UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Guidebook,
1983 Friends of the Pleistocene Field Trip,
Glacial Sequence near McCall, Idaho

by

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INTRODUCTION

The glacial deposits near McCall, Idaho were deposited by piedmont lobes of valley glaciers that periodically descended southward to the floor of Long Valley from large ice masses in the Salmon River Mountains. Long Valley is one of a number of north-trending valleys formed by late Tertiary and Quaternary normal faulting along the west margin of the Idaho Batholith (Cretaceous) (fig. 1). Columbia River Basalt (Miocene) overlaps the west margin of the batholith and commonly is tilted 15-30° to the west (Schmidt and Mackin, 1970). Late Tertiary to early Quaternary sediments that appear to be associated with faulting are tilted as much as 20° (Schmidt and Mackin, 1970). Although no Quaternary fault scarps have been identified in Long Valley, such scarps are present in similar nearby basins (Schmidt and Mackin, 1970; Gilbert and Piety, 1983).

The Quaternary geology of the Long Valley area was mapped and studied by J. H. Mackin and D. L. Schmidt in the 1950's during work relating placer deposits of monazite and euxenite to surficial geology. Their report (Schmidt and Mackin, 1970), published after Mackin's death in 1968, identified a basic Pinedale-Bull Lake glacial sequence similar to that observed in many areas of the Rocky Mountains. In addition, they identified deeply eroded and weathered deposits (their unit QTd) of possible glacial origin with a suggested age of late Tertiary or early Quaternary. The guidebook for the 1965 INQUA Field Conference refers to morphologically distinct Pinedale and Bull Lake moraines south of Payette Lake (Fryxell and others, 1965).

We began work in the McCall area in 1975 as part of a regional study of weathering rinds on volcanic clasts as an age indicator for glacial sequences in the western United States. More than 1,500 rind measurements at more than 40 sites in the McCall area allowed us to subdivide Schmidt and Mackin's (1970) Pinedale-Bull Lake sequence into deposits of four distinct ages (fig. 2), and to estimate their numerical ages (Colman and Pierce, 1981). We have modified Schmidt and Mackin's (1970) mapping and interpretation of the field relations only in the following ways: (1) we have subdivided the Pinedale into younger (Pilgrim Cove) and older (McCall) moraines and outwash; (2) we have distinguished small morainal remnants (Williams Creek), previously mapped partly as Pinedale and partly as Bull Lake, which are intermediate in age between the two.

In addition to defining a detailed sequence of deposits by weathering-rind thicknesses, we also collected soil, surface-rock weathering, and morphologic data for the deposits. These data, especially the soils data, generally support the age distinctions based on weathering rinds. In addition, these data allow comparisons with other glacial sequences in the western United States.

The stratigraphic names we use (fig. 2) are informal. We reluctantly introduce these new names and do so only because the use of the Pinedale-Bull Lake nomenclature for the four-fold sequence is awkward, and because correlation with the type deposits in the Wind River Mountains is uncertain.

METHODS

Figure 3 shows a generalized map of glacial deposits in the McCall area and the location of our data-collection sites.

Weathering rinds.--Sampling methods, measurement procedures, and statistical analyses for weathering-rind data are discussed in detail by

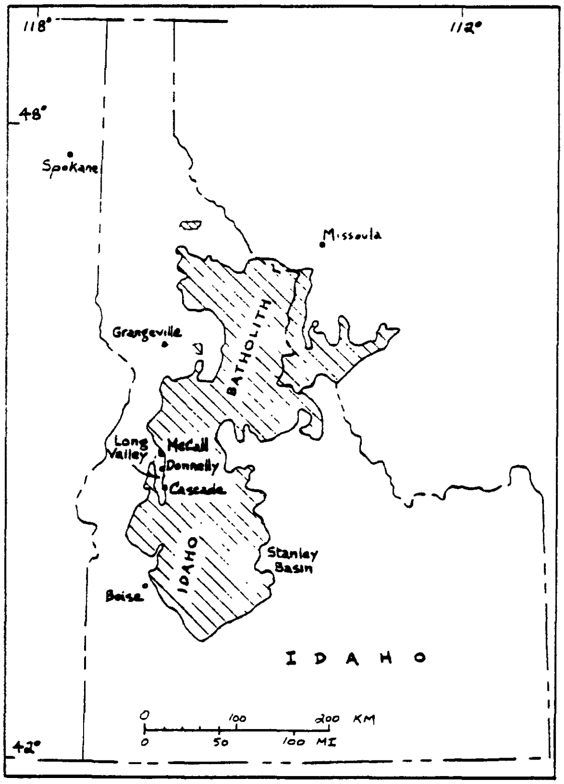


Figure 1.--Location map for the McCall area.

SCHMIDT & MACKIN (1970)	THIS REPORT	
DEPOSIT	DEPOSIT	INFERRED AGE (10^3 YR)
	Pilgrim Cove	14
Pinedale	McCall	20
	Williams Creek	60
Bull Lake		
	Timber Ridge	140-150
QTd	QTd	>500

Figure 2.--Comparison of nomenclature used in this report with that of Schmidt and Mackin (1970). Our stratigraphic names are informal. Ages are derived from the rind-thickness curve in figure 5 and other data discussed in the text.

Colman and Pierce (1981). Weathering rinds were measured on basalt clasts collected from depths of 20 to 50 cm in the upper parts of B-horizons of soils developed in the deposits. At least 30 rinds were measured to the nearest 0.1-0.2 mm at each sampling site with a six-power magnifying comparator. Several sites were sampled on each landform and each age of deposit, forming a nested sampling design.

Weathering rinds begin to develop on clasts in weathering profiles shortly after clast deposition, and the duration of weathering represented by the clast is essentially the same as the age of the deposit. Few clasts that showed evidence of deposition with pre-existing rinds were observed, and clasts that showed such evidence (asymmetric rinds, for example) were discarded. Clasts in the unweathered parts of the deposits show little or no evidence of rinds.

Sampling methods were designed to minimize variation in all factors other than time that might influence rates of rind formation. Sampling sites were located in stable areas of low relief on broad moraine crests or outwash-terrace surfaces. Vegetation varies because the deposits are at the transition from grass-sage to forest, but the amount of climatic variation among the sampling sites is thought to be small.

Soils.--Soil description and sampling methods and horizon nomenclature follow those of Birkeland (1974). Soils developed in each deposit were described in the field in hand-dug soil pits or artificial exposures at least 1.5 m deep. Horizons were channel-sampled for laboratory analyses of grain-size (by seive and pipette), bulk density (by wax-coated, water displacement method) and losses at 105°C and 540°C.

The same attempts to minimize the influence of factors other than time that were made for weathering-rind measurements were made for soil sampling sites.

Surface-rock weathering.--A wide variety of surface-rock weathering features that are presumed to change with time have been measured by workers in the western United States in attempts to subdivide glacial sequences. Burke and Birkeland (1979) and Birkeland and others (1979) review most of these types of measurements. We have measured several kinds of surface-rock weathering features on moraine crests, modifying previous methods to fit local conditions, as follows:

(1) Surface boulder frequency--Number of boulders more than 30 cm in maximum diameter in a 30 by 2 m area. The frequency of both granitic and basaltic stones and the total frequency were measured.

(2) Rough/smooth ratio--Percentage of granitic boulders with more than one-grain relief on more than half their surface.

(3) Basalt/granite ratio--Percentage of basaltic boulders among total (basaltic plus granitic) boulders 10 to 40 cm in maximum diameter at least partly within a traverse 40 cm wide. The size range of boulders counted was limited to 40 cm because larger basaltic boulders are rare.

(4) Pitting of granitic and basaltic boulders--Average and maximum depths of weathering pits and percentage of boulders with pits on 25 boulders more than 50 cm (granitic) or 30 cm (basaltic) in diameter. Sizes of boulders were selected to minimize the number of boulders previously buried by loess.

Figure 3. (next page)--Generalized map of the McCall glacial sequence showing distribution of data collection sites. Williams Creek deposits are patterned for emphasis. Mapping modified from Schmidt and Mackin (1970). Stratigraphic names are informal.

Explanation

Holocene	Qa	alluvium
Pleistocene	Qpo	outwash of Pilgrim Cove age
	Qpt	till of Pilgrim Cove age
	Qmo	outwash of McCall age
	Qmt	till of McCall age
	Qwo	outwash of Williams Creek age
	Qwt	till of Williams Creek age
	Qto	outwash of Timber Ridge age
	Qtt	till of Timber Ridge age
	(solid line)	contact
	(dashed line)	moraine crest

Data collection sites

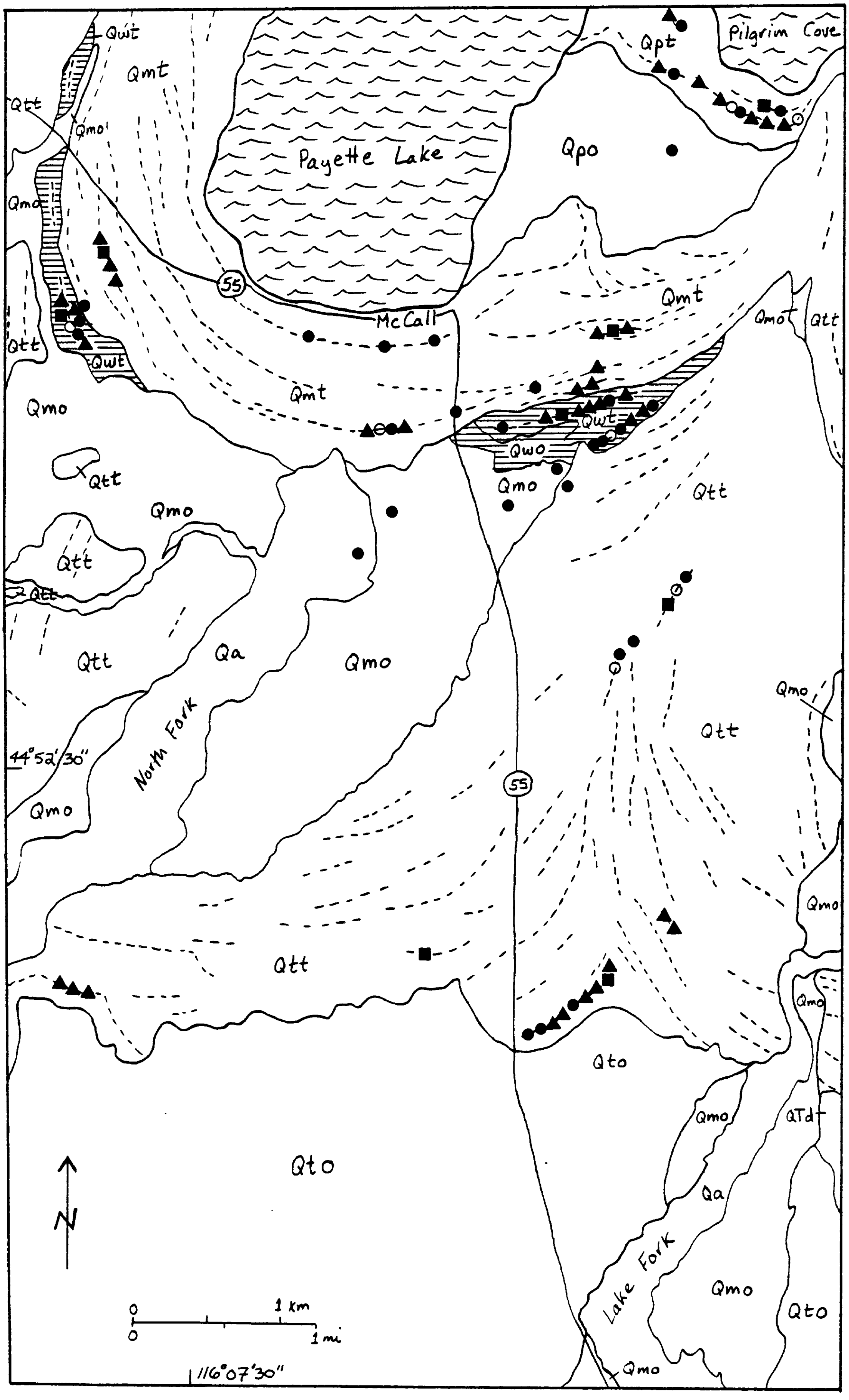
- ● weathering rinds
- ○ soils
- ■ surface-rock weathering and morphology
- ▲ moraine profiles

In addition to these measurements, we made observations on the degree of grussification of granitic stones in soil pits and artificial exposures, and on the presence of miscellaneous features such as cavernous weathering and "hat rocks" (those beveled at the ground surface) for granitic boulders.

Moraine morphology.--As with surface-rock weathering, a variety of morphologic measurements have been made on moraines in the western United states. The measurements we have made are:

(1) Crestal width--distance between two points one-eye height (168 cm) below the crest on either side of the crest.
(2) Proximal slope--general slope of the midsection (more than 10 m long) of the proximal side of the moraine.
(3) Distal slope--general slope of the midsection (more than 10 m long) of the distal side of the moraine.
(4) Microrelief--three types of features were measured: mound, saddle, and depression. The distance along the slope between the crest and the base of a mound with 50 cm of relief from the general slope was measured. Slope distances to a point 168 cm vertically up from the bottom of a saddle on a ridge or a depression were also measured.

In addition to these measurements, we measured continuous profiles normal to moraines crests. From these profiles we obtained sets of data on maximum



Qwt
Qmt
Pilgrim Cove
Qpt
Qtt
Qmo
Payette Lake
Qpo
55
McCall
Qmt
Qmot
Qtt
Qwt
Qmo
Qmt
Qwt
Qwo
Qtt
Qmo
Qtt
Qmo
Qtt
Qtt
Qtt
Qa
Qmo
Qmo
Qtt
North Fork
44°52'30"
Qmo
55
Qmo
Qtt
Qmo
Qto
Qmo
QTdf
Qa
Qto
N
Lake Fork
Qmo
Qto
0
1 km
0
1 mi
116°07'30"
Qmo

slope angles and associated heights for both proximal and distal slopes, analogous to data recently used to estimate the ages of fault scarps (Bucknam and Anderson, 1979; Colman and Watson, 1983). Maximum slope angles were measured for slope distances of about 3 m.

STRATIGRAPHIC SUBDIVISIONS AND AGES

All of the glacial deposits discussed here are associated with distinct landforms (moraines or outwash terraces). Therefore, by collecting weathering and morphological data for the various landforms (fig. 3) we were able to separate the landforms and associated deposits into distinct groups.

We have used weathering-rind thicknesses as the basic framework for stratigraphic subdivision and age estimates. The other relative-age methods were to varying degrees less suitable for these purposes. Weathering-rind thicknesses have the following advantages for estimating ages: (1) rind thickness is a single, simple, easily reproduced measurement, (2) the parent material of the rind is known and the clasts begin with no rind, (3) the influence of factors other than time on rind thickness is easier to minimize than it is for other methods, and (4) large numbers of rind-thickness measurements can be made in a relatively short time, allowing quantitative assessment of representativeness and sources of variation.

Our approach has been first, to use weathering-rinds to establish the stratigraphy and to estimate ages, and then to see how soils, surface-rock weathering, and moraine morphology reflect the stratigraphy and ages. The latter types of data are also useful for comparing the McCall glacial sequence to those in other areas of the western United States. The following sections discuss each of the different types of data and their relation to stratigraphy and ages.

Weathering rinds.--Weathering-rind thicknesses and landform associations clearly distinguish four different ages of deposits (fig. 4) within the McCall glacial sequence. We have separated the deposits mapped as Pinedale by Schmidt and Mackin (1970) into two ages: Pilgrim Cove and McCall. In addition to a small but significant difference in their rind thicknesses, these deposits form two distinct moraine belts separated by Pilgrim Cove outwash. Williams Creek moraines are small remnants of deposits with rind thicknesses intermediate between those of McCall and Timber Ridge age. Williams Creek deposits were mapped partly as Pinedale and partly as Bull Lake by Schmidt and Mackin (1970), and were called "Intermediate" by Colman and Pierce (1981). Timber Ridge deposits comprise the bulk of those mapped by Schmidt and Mackin (1970) as Bull Lake.

Statistical analysis of the rind-thickness data for the McCall area is discussed in detail in Colman and Pierce (1981). To summarize, this analysis indicates that age is by far the most important variable affecting rind thickness. All of the differences in rind thickness between ages of deposits are significant; in contrast, none of the variation in rind thickness among moraines of one age is significant. Variation among sites of one age is only locally significant; where it is significant, it must be due to factors other than age.

We have attempted to estimate the numerical ages of the deposits using their average rind thicknesses (table 1). We concluded (Colman and Pierce, 1981) that a logarithmic function best describes the relation between rind thickness and time (fig. 5), and calibrated a rind curve for the dated glacial

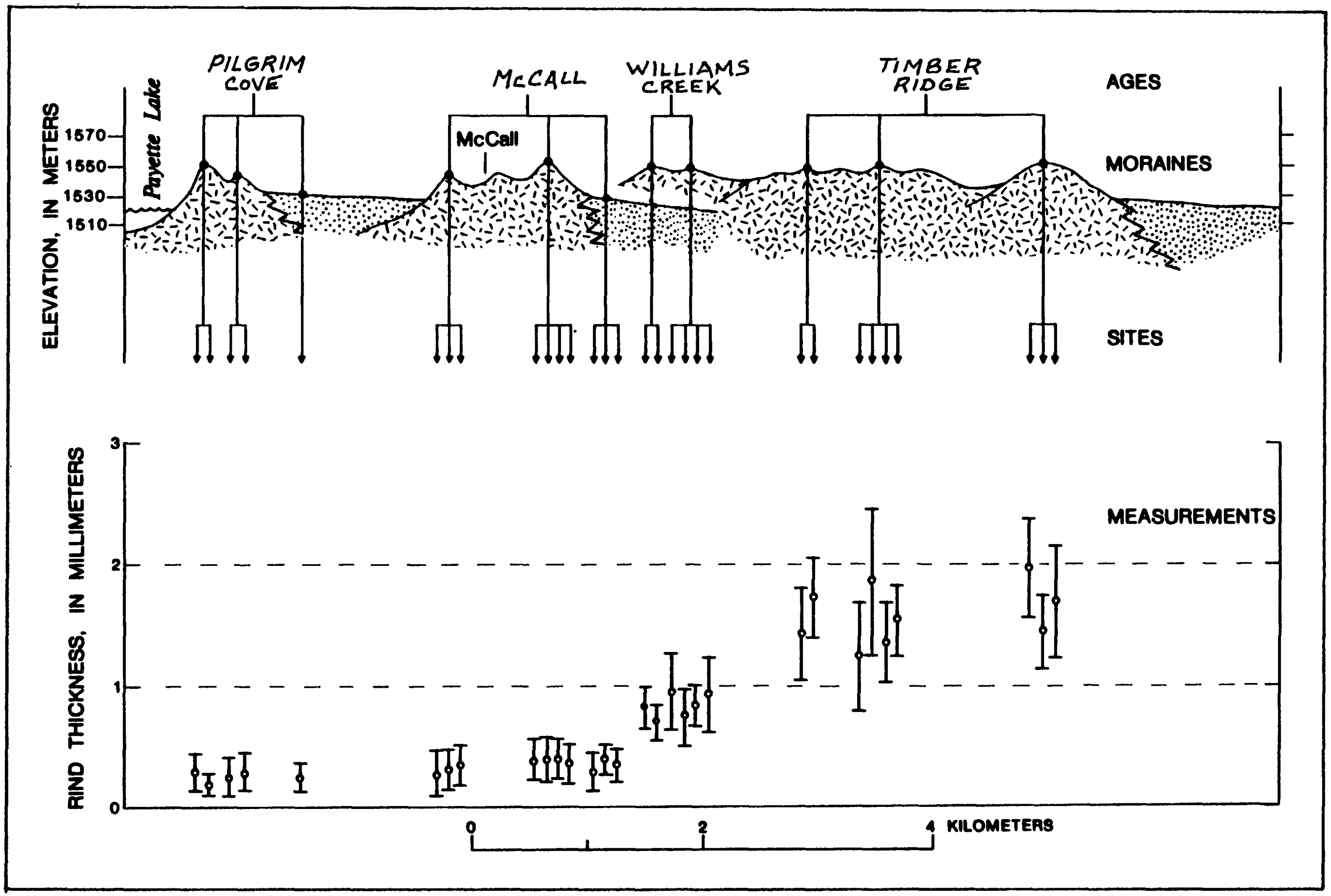


Figure 4.--Rind thicknesses for each sampling site and diagrammatic sketch of the sampling design for the McCall area. Line pattern, till; stipple, outwash. Thickness data is given as the mean ± one standard deviation. Modified from Colman and Pierce (1981).

Table 1.--Weathering-rind thickness data for each age of deposits

Deposit	Mean of all measurements	Standard deviation[1]	Mean of site means	Standard error[2]
Pilgrim Cove	0.25	0.14 (203)	0.26	0.04 (5)
McCall	0.35	0.16 (354)	0.35	0.05 (10)
Williams Creek	0.85	0.24 (238)	0.84	0.10 (6)
Timber Ridge	1.61	0.41 (354)	1.57	0.24 (9)

1 Standard deviation of measurements; number of measurements in parentheses
2 Standard deviation of site means; number of sites in parentheses.

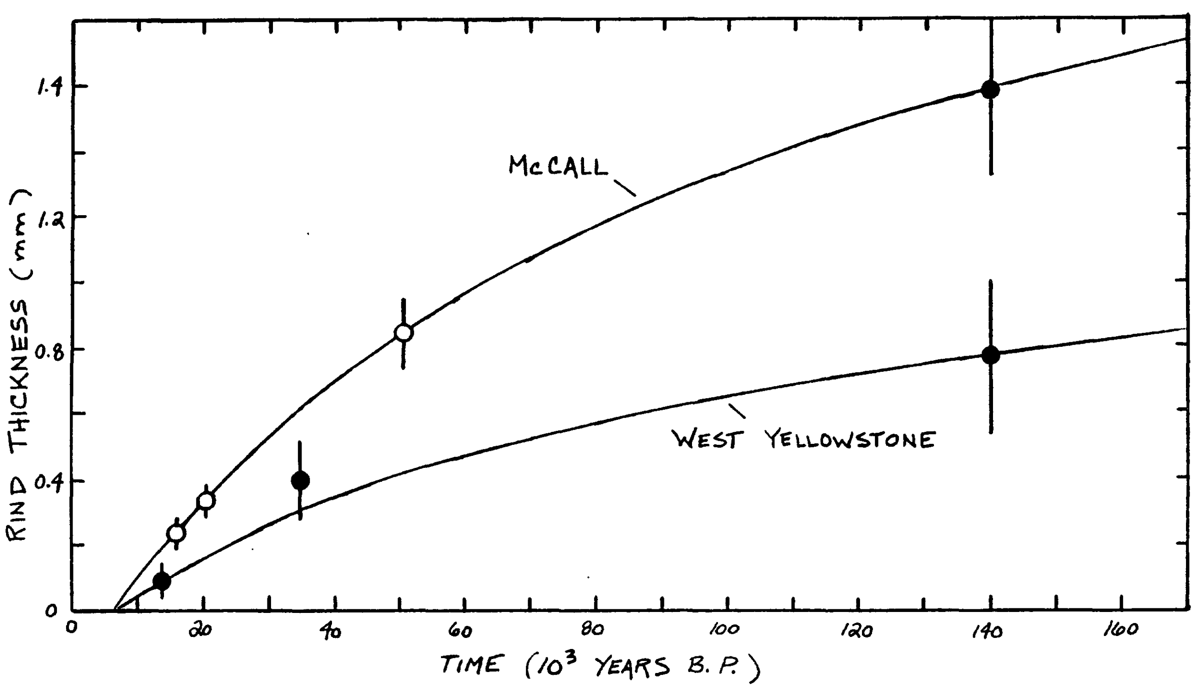


Figure 5.--Curves of rind thickness versus time for the McCall and the West Yellowstone, Montana areas. Rind thickness is shown as a logarithmic function of time (Colman and Pierce, 1981). Solid circles for the West Yellowstone curve are deposits dated by combined obsidian-hydration and K-Ar methods (Pierce and others, 1976). Solid circle on the McCall curve represents Timber Ridge deposits, inferred to correlate with the West Yellowstone Bull Lake deposits, and used for calibration of the curve. Open circles are other deposits near McCall, plotted according to their rind thicknesses. Vertical lines represent ± one standard error of the rind thicknesses. See text.

deposits near West Yellowstone, Montana (Colman and Pierce, 1981). These deposits are dated by a combination of obsidian-hydration, K-Ar, and radiocarbon methods (Pierce and others, 1976; Pierce, 1979). The McCall glacial sequence, like most others in the western United States, has no independent numerical dates. However, if we assume that the rind curve for the McCall area has the same form as the curve for West Yellowstone, and if we assume the age of one of the McCall deposits and use it for calibration, we can construct a tentative curve of rind thickness versus time for the McCall area.

We infer that the Timber Ridge deposits near McCall correlate with the West Yellowstone Bull Lake, and are thus about 140,000-150,000 years old. The degree of soil and rind development certainly suggests that the Timber Ridge deposits are no younger than the West Yellowstone Bull Lake. Similar subdued but distinct morainal morphology and similar loess stratigraphy on the two deposits suggest they are equivalent in age.

We obtained the McCall curve simply by multiplying the West Yellowstone curve by a constant, so that that the new curve passed through the Timber Ridge calibration point. The difference between the two curves is due largely to differences in lithology and climate between the two areas. McCall is somewhat wetter and warmer than West Yellowstone (65 cm versus 50 cm mean annual precipitation; 4.4°C versus 1.7°C mean annual temperature). Rind thicknesses for Pinedale deposits west of Cascade Reservoir and data from other areas suggest that precipitation is the most important climatic variable affecting rind thickness. In addition to differences in climate, the basalt at McCall contains more glass and olivine than that at West Yellowstone, which favors more rapid rind formation (Colman, 1982a).

Details of the assumptions and methods used to construct rind-thickness curves for McCall and other areas are discussed by Colman and Pierce (1981).

Soils.--Soils developed in the glacial deposits near McCall show a systematic progression with age. General temporal trends include thickening of the total soil and of the B and C horizons, reddening of the B and C horizons, increasing enrichment of the B horizons in secondary clay, and progressive development of structure in the B horizons (table 2). The differences between the soils on deposits of different ages are visually striking, and are qualitatively useful for distinguishing deposits in the field (fig. 6).

We considered several quantitative soil properties as numerical measures of soil development (fig. 7). These properties include depth of oxidation, thickness of B horizons, increase in percentage of clay in B horizons, total secondary clay, and Harden's (1982) structure and rubification indices. Total secondary clay, in g/cm^2, is calculated for each horizon as follows,

$$ct = (c_3 p_3 - c_1 p_1)\ (d)\ (n)$$

and then summed for all horizons in the profile; ct is the secondary clay in each horizon; c is clay percent and p is bulk density (1=present, 3=parent material); d is horizon thickness; and n is the percentage of material less than 2 mm in diameter. Total clay includes loess and other eolian material that has been mixed or translocated into the profiles. Normalized structure and rubification indices (Xsn and Xrn, respectively) are quantities derived from field observations (Harden, 1982). Points are accumulated for each shift in strength and type of structure and for each shift in hue and chroma of color, and the total is normalized by maximum values for the index (60 for structure and 190 for rubification). The indices are presented in two ways in fig. 7: the maximum normalized index for any horizon in the profile, and the

Table 2. Soil data

[Field trip stops as indicated]

Sample	Horizon	Depth (cm)	Texture[1]	Color[2]	Structure[3]	Grain Size[4] sand	Grain Size[4] silt	Grain Size[4] clay	Weight Percent 2-50 mm[5]	Bulk Density[6] (g/cm^3)	Percent Loss on Ignition[7]	Percent H_2O[8]
Pilgrim Cove												
78C131F (STOP 1)	A	0-12	sl	10YR2/2	sg	62.1	30.7	7.2	10.2	1.25[e]	8.47	2.44
G	B1	12-18	sl	7.5YR3/4	w, vf, gr	70.9	24.5	4.6	39.8	1.40[e]	5.64	1.93
H	B21	18-27	ls	7.5YR3.5/4	w, vf, gr	78.1	18.1	3.8	14.9	1.50[e]	3.22	1.39
I	B22	27-43	ls	10YR3.5/3	w, vf, gr	81.5	14.9	3.6	29.4	1.70[e]	1.79	0.91
J	Cox	43-76	ls	10YR 4.5/3	m	76.2	18.3	5.5	26.6	1.70[e]	1.46	0.77
K	Cn	76-108	ls	10YR 5/2	m	81.8	14.5	3.7	27.6	1.70[e]	1.17	0.59
83C03 A	A	0-10	sl	10YR3/2	sg	62.3	30.8	6.9	11.2	1.25[e]	5.09	2.01
B	Bs	10-25	sl	10YR4/4	w, vf, gr	68.2	26.6	5.2	20.1	1.40[e]	3.41	1.95
C	IIClox	25-35	sl	2.5Y4/4	w, vf, gr	72.8	22.2	5.0	21.1	1.44	1.71	1.06
D	IIC2ox	35-60	sl	2.5Y4/3	m	71.6	22.1	6.3	13.6	1.70[e]	1.22	0.95
E	IICn	60-90	ls	2.5Y5/3	m	75.1	19.9	5.0	24.5	1.70[e]	1.06	1.13
McCall												
76P53 A (STOP 2)	A	0-10	sl	10YR2/2	sg	67.2	25.5	7.3	14.3	1.25[e]	5.45	1.66
B	B1	10-30	sl	7.5YR4/5	w, vf, gr	74.6	20.5	4.9	13.1	1.40[e]	3.25	1.30
C	IIB2	30-65	ls	10YR5/6	w, m, sbk	79.5	15.6	4.9	22.2	1.60	1.73	0.89
D	IICox	65-105	ls	2.5Y5/5	m	86.8	10.5	2.7	13.4	1.70[e]	1.12	0.64
E	IICn	105-155	s	2.5Y5/3	m	87.3	10.1	2.6	19.5	1.70[e]	0.87	0.61
F	till	300-350	ls	2.5Y5/2	m	84.1	13.4	2.5	16.7	1.70[e]	0.39	0.29
Williams Creek												
76P54 A	A	0-7	l	10YR3/2	sg	48.2	37.9	13.9	6.0	1.25[e]	11.02	2.91
B	AB	7-40	sl	10YR3/4	w, m, sbk	52.9	34.6	12.5	7.1	1.50[e]	6.24	2.23
C	IIB21tb	40-63	l	7.5YR4/5	m, m, sbk	50.2	30.7	19.1	5.5	1.70	3.76	1.87
D	IIIB22tb	63-84	sl	7.5YR4/4	m, m, sbk	58.1	28.0	13.9	45.2	1.79	3.53	1.97
F	IIIBCb	84-113[9]	l	7.5YR4/4	m, m, sbk	38.5	37.1	24.4	15.0	1.70[e]	4.18	2.58
E	IIICBb	84-113[9]	sl	2.5Y4/4	m	74.0	21.8	4.2	10.5	1.70[e]	1.76	0.92
G	IIICox	113-150	sl	10YR4/4	m	68.3	21.4	10.3	18.0	1.70[e]	3.28	1.71
83C02 A (STOP 3)	A	0-10	sl	10YR2/3	sg	54.0	29.5	16.5	6.7	1.20	7.03	2.33
B	B1	10-23	sl	10YR4/3	w, c, sbk	54.2	29.1	16.7	9.7	1.38	6.00	2.71
C	IIB21t	23-43	sl	7.5YR4/2	w, c, sbk	55.6	27.0	17.4	8.6	1.49	4.85	2.56
D	IIB22t	43-74	sl	7.5YR4/3	m, c, abk	59.6	24.8	15.6	12.4	1.72	3.41	2.91
E	IIB23t	74-100	sl	7.5YR4/3	w, c, abk	57.6	24.2	18.2	14.7	1.75	3.27	3.81
F	IIClox	100-144	sl	10YR4/3	w, c, abk	66.7	20.8	12.5	15.7	1.76	2.62	3.38
G	IIC2ox	144-156	scl	10YR4/3	w, c, abk	52.1	27.1	20.8	4.1	1.61	3.57	3.19
H	IICn	156-174	sl	2.5Y4/2	w, c, abk	72.8	18.7	8.5	16.9	1.70[e]	1.63	1.92

Table 2. (continued)

Sample	Horizon	Depth (cm)	Texture[1]	Color[2]	Structure[3]	Grain Size[4] sand	silt	clay	Weight Percent 2-50 mm[5]	Bulk Density[6] (g/cm^3)	Percent Loss on Ignition[7]	Percent H_2O[8]
Timber Ridge												
76P55 A (STOP 5)	A	0-15	1	10YR3/2	sg	43.8	40.7	15.5	2.8	1.25[e]	10.95	3.37
B	AB	15-40	1	7.5YR3/2	m, m, sbk	43.6	40.1	16.3	6.0	1.40[e]	7.26	2.77
C	IIB1tb	40-52	1	5YR3/3	m, m, sbk	43.2	39.4	17.4	16.4	1.49	6.18	2.56
D	IIIB21tb	52-73	1	7.5YR4/4	m, m, sbk	46.5	36.2	17.3	7.1	1.47	5.63	2.25
E	IIIB22tb	73-100	1	10YR5/7	m, m, sbk	45.7	33.8	20.5	12.7	1.51	6.38	3.15
F	IIICgxb	100-145	sl	2.5YR5/4	s, c, pl	72.4	24.0	3.6	73.9	1.81	3.77	2.70
G	IIICoxb	145-165	sl	10YR4/4	m	68.3	25.9	5.8	37.2	1.80[e]	4.22	2.30
76P49 Q (STOP 6)	A	0-10	1	5YR3/2	sg	50.5	34.0	15.5	6.4	1.25[e]	8.00	2.37
R	B1	10-30	1	5YR3/3	w, f, sbk	48.7	29.2	22.1	7.4	1.46	6.39	2.43
S	IIB2t	30-95	scl	7.5YR4/5	m, f, sbk	51.9	27.6	20.5	3.3	1.52	6.05	2.66
T	IIB3t	95-155	sl	10YR4/3	w, m, sbk	62.1	23.6	14.3	15.2	1.60	5.26	2.33
U	IICox	155-195	ls	2.5Y4/4	w, m, sbk	80.0	16.9	3.1	47.1	1.91	2.03	1.28
V	IICn	195-245	ls	2.5Y4/3	m	76.5	19.7	3.8	53.6	1.80[e]	1.40	1.13
W	till	245-495	ls	2.5Y4/2	m	76.2	20.1	3.7	53.6	1.90[e]	0.86	0.94
X	B21tb	495-525	sl	7.5YR3/2	s, c, pl	53.6	27.4	19.0	23.0	1.94	3.07	2.34
Y	B22tb	525-565	sl	7.5YR3/2	s, c, pl	59.3	24.3	16.4	31.3	1.94	2.91	2.24
Z	Coxb	565-675	sl	7.5YR5/6	m	74.4	18.4	7.2	47.9	1.90[e]	2.25	1.87

1 Textures (<2 mm fraction), based on seive and pipette analyses: 1, loam; ls, loamy sand; sl, sandy loam; scl, sandy clay loam.
2 Moist Munsell colors.
3 Except for massive (m) and single grain (sg), structure is given in three parts: (1) strength: w, weak; m, moderate; s, strong; (2) size: vf, very fine; f, fine; m, medium; c, coarse; (3) type: abk, angular blocky; sbk, subangular blocky; gr, granular; pl, platy.
4 Weight percent of less than 2 mm fraction: sand (2.0-0.05 mm), silt (0.05-0.002 mm), and clay (<0.002 mm).
5 The deposits contain about 30-40 percent by volume clasts >50 mm in diameter, which were not sampled.
6 Wax-coated, water displacement method; e, estimated.
7 Loss of oven-dry (105°C) sample at 540°C.
8 Loss of air-dry sample at 105°C.
9 B and C horizon material are distinct, but complexly mixed in this interval.

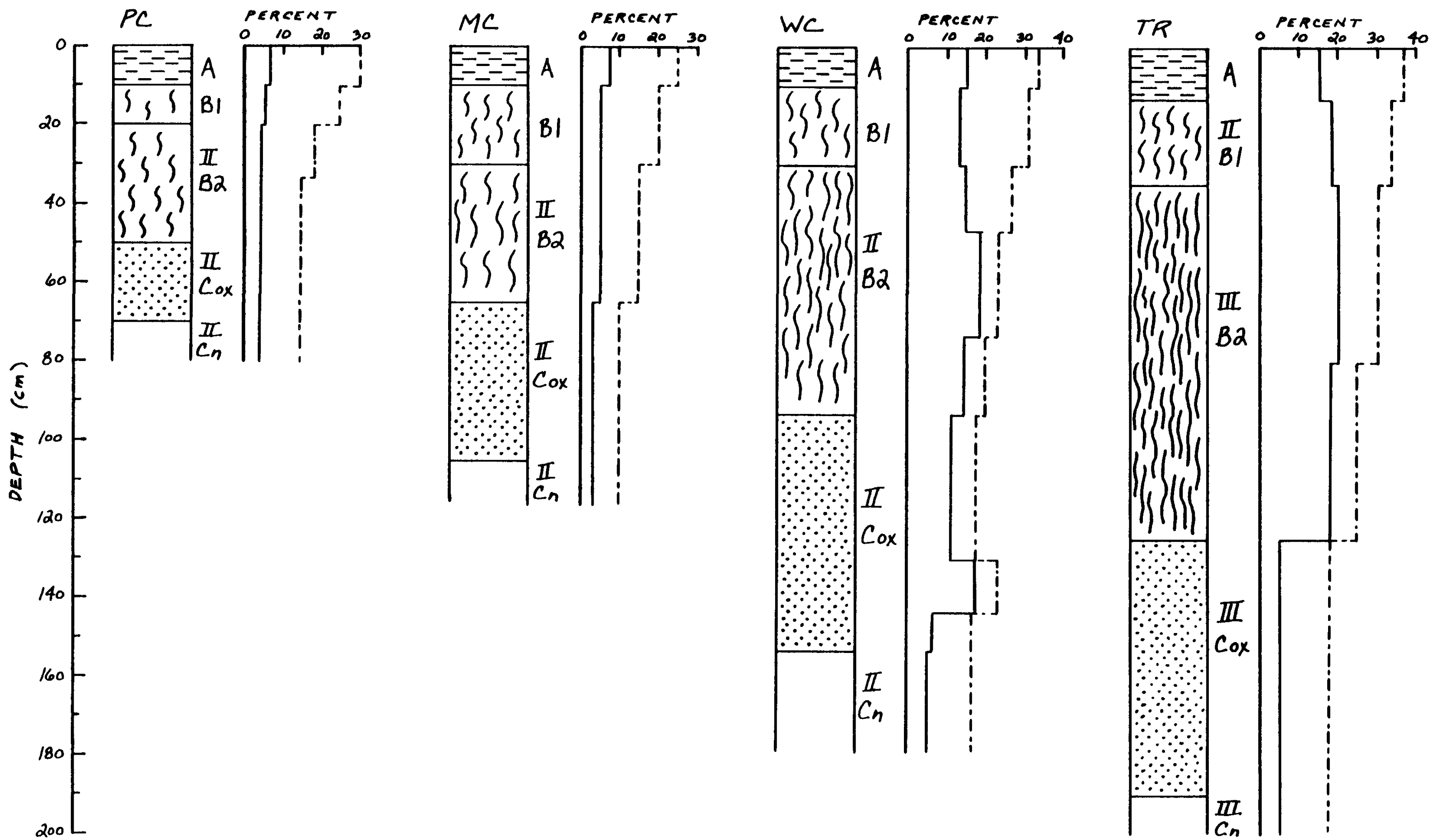


Figure 6.--Generalized soil profiles developed in four ages of till near McCall. Grain-size profiles are for clay (less than .002 mm), solid line, and silt (.05-.002 mm), dashed line. Density of symbol for B horizons indicates degree of development. PC, Pilgrim Cove; MC, McCall; WC, Williams Creek; TR, Timber Ridge. Compare with data in table 2.

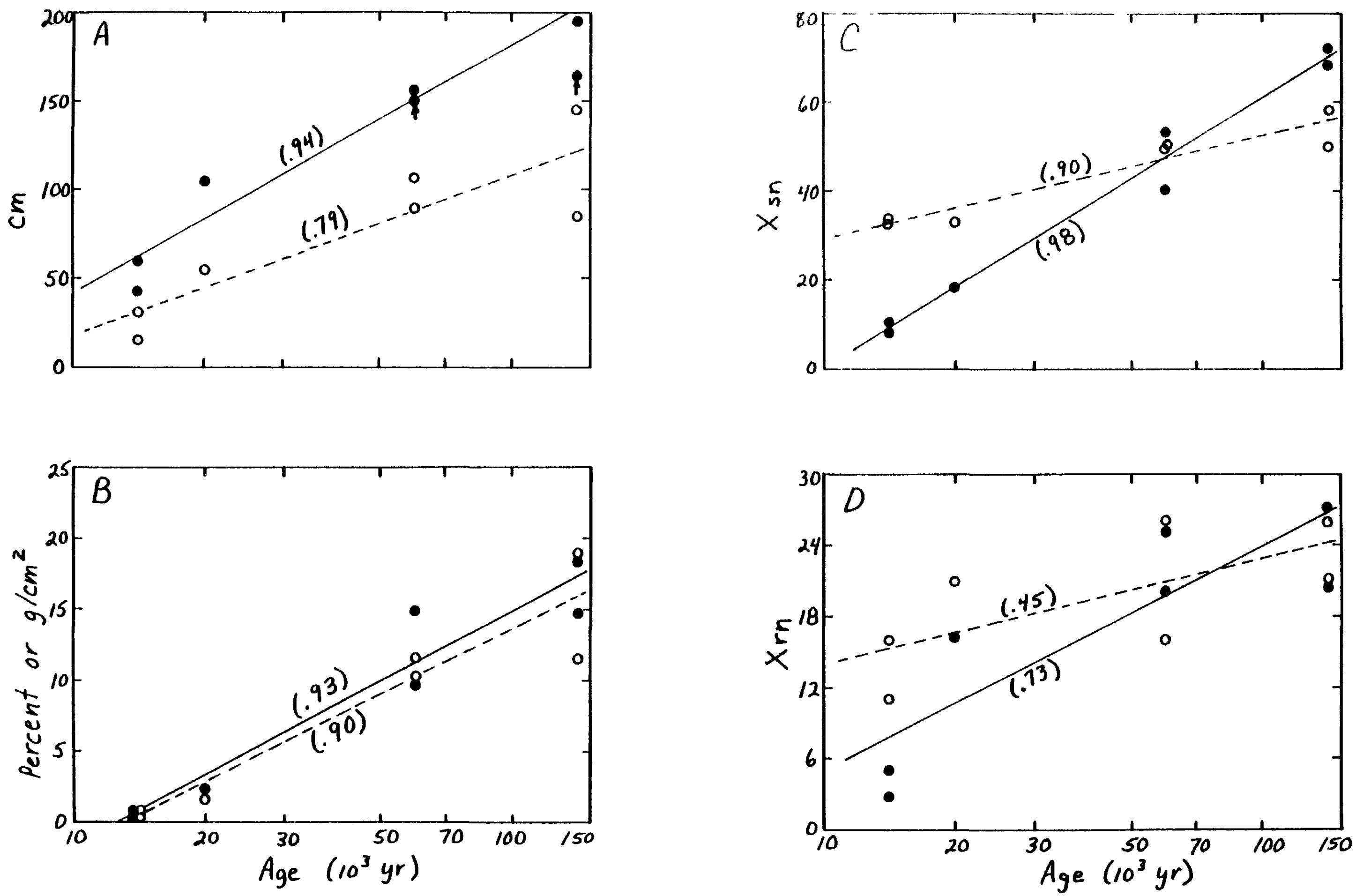


Figure 7.--Soil properties plotted against the logarithm of deposit age. Ages are derived from weathering rind-thicknesses and other data (fig. 5 and text). Lines are least-squares regression lines; coefficients of determination (r^2) are given in parentheses. A, depth of oxidation (solid), and B-horizon thickness (open); arrows indicate minimum values not used in the regression. B, maximum percent clay increase in the B horizon (solid), and total secondary clay in the profile in g/cm^2 (open). C, Harden's (1982) structure index: total profile index, in index-cm (solid), and maximum horizon index (open). D, Harden's (1982) rubification index: total profile index, in index-cm (solid), and maximum horizon index (open).

profile sum of the normalized index for each horizon multiplied by horizon thickness.

When these measures of soil development are compared to the ages derived from weathering rind thicknesses (see Age and Correlations section), all show systematic changes with time. The rates of change of all properties in figure 7 decrease with time, commonly similar to logarithmic curves. None of the properties appear to have reached a steady state within the age of these deposits, although the rate of change of the rubification index appears to be decreasing faster than a logarithmic time function (fig. 7).

The soil properties clearly separate deposits of different ages, and most of the properties show high correlations with logarithmic time functions. The soils in Pilgrim Cove and McCall deposits are clearly different, which is unusual for deposits assigned to the Pinedale Glaciation. Timber Ridge and Williams Creek soils are relatively similar in many properties, although Timber Ridge soils are consistently better developed; the differences in soils between these two deposits might not have been enough to separate them in a reconnaissance study of the deposits. The main constraint on both qualitative and quantitative analysis of the soil development in these deposits is uncertainty about the degree of variation in soil development within each age of deposit.

Soil development in the deposits of the McCall glacial sequence seems greater than that in many Rocky Mountain glacial sequences. Two factors are probably responsible for this difference: (1) the climate at McCall is somewhat warmer and moister than many places in the Rocky Mountains (see Weathering Rinds section), and (2) the deposits near McCall contain large amounts of basalt, unlike glacial deposits in most other areas of the Rocky Mountains, which are dominated by coarse-grained granitic rocks. In Timber Ridge deposits, the outer 1.5-2.0 mm of basaltic clasts (the weathering-rind) is highly altered and contains high percentages of secondary clay-size material, although this material is X-ray amorphous (Colman, 1982a,b). Presumably, basaltic particles less than 3-4 mm in diameter in the matrices of Timber Ridge soils have been altered to similar clay-rich material. The clay-size fractions of Timber Ridge soils contain large amounts of X-ray-amorphous material similar to that in the weathering rinds (Colman, 1982b). These observations may partly explain the relatively high degree of development and clay contents of the soils in the McCall sequence compared to soils in other Rocky Mountain glacial deposits.

Surface-rock weathering.--In general, surface-rock weathering indicies proved marginally useful for differentiating deposits according to the stratigraphic sequence derived from weathering rinds (fig. 8). Measures of boulder frequency showed virtually no relation to stratigraphic age, and basalt/granite ratios showed only a weak relation. Rough/smooth ratios and various measures of pitting on both granitic and basaltic boulders seem to change progressively with stratigraphic age, but reversals and overlaps in the data are common. In all the data that bear some relation to age, Pilgrim Cove and McCall deposits tend to group together, as do Williams Creek and Timber Ridge deposits. Cavernously weathered granitic boulders and "hatrocks" (those beveled at the ground surface) were observed only in unforested areas underlain by Timber Ridge deposits.

In addition to surface-rock weathering, we observed a systemmatic increase in the grussification of subsurface granitic stones with time. No grussified clasts were observed in Pilgrim Cove deposits, and McCall deposits contain only rare, slightly grussified clasts. Most granitic clasts in

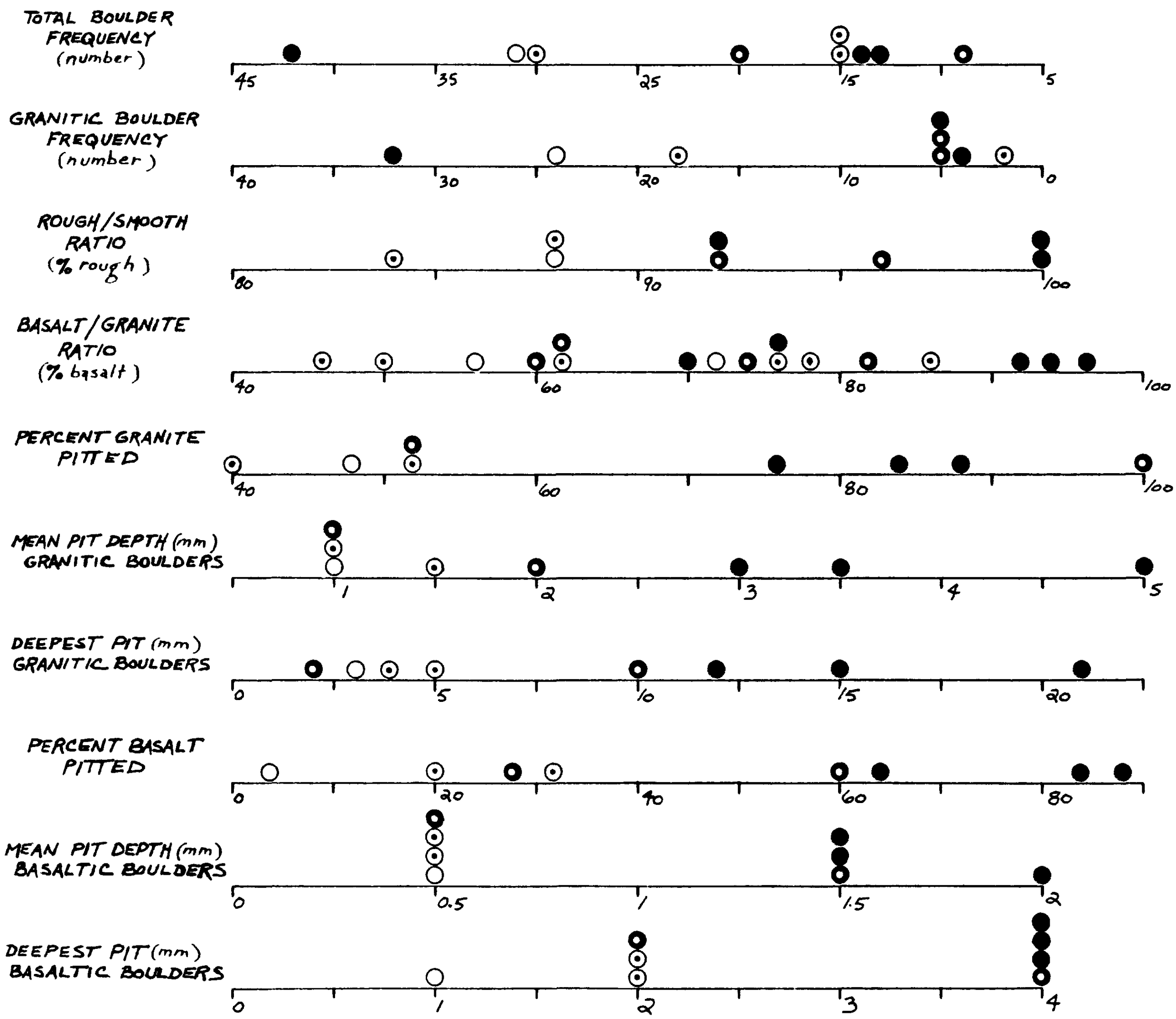


Figure 8.--Surface-rock weathering data. Symbols represent different ages of deposits: open circles, Pilgrim Cove; open circles with solid centers, McCall; closed circles with open centers, Williams Creek; closed circles, Timber Ridge. See Methods section for measurement procedures.

Williams Creek deposits are fresh, but grussified clasts are common. In Timber Ridge deposits, 40-70 percent of the granitic clasts are grussified.

Even though the climate and lithologies in the McCall area are relatively constant, several factors combine to limit the usefulness of surface-rock weathering measurements for differentiating deposits according to age. Variations in original relative abundances of basalts and granites appear to strongly affect measures of boulder frequency and basalt/granite ratios in the McCall area. In addition, post-depositional events, including loess deposition and disturbance of surface boulders may affect measurements of surface weathering on the boulders. Post depositional disturbance of boulders has been discussed by Burke and Birkeland (1979) and Colman and Pierce (1981);

spalling of rock surfaces due to forest fires, which produces fresh surfaces, may be especially important near McCall. We observed abundant evidence of rock spalling on forested deposits near McCall.

Moraine morphology.--Moraine morphology generally reflects the stratigraphic ages of the deposits in the glacial sequence. Younger moraines tend to be narrower and to have steeper slopes than older moraines, and small-scale constructional topography is better preserved on younger moraines. Closed depressions are common in areas of Pilgrim Cove and McCall deposits; they are rare in areas of Timber Ridge deposits.Two types of morphological data were collected (see Methods section): (1) simple, direct measurements of crestal width, slope steepness, and the size of microrelief features, and (2) sets of data pairs, consisting of height and maximum slope angle, derived from continuous profiles across the moraines.

Of the simple, direct measurements, all seem to reflect stratigraphic age, although overlaps and reversals are common (fig. 9). Variations in slope steepness may be partly due to the influence of height on slope steepness, analogous to the height effect observed on fault scarps (Bucknam and Anderson, 1979). Much of the variation in these data may also be due to variation in original depositional morphology. These data tend to group thePilgrim Cove and the McCall deposits together, as well as grouping the Williams Creek and Timber Ridge deposits together.

When maximum slope angle is plotted against the logarithm of moraine height, both of which are derived from moraine profiles, moraines separate according to age reasonably well (fig. 10). For distal slopes, the regression lines for each age are approximately parallel, and their positions are in stratigraphic order. Considerable scatter about the regression lines exists, especially for McCall moraines, probably due to variation in the original constructional morphology of the distal slopes. For proximal slopes, the relations are poor, possibly due to greater variation in the original constructional morphology of the ice contact slopes.

These data are analogous to morphologic data that have recently been used to estimate the ages of fault and wave-cut scarps (Bucknam and Anderson, 1979). Such data have also been mathematically modeled by a diffusion equation in attempts to directly calculate scarp ages (Nash, 1980; Colman and Watson, 1983). Mathematical modeling of morphologic data has not yet been attempted for morainal landforms.

For terrace or fault scarps of a given slope angle, the age ratio of two scarps is proportional to the ratio of their heights squared (Nash, 1980). This type of comparison, using the data in figure 10, would suggest age ratios of three to four between successively older deposits. Such age differences are greater than those indicated by weathering rinds, but because, unlike scarp height, moraine height decreases with time, these comparisons are not strictly valid. Nevertheless, the morphologic data suggest important age differences among the stratigraphic units.

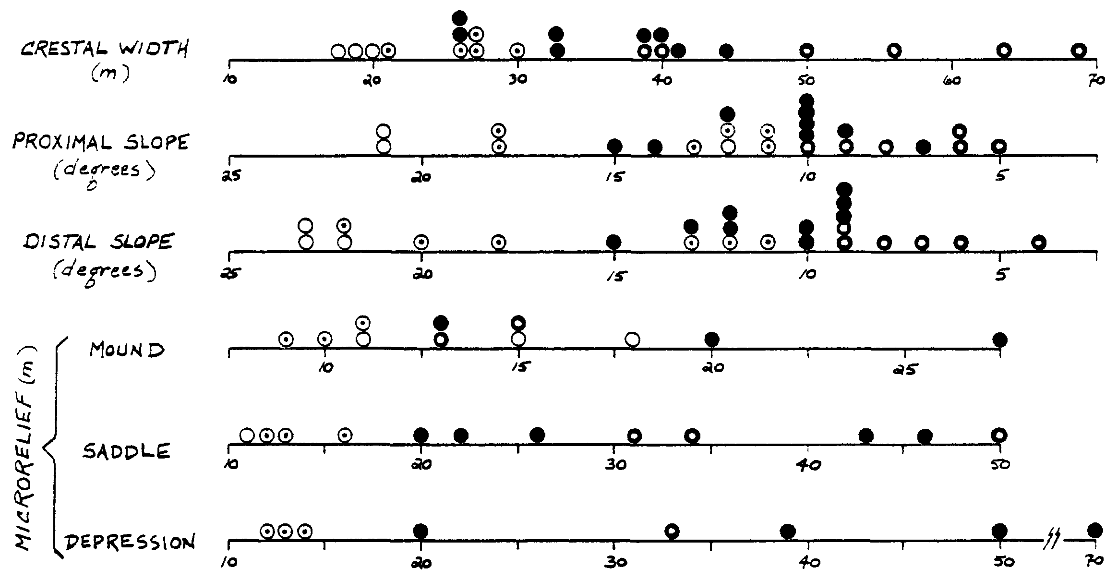


Figure 9.--Moraine morphology data. Symbols are the same as those in figure 8. See Methods section for measurement procedures.

DISCUSSION OF METHODS, AGES, AND CORRELATIONS

Thicknesses of weathering rinds on basaltic clasts appear to be the best age indicator for the glacial deposits in the McCall area. Rind measurements clearly and effectively differentiate deposits according to age, and subject to the validity of assumptions used for calibrating their logarithmic relation to time, they can be used to estimate numerical ages. Large numbers of rind measurements allow statistical analysis of representativeness, error, and sources of variation.

Soil development is also a good relative-age indicator for these deposits. Soils show a systematic progression, both qualitatively and quantitatively, with time, and they can be used to differentiate deposits according to stratigraphic age. Quantified measures and indices of soil development are complexly related to the ages estimated from weathering rinds, but are clearly a function of time. The rate of change of most of the indices decreases with time, commonly approximating a logarithmic time function. Statistical tests based on large numbers of soil profiles for each age of deposit are generally impractical.

Various measures of moraine morphology and surface-rock weathering tend to show a progression with deposit age, but in general, these data are rather crude age indicators compared to weathering rinds and soils. They tend to separate the deposits into two groups, Pilgrim Cove-McCall and Williams Creek-Timber Ridge.

The ages estimated from weathering-rind thickness (fig. 5) for the glacial deposits near McCall seem to correlate with times of high world-wide ice volume suggested by the marine oxygen-isotope record (Shackleton and Opdyke, 1973; Hays and others, 1976). Pilgrim Cove and McCall deposits clearly represent oxygen-isotope stage 2, and correlate with late Wisconsin deposits elsewhere. Rind thicknesses indicate ages in the range of 10,000 to

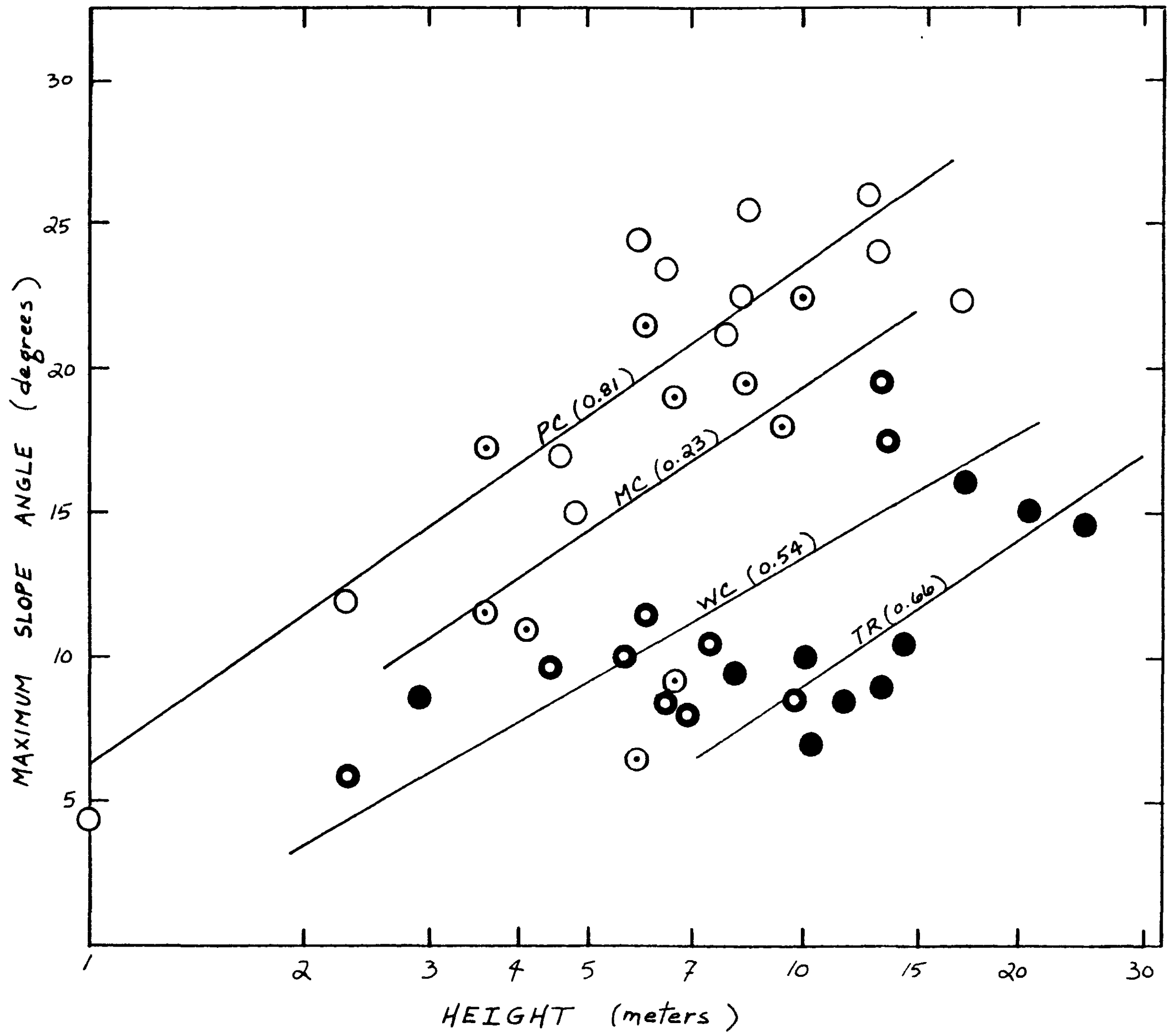


Figure 10.--Maximum distal-slope angle plotted against moraine height (logarithmic scale). PC and open circles, Pilgrim Cove; MC and open circles with closed centers, McCall; WC and closed circles with open centers, Williams Creek; TR and closed circles, Timber Ridge. Lines are least-squares regressions; r^2 values are given in parenthesis. See Methods section for measurement procedures.

25,000 years, with McCall deposits definitely older than Pilgrim Cove deposits (fig. 5). On the basis of regional age relations for late Wisconsin deposits in the western United States (Porter and others, 1983), 14,000 and 20,000 years are reasonable guesses for the ages of Pilgrim Cove and McCall deposits respectively.

Rind thicknesses suggest an age of about 50,000 years for Williams Creek deposits (fig. 5). These deposits are probably correlative with early Wisconsin deposits elsewhere and with oxygen-isotope Stage 4. If so, Williams Creek deposits are probably more like 60,000 years old, well within the age range associated with the standard error of the rind measurements. Measures of soil development (fig. 7) also are more consistent with an age of about 60,000 years.

We correlate Timber Ridge deposits with Bull Lake deposits near West Yellowstone, Montana, (Colman and Pierce, 1981) which are dated at about 140,000-150,000 years old (Pierce and others, 1976; Pierce, 1979). Although this correlation is subjective, relative-age data, especially weathering rinds and soil development, support it. This age places Timber Ridge deposits in the later part of oxygen-isotope Stage 6, and indicates a correlation with late(?) Illinoian deposits elsewhere.

Pre-Timber Ridge glacial deposits in which a buried soil is developed are exposed beneath Timber Ridge deposits along the Farm-to-Market Road near McCall. Rinds from the pre-Timber Ridge buried soil average only slightly less thick than the mean for Timber Ridge deposits (1.42 versus 1.61 mm), but they are well within the standard errors. These data suggest that pre-Timber Ridge glacial deposits are about twice as old as Timber Ridge deposits. If Timber Ridge deposits are about 140,000-150,000 years old and correlate with oxygen isotope stage 6, the buried pre-Timber Ridge deposits are probably one full glacial-interglacial cycle older, and may correlate with oxygen-isotope stage 8, which culminated about 260,000 years ago.

As Schmidt and Mackin's (1970) original study and mapping indicate, the McCall glacial sequence is in many ways similar to the classic Pinedale-Bull Lake sequence in other areas of the Rocky Mountains. However, because numerical dating control on Rocky Mountain glacial deposits is poor, support for regional correlations is generally weak. Pilgrim Cove and McCall deposits appear to correlate with the classic Pinedale, but similar separation of Pinedale deposits by relative-age criteria is rarely possible; early, middle, and late Pinedale deposits are commonly mapped, but such distinctions are based on sequence relations, not relative-age data. Williams Creek deposits are newly defined here and have relative-age properties that are clearly distinct from, and intermediate between, Pilgrim Cove-McCall (Pinedale) deposits and Timber Ridge (Bull Lake) deposits. If our correlation of Timber Ridge deposits with West Yellowstone Bull Lake deposits is correct, Williams Creek deposits are assuredly early Wisconsin in age. To our knowledge, Williams Creek deposits are the only strongly documented early Wisconsin glacial deposits in the Rocky Mountains, although we have suggested this age for glacial deposits in areas of the United States west of the Rocky Mountains (Colman and Pierce, 1981). Timber Ridge deposits appear to correlate with much of what has been called Bull Lake in the Rocky Mountains, including the dated West Yellowstone Bull Lake. However, the relation of the Timber Ridge and the West Yellowstone Bull Lake deposits to early and late Bull Lake deposits in the type area is uncertain.

ADDITIONAL DISCUSSION TOPIC

Our age estimates to a large degree hinge on correlation of Timber Ridge deposits with the 140,000-150,000-year-old West Yellowstone Bull Lake deposits. This correlation is strongly supported by relative-age data (Colman and Pierce, 1981). The relative-age data, especially rind-thickness and soil-development data, seem to require that Timber Ridge deposits be no younger than about 140,000 years, but they may not preclude an older age.

Deposits with characteristics that led to a Bull Lake age assignment were traditionally considered early Wisconsin in age. This tradition has been challenged in recent years by arguments for a pre-Wisconsin (oxygen-isotope stage 6) age for the Bull Lake at (1) West Yellowstone (Pierce and others, 1976; Pierce, 1979); (2) McCall (Colman and Pierce, 1981); (3) the Colorado Front Range (Madole and Shroba, 1979; Shroba and others, 1983); and (4) the

Wind River Mountains (Shroba, 1977; Pierce, 1979). Two of these areas, West Yellowstone and the Colorado Front Range, have numerical dates supporting the oxygen-isotope stage 6 correlation. The possibility of an age even older than 150,000 (for example, oxygen isotope stage 8, about 260,000 years old) has rarely, if ever, been considered. If many deposits with "Bull Lake character" are about 150,000 years old and correlate with oxygen isotope stage 6, their well-preserved morainal morphology suggests that stage 8 deposits (about 260,000 years old), if not buried by subsequent glaciations, might also retain morainal morphology. Thus, one of the key characteristics traditionally used to assign a Bull Lake age to deposits could be expected on stage 8 deposits. Thus, the relative-age criteria do not exclude the possibility that Timber Ridge deposits and some other deposits assigned to the Bull Lake may correlate with stage 8; this correlation would probably make Williams Creek deposits correlative with stage 6. Little data exist to place an older limit on the age of the Bull Lake Glaciation, and these speculations raise several questions. How long can morainal topography be preserved? What is the oldest that deposits of "Bull Lake character" can be?

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ROAD LOG

Trip begins at the visitor center parking lot of Ponderosa State Park. The field trip route is shown in figure 10. The flats around the visitor center are underlain by outwash of Pilgrim Cove age. We will be driving across this outwash from here to Stop 1.

Mileage Cummul.	Between	Observations
0.0	0.0	Exit to Ponderosa State Park. Turn right.
0.2	0.2	Bear left, stay on paved road.
0.6	0.4	Flashing red light; turn left (Lick Creek Road).
1.3	0.7	Fairways of the McCall golf course on the right.
1.8	0.5	Road bears to the left. Ridges on skyline to the right are lateral moraines of McCall age.
2.1	0.3	Turn sharply left onto small dirt road and park.

STOP 1. Moraines of Pilgrim Cove age. The roadcut along Lick Creek Road exposes a shallow weathering profile in till of Pilgrim Cove age. This is the youngest of the glacial deposits observed in the McCall area, and the inner part of what was mapped as Pinedale by Schmidt and Mackin (1970). On the basis of weathering rinds and dates of deglaciation elsewhere in the Rocky Mountains, we think Pilgrim Cove deposits are about 14,000 years old (fig. 5). Rinds on basaltic clasts from Pilgrim Cove deposits range from about 0.1 to 0.4 mm thick and average 0.25 mm. The soil developed here is shallow, with only incipient (cambic) B horizon development (table 2). Oxidation is slightly shallower and less intense than at other localities on Pilgrim cove deposits (table 2), possibly because of a lower percentage of basaltic clasts here (about 20 percent here; generally 60-80 percent at other sites). Morainal morphology is fresh and distinct, and many closed depressions and small topographic features are preserved.

2.1	0.0	Turn around; retrace route along Lick Creek Road to the west.
3.6	1.5	Flashing red light; turn left onto Davis Avenue.
4.0	0.4	Leave Pilgrim Cove outwash, enter McCall moraine belt.
4.1	0.1	Flashing yellow light; turn right onto Hemlock Street.
4.3	0.2	Follow pavement to the left onto Roosevelt Avenue.
4.5	0.2	Follow pavement to the right onto Pine Street.
4.6	0.1	Bear left onto Lake Street. Payette Lake is ahead and on the right.

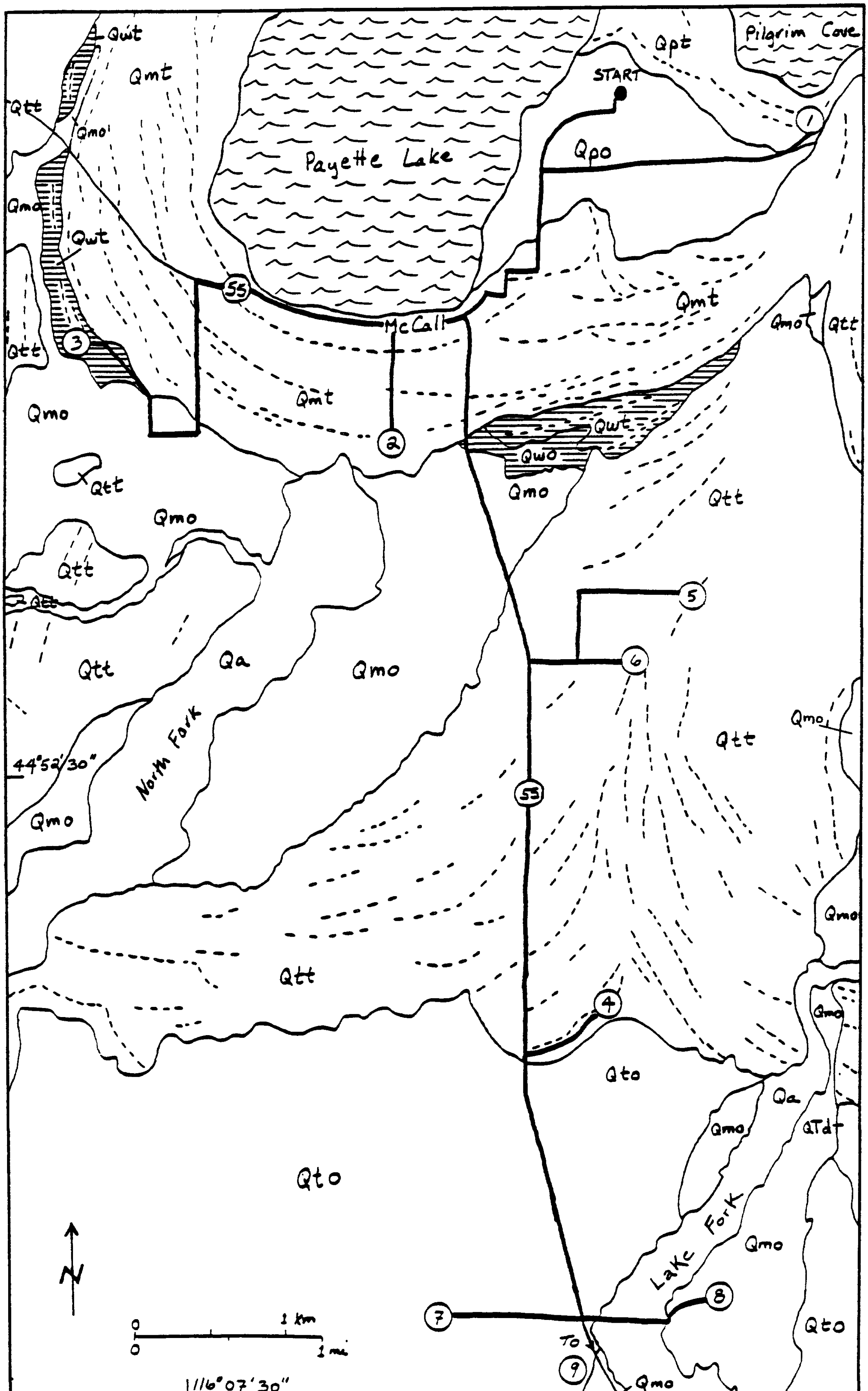

Figure 11.--Generalized map of the McCall glacial sequence showing field trip stops and route. Map units the same as those in fig. 3. Mapping modified from Schmidt and Mackin (1970).

4.7	0.1	Flashing red light and stop sign; bear right and continue on Lake Street through downtown McCall. Continue west on Lake Street.
5.1	0.4	Flashing yellow light; turn left onto Mission Street. Forest Service Headquarters is on the corner.
5.2	0.1	Roadcut through prominent moraine of the McCall moraine belt.
5.5	0.3	Roadcut through indistinct moraine.
5.8	0.3	Roadcuts through Cemetery moraine, the outermost moraine of the McCall moraine belt. Park beyond the moraine.

STOP 2. Moraines of McCall age. Roadcut on Mission Street exposes the weathering profile in till of McCall age, the outer part of the deposits mapped by Schmidt and Mackin (1970) as Pinedale. Based on weathering rinds, we think this deposit is about 20,000 years old (see fig. 5). Rinds on basaltic clasts in McCall deposits average 40 percent thicker (0.39 ± 0.18 mm here) than those in Pilgrim Cove deposits, and although the standard errors overlap, the difference is significant. Soils in McCall deposits tend to be deeper and better developed than those in Pilgrim Cove deposits, with incipient argillic B horizons (table 2). The moraines tend to be low and broad compared to Pinedale moraines in other areas, but closed depressions and small topographic irregularities are common. The weathering profile in the east roadcut is typical of McCall deposits; the west roadcut exposes a broad overthickened weathered zone that appears to represent the filling of a gentle swale along a double-crested section of the moraine.

5.8	0.0	Turn around; retrace route north along Mission Street.
6.4	0.6	Flashing red light and stop sign; turn left (west) onto West Lake Street.
6.7	0.3	Southern end of Payette Lake visible to the right. Payette Lake is dammed by moraines of the McCall moraine belt along which we are driving.
7.1	0.4	North Fork of the Payette River, the outlet of Payette Lake.
7.3	0.2	Power substation on the left.
7.5	0.2	Turn left onto dirt road (Boydston Street) at Doc's Doughnut sign.
7.9	0.4	Pavement begins.
8.0	0.1	Roadcut through low outermost McCall moraine.
8.2	0.2	Pavement bears to the left; continue straight on dirt road. Leave the McCall moraine belt and drive onto McCall outwash.

8.3	0.1	Turn right at unmarked intersection.
8.6	0.3	Road turns to the left; stop just beyond corner and park. Walk about 1.5 km due north along fence line road to gate, then northwest to Stop 3. If gate is open we will drive into Stop 3.

STOP 3. Williams Creek moraine. This moraine is a remnant of one of two small moraines that appear to be intermediate in age between the two general moraine belts mapped by Schmidt and Mackin (1970) as Pinedale and Bull Lake, respectively. The moraine at Stop 3 was mapped as Pinedale; similar small remnants on the east side of the Payette ice lobe were mapped as Bull Lake. Based on weathering rinds and other data, we think these deposits are about 60,000 years old (see text and fig. 5). Both soils and weathering rinds in Williams Creek deposits are clearly intermediate between those in McCall (Pinedale) and Timber Ridge (Bull Lake) deposits. The soil pit exposes a soil with distinct argillic B horizons and oxidation to a depth of 156 cm (table 2). Weathering rinds on basaltic clasts are 0.84 ± 0.19 mm thick at a nearby site. Williams Creek moraines tend to be broader and have gentler slopes than McCall moraines (fig. 9), although the difference is not striking.

		Walk or drive back to corner at mileage 8.6.
8.6	0.0	Retrace route back to Boydston Street and north along Boydston Street back to West Lake Street.
9.8	1.2	Stop sign; turn right (east) onto West Lake Street.
10.2	0.4	North Fork of Payette River.
10.8	0.6	Flashing yellow light at Mission Street; continue straight on Lake Street.
11.2	0.4	Flashing yellow light; turn right, following State Highway 55, south out of McCall.
11.7	0.5	Roadcut on left through outermost McCall moraine. Leave McCall moraine belt and drive onto outwash terrace of McCall age.
12.2	0.5	McCall airport on the right, built on the outwash terrace of McCall age.
12.8	0.6	Leave the McCall outwash terrace and rise onto morainal topography of the Timber Ridge moraine belt. From here to Stop 4, note the subdued but distinctly morainal topography of the Timber Ridge moraine belt, with large poorly drained areas and broad, subdued ridges. Much of the surface we are driving across is covered by 0.5-1.5 m of loess.

14.5	1.7	Outermost Timber Ridge moraine visible to the left from about 10 o'clock to about 12 o'clock. Note the distinct morainal form.
15.3	0.8	Turn left onto small unmarked dirt road on the nose of the outermost Timber Ridge moraine. Follow dirt road along the distal slope of the moraine.
15.9	0.6	Cul-de-sac at the end of the dirt road.

STOP 4. Outermost Timber Ridge moraine. We correlate Timber Ridge deposits with the West Yellowstone Bull Lake, about 140,000-150,000 years old (see text). This moraine is subdued, but retains well-preserved, distinct morphology. This and other Timber Ridge moraines tend to be broader and to have gentler slopes than younger moraines (fig. 9), but the basic form is clearly constructional. There are no closed depressions in the terminal area, but poorly drained areas are common. A few bogs are located between Timber Ridge lateral moraines west of Payette Lake. Visible just beyond this moraine is a line of large, cavernously weathered, grantitic boulders that probably marks the greatest extent of Timber Ridge ice (Schmidt and Mackin, 1970). Average rind thicknesses on basaltic clasts at sites along the crest of this moraine ranged from 1.44-1.96 mm. Low roadcuts from here back to the highway expose a thin loess mantle and a well-developed soil containing an argillic B horizon and thick, soft weathering rinds.

15.9	0.0	Retrace route back to State Highway 55.
16.5	0.6	State Highway 55; turn right (north).
18.0	1.5	Ridge to the right, essentially parallel to the road, is Timber Ridge, which is probably bedrock cored (Schmidt and Mackin, 1970). During Timber Ridge time, the ridge was a medial moraine between the Lake Fork ice lobe and the Payette Lake ice lobe.
18.6	0.6	Turn right onto Farm-to-Market Road.
18.9	0.3	Turn left at unmarked intersection.
19.2	0.3	Turn right onto dirt road at unmarked intersection.
19.9	0.7	Stop and park at T intersection.

STOP 5. Roadcut in Timber Ridge moraine. Roadcut through low ridge exposes a well developed weathering profile in till of Timber Ridge age. The soil contains a well developed argillic B horizon and is capped by post-Timber Ridge loess (table 2). It also contains a fragipan that is unoxidized except along joints. The genesis of this fragipan is not known, but silica, clay, or iron may be involved. Weathering rinds on basalt clasts from this locality averaged 1.52 ± 0.29 mm thick, and are relatively soft; such rinds would not survive on surface stones.

19.9	0.0	Turn around; retrace route back to Farm-to-Market Road.

20.5	0.6	Stop sign; turn left onto paved road.
20.9	0.4	Stop sign at junction with Farm-to-Market Road; turn left onto Farm-to-Market Road.
21.2	0.3	Roadcut on right exposes till of Timber Ridge age and a pre-Timber Ridge buried soil developed in drift. Park just beyond the roadcut on the right hand side of the road, on a small dirt road parallel to the paved road.

STOP 6. Till of Timber Ridge age and pre-Timber Ridge buried soil and drift. The roadcut along Farm-to-Market Road exposes drifts of two ages, Timber Ridge and pre-Timber Ridge, separated by a buried soil. The surface soil is developed in till of Timber Ridge age, and is similar to that at Stop 5, but does not contain an indurated pan (table 2). Rinds on basaltic clasts in the surface soil average 1.85 ± 0.61 mm thick and are relatively soft; rinds are virtually absent in the underlying unoxidized till. The buried soil is developed in pebbly sand (kame deposit?) underlying a surface sloping to the east. The buried soil is truncated and appears to be largely removed near the west end of the cut. It consists of a truncated, clayey, partially gleyed B horizon overlying a brightly oxidized C horizon (table 2). Rinds from the buried soil average 1.42 ± 0.29 mm thick, suggesting that the pre-Timber Ridge deposits are about twice as old as the Timber Ridge deposits. If Timber Ridge deposits correlate with oxygen-isotope stage 6 (about 140,000 years old), these pre-Timber Ridge deposits probably correlate with stage 8 (about 260,000 years old).

21.2	0.2	Turn around; retrace route following Farm-to-Market road back to State Highway 55.
21.8	0.6	Stop sign at State Highway 55; turn left (south) onto State Highway 55.
23.8	2.0	Outermost Timber Ridge moraine on the left. Leave the Timber Ridge morainal belt and drive out onto the Timber Ridge outwash terrace.
25.3	1.5	Enter the town of Lake Fork.
25.4	0.1	Turn right onto paved road at main intersection.
26.1	0.7	Stop and park on pull-out on the left-hand side of the road. Be careful parking.

STOP 7. Timber Ridge outwash. The gently sloping roadcut exposes 2.2 m of pebbly, fine-grained sediment overlying relatively well sorted, oxidized, sandy outwash gravel. The upper one meter of the fine-grained mantle is silty and stone-poor and seems to be primarily a coarse loess. The lower part of the fine-grained mantle has abundant coarse sand and pebbles in addition to silt and clay, and may be an overbank alluvial deposit. Weathering in the fine-grained mantle seems to increase progressively downwards, although no distinct buried soil is evident. The depth of gravel below the surface is too great for maximal rind development, but soft, orangish rinds 1-2 mm thick are present on basaltic clasts in the upper part of the gravel and the lower part

of the fine-grained mantle.

26.1	0.0	Retrace route back to town of Lake Fork.
26.9	0.8	Junction with State Highway 55 in the town of Lake Fork. Cross State Highway 55 and proceed straight ahead.
27.1	0.2	Descend from the Timber Ridge outwash terrace down onto the floodplain of Lake Fork.
27.3	0.2	Cross Lake Fork.
27.4	0.1	Ascend onto the McCall outwash terrace. Turn left into gravel pit.
27.7	0.3	East end of gravel pit.

STOP 8. McCall outwash. Gravel pit exposes outwash of McCall age from the Lake Fork glacial lobe. Basalt clasts are much less common than they are in deposits of the North Fork lobe. Rinds on basaltic clasts here range from about 0.2 to 0.5 mm. The gravel is continuously oxidized to depths of about 65 cm, and discontinuously oxidized along permeable beds to depths of about one meter.

OPTIONAL SIDE TRIP

This trip is to view highly weathered glacial drift(?) mapped as unit QTd_2 by Schmidt and Mackin (1970). Mileage begins at the main intersection in the town of Lake Fork.

0.0	0.0	"Downtown" Lake Fork. The town of Lake Fork is located on the Timber Ridge outwash terrace. Proceed south on State Highway 55.
0.1	0.1	Descend from the Timber Ridge outwash terrace onto the McCall outwash terrace.
2.5	2.4	Descend from the McCall outwash terraces onto Holocene terrace and the floodplain of Lake Fork.
3.1	0.6	Cross Lake Fork.
3.3	0.2	Rise from the floodplain of Lake Fork back onto the McCall outwash terrace.
7.0	3.7	Donnelly town limits.
7.2	0.2	Turn right, following signs for Rainbow Point campgrounds.
8.0	0.8	Upper end of Cascade reservoir. Reservoir bluffs are cut into the McCall outwash terrace. The outwash here is composed primarily of sand and fine gravel.

8.8	0.8	Follow paved road to left.
9.8	1.0	Follow main road to the right.
11.5	1.7	T intersection. Tamarack Falls store straight ahead. Turn sharply left onto dirt road. Proceed south along the west shore of the reservoir.
14.1	2.6	Turn right at sign: "Royal Scott Subdivision".
14.2	0.1	Turn right on first subdivision road to the right.
14.4	0.2	Low roadcuts and deeply weathered unit QTd_2.

STOP 9. Early Quaternary(?) glacial(?) deposits along the west side of Cascade Reservoir. Roadcuts expose deeply weathered deposits of possible glacial origin mapped as unit QTd_2 by Schmidt and Mackin (1970). The deposit seems to have been a sandy, poorly sorted diamicton that is now highly weathered to material with a clayey, reddish matrix to depths of more than 7 m. Granitic clasts are completely grussified and commonly difficult to even recognize. Basaltic clasts are generally altered all the way through, although some of the larger ones have small, relatively fresh cores. Many have exfoliating outer shells and can be cut through with a shovel. Only clasts composed of pegmatitic quartz are unaltered. Basalt weathering and rind development conservatively suggest an age of more than 0.5 m.y. for these deposits.

End of Field Trip