Quaternary Glaciation of Middle Roaring Creek Valley
Spar City Quadrangle, Colorado

A thesis submitted in partial
requirement of a Bachelor of Science Degree in Geology
by
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Table of Contents

Abstract

Major morphological features associated with Quaternary glaciation of Middle Roaring Creek Valley, Spar City Quadrangle, Colorado divide the valley into three regions of varying topography. Analysis of weathering rind data, slope profiles, and soil development throughout the valley show three regions, not necessarily associated with the morphologically unique zones, of differing relative ages. These differences suggest that Middle Roaring Creek Valley has been subject to at least three episodes of glaciation throughout its Quaternary history.

Introduction

Middle Roaring Creek Valley, located on the northeast face of Fisher Mountain (elevation 12, 865 ft.) in the eastern San Juan Mountains is a small sub-alpine valley which has been subject to glaciation during the Quaternary (Figure 1). Middle Roaring Creek Valley is characterized by a large rectangular cirque that narrows dramatically at the valley midpoint near Middle Lake. Below Middle Lake, the valley drops down four or five steps, widens out into an area of hummocky ice stagnation features, and finally reaches what is now the valley of the Roaring Fork River in a broad complex of terminal moraines.

The objectives of this project were to define and map the major geomorphic features in Middle Roaring Creek Valley and then to create a Quaternary chronology of ice advance into the valley using relative dates from these features. Lateral, terminal, and recessional moraines, as well as possible debris flows and rock glaciers are prominent in the valley and were consequently of the greatest interest. These features were included in the geomorphic map of the valley. Smaller unmapped features will be considered in the paper.

Through comparisons of soils, slope profiles, and weathering rind data, this project will also attempt to determine relative ages of prominent features in the valley. Where absolute ages of features are often impossible to obtain in Quaternary studies, relative age dating becomes an important tool for recognizing deposits from separate Quaternary events. Soils, weathering rinds, and slope profiles are used for relative dating as these characteristics of landforms are known to change more or less solely as a function of time (Birkeland, 1980).

In Middle Roaring Creek Valley, apparent differences in age between the terminal moraines and moraines farther up valley, as seen through relative dating techniques, would suggest multiple readvances of ice to elevations above the terminal moraines. Ultimately, a chronology of glaciation of the valley during Pleistocene and possibly Holocene time may be created.

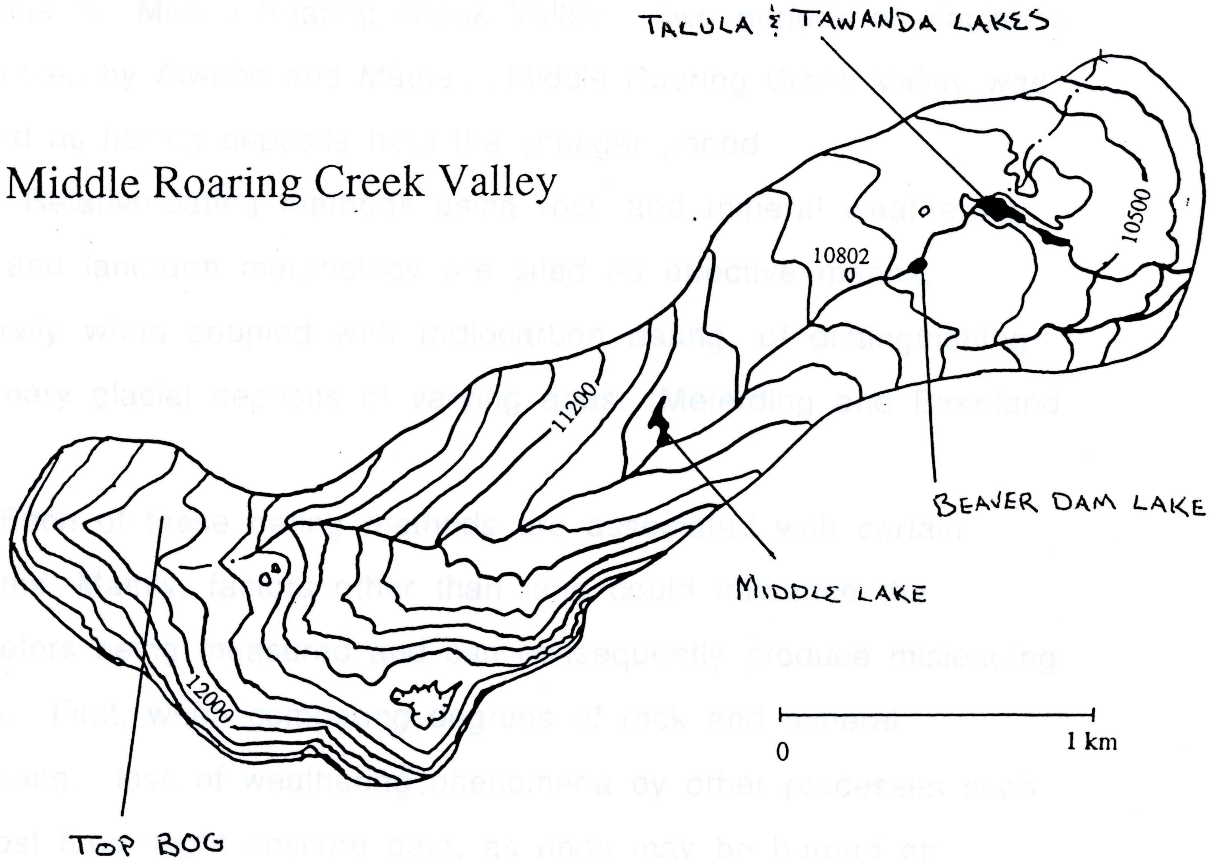


Figure 1: Middle Roaring Creek Valley Topography

PREVIOUS WORK

Atwood and Mather (1932) documented ice limits and flow directions of the latest Pleistocene ice in the San Juan Mountains. The study was extensive, but contained only general boundaries of ice limits in Middle Roaring Creek Valley. Two periods of glaciation were noted by Atwood and Mather. Middle Roaring Creek Valley was mapped as having deposits from the younger period.

Relative-dating methods using rock and mineral weathering, soils, and landform morphology are sited as effective means, especially when coupled with radiocarbon dating, of distinguishing quaternary glacial deposits of varying ages. (Meierding and Birkeland 1980)

Each of these dating methods are associated with certain problems. Mainly, factors other than time could influence the parameters being measured and can consequently produce misleading results. First, when comparing degrees of rock and mineral weathering, loss of weathering phenomena by other processes such as forest fires might obscure data, as rinds may be burned off. Erosion of soil surfaces as well as younger deposition from slopewash or eolian transport might influence soil profiles from region to region. Finally, uncertainty of original shapes of deposits such as moraines, and variation from region to region in weathering rates may detrimentally effect comparisons of landforms for relative dating (Meierding and Birkeland, 1980)

Three major epoches of Quaternary glaciation have been identified from Colorado glacial deposits,. Bull Lake, Pinedale, and

Holocene. (Richmond, 1960). Bull Lake deposits are characterized as being slightly more extensive than Pinedale glaciers with rounded crests and subdued sides. Boulders on Bull Lake deposits are more weathered and fewer in frequency than those of Pinedale boulders. Bull Lake soils show great amounts of clay in the B horizons, and loess is often present in A horizons (Miller, 1979). The age of Bull Lake deposits is estimated at 140,000 years BP.

Pinedale moraines show steep sides and sharp crests. Boulder frequency is high, and soils vary in apparent degree of development, particularly in higher elevations (Miller, 1979). Pinedale deposits are estimated to be between >30,000 and 14,000 years old with Pinedale ice receding from the cirques by 10,000 years BP.

Holocene glacial deposits are not uncommon in Colorado. Most of these deposits, though, especially in ranges outside of the Rockies, are dated as early Holocene. Periglacial depositional events of the late Quaternary in Colorado are summarized by Benedict (1967) and Morris (1987) and divided into three separate events, 1) early Neoglacial 4500-2500 BP, 2) middle Neoglacial 1900-1000 BP, and Little Ice Age 350-150 BP. Soils and weathering data distinguished these deposits from those of Pinedale age glaciers.

Field Observations

A geomorphic map a 1:24,000 scale of major features in Middle Roaring Creek Valley was compiled based on morphology, the presence or absence of diamictons, boulders, and/or stratified soils, and aerial photography (Figure 2). In general the valley can be divided into three main zones of differing characteristic topography. Beginning at the bottom of the valley, Zone One contains the terminal limit of ice in the valley as well as an area of ice stagnation features located behind it. Zone two is composed of a series of defined "steps" up the valley terminating just above Middle Lake. Zone three is the area above Middle Lake containing various rock-glacier like features and abundant post-glaciation talus within the cirque (Figure 3).

Geomorphic features such as terminal and recessional moraines, which are normally associated with the glaciation of an individual glacier system, were easily recognized and mapped in Middle Roaring Creek Valley. The valley contained, however, a variety of peculiarities which could either have been a direct product of glaciation, or a product of subsequent erosion through fluvial events. The following is a more detailed description of the valley and its features

Zone One

The terminal limit of ice in the northeast end of the valley is represented by a broad complex of nested moraines at 10,500 ft, rather than one large moraine. The ridges in this terminal moraine complex slope steeply off on the northeast side reaching

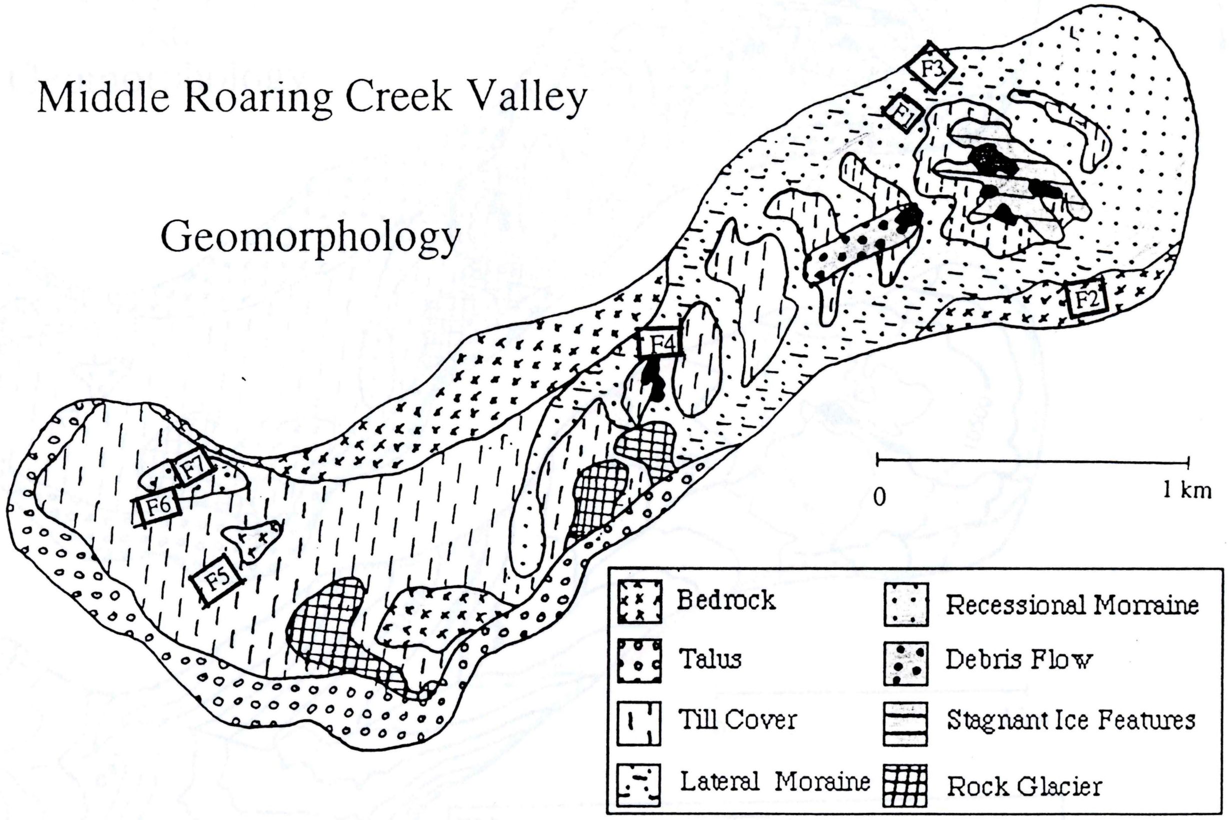


Figure 2: Middle Roaring Creek Valley Geomorphology

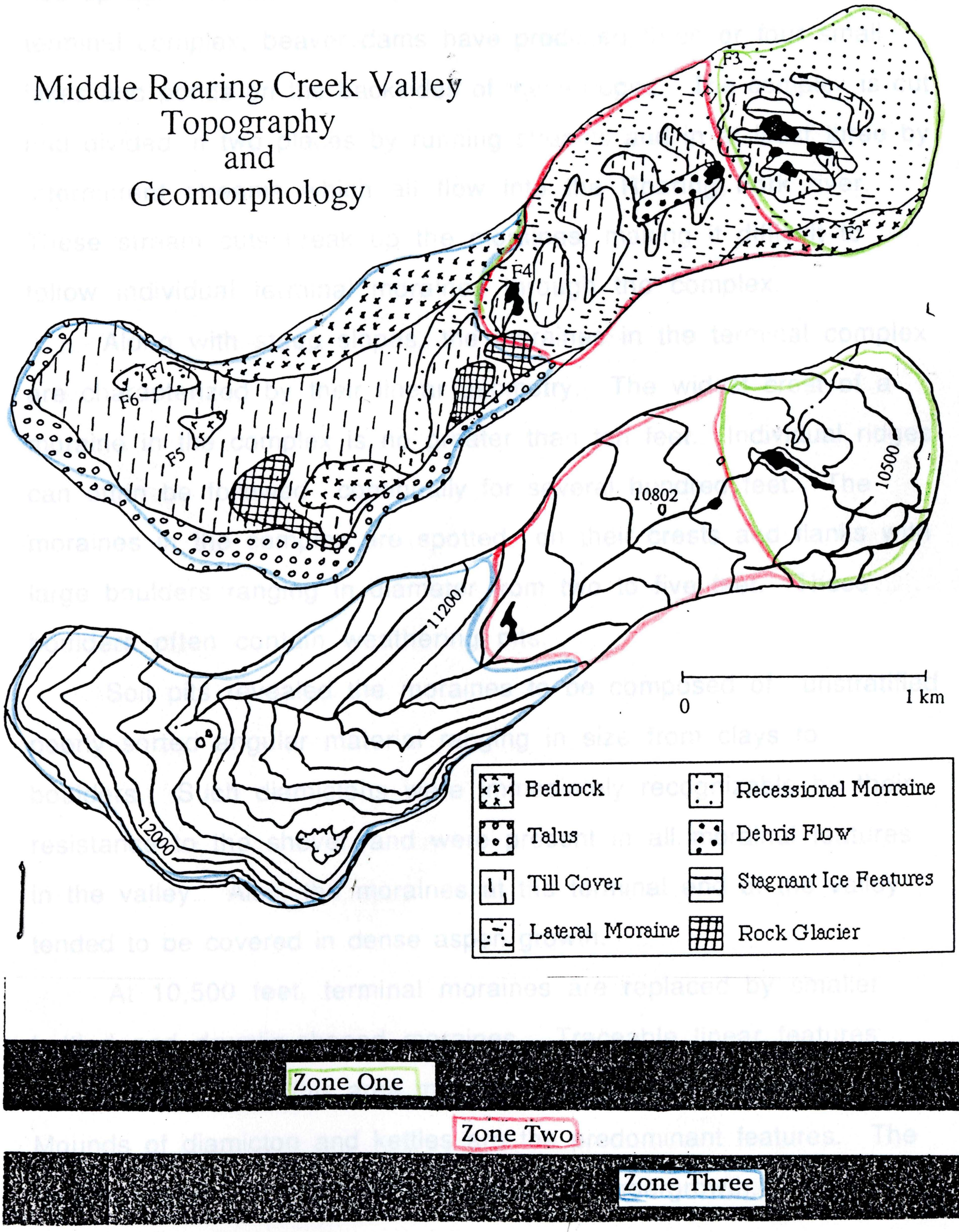


Figure 3: Middle Roaring Creek Valley, Zones 1, 2, and 3.

approximately 10,320 ft. The backside of the ridges in the complex, though steeply sloping, fall slightly in elevation, 5 to 10 ft, only to rise up again to the next ridge. Around 10,400 ft. in the east of the terminal complex, beaver dams have produced three or four small lakes and ponds on the backsides of these ridges. The complex is cut and divided in two places by running streams and in at least three by intermittent streams which all flow into the Roaring Fork river. These stream cuts break up the moraines, making it difficult to follow individual terminal moraines through the complex.

Along with steep slopes, the moraines in the terminal complex are characterized by their linear geometry. The widest crest of a moraine in the complex is no greater than ten feet. Individual ridges can often be followed continually for several hundred feet. The moraines in the complex are spotted on their crests and flanks with large boulders ranging in diameter from two to five feet. These boulders often contain weathering pits.

Soil pits revealed the moraines to be composed of unstratified poorly sorted angular material ranging in size from clays to boulders. Such diamictons were immediately recognizable by their resistance to the shovel, and were present in all morainal features in the valley. Also, the moraines at the terminal end of the valley tended to be covered in dense aspen growth.

At 10,500 feet, terminal moraines are replaced by smaller kettled and drumlin-shaped moraines. Traceable linear features cannot be found in this area making the topography confusing. Mounds of diamicton and kettles are the predominant features. The kettles, round, flat depressions covered in undergrowth, range in size from ten feet in diameter to 100-150 feet in diameter. The mounds, though at times somewhat linear and paralleling the strike of the valley, are sporadic, with low slopes and moderate boulder coverage.

Kettled moraines then grade into a relatively large area of ice stagnation features at 10,600 ft. This area, approximately .75 square km in size, includes belts of ice contact stratified drift (ICSD) as well as at least two eskers (Figure 4). It is characterized by a subdued topography of small hills and depressions, often in the form of lakes and marshy land. Digging soil pits in the sides of these hills showed a typical stratigraphy of, first, about 50 cm of glacial till. Below this layer, a thick section of stratified, fining upward sands and muds containing rounded cobbles could be found (Figure 5). A north-south orientation of larger cobbles is apparent in some of the hills. Two of these ICSD features seemed to meander down-valley suggesting that they are eskers, which are deposits of streams flowing under stagnant ice, carrying sands and cobbles which have melted out of the glaciers from further up valley.

Distinct lateral moraines border the ice stagnation zone to the northeast and southwest. These lateral moraines are similar to the terminal moraines described earlier in that they are steeply sloping and decrease dramatically in elevation towards the outside of the valley while only slightly towards the inside of the valley. They are covered in large boulders and aspens and are composed of diamicton. These prominent moraines begin at the nose of a bedrock ridge

Figure 4: Icsd Area, Zone 1.

Figure 5: Soil pit dug in ICSD mound.

farther up valley near Middle Lake at 11,000 ft. and continue down valley merging with the terminal moraines below the kettled area of Zone one.

A small terrace, which is possibly an older moraine, borders the main lateral moraine in the northwest. This terrace is approximately twenty feet in width and is continuous for about two hundred feet. It is covered in small to medium sized boulders and has a gentle slope out of the valley. To the southeast of the valley, what appeared to be the pair to this "older" moraine is actually bedrock that marks a valley boundary. No large boulders or diamictic material were found in the pit dug on this feature.

Zone Two

Above the ICSD region, the topography of Middle Roaring Creek Valley progresses from the rolling hills and kettles of the ice stagnation area into a series of "steps" visible in air photos and obvious when walking up valley. This zone continues from 10,700 ft up to 11,100 ft. with five steps between the ICSD area and Middle Lake. Steps one, four, and five are recessional moraines. Each of these steps consists of one large linear ridge cutting across the valley, backed by mounds and kettles similar to those in Zone One. Boulder coverage on these moraines is mixed in size and more extensive than down valley. Steps two and three appear to be partially till-covered bedrock. Boulder coverage on these steps is large in size and extensive, with some of the larger boulders possibly being outcrops. Also, steps two and three lack the steep, well defined, linear appearance of the moraines.

Along the southwest side of the valley from Middle Lake is a series of boulder fields, each correlating in elevation with the morainal ridge of a step in the valley. The fields are approximately two hundred feet in width with boulders ranging in diameter from one to four feet. The block fields often show signs of ice-patterned ground with polygonal weathering of boulders reducing in grain size towards their centers (Figure 6). The stream that flows from Middle Lake, often flows beneath these block fields, reappearing as small bogs and ponds at the base of the step upon which the block fields lie. A large debris flow with visible levees extends from step three at approximately 10,800 ft. in the center of the valley down to Beaver Dam Lake at 10,700 ft. Though the material making up the flow feature was similar to that of the moraines, it was somewhat coarser and contained less silt and clay sized sediment.

The lateral moraines that boarder the ICSD region of Zone One continue up through Zone Two becoming somewhat broader until 11,000 ft.
where they terminate into bedrock ridges on both the northwest and southeast sides of the valley. At this elevation, the valley narrows dramatically, and is contained by the bedrock. Small lateral moraines appear at the elevation of Middle Lake. They appear to be pushed up against the bedrock ridges. These lateral moraines as well as the steps do not proceed in an obvious fashion much above 11,100 ft into Zone Three.

Figure 6: Block fields, Zone 2

Figure 7: Rock glaciers, Zone 3.

Zone Three

Zone three consists of the till-covered area above Middle Lake in Middle Roaring Creek Valley, as well as the cirque, the large broadening rectangular area at the top of the valley. There is a considerable rise in elevation from Middle Lake to the top of the cirque, approximately 1000 ft, but there are no large steps in Zone Three as there were in Zone Two. Instead, the floor of the valley rises gradually. In Zone Three, the stream that feeds Middle Lake forks into two or three smaller streams. Consequently the landscape is confusing, with small stream valleys within the main glaciated valley. The entire area is covered in boulders of all sizes.

The valley broadens and expands to the northwest around a bedrock knob at 11,800 ft. Small recessional and lateral moraines appear in the northwest corner of the valley where it broadens. The lateral moraines occur as a series of small linear ridges running parallel to the valley. There are two or three small recessional moraines in this area with one of the uppermost moraines damming off a small bog, Top Bog, at 11,800 ft. approximately fifty meters in diameter. A core was taken from its center for Carbon-14 dating. Another block field, similar to those in Zone Two boarders these moraines to the north.

The cirque of Middle Roaring Creek Valley is covered with talus cones, pro-talus ramparts and occasional indications of recent debris flows and avalanches, including levees, and marred vegetation. Talus slopes cover the southeast wall of the valley beginning as far into the valley as Middle Lake. The slopes do not appear on the northwest wall until above 12,000 ft. The talus coverage is greatest and most extensive on the far southwest wall of the valley. Most of the talus is covered in lichens, but fresh surfaces of rock can be found indicating that the slopes are still active.

Extending from the cirque in at least three areas are large lobate structures that resemble small rock glaciers. These features resemble block fields in proximity, but have a definite lobe shape when viewed from a distance (Figure 7). The noses of these rock-glaciers rise as much as 15 feet off of the floor of the valley, and slope off at angles of greater than 40-45 degrees. Evidence of solifluction is visible around the edges of the features in some areas. Three of these lobes are found on the southeast wall of the cirque just above Middle Lake, and one larger, possibly compound feature of more than one rock glacier, is located in the southwest end of the cirque. A more detailed description of the cirque in Middle Roaring Creek Valley, as well as of the ICSD region mentioned earlier may be obtained from the work of Eric Jenson or Eric Small, respectively (KECK, San Juans Project, 1993).

Methods and results

Relative ages of the mapped prominent features of Middle Roaring Creek Valley were investigated in order to evaluate the consideration of one or more readvances of ice into the valley. Even if only one advance of ice had occured in the valley, the most likely difference in ages would be found between the small moraines found in the cirque of the valley which would have been deposited by the last retreat of ice, and the complex of terminal moraines in the northeast which would have been deposited by the furthest advance. The small moraine to the northwest of the lateral moraine in Zone One was of interest as an older deposit than that of those of the terminal moraines. The bedrock hill to the southeast of Zone One, though originally of interest as the sister to the small "older" moraine, became a control feature, whose age was not necessarily associated with the glaciation of Middle Roaring Creek Valley.

Ultimately seven features (F1-F7) in the valley were chosen for analysis by relative dating (Locations spotted on Figure 2).

F1 - Northwest main lateral moraine associated with terminal limits of ice

F2 - Bedrock hill marking the southeast border of the valley

F3 - The "older" moraine bordering the northwest main lateral moraine

F4 - Moraine below Middle Lake, elevation 10,990 ft, on top of Step 5.

F5 - Moraine below West Bog, elevation 11,980 ft.

F6 - Southwestern most lateral moraine in the northwest corner of the cirque

F7 - Highest lateral moraine near West Bog

It was decided that analysis of boulder frequency, weathering rinds, slope profiles, and soil development would prove the most effective for obtaining relative ages of the features. These analyses were chosen for comparison, as data concerning them was simply obtained and available on all features in question. Boulder frequency, weathering rind, and slope data were also collected from other moraines and block fields throughout the valley.

Boulder Frequency

Boulder frequency data was collected with the expectation of finding fewer boulders on older moraines due to weathering and erosion (Miller 1979). With time, smaller boulders weather and fragment into cobbles, leaving behind a coverage of only larger erratics. Older moraines would be expected to show not only less boulder coverage, but also fewer small boulders. Frequency was gauged on a scale of 0 to 5 with "0" being an area of no boulder coverage, and "5" being an area complete boulder coverage. Associated with each number is a letter, S, M, L, N. "S" if the majority of boulders on a feature were less that 30 cm; "L" if the majority were greater than 30 cm; "M" if the boulders were of mixed sizes; and "N" for no boulders. This measurement of 30 cm was chosen on the basis of an average size boulder in the valley.

In general boulder frequency and the number of smaller boulders present on top of moraines increase up valley. Large boulders were found throughout the valley (Figure 8). The terminal moraine complex (Figure 8, F1) was covered in predominantly very large erratics, and showed a somewhat clean ground cover with few if any small sized boulders. Eskers and mounds in the ICSD area had sparce boulder covering of mixed sizes. The steps in Zone Two showed, if they were moraines, somewhat extensive mixed coverage.(Figure 8, F4). The steps which were considered to be bedrock were thickly covered in boulders, both extremely large and measurable in meters as well as small in size. The debris flow was also relatively thickly covered with small sized boulders. Rising in elevation into Zone Three of the valley, the number of small sized boulders with respect to large ones increased. The block fields and rock glaciers were almost entirely large boulders with no soil development.

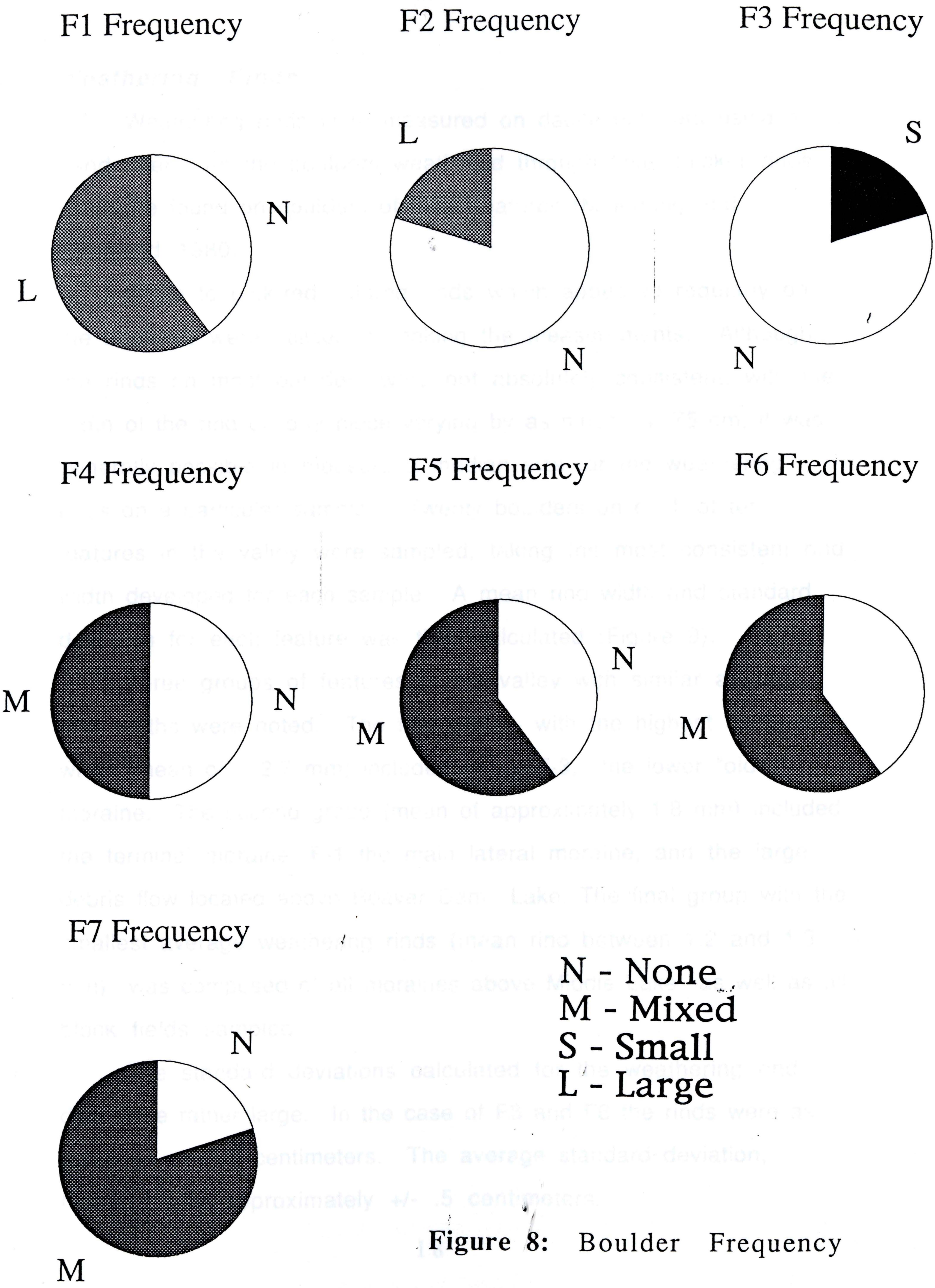


Figure 8: Boulder Frequency

Weathering Rinds

Weathering rinds were measured on dacite boulders using a hand ruler. As the boulders weathered through time, thicker rinds would be found on boulders of older features (Meierding and Birkeland 1980).

White to pink-red colored rinds which appeared regularly on the boulders were utilized in making the measurements. Although the rinds on most boulders were not absolutely consistent, with the width of the rind on one piece varying by as much as .75 cm, it was generally possible to measure a median size for the weathering rinds on a particular sample. Twenty boulders on each of ten features in the valley were sampled, taking the most consistent rind width developed for each sample. A mean rind width and standard deviation for each feature was then calculated (Figure 9).

Three groups of features in the valley with similar average rind widths were noted. The first group with the highest mean rind width (mean of 2.7 mm) included solely F-3, the lower "older" moraine. The second group (mean of approximately 1.8 mm) included the terminal moraine, F-1 the main lateral moraine, and the large debris flow located above Beaver Dam Lake. The final group with the smallest average weathering rinds (mean rind between 1.2 and 1.3 mm) was composed of all moraines above Middle Lake as well as all block fields sampled.

The standard deviations calculated for the weathering rind data were rather large. In the case of F3 and F6 the rinds were as much as +/- 1.2 centimeters. The average standard deviation, however was approximately +/- .5 centimeters.

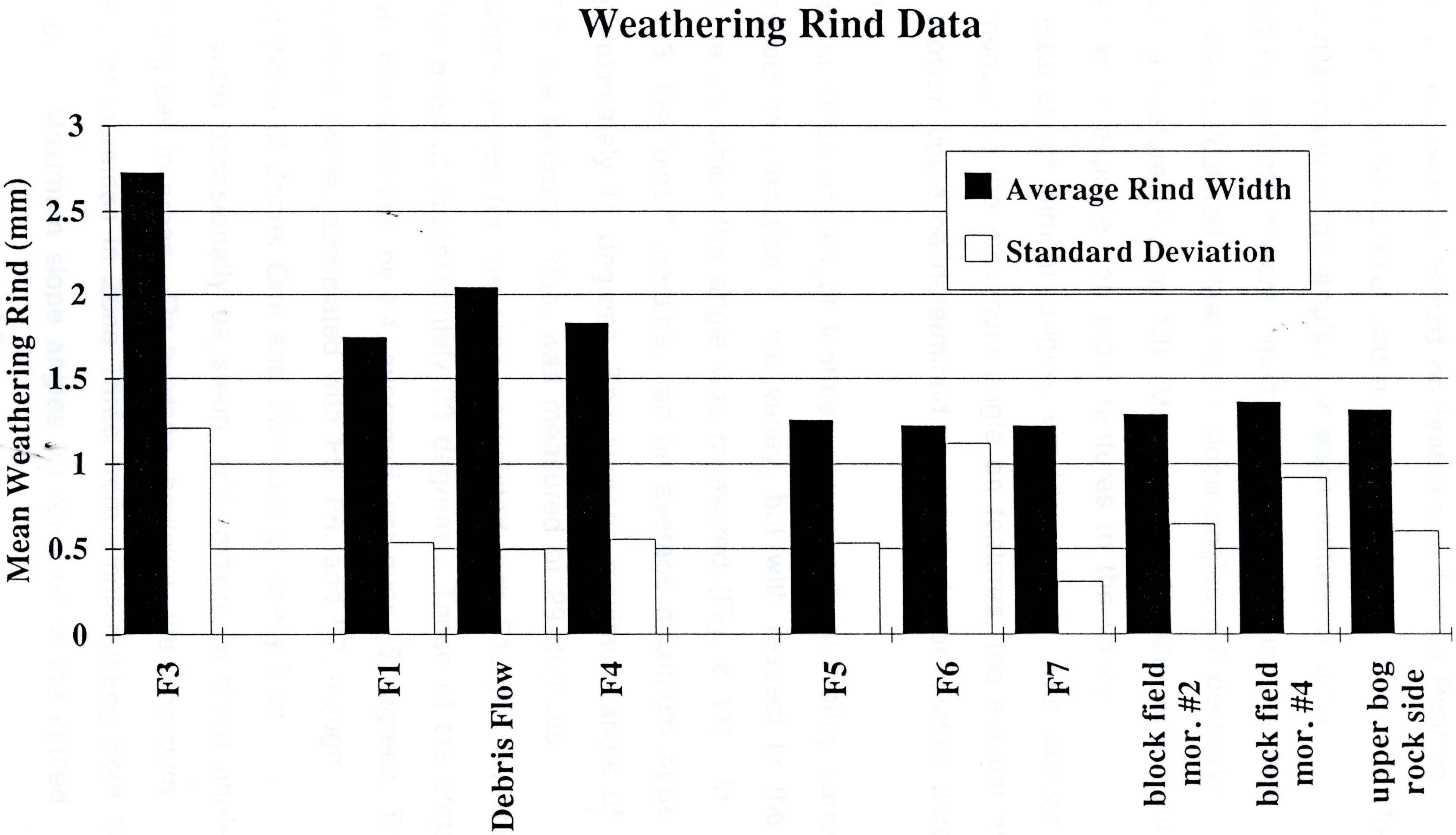


Figure 9: Average weathering rind width; three groups of similar average rinds.

Slope Profiles

Slope angles were measured on features in Middle Roaring Creek Valley using a hand level and a measuring tape. Several of the approximate maximum slope angles for each feature or area characterized by a feature were noted, and the average maximum slope angle was calculated. Maximum slope angles will decrease with time on a feature (Figure 10) (Miller 1979). Smaller maximum slope angles were expected on older features in the valley. Assuming features of similar origins would originate with similar angles, by measuring the maximum angle on features, the amount of change by erosion could be determined, and a basis for relative dates established.

Maximum slope angles of features throughout the valley varied, not with respect to elevation in the valley, but with respect to the type of feature for which the angle was measured (Figure 11). In Zone One, F-3, the "older" moraine, had an average maximum slope angle of approximately 11 degrees. The average maximum angle of slope for F-2, the bedrock ridge, was measured at 29 degrees. Maximum slope angles for the area associated with F1, the terminal moraines, averaged at approximately 23 degrees. Those of the steps in Zone Two, characterized by F4, averaged just over 25 degrees. The moraines in Zone Three, associated with F5, F6, and F7, though smaller than those of Zones One and Two and generally less continuous, were occasionally as steep, with maximum slope angles of up to 22 degrees in areas. On average, however, the maximum slope angles for moraines in Zone Three were small ranging from 10 to 12 degrees. Maximum slope angles for features in the kettled areas of Zone One and Two and the ICSD area averaged at around 12 degrees. The maximum slope angles for the rock glaciers and talus slopes of Zone Three averaged 45 degrees.

With a partner, slope profiles of lines going both up-valley and across-valley were completed for Zone One and the northwest edge of Zone Two up onto the bedrock ridge (Figure 12). Terminal moraines and lateral moraines in Zone One are marked by obvious increases in relief, while the kettles and ICSD region are more subdued. The line surveyed in Zone Two runs predominantly up and along the side of bedrock ridge on the boarder of the valley. The small ridges apparent near the bottom of the profile are perhaps areas where moraines were deposited up onto the ridge, as some of them did appear linear and morainal in shape.

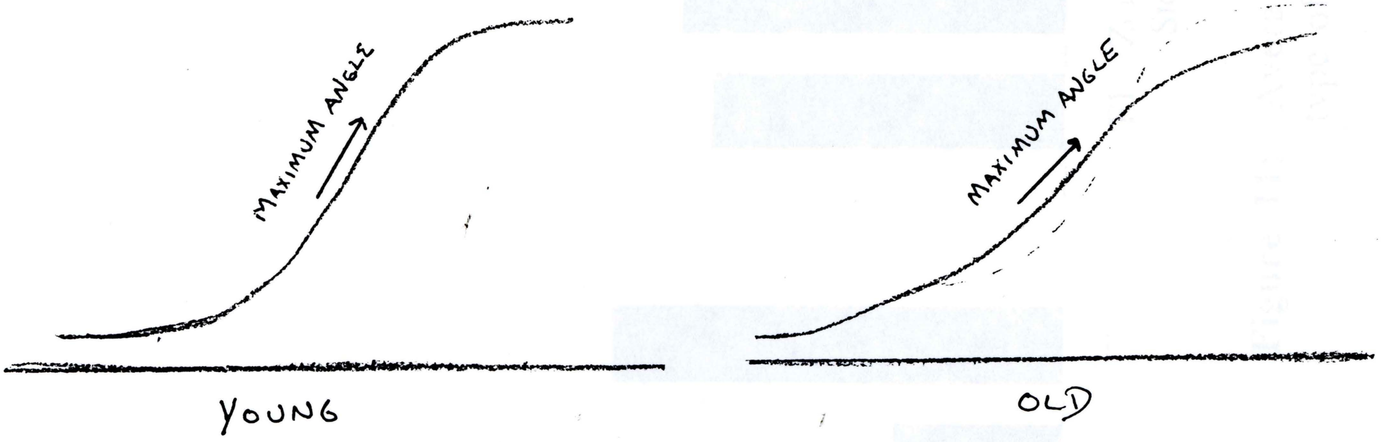


Figure 10: Maximum slope angles on a hillslope through time.

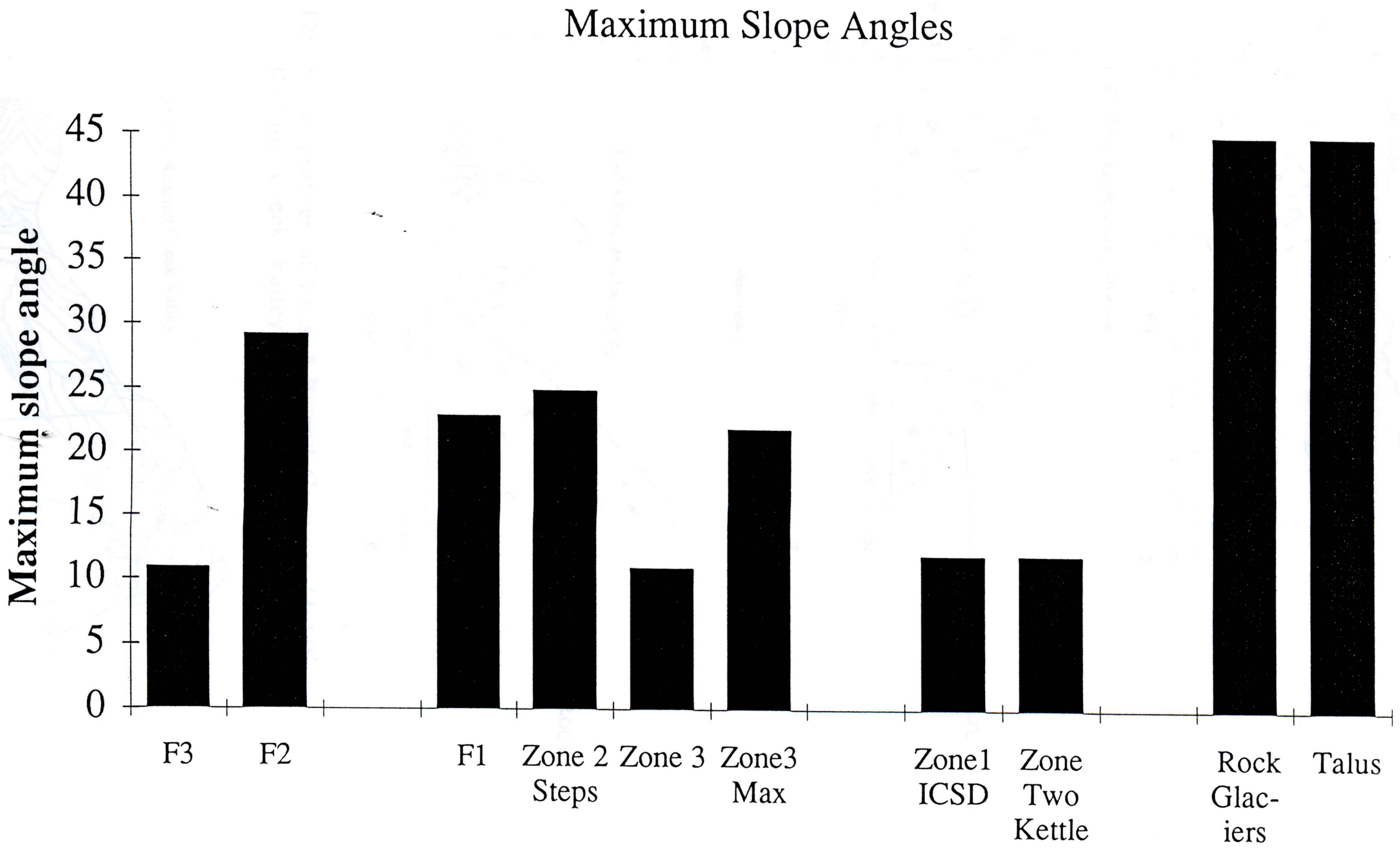


Figure 11: Average maximum slope angles grouped by type of feature.

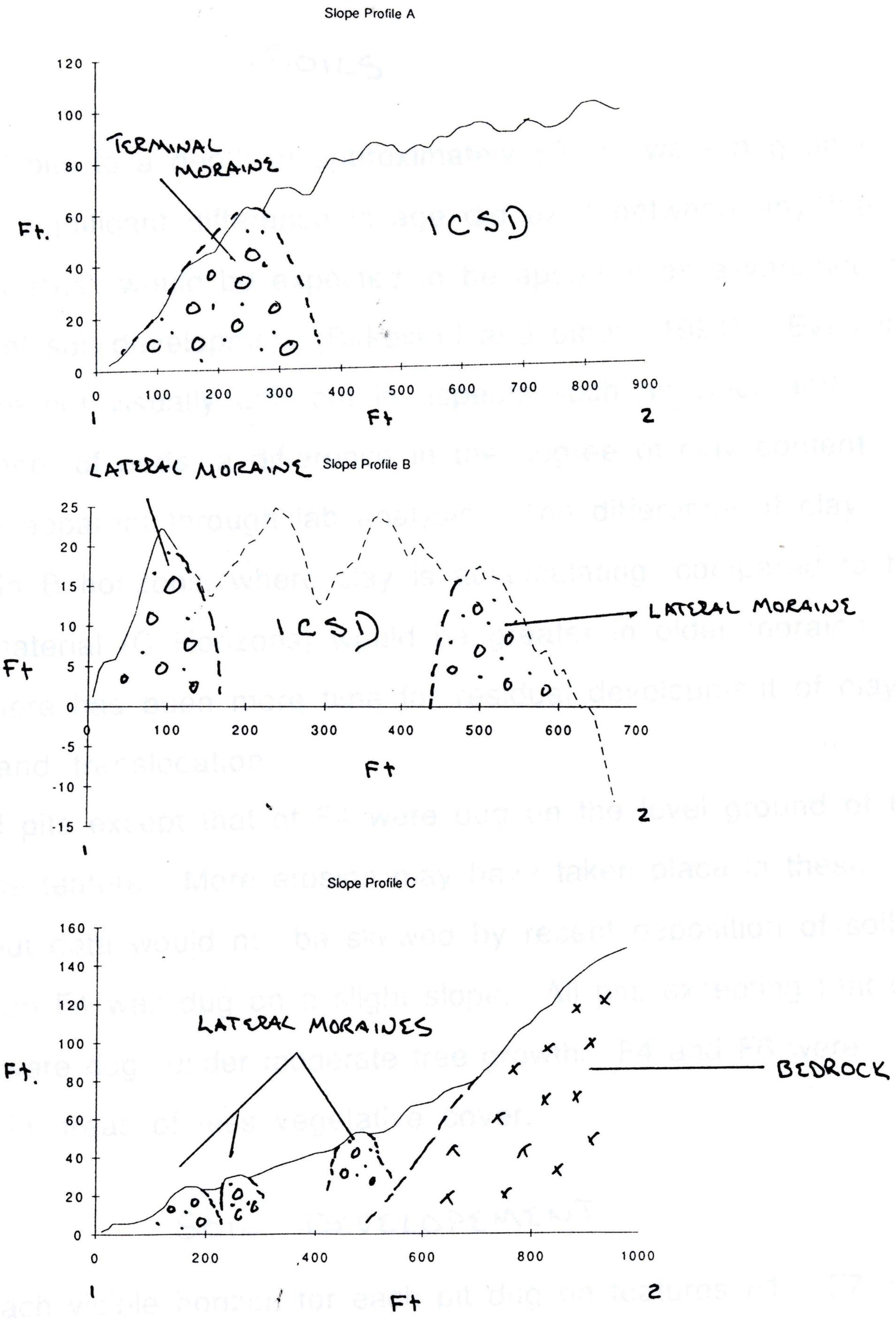
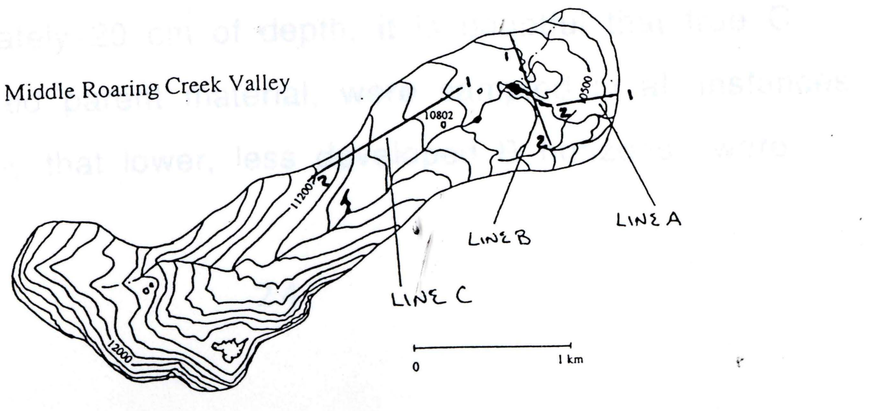


Figure 12: Slope profiles of lines A,B, and C across Middle Roaring Creek Valley.



SOILS

Soil pits to a depth of approximately 60 cm were dug on F-1 - F7. If a significant difference in age did exist between any features, the differences would be expected to be apparent as a variance of degrees of soil development (Birkeland and others 1991). Even if the soils were not visually different in aspects such as color and development of peds, a difference in the degree of clay content might be apparent through lab analysis. The difference of clay content in B horizons, where clay is accumulating, compared to the parent material (C Horizons) would be greater in older moraines where there has been more time for residual development of clays by mixing and translocation.

All pits except that of F4 were dug on the level ground of the top of the feature. More erosion may have taken place in these areas, but data would not be skewed by recent deposition of soils. The pit on F4 was dug on a slight slope. All pits excepting that of F4 and F6 were dug under moderate tree growth. F4 and F6 were located in areas of less vegetative cover.

SOIL DEVELOPEMENT

Each visible horizon for each pit dug on features F1 - F7 was first described and then sampled for further analysis in the lab (Figure 13). Though discernable B horizons were reached within all pits at approximately 20 cm of depth, it is doubtful that true C horizons, unaltered parent material, were sampled in all instances. Rather, it is likely that lower, less developed B horizons were sampled beginning at a depth generally of 30 cm. All B and C horizons showed weak blocky structure and 2 to 3 cm peds.

Soil color of dry samples was determined for each horizon of features F1- F7 using the Munsell system of color identification. Hues of color are designated by numbers and letters such as 5YR and 10YR (yellow red). A ratio of values, light to dark, versus chroma, degree of saturation, is associated with each hue, where the larger the numbers, the lighter the value, the more vivid and less grey the chroma (Rock-Color Chart Committee, 1980).

Of the soils sampled, those in Zone three, F5,F6, and F7, showed, in general, the highest Munsell numbers, that is, darkest and most vivid coloring. The B and C horizons of these soils were reddish orange in color. The colors of soils in Zones One and Two showed smaller Munsell colors. They were lighter and more grey in color than those of F5, F6, and F7. These results are backwards from what is expected, as older soils generally show more color development. Little other variation in color existed between soils.

Soil Developement Characteristics

Soils F1 - F7

SOIL	DEPTH TO BOTTOM OF HORIZON (CM)	GRAVEL %	STRUCTURE	DRY COLOR	PEDS (CM)
F1 - A	19	5	Weak Blocky	10yr 6/2	2
F1 - B	42	13	V. Weak Blocky	7.5yr 5/2	1
F1 - C	60+	10	Weak Blocky	10yr 6/2	1
F2 - A	17	5	Weak Blocky	10yr 2/1	1
F2 - B	45	7	Somewhat Weak Blocky	10yr 5/2	2
F2 - C	75+	7	Somewhat Weak Blocky	10yr 6/3	3
F3 - A	17	3	Weak Blocky	10yr 5/2	2
F3 - B	44	13	V. Weak Blocky	7.5yr 6/2	1.5
F3 - C	54+	10	Weak Blocky	10yr 6/3	1.5
F4 - A	12	30	Weak Blocky	10yr 6/1	2
F4 - B	49	15-20	Weak Blocky	10yr 5/2	3
F4 - C	60 +	10	Weak Blocky	10yr 6/2	3
F5 - A	26	5	Weak Blocky	10yr 3/2	3
F5 - B	49	10	Weak Blocky	10yr 5/4	1
F5 - C	75 +	15	Weak Blocky	10yr 5/4	0.5
F6 - A	17	5	Weak Blocky	7.5yr 4/2	3
F6 - B	32	13	Weak Blocky	10yr 4/3	2.5
F6 - C	45+	25	/. Weak/Somewhat Block	10yr 3/3	1
F7 - A	25	5	Weak Blocky	10yr 5/2	2.5
F7 - B	47	10	V. Weak Blocky	10yr 4/4	3
F7 - C	57+	25	V. Weak Blocky	10yr 6/3	1.5

Figure 13: Table of recorded soil developement characteristics

GRAIN SIZE ANAYSIS

Soil samples obtained from F1-F7 were analyzed for grain size in the lab. The A, B, and C horizons for each pit were first wet and dry sieved. The samples were prepared in the following manner. Each sample was first oven-dried, weighed, and run through a 2 mm sieve. That part of the sample less than 2 mm was then placed in a 1000+ cc beaker. A deflocculating agent, Sodiumhexametaphosphate, was used to disengage clay sized particles from larger particles and from each other. A solution was prepared by diluting 20 g of the agent in 1000 ml water. 125 cc's of this solution was added to the samples and this mixture was allowed to sit for 8-12 hours. Each mixture was then diluted to 1000 cc's with water, mixed thoroughly, and run through a silt size, .075 mm, wet sieve. That part of the solution which passed through the sieve was then returned to a clean beaker for hydrometer analysis.

That portion of the sample which was greater than .075 mm was then oven-dried, weighed, and dry sieved using a RO-TAP machine. A stack of five sieves, 1, .5, .25, .025, and .075 mm, was used. That part of the sample which was left on each sieve was weighed and this data was used to calculate the percent finer for each grain size. That part of the sample which passed through the .075 mm sieve, generally between 5 and 8 g, was also weighed and then added to the 1000+ beakers for analysis by hydrometer.

The portions of samples left in the beakers were then analyzed for clay size percentages using a hydrometer. Each beaker was first brought to 1000 cc's with water. Each sample was then thoroughly mixed using a blender. From the time the sample was returned to the beaker, readings were made from a hydrometer at the following intervals: 0.15 sec, 0.30 sec, 1 min, 2 min, 4 min, 8 min, 15 min, 30 min, 1 hr, 2 hr, 4 hr, 8 hr, 24 hr, and 48 hr. Using a control of water and deflocculating agent, a meniscus, zero, and temperature correction were noted. The data collected from these readings was then manipulated to calculate percent finer for grain sizes associated with each time interval (Das, 1989). These calculated percentages were used with those of the sieve data to calculate clay percentages, particles finer than .032 mm, in the soils sampled.

The differences of clay content in the A, B, and C horizons of the soils were compared expecting that the change in clay content over time between parent material and B horizons would be greater for older features. (Figure 14) Clay percentages versus depth were also considered (Figure 15). In general the depth of the A, B, and C horizons was similar for the features in question. F1, F2, F3, and F4, the terminal moraines, the bedrock ridge, the "older" moraine and the step, all showed relatively high clay percentages in both the B and the C horizons. Even though F4 and F1 had similar percentages for the A horizons, approximately 6%, and for the C horizons, approximately 4%, the clay percentage in the B horizon of F4 was extremely continuous and large, 18% compared to the 9% of F1. Both the B and C horizons of F2 and F3 contained very large percentages, 17% and 11%, and 7% and 10% respectively. The percentage of clay in the A horizon of F2 was minute at .14%, while that in F3 was large at 8%.

The clay percentages in the horizons of F5, F6, and F7 differed from those of F1 - F4 in that the percentages of clay in the B and C horizons of F5-F7 were small and the percentage of clay in the A horizons were great. The C horizons for all three features had clay percentages of less than 1%. The percentage of clay in the B horizons for features F6 and F7 was approximately 6%. That of F5 was 4%. The percentage of clay sized particles in the A horizons for features F5, F6, and F7 was considerable, ranging from 6% to 11%. The clay percentages in the A horizons relative to B horizons of soils in Zone Three were all unexpected high.

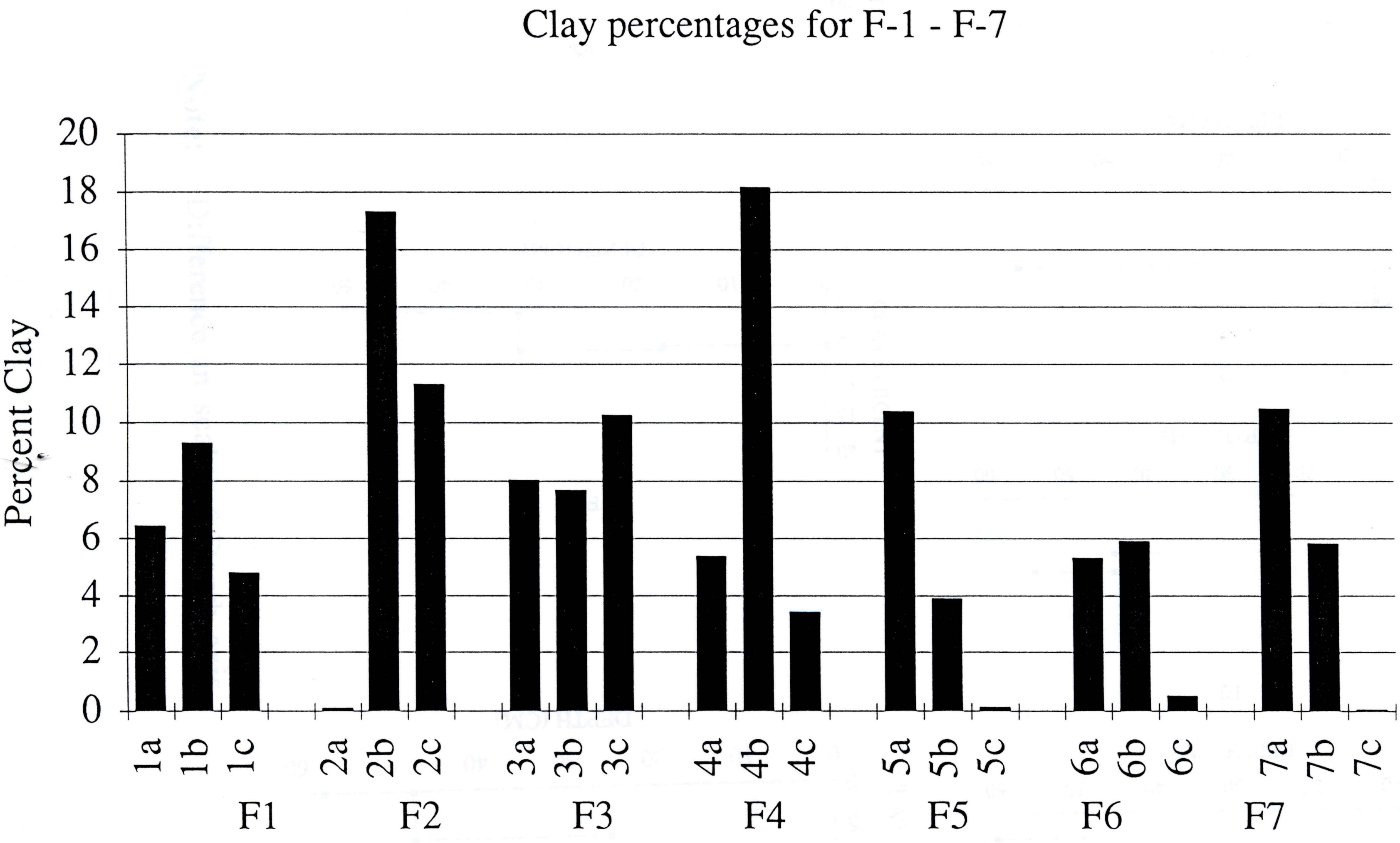
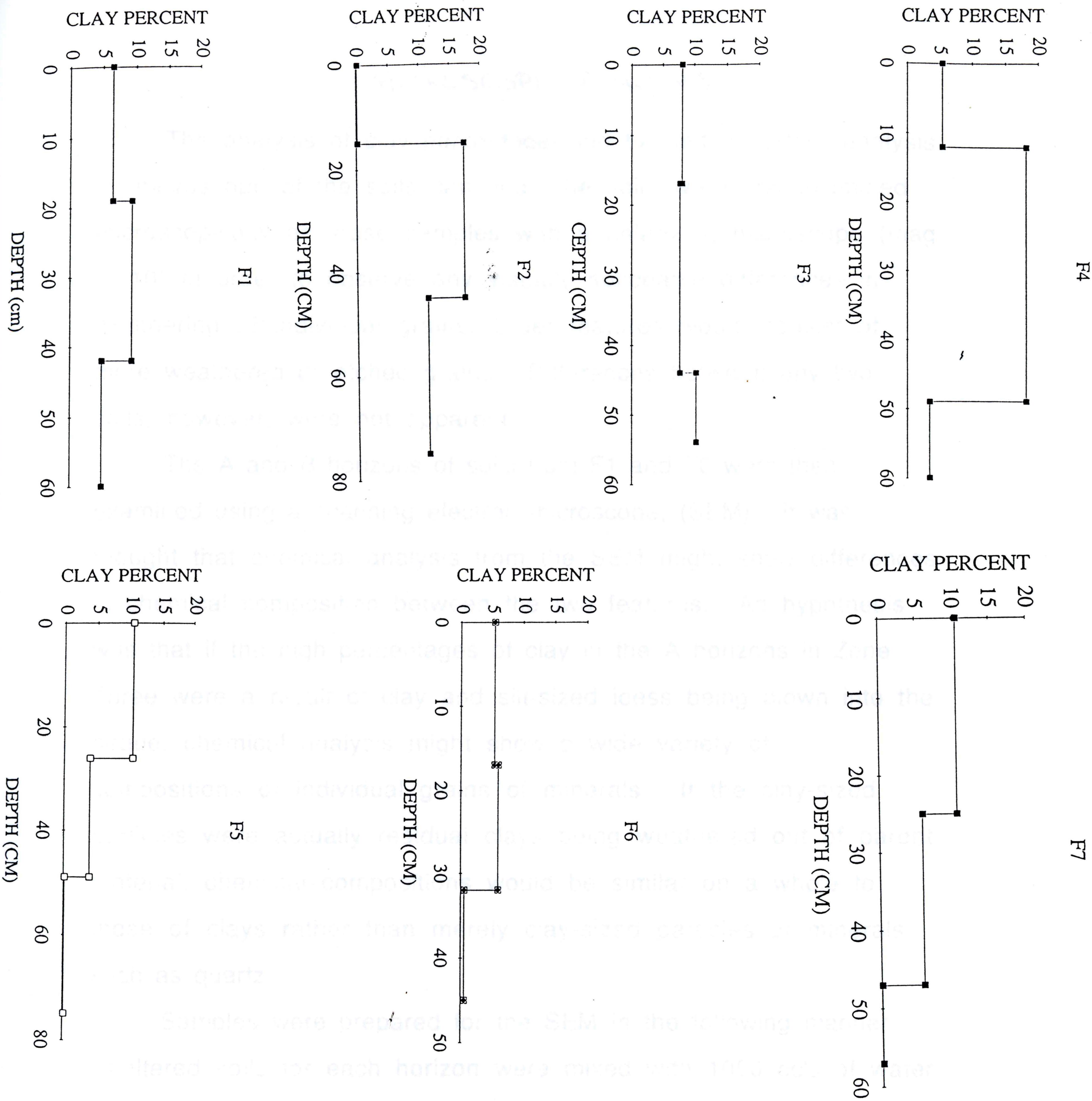


Figure14: Clay percentages, F1 - F7.



Note: Difference in scale of Depth axis

Figure 15: Clay percentage vs. depth.

MICROSCOPIC ANALYSIS

The analysis of clay percentages led to led to further analysis by microscope of the soils sampled. The soils were first examined microscopically as loose samples with a polarizing microscope (mag - x10) in order to observe any visually noticeable differences in weathering of individual grains. Older features would consist of more weathered or etched grains. Differences between any two soils, however, were not apparent.

The A and B horizons of soils from F1 and F6 were then examined using a scanning electron microscope, (SEM). It was thought that chemical analysis from the SEM might show differences in chemical composition between the two features. An hypothesis was that if the high percentages of clay in the A horizons in Zone Three were a result of clay and silt-sized loess being blown into the cirque, chemical analysis might show a wide variety of compositions of individual grains of minerals. If the clay-sized particles were actually residual clays being weathered out of parent material, chemical compositions would be similar on a whole to those of clays rather than merely clay-sized particles of minerals such as quartz.

Samples were prepared for the SEM in the following manner. Unaltered soils for each horizon were mixed with 1000 cc's of water in large beakers. This soil solution was then thoroughly mixed and allowed to settle for approximately 15 minutes. Using a pipette, a portion of the solution was transfered to a spot plate where it was allowed to dry. A small amount of the sample was then attached to aluminum stubs using double sided clear tape. Finally, the samples were coated with gold for analysis by the SEM.

Chemical analysis showed very little variation from sample to sample. All of the individual particles in each sample contained relatively large amounts of Si and Al, and trace amounts of Fe, Mg, K, and Ca. The presence Ca and Mg tended to vary from grain to grain. Overall the chemistry of all the soils sampled on the SEM were basically homogeneous with respect to these minerals.

Visual analysis of grain texture showed not only some differences between A horizons and B horizons for F1 as well as F6, but also differences between the overall textures of F1 and F6 (Figure 16, plates 1-4). Grains of the A horizon for F1 were clean with smooth surfaces and little if any plate-like attachments. The grains varied in shape from somewhat spherical to columnar, and all were relatively angular. Grains from the B horizon of F1 were almost invariably covered partially, if not completely, in small, 0.3 micron diameter plates which appeared on some grains to be weathering out of the larger, 20 - 30 micron diameter, individual grains. Other than the appearance of these plates, grains differed little from those of the A horizon.

Grains in the A horizon of F6 were different from those in F1. Where grains in the A horizon of F1 were subangular and not spherical, the grains in the A horizon of F6 were predominantly spherical. Also, their surfaces were irregular. Instead of built up plates, the grains seemed to contain pits or etched areas. The B horizon of F6 also contained some of these rounded grains, but it also contained many large grains similar to those of the B horizon of

F1. These grains are sub-rounded and show some of the plate build-up seen in the samples from F1.

Figure 16: SEM microphotographs of clay and silt size particles.

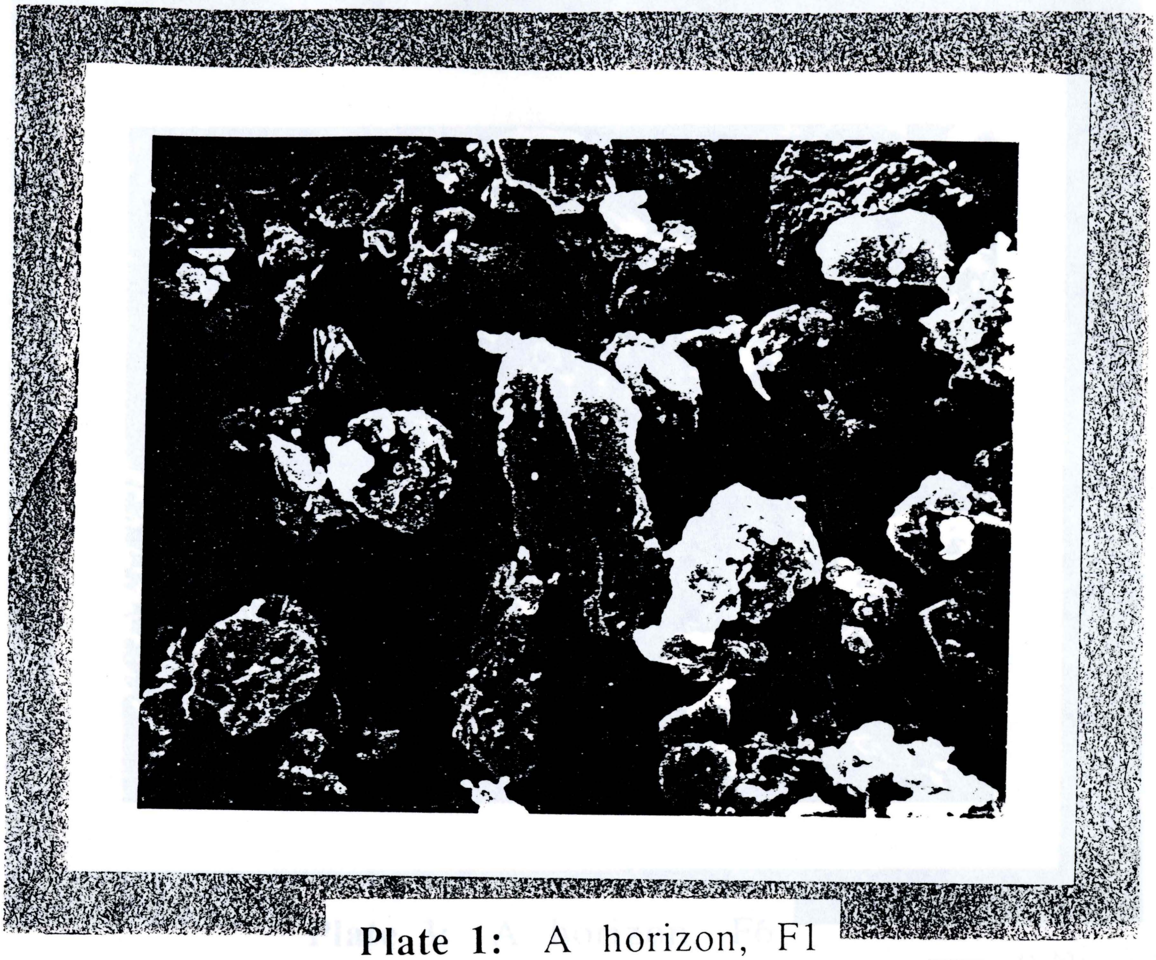


Plate 1: A horizon, F1

— 10 microns

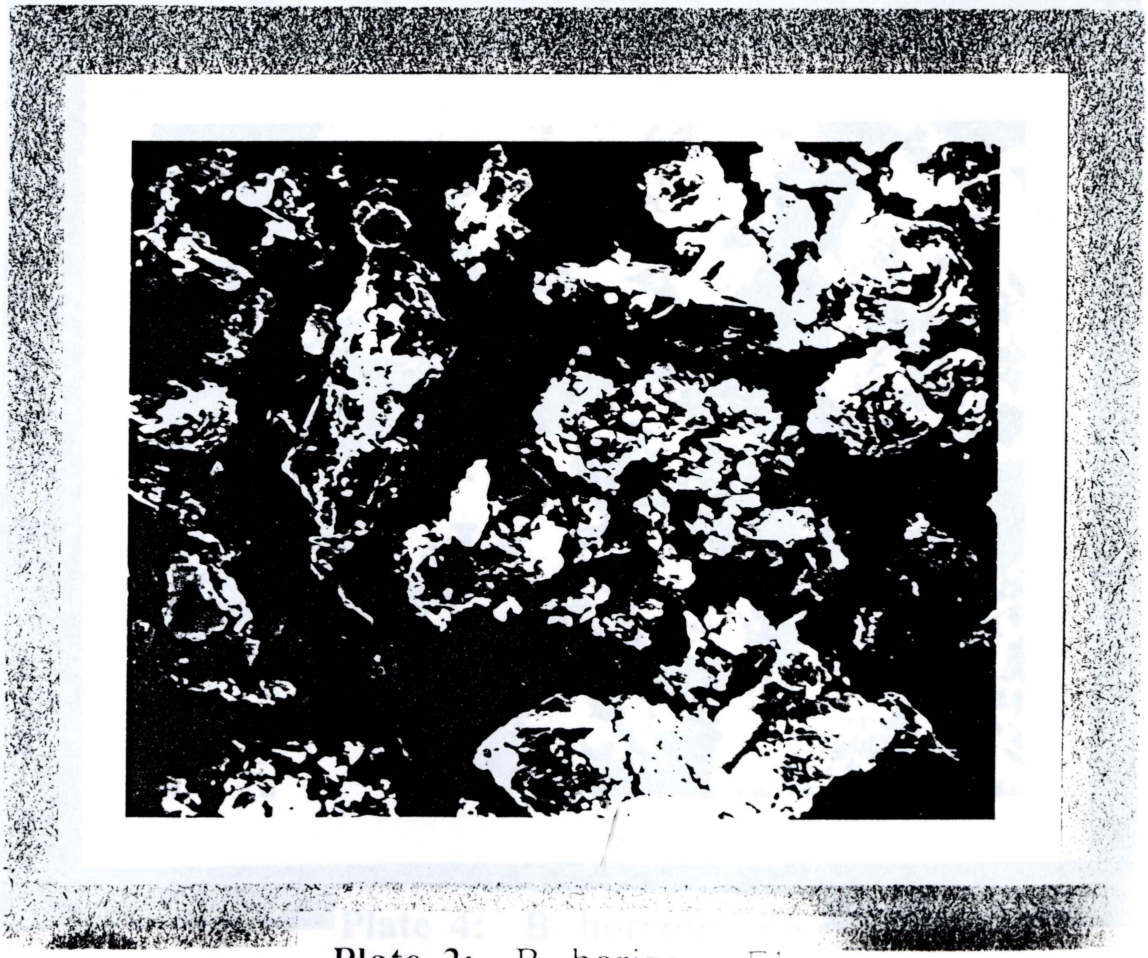


Plate 2: B horizon, F1

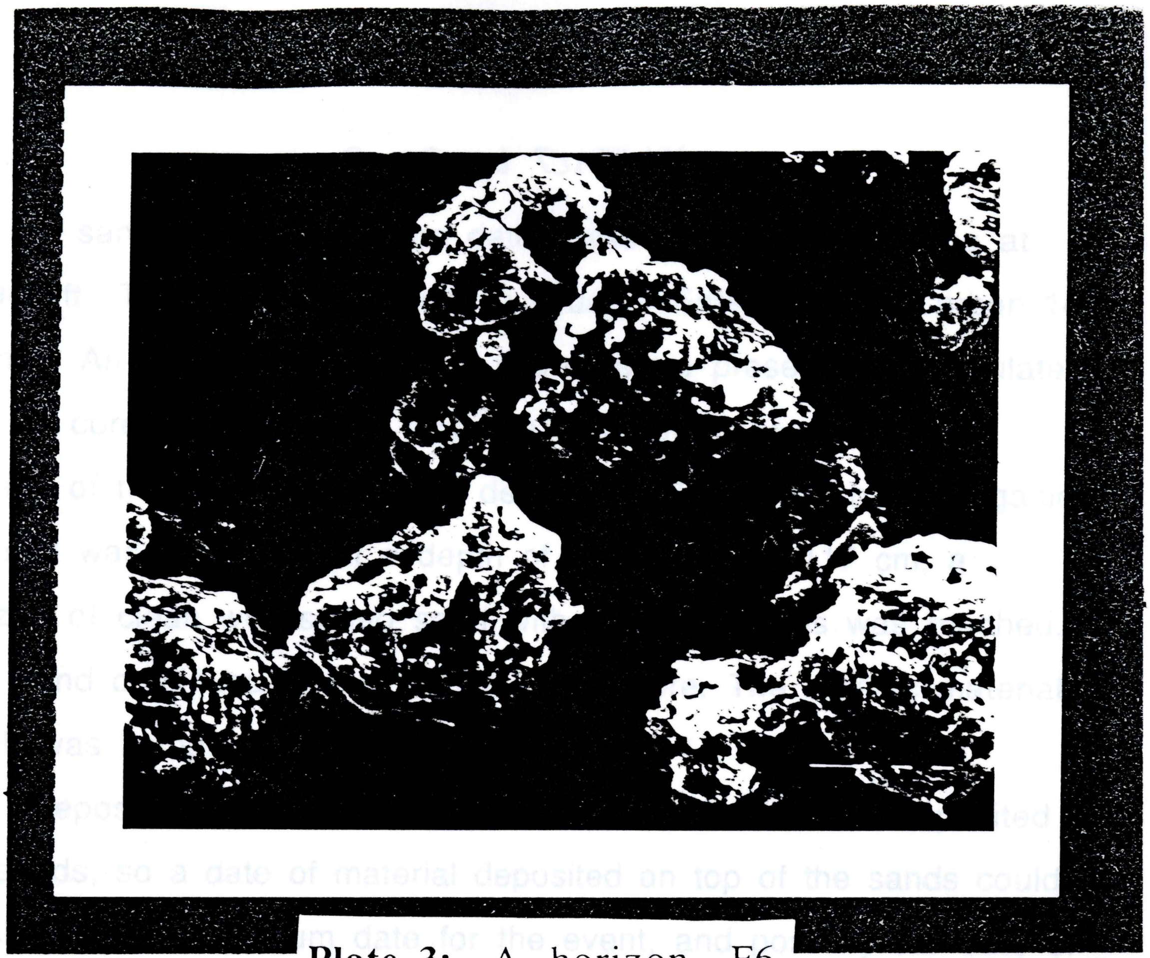


Plate 3: A horizon, F6

10 MICRONS

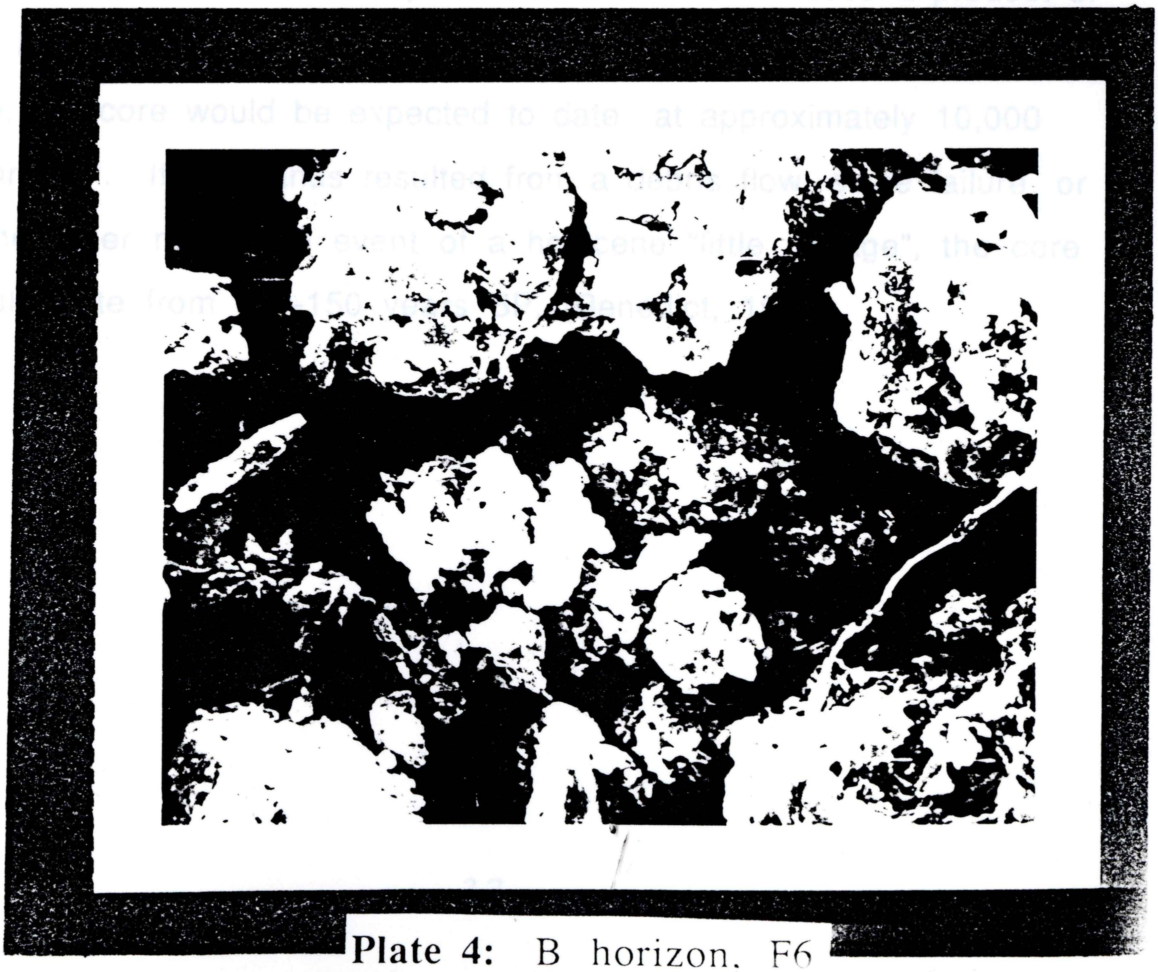


Plate 4: B horizon, F6

CARBON DATING

A sample for radiocarbon dating was taken from Top Bog at 11,940 ft The sample was sent to Crueger Enterprises of Carbon 14 dating. An age of 4705 +/- 155 years before present was calculated.

A core was dug in the bog to a depth of 191 cm. From the surface of the ground through a depth of 117 cm rich, black, organic material was augured. At a depth of approximately 117 cm, a horizon of clean well sorted sand with sparce cobbles was reached. This sand continued to the bottom of the core. The organic material which was sampled was taken from 114 to 117 cm.

Deposition would have begun after the event which deposited the sands, so a date of material deposited on top of the sands could possibly give a minimum date for the event, and possibly the date of retreat of ice from the valley. If the sands were indeed a product of the last retreat of glacial ice from the valley, perhaps Pinedale in age, the core would be expected to date at approximately 10,000 Years BP. If the sands resulted from a debris flow, slope failure, or some other neoglacial event of a holocene "little ice-age", the core would date from 350-150 years BP. (Benedict, 1967)

DISCUSSION

Morphological observations as well as relative-dating techniques suggest that Middle Roaring Creek Valley divides into three areas (G1, G2, and G3) of decreasing age which are not necessarily associated with the three zones of differing topography described earlier (Figure 17). The marked differences in relative ages of features suggests that the regions were indeed the result of three separate periods of glaciation in the valley. The nature of the differences between the areas is similar to those sited by Meierding and Birkeland (1980) as being typical of differences between Bull Lake, Pinedale, and Holocene glacial periods.

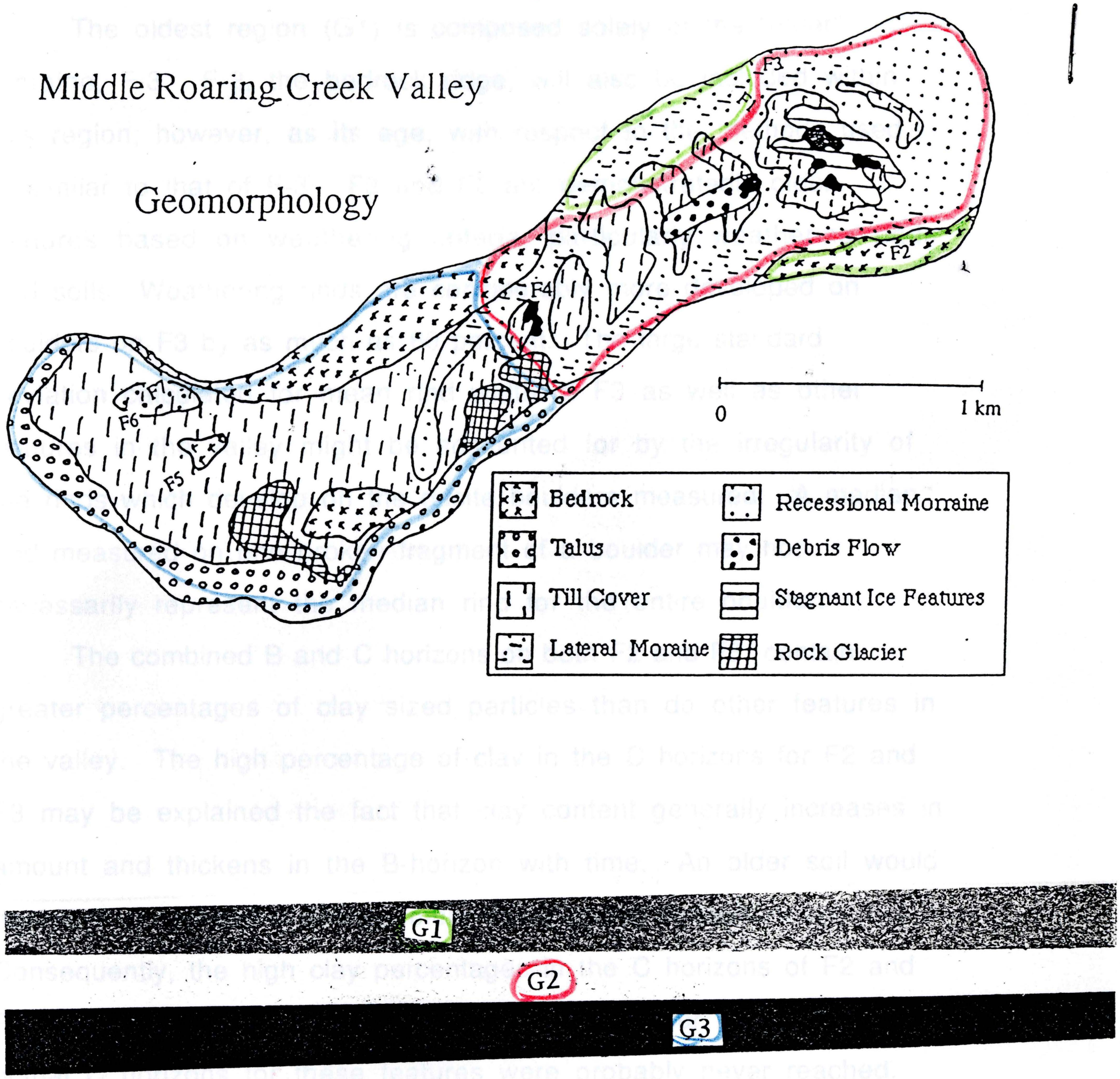


Figure 17: Middle Roaring Creek Valley, Areas G1, G2, and G3.

AREA G1

The oldest region (G1) is composed solely of the "older" moraine, F-3. F-2, the bedrock ridge, will also be included within this region, however, as its age, with respect to the methods used, is similar to that of F-3. F3 and F2 are demonstratedly older features based on weathering criteria, particularly weathering rinds and soils Weathering rinds are considerably more developed on boulders on F3 by as much as 60 percent. The large standard deviation calculated for mean rind width of F3 as well as other features in the valley might be accounted for by the irregularity of the rinds which develop on the dacite boulders measured. A median rind measured on one broken fragment of a boulder may not necessarily represent the median rind for the entire boulder.

The combined B and C horizons on both F2 and F3 contain greater percentages of clay sized particles than do other features in the valley. The high percentage of clay in the C horizons for F2 and F3 may be explained the fact that clay content generally increases in amount and thickens in the B-horizon with time. An older soil would be expected to have a deeper, more developed B horizon. Consequently, the high clay percentages in the C horizons of F2 and F3 likely represent the percentages of clay in lower B horizons. The actual C horizons for these features were probably never reached.

The maximum slope angle of F-3 is markedly different from that of all other lateral moraines in the valley. The terrace associated with F3 is rounded with no obvious crest. It is linear in shape down valley, however, suggesting that is was a lateral moraine. Its close association with the main lateral moraine of Zone

AREA G2

The next oldest region in Middle Roaring Creek Valley, G2, is composed of all of Zone One excepting F2 and F3, and of Zone Two. The boundaries of this area begin above Middle Lake at approximately 11,100 ft. and continue to Roaring Fork River at 10,200 ft. The relative-dating results for G2 showed results falling between those of G1 and G3. Boulder frequency was moderate, and weathering rinds for moraines fell within a median range of other features within the valley. Block fields fell in the lower end of this range. If streams are indeed exhuming these boulders, they would expectedly be younger than those boulders found on top of moraines and have less time for developing rinds. Moraines in G2 showed well defined crests and steep slopes. The unusual clay bulge in the B horizon of F4, a step of Zone 2, can probably be accounted for by the fact that the pit was dug on a slope. Fines developing on the top of the hill could have been eroded and deposited on the sides of the feature.

G2 represents the farthest, "second" advance of ice in the valley, wiping out any evidence of previous advances of ice with the exception of that associated with F-3. The ice then retreated from its terminal limits, depositing the massive terminal complex of moraines now seen at the toe of the valley. As ice continued up valley, small blocks of ice, perhaps 10-100 m in diameter, were left behind and formed pock marks in the landscape seen now as kettled moraines. The ice then paused and stagnated in the region of Tulula and Tawanda Lakes as is indicated by the presence of ICSD in the area. The stream valleys which cut the terminal moraines were likely formed as meltwater from the receding glacier drained out of the valley via the eskers whose deposits are now present in the ICSD area.

Ice continued its retreat up the valley, pausing in the areas of the steps of Zone Two and depositing the diamictons that make up those moraines. In each of those instances, it appears that blocks of ice were left behind, as the major moraines of these steps are backed by areas of kettled topography.

It appears that a portion of the third step going up valley has failed, producing the large debris flow which now is seen as large levees running down the valley. On the other hand, the block fields in this area of Middle Roaring Creek Valley do not seem to be associated with a debris flow or slope failure, as they are predominantly on level surfaces. Instead, it appears that the streams which run through and under them are washing out fines from diamictic material and leaving the boulders behind.

AREA G3

G3 is that region of the valley associated with Zone 3. The difference in data between G2 and G3 is enough to suggest that G3 represents a smaller readvance of ice into the middle of the valley covering the upper part of the second advance associated with the terminal moraines. Were G3 simply part of the retreat of the "second" advance of ice associated with G2 in Middle Roaring Creek Valley , a more continual grade of data would be apparent from the bottom to the top of the valley. Instead, there is a marked difference of results between G2 and G3 especially with respect to weathering rinds, and soils. Weathering rinds are smaller than those of G2 by as much as 50%. Although some slopes of features in G3 are as great as those in G2, on average they are considerably less.

The clay percentages in the B and especially the C horizons of soils in G3 are considerably less than those of soils on F1 and F4. Not only does this suggest that clay development has not been as great in this area of the valley, but also that it has not progressed as deeply. The percentages of clay in the A horizons, however, exceeds those of any other feature in the valley.

The subdued topography near the area of the cirque may be accounted for at least partially by harsher weathering conditions at the higher elevations in the valley. Also, less material was available in the cirque during glaciation, and consequently smaller, more easily eroded moraines were being deposited.

The phenomenon of high percentages of clay sized particles in the A horizons might be explained by the process of loess blowing into the cirque off of the ice covered Fisher Mountain. In addition, Birkeland (1991) documented the possibility of translocating clay size particles by suspension in rainwater.

There is a definite difference in the textures of grains in the A horizon of these soils, compared with that of grains of the A and B horizons from moraines lower in the valley. The increased sphericity and decreased roundness suggests that the source of these grains in G3 differed from those of G2. These differences also suggests that they were perhaps, indeed, products of eolian deposition. The presence of clay plates in the B horizons of both soils sampled suggests that at least a portion of the percentage of clay sized particles in the soils may be accounted for by clay development rather than translocation.

The procession of ice during this readvance of ice into Middle Roaring creek valley was probably ended when the glacier spread out and stopped near the confining bedrock boundaries above Middle Lake. This readvance of ice also accounts for the disordered appearance of moraines above Middle Lake. As ice advanced, older moraines from previous advances were reworked and till was deposited over them as ice retreated.

The talus slopes and rock glaciers in the valley are probably associated with later Holocene periods of neoglacial development. Meierding and Birkeland (1980) recognize rock glaciers as the most common Holocene glacial deposits in cirques in the Colorado Rockies. Though these lobate features are not as large as rock glaciers described by Meirding and Birkeland, they do have the general appearance. The presence of solifluction features and the high angle, greater than 45 degrees in some instances, of the nose of these

CONCLUSION

The observations of the morphology as well as the differences in results of relative-dating methods of features in Middle Roaring Creek Valley suggest that the valley has been subject to at least three periods of glaciation during the Pleistocene. Through particularities existed throughout the valley which brought about some unexpected results, these exceptions could usually be explained. The similarities of results from the three areas of the valley with those sited for similar methods in other glaciated areas of Colorado suggest that these deposits in Middle Roaring Creek Valley can be associated with the Bull Lake, Pinedale, and Holocene deposits mapped throughout Colorado.

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