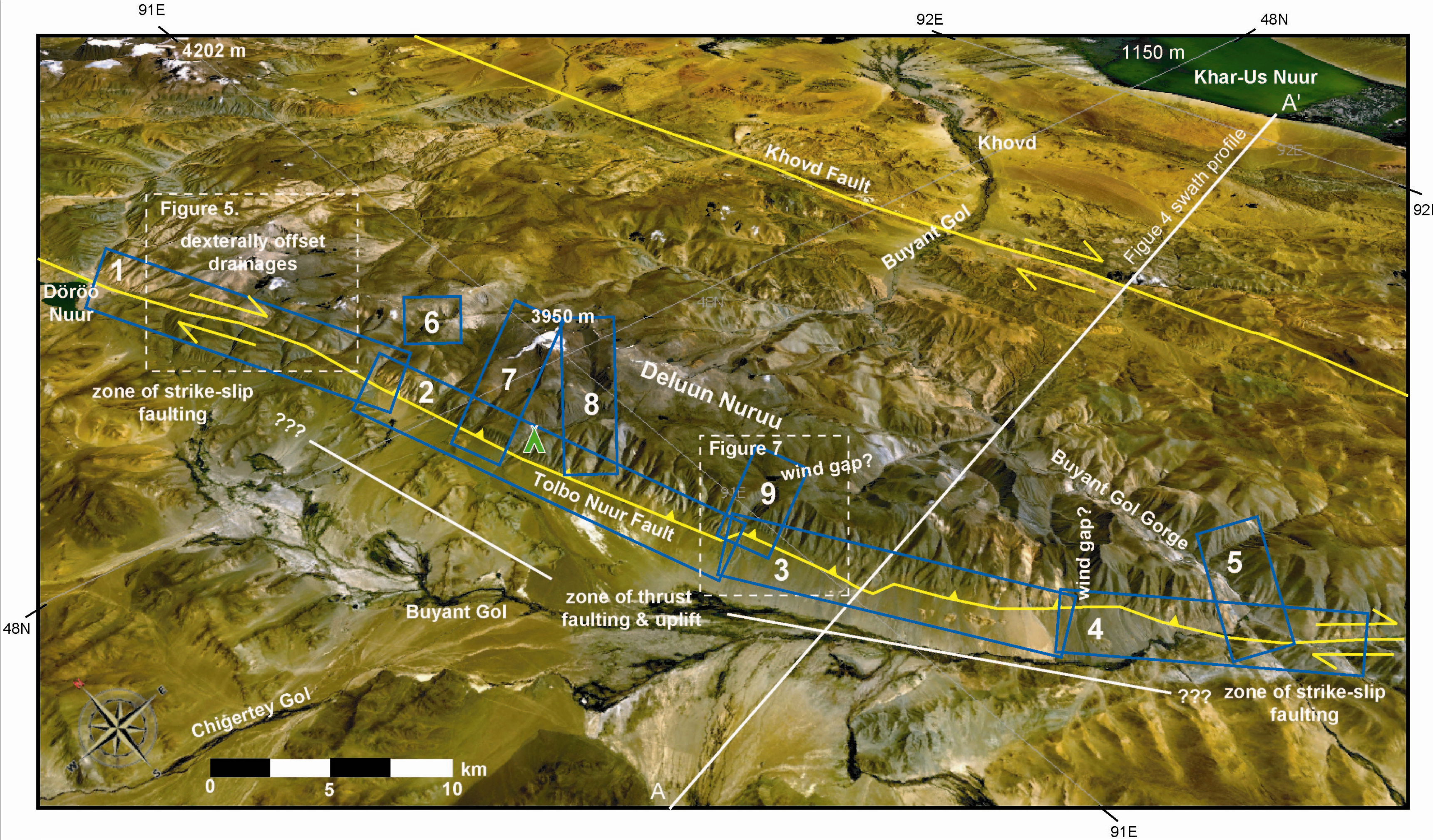

Figure 3. Oblique aerial view to NE across the Deluun Nuruu. The Tolbo Nuur Fault, which bounds the west side of the range, is in the foreground, while the Khovd Fault is in the background. The base camp location, denoted by the green tent symbol, is central to the individual project areas. Individual student project areas are outlined in blue boxes, with the number corresponding to the project designation (see text). The locations of Figures 4, 5, and 7 are shown. The image was generated from LandSat7 photography draped over an SRTM 90-m DEM and manipulated using NASA's World Wind software.

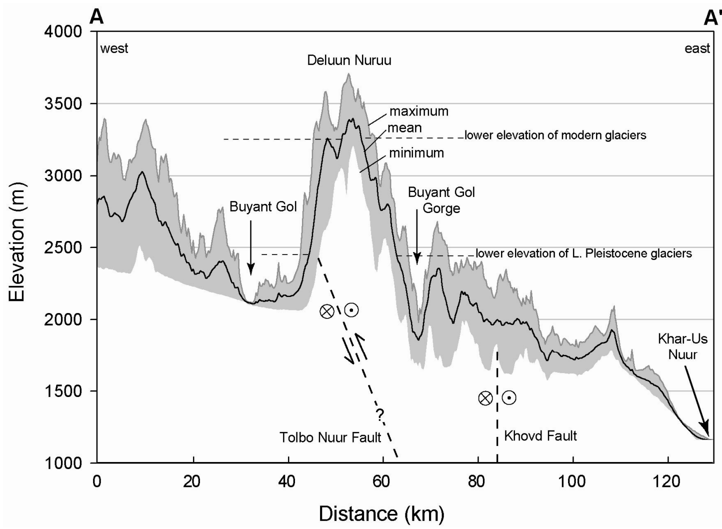

Figure 4. Swath topographic profile of maximum, mean, and minimum elevations across the Deluun Nuruu; see Fig. 3 for location. Topography was evenly sampled every 250 m from a 90m SRTM DEM along 10 parallel profiles spaced 1 km apart. It is hypothesized that the topography of the Deluun Nuruu is the result of localized Quaternary thrust motion on the predominantly dextral Tolbo Nuur Fault. The Buyant Gol cuts orthogonally across the southern end of the range in an impressive 1500-m-deep gorge.

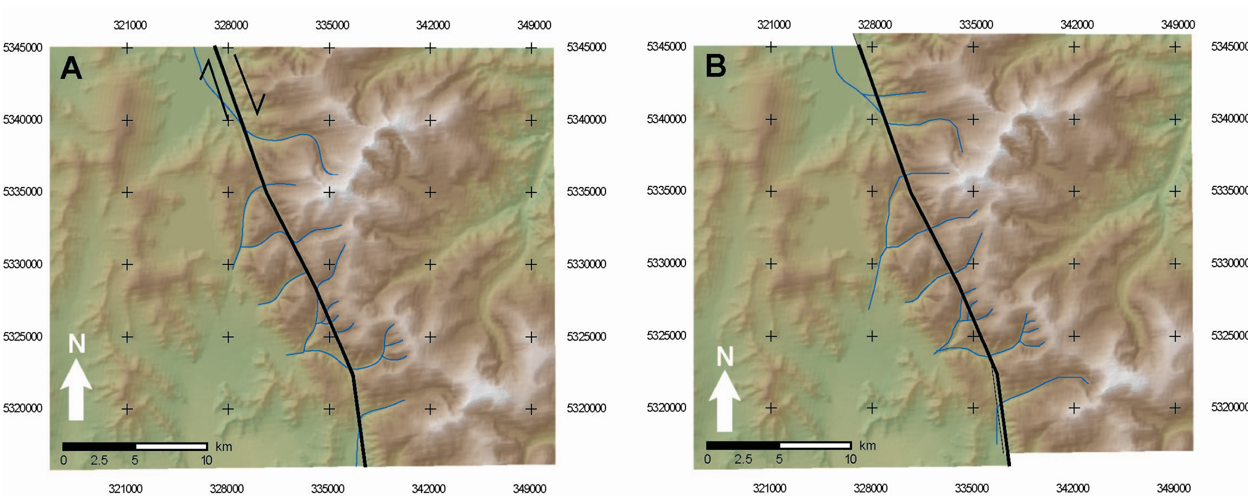

Figure 5. Right-lateral displacement of drainages by the Tolbo Nuur Fault (TNF) at the northern end of the Deluun Nuruu, see Fig. 3 for location. **A.** A 90-m SRTM DEM showing present topography and drainage along the TNF. **B.** Approximately 750 m of restorative left-lateral displacement along the fault results in realignment of offset drainages. If the long-term slip rate for the TNF is 1 mm/yr, the amount of offset preserved by the drainages represents 750 ka of accumulated slip along the fault. If the slip rate is 3 mm/yr, the offsets would have accumulated in only 250 ka.

Geomorphology – glacial, periglacial & fluvial:

The Deluun Nuruu is one of several ranges in the Mongolian Altai with active small, retreating glaciers (Lehmkuhl, 1998). At about 2800 m, the last glacial maximum (LGM) equilibrium line altitude (ELA) was more than 1000 m below today's so that there are extensive cirques, glacial troughs and small lake basins (Figs. 3, 4). In the central Hangay Mountains to the east, Coggan and others (2007) determined that older, likely oxygen isotope stage (OIS) 6 glacial deposits are present downvalley from the outermost LGM moraines, as did Bevis and Carson (2005) for the Kharkhiraa Uul range of the northern Mongolian Altai. In contrast, research at three other sites in northern Mongolia (e.g. Carson et al., 2003) and at one site in the northwestern Hangay (Carson and Carson, 2004) revealed the most extensive glaciation to have been the LGM during OIS 2, consistent with data suggesting that these are areas of active uplift during the Late Quaternary. Similarly, preliminary remote sensing analysis of the Deluun Nuruu suggests that LGM glaciers advanced further than earlier glacial events, perhaps due to a tectonic lowering of the ELA during the 120 ka between OIS 6 and 2 as the range was uplifted along the TNF.

Due to low winter temperatures and small amounts of snow, frost weathering occurs down to the lowest elevations in Mongolia and discontinuous permafrost is prevalent at higher elevations (Lehmkuhl et al., 2003). Although there are no published records of periglacial features in the Deluun Nuruu, it is fully expected that landforms such as cryoplanation terraces, sorted polygons and stone stripes, palsas, and perhaps rock glaciers will be found.

There are no published reports on the river systems and their deposits surrounding the Deluun Nuruu. The Buyant Gol, which drains the western flank of the Deluun Nuruu, cutting orthogonally across the range in an impressive 1500-m deep gorge, is the only river that drains to the Valley of Lakes that has cut entirely across one of the Mongolian Altai ranges (Tomurtogoo, 1998) (Figs. 3, 6). It is quite possible that the Buyant Gol is an antecedent drainage, pre-dating uplift of the range along the TNF. The longitudinal profile of the Buyant Gol from its headwaters in the northwestern part of the Deluun Nuruu to where it enters into the gorge has a concave-up profile typical of graded alluvial streams (Mackin, 1948) (Fig. 6). A prominent knickpoint is apparent where the river crosses the trace of the TNF, at the range front. Downstream of the knickpoint, the longitudinal profile is remarkably linear, suggestive of active tectonic modification (e.g. Kirby and Whipple, 2001) (Fig. 6). Variations in climatically-modulated sediment load to the Buyant Gol may be represented in river terraces. There is a high likelihood that terrace sequences preserved in the upper 10 to 15 km of the Buyant Gol gorge will preserve evidence for increasing deformation with time related to activity on the TNF in the form of a down-to-the east tilt (Fig. 6). The spatial and temporal distribution of river terraces within the upper part of the Buyant Gol Gorge may provide important geometric and timing constraints on activity of the TNF. Late Pleistocene-to-Holocene alluvial fans preserved along the mountain front likely also preserve evidence for the style and rate of activity of different segments of the TNF (Fig. 3).

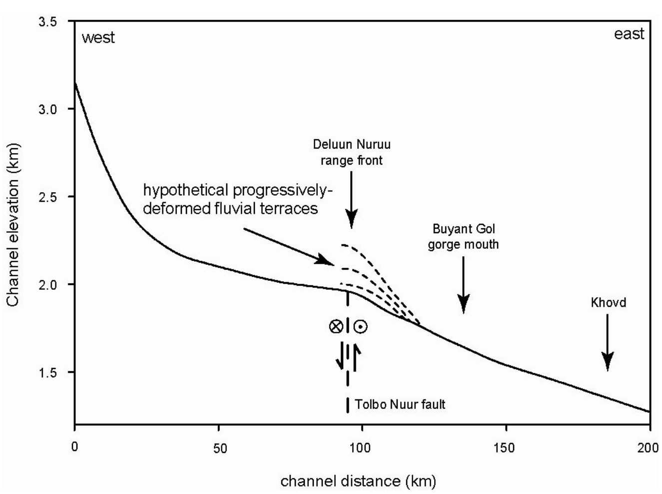

Figure 6. Longitudinal profile of channel elevation as a function of distance for the Buyant Gol from its headwaters in the NW Deluun Nuruu to just past Khovd (near its terminus in Khar-Us Nuur). Note the prominent knickpoint and steepening of the profile that occurs at the range front, where the river crosses the trace of the Tolbo Nuur Fault and enters into a ~30-km-long gorge. River terraces preserved at the head of the gorge might provide insights into the type and rate of deformation of the Tolbo Nuur Fault.

Goals and Significance of the Project:

The primary goal of the proposed research is to engage senior undergraduate-level geoscience majors in testing hypotheses via independent field research around a coupled tectonic-geomorphic problem. Cross-cultural scientific exchange is also of significant importance to our project. Our proposal is built around several key observations. First, The Tolbo Nuur Fault shows ample geomorphic evidence for Pleistocene-to-Holocene activity. Geomorphic relationships suggest that the TNF is predominantly right-lateral strike-slip at the northern and southern ends of the Deluun Nuruu (e.g. offset drainages; Fig. 5). In contrast, the central portion of the TNF displays relationships more in line with thrust motion (Fig. 3). Second, the east-flowing Buyant Gol cuts across the axis of the Deluun Nuruu, the only such river to cross a major range of the Mongolian Altai. Third, the furthest downvalley moraines appear to be LGM (OIS 2) in age (title page).

Collectively, these observations lead us to hypothesize that the predominantly right-lateral strike-slip Tolbo Nuur Fault displays a large thrust component along the west flank of the Deluun Nuruu, which is responsible for recent (Quaternary) and ongoing uplift of the range. Range-front hypsometry indicates that the locus of compressional deformation along the TNF may be propagating southward, and that the Buyant Gol is an antecedent stream, which has progressively migrated southward around the southern Deluun Nuruu syntaxis, leaving several 'perched' east-facing drainages as wind gaps (Fig. 3). Accordingly, glaciers of the LGM extended downvalley further than previous glacial advances due to continuing tectonic uplift of the range, which resulted in an effective lowering of the ELA between OIS 6 and OIS 2. We envision that each student's project, while being individually self-contained, will add critical data necessary to support or reject the broader hypothesis. It is our hope that such an approach will foster scientific curiosity and cross-project dialogue and collaboration among and between the American and Mongolian students.

Specific problems for student research:

We are interested in student projects in 2 to 3 complimentary areas: 1) neotectonic – tectonic geomorphology, fault characterization, and paleoseismology; 2) glacial, periglacial, and fluvial geomorphology, and 3) paleoclimatic proxies of Late Quaternary climate change. We have pre-identified nine individual projects (Fig. 3) and additional projects may be added based upon student-faculty sponsor interests and field opportunities.

Projects 1-4 → Tolbo Nuruu Fault: These projects will focus upon the geometry, kinematics, age and evolution of the Tolbo Nuruu Fault. Each project will cover ~25 km along strike that is characterized by differing geometry and apparent rupture behavior. Paleoseismic trenching is a possibility for each of these 4 projects. Projects 1 & 4 will focus upon the TNF near the ends of the Deluun Nuruu, where it is hypothesized that fault motion transitions from predominantly right-lateral strike-slip to a larger thrust component. Project 1 will utilize offset drainages to provide constraints on the amount of right-lateral slip (e.g. Fig. 5). Projects 2 and 3 will utilize alluvial fan relationships to characterize the style and amount of movement on the central part of the TNF (e.g. Walker et al., 2006).

Project 5 → Fluvial terraces: This project will focus upon mapping and dating fluvial terrace deposits above and within the upper few kilometers of the Buyant Gol gorge, straddling the trace of the TNF. The student will use geomorphic and sedimentologic evidence to develop a terrace chronostratigraphy, augmented by radiocarbon and/or cosmogenic age control. Terrace longitudinal profiles will be constructed in order to provide constraints on the kinematics of deformation along this portion of the TNF (e.g. Fig. 6). It is anticipated that this student will collaborate with the student working on the southern segment of the TNF (Project 4).

Project 6 → Pleistocene-Holocene Paleoclimatology: In sparsely populated western Mongolia, long-term climate measurements are rare. As a result paleo-records preserved in sedimentary or dendrochronologic archives may provide detailed information about past climate changes in this portion of central Asia. The focus of this project will be to retrieve proxy paleoclimatic records for the Holocene and possibly late Pleistocene. Examination of such records may reveal important climate forcing periodicities and potential driving mechanisms for climate change on various temporal scales. Predicative paleoclimate research is much needed in Mongolia, a dominantly agrarian society dependent upon dry-land grazing, especially in the face of warming temperatures during the 20th and 21st centuries. Paleoclimate records could be retrieved from *Larix sibirica* (Siberian larch) trees (e.g. Stratton et al., 2007; Jacoby et al., 1996), from sediment cores recovered small glacial lakes (e.g. Blyakharchuk et al., 2007), or from peat cores.

Projects 7 & 8 → Glacial and periglacial geomorphology: These projects will focus upon the number, extent, age, and climatic significance of glaciations in the Deluun Nuruu region. Of importance is the validation (invalidation) that the OIS 2 glaciers extended further downvalley than previous glacial advances. Because several of the larger valley glacier systems exited onto the piedmont, there is the opportunity to constrain the rate of offset on the TNF by dating offset glacial features (moraines and outwash terraces). It is anticipated that the students working on Projects 7 & 8 will collaborate with those working on segments 2 & 3 of the TNF projects (Fig. 3). Additionally, Holocene and modern glacial and periglacial processes could be incorporated into these projects.

Project 9 → Mass wasting deposit and incipient drainage capture: A conspicuous debris flow deposit is observable overlying Holocene alluvial fans (Figs. 3, 7). The deposit was derived from a deeply incised valley exiting the mountain front along the TNF, and may be cut by the fault. The head of this valley may be sapping a small glacial lake in a drainage exiting the east side of the range, and thus may be in the process of generating a near-future drainage capture. This student would collaborate with students on projects 3, 7, and 8.

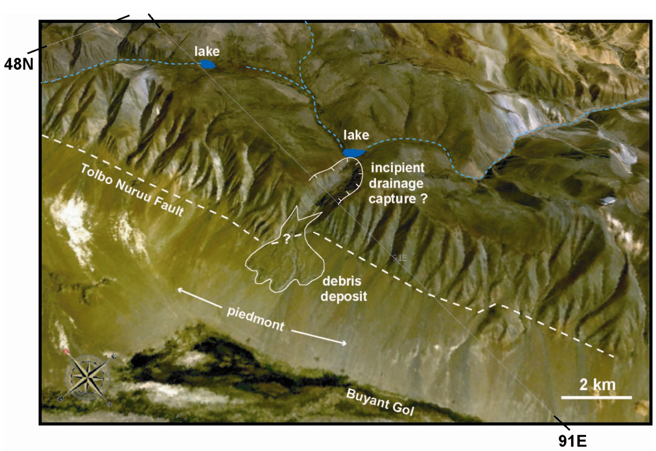

Figure 7. Oblique aerial view to NE of piedmont debris flow deposit. Sapping of a small moraine-dammed lake may have generated the debris flow. In addition the headward-retreating valley may capture the lake and upstream drainage in the near future. Dating of the debris deposit could constrain the rate of faulting along this portion of the Tolbo Nuur Fault.

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Project Logistics:

Preferred student background:

We will have two or three projects in each of the following subject areas: (1) neotectonics, (2) geomorphology, and (3) paleoecology - climatology. Students will be selected to fill these slots. A general requirement is a course in field methods or field camp. Those interested in geomorphology should have a course in geomorphology or Quaternary geology. Those interested in neotectonics should have courses in structure and geomorphology.

Travel to Field Area:

We will fly to Mongolia's capital, Ulaanbaatar, and spend one night there with a day of orientation at Mongolian University of Science and Technology. Bayasaa will be responsible for logistics in Mongolia, including food and cooks, and 4WD vehicles with drivers. We will fly domestically from Ulaanbaatar to Khovd, where we will meet the caravan of field and supply vehicles sent ahead the week before. From Khovd it is a half-day drive to the field area. After a few days of reconnaissance, students will pick their projects and begin fieldwork. The last two nights will be in Ulaanbaatar, with a day for packing samples. Except for the first and last two nights, we will be camping. Each student should bring a tent, pad, sleeping bag, and lots of warm and waterproof clothes. We will filter, boil, and/or otherwise purify water. We will have a cook; vegetarians should be aware that most Mongolian meals include sheep or goat.

Safety and security:

As of April 2007, the Centers for Disease Control have no "outbreaks" listed for Mongolia. We will be careful about what we eat and drink to reduce the incidence of diarrhea, the number one illness of travelers everywhere. There is no risk of malaria in Mongolia. There have been no outbreaks of avian influenza in Mongolia. There is the potential for plague ("marmot fever"), but we will not hunt or eat marmots. Meningitis is a winter disease. Typhoid is unlikely, but has occurred in Siberia. Not handling animals greatly reduces the chance of a bite causing rabies. All participants should get vaccines for typhoid, Hepatitis A, and Hepatitis B, and a booster for tetanus-diphtheria. As for the three-previous Keck Mongolia research projects, we again plan to have a U.S. doctor on the expedition (at his own flight expense). The regional hospital in nearby Khovd has seven departments, including surgery. We will have a satellite phone.

Similarly, as of April 2007, the U.S. State Department have no travel warnings for Mongolia. The Consular Information Sheet states: “Over the past few years there has been a significant rise in crime in Mongolia, particularly in Ulaanbaatar, the capital. Violent crime is increasing, and it is no longer advisable to walk alone through the city after dark. The most common crimes against foreigners are pickpocketing and bag-snatching.” In the summers of 2003, 2004, and 2006 we were not aware of any crime in Ulaanbaatar or outlying areas. However, we will stay in groups and be especially careful at night.

The outbreak of SARS in China and elsewhere in the winter of 2003 gave us some concern as to whether or not the 2003 Keck project in Mongolia would occur. Fortunately there were only a few cases of SARS in Mongolia. SARS was not a problem in 2004 or 2006, and now the world knows better how to handle it.

Notes:

It is our hope and intent to continue the cultural and geologic exchange of the 2003, 2004, and 2006 Keck projects in Mongolia. In general, each project will be worked on by one American and one Mongolian. The Mongolians are full participants in terms of field work, including descriptions, measurements, sample collecting, and other data collection. Due to the different degrees of English proficiency among the Mongolians, their level of contribution to the Keck research papers will vary. Drafts of the research papers will be sent to all project faculty. Bayasaa will go over the drafts with the Mongolian students, and their recommendations will be incorporated into the Keck paper before publication. As in the past, theses by American students will not have Mongolian co-authors.

We anticipate being joined by two additional geologists during the project. Richard Walker of Oxford University plans to join us for a week or two, as he did for the 2004 (4 weeks) and 2006 (1 week) Mongolia projects. He was lead author of the Jid Fault Paper in the Journal of Structural Geology (Walker et al., 2006) and provided valuable help in our study of the Egiin Davaa Fault in 2006. He will pay his own expenses. S. Dandar, a professor of economic geology and stratigraphy at the Mongolian University of Science and Technology also plans to join the group. He has extensive field geology experience in western Mongolia, and will work to assist Mongolian students interested in studying the sedimentology, stratigraphy, and micropaleontology of Ordovician and Devonian marine sequences exposed near our camp site.

Mongolia is not a wealthy country. The budget below is designed to subsidize the expenses of eight Mongolian students while we are in Mongolia. It will be impractical to fly the Mongolian students to our symposium. However, if the Mongolian students find funds to fly to the USA, it is our expectation that the Consortium will cover their expenses at the symposium.