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GLACATIONS OF THE DAVAATIIN REGION OF THE HANGAY NURUU, CENTRAL MONGOLIA

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INTRODUCTION

Currently the only active glaciers in Mongolia are located in the Mongolian Altai, where glacial ice covers an estimated 300 km2 (Lehmkuhl, 1998). In the Pleistocene, however, there were four areas that were glaciated: the Khentey,Hangay, Darhad and Altai. Russian geologists identified the last two major glaciations as the Sartan Glaciation (35.3 ± 0.6 ka 14C) and the Early Zyrianka Glaciation (103 ± 12 ka TL). We refer to them as the LGM (Last Glacial Maximum, probably OIS 2) and the PEN (Penultimate glaciation, possibly OIS 6).

The total LGM glacier coverage in the Hangay Nuruu according to Lehmkuhl was 12,900 km2 at the LGM. Currently there is a firn field present on Otgon Tengor (4,021 m) in the western Hangay (Lehmkuhl, 1998), but we did not find any permanent snowfields in the Egiin Davaa region.

METHODS

Ice limits were delineated with topographic maps and a GPS. Individual geomorphic features such as moraines, kettles, and erratics were identified, located, and photographed. Several core samples were taken for later dating and sedimentological analysis. A GIS was utilized to georeference topographic maps, satellite images, and aerial photographs as well as to generate 3D models of glacial extent and glacial equilibrium line altitudes from the study area.

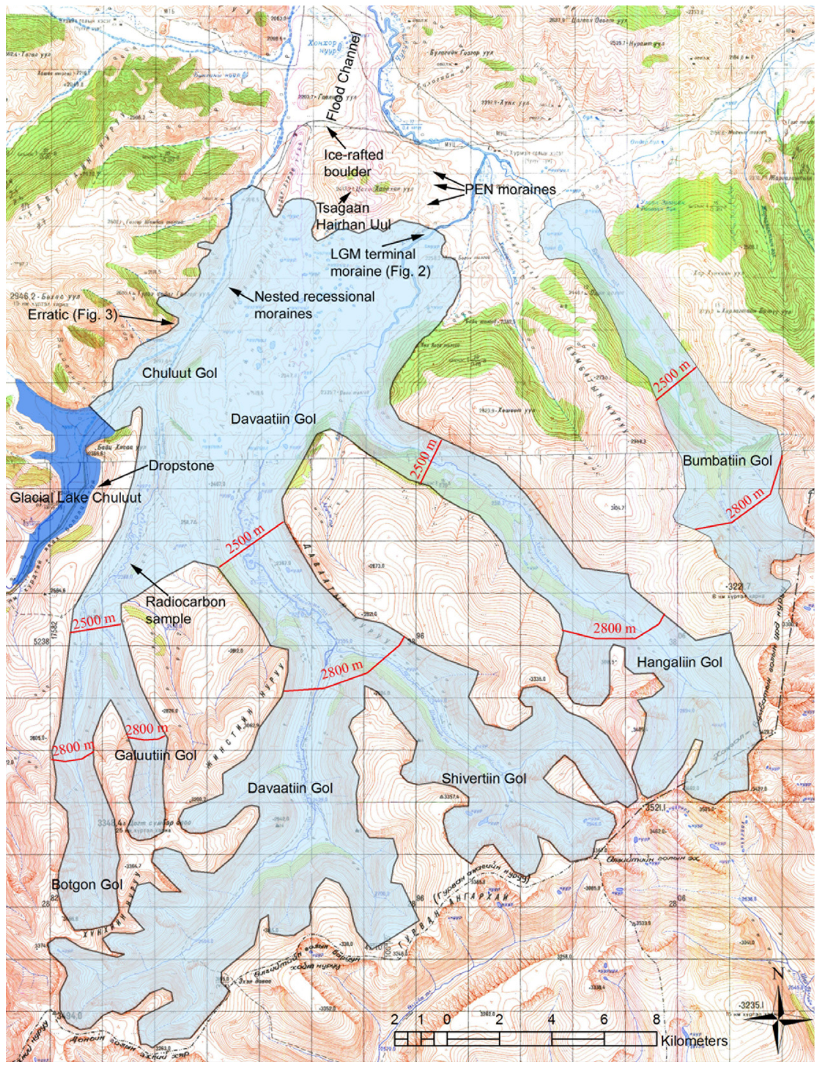

Figure 1: Topographic map of study area with river names, labels, shaded ice coverage area, minimum glacial Lake Chuluut level, and ELA lines (in red) (topographic contour interval=20 m).

GEOMORPHOLOGY

Five significant river valleys contribute ice to the glacial system in the study area, which from west to east are Botgon Gol, Galuutiin Gol, Davaatiin Gol, Shivertiin Gol, and Hangaliin Gol (Fig. 1). In the Davaatiin valley, the largest valley in the study area, the LGM terminal moraine is 1,293 m lower than and 38 km downvalley from the cirque headwall. The total area of ice coverage for the entire system is approximately 349 km^2.

Ice from the Davaatiin, Shivertiin, and Hangaliin valleys coalesced, forming a large terminal moraine complex east of Tsagaan Hairhan Uul (Fig. 2). This ice had sufficient thickness to overtop the 80-m-high plateau separating the Davaatiin and Chuluut valleys, where it would have merged with ice coming out of the Botgon and Galuutiin valleys.

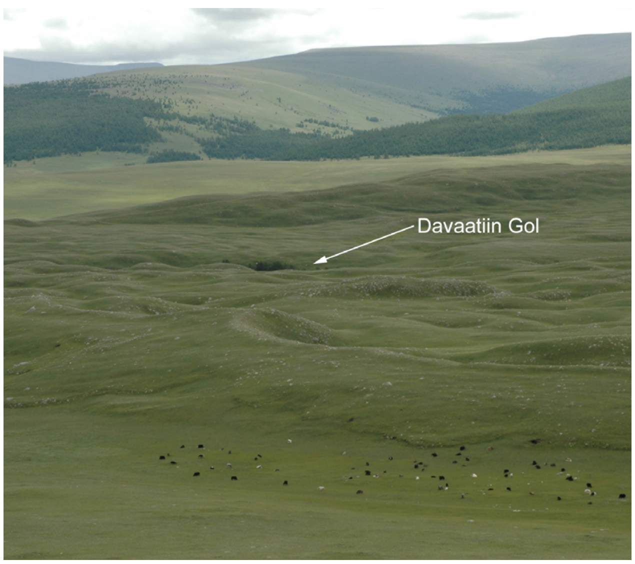

Figure 2: Looking east from Tsagaan Hairhan Uul at the large terminal moraine (4 km across) cut by the Davaatiin Gol. Note yak herd in foreground for scale.

Ice from these tributary valleys flowed into the Chuluut valley, depositing large amounts of till on the west side of Chuluut Gol (Fig. 3). Four kilometers upriver from the confluence of the Botgon and Chuluut valleys, the presence of drift of any sort ceases to exist. Although there is evidence for extensive glaciation farther upvalley, it appears that this segment of the Chuluut valley remained ice-free. The lack of till, gentle V-shaped valleys, and metasedimentary outcrops on the valley sides unlikely to survive glacial erosion collectively suggest that an 8-km section of the Chuluut valley was not glaciated.

Field evidence and theory strongly point toward the existence of glacial Lake Chuluut in the unglaciated portion of the valley. Fine-grained sediment in solifluction lobes on the east side of the Chuluut valley 3.5 km upstream from the drift limit is possibly lacustrine. A granitic dropstone in this area delineates the minimum lake level at 2260 m. Using the elevation of this dropstone as the minimum lake surface, the volume of the lake would have been at least 309,000,000 m3. The maximum ice level is recorded along the hillside on the west side of Chuluut Gol by granitic erratics on predominantly metasedimentary rock (Fig. 3) as well as numerous meltwater channels incised into the bedrock of the valley wall. These deposits constrain the maximum possible elevation of the glacial Lake Chuluut surface. At a minimum the lake would have extended 7.2 km up valley toward the terminus of a larger glacier originating near Egiin Davaa pass and 3.6 km up the main tributary valley to the west.

Figure 3: Granite erratic on metasedimentary bedrock, looking south up the Chuluut Gol. Field notebook for scale.

Evidence for glacial outburst floods in the Russian Altai Mountains to the northwest has been presented by Reuther and others (2006), and it is likely that glacial Lake Chuluut also drained in one or more cataclysmic floods. An elevated fluvial channel beyond the ice limit and between Chuluut Gol and Davaatiin Gol is possibly of flood origin. A large, angular boulder is located along the margin of this flood channel far beyond the ice limit. The boulder's angularity suggests that it was not deposited by a much older and more extensive glaciation whose landforms have since been subdued. It is more likely that this boulder was carried by ice during a glacial outburst flood. This implies that the flood was the result of an ice-dam failure, which may have occurred repeatedly as long as the Davaatiin glacier continued to advance.

The presence of nested recessional moraines demonstrates that the toe of the Davaatiin glacier retreated about 1.5 km before ice on the plateau became too thin to allow for glacial flow, causing stagnation. Evidence for ice stagnation includes abundant ablation till and numerous kettles. Once the glaciers receded from the piedmont back into their valleys, they appear to have retreated without depositing appreciable amounts of till except for scattered, small, recessional moraines.

TIMING OF THE GLACIATIONS

Our findings agree with those of Lehmkuhl (1998) and previous studies that there is evidence for at least two stages of glaciation, the LGM and PEN. Along much of the ice limit in our study area, one boundary could be assigned along the edge of the till while another, slightly beyond, consists of isolated erratics. Evidence that till from the most recent glaciation is superimposed on much older till exists at the terminal moraine complex of Davaatiin Gol. Here, outside of the most prominent LGM moraine are four additional curved ridges that are likely moraines from one or more older glaciations (Fig. 1).

Surface boulder frequency counts on the five moraines were used for relative dating. Boulders above the surface are exposed to harsh physical weathering conditions, resulting in a decrease of boulder height above the moraine surface as a function of time. Older moraines likely have thicker accumulations of loess, which would also decrease the boulder height as a function of age. We hypothesized that the inner, younger moraine would have a higher mean boulder height and frequency than the outer moraines.

Our results indicate that there is a correlaion between age and mean surface boulder height and frequency (Fig. 4). The innermost moraine has a boulder frequency of 0.18 boulders/m2 and an average height of 113 mm. The other four moraines are clustered with a range of boulder frequencies from 0.02 to 0.04 boulders/m2 and average boulder heights of 38 to 55 mm. The fact that the other four are clustered may suggest that the outer four moraines are of a similar age and from the same glaciation, or it may simply suggest that there is a limit to how much the boulders on the moraine can weather. Based on the fact that there are two clear sets of moraines of different ages in a region that has a record of only two known Pleistocene glaciations, it is probable that the innermost moraine correlates with the LGM while the outer four moraines date to the PEN.

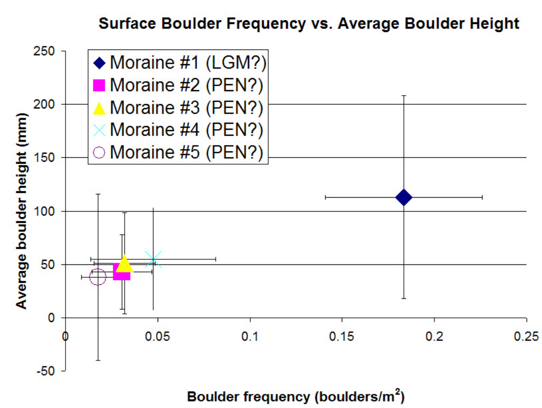

Figure 4: Graph of surface boulder frequency versus average boulder height on moraines of the Davaatiin valley, with standard deviation bars displayed. The two clusters of data points suggest two glaciations.

RADIOCARBON DATING

In order to constrain the timing of the most-recent glacial retreat, we took samples from kettles and lakebeds for radiocarbon dating. Material from a cutbank of Botgon Gol inferred to be glaciolacustrine sediment due to its rhythmic laminated nature and the presence of dropstones yielded a calibrated age of 13,155 ± 70 ybp. This suggests that not only did a moraine-dammed lake exist at this time, but that there must have also been upvalley glacial ice calving into the lake to account for the dropstones.

PALEOCLIMATE

According to Lehmkuhl (1998) the ELA for the Hangay today is 3900-4000 m, or above the height of all but the tallest peaks. He calculated the LGM ELA based on the Toe to Summit Altitude Method (TSAM, which assumes that the ELA is halfway between the elevation of the toe of the glacier and the highest peak in the catchment area) to determine a value of 2800 m. Using the same method with elevations taken from topographic maps, the ELA for the Davaatiin glacial system corroborates his calculation with a value of 2827 m. However, using this method on a much simpler glacier system in the Bumbatiin Valley immediately to the east yields an ELA of 2680m.

Lehmkuhl argues against the use of the Accumulation Area Ratio (AAR, which stipulates that the ratio of the accumulation area to the total glacier surface area is fixed for a glacier in equilibrium) for determining the ELA because he believes that cold-based glaciers in central Asia have not been studied enough to yield a dependable AAR. In the Chuluut glacial system immediately to the west, a few glacial striations were found on bedrock indicating that the glacier here was at least partly warm-based. In their paleoglacier reconstruction of the Sawatch Range in Colorado, Brugger and Goldstein (1999) use an AAR of 65% for glaciers with typical area-altitude distributions and 55% for more piedmont style glaciers. Due to the continental climate of both Mongolia and Colorado, glaciers in both regions should behave similarly and their AARs should be comparable. Finally, the TSAM is merely a subset of the THAR (Toe to Headwall Altitude Ratio) with an assumed ratio of 50%, which makes it no more legitimate than an assumed AAR.

When accumulation areas and THARs were calculated for various hypothetical ELAs for the Davaatiin and Bumbatiin glaciers (Table 1), an ELA of 2800 m yielded small AARs and a large discrepancy in the values between glaciers (49% for the Davaatiin glacier and 22% for the Bumbatiin glacier). At ELAs of 2500 m, the values of both glaciers converge at the AAR of 64% for the Davaatiin glacier and 65% for the Bumbatiin glacier. According to Brugger and Goldstein's work, an AAR closer to 67% is more reasonable than 22%. Additionally, the consistency in AARs at an ELA of 2500 m suggests that this value may be more salient.

In an eolian study of central Mongolia, Feng and others (2006) show that precipitation variation was not strictly synchronous with glacial and interglacial periods, implying that the Pleistocene glaciations of Mongolia were not controlled by precipitation. Assuming that the mean annual precipitation was about the same in the LGM as it is currently, and an environmental lapse rate of 6.5°C/km, the 300 m uncertainty in the ELA would be accompanied by a 2°C uncertainty in mean summer temperature during the LGM. Based on a modern ELA of 4000 m in the Hangay, mean summer temperatures in the LGM would have been 7.8°C or 9.75°C cooler for LGM ELAs of 2800 m and 2500 m, respectively. Considering that the uncertainty in temperature during the LGM is 20-25% the temperature variation between modern and LGM conditions, the inconsistency in the LGM ELA seems important to resolve if a paleoclimatic analysis is to be made.

	ELA	AAR	THAM
Davaatiin Glacier	2500 m	64%	23%
	2600 m	59%	31%
	2700 m	55%	39%
	2800 m	49%	46%
Bumbatiin Glacier	2500 m	65%	34%
	2600 m	58%	43%
	2700 m	50%	53%
	2800 m	22%	62%

Table 1: Comparison of AARs and THARs for select ELAs of the Davaatiin and Bumbatiin glaciers.

CONCLUSION

The geomorphology of the Davaatiin glacial system is characterized by large terminal moraine complexes, kettles, and erratics. Using the ice limits in a GIS, the surface area of the Davaatiin glacier was 349 km2 with an ice volume of 55 km3. The glacier blocked the Chuluut Gol, creating a lake with a minimum volume of 0.3 km3 that likely drained catastrophically as jökulhlaups. A radiocarbon analysis constrains the glacial retreat to before 13 ka. The LGM ELA is 2800 m or 2500 m when calculated from the TSAM and AAR methods, respectively. This implies that mean summer temperature was 7.8°C to 9.75°C cooler in the LGM than it is today, assuming no change in precipitation.

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