KECK GEOLOGY CONSORTIUM

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

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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

INTRODUCTION

The Vostoch Range, located on the border of Mongolia and Siberia, is widely acknowledged to have been glaciated during the late Pleistocene, but the timing and extent of these glaciations have yet to be determined. Moraines in the valleys south of these mountains are remaining evidence of these glaciations. This area, particularly the Horoo Gol valley, was studied in order to determine the extent and timing of the advances and retreats of these glaciers. Through measurements of boulder frequency, size, and strength; cosmogenic dating; and GPS surveying, the glacial history of this valley can be better understood. The nested outermost moraines in this valley were likely deposited by one glaciation that experienced several advances and retreats, and a farther up-valley moraine was likely caused by a later glaciation.

This project will further enable correlation of glaciations in Mongolia, as well as provide evidence for past climate and environments in northern Mongolia. This region has not been thoroughly researched before, though other areas in Mongolia have been studied in similar contexts. It is important to determine the climatological history of this area to determine whether glacial advances in Mongolia and central Asia are synchronous, or whether they differ among regions (Gillespie et al., 2008). Furthermore, future climate variations can be inferred from paleoclimates, which can aid in predicting future glacial movement.

Geographic Setting

The area of study is the Horoo Gol valley, on the northwest shore of Lake Hövsgöl, a freshwater lake that has a surface area of 2760 km2. This remote area is near the border with Russia, and is framed by the Bayan Mountains to the west and the Vostoch Range to the north. Field work was conducted solely in the Horoo Gol valley, which the Horoo Gol bisects. The biome in this region is taiga that ranges from forested steppes and mountains to grassy glacially-formed valleys (Gillespie et al., 2008). The landscape of the Horoo Gol valley is characterized by a complex of low-relief, rolling terminal moraines. These moraines have grassy cover; sporadic boulders crop out on their crests.

Glacial History

The geology and topography of Mongolia has been affected by glaciations in many regions of the country. There is evidence for several middle-to-late Pleistocene glaciations across Mongolia. The last glaciation is divided into two glacial periods, the Sartan Glaciation and the Early Zyrianka Glaciation. Other studies in central Asia have confined the most recent glacial advance between 21-28 ka, an intermediate glacial advance between 35-38 ka, and the oldest glacial advance to be older than 50 ka (Xu et al., 2009; Gillespie et al., 2008; Lehmkuhl and Lang, 2001). Glacial landscapes in Mongolia are characterized by features such as U-shaped valleys and cirques in inner mountain massifs and erratic-covered moraines (Lehmkuhl and Lang, 2001).

Moraine Dating

Relative age dating is a method of determining the comparative age of past events. Though it yields no specific dates, it can determine the order of events, which is essential for determining the geologic history of an area. Common methods used in relative age dating of moraines include oxidation and weathering of rock clasts, rock weathering rind thickness, and examination of soil properties (Shiraiwa and Watanabe, 1991). The methods of relative age dating that were used in this study were the collection of boulder frequency, height, volume and rebound strength on the crests of moraines. These data can be used to determine the relative age of the moraines, as moraines with fewer boulders exposed should be older due to more time for the boulders to erode and for soil to accumulate and partially-to-fully bury the boulders. Boulders on older moraines should also be smaller in volume and height due to physical and chemical weathering, and have lower rebound strength because rocks become more weathered and prone to disintegration as duration of surface exposure increases. Differential GPS profiles were collected across each moraine. These profiles show the height and width of each moraine and can also be used for relative age dating because lower relief moraines should be older due to being exposed longer, thus having more time for erosion. Mapping was also done to determine the exact location and extent of moraines in the valley. Similar methods have been used successfully in other glacial studies (Pearson, 2007; Shiraiwa and Watanabe, 1991; Sharp, 1969).

METHODS

Two weeks of field work were completed in the Horoo Gol valley in July and August of 2010. Following two days of field reconnaissance, it became apparent that the majority of this valley had been glaciated due the presence of a large moraine complex.

Mapping

The moraines in this area were mapped through several days of field observation. This information can be used to determine the down-valley extent of the glacier. This was done using 1942 1:100,000-scale Russian topographic maps. Moraine locations were subsequently confirmed with a Garmin 12XL GPS unit using the WGS 84 datum. These GPS points were later imported into ArcGIS and the topographic maps were scanned and georeferenced. These data were used to digitize polygons of moraines, which were overlaid on the topographic map, creating a map of moraine location and extent in the Horoo Gol valley. The map is projected in the Gauss Kruger coordinate system using the Pulkovo 1942 datum in zone 17. The general area and width of each moraine are accurate to ± 50 m. The starting and ending locations of each moraine are accurate to ± 100 m, as they were not readily apparent in the field and thus were approximated.

Boulder Frequency, Height, Volume and Rebound Strength

Two to five areas of boulders on the crests of moraines were examined to determine boulder frequency, height, volume, and rebound strength in that area. These data were collected on eight moraines- Qma, Qmb, Qmb1 (a smaller continuation of Qmb), Qmc, Qmd, Qmi, Qmi1 (a smaller continuation of Qmi), and Qmj. These moraines were labeled so that the farthest down-valley moraine is Qma, the second farthest down-valley moraine is Qmb and so on, up to Qmj, the farthest up-valley moraine used in this study.

For each boulder count, a spot on the crest of the moraine was randomly selected, and a circle with a radius of 5 m was delineated from that point. The number, length, width, and height of all boulders greater than 25 cm in that circle were recorded. The rebound strength of all granitic boulders was then tested using a Schmidt Hammer, which measures in rebound movements (R) between 10 and 100. This is a measure of the unconfined compressive strength of the rock based on the rebound of a spring-loaded mass against the surface of the sample.

Statistical Testing

All four sets of averaged data were analyzed using the analysis of variance (ANOVA) statistical test, accompanied by the Tukey Honestly Significant Difference test, using JMP data analysis software. The former tests whether or not the means of several groups are all equal and whether variations among these means are statistically significant, and the latter is used to identify where the difference between means is greater than the standard error would be expected to allow, thus telling which of the means are different from the others. In this study the ANOVA test would be expected to find differences in means among the moraines, and the Tukey Honestly Significant Difference test should find that boulder properties on the moraine farthest up-valley (Qmj) are significantly different than on the moraines located down-valley

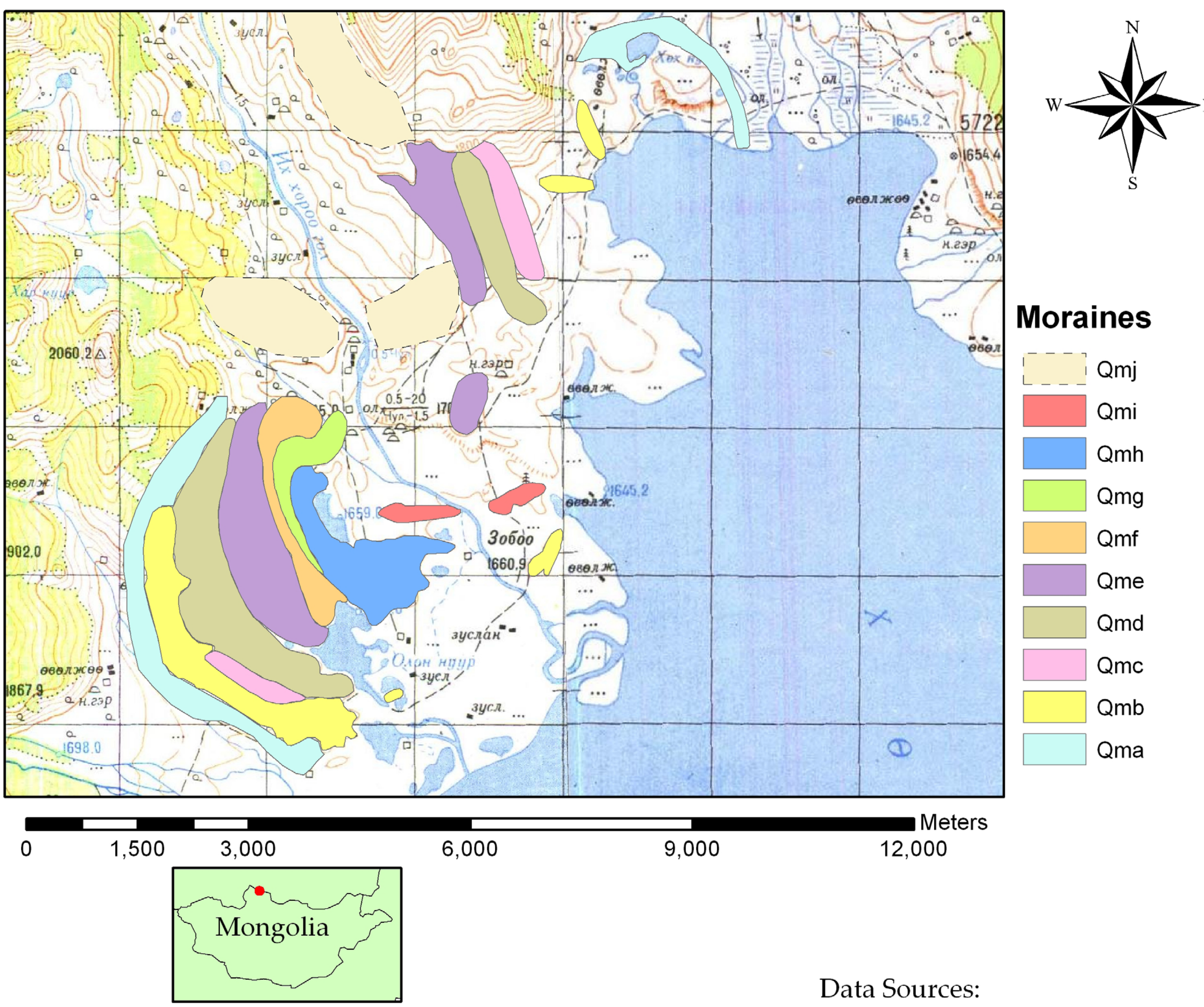
(Qmd, Qmc, Qmb, Qmb1, Qma) if the up-valley moraines are a younger population from the terminal moraine.

Moraine Profiles

Measurements were made using a differential Trimble GeoXH handheld GPS receiver, which has an accuracy of ±30 cm. The position measurements were differentially corrected using a temporary base station and GPS Pathfinder Office software. Each moraine was measured by traversing it four times, with each traverse spaced at least 50 m apart. Traverses were walked in a straight line from the start of the moraine, over the crest, and to the end of the moraine on the other side. Once collected, the profiles were uploaded to a computer and differentially corrected using the base station receiver data.

RESULTS

Ten terminal moraines were field mapped in the western Horoo Gol valley. Some also continue in the eastern Horoo Gol valley (Fig. 1). Qma was found to be the farthest down-valley moraine, the longest moraine, and was also found to continue in the eastern valley. Qmb, the next down-valley moraine, is nestled along the southern three-quarters of Qma in the western valley, and has smaller continuations farther east in the western valley that are no longer connected to the rest of the moraine due to shoreline erosion. Qmb was also found to continue in the eastern valley. Qmc, Qmd, and Qme all have similar shapes as farther down-valley moraines, and all have



Datum: Gauss Kruger
Coordinate System: Pulkovo 1942

Data Sources:
Mongolia Digital Terrain Elevation Data, Geocomm.com
Moraine Locations, mapped by the cartographer in the field

Figure 1. Locations of moraines in the Horoo Gol valley.

significant continuations in the eastern valley, with Qmc being significantly smaller in the western valley than any of the other moraines. Qmf, Qmg, Qmh, and Qmi are farther up-valley moraines, with Qmi being smaller and bisected by the Horoo Gol. The farthest up-valley moraine, Qmj, has a much longer extent than the other moraines, and continues much farther up-valley.

Boulder Frequency, Height, Volume, and Rebound Strength

Boulder frequency, height, volume, and rebound strength were recorded on 6 moraines, Qmj, Qmd, Qmc, Qmb, and Qma. The means and standard deviations of these metrics for each moraine are shown in Figure 2. It should be noted that though measurements were taken on Qmi and Qmi1, those data were not used in the boulder statistical analysis because it was particularly difficult to define the extent of that moraine, and may even represent more than one moraine.

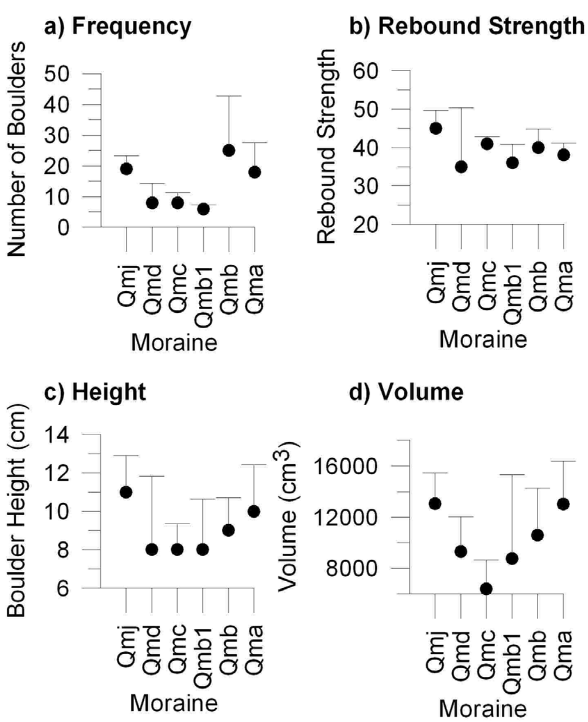


Figure 2. Charts of mean boulder frequency, rebound strength, height and volume per moraine.

Average boulder frequency per moraine was found to range between 6 and 25, with an average of 12. It appears to be fairly similar for Qmd through Qmb1, and higher for Qmj, Qmb, and Qma. Rebound strength was found to range from 35 to 48, with an average of 41. It appears to decrease slightly on moraines farther down-valley. Boulder height ranged from 8 to 11 cm, with an average of 9 cm. There was no distinct pattern in boulder heights. Boulder volume ranged from 6000 to 14000 cm^3, with an average of 9000 cm^3. It appeared to very slightly decrease from Qmj to Qmc and increased from Qmb1 to Qma.

Statistical Testing

Statistical testing was done on average boulder frequency, volume, height, and rebound strength per moraine. P-values were determined by a one-way ANOVA test (Table 1). Three data sets- frequency, volume, and rebound strength, have P-values that are less than the significance level of 0.05, so it can be said that there are significant differences among the means. If a significance level of 0.10 is used, all four data sets have significant differences among their means.

Data Set	Frequency	Height	Volume	Strength
P Value	0.023	0.084	0.042	0.038
Level at which a Tukey HSD Test finds significantly different means	0.10	n/a*	0.05	0.05

*n/a= not applicable

Table 1. ANOVA test results for boulder data sets

Upon comparing means with the Tukey Honestly Significance Difference test, frequency, volume, and rebound strength were found to have some means that were significantly different from the others. For the volume data at a 0.05 significance level, Qma was found to have a mean significantly higher than the rest of the data, while Qmc was found to have a mean significantly lower than the rest of the data. For rebound strength Qmj was found to have a mean significantly higher than the rest of the data, while Qmd had a mean significantly lower than the rest of the data. For the frequency data at a significance level of 0.10, Qmb was found to have a mean significantly higher than the rest of the data, while Qmb1 was found to have a mean significantly lower than the rest of the data.

Moraine Profiles

Profiles of 9 moraines were collected in the western Horoo Gol valley. The dimensions that were recorded with those profiles are summarized in Table 2. Qmj has the highest elevation, at 1747 m, whereas Qmf has the lowest elevation, at 1679 m. Qme has the largest width, at 620 m, whereas Qmh has the smallest width, at 240 m. Qmj and Qma have the highest slopes, at 0.21 and 0.20, respectively. Slope ranges from 0.05 to 0.15 on the other moraines. Qmj, at 40 m, has the highest relief, and Qmf and Qmb have the lowest, at 9 m. All the moraines have elevations within 23 m of each other, except for Qmj, which is nearly 50 m higher than the second highest moraine. There is no distinct pattern in the width, slope, or relief.

Moraine	Peak Elevation (m)	Total Relief (m)	Total Width (m)	Down-valley Slope
Qmj	1747	40	390	0.21
Qmh	1684	18	240	0.15
Qmg	1688	23	440	0.10
Qmf	1679	9	380	0.05
Qme	1685	36	620	0.12
Qmd	1685	19	595	0.06
Qmc	1699	30	550	0.11
Qmb	1699	9	295	0.07
Qma	1697	29	290	0.20

Table 2. Moraine dimensions in the western valley.

Profiles of 6 moraines were collected in the eastern Horoo Gol valley, whose dimensions are summarized in Table 3. Qme has the highest elevation, at 1785 m, whereas Qma has the lowest elevation, at 1698 m. Qmc has the largest width, at 850 m, whereas Qma has the lowest, at 490 m. Qma has the highest slope, at 0.16, whereas Qmd has the lowest, at 0.06. Qmc has the highest relief, at 69 m, whereas Qmd has the lowest, at 16 m. There are no distinct patterns in the elevation, width, slope, or relief.

Moraine	Peak Elevation (m)	Total Relief (m)	Total Width (m)	Down-valley Slope
Qme	1785	26	610	0.08
Qmd	1777	16	495	0.06
Qmc	1768	69	850	0.15
Qmb	1703	45	670	0.13
Qma	1698	39	490	0.16

Table 3. Moraine dimensions in the eastern valley.

DISCUSSION

The purpose of this study was to map and date moraines in the Horoo Gol valley. Figure 1 shows the arrangement of moraines in the Horoo Gol valley. They appear to have a lobate shape across the entire valley, though glacial outwash, subsequent river erosion, and an increase in the level of Lake Hövsgöl since moraine deposition has eliminated some of the extent of the moraines.

The boulder properties of frequency, height, volume, and rebound strength are generally similar among moraines (Fig. 2). However, it can be observed in the chart for rebound strength that the averages appear to get smaller farther down valley. These qualities support the hypothesis that Qmj is the youngest moraine, and that moraines get older further down-valley, with Qma being the oldest. The ANOVA test results shown in Table 1 show that there is significant variation in the means of the collected frequency, volume, and rebound strength data among moraines. The Tukey Honestly Significant Difference tests that were performed indicate that there is significant variation in the means of volume, frequency, and strength among moraines. Ideally, Qmj would have had the highest means for all of these qualities, while Qma would have had the lowest. The rebound strength results show that Qmj has the highest, while Qmd has the lowest, a result that makes sense due to Qmj being the youngest moraine, but the results for volume and frequency are not necessarily logical. There is no distinct pattern to these test results, but they do show that the moraines have not weathered uniformly, or that they had non-uniform initial boulder properties at the time of deposition.

Tables 2 and 3 of moraine profile dimensions, show that moraines vary widely in width, and have slopes ranging from 0.03 to 0.21. The slopes of the moraines in the western valley have high inter-moraine variation, but Qmj and Qma have the highest slopes, which would make sense because Qmj is the youngest moraine, and Qma has high relief. The slopes of moraines in the eastern valley appear to get smaller further up-valley, with Qma having the largest slope and Qme and Qmd having smaller slopes. However, the profiles that were taken in the eastern valley may be less accurate than those taken in the western valley, because the field expression of the eastern moraines was not as clear. There is some evidence for alignment of moraines between the western and eastern valleys, as mapped on Figure 1, particularly Qme and Qmd.

CONCLUSION

This study resulted in the successful mapping of the outermost moraines present in the Horoo Gol valley, along the northwestern shore of Lake Hövsgöl and an attempt to perform relative age dating on them. This is the first time the moraines in this valley have been mapped. A reconstruction of the extent of the glacier at its farthest advance, as well as determining the equilibrium-line altitude would allow for further determination of how the shapes of moraines fit with the shape of the glacier, as well as the extent and ice volume of the glacier.

This study would also be further aided by the results of ^{10}Be in situ cosmogenic nuclide exposure age dating, which will give estimates of the timing of deposition for three of the moraines (Qmj, Qmb, and Qma). This will allow for comparison of moraine emplacement timing with other glaciated regions in Mongolia and Central Asia, thus adding more evidence for the ongoing conversation of whether glaciations in the region were synchronous.

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