Late Pleistocene history of glacial Lake Atwood, San Juan Mountains, Colorado

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Introduction. The glacial history of the San Juan Mountain Range, located in southwestern Colorado, was first discussed in a 1932 paper (Atwood and Mather). The two men produced a surficial map of the entire range, covering 20,000 square km, as well as a reconstruction of the most recent glaciation, which roughly coincides with the continental Wisconsinan event. Located within the eastern part of the range near the present-day Hinsdale and Mineral County line, Atwood and Mather mapped a glacial lake dammed by ice emerging from South Clear Creek Valley. The purpose of my project was threefold. First, I considered the physiography and sediment distribution of the North Clear Creek Park area and compared my findings to those of Atwood and Mather (1932). The subsequent surficial geologic map enabled me to decipher broad patterns of sedimentation in glacial Lake Atwood. I then reconstructed the paleoflow dynamics of the lake through a detailed sedimentological analysis of glaciolacustrine sediments, including paleocurrent indicators in coarse-grained turbidity deposits. Finally, in conjunction with the work of Scott McMillin, Maria Panfil and Denise Muriceack (this volume), catastrophic drainage of the lake was considered - a grande finale to Late Pleistocene glacial events in the area. Paleomagnetic data was used as a geochronologic correlation tool to place the existence of glacial Lake Atwood within the context of regional glaciation in the Rocky Mountains.

Surficial Mapping. Deltaic deposits consist of massively bedded sand, gravel and cobbles within which individual beds dip at angles from 10-17°, with an azimuth of 050° NE; both direction and dip angles suggest these sediments are the topset component of a classic Gilbert-type delta (Gilbert 1885). Although the foreset/topset contact was not seen in the sediments, the deltaic foreslope is dramatically evident both in the field and in air photos, marking the contact. The elevation of the maximum and most persistent lake stand is thus fixed at 10,150 ft.. No other such contacts were found suggesting additional significant lake stillstands. Scott McMillin (1993) identified two possible spillways carved in bedrock along the eastern edge of Santa Maria Canyon; one located at an elevation of 10,150 ft.(3093 m) and the other at 10,070 ft.(3069 m). The higher spillway confirms the prominent lake level to which the delta was graded. A kame terrace located approximately 1.5 km southwest of the delta front suggests ice overtopped a lateral moraine and bedrock, and the stagnant ice became the major source for deltaic sediment and meltwater entering the lake. Another large area of outwash material exists in the northern portion of the paleobasin, beyond the mouth of North Clear Creek.

Fine-grained lacustrine deposits exist in two clusters: a southern exposure near the ice contact/lake margin, and a northern group within the foreset slope of the delta. No other rhythmically-bedded sediments were discovered. Massive clays exist at two other locations, and are likely the result of slumped lacustrine deposits from the basin sides. (Figure 1)

Sediment Analysis. Six sections of rhythmically-bedded sands, silts and clays totalling over 14 meters of stratigraphic section were studied. Sediment samples were collected and grain size analysis performed with a laser particle counter. Sections were divided into facies based on sand and clay percentages, presence of massive or rippled sand beds, and deformation features. TOTAL Theodolite Station data revealed that the rhythmite sections spread out over 41 meters of vertical space, but no overlap exists from one site to another.

In the southern rhythmite exposures, many factors suggest that turbidity underflows - surge currents - were the primary force in distributing sediment into the lake. At least half of the total stratigraphic section is dominated by sand in the form of thin laminae within silts and clays, massive layers up to 14 cm thick, and cross-bedded ripple laminae that show paleoflow in a west/northwesterly direction. Varves are couplets deposited within the time frame of exactly one year: summer silts through underflow in the hypolimnion are dominated by gravity, topography and sediment availability, and winter clays are distributed by over- and interflow and settle slowly and evenly over the entire basin (Smith and Ashley, 1985 and Ashley, 1975). The difference between the two mechanisms creates a sharp contact between the summer and winter layers. Fining upward sequences between silts and clays are dominant in glacial Lake Atwood and suggest that the deposits are surge rhythmites deposited by a single flow mechanism (underflow). The large amounts of silt, even in the finer 'clay' portion of the sequences, as well as the numerous sand and silt laminae within a single fining upward sequence, confirm the dominance of underflow in sediment distribution. Some winter clay layers do exist; they have a higher clay content compared to the fine portion of the surge rhythmites, and are distinguished by sharp contacts above and below. The thicknesses of these occasional clay

Mountain Creek. The same trend holds for the kaolinite present in the Rio Grande soils but the relative abundance at equal depths within the two types displays the same trend as the given example.

Discussion

The presence of the moraines previously described prove that the two glacier systems were not confluent in the last phase of glaciation. This is further substantiated by the mafic weathering rind data, as it separated into two separate populations thus suggesting two distinct ages of till in each of the valleys (Fig.4). Thicker rinds suggest a greater amount of weathering which is usually accomplished with time since the clasts were of similar lithology and have fairly non-variable rates of weathering. From the X-ray analysis, it can be said that the two valleys have different weathering patterns. Decreasing amounts of vermiculite and/or kaolinite with depth possibly indicate clay mineral formation due to post-depositional weathering. At this time, it is difficult to say definitively that there are two distinct ages based on the X-ray data. However, Site#1 and Site #2 appear to have more intense smectite peaks than their counterparts. The bedrock in both glaciers' source areas is mostly tuff (volcanic glass) from the cauldera complexes which weathers primarily to smectite. This allows the speculation that there might be two different ages represented by the soils. If this is true, it only adds evidence that the two glaciers were not confluent, and possibly they did not converge at all in Late Pleistocene history.

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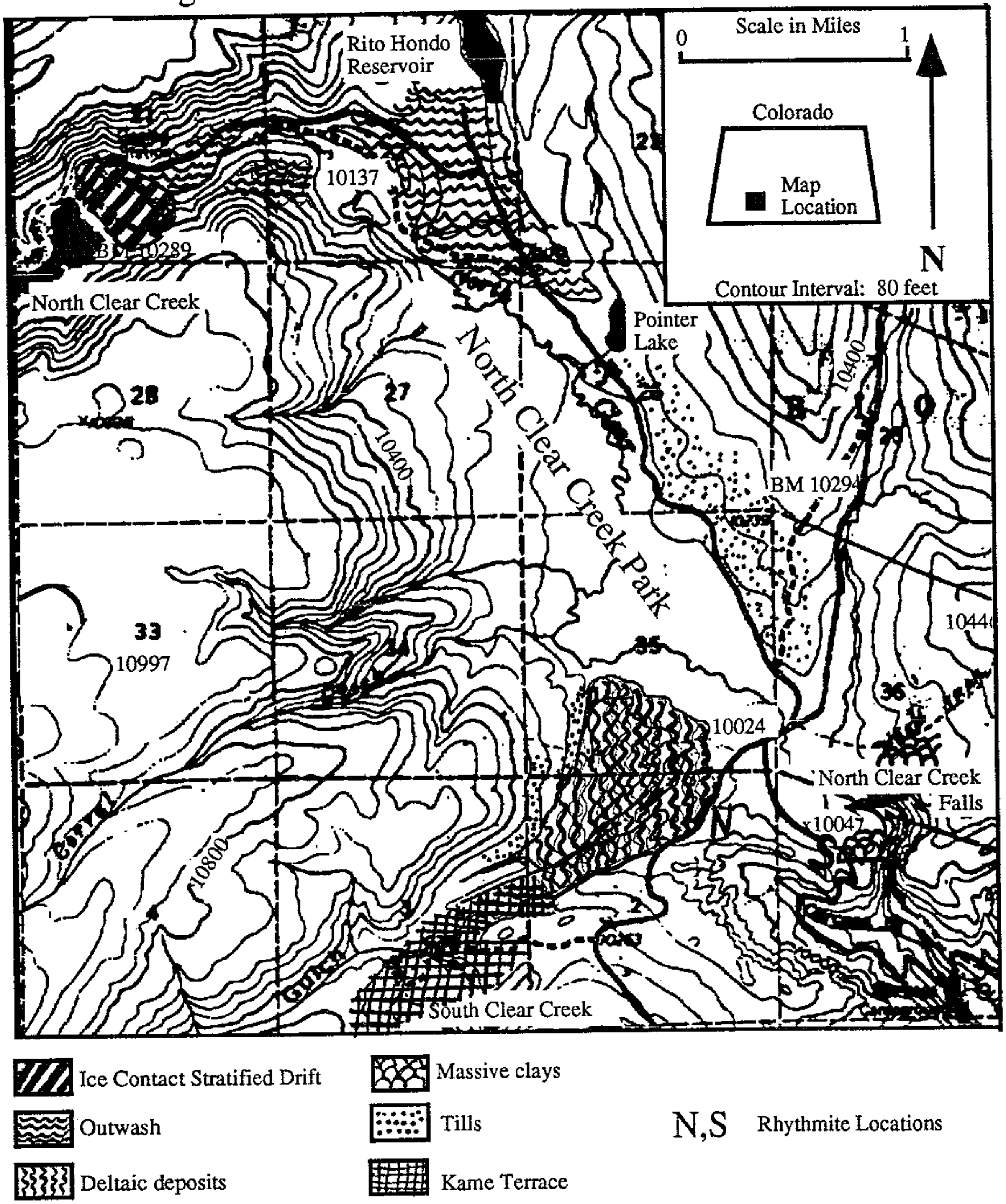
Figure 1. Surficial Sediments in the Field Area



layers is generally consistent within one stratigraphic section, usually between 1-4mm. Varve couplets remain too difficult to distinguish in their entirety because of the complexity of the 'summer' layer.

The northern rhythmites are very similar to the southern exposures in the occurence of surge deposits; however, the overall percentage of sand is 10-30% lower, and the number of winter clay layers is about 50% higher. Silt is the dominant sediment, suggesting there is less availability of the coarser sands. Paleocurrents flowed in an east/southeasterly direction. Rhythmites here are capped with coarse outwash material at an elevation of 10,118 ft. (3081 m), making the most shallow rhythmite near the delta forming at a depth of over 40 feet. The disparity in composition between the two sites suggest that direct melting of glacial ice into the lake produces much coarser deposits than sediment entering glacial Lake Atwood through meltwater across the delta. The higher stratigraphic position of the northern rhythmites may have affected the type of sediment deposited - coarse turbidity flows search for topographic lows. The location of the rhythmites within the foreset beds, out of the main flow path of meltwater, may have some impact on the comparative percentage of sands.

Paleomagnetics. As fine-grained sediments are deposited in a subaqueous environment, small grains of minerals such as magnetite and hematite align with the current magnetic field during deposition and prior to compaction. Fluctuations in the earth's magnetic declination and inclination over time are recorded in glaciolacustrine sediments and have recently become a good method for determining ages and sedimentation rates of glacial lakes (in conjunction with radiocarbon dating of organics) and for correlating glacial events from one place to another. Although there was no organic material found in the Lake Atwood rhythmites, paleomagnetic sampling was conducted with the hope of 'matching up' inclination and declination patterns from Lake Atwood to an existing radiocarbon dated-record for two lakes in the northern Colorado Rockies (Rosenbaum and Larsen, 1983).

The natural remanent magnetic intensity of the glaciolacustrine sediments was very strong, dropping off gradually during alternating field demagnetization. Patterns of inclination and declination from glacial Lake Atwood correspond closely with the Rosenbaum and Larsen study, especially with the Devlins Park patterns. The correlation occurs between 15,000 years B.P. and 13,500 years B.P. (Figure 2). Assuming sedimentation rates are generally constant at this particular location (minor facies changes), the minimum length of time the lake existed is about 2,880 years, with an average of one meter of rhythmites deposited every 714 years. The minimum oldest date for rhythmite formation at this site is 16,380 years B.P..

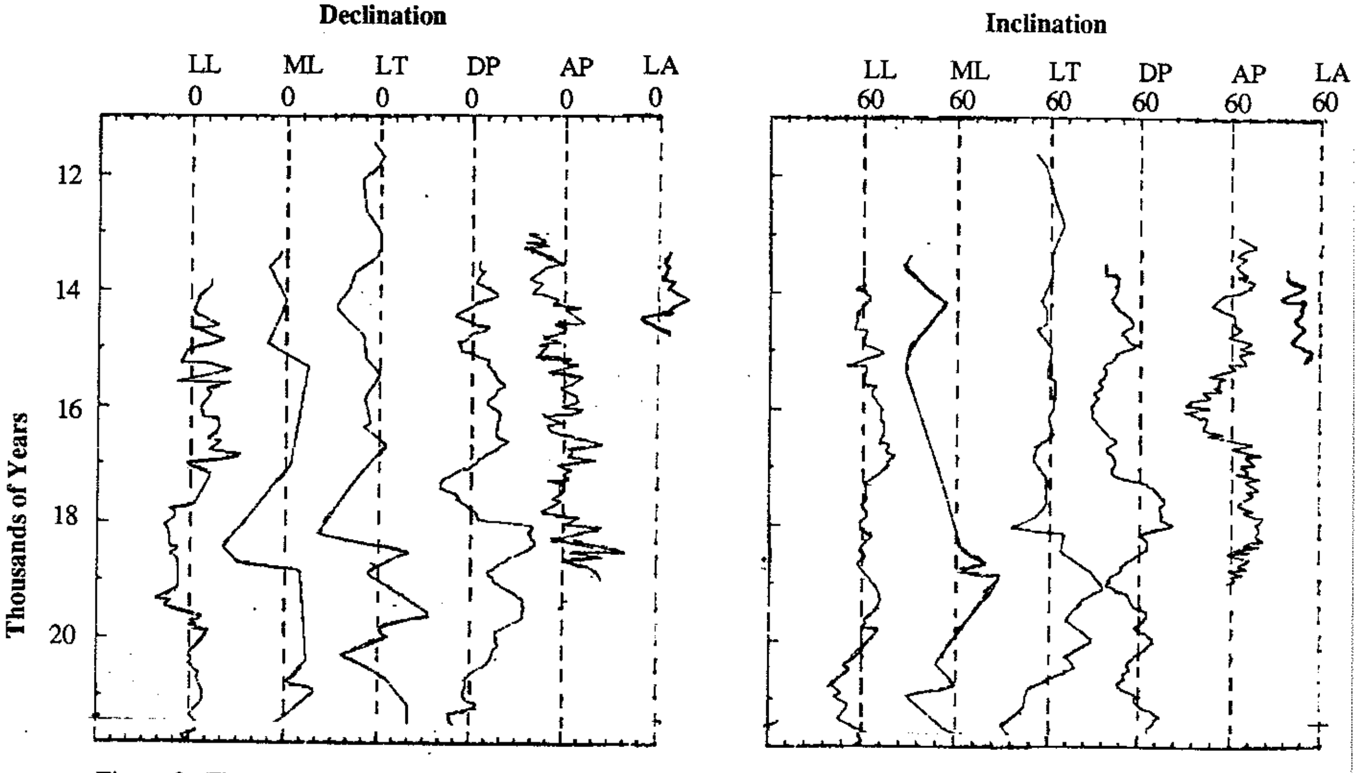


Figure 2. Figure from Rosenbaum and Larsen (1983), including paleomagnetic data from Lake Atwood, LA. Paleomagnetic records from Lake Lahontan, LL (Liddicoat and Coe, 1974); Mono Lake, ML (Denham and Cox, 1971); Lake Tahoe, LT (Palmer et al., 1979); Devlins Park, DP (Rosenbaum and Larsen, 1983); and Andersen Pond, AP (Lund, 1981). Directional data are plotted versus the ages indicated by the various authors.

Conclusions. By matching up paleomagnetic data from glacial Lake Atwood with the Rosenbaum and Larsen study, we know the lake existed between 15,000 and 13,500 years B.P.. The age represents only the time during which the lacustrine sediments were deposited; some water must have existed in the basin during the glacial maximum, but the lake may have been too shallow or turbid for rhythmites to form. There is some question as to whether ice existed in North Clear Creek Park in the Pinedale. Scott McMillin and Alex Durst (both this volume) determined the ICSD at the mouth of the Continental Reservoir to be of Pinedale age (soil pit evaluation). This finding suggests ice began to emerge from North Clear Creek into the paleobasin during the Pinedale, and would account for the amount of outwash that exists in this end of North Clear Creek Park. The Pinedale glacial maximum occured around 23,500-21,600 years B.P. (Madole, 1986); it is during this time when ice would have most certainly existed in this northern section. There is no direct evidence to suggest sediment from this northern outwash affected the rhythmites at the delta or near the ice, and the outwash does not have any features suggesting it was graded to a lake level; it is difficult to determine when (during the existence of the lake) ICSD began to contain outwash and meltwater in North Clear Creek. Till does exist within the paleobasin (Figure 1) but its age is problematic.

Sedimentation in glacial Lake Atwood was dominated by underflow, both in the winter and the summer, although the presence of winter clay layers through suspension settling suggests that some type of stratification did exist (either thermal or sediment) and that turbidity probably decreased in magnitude during the winter months from ice cover. Coarser sediment was deposited in the rhythmites near the glacier, where no sediment traps existed between melting ice and the basin. Facies changes found within the stratigraphy of rhythmites near the glacier reveal possible fluctuations in sediment inflow over time. Sections with smaller percentages of sand and higher percentages of clay are representative of periods of low inflow, and sections with many cross-bedded and massive sand layers and a high silt percentage reflect increased turbidity. Because the identification of varve couplets is impossible from the complex rhythmicity, a precise longevity of the lake is not known. However, the considerable thicknesses and frequency of turbidity deposits suggests a fairly high rate of sedimentation, and paleomagnetic results indicate the rate is 1 meter every 714 years at the ice/lake contact.

Paleomagnetic data also helps to bracket the catastrophic drainage of the lake. Maria Panfil (this volume) has radiocarbon dated material from Ghost Lake in Santa Maria Canyon at 7,610 +/- 90 yrs. The date represents the youngest possible date for debris to have covered the lower spillway of glacial Lake Atwood, and therefore the absolute latest date for catastrophic drainage of the lake. The drainage thus occured at some time between 7,610 and 13,500 years B.P.. These dates are coherent with others findings for Pinedale deglaciation in the San Juans (Carrara et al, 1991, Gillam et al, 1984). The volume of water in glacial Lake Atwood at its maximum (lake level 10,150') was approximately 6,636,447 cubic meters: the lower spillway at 10,070 ft. would have been responsible for the catastrophic drainage of some 6,087,090 cubic meters of water.

The approximate size of glacial Lake Atwood in map view is consistent with the findings of Atwood and Mather. The use of paleomagnetics, surficial mapping, and consideration of glaciolacustrine sediments provides us with a more detailed understanding of glacial Lake Atwood. Paleomagnetics is especially helpful in placing the age of lacustrine sediments within the period of Pinedale deglaciation in the Colorado Rocky Mountains.

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LATE PLEISTOCENE DEGLACIATION OF THE CLEAR CREEK GRABEN, SAN JUAN MOUNTAINS, COLORADO

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Goals The goals of this study are:

1) to create a 1:12,000 map of the glacial and surficial deposits in the Clear Creek Graben
2) to determine ice extent at the last glacial maximum
3) to determine the chronology of deglaciation based on this information

Introduction and Field Area

This study examines the glacial geology of the Clear Creek Graben in the eastern San Juan Mountains, southwest Colorado. The mountain range covers 20,000 square kilometers, extending from San Luis Park on the east to within 50 miles of Utah on the west. Thirteen peaks exceed 14,000 feet, and over twenty others exceed 13,000 feet (Atwood and Mather, 1932, Carrara, 1984). The continental divide bisects the center of the range, with the Rio Grande River draining to the east and the Colorado River draining to the west. My research looks at the area where South Clear Creek and the Rio Grande River flow east out of confined valleys into the large Clear Creek Graben. This area is located within the USGS 1:24,000 topographic maps of the Hermit Lakes quadrangle and the Bristol Head quadrangle; 37°45' to 37°52' north latitude and 107°4' to 107°13' west longitude. Elevation ranges from 9500 feet in the south, to 10,400 feet along the eastern edge of the graben.

In this study, the most recent glaciation will be termed Pinedale, and the second most recent will be termed Bull Lake. Quaternary deposits in the San Juan Mountains have been correlated with glaciations defined in the Wind River Mountains, Wyoming (Blackwelder, 1915, Meierding and Birkeland, 1980). The Pinedale glacial maximum has been dated at 23,500 to 21,000 years BP in the Front Range, Colorado (Madole, 1986). The Pinedale glaciation erased many Bull Lake deposits, but some Bull Lake till outcrops in the eastern and southeastern portions of the study area. No deposits from glaciations older than Bull Lake were evident.

During the last glacial maximum, the San Juan range was covered by a complex of large regional ice fields, transection glaciers and valley glaciers (Carrara et al, 1984). This glaciation was not as extensive as the second most recent. Most major valley glaciers did not reach the foothills of the mountains, but left long valley trains of glacial debris extending downvalley from their former glacial termini. The Rio Grande glacier was formed by the confluence of ice flowing out of South Clear Creek Canyon, Crooked Creek Canyon, House Canyon, and Road Canyon. The Rio Grande Glacier was fed by cirques on Rio Grande pyramid along the continental divide. It was over 30 miles long and occupied over 375 mi^2, making it the second largest glacier in the San Juans (Atwood and Mather, 1932).

Methods Four techniques were used to achieve the goals of this study:

1) field mapping and air photo interpretation
2) relative dating methods using soils and weathering rinds
3) ice provenance studies
4) glacier modeling

The entire area was mapped using a combination of field mapping and stereoscopic aerial photograph interpretation. The small size of the study area made it possible to map by examining topography on foot, digging exposures in landforms to determine sediment composition, and walking the contacts between units. Air photographs were used as a means of examining topography and mapping out contacts.

Relative dating techniques were used to determine whether deposits in the study area were from the Pinedale or Bull Lake glaciation, and also to see whether any differentiation between Pinedale deposits was possible. Soil pits were dug in thirteen places either on moraine crests or the top of kame terraces. In the field, horizon depth, color, texture, structure, and percent gravel were noted at each site. In the lab, particle size analysis was performed on samples from each horizon and dry color was recorded. Mafic weathering rinds were measured on basalts or andesitic basalts at fourteen locations in the study area, generally moraine crests or the top of kame terraces. Rinds were also measured at ten locations near the Pinedale terminus of the Rio Grande Glacier to correlate the study area measurements with other known Pinedale deposits, and to determine a more complete chronology of deglaciation.

Two techniques were used to determine ice flow direction from each small, confined valley: 1) the ratio of crystalline to volcanic rocks in glacial deposits, 2) the orientation of the long axes of rock drumlins. The crystalline source area is located along the continental divide to the southwest of the study area. A large ice field situated over this area fed all four of these glaciers. There is a significant decrease in the percentage of crystalline erratics from the