KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-FOURTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2011
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2010-2011 PROJECTS

FORMATION OF BASEMENT-INVOLVED FORELAND ARCHES: INTEGRATED STRUCTURAL AND SEISMOLOGICAL RESEARCH IN THE BIGHORN MOUNTAINS, WYOMING
Faculty: *CHRISTINE SIDDOWAY*, *MEGAN ANDERSON*, Colorado College, *ERIC ERSLEV*, University of Wyoming
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EXPLORING THE PROTEROZOIC BIG SKY OROGENY IN SOUTHWEST MONTANA
Faculty: *TEKLA A. HARMS*, *JOHN T. CHENEY*, Amherst College, *JOHN BRADY*, Smith College
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INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO
Faculty: *DAVID P. DETHIER*, Williams College, *WILL OUIMET*. University of Connecticut
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SEDIMENT DYNAMICS & ENVIRONMENTS IN THE LOWER CONNECTICUT RIVER
Faculty: *SUZANNE O'CONNELL*, Wesleyan University
Students: LYNN M. GEIGER, Wellesley College, KARA JACOBACCI, University of Massachusetts (Amherst), GABRIEL ROMERO, Pomona College.

GEOMORPHIC AND PALEOENVIRONMENTAL CHANGE IN GLACIER NATIONAL PARK, MONTANA, U.S.A.
Faculty: *KELLY MACGREGOR*, Macalester College, *CATHERINE RIIHIMAKI*, Drew University, *AMY MYRBO*, LacCore Lab, University of Minnesota, *KRISTINA BRADY*, LacCore Lab, University of Minnesota

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GEOLOGIC, GEOMORPHIC, AND ENVIRONMENTAL CHANGE AT THE NORTHERN TERMINATION OF THE LAKE HÖVSGÖL RIFT, MONGOLIA
Faculty: *KARL W. WEGMANN*, North Carolina State University, *TSALMAN AMGAA*, Mongolian University of Science and Technology, *KURT L. FRANKEL*, Georgia Institute of Technology, *ANDREW P. deWET*, Franklin & Marshall College, *AMGALAN BAYASAGALN*, Mongolian University of Science and Technology.
Students: *BRIANA BERKOWITZ*, Beloit College, *DAENA CHARLES*, Union College, *MELLISSA CROSS*, Colgate University, *JOHN MICHAELS*, North Carolina State University, *ERDENEBAYAR TSAGAANNARAN*, Mongolian University of Science and Technology, *BATTOGTOH DAMDINSUREN*, Mongolian University of Science and Technology, *DANIEL ROTHBERG*, Colorado College, *ESUGEI GANBOLD, ARANZAL ERDENE*, Mongolian University of Science and Technology, *AFSHAN SHAIKH*, Georgia Institute of Technology, *KRISTIN TADDEI*, Franklin and Marshall College, *GABRIELLE VANCE*, Whitman College, *ANDREW ZUZA*, Cornell University.

LATE PLEISTOCENE EDIFICE FAILURE AND SECTOR COLLAPSE OF VOLCÁN BARÚ, PANAMA
Faculty: *THOMAS GARDNER*, Trinity University, *KRISTIN MORELL*, Penn State University
Students: *SHANNON BRADY*, Union College. *LOGAN SCHUMACHER*, Pomona College, *HANNAH ZELLNER*, Trinity University.

KECK SIERRA: MAGMA-WALLROCK INTERACTIONS IN THE SEQUOIA REGION
Faculty: *JADE STAR LACKEY*, Pomona College, *STACI L. LOEWY*, California State University-Bakersfield
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EOCENE TECTONIC EVOLUTION OF THE TETONS-ABSAROKA RANGES, WYOMING
Faculty: *JOHN CRADDOCK*, Macalester College, *DAVE MALONE*, Illinois State University
Students: *JESSE GEARY*, Macalester College, *KATHERINE KRAVITZ*, Smith College, *RAY MCGAUGHEY*, Carleton College.

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Keck Geology Consortium: Projects 2010-2011
Short Contributions— Hövsgöl Rift, Mongolia

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MAPPING AND RELATIVE AGE DATING OF MORAINES IN THE HOROO GOL VALLEY, HÖVSGÖL RIFT, MONGOLIA
BRIANA BERKOWITZ, Beloit College
Research Advisor: Susan Swanson

PALEOLIMNOLOGY AND PALEOCLIMATE ENVIRONMENT REVEALED THROUGH HOLOCENE LAKE SHORE SEDIMENTS FROM HÖVSGÖL, MONGOLIA
DAENA CHARLES, Union College
Research Advisor: Donald Rodbell

A MULTI-PROXY STUDY OF HOLOCENE PALEOCLIMATE AND DEPOSITIONAL ENVIRONMENT, HÖVSGÖL, MONGOLIA
MELLISSA CROSS, Colgate University
Research Advisor: Bruce Selleck

CORRELATION OF TREE RING ANALYSIS AND CLIMATOGICAL RECORDS IN THE LAKE HÖVSGÖL REGION OF MONGOLIA
JOHN MICHAELS, North Carolina State University
ERDENEBAYAR TSAGAANNARAN, Mongolian University of Science and Technology
BATTOGTOH DAMDINSUREN, Mongolian University of Science and Technology
Research Advisor: Karl Wegmann

LATE PLEISTOCENE GLACIATION AND TECTONICS AT LAKE HÖVSGÖL
DANIEL ROTHBERG, Colorado College
Mongolian Participants: Esugei Ganbold, Aranzal Erdene
Research Advisor: Eric Leonard

TIMING AND EXTENT OF LATE QUATERNARY GLACIATIONS NEAR LAKE HÖVSGÖL, MONGOLIA: IMPLICATIONS FOR CLIMATE CHANGE IN CENTRAL ASIA
AFSHAN SHAIKH, Georgia Institute of Technology
Research Advisor: Kurt L. Frankel

THE PALEOSEDIMENTARY ENVIRONMENT AND PALEOCLIMATIC CONDITIONS REVEALED BY STRATIGRAPHY IN HOLOCENE BOG AND TERRACE SEDIMENTS, NORTHWEST OF LAKE HÖVSGÖL, MONGOLIA
KRISTIN TADDEI, Franklin and Marshall College
Research Advisor: Dr. Andy deWet

PLEISTOCENE GLACIATION OF THE EASTERN SAYAN RANGE, NORTHERN MONGOLIA
GABRIELLE VANCE, Whitman College
ESUGEI GANBOLD, Mongolia University of Science and Technology
Research Advisors: Bob Carson and Nick Bader

LATE-CENOZOIC VOLCANISM IN THE HÖVSGÖL RIFT BASIN: SOURCE, GENESIS, AND EVOLUTION OF INTRAPLATE VOLCANISM IN MONGOLIA

ANDREW ZUZA, Cornell University
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LATE PLEISTOCENE GLACIATION AND TECTONICS AT LAKE HOVSGOL

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Mongolian Participants: Esugei Ganbold, Aranzal Erdene
Research Advisor: Eric Leonard

INTRODUCTION

Glaciers have occupied the Vostoch and Bayan Nuruu mountain ranges (fig. 1) intermittently over the past million years (Hovsgol Drilling Project Members, 2010). Abundant glacial features including terminal and recessional moraines, glacial outwash terraces, and glacial kettles are preserved in the Il-Horoo-Gol Valley and piedmont. Two distinct moraine complexes exist: one containing a series of inset recessional moraines whose terminal moraine is currently under Lake Hovsgol, and the other whose terminal moraine ends at the head of the Il-Horoo-Gol Valley delta plain, about seven kilometers up valley (north) of the largest terminal moraine. Based on morphology of moraine crests we believe that the inner moraine complex is of Last Glacial Maximum (LGM) age while the outer complex is of MIS 4-6 age.

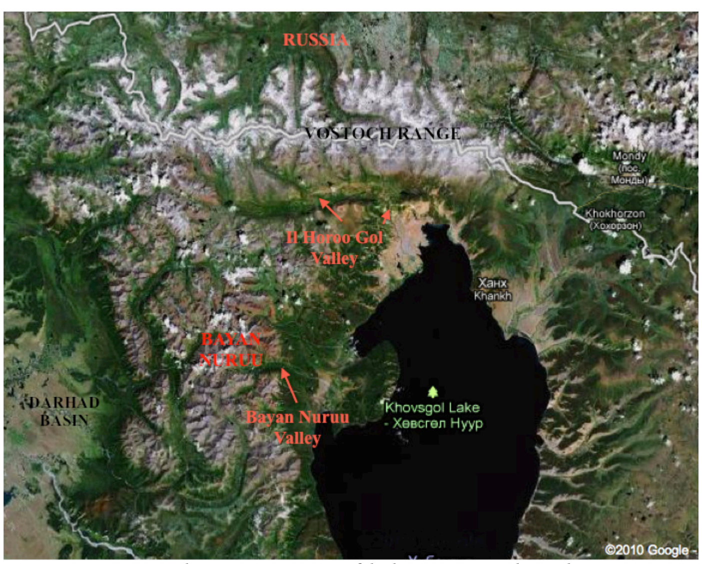

Figure 1. Northern portion of lake Hovsgol with surrounding mountains and Darhad Basin to the west.

In the Bayan Nuruu, about 20km to the southwest of the outlet of the Il-Horoo-Gol Valley (fig. 1), only a probable LGM moraine (based on "sharp" and comparable morphology to the inner Il-Horoo-Gol moraine) is preserved. The Bayan Nuruu has experienced significant Quaternary uplift as it forms the active flank of the east-west extending Hovsgol Rift (Krivonogov et al., 2003, Gillespie et al., 2008). We believe that uplift of the Bayan Nuruu between proposed MIS-4/6 and MIS-2 glaciations caused the terrain to be raised through the glacier's equilibrium line altitude (ELA), increasing the accumulation area and causing the younger glacier to extend farther down-valley than the older glacier, covering its predecessor's remains.

The primary goal of this project is to constrain the timing and extent of Late Pleistocene glaciers around the north end of Lake Hovsgol. This will be done with digital mapping on arcGIS constrained by topographic field maps of geomorphologic features and GPS measurements. In addition, cosmogenic radionuclide dates from moraine-top boulder erratics and boulder counts (explained further below) will help constrain timing. The secondary goal of this project is to measure the amount of uplift, relative and absolute, of the Bayan Nuruu between the two most recent glacial episodes, and assess the affect this uplift had on the growth of glaciers. This will be done using Toe-To-Headwall-Altitude (THAR) calculations as well as morphometric analysis of geomorphologic features of the range-fronts.

METHODS and RESULTS

In the field Gabrielle Vance, Esugei Ganbold, Aranzal Erdene, and I directed the majority of our efforts towards mapping all glacial and glacio-fluvial features on Soviet topographic maps from 1970. We mapped all terminal, recessional, and lateral moraines, and fluvial and glacial outwash terraces from the northwest shore of Lake Hovsgol up to the mountains about ten kilometers from the Russian border. In addition, boulder counts were conducted on each moraine. All

Figure 2. North flank of the LGM terminal moraine in the Il-Horoo Gol Valley looking south towards Lake Hovsgol. Note Hummocky terrain on the inside (right) of the moraine crest, characteristic of dead-ice terrain at the terminus of the LGM glacier.

moraine-top boulders with a long axis of over 25 cm within a circle of five-meter radius were measured (length, width, and height about ground surface) and counted, their lithology noted, and compressive strength tested using a Schmidt Hammer. This relative dating technique makes use of the assumption that the longer the boulders are exposed to erosion, the less relief relative to the moraine crest they have (Hallet, 1994). A boulder's compressive strength as well is a function of time as it decreases with weathering (Goudie, 2006). We used differential GPS measurements to make latitudinal profiles across moraine crests. Younger moraines are assumed to have steeper profiles as the effects of erosion decrease features' topographic sharpness (Bursik, 1990). Six samples of moraine-top granite erratics were collected from each moraine in the Il-Horoo Gol Valley piedmont and one moraine from the Bayan-Nuruu valley to be analyzed and dated using the Beryllium-10 cosmogenic radionuclide method.

With these data I reconstructed the spatial distribution of the two paleo-glaciers in the Il-Horoo-Gol Valley at their maximum extents using ArcGIS (fig. 3). Given that we only mapped approximately 6km up the Il-Horoo-Gol valley, the up-valley ice extent is inferred from satellite imagery. Also, the dimensions of the largest paleo-glacier in the Bayan Nuruu were mapped from satellite images (fig. 4). I compare moraine ridge profiles and perform a statistical analysis of boulder count data. I calculated the LGM and pre-LGM Toe-To-Headwall-Altitude-Ratio (THAR) Equilibrium Line Altitudes (ELA) from the Il-Horoo Gol valley. The ELA is the altitude on the glacier where net annual accumulation equals net annual ablation (steady-state conditions are assumed). The THAR method assumes that the ELA exists at a given ratio of the relief spanned by the glacier, from toe to headwall. I used the THAR method given our lack of constraint on paleo-glacier dimensions, climate, and the fact that Gillespie et al. (2008) and the majority of research on Central Asian glaciers have used THAR. I will use the THAR method where the ELA lies at an elevation halfway between the elevation of the head and toe of the glacier because this is the ratio that Gillespie et al. used in the Darhad Depression, 50km to the west.

Next, I investigate the hypothesis that surface uplift of the Bayan Nuruu between MIS-4/6 and MIS-2 resulted in the younger glacier descending farther than the older glacier, while the LGM glacier in the stable

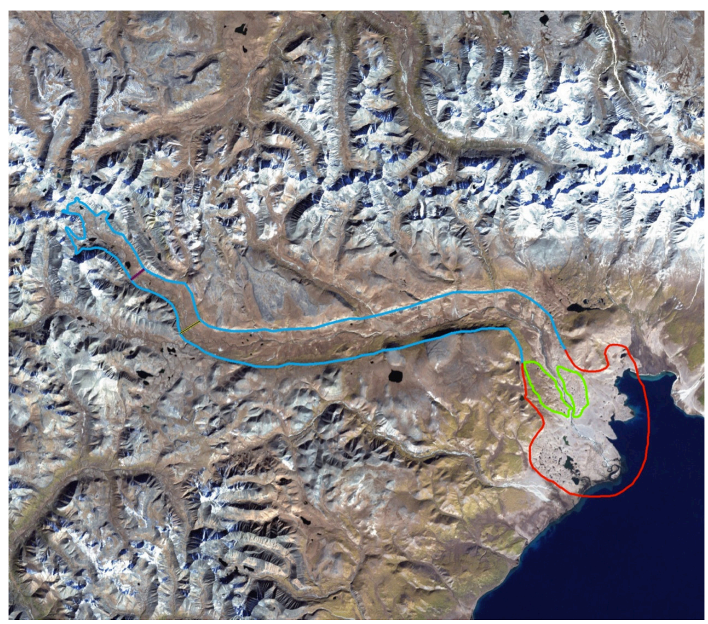

Figure 3. Satellite image of the Il-Horoo Gol Valley with ice extents and ELAs. Green: mapped LGM end moraine. Red: outermost extent of mapped, pre-LGM moraine (part in lake is inferred from published depth). Blue: inferred maximum up-valley ice extent. Yellow/black stripped line: Pre-LGM ELA (2067m). Red/black stripped: LGM ELA (2145m).

Vostoch mountains was smaller than it's predecessor. I calculate the theoretical amount of uplift needed in the Bayan Nuruu for this to happen using the THAR method. Using the pre-LGM ELA (where half of the relief covered by the glacier is above the ELA and half is below), already calculated for the larger glacier in the Il Horoo Gol Valley, I set the altitude of the toe of the pre-LGM, Bayan Nuruu glacier at the same elevation as the toe of the LGM, Bayan Nuruu glacier and calculate the altitude of the hypothetical, pre-LGM glacier headwall. The difference in altitude between the toe and the ELA of this theoretical pre-LGM glacier is the difference in altitude between the ELA and the head of the glacier. Assuming negligible rock uplift in the Vostoch range and similar climate variability between the two areas, the difference between the headwall altitudes (current-theoretical pre-LGM) is the minimum amount of uplift between glaciations needed for the LGM glacier to surpass the pre-LGM glacier (fig. 4). These results are supplemented by Gillispie et al., (2008)'s work which found evidence of older glaciations on the inactive, west side of the Darhad Depression, while only LGM moraines are preserved on the active east side of the basin (the Bayan Nuruu).

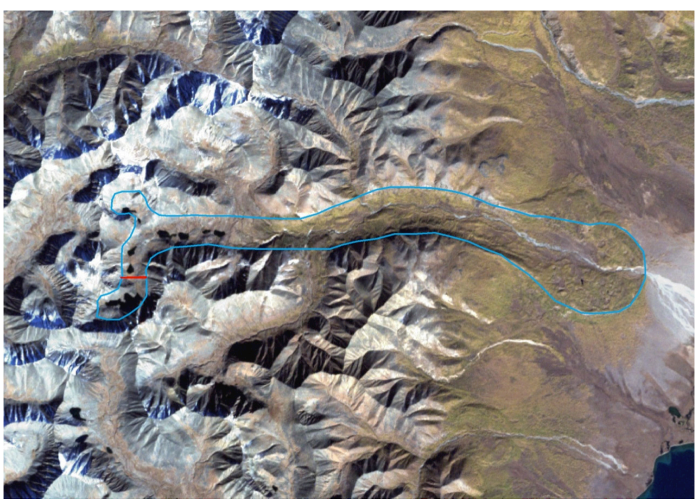

Figure 4. Satellite image of Bayan Nuruu valley with inferred LGM glacier extent drawn in blue. Red line represents the highest possible pre-LGM headwall (2420m).

I use morphometric techniques to assess relative rates of uplift. Gillespie, et al. (2008) reported eight-meter offsets of Late Pleistocene moraines on the east side of the Darhad Basin, verifying activity of the normal fault on the west side of the Bayan Nuruu. I compare longitudinal river profiles between drainages on the east and west side of the Bayan Nuruu to establish whether the Lake Hovsgol side is uplifting more intensely than the Darhad side (Kirby and Whipple, 2001). Also, I compare sinuosity of range fronts between the Vostoch range front and the eastern Bayan Nuruu range front to determine if the Bayan Nuruu Range is more active than the Vostoch range (Silva, 2002).

I use the Petit et al., (2009) method for determining mean slip rate from triangular-facet height on a series of triangular facets on the eastern Bayan Nuruu range front. Petit et al., (2009) developed a numerical model based on surface and tectonic processes. This model contends that throw rate, in mm/yr, is equal to 0.0013 times the height of the faceted spur. This model was tested on populations of facets in Lake Baikal, about 100km to the northeast, and found that it was broadly consistent with previously published data on fault throw rate. The population of triangular facets just south of the Bayan Nuruu paleo-glacier fits Petit et al.'s criteria. Once the mean fault throw rate is estimated, it can be applied to the difference in timing of the two glaciations (radiometrically constrained) to determine whether the amount of uplifted calculated (as discussed above) is reasonable.

CONCLUSIONS

I am still in the preliminary stages of data analysis. I have calculated approximate equilibrium line altitudes of the LGM and pre-LGM glaciers in the Il-Horoo-Gol Valley. The LGM ELA is 2145m calculated from a headwall altitude of 2600m (inferred from satellite imagery–hypsometry and slope analysis) and a toe altitude (supported by GPS) of 1690m. The ELA of the pre-LGM glacier is 2067m calculated from the same headwall altitude and a toe altitude of 1535m, which is 100m below lake level (Fedotov et al., 2007). When applied to the method outlined above, the minimum surface uplift of the headwall needed for the toe of the younger glacier in the Bayan Nuruu to surpass that of the older glacier is 156m. If our presumed dates of glaciations are correct at MIS-6 (186-128ka) and MIS-2 (24-12ka), then the average uplift rate during this time period to achieve a net slip of 156 meters would be .0013 m/ka (1.3 mm/yr). We will know shortly the true dates as the CRN results come out. The ELA depression compared with today is 1055m (LGM) and 1133m (pre-LGM) (Gillespie et al., 2008).

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