GEOMORPHOLOGY OF NARAN KHONDII (VALLEY), HÖH SERH RANGE, MONGOLIAN ALTAI, WESTERN MONGOLIA

by
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under the supervision of Professor Laura Triplett

ABSTRACT

Naran Khondii is a glacially formed U-shaped valley in the Höh Serh range of western Mongolia. Field research was conducted during the summer of 2008 within the drainage of the valley to map and describe geomorphological landforms and constrain past glacial extent. GIS analysis of moraine locations, DEM images, and SPOT satellite imagery yielded glacial reconstructions for Last Glacial Maximum and Neoglacial advances. These reconstructions showed that the surface area of the modern glacier has decreased by 79% since the Last Glacial Maximum in the late Pleistocene, 51% since the Neoglacial period, 38% since the Little Ice Age, and 4.3% since the SPOT imagery was taken in 2007.

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INTRODUCTION

The retreat of glaciers on the Tibetan plateau, as elsewhere, is a great concern as they provide water to millions of people for both drinking and irrigation. In the near future, consequences of warming in this area may include changes in the season of water availability, flooding, and higher precipitation variability (Kehrwald 2008). Rivers with headwaters in the Tibetan Plateau, such as the Indus, Ganges, and Brahmmaputra, are barely making it to their deltas as water demand increases and tributaries contribute less flow (Kehrwald 2008). Forty-five percent of the above mentioned rivers' flows are the result of glacial melt, placing a great emphasis on the importance of annual melt waters acting as a resource to local people (Kehrwald 2008). Naran Khondii and the surrounding mountain ranges have arid climates (Mongolian Institute of Meteorology and Hydrology, 2009, Kehrwald 2008, An 2008), so water stored in glaciers is a crucial resource that is quickly dissipating. The extent of this risk must be assessed and efforts of this and other research studies must be combined so that the effects of global climate change acting on the glaciers might be better understood.

The purpose of this study is to provide a detailed geomorphic description of and to assess the retreat of a glacier in Naran Khondii, a broad valley that drains the Höh Serh Mountains, a sub-range of the Mongolian Altai.

Geologic Setting

The area in which the valley is located has been depicted on maps completed by satellite imagery, but no field mapping has previously been conducted. The Höh Serh Range lies in western Mongolia and runs approximately north-south (fig. 1). Directly south of the Höh Serh Range is the Deluun Nuruu Range, separated by Yamaatt Valley. To the west of the Höh Ser lies the bulk of the Mongolian Altai and to the east is the central basin and lakes region. The Höh Serh and Deluun ranges extend 100 km and are about 40 km wide throughout. The mountains extend down to a piedmont, or gentle slope characterized by glacial outwash sediment. Maximum elevation is around 4000 m and the total relief of the ranges is greater than 1700 m. The nearest major town to the study area is Khovd (elevation 1425 m), which is to the East of the Deluun Nuruu (Carson 2008).

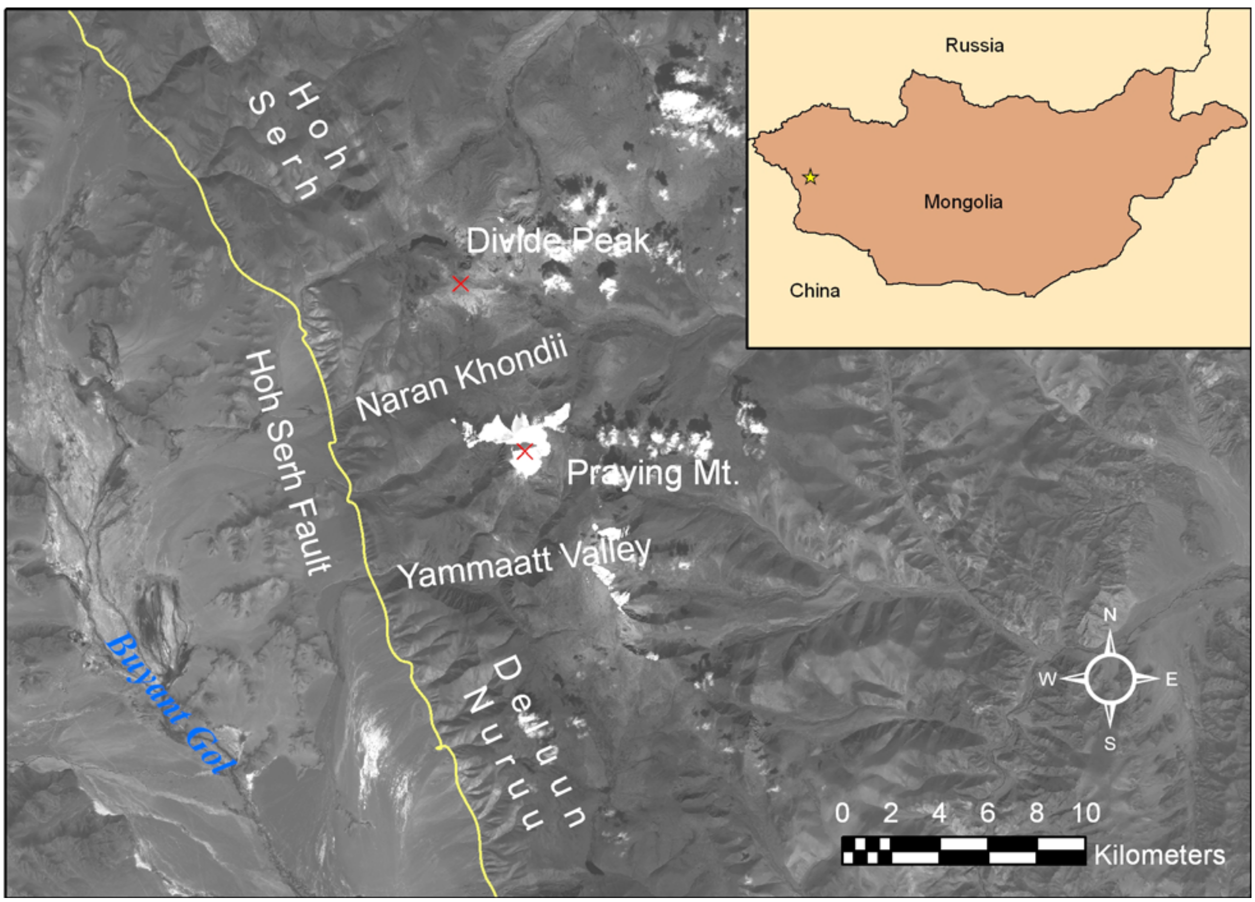

Fig. 1 – A general map showing the location of Naran Khondii. The location of the study area is represented by the star the map of Mongolia.

Formation of the Höh Serh

The Mongolian Altai trend to the northwest and consists of a belt of "Paleozoic arc terranes, accretionary complexes and continental fragments” (Cunningham 2003). The belt was reactivated in the late Cenozoic as a result of the Indo-Eurasion plare collision, forming much of the modern mountain range (Cunningham 2003). The Höh Serh Range runs along the Höh Serh Fault, which strikes north-northeast and is believed to have been most active during the Quaternary period. The fault exhibits both dextral strike slip, with the western block moving north and the eastern block moving south, and thrust motion. The mountain range itself sits on the thrust block that overlies the Buyant Gol halframp formed from the fault, causing it to tilt to the east (Carson 2008). The bedrock in this region is mostly Cambrian and Ordovician marine sedimentary sequences. Some Devonian strata do exist, exposed on the footwalls of local faults. Generally, the Devonian strata have experienced low-grade metamorphism (Carson 2008). Many igneous rock types are also present, including pegmatitic granite and flow-banded rhyolite.

Past and Present Climate in Mongolia

The climate proxies in Mongolia show that the weather here has been influenced by three systems in the past: The Mongolian High Pressure system, westerlies related to the North Atlantic Oscillations, and East Asian summer monsoons (An 2008). Currently, the climate in western Mongolia is controlled by westerlies that bring precipitation from the Atlantic and the Mediterranean, not from the monsoons, which are blocked by the Karakorum and Himalaya (Gillespie 2003). The varying influence of these two systems results in a precipitation decrease from west to east across Mongolia (Lehmkuhl 2004). An (2008) also describes a general increase in temperature and decrease in humidity from north to south across Mongolia. Because the Naran Khondii Valley is located in the western part of Mongolia, it therefore receives more precipitation to aid in glacier development.

Mongolia is an extremely continental area so there is little precipitation in the winter months due to low-altitude thermal high-pressure cells over central Asia (Gillespie 2003). This seasonal precipitation trend is seen the precipitation data collected by the Institute of Meteorology and Hydrology of Mongolia. They have been collecting climate data in Khovd since 1937 and in Deluun, a small village a few kilometers south of the study site, since 1993. During the winter months, precipitation varies from zero to just a few centimeters, where precipitation in the summer months ranges from a few centimeters to 141 cm (Deluun, June 1993). Precipitation data from Deluun shows that the trend in average annual precipitation has been decreasing over the past decade and a half.

Temperature data collected by the Institute of Meteorology and Hydrology of Mongolia shows that the average annual temperatures in Deluun since 1993 are generally a few degrees-C below zero. In Khovd, average annual temperatures are generally within three degrees-C of sexo degrees-C as observed since 1937. Neither city shows a major increase or decrease in the general temperature trend over the past few decades. However, the longer record in Khovd may depict a slight increase in the average temperature during winter months (November through March).

The early Holocene is considered to have been a time of increasing temperature and humidity. This trend changed during the Mid-Holocene when the climate became more arid. By the late Holocene the summer monsoons and solar radiation both became weaker, resulting in lower temperatures and increased humidity from decreased evaporation (An 2008).

Glacial History of Western Mongolia

Within Mongolia, two late Pleistocene glacial advances have been identified: the Early Zyrianka (Early Wurmian or Oxygen Isotope Stage 4) 50-70 kyr BP and the Sartan (Late Wurmian or OIS 4) 15/ 20-32 kyr BP (Lehkhul 2004). Records of Pleistocene glaciations in Mongolian mountain ranges can be found in the Khentey, Khangai, Mongolian Altai, and mountains surrounding Hovsgol Nuur. The maximum ice extent in the Mongolian Altai during the Pleistocene has been calculated to have been between 20,700 km^2 and 28,750 km^2. Research has indicated that the Mongolian Altai Pleistocene ELAs were depressed at least 500 m compared to present values (Lehmkhul 2004).

Two other main glacial advances are those that correspond to the Late-glacial Wurmian (10-15 kyr BP) and the Little Ice Age (LIA), from the Middle Ages to around 1850 AD. Both advances are OIS 1. This study also makes reference to Neoglacial moraines, which formed sometime in the last 4000 yr.

Equilibrium line altitudes (ELAs) are generally low in the outermost ranges of central Asia, but rise as the climate becomes more humid near the central areas of Mongolia. The glaciers of western Mongolian often have lower ELAs than eastern glaciers because precipitation decreases from west to east, a pattern that has been even more pronounced during glacial periods. This may be related to the monsoons, as seen from trends observed in China (Lehmkhul 2004).

METHODS

The project studying Naran Khondii was part of the Keck Consortium Mongolian trip that took place July 13, 2008 through August 9, 2008 during which all field data was collected.

Notes, sketches, and photographs were collected in order to provide a geomorphic description of the processes and formations within the valley. A Garmin 76 was used to record the locations of various landforms, such as moraines, erratics, and rockfalls. Relative age approximations of the moraines were made in the field based on morphology, stability, and soils (Pearson 2007).

Data analysis was completed at Gustavus Adolphus College using ArcGIS (ESRI, Redlands, California). The waypoints were uploaded into GIS and analyzed over a digital elevation model (DEM) and SPOT satellite imagery. All data was projected as WGS 1984 UTM zone 46N.

Glacial ice limits were reconstructed by connecting locations of evidence for the past ice margin, which in this case consisted of moraines, erratic boulders, changes in rock appearance, and changes in the stability of moraines. By associating these landforms, the minimum glacial extent was determined. Landforms only existed around the ablation zone of the glaciers, so the limits for glacial extent in the accumulation zone were estimated based on the location of the modern glacier.

In Naran Khondii, ELAs were estimated using the toe-summit altitude method (TSAM) and the accumulation-area ratio (AAR) method. The TSAM method assumes that the ELA is halfway between the elevation of the terminal moraine and the elevation of the highest peak in the drainage. The AAR method places the ELA such that 67% of the glacial area for that time period is above the ELA, where accumulation is occurring.

These methods were selected based on the work of Benn (2000), which recommends AAR for clean, snowfall-fed glaciers in alpine regions and TSAM as an often accurate method for estimating ELAs on Mongolian Pleistocene glaciers. Lehmkhul (1998) suggests the use AAR at 67%, but warns that there are not detailed enough maps of Mongolia for an accurate measurement of this method; however, this project completed the necessary mapping to make accurate measurements.

Gillespie et al (2008) found that a similar method to TSAM, the toe-to-headwall ratio (THAR), usually underestimated the ELA in areas of Mongolia. THAR assumes that the ELA is halfway between the toe of the glacier and the elevation of the base of the headwall (Benn 2000). In that case, however, the researchers had data on lateral moraines that were not subject to postglacial stream erosion, so the highest lateral moraine method proved to be the most accurate. Lehmkhul (1998) found that while the TSAM method estimated the ELA about 100 m too high in the Alps, it fit well with his field observations in Mongolia.

GEOMORPHOLOGY

Naran Khondii is a broad, U-shaped valley that consists of north and south forks that come together to form the main valley (fig. 2). Streams in both forks of the valley converge to form a single flow, which becomes a tributary to the Buyant Gol. As discussed in detail earlier in the paper, average annual temperatures are usually a couple of degrees-C below zero and annual precipitation is between 5 and 20 cm. There has been a general decrease in precipitation since 1993. Precipitation is likely the result of Atlantic evaporation transported by westerlies (2003). Given the dry climate, this and other mountain streams act as important water sources for the local population.

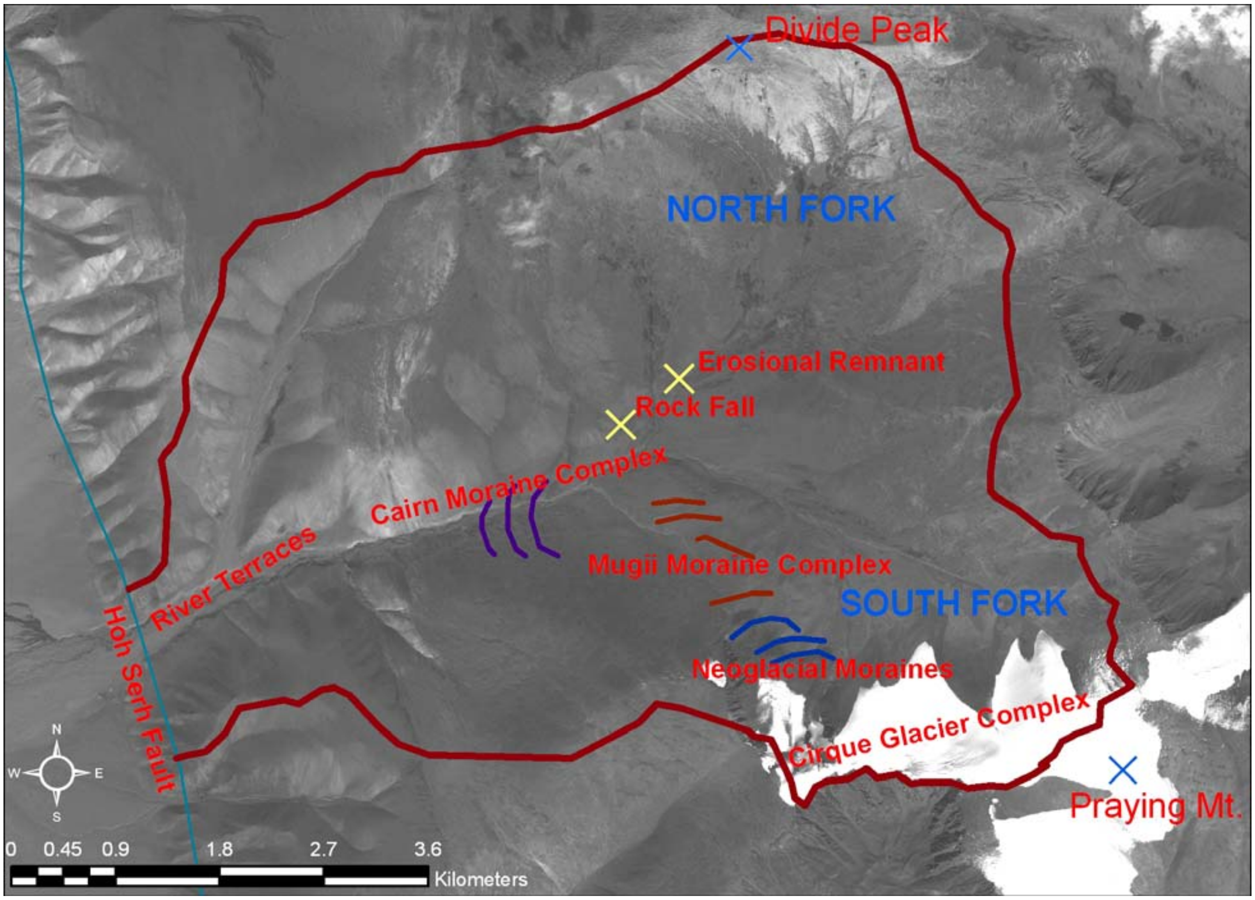

Fig. 2 – Map depicting various landforms in Naran Khondii described in this paper. The red line circling the map indicates the drainage area of the valley.

Glacial landforms are evident to a varying degree throughout the valley. There are three moraine complexes preserved in the valley. The Cairn Complex contains the down-valley terminal moraine and is in the main, central valley. The Mugii Complex is further up-valley, southwest of where the valley splits. A Neoglacial moraine complex is present primarily in the vicinity of and down-slope from the westernmost extant glacier. The south side of the central valley lacks glacial landforms due to periglacial processes. This area now consists of a large solifluction apron that covers the valley wall.

There is sparse vegetation in the valley (elevation 2,500 m to 4,000 m), consisting mostly of short grasses and the occasional alpine wildflower. A few individual willows grow horizontally on the valley slopes and some small willow stands are found along the river banks near the mouth of the valley. The predominant fauna are herd animals, mostly sheep, goats, yaks, horses, and camels, belonging to the local inhabitants.

An erosional remnant (fig. 3) was found near where the north fork separates from the south. It appeared to be some form of intrusive dike that was more resistive to erosion than the surrounding rock. Below it is an area with a lot of rock fall debris that appears to be the result of multiple rock fall deposits against the edge of the glacier. The highest erratic boulders were also found along the north side of the valley, above the rock fall and erosional remnant. The boulders are course-grained granite of a type that is found in the north headwall. The locations of these boulders and the locations of the end moraines were used in reconstructing glacial extent.

Fig. 3 – An erosional remnant found in the north fork of Naran Khondii.

Near the mouth of the valley, along the creek that flows through it, there are four sets of Quaternary strath terraces, named Qt1 through Qt4 from oldest to youngest (fig. 4). The formation of these terraces is related to the Höh Serh Fault. Following each episode of uplift, the nickpoint of the stream would retreat and the stream would downcut through alluvium and bedrock. Qt1 is estimated to correlate with the LGM (personal communication with Karl Wegmann). Qt2 and Qt3 are Holocene strath terraces. Little data was collected for Qt4, so it was not included in analysis. There are also two strath terraces in a side channel that branches off to the south of the main valley just east of the other terraces. However, these terraces could not be coordinated with those of the main valley.

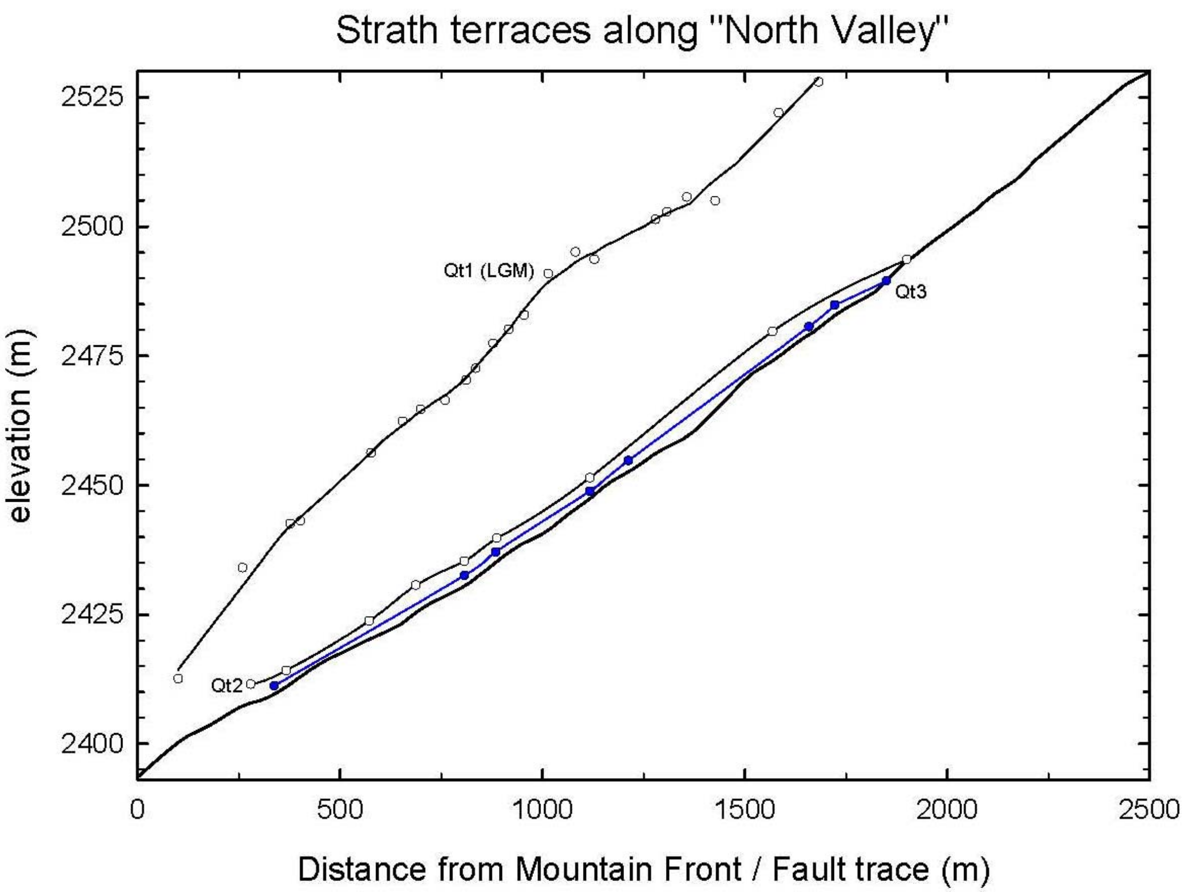

Fig. 4 – Profile of three strath terraces and the river bottom near the mouth of Naran Khondii Valley.

There are four separate bedrock units in Naran Khondii. The valley is dominated by coarse-grained granite to the north, rhyolite to the south, and a phyllite formation near the mouth of the valley that cuts across the valley almost directly north to south (fig. 5). A less dominant, fine-grained granite is located on the ridge along the eastern edge of the drainage basin. Many xenoliths protrude from the course granite found in the north fork of Naran Khondii. These xenoliths signify that the coarse granite of the valley is an intrusive body.

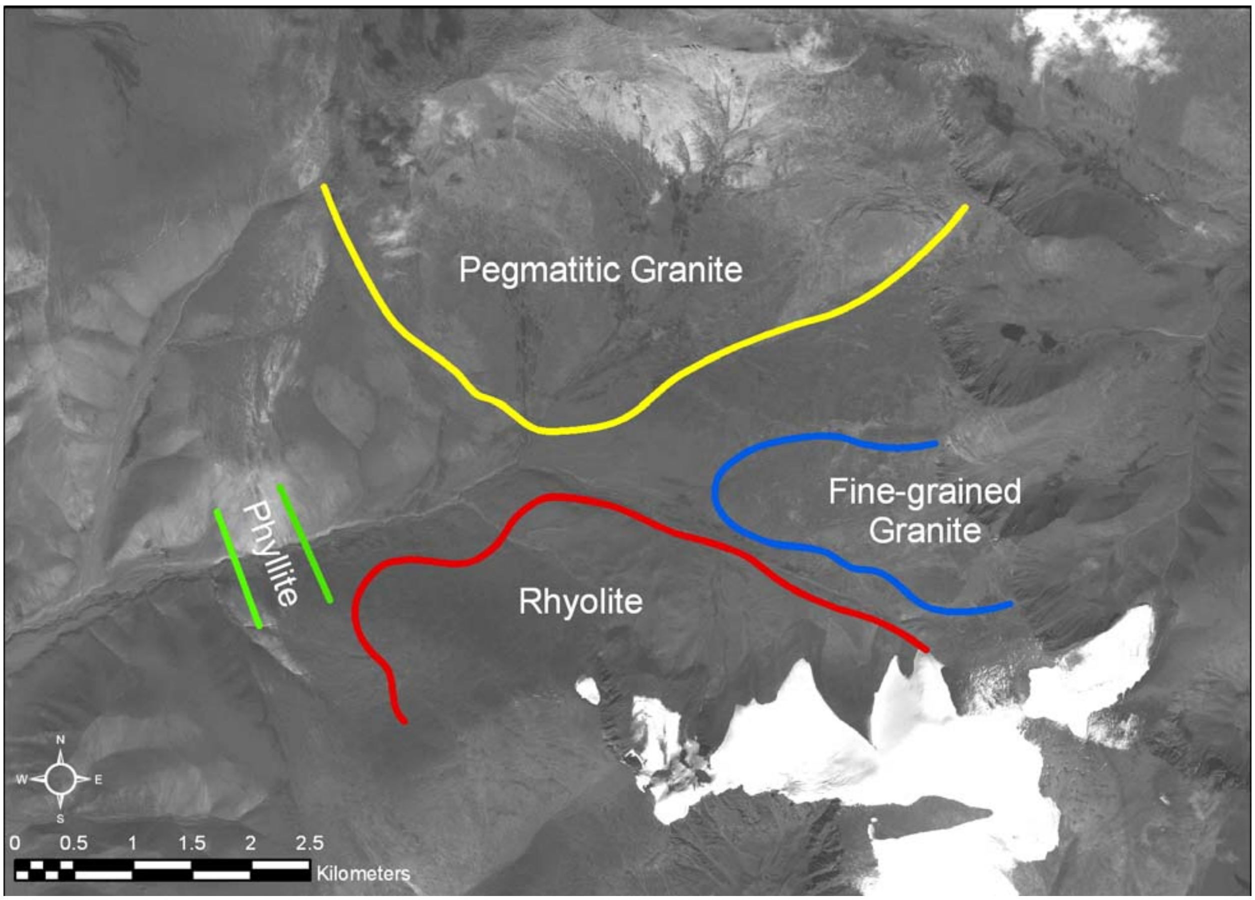

Fig. 5 – A geologic map of Naran Khondii showing the approximate location of varying bedrock types.

The center of the valley is filled with till. It consists of clay to boulder sized clasts up to 3 m across. Most boulders are subrounded granite, with some angular rhyolite, and some metasedimentary rocks. The matrix is not compact and is nearly all sand with little clay present. Much of the fine sediment has been eroded from the surface. The till appears to be about 75% boulders and 25% matrix; however, the actual ratio beneath the surface could be as little as 50% boulders to 50% matrix.

The north headwall contains several cirques and tors that formed on the ridge between Naran Khondii and the valleys to the north and east. The highest point of elevation along the headwall, at 3593 m, is called Divide Peak. The summit of Divide Peak and the surrounding area are characterized by coarse-grained granite, undergoing exfoliation and marked with tafoni. The surface is mostly covered by boulder sized clasts, but grus is found between the boulders.

There are two cirques in the valley to the east of Naran Khondii – one eastern and one western (fig. 6). The east cirque faces south and contains a moraine or possible protalus rampart, likely deposited in the LIA. The west cirque faces southeast and does not contain a significant moraine large enough to be visible from the saddle.

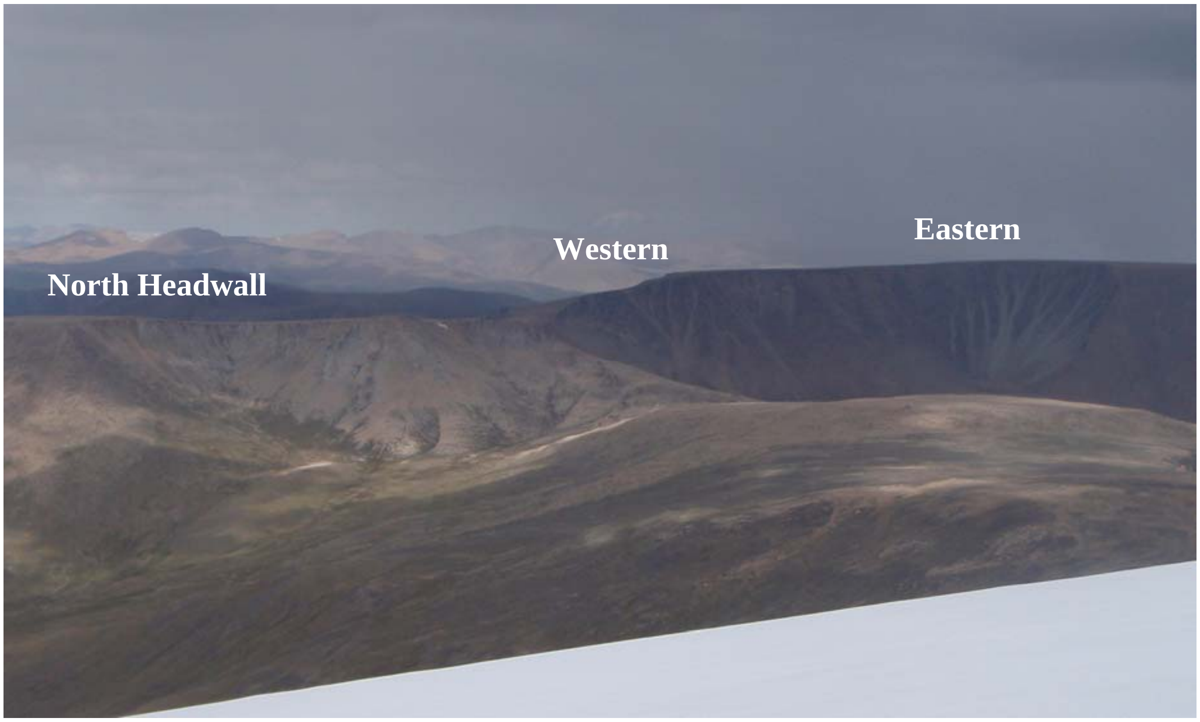

Fig. 6 – A view of the north headwall of Naran Khondii and the western and eastern cirques of a valley located to the east of Naran Khondii. Photo was taken from the summit of Praying Mountain.

The southern headwall also contains a peak called Praying Mountain. This peak is one of the highest in Mongolia at 3980 m.

GLACIAL HISTORY

The Cairn Moraine complex is located on the north side of the central valley. The moraines have been somewhat covered by alluvium and colluvium and all consist of all LGM age deposits as determined the approximate boulder frequency of the moraines (Pearson 2007). A small moraine is the westernmost glacial landform. The presence of only a few granite boulders and the moraine's small size indicate that the ice margin was not here long. A larger recessional moraine that is a few meters high is located 100 m further east of the ice terminus. It has been mostly eroded from melt water running along the recessional moraine, but many large boulders remain. A second recessional moraine is located approximately 100 to 200 meters east of the first recessional moraine. This moraine is a few meters high and contains many large surficial boulders.

Moraines are not present in the north fork of the valley, but there is abundant ground moraine. There is not any ice on the headwall, but the wall has several cirques and tors that formed on the headwall and ridge between Naran Khondii and the valleys to the north and east (fig. 7). There are also lots of striations and chattermarks in this area that suggest the glacier in Naran Khondii was warm based at least for part of its history.

Fig. 7 – The north headwall of Naran Khondii located in the valley's north fork.

There is a large moraine complex located due north of the western most glacier that contains two discernable parts (fig. 8). Mugii A, the older part of the complex, extends farther down valley; Mugii B, the younger and steeper part of the complex, is located above Mugii A. Both parts of the complex are believed to be late Pleistocene in age. They consist of large lichen-covered boulders and both parts exhibit extensive soil development. The Mugii Complex is only below the western cirque glacier.

Fig. 8 – Late-Pleistocene moraines in the south fork, near where it meets with the north fork of Naran Khondii.

There is a three-part cirque glacier complex on the southern headwall of the valley (fig. 9). The cirque complex is nestled next on the northern side of Praying Mountain and consists of three glaciers, and eastern, central, and western. The eastern glacier has eastern and western lobes. Stagnant ice was observed to stretch several hundred meters below the western and eastern glaciers

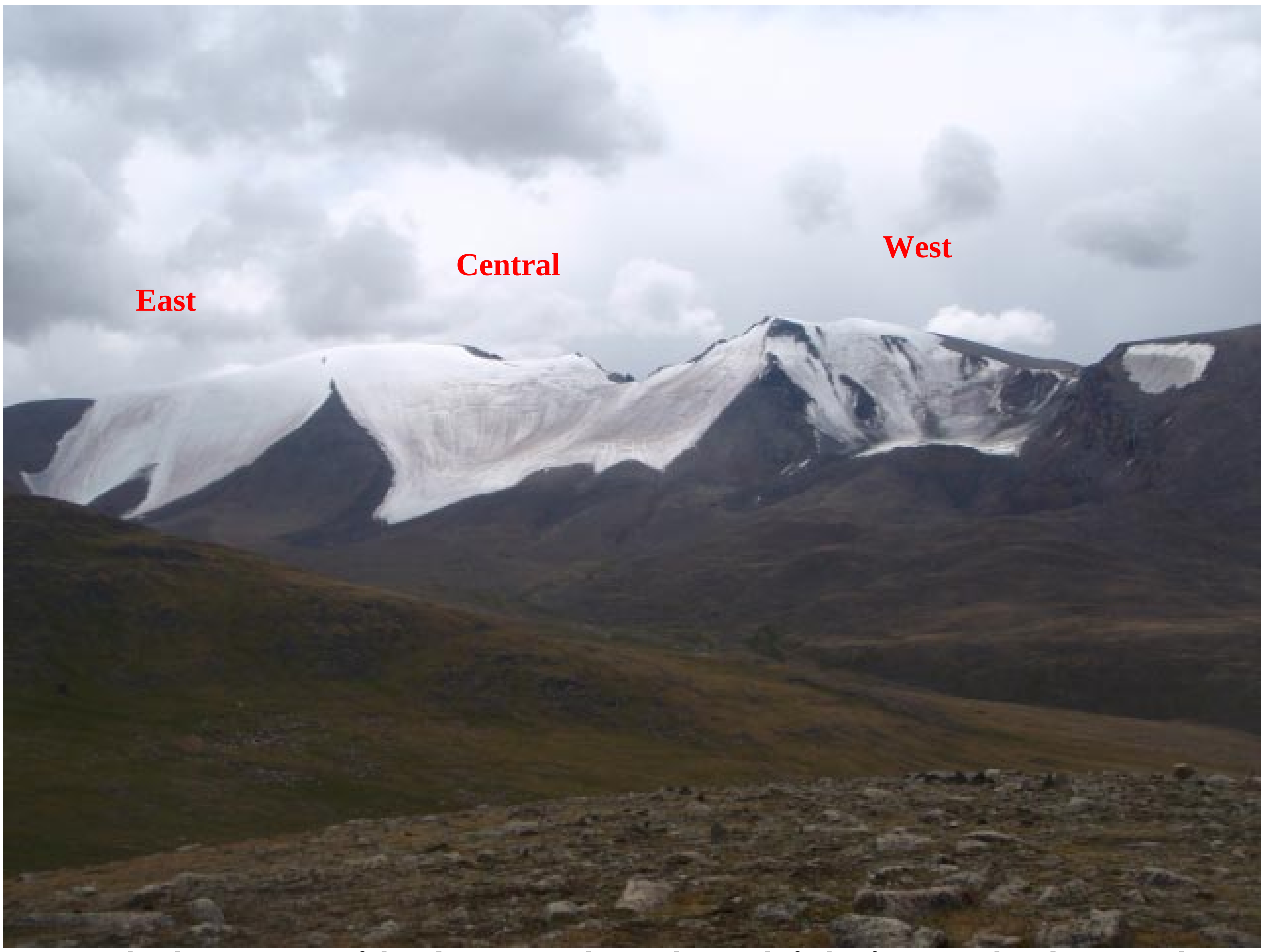

Fig. 9 – The three cirques of the glacier complex in the south fork of Naran Khondii. Note the two lobe of the eastern cirque (west to the right and east to the left on the image).

There is a Neoglacial moraine complex below the western cirque (fig. 10). These moraines consist of angular rhyolite blocks that are up to three meters across, with no fines present. The moraine is extremely unstable and there are no lichens present. There are also several boulders that jut out from the side of the moraine that are likely ice-cemented into the moraine. The moraines closest to the glacier are from the Little Ice Age or more recent as they are so unstable and there has been no evidence that they were affected by earthquakes produced from the nearby fault.

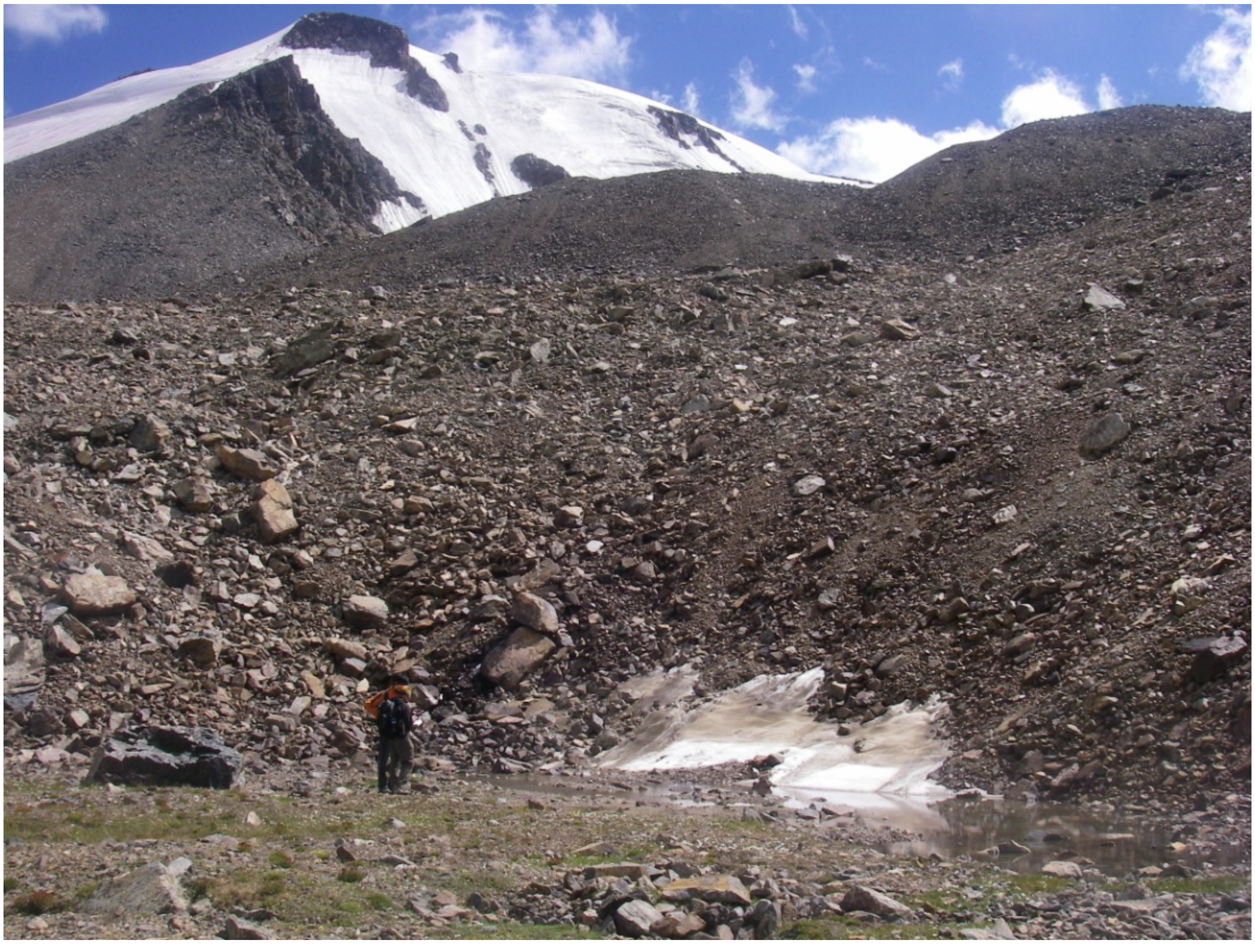

Fig. 10 – Myself and Mugii standing in front of the Neoglacial moraine below the western cirque. Higher up in the background are LIA moraines.

In the modern cirque complex, the central and eastern glaciers lack prominent moraine deposits, but are bordered down-valley by areas of rock that have been exposed more recently than the Pleistocene deposits. The recently-exposed sediments around the perimeter of the glacier are dark-colored, unstable, and lichen free; further from the ice, sediments are lighter in color, more stable, and sparsely colonized by lichens (fig. 11). The lighter area shows signs of solifluction, but the darker section does not. The lighter material may have been exposed since the early Neoglacial and the younger, darker material since the LIA.

Fig. 11 – The dark and light boundary area of the rock below the central and eastern cirques.

ANALYSIS

According to both TSAM and AAR 67% methods, the ELA in the south fork was about 300 m higher than that of the north fork during the LGM. The ELA of the north fork rose by 90-230 m between the LGM and Neoglacial periods. From the Neoglacial to the LIA, ELAs rose by another 36-50 m. In general, the AAR method produced similar or lower values than the TSAM method. Results are recorded in Table 1, including toe and summit elevations of the glacier.

Table 1 – The summits, toes, ELAs, and percent surface area lost for the glacier in Naran Khondii at different time periods.

Age/Location of Ice	Glacier Area (m^2)	summit (m)*	toe (m)*	AAR 67% (m)	TSAM (m)	% total surface area lost (m^3)
LGM - South	10008843	4200	2683	3460	3440	79
LGM - North	8107879	3600	2683	3175	3140	100
Neoglacial	4322070	4200	3186	3550	3693	51
LIA	3388725	4200	3259	3600	3729	38
SPOT (2007)	2199434	-	-	-	-	4.3
Modern	2104710	4200	3278	-	-	-

*Elevations obtained from the DEM imagery used in analysis.

Ice contour lines were created from the ELAs values (fig. 12). These were intended to be used to interpret percent ice volume loss, but this analysis was not completed.

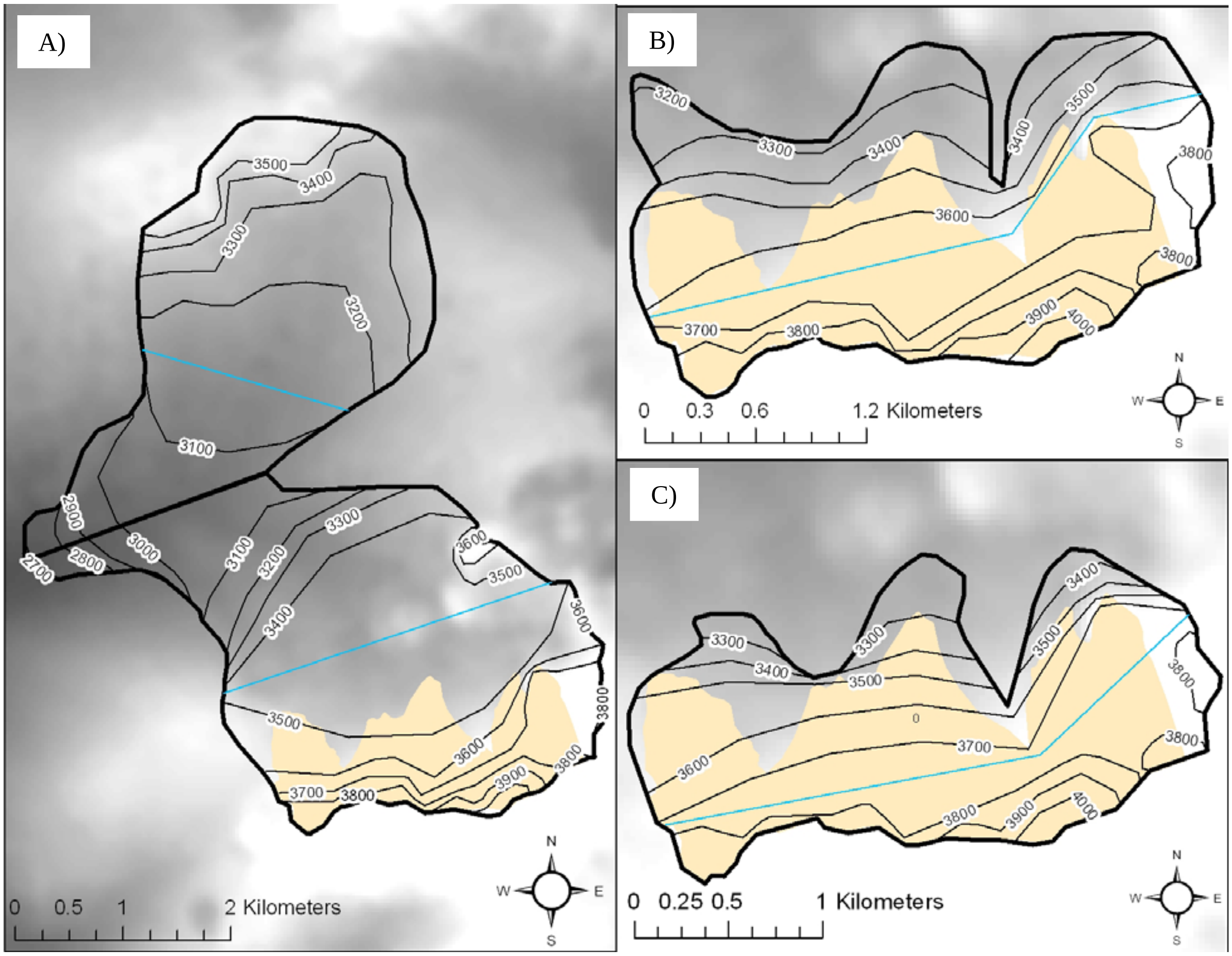

Fig. 12 – Reconstructed ice extents and contours for A) LGM, B) early Neoglacial, and C) LIA. TSAM ELAs are drawn in blue and current ice extent is shown in tan area.

Lehmkuhl et al (2004) estimate that modern ELAs in the Mongolian Altai and Chinese Altai are between 3,000 m and 3,600 m. However, based on the snowpack observed on top of Praying Mountain and an approximately 35 m drop in elevation at the mountain's summit from current values compared to maps produced in the 1970s, it is believed that the current ELA is located above the mountain's summit.

ELAs are often used to calculate temperature changes. The average change of temperature with elevation is 6.5° C/km (Ruddiman 2001). With this assumption and the total meters the ELAs have risen, the temperature increased 0.59° C - 1.5° C between the LGM and

Neoglacial periods and 0.23° C - 0.33° C between the early-Neoglacial and LIA periods. These values cannot be compared to modern values because the modern ELA is assumed to be above the mountain's summit. Because the mountain's summit is at 4200 m (according to the DEM that the ELAs are based on), the temperature must have risen 3.1° C – 3.9° C since the Little Ice Age. This conclusion assumes that precipitation must have remained the same, but that is not certain in Mongolia. It is believed that the monsoon systems have remained south of this area since at least 10,000 to 9,000 yr BP, but is uncertain prior to those dates. There is also limited modern data to represent precipitation change.

The ELAs produced in this study used elevations created by the DEM imagery. Praying Mountain, as marked by these elevation contours is about 200 m taller than its elevation on a topographic map produced in 1963. Therefore, it is likely that the paleo-ELA values recorded here are 100 m to 200 m higher than actual.

DISCUSSION

There is no evidence of a medial moraine remaining in the valley to indicate the timing and extent of the glacial advance in the north fork, as compared to the advance in the south fork. However, there is little granite in the moraines of the Cairn Complex. This indicates that the glaciers from the south fork must have been the predominant source of ice. This also is consistent with the fact that the headwall in the north fork faces southward, where the headwall in the south fork faces north resulting in less solar heating. Because of this and assuming that the north and south headwalls obtained similar precipitation amounts, the south fork glacier would have been favored for snow preservation.

This study suggests that 4.3% of the glacier's surface area was lost between the summers of 2007 and 2008. This decrease stresses the importance of continuing to monitor glacial ice throughout the world. It is possible that error occurred in the locations of the waypoints used to reconstruct glacial extents or in the means that the waypoints were interpreted. It may also have just been an anomalous year, but given the stability of temperature and precipitation, this is not likely. Only continued study will be able to determine exactly how alarming this value truly is.

Nick Bader (Whitman College) and Bob Carson (Whitman College) combined the LGM glacier extent in Naran Khondii valley with the LGM glacial extents of a valley to the north and three to the south of Naran Khondii. This work produced an image that shows LGM glacial extent in a large portion of the Deluun Nuruu and Höh Serh mountains (fig. 13). By analyzing research findings on glacial extents for entire mountain ranges verses just single valleys, climate modelers are better able to estimate climate change for a region.

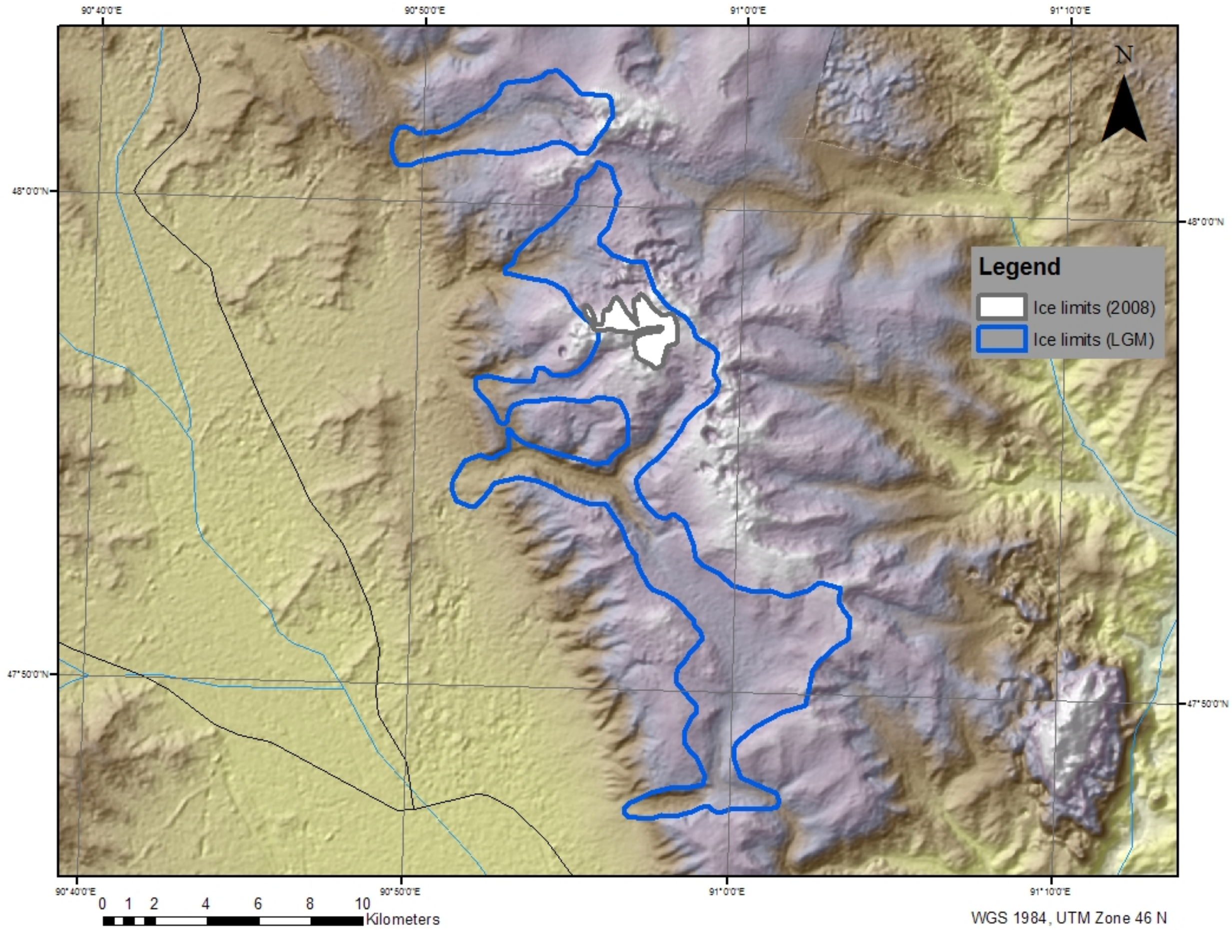

Fig. 13 – LGM and modern glacial extent in a portion of the Deluun Nuruu and Höh Serh mountains. Produced by Nick Bader and Bob Carson of Whitman College.

Naimona'nyi, of the Tibetan Himalaya, is a high alpine glacier (6050 masl) that receives between 200 mm and 1000 mm of water equivalent as precipitation annually. Though it is still seeing annual precipitation, the glacier is experiencing net loss (Kehwald 2008). Kehwald et al noted that there is no evidence of nuclear test fallout in cores drilled on the glacier, implying that it has been retreating since before the 1950s. The group also estimates that glacier retreat has been increasing over the past four decades. Along with changes in temperature and precipitation, the increased rate of melt may also be caused by the positive cycling effect that occurs as a glacier begins to melt, causing its albedo to decrease, and melt to accelerate. If a glacier located at 6050 masl is experiencing net loss, it would make sense that many other high elevation glaciers in central Asia could be similar.

ELAs are an important climate proxy when examining a glacier in that they fluctuate with varying precipitation amounts and temperatures; rising with increased temperature and/or decreased precipitation, and lowering with decreased temperature and/or increased precipitation. The ELA thus represents a glacier's response to climate change. The ELAs in this study, both produced with TSAM and AAR methods, show a marked increase in elevation since the LIA, indicating that the glaciers have been retreating. The glacier's retreat will eventually have noticeable effects on the water supply for the local people, who depend on glacial melt for water in an otherwise arid climate.

CONCLUSIONS

This study completed the necessary mapping of Naran Khondii to accurately reconstruct minimum glacial ice extents and to analyze ELA changes with time. From the ELA values, it is estimated that the average annual temperature has increased 3.1° C – 3.9° C since the LIA. This value assumes that precipitation has remained the same, which cannot be analyzed with current records. However, by comparing it to the previously small temperature increases (about 1.9° C maximum increase from the LGM to LIA), it shows a great acceleration in temperature rise. The temperature increase is supported by recent, rapid glacial retreat up the valleys (as evidenced by moraines and fresh rock exposures) and a potentially large volume of ice loss (4.3%) over one year.

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