Lubetkin

FRIENDS OF THE PLEISTOCENE
1979
Man, a year of this and I'm off to Scripps and the South Seas!
Chow time
Hey, quit it, I'm a FRIEND Also!
MONO MAN
Question: How FAR SHOULD STUDENT CARRY DOG OF PROF'S FAMILY in MOUNTAINS? ANSWER: 27½ miles and up 8437'!!
MOE
Ask the automatic pipette
Soil data wrong??
WATCH FOR PEDS
$2.99/fifth
PEDO WATER
Notice: Please do not party beyond breakfast, unless a leader
Hunting rock glaciers w/ Mono Pass, 1962: Allan, Clyde, & Sue
Same rocks
Same place, 1976 w/ digging duo
QUESTION: How LIGHT ARE WEATHERED BOULDERS? ANSWER: LIGHT ENOUGH TO SNATCH AN JERK OVER YOUR HEAD!
Question: How deep do pits get?? ANSWER: Knee deep to a professor!
Pedo Tool G-15
SOILED Color Book
How deep shall I dig? Any one got a flash light?
pH
QUESTION: How DO YOU TELL SOIL FROM DIRT? ANSWER: Soil is in my hands, dirt is on my !!!
GET OUT OF HERE, THIS IS A FRIENDS OF THE PLEISTOCENE TRIP
Oh, darn it was fun
These guys are crazy, this isn't a IIB21tgcab!
THAT IS A SOIL ???
Notice: This COVER has not been authorized by the director of anything, nor have the field trip Leaders......
Superfluous Publication number DC-10 OF UNIV. OF COLORADO QUAT-ALUMNI!
yes, clyde used to be a budding soil scientist!

1979 Friends of the Pleistocene

Field Conference

Part I

Glacial and Periglacial Deposits of the Mono Creek Recesses, west-central Sierra Nevada, California: Measurement of Age-dependent Properties of the Deposits

James C. Yount[1], Peter W. Birkeland[2], and R. M. Burke[2,3]

[1] 600 Terrace Ave., Half Moon Bay, Ca. 94019

[2] Department of Geological Sciences, University of Colorado, Boulder, CO. 80309

[3] Department of Geology, Humboldt State University, Arcata, Ca., 95521

Glacial and Periglacial Deposits of the Mono Creek Recesses, west-central Sierra Nevada, California: Measurement of Age-dependent Properties of the Deposits

The Recesses of Mono Creek consist of five north to northwest trending valleys, 2½ to 4½ miles (4.2 to 7.5 kilometers) long, connecting cirques on the north side of Mono Divide with the west-south-west flowing Mono Creek (Figure I-1). We will be examining glacial deposits, originally described and mapped by Birman (1964) as products of post-Altithermal glaciation, in the Fourth and Third Recesses.

Our fieldwork in this area took place during the summers of 1973 and 1976, with the intent of finding out how well relative-age techniques, as used on Neoglacial deposits in the Rocky Mountains (Benedict 1967, 1968; Birkeland, 1973; Carroll, 1974) would work in a Sierra Nevada region. Thus, the main theme of this day's discussion will be relative dating of cirque deposits in the Fourth and Third Recesses, with particular emphasis on the kinds of measurements made and the relative-age groupings of deposits that can be interpreted from the data.

Relative Dating Methods

We are looking for age-dependent properties of Neoglacial deposits which will vary sufficiently over the past 10,000 years of Holocene time to be detectable by simple measurement or estimate. Such properties can be grouped into three catagories: those involving growth of vegetation on the deposits; those reflecting weathering of clasts at the surface of the deposit; and those indicating progressive degradation of the deposit's form. Table I-1 summarizes the properties and specific measurements which will be discussed during the traverse of Fourth and Third Recess.

Figure I-1: Index Map Of The Mono Recesses

(Numbers refer to localities listed in Table I-2)

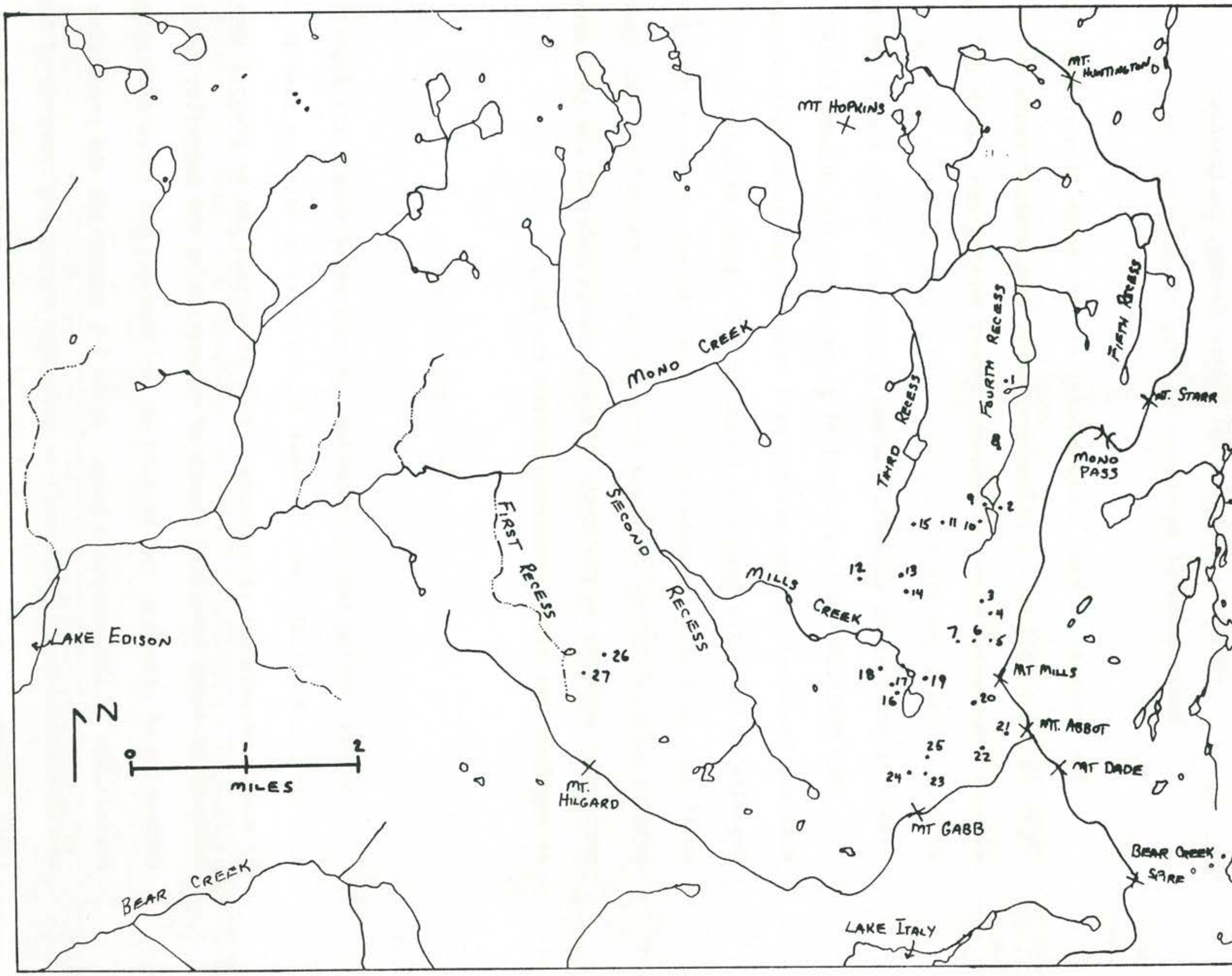


Table I-1 Relative Age Parameters

	Type	What Measured	Comment
VEGETATION	Lichen Diameters	Minimum diameter of thallus	Largest minimum diameter more useful than average diameter for age discrimination
	Lichen Cover	Percent of stone area covered by all lichens	Record average and maximum percent covers
	Tundra Cover	Percent of intraclast ground surface covered by tundra	Avoid areas of foot traffic
STONE AND DEPOSIT WEATHERING	Weathering Rinds	Thickness of weathering rind measured as nearly normal to clast surface as possible	Use average of ten or more stones
	Weathering Pits	Depth of weathering pits and percentage of clasts that have pits	Maximum pit depth more useful than averages. Avoid joints. Count 50 or more clasts for "percent pitted" measurement
	Inclusion Height	Relief of inclusion above clast surface	Measure both mafic and felsic types. Maximum height most useful, limited by inclusion diameter, however.
	Aplite Dike Relief	Relief of dike above clast or bedrock surface	Maximum value most useful discriminator
	Bedrock Knobs	Relief of knob above clast surface	Same as above
	Joint Depth	Depth below clast or bedrock surface that joint is enlarged due to weathering	Same as above
	Fresh/Weathered	Ratio of fresh to weathered clasts at deposit surface	Keep running tally of 50 or more clasts
	Oxidized/Non-oxidized	Ratio of clasts showing surface oxidation (iron staining) to those lacking oxidation	Same as above
	Soil Parameters	Profile development, depth to C_n, texture, color	
MORPHOLOGY	Slopes	Proximal and distal slope angles on moraines; Front angles on rock glaciers	
	Crest Widths	Width between points where proximal and distal moraine slopes exceed 5 degrees	Moraines only

No mention is made of the well-documented techniques of dendrochronology because most of the glacial deposits in the upper portions of the Recesses lie above tree line. Lichens are measured along their minimum width, in order to guard against measuring two intergrown thalli as one specimen. Various species of the
yellow/lime green w/ black spots — pea green or black (brown) — Lime green w/out black dots
genus *Rhizocarpon*, a few species of the genus *Lecanora*, and the species *Acarospora*
slow growing — fast growing
chlorophana have slow enough growth rates in this region to be useful as dating tools. Good examples of the application of lichenometry to dating of Holocene glacial deposits in the western United States may be found in Benedict (1967), Curry (1969, 1971), and Miller (1969).

Weathering properties which involve relief of some sort (pits, knobs, inclusions, joints, dikes) on clasts or bedrock surfaces are determined by measuring the distance normal to the clast or bedrock surface, that intersects the horizontal projection of the maximum relief element for any feature. The criteria for classifying a clast as "weathered" rather than "fresh" are presence of grain relief of more than one-half a grain diameter on more than one-half of the clast surface and rough, jagged facet intersections where clasts are derived from well-jointed sourcerock.

Soil description includes thickness, textural estimate , and moist color of discernable horizons in the field, supplemented by dry color, pH, texture, and percent organic matter from laboratory analysis of representative samples from each horizon.

Glacial Deposits in the Fourth and Third Recesses: Thursday August 23, 1979

Leaving the outlet of Fourth Recess Lake, find a fisherman's trail on the west side of the lake, and ascend steeply to about the 10,800 foot elevation. Contour to the south into Fourth Recess to:

Figure I-2: Sketch Map of Deposits in Fourth Recess

t = talus and scree covered slopes

L = lake

m = moraine

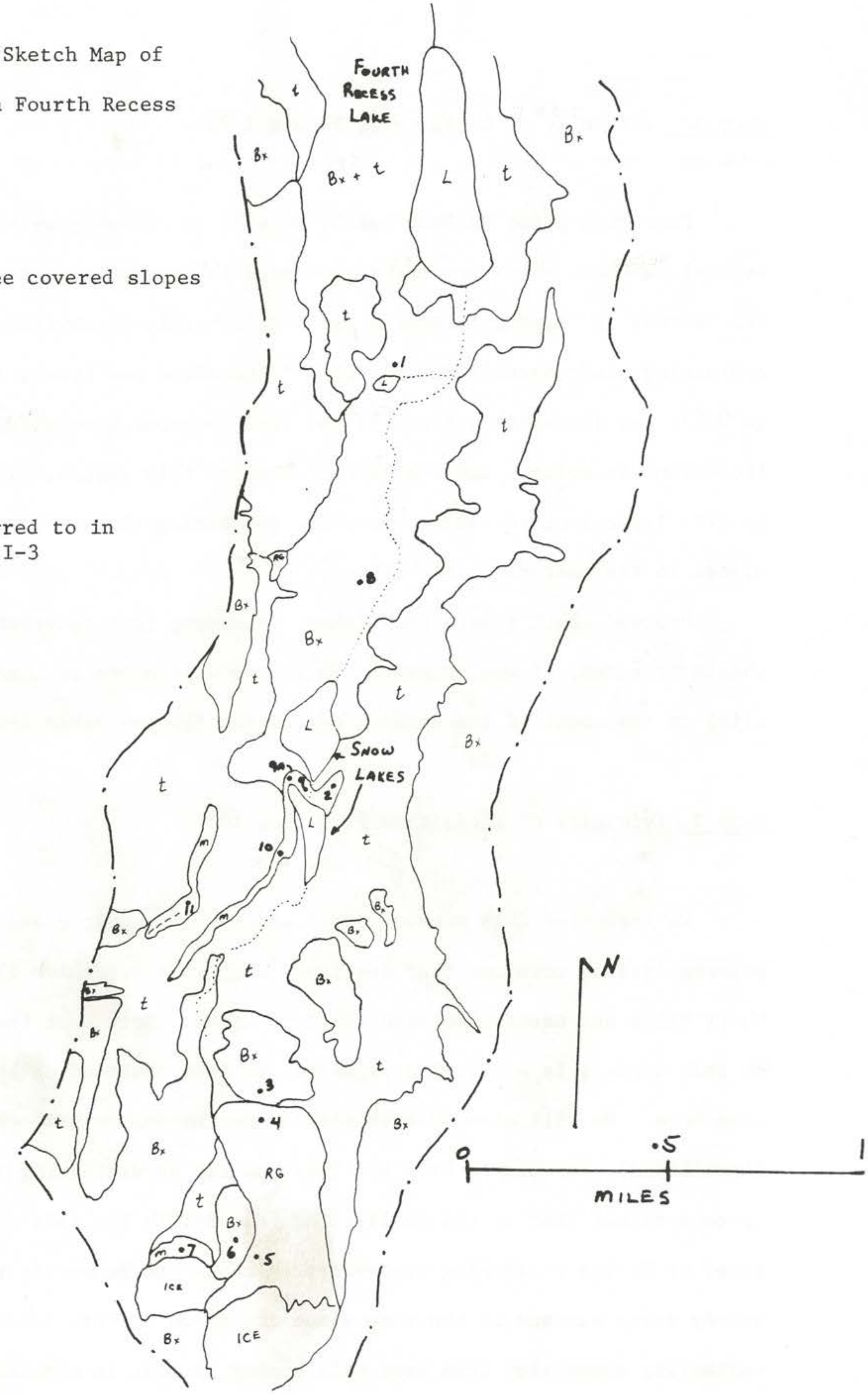
RG = rock glacier

Bx = bedrock

.8 = locality referred to in Tables I-2, I-3

——·——. = ridge crest

·······.·· = drainage



Stop 1 (vicinity of Locality 1, Figure I-2)

From this point to Snow Lakes, we will be crossing an erratic littered bedrock pavement which provides a good area to examine rock weathering features. The bedrock is "typically coarse grained, strongly porphyritic quartz monzonite containing minor hornblende and sphene" (Lockwood and Lydon, 1975). As indicated in Table I-2 (Localities 1 and 8), we find numerous weathering pits, knobs, inclusions in relief, and weathered joints in this region. This degree of weathering appears typical of post-late Wisconsin weathering that we have observed in other places in the western United States.

Proceed south toward Snow Lakes, recording your observations on the data sheets provided, if you so wish. Skirt the west shore of lower Snow Lake and climb to the crest of the moraine separating the two lakes for:

Stop 2 (vicinity of Localities 2, 9, 9A, 10)

We interpret this sinuous ridge and the one upslope and to the west to be western lateral moraines that developed alongside ice which flowed north off Mount Mills and terminated amid the Snow Lakes. Note that the clast weathering on this deposit is similar in magnitude to that observed on bedrock downvalley from here. We will also observe similar weathering on bedrock upvalley from here (Locality 3), enroute to Stop 3. Thus, as far as weathering is concerned, it appears either that 1) the still-stand responsible for this moraine was very short lived or 2) the weathering properties which we are measuring reach some kind of steady state maximum in the time since ice stood at this point, meaning that weathering downvalley from here will appear similar in magnitude even though

Table I-2: Relative Age Data From The Mono Recesses

Locality	Maximum Pit Depth (cm)	Percent Pitted (%)	Maximum Aplite Dike Relief (cm)	Maximum Joint Depth (cm)	Maximum Knob Relief (cm)	Maximum Felsic Inclusion Height (cm)	Maximum Mafic Inclusion Height (cm)	Percent Fresh Stones (%)	Average Weathering Rind Thickness[1] (mm)
1	12		8.5	21	11	23	5		
2	17								
3	14		8	24	12				
4	1.5	20				1.2		85	
5	0.5	4				0.5		95	
6	12		4	18	11	2.5		3	
7								100	
8	16			41	8	4			
9	14	31	2.5		14	3	4	11	9.3 (20)
9 A	14				13	2.2	11		
10	13	38	7		15	2	9	8	9.25 (20)
11	14	49	3		17	3.2	6	11	7.7 (20)
12	11	71	8	13	9	2	9	28	8.9 (10)
13	3	47	6			2	2	13	5.8 (12)
14		32						43	
15	14	83	10		10	3	5	7	9.3 (14)
16									
17	3.4	56				1.5		45	8.4 (25)
18	5.6	80	1.7		7	2	3.6	62	8.5 (25)
19	9.2					2			
20	5.7	78	1.5			1.2		36	3.8 (25)
21	0.0	0.0						100	0.0 (10)
22	14		3.3	27	15	2			
23	0.0	0.0						100	0.0 (10)
24	1.9	50				1.5		54	3.2 (24)
25									
25 A	8.6	56		8.5	9		2	40	
26	11	92	10.2		5.9	2.8		24	9.4 (25)
27	6	80	3.9		5.5	3	3.9	78	4.3 (25)

Table 1-2: Continued

Locality	Maximum Rhizocarpon Diameter (mm)	Maximum Acarospora Diameter (mm)	Maximum L. thompsonii Diameter (mm)	Average Percent Lichen Cover (%)	Suggested[2] Age Grouping	Age From Birman (1964)[3]
1						H?
2						H?
3				20	PA	Ti
4	23	11	120	5		M
5	30	51	52	5	H2	M
6				75	PA	Ti
7				0	H3	M
8	110				PA	H?
9	81	41	70	85	PA	
9 A					PA	M
10	75	46	85	85	PA	M
11	70	41	75	70	PA	
12			100	80	PA	RP
13	53	79	78	80	H1	M
14	34	75	105	10	H2?	M
15	87	67		80	PA	RP
16						
17	38		62	80		RP
18	63	19	.3	80		RP
19						RP
20	24	17	90	70	H2?	RP?
21		2		0	H3	M
22					PA	Ti?
23		21	39	1	H3	M
24	25	46	49	20		M
25	17	24	71	25		M
25 A						Ti
26	50		124	80	PA	RP?
27	51	20	48	75		RP (Type)

NOTES: [1] Number in parenthesis is number of stones measured.

[2] H3=Late Neoglacial, H2=Mid Neoglacial, H1=Early Neoglacial, PA=Pre-Altithermal

[3] M=Matthes, RP=Recess Peak, H=Hilgard, Ti=Tioga

Table I-3: Soil Profile Descriptions

Locality 9

Depth (cm)	Horizon	Description
0		*
	B_t	nonsticky gritty,sandy loam 10YR 4/3 (moist)
10		
20		
	C_{ox}	gritty sandy loam 2.5Y 5/3 (slightly moist)
30		
40	C_n	nonsticky,nonplastic, gritty sandy loam to loamy sand; 2.5Y 7/2 (slightly moist)
50		

* Just a trace of A-Horizon under sparse vegetation

Locality 10

Depth (cm)	Horizon	Description
0		gruss
5		
	B_s	sandy loam, 10YR 4/3 (slightly moist)
10		
15		
	C_{ox}	sandy loam, 2.5Y 5/2 (moist)
20		
25		
30	C_n	sandy loam, 2.5Y 6/2 (moist)

Locality 11

Depth (cm)	Horizon	Description
0		gruss
10		
	B_t	slightly plastic, nonsticky sandy loam 10YR 4/3 (moist)
20		
30	C_{ox}	nonsticky, nonplastic sandy loam to loamy sand 2.5Y 5/2 (moist)
40	C_n	same texture as C_{ox}; 2.5Y 6/2 (moist)

Locality 13

Depth (cm)	Horizon	Description
0		gruss
5	C_{ox}	gritty sandy loam to loamy sand 2.5Y 5/2 (moist)
10		
15	C_n	same texture as C_{ox}; 2.5Y 6/2 (moist)
20		

that region may have been ice-free for a significantly longer period of time.

Our preference, at this time, is that these deposits are the latest Wisconsin recessional moraines in Fourth Recess. The soils developed here (Table I-3) provide most of the support for this conclusion. Soil profiles with color or argillic B horizons, and oxidation to 30 or more centimeters depth, are more akin to profiles developed on late Wisconsin Tioga moraines, than to any Neoglacial soils from this region.

If our guess at a late Wisconsin age for these deposits is correct, then lichens will be of little age-determinant value here, because Rhizocarpon and Acarospora reach maximum diameter (120 mm or so) within 2800 years in the High Sierra (Curry, 1969).

Now ascend to the lip of the rock glacier south of here, beneath Mount Mills (an easy enough thing to say, but not so easy to do. Use extreme care working up to the top of rock glaciers. Most boulders in the active face are unstable!!). Be sure to note the degree of bedrock weathering near Locality 3, on your way to:

Stop 3 (vicinity of Localities 4 and 5)

Note immediately the fresher nature of clasts and lower lichen and tundra covers than on deposits seen previously. The lichen story is a bit inconsistent here, with Locality 5 Rhizocarpon and Acarospora diameters larger than those at Locality 4, and weaker lichen covers (5%) than are usually associated with lichens this big. Still, lichens are large enough and weathering strong enough that much of the debris here appears to pre-date the "Little Ice Age" or Matthes age deposits of the last few hundred years. Traversing to the west from Locality 5 we arrive at:

Stop 4 (Locality 7)

This moraine is a good example of a "Little Ice Age" deposit, typically found immediately in front of small cirue glaciers in the Sierra. Note the lack of weathering of clasts and the virtual lack of lichens.

Continue traversing to the northwest into the col above Locality 11 which leads to Third Recess. From the col, pick your way carefully down the large crack to the left (south) of the prominant bedrock slabs, then work your way to the surface of the rock glacier in the back of Third Recess:

Stop 5 (Localities 13 and 14)

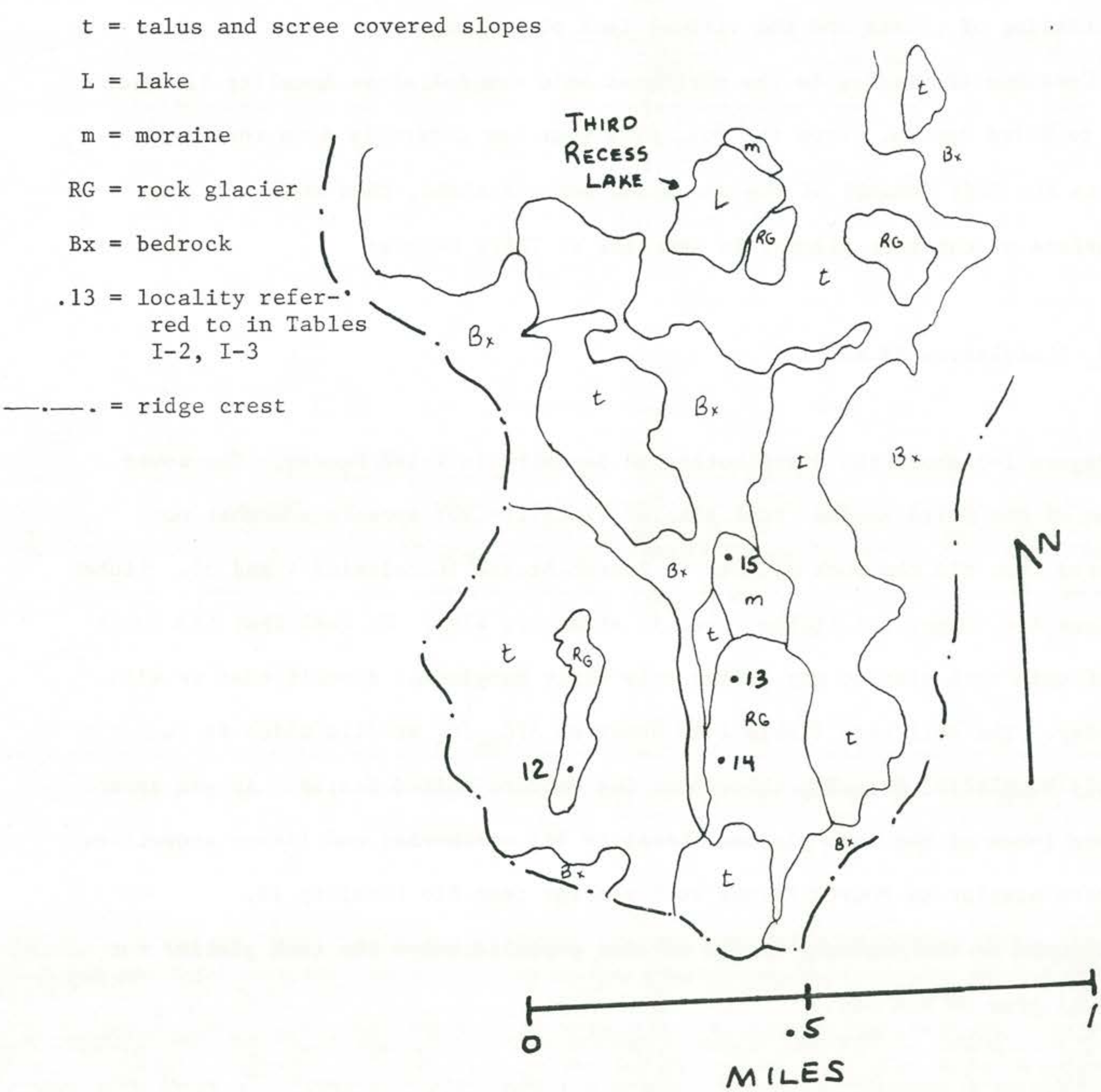
Figure I-3 shows the distribution of deposits in Third Recess. The lower portion of the Third Recess rock glacier (locality 13) appears somewhat more weathered than did the rock glacier in Fourth Recess (Localities 4 and 5). Lichen diameters are larger and lichen cover is stronger, also. We feel that the outer lobe of this rock glacier may be the only early Neoglacial deposit that we will see today. The soil here (Table I-3) shows an $A/C_{ox}/C_n$ profile which is common on early Neoglacial deposits throughout the western United States. As you ascend to inner lobes of the rock glacier (Locality 14) weathering and lichen properties look more similar to Fourth Recess rock glacier than did Locality 13.

Descend to the hummocky tundra covered deposits below the rock glacier for the final stop of the day:

Stop 6 (Locality 15)

These probable moraines were mapped by Birman (1964) as Recess Peak (early

Figure I-3: Sketch Map of Deposits in Third Recess



Neoglacial) in age. Our weathering data strongly suggests that these deposits are similar to those in the vicinity of Snow Lakes (Localities 2, 9, 9A, 10). Again, we feel that weathering of this degree, and soils of this development are more typical of late Wisconsin deposits than post-Altithermal deposits, but until more absolute ages are available in the Sierra Nevada, we will have treat this as a tentative correlation.

Exit Third Recess by descending to Third Recess Lake and finding the trail on the east side of the outlet, which stays east of the creek to Mono Creek. After crossing to the north side of Mono Creek, a good trail will take you east to Fourth Recess and a well-deserved night's sleep!

Leaving the Mono Recesses:
Friday August 24, 1979

Although examining alpine glacial deposits may be less attractive than it was before yesterday, your route back over Mono Pass will take you near some features that might be worth looking at. Figure I-4 shows locations of some deposits near Mono Pass. The rock glacier south of Trail Lakes, the moraine about one-half mile north of Summit Lake, and the deposits just south of Mono Pass are easily accessible. We have not collected data from these deposits yet, but some extra data sheets are provided if you would like to compare what you have seen yesterday with some unknowns.

In addition, after returning to cars at Mosquito Flat, you will drive through a sequence of Wisconsin and pre-Wisconsin moraines as you descend Rock Creek. Figure I-5, taken from Birman (1964), shows the major moraine crests between Rock Creek Lake and Highway 395.

Figure I-4: Sketch Map of Deposits in West Half of Fifth Recess and South of Mono Pass

t = talus and scree covered slopes

L = lake

m = moraine

RG = rock glacier

Bx = bedrock

—.—· = ridge crest

·.·.·.· = drainage

– – – – = Mono Pass Trail

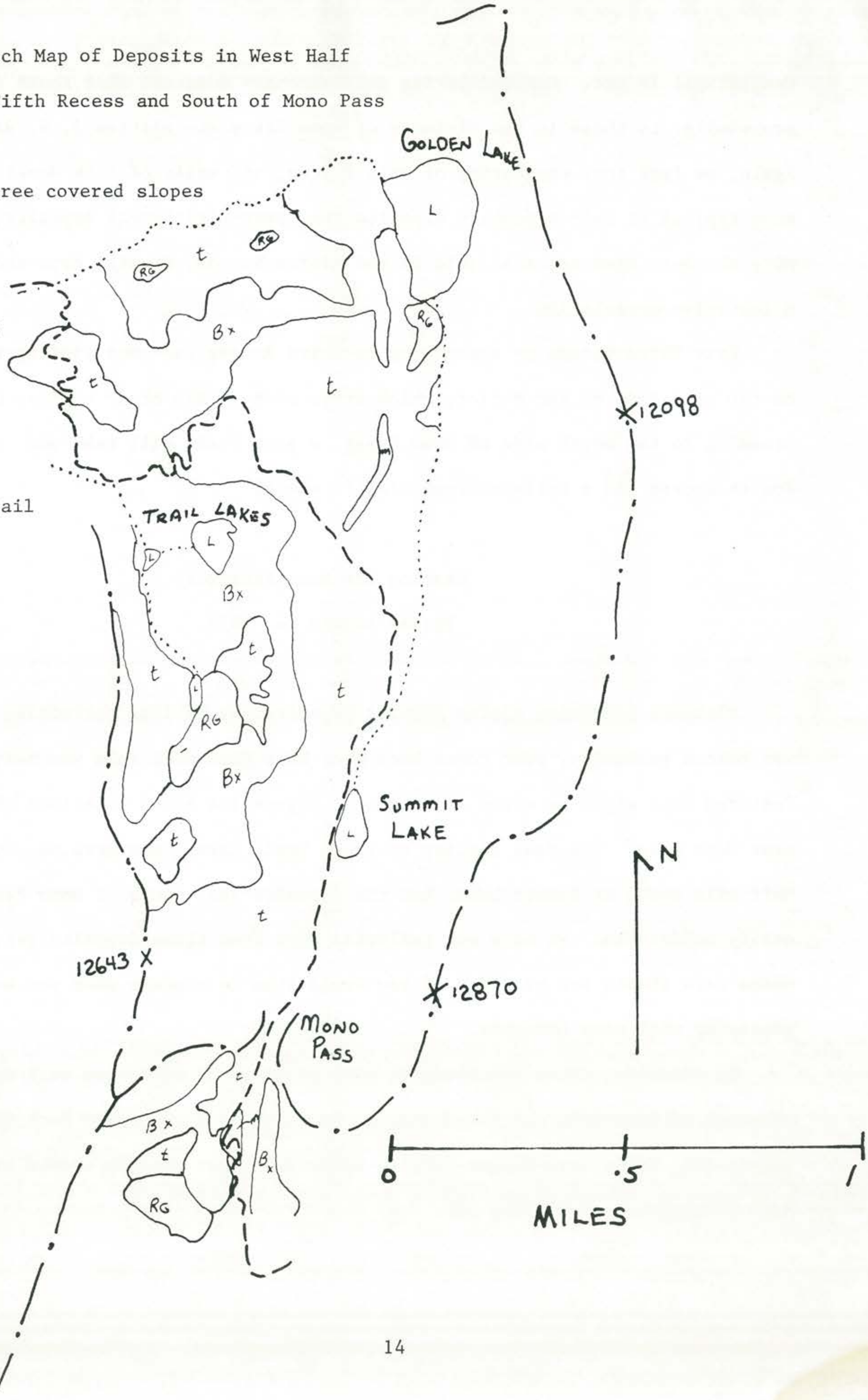


Figure I-5: Wisconsin and Pre-Wisconsin Moraines

Along Rock Creek-- From Birman, 1964

H = Hilgard

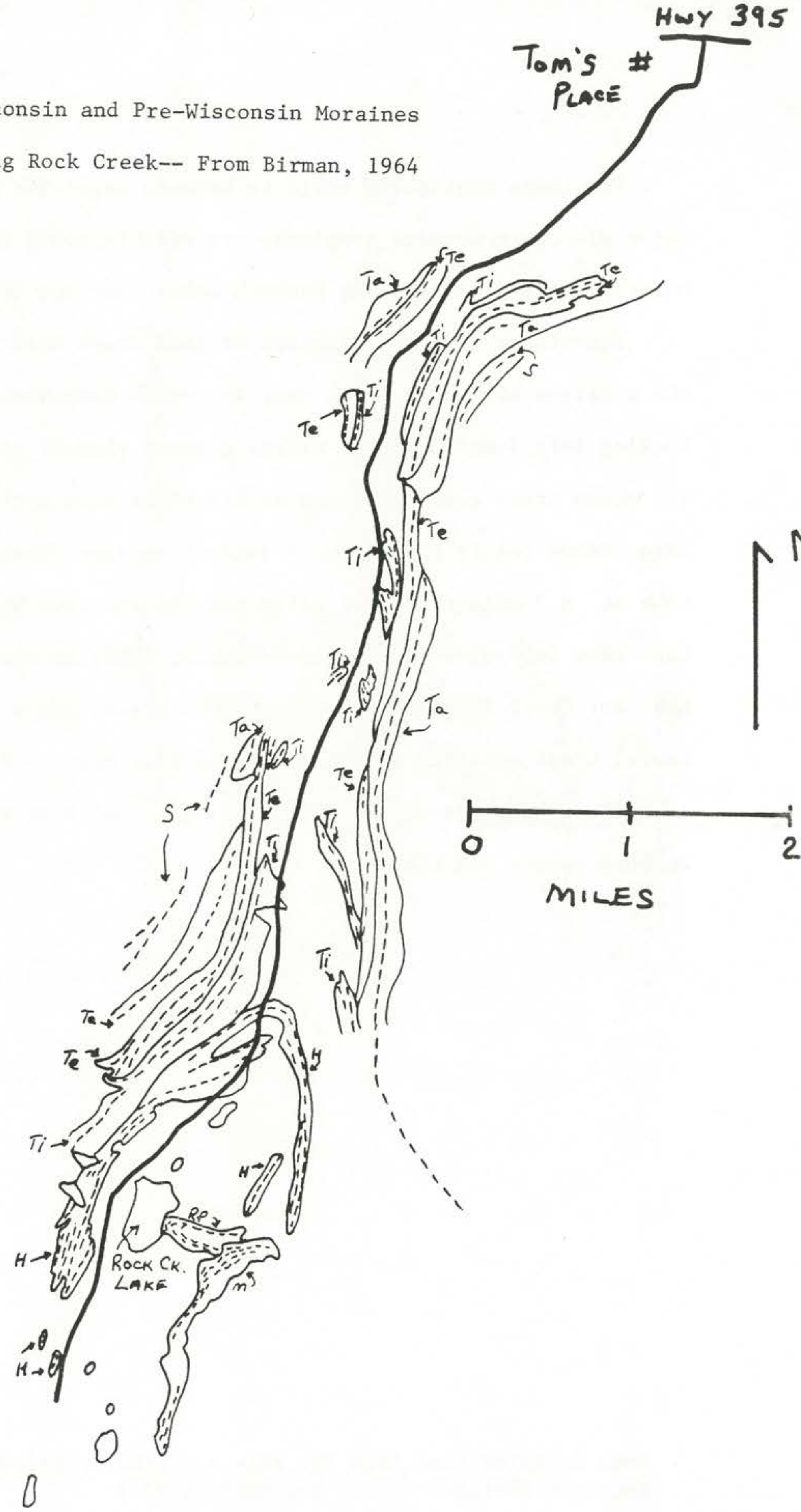
Ti = Tioga

Te = Tenaya

Ta = Tahoe

S = Sherwin

---- = moraine crest



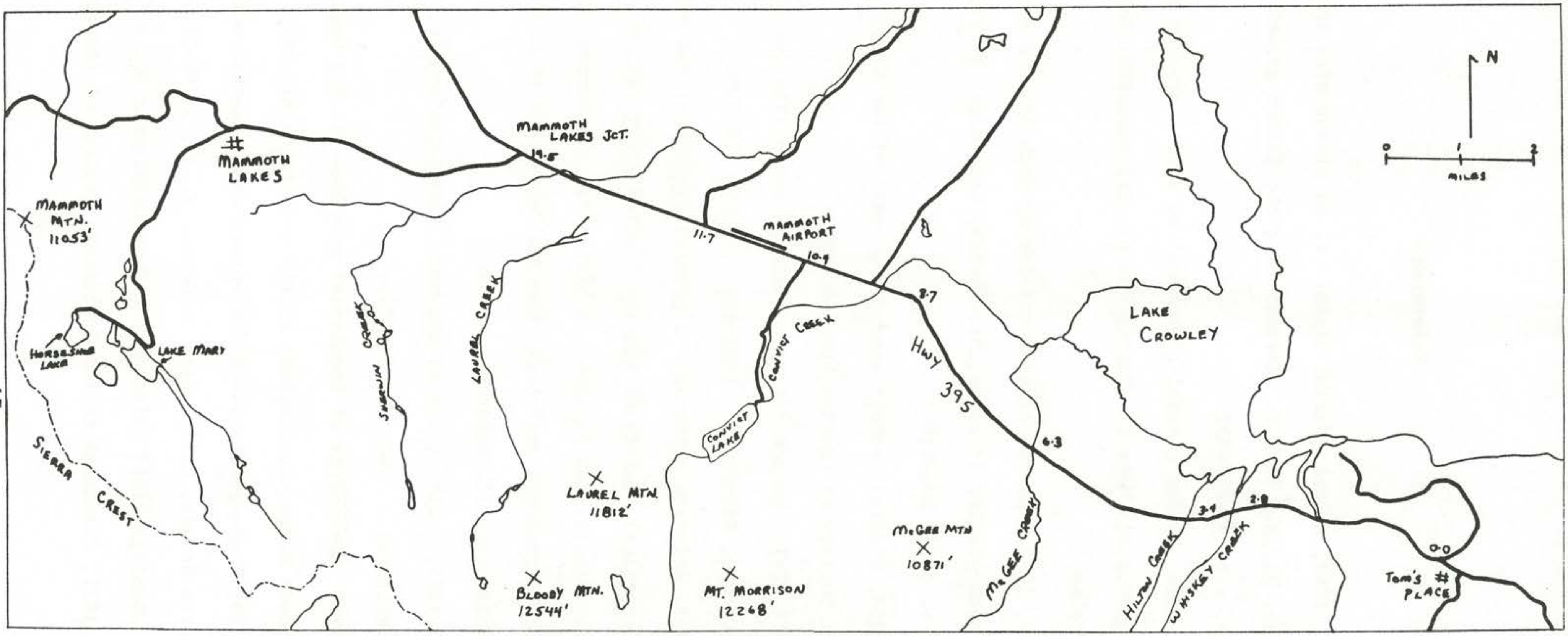
For those continuing north to Mammoth Lakes for Part II of the trip, four major Wisconsin moraine complexes are visible south and west of Highway 395, between Tom's Place and the Mammoth Lakes Junction (Figure I-6).[1]

Starting at the intersection of Rock Creek Road and Highway 395 (0.0 miles), the moraines of McGee Creek come into view dead ahead (west) at 2.8 miles. Looking left (south) at 3.4 miles, gives a view of the Hilton Creek moraine complex. The McGee Creek turn-off comes at 6.3 miles from Rock Creek Road, followed by the large Tahoe (early Wisconsin ?) lateral moraines trending northeast from Convict Lake at 8.7 miles. At 9.1 miles the mid and late Wisconsin moraines of Convict Lake come into view (described by Sharp, 1969) on the left (south). The Convict Lake-Hot Creek turn-off follows at 10.4 miles, and a good view left (south) of the Laurel Creek moraines comes shortly at 11.7 miles. Mammoth Lakes Junction (14.5 miles) is the correct turn-off to the group camp which is reserved at Horseshoe Lake. We hope to see you there.

[1] More detailed road logs for this and other portions of Highway 395 can be found in Sheridan (1971) and Sharp (1972)

Figure I-6: Geographic Features Between

Rock Creek and Mammoth Lakes



** Numbers along Highway 395 are milages

from Tom's Place referred to in text.

References

Benedict J. B., 1967, Recent glacial history of an alpine area in the Colorado Front Range, U.S.A., Part I. Establishing the lichen growth curve: Jour. Glaciology, v.6, p. 817-832.

______________ 1968, Recent glacial history of an alpine area in the Colorado Front Range U.S.A., Part II. Dating the glacial deposits: Jour. Glaciology, v. 7, p. 77-87.

Birkeland P. W., 1973, Use of relative are-dating methods in a stratigraphic study of rock glacier deposits, Mt. Sopris, Colorado: Arctic and Alpine Research, v. 5, p. 401-416.

Birman J. H.,1964, Glacial geology across the crest of the Sierra Nevada, California: Geological Society of America Special Paper 75.

Carroll T., 1974, Relative age dating techniques and a late Quaternary chronology, Arikaree Cirque, Colorado: Geology, v. 2, p. 321-325.

Curry R.R., 1969, Holocene climatic and glacial history of the central Sierra Nevada: Geological Society of America Special Paper 123, p.1-48.

__________,1971, Glacial and Pleistocene history of the Mammoth Lakes Sierra, California--A geologic guidebook; Montana Department of Geology, Geological Serial Publication 11, Missoula, Montana.

Lockwood J. P.,1975, Geologic map of the Mount Abbot Quadrangle, central Sierra Nevada, California: USGS Map GQ-1155.

Miller C. D.,1969, Chronology of Neoglacial moraines in the Dome Peak area, North Cascade Range, Washington: Arctic and Alpine Research, v.1, p. 49-66.

Sharp R. P.,1969, Semiquantitative differentiation of glacial moraines near Convict Lake, Sierra Nevada, California: J. Geol., v. 77, p. 68-91.

__________1972,Geology field guide to Southern California:Wm. C. Brown Co. Dubuque,Iowa

Sheridan M.F.,1971, Guidebook to the Quaternary geology of the east-central Sierra Nevada.

RELATIVE AGE DATA SHEET

Stop No. ____________________ Deposit Type and Location ____________________

____

Clast Lithologies ____________________

Morphology: Crest Width __________; Proximal Angle __________; Distal Angle __________

Weathering: Pit Depth __________; % Pitted Clasts __________; Joint Depth __________

Mafic Inclusion Relief __________; Felsic Inclusion Relief __________

Aplite Dike Relief __________; Knob Relief __________

Fresh/Weathered __________; Ox/ No Ox __________

Gruss/Boulder __________

Rinds: ____ ____ ____ ____ ____ ____ ____ ____ ____
____ ____ ____ ____ ____ ____ ____ ____ ____ ____
____ ____ ____ ____ ____ ____ ____ ____ ____

n = __________; $\bar{x}$ = __________

Vegetation: Maximum *Rhizocarpon* ____ ____ ____ ____ ____ ____

Maximum *Acarospora* ____ ____ ____ ____ ____ ____

Maximum *L. thompsonii* ____ ____ ____ ____ ____ ____

Other Lichens __________ ____ ____ ____ ____

__________ ____ ____ ____ ____

Maximum Lichen Cover __________; Average Cover __________ n = ______

Tundra Cover __________

Comments: ____________________________________

____

____

Name; Address:

I would like to receive a compilation of relative age data submitted by FOP participants. YES NO

RELATIVE AGE DATA SHEET

Stop No. ______________ Deposit Type and Location ______________

____

Clast Lithologies ______________

Morphology: Crest Width ________; Proximal Angle ________; Distal Angle ________

Weathering: Pit Depth ________; % Pitted Clasts ________; Joint Depth ________

Mafic Inclusion Relief ________; Felsic Inclusion Relief ________

Aplite Dike Relief ________; Knob Relief ________

Fresh/Weathered ________; Ox/ No Ox ________

Gruss/Boulder ________

Rinds: ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____

n = ________; $\bar{x}$ = ________

Vegetation: Maximum Rhizocarpon ____ ____ ____ ____ ____ ____

Maximum Acarospora ____ ____ ____ ____ ____ ____

Maximum L. thompsonii ____ ____ ____ ____ ____ ____

Other Lichens ________ ____ ____ ____ ____

________ ____ ____ ____ ____

Maximum Lichen Cover ________; Average Cover ________ n = ____

Tundra Cover ________

Comments: ______________

____

____

Name; Address:

I would like to receive a compilation of relative age data submitted by FOP participants. YES NO

RELATIVE AGE DATA SHEET

Stop No. ____________ Deposit Type and Location ____________

____

Clast Lithologies ____________

Morphology: Crest Width ________; Proximal Angle ________; Distal Angle ________

Weathering: Pit Depth ________; % Pitted Clasts ________; Joint Depth ________

Mafic Inclusion Relief ________; Felsic Inclusion Relief ________

Aplite Dike Relief ________; Knob Relief ________

Fresh/Weathered ________; Ox/ No Ox ________

Gruss/Boulder ________

Rinds: ___ ___ ___ ___ ___ ___ ___ ___ ___

___ ___ ___ ___ ___ ___ ___ ___ ___ ___

___ ___ ___ ___ ___ ___ ___ ___ ___

$n =$ ________; $\bar{x} =$ ________

Vegetation: Maximum _Rhizocarpon_ ___ ___ ___ ___ ___ ___

Maximum _Acarospora_ ___ ___ ___ ___ ___ ___

Maximum _L. thompsonii_ ___ ___ ___ ___ ___ ___

Other Lichens ________ ___ ___ ___ ___

________ ___ ___ ___ ___

Maximum Lichen Cover ________; Average Cover ________ $n =$ ________

Tundra Cover ________

Comments: ____________

____

____

Name;

Address:

I would like to receive a compilation of relative age data submitted by FOP participants. YES NO

RELATIVE AGE DATA SHEET

Stop No. ______________ Deposit Type and Location ______________

____

Clast Lithologies ______________

Morphology: Crest Width ________; Proximal Angle ________; Distal Angle ________

Weathering: Pit Depth ________; % Pitted Clasts ________; Joint Depth ________

Mafic Inclusion Relief ________; Felsic Inclusion Relief ________

Aplite Dike Relief ________; Knob Relief ________

Fresh/Weathered ________; Ox/ No Ox ________

Gruss/Boulder ________

Rinds: ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____

$n =$ ________; $\bar{x} =$ ________

Vegetation: Maximum *Rhizocarpon* ____ ____ ____ ____ ____ ____

Maximum *Acarospora* ____ ____ ____ ____ ____ ____

Maximum *L. thompsonii* ____ ____ ____ ____ ____ ____

Other Lichens ________ ____ ____ ____ ____

________ ____ ____ ____ ____

Maximum Lichen Cover ________; Average Cover ________ n = ________

Tundra Cover ________

Comments: ______________

____

____

Name; Address:

I would like to receive a compilation of relative age data submitted by FOP participants. YES NO

RELATIVE AGE DATA SHEET

Stop No. ____________________ Deposit Type and Location ____________________

____

Clast Lithologies ________________________

Morphology: Crest Width _________; Proximal Angle ________; Distal Angle _________

Weathering: Pit Depth _________; % Pitted Clasts ________; Joint Depth _________

Mafic Inclusion Relief ___________; Felsic Inclusion Relief ___________

Aplite Dike Relief _____________; Knob Relief ___________

Fresh/Weathered _____________; Ox/ No Ox ______________

Gruss/Boulder _______________

Rinds: ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____

$n =$ __________; $\bar{x} =$ ______________

Vegetation: Maximum _Rhizocarpon_ ____ ____ ____ ____ ____ ____

Maximum _Acarospora_ ____ ____ ____ ____ ____ ____

Maximum _L. thompsonii_ ____ ____ ____ ____ ____ ____

Other Lichens ____________ ____ ____ ____ ____

____________ ____ ____ ____ ____

Maximum Lichen Cover ________; Average Cover ________ n = ______

Tundra Cover ________

Comments: ____

____

____

Name; Address:

I would like to receive a compilation of relative age data submitted by FOP participants. YES NO

RELATIVE AGE DATA SHEET

Stop No. ______________________ Deposit Type and Location ______________________

____

Clast Lithologies ____________________________

Morphology: Crest Width __________; Proximal Angle _________; Distal Angle __________

Weathering: Pit Depth __________; % Pitted Clasts _________; Joint Depth __________

Mafic Inclusion Relief ____________; Felsic Inclusion Relief _____________

Aplite Dike Relief ________________; Knob Relief ______________

Fresh/Weathered ________________; Ox/ No Ox _________________

Gruss/Boulder __________________

Rinds: ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____

n = ____________; $\bar{x}$ = _________________

Vegetation: Maximum *Rhizocarpon* ____ ____ ____ ____ ____ ____

Maximum *Acarospora* ____ ____ ____ ____ ____ ____

Maximum *L. thompsonii* ____ ____ ____ ____ ____ ____

Other Lichens ______________ ____ ____ ____ ____

______________ ____ ____ ____ ____

Maximum Lichen Cover _________; Average Cover _________ n = ______

Tundra Cover _________

Comments: ____

____

____

Name; Address:

I would like to receive a compilation of relative age data submitted by FOP participants. YES NO

RELATIVE AGE DATA SHEET

Stop No. ____________________ Deposit Type and Location ____________________

____

Clast Lithologies ________________________

Morphology: Crest Width _________; Proximal Angle ________; Distal Angle ________

Weathering: Pit Depth _________; % Pitted Clasts ________; Joint Depth ________

Mafic Inclusion Relief ___________; Felsic Inclusion Relief ___________

Aplite Dike Relief ______________; Knob Relief ___________

Fresh/Weathered ______________; Ox/ No Ox _______________

Gruss/Boulder ________________

Rinds: ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____ ____

____ ____ ____ ____ ____ ____ ____ ____ ____

$n =$ __________; $\bar{x} =$ ______________

Vegetation: Maximum Rhizocarpon ____ ____ ____ ____ ____ ____

Maximum Acarospora ____ ____ ____ ____ ____ ____

Maximum L. thompsonii ____ ____ ____ ____ ____ ____

Other Lichens ____________ ____ ____ ____ ____

____________ ____ ____ ____ ____

Maximum Lichen Cover ________; Average Cover ________ n = ______

Tundra Cover ________

Comments: ____

____

____

Name; Address:

I would like to receive a compilation of relative age data submitted by FOP participants. YES NO

RELATIVE AGE DATA SHEET

Stop No. ____________________ Deposit Type and Location ____________________

____

Clast Lithologies __________________________

Morphology: Crest Width __________; Proximal Angle ________; Distal Angle ________

Weathering: Pit Depth __________; % Pitted Clasts _________; Joint Depth __________

Mafic Inclusion Relief ___________; Felsic Inclusion Relief ____________

Aplite Dike Relief ______________; Knob Relief ____________

Fresh/Weathered ______________; Ox/ No Ox _______________

Gruss/Boulder ________________

Rinds: ____ ____ ____ ____ ____ ____ ____ ____ ____
____ ____ ____ ____ ____ ____ ____ ____ ____ ____
____ ____ ____ ____ ____ ____ ____ ____ ____

n = __________; $\bar{x}$ = ______________

Vegetation: Maximum <u>Rhizocarpon</u> ____ ____ ____ ____ ____ ____

Maximum <u>Acarospora</u> ____ ____ ____ ____ ____ ____

Maximum <u>L. thompsonii</u> ____ ____ ____ ____ ____ ____

Other Lichens ____________ ____ ____ ____ ____

____________ ____ ____ ____ ____

Maximum Lichen Cover ________; Average Cover ________ n = ______

Tundra Cover ________

Comments: ____

____

____

Name; Address:

I would like to receive a compilation of relative age data submitted by FOP participants. YES NO

SOIL DESCRIPTION SHEET

DATE__________

DESCRIBED BY__________

PARENT MATERIAL__________

AGE__________

LOCATION__________

GEOGRAPHICAL LANDSCAPE__________

ELEVATION__________ SLOPE__________ ASPECT__________ EROSION__________

CLIMATE__________

VEGETATION__________

GREAT SOIL GROUP__________ DEVELOPMENT__________

REMARKS__________

HORIZON & DEPTH	COLOR	TEXTURE	STRUCTURE	CONSIST-ENCE	pH	OTHER

SOIL DESCRIPTION SHEET

DATE ____________

DESCRIBED BY ____________

PARENT MATERIAL ____________

AGE ____________

LOCATION ____________

____

GEOGRAPHICAL LANDSCAPE ____________

ELEVATION ____________ SLOPE ____________ ASPECT ____________ EROSION ____________

CLIMATE ____________

VEGETATION ____________

____

GREAT SOIL GROUP ____________ DEVELOPMENT ____________

REMARKS ____________

HORIZON & DEPTH	COLOR	TEXTURE	STRUCTURE	CONSIST-ENCE	pH	OTHER

SOIL DESCRIPTION SHEET

DATE ____________________

DESCRIBED BY ____________________

PARENT MATERIAL ____________________

AGE ____________________

LOCATION ____________________

GEOGRAPHICAL LANDSCAPE ____________________

ELEVATION __________ SLOPE __________ ASPECT __________ EROSION __________

CLIMATE ____________________

VEGETATION ____________________

GREAT SOIL GROUP __________ DEVELOPMENT __________

REMARKS ____________________

HORIZON & DEPTH	COLOR	TEXTURE	STRUCTURE	CONSIST-ENCE	pH	OTHER

SOIL DESCRIPTION SHEET

DATE ______________________

DESCRIBED BY ______________________

PARENT MATERIAL ______________________

AGE ______________________

LOCATION ______________________

____

GEOGRAPHICAL LANDSCAPE ______________________

ELEVATION __________ SLOPE __________ ASPECT __________ EROSION __________

CLIMATE ______________________

VEGETATION ______________________

____

GREAT SOIL GROUP __________ DEVELOPMENT __________

REMARKS ______________________

HORIZON & DEPTH	COLOR	TEXTURE	STRUCTURE	CONSIST-ENCE	pH	OTHER

FIELD GUIDE TO RELATIVE DATING METHODS APPLIED TO GLACIAL DEPOSITS IN THE THIRD AND FOURTH RECESSES AND ALONG THE EASTERN SIERRA NEVADA, CALIFORNIA, WITH SUPPLEMENTARY NOTES ON OTHER SIERRA NEVADA LOCALITIES*

by

R. M. Burke[1a] and P. W. Birkeland[1]

with contributions by

M. M. Clark[2], A. L. Walker[1a], and J. C. Yount[2]

Field Trip Guidebook for the

FRIENDS OF THE PLEISTOCENE

PACIFIC CELL

August 22-26, 1979

*This guidebook has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature. Many preliminary data and ideas are herein expressed, and no part of this guidebook should be used or referenced without the authors' permission.

[1]Geological Science, University of Colorado, Boulder, CO. 80309
[1a]Present address: U.S. Geological Survey, Menlo Park, CA 94025
[2]U.S. Geological Survey, Menlo Park, CA 94025

PREFACE

Welcome to the 1979 Pacific Cell Friends of the Pleistocene conference. We requested the opportunity to lead the 1979 FOP trip to demonstrate and discuss our use of various techniqus for determining relative age of glacial and periglacial deposits, as well as to introduce or re-introduce the friends to the Quaternary stratigraphy of the Sierra Nevada.

The works of many investigators including those by Blackwelder (1931), Putnam (1949, 1962), Matthes (1960), Sharp and Birman (1963), Birkeland (1964), Birman (1964), Janda (1966), Curry (1966, 1969, 1971), Clark (1967), and Sharp (1968, 1969, 1972) stand as ample evidence of the scrutiny that the Quaternary record of this region has undergone. Most of these previous studies have relied to some degree upon relative dating techniques for the development of local stratigraphies. Partly because of the extensive previous work, we choose this study area in an attempt to advance the usefulness of relative dating techniques.

Because of the paucity of radiometrically datable materials in meaningful stratigraphic positions and the ever growing need to know something about the age of Late Cenozoic deposits, relative dating is a very valuable geologic tool. In principle, relative dating is a measurement of those properties which are thought to change with time. Deposits exhibiting similar degrees of weathering, form, or soil development, as demonstrated by measurement of specific properties such as ratios of fresh to weathered clasts, degree of stream dissection, and depth to unweathered parent material are thought to be similar in age.

Our purposes in this field conference are to acquaint the participants with just how these specific properties are measured, and to introduce our relative dating results which yield somewhat different stratigraphic groupings than those previously established. We hope to create a type of workshop atmosphere, to stimulate lively discussion about the utility of the various relative dating techniques, and we want the participants to do a healthy amount of measuring and describing. We have included numerous work sheets within the guidebook for recording your own observations. Please use them and include any other observations that you think valuable age criteria. The leaders will be happy to tabulate and distribute the various measurements made by this year's participants if the group desires.

Part I of the field conference deals with various relative age measures applied to Holocene glacial and periglacial cirques deposits in the Fourth and Third Recesses, two north-south trending valleys just west of the Sierra Nevada crest, in the headwaters of Mono Creek.

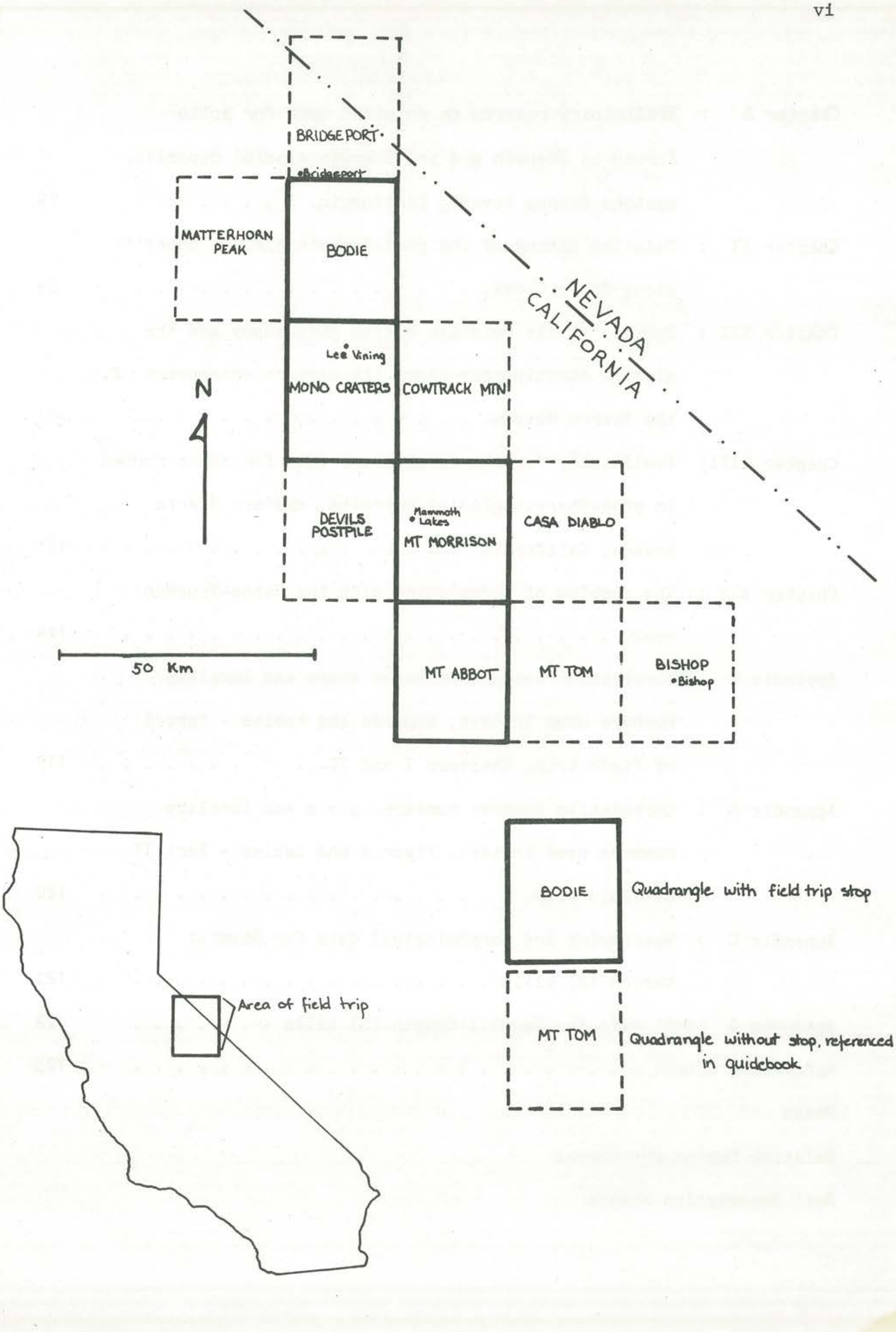
Part II of the field conference deals with the various relative age measures applied to several of the pre-Holocene glacial deposits lying along the eastern escarpment of the Sierra Nevada, btween Mammoth Lakes and the Bridgeport Basin.

The guidebook has been prepared from a series of papers that either have been published, are in review, or are in preparation for future publication. These papers have been somewhat segmented to facilitate their use in a step-by-step guidebook format, but will hopefully retain some of their cohesiveness. The guidebook and trip have been organized with an attempt to retain the professional informality of the FOP while giving the necessary organizational structure required by the present day population of our group.

Considering the large size of our group and the delicate terrain over which the field trip takes place--Part I lies within the John Muir Wilderness and both parts I and II are on very limited exposures of key geologic deposits--special constraints need to be involved. An overriding theme of this year's trip will be to minimize the environmental impact by our group. We request that no fires be used while camping in the wilderness. Please observe the open soil pits and the rinds developed on previously broken clasts, but minimize the breaking of all turf and boulders. This request to limit the use of hammers and picks should not be taken as an attempt to stifle your scientific curiosity, but rather an attempt to preserve the outcrop for more detailed analyses than we can perform in our short visit. A major measure of the success of this trip and of the true nature of the FOP will be the lack of any sign of our presence after we have left.

While some acknowledgments occur through the guidebook, we would like to recognize a number ofindividuals for their input. We wish to thank J. P. Whipple for his capable field assistance. The comments of J. H. Birman, R. R. Curry, G. B. Dalrymple, and R. P. Sharp concerning their previous works are most appreciated. This study has benefited from our discussions over the years with R. A. Bailey, M. M. Clark, S. M. Colman, R. R. Crandell, R. R. Curry, R. J. Janda, K. L. Pierce, R. P. Sharp, and C. Wahrhaftig. We appreciate the constructive criticisms of Clark, Janda, Pierce, and Sharp on parts of the manuscript (particulary Chapters III, IV, and XI) in its various stages. The valuable guidebook contributions by M. M. Clark, K. R. Lajoie, and A. L. Walker are most appreciative. The conclusions in each chapter are those of the author(s) and none of the above are necessarily in agreement with them. We also wish to thank Mr. Rolf Kihl of INSTAAR, University of Colorado, for much of the laboratory data. In preparation for the FOP trip, P.S. Mozley and A. L. Walker provide several hours of invaluable assistance. Part of the work of Burke and Birkeland was supported by U.S.G.S. Grant No. 14-08-0001-G-202, and part of the work by Birkeland, Burke, and Walker was supported by N..S.F. Grant No. EAR7681241. Our thanks to all involved.B. B., J. Y., P. B., August, 1979.

Table of Contents


BRIDGEPORT
•Bridgeport
MATTERHORN PEAK
BODIE
NEVADA
CALIFORNIA
Lee Vining
MONO CRATERS
COWTRACK MTN
N
DEVILS POSTPILE
Mammoth Lakes
MT MORRISON
CASA DIABLO
50 Km
MT ABBOT
MT TOM
BISHOP
•Bishop
Area of field trip
BODIE
Quadrangle with field trip stop
MT TOM
Quadrangle without stop, referenced in guidebook

CHAPTER II

Preliminary thoughts on chemical trends in late Quaternary Soils, Recesses area, Sierra Nevada

P. W. Birkland, A. L. Walker, and R. M. Burke

We have been analyzing soils formed on late Quaternary deposits in the alpine area of the Recesses in order to determine those chemical data which best correlate with the relative ages of deposits. We here give data on oxalate-extractable Fe and Al (Fe_o, Al_o), dithionite-extractable Fe and Al (Fe_d, Al_d), acid-extractable P (P_a), and organic-bound P (P_o). See Chapter X for what the extracts are, and the expected trends. We here give data (Table II-1) for the 3rd and 4th Recesses (locs. 13, 9, and 11), and for the 2nd and 1st Recesses (loc. 24, 18, 20, 26). Although the soil data are better for the latter area, this field trip is confined to the former field area.

A brief summary of the trends shown in figures II-1, II-2, II-3, and II-4 follows:

1. The Fe and Al fractions follow predictable accumulation patterns with time; soils in the 2nd and 1st Recesses show accumulations to greater depths than those in the 3rd and 4th.

2. Po accumulates with time, but Pa behaves a bit erratic; in some profiles Pa increases toward the surface, whereas in others it decreases toward the surface.

3. Compared with other alpine areas for which we have similar data (Rocky Mountains, Himalaya, Southern Alps of N.Z. (Birkeland and others, 1979), the rate of chemical change with time is slowest in the Sierra Nevada, perhaps because it is the driest of all areas thus far studied.

Table II-1. Chemical data for soils formed on glacial deposits of the Recesses. Figures II-1—II-4 show the age related trends with depth.

Field Location	Soil Locality	Horizon	Fe_o	Fe_d	Ab	Ald	Pa	Po
1st and 2nd Recesses	24	Cox	.07	.06	.13	.05	41.0	----
	24	Cn	.11	.05	.11	.04	39.6	----
	18	A	.11	.25	.46	.26	25.3	19.4
	18	Bs	.05	.12	.44	.18	35.6	8.2
	18	Cox	.03	.06	.34	.10	37.1	3.8
	18	Cn or C2ox	.01	.04	.26	.07	38.0	----
	20	A	.11	.23	.07	.06	61.3	3.6
	20	B	.03	.30	.15	.08	45.3	11.2
	20	IICox	.04	.17	.15	.06	40.4	13.3
	20	IICn	.03	.15	.09	.05	33.5	3.6
	26	A	.07	.18	.25	.17	44.2	8.0
	26	B2	.13	.34	.59	.30	50.1	13.8
	26	IIB3	.07	.23	.28	.16	35.9	4.2
	26	IICox top ½	.09	.15	.17	.09	48.9	.2
	26	IICox bottom ½	.03	.09	.10	.07	31.5	1.0
3rd and 4th Recesses	13	Cox	.06	.11	.16	.06	41.3	3.2
	13	Cn	.11	.08	.08	.02	32.6	.8
	9	Bt	.07	.14	.24	.11	28.2	37.3
	9	Cox	.06	.10	.17	.06	35.5	11.8
	9	Cn	.06	.09	.10	.05	45.1	4.2
	11	Bt	.08	.19	.46	.20	57.1	19.6
	11	Cox	.03	.08	.17	.06	46.5	3.6
	11	Cn	.04	.06	.14	.04	40.2	7.8

Fe_o -- Oxalate-extractable Fe

Fe_d -- Dithionite-extractable Fe

Al_o -- Oxalate-extractable Al

Ald -- Dithionite-extractable Al

Pa -- Acid (H_2SO_4)-soluble P

Po -- Organic-bound P

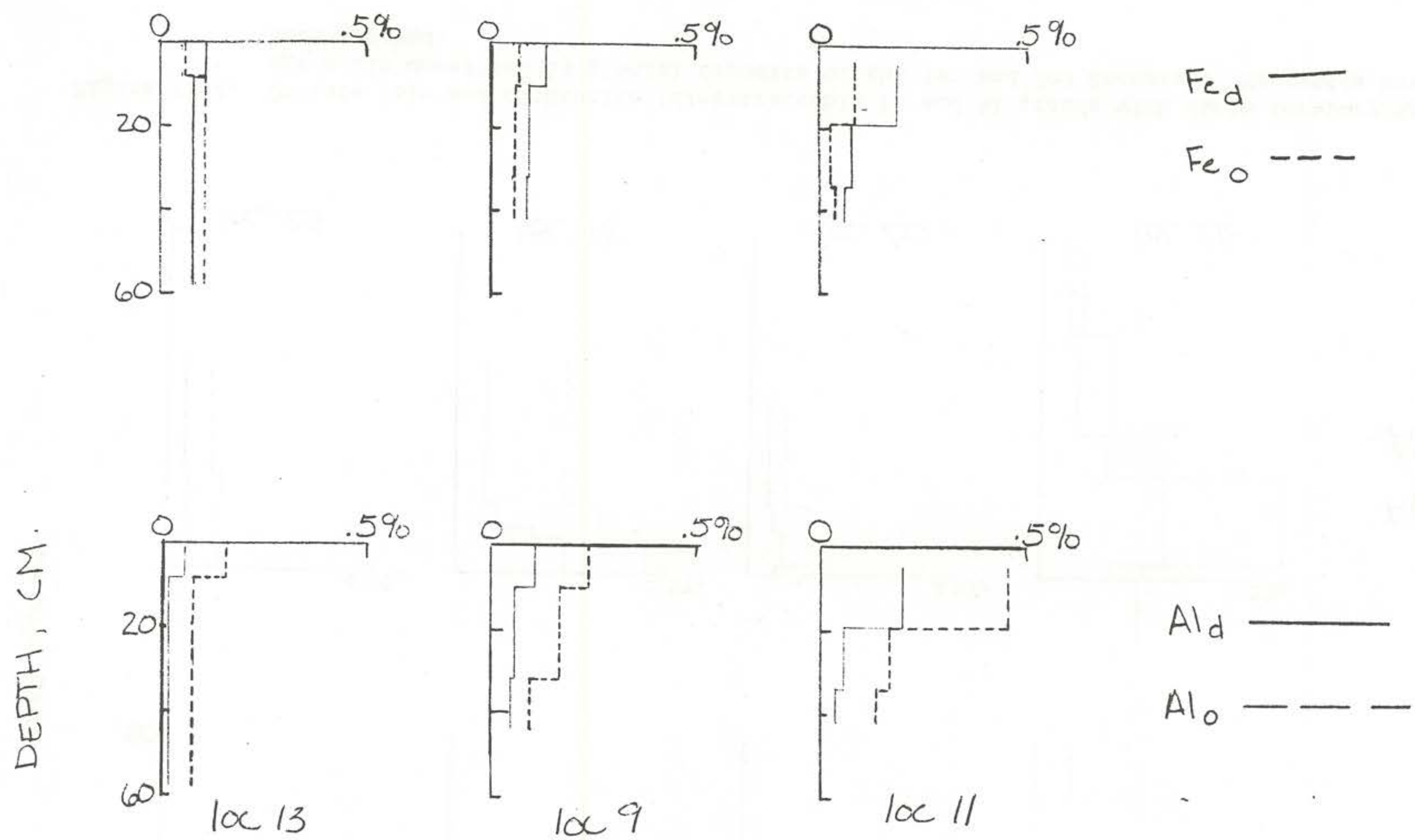


Figure II-1. Oxalate (o)- and dithionite (d)- extractable Fe and Al trends with depth for varying age soils developed in glacial deposits of the 3rd and 4th Recesses. Magnetics have been removed. Localities 13, 9, and 11 correspond to stops 7,3 and 5a of chapter I.

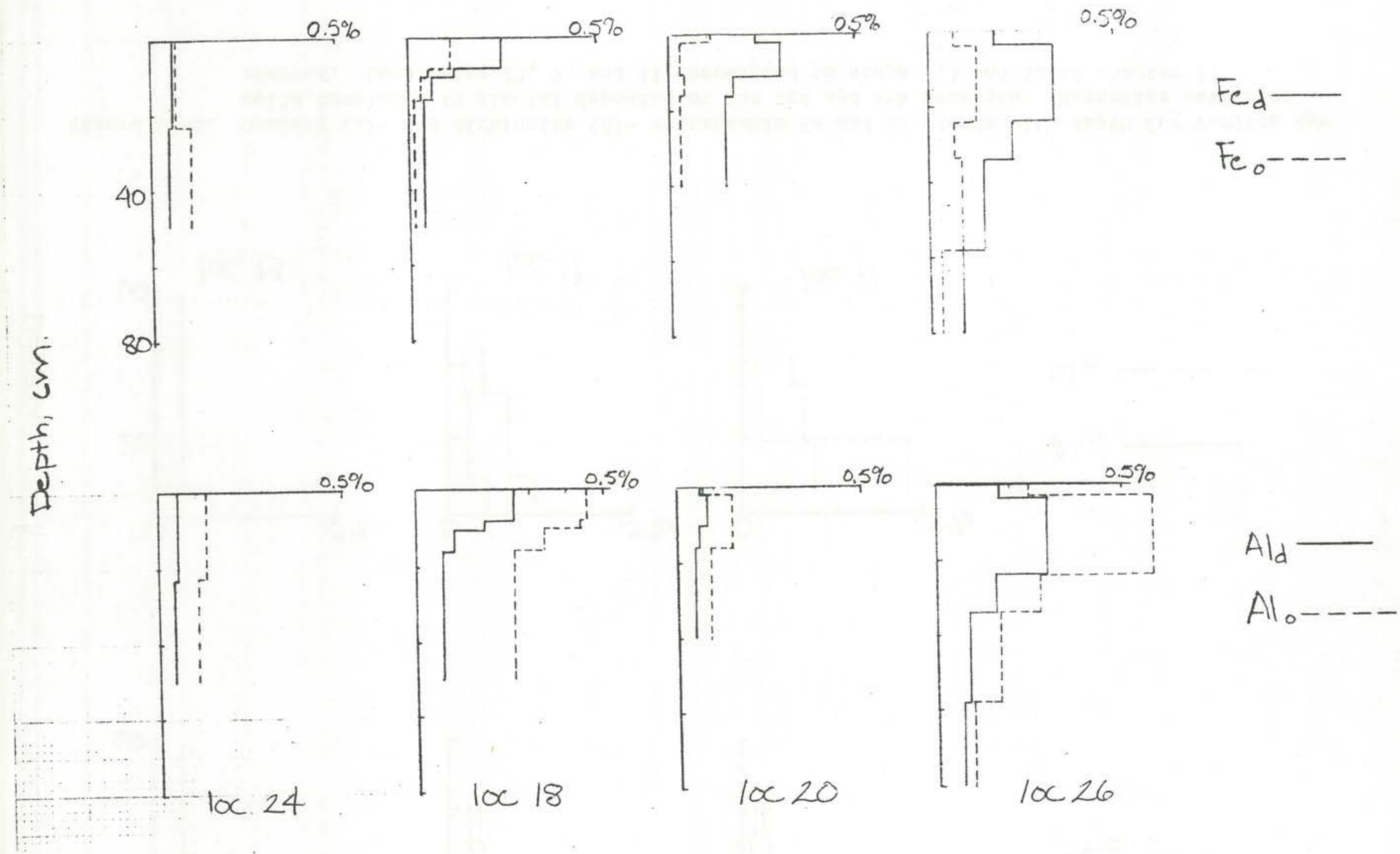


Figure II-2. Oxalate (o)- and dithionite (d)-extractable Fe and Al trends with depth for varying age soils developed in glacial deposits of the 1st and 2nd Recesses. Magnetics have been removed.

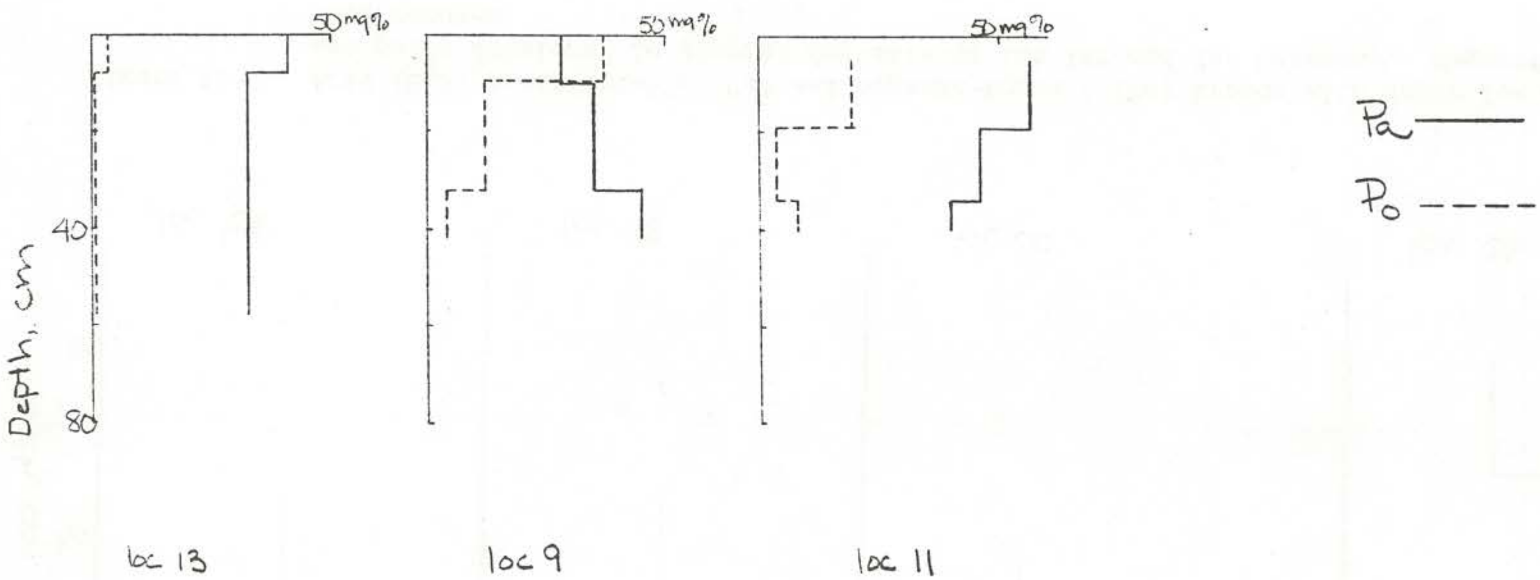


Figure II-3. Acid (H_2SO_4)-extractable (Pa) and organic-bound P (Po) trends with depth for varying age soils developed in glacial deposits of the 3rd and 4th Recesses. Magnetics have been removed. Localities 13, 9, and 11 correspond to stops 7, 3, and 5a of chapter I.

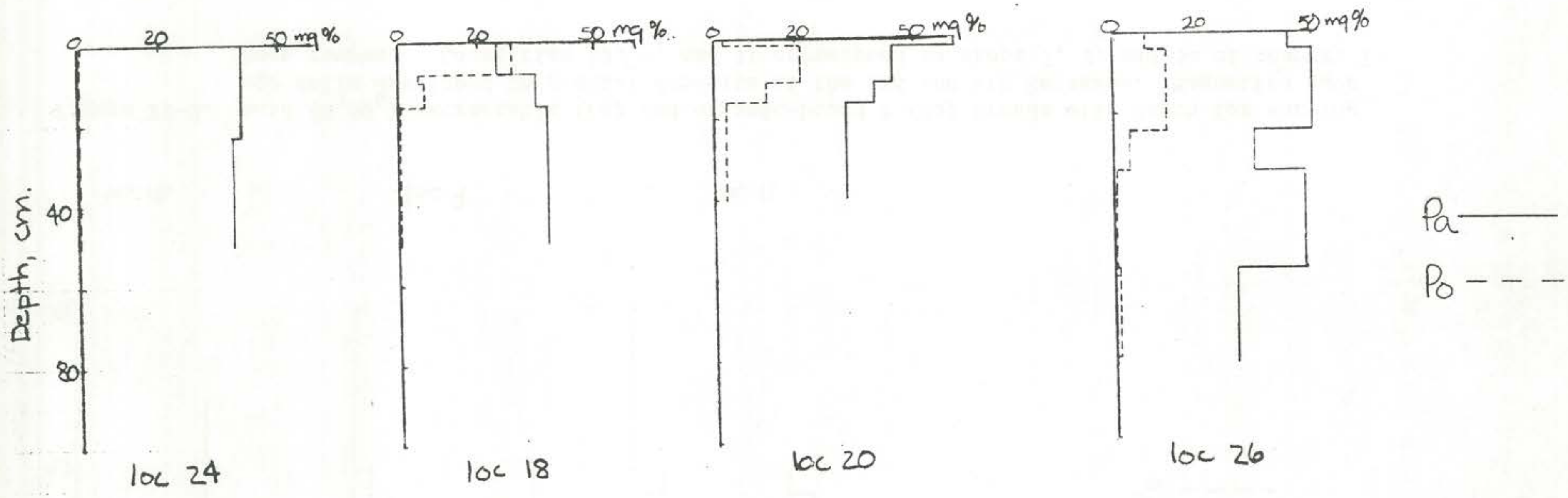


Figure II-4. Acid (H_2SO_4)-extractable (Pa) and organic-bound P (Po) trends with depth for varying age soils developed in glacial deposits of the 1st and 2nd Recesses. Magnetics have been removed.

4. An unexpected result is that the amount of Fe and Al accumlation is greater in the alpine soils than in many of the soils formed in Tioga and Tahoe Tills along the eastern escarpment, even though the latter may be 3-10 x older (see Chapter XIII). Climate differences could explain this pattern. It might also mean that the climate along the eastern escarpment has not been much wetter in the past than the present climate.

CHAPTER III

Relative dating and reevaluation of the glacial deposits along Mammoth Creek, California

R. M. Burke and P. W. Birkeland

The majority of this chapter is taken from Burke and Birkeland (1979) and is reproduced here with the permission of Quaternary Research and the University of Washington. All references of this material should be made to the original paper. The soil chemical data are recently out of our lab and not included in Burke and Birkeland (1979). See Chapter XIII for a brief discussion of the soil chemistry data. The abstract of this chapter applies to a broader study along the eastern Sierra Nevada than we have time to investigate during this trip. It does however, outline our conclusions and deals directly with deposits discussed in Chapters III, V, and XI of this guidebook. Figure III-1 shows the location of stops 1 and 2 where we will view, respectively, Tioga and Casa Diablo Till (Table III-1). These two stops will not be used to teach RD methods, but are viewed for a quick evaluation and reference during the remainder of the trip.

ABSTRACT

Four valleys, recently studied by other workers, were examined along the eastern Sierra Nevada to refine relative dating techniques. A variety of weathering parameters and soil properties fail to delineate more than two major post-Sherwin Pleistocene glaciations. We correlate these two

Figure III-1. Topographic map of Horseshoe Lake campground and stops 1 and 2, part II of field trip. Base maps are the Mt. Morrison and Devils Postpile 15' quadrangles.

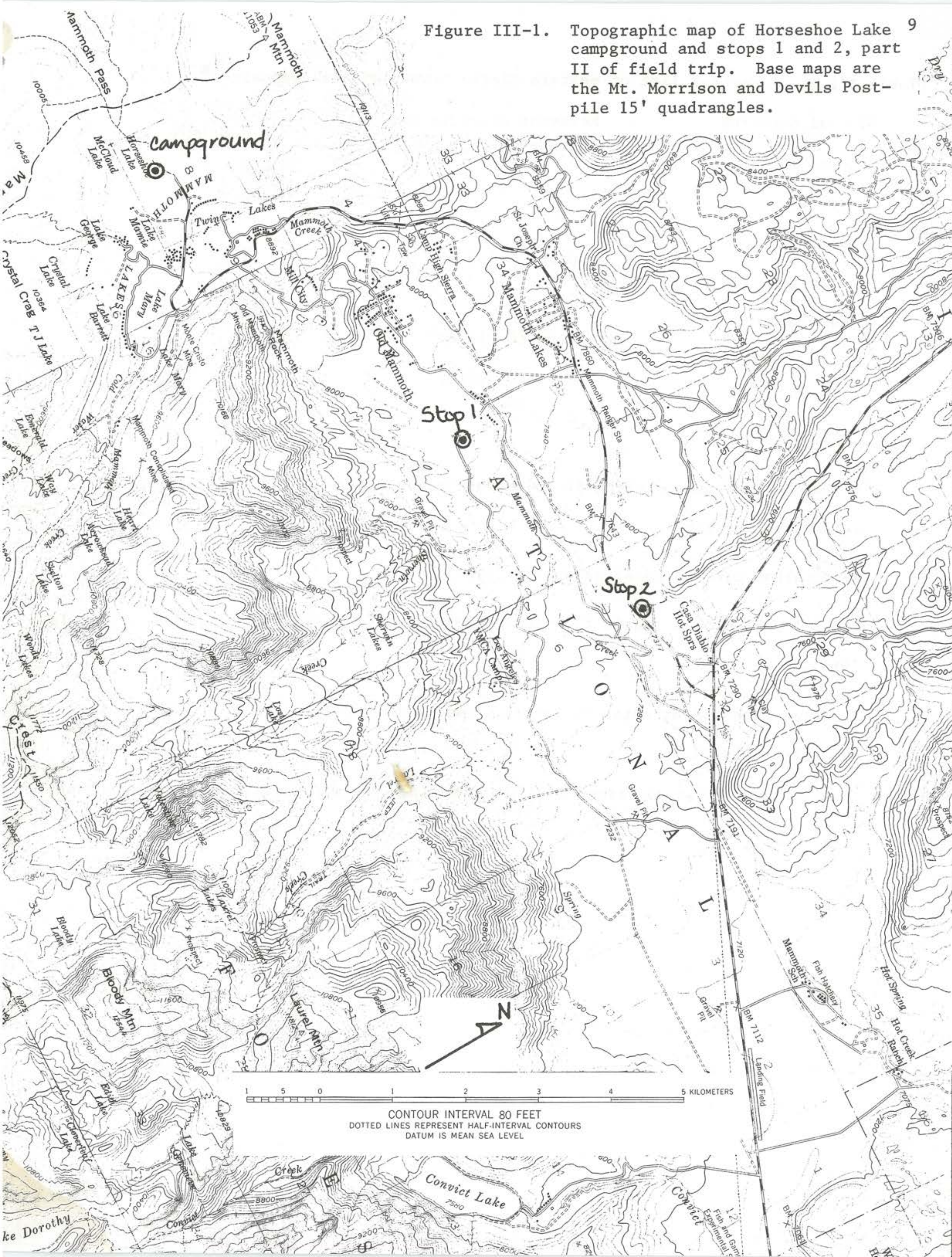


Table III-1. A partial list of eastern Sierra Nevada glacial deposits.[a]

Glacial deposits	Relevant absolute ages
	9,800±800 years[b]
Tioga	
Tenaya	
Tahoe	
	0.060±0.050 my[c]
	0.090±0.090 my[c]
Mono Basin	0.062±0.013 my[d]
Casa Diablo	0.126±0.025 my[d]
	0.710 my[e]
Sherwin	

[a]For details on the complete Sierra Nevada nomenclature see Sharp (1972) and references therein.

[b]Radiocarbon date on basal peat (Adam,1967).

[c]Two K-Ar dates on a basalt flow that underlies till designated as Tahoe (Dalrymple, 1964).

[d]The most recent K-Ar dates on basalt flows that bracket Casa Diablo Till (Bailey and others, 1976).

[e]Mean of K-Ar dates on Bishop Tuff that overlies Sherwin Till (Dalrymple and others, 1965).

glaciations with the Tahoe and Tioga Glaciations. Type Mono Basin Till, usually considered to be pre-Tahoe, exhibits the following weathering similarities with Tahoe Till, if both are under sagebrush: (1) grusification of subsurface granitic boulders; (2) degree of pitting, mineral relief and rind development on surface granitic boulders; and (3) very slight clay increase in the B horizon. Type Casa Diablo Till also has weathering characteristics similar to Tahoe Till, except a slightly more developed Bt horizon is present. Hence, dates on basalt of 0.126 ± 0.025 my and 0.062 ± 0.013 my (Bailey and others, 1976), which bracket type Casa Diablo, may provide age control on the Tahoe Glaciation. In addition, we are unable to demonstrate that the Tenaya is a separate glaciation. In three of the four valleys studied our weathering data for Tenaya Till are equivalent with those for Tioga Till, but with those for Tahoe Till in the fourth valley.

We were not satisfied with our ability to differentiate the Casa Diablo, Mono Basin, and Tenaya as separate glaciations even though data were collected in the type areas for two of these deposits. Reasons for suggesting a change back to a two-fold Tahoe-Tioga glacial sequence, rather than the present five-fold sequence, are that we have measured a greater number of parameters than has been done previously, soils were submitted to detailed laboratory analyses, and surface weathering features were studied under consistent present vegetation cover to avoid possible problems induced by ancient forest fires. Nevertheless our relative dating scheme does not rule out the possibility of a more detailed glacial sequence.

Introduction

The Quaternary geology of the Mammoth Lakes area has been mapped in two previous studies. Rinehart and Ross (1964) mapped the moraines between Mammoth Lakes Village and Highway 395 (Fig. III-2) as an undifferentiated unit which could tentatively correlate with any or all of the Tioga, Tahoe, and a pre-Tahoe, post-Sherwin deposit. Curry (1968, 1971) subdivided the major moraines into Tioga, Tenaya, Tahoe, and Mono Basin, but on his map they are shown only as Group B deposits. Curry (1971) also recognized an older till which he named the Casa Diablo. The type Casa Diablo Till lies between the lower and middle of three basalt flows originally dated at 0.441 ± 0.040 my (KA2098), 0.280 ± 0.067 my (KA2012), and 0.192 ± 0.035 my (KA1928) (Curry, 1971). Bailey and others (1976), however, have redated the lower and upper of the above mentioned three basalt flows at 0.126 ± 0.025 my (73G012) and 0.062 ± 0.013 my (73G014), and these latter ages are herein accepted as bracketing the Casa Diablo Till.

Tioga Glaciation

The RD data from our study (Fig. III-3a; Table III-2) do not permit any major subdivision of the post-Casa Diablo Tills, even though the text of Curry (1968, 1971) indicates that a four-fold subdivision of Tioga, Tenaya, Tahoe and Mono Basin exists (Fig. III-2). There is a suggestion of a progressive change of some RD values which generally agrees with stratigraphic position, but the presence of reversals in the trends confounds grouping the deposits into separate ages. Given this, subsurface data may be more satisfactory in differentiating the post-Casa Diablo tills. None of the deposits have

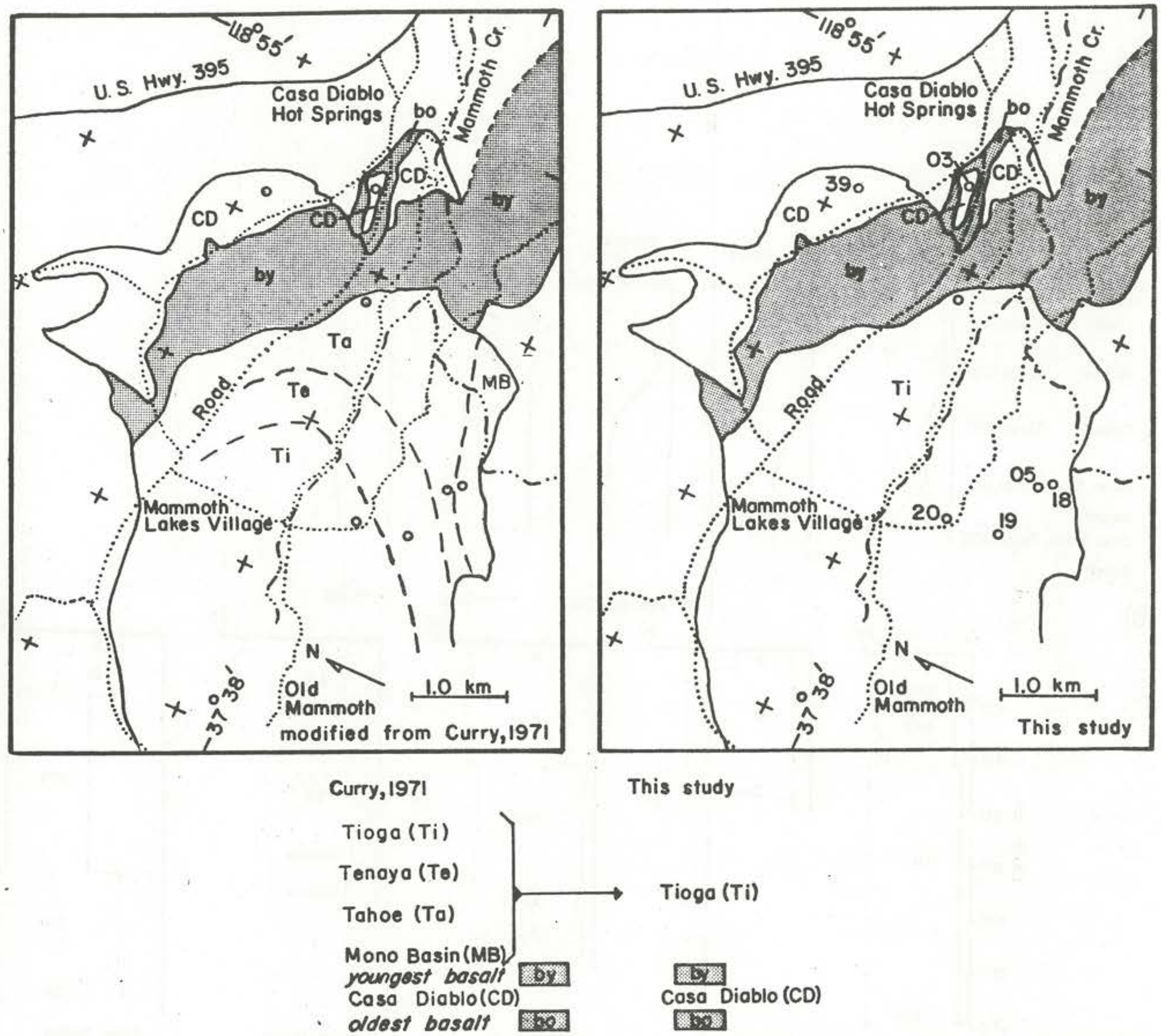


Figure III-2. Glacial deposits along Mammoth Creek according to Curry (1971) and this study. The age boundaries for Curry (1971) are an approximation taken from his text, as he maps all post-Casa Diablo tills as Group B. The basalts shown are the youngest and oldest of those mapped by Curry (1971), and are the flows dated by Bailey and others (1976). The base map is the Mt. Morrison 15-minute quadrangle, California. See Appendix B to correlate stop numbers to site numbers.

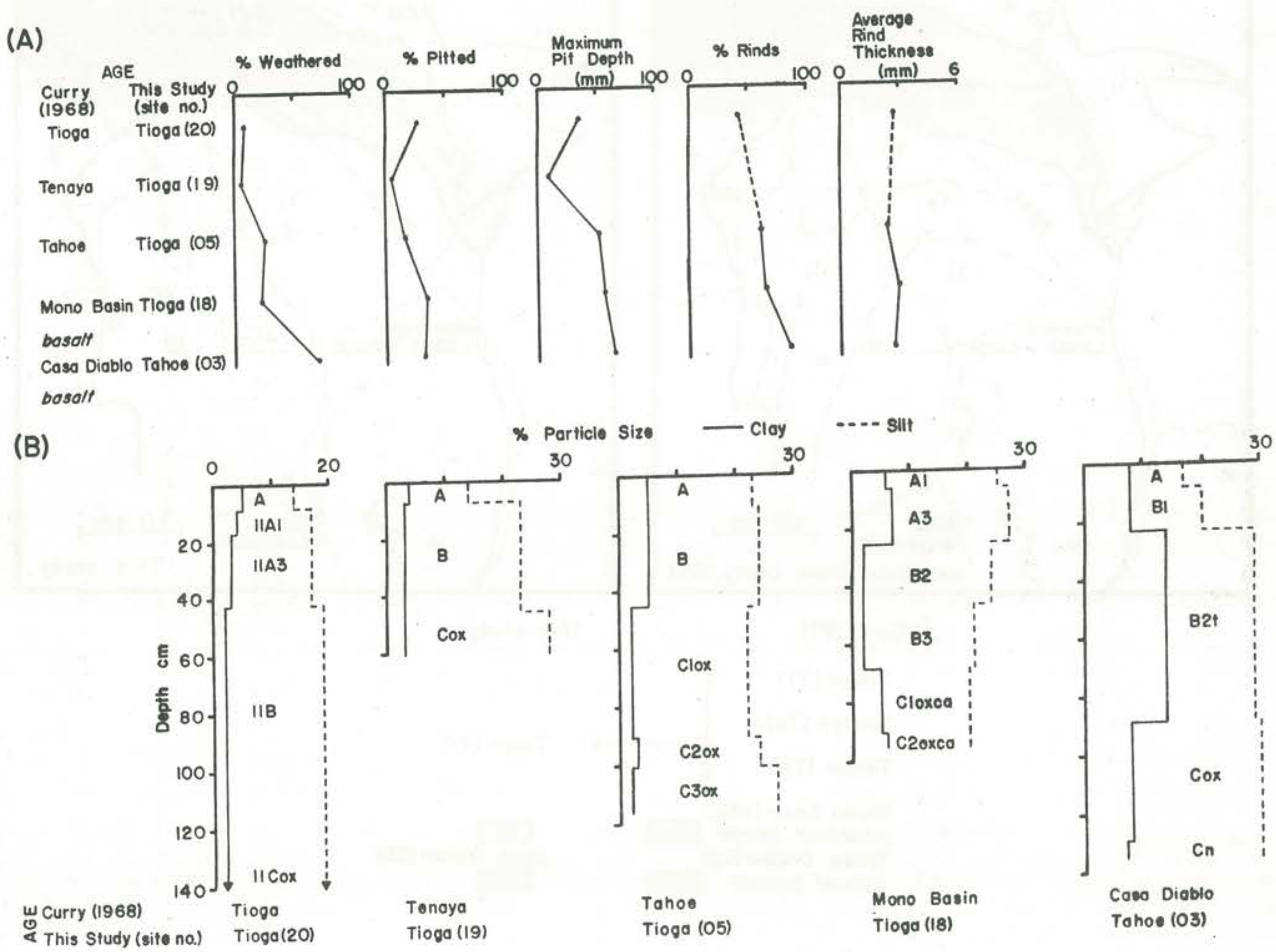


Figure III-3. Selected RD (A) and soil (B) data for deposits in Mammoth Creek. Complete data and actual numbers are given in tables III-2 and III-3. See appendix B to correlate stop numbers to site numbers.

Table III-2. Weathering and morphological data for Mammoth Creek tills.

Valley	Age, site number: This study	Age, site number: Original Study	% Weathered	% Pitted	Maximum Pit Depth mm	Average Pit Depth mm	Maximum Height of Mafic Inclusions mm	% Rinds	Average Rind Thickness mm	Fresh: Weathered: Grus by hammer blow	SBF	% Granitic Boulders[a]	% Split	Oxidized: Partially Ox: Unoxidized[b]	Moraine Morphology: Moraine Width (meters)	Moraine Morphology: Distal Slope (degrees)	Moraine Morphology: Proximal Slope (degrees)
Mammoth Creek	Ti / 20	Ti	10	34	35	–	–	44	2.8	50:0:0	80	78	24	–	–	–	–
			8	22													
	19	Te	7	6	10	–	–	–	–	34:0:0	58	2	–	–	7	15	22
	05	Ta	28	16	52	–	32	64	2.5	50:0:0	42	32	28	–	16	21	19
			28	20	53	–	–	–	–	50:0:0	89	44	24	–	–	–	–
	38	Ta	24	22	75	–	60	48	2.0	48:2:0	50	94	30	–	undefined		
			48	40													
	18	MB	20	42	57	–	40	68	3.1	46:4:0	91	82	26	–	5	17	25
			26	34													
	Ta / 03	CD	71	33	65	–	122	88	2.8	21:3:0	13	42	22	–	undefined		

[a]The non-granitic component consists of volcanic and metavolcanic rocks.

[b]Where only two numbers appear, the count was oxidized: unoxidized boulders only.

[c]A dash (–) represents no data available.

Table III-3. Soil data for Mammoth Creek tills.

Location	Site number	Age[a] Previous Study	Age[a] This Study	Horizons[b]	Depth (cm)	Color[c]	Texture[d]	Estimated % gravel	% < 2 mm fraction Sand	Silt	Clay	pH[e]	% Organic Matter[f]	Remarks
Mammoth Creek	20	Ti	Ti	0	0-8	10YR 4/2.5	LS	75	81	14	5	5.9	57	Depositional unit I appears to be largely extraneous material mixed with the till, unit II.
				IIA	8-16	10YR 4/2	LS	75	79	17	4	6.1	3	
				IIA3	16-42	10YR 4/3	LS	75	80	17	3	6.1	4	
				IIB	42-120	10YR 5/3	LS	75	79	19	2	6.0	2	
				IICox	120-165+	10YR 5/2	LS	75	79	19	2	6.0	2	
	19	Te	Ti	A	0-7	10YR 4/2	LS	50-75	82	14	4	6.1	2	
				B	7-45	10YR 3.5/3	LS	50-75	74	23	3	6.0	1	
				Cox	45-60+	2.5Y 7/2	SL	50-75	69	28	3	6.2	0	
	05	Ta	Ti	A	0-11	10YR 3/3	SL	75-90	72	23	5	5.9	1	The A and B horizons may have a slight admixture of eolian material.
				B	11-45	10YR 4.5/4	SL	75-90	71	24	5	6.1	4	
				C1ox	45-90	2.5Y 8/3	LS	75-90	76	22	2	6.2	1	
				C2ox	90-100	2.5Y 7/4	LS	75-90	73	24	3	6.3	2	
				C3ox	100-116+	2.5Y 7/3	SL	75-90	71	27	2	6.4	1	
	38	Ta	Ti	A1	0-8	10YR 4/2	S	25	89	9	3	5.3	2	This is an end moraine and the low % gravel is anomalous. Perhaps not comparable to other soils because of parent material variation.
				A3	8-20	10YR 4/3	LS	10	82	14	4	5.7	3	
				B1	20-35	10YR 5/3	LS	10	80	15	5	6.0	2	
				B2	35-70	10YR 5/3.5	SL	10	74	20	6	6.1	2	
				Cox	70-140+	2.5Y 6.5/3	LS	10	77	20	3	6.3	2	

[a]Age of previous study is based upon works of Dalrymple (1964)-Sawmill Canyon (S), Curry (1971)-Mammoth Creek, Sharp and Birman (1963)-Sawmill Canyon (N)-Bloody Canyon, and Sharp (1972)-Green Creek. Age assignments are Tioga (Ti), Tenaya (Te), Tahoe (Ta), Mono Basin (MB), and Casa Diablo (CD).

[b]Nomenclature follows Soil Survey Staff (1975) and Birkeland (1974).

[c]Colors are dry, determined on less than 2 mm fraction.

[d]Textural designations are loamy sand (LS), sandy loam (SL), and sand (S).

[e]pH determinations are by meter on a 2:1 water to soil mixture.

[f]Organic matter determined by loss on ignition, corrected for structural water loss by subtracting loss on ignition of organic free silt + clay fraction.

grusified granitic boulders at depth, nor do the soils differ much one from another (Fig. III-3b and Table III-3). The soils consist of A/B/Cox profiles, and although they show an increase of clay content toward the surface, these increases are slight and could reflect the deposition of ash and other eolian material mixed with the tills. Therefore, based primarily upon the lack of subsurface grusification and progressive soil development we tentatively correlate all of Curry's (1971) Group B with the Tioga Glaciation.

Casa Diablo Glaciation

Surface exposure of Casa Diablo Till is limited, and the lack of true morainal form makes comparisons with the younger deposits difficult. Few surface data demonstrate that the Casa Diablo Till is much older than the Tioga Till of this study. Only the percent weathered granitic stones (Fig. III-3a) and the maximum height of mafic inclusions (Table III-2) show a clear separation of the Casa Diablo from the Tioga. In addition, the numerical values for these two weathering phenomena resemble Tahoe values of other drainages.

Subsurface data for the Casa Diablo Till do indicate an age greater than the Tioga. Many subsurface boulders are completely grusified, but the oxidation of the grus is slight. In addition, the soil has the strongest textural B horizon development within the study area for post-Sherwin tills. The 6% clay increase from the Cox to the B2t horizon is thought to be pedogenic because of both the color and the presence of clay films (Site 03, Fig. III-3b and Table III-3). The clay increase is greater than other soils in the eastern Sierra Nevada thought by us to be of similar age. Weathering rind data collected from near the top of the B horizon also corroborate the

Table III-4. Data on weathering rinds in the Mammoth Lakes area.[a]

Age of moraine[b]	Mean rind thickness(mm)	
	basalt	quartzite
Tioga	0.23	0.21
Tenaya	0.17	0.25
Tahoe	0.26	0.18
Casa Diablo	0.50	0.50

[a]from Colman (1977)

[b]age according to Curry (1971)

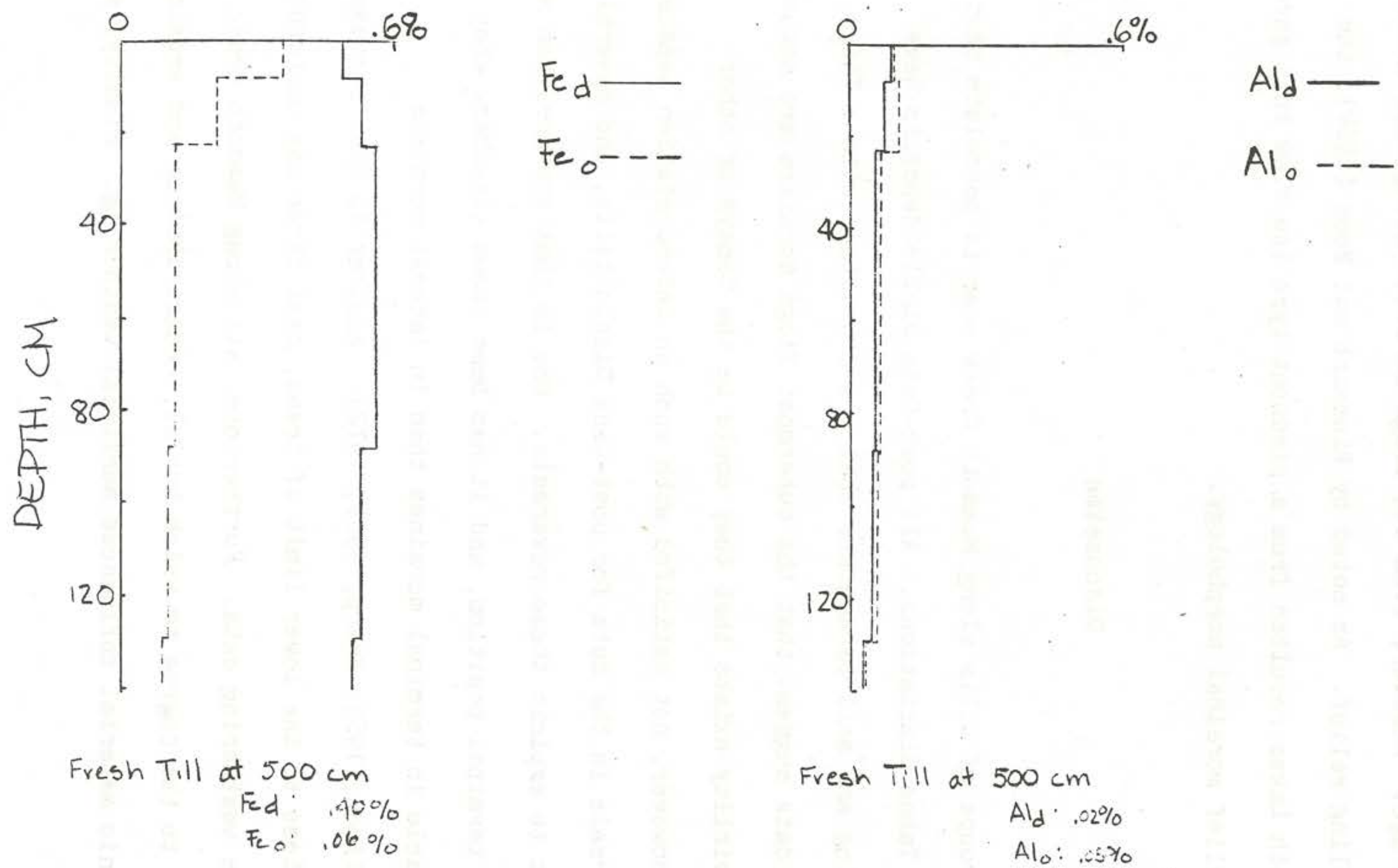


Figure III-4. Oxalate (o)- and dithionite (d)-extractable Fe and Al trends with depth for the soil developed in the type Casa Diablo Till. Magnetics have been removed. Locality is stop 2, Figure III-1.

above subdivision based on soil and grusification data (Table III-4). Soil chemical data show very little trends with depth (Fig. III-4). These data all suggest that the Casa Diablo Till has many characteristics similar to the Tahoe elsewhere.

The lack of morainal form in the Casa Diablo Till may suggest to some workers a pre-Tahoe age. However, even the Tioga moraines along this creek show only a low rolling relief. As noted by Rinehart and Ross (1964), the deposits near Mammoth Lakes resulted from a piedmont type ice flow that gave rise to this low-relief morainal morphology.

Discussion

The two age groups of tills along Mammoth Creek seem to correlate best with the Tioga and Tahoe Glaciations. All post-Casa Diablo deposits have subsurface weathering and soil parameters that are consistent with a Tioga age. Some surface data suggest that the outermost Tioga moraines are somewhat older, and the possiblity exists that they could be the Tenaya of other workers. We are, however, not satisifed with such an interpretation because of some trend reversals in the data for post-Casa Diablo tills, and several possibilities exist to explain these reversals. One is that the moraines were sampled near their terminal position, and it has been shown elsewhere that RD data are more variable in terminal moraines than in lateral moraines (Janda, 1966; McCulloch, 1963; Sharp, 1969, 1972). Another is that because the deposits are close to the lower limit of trees, past fires may confound some of the surface weathering data. Furthermore, all along Mammoth Creek, a question exists as to the degree to which burial, redistribution and erosional stripping of volcanic material influenced surficial weathering. Finally, as in every drainage in this study one could argue that we do not have data from a sufficient number of sample sites. These same factors could account for the lack of differentiation between Casa Diablo and post-Casa Diablo tills on surface weathering data. Hence, this area can be used as an example of where the usefulness of subsurface RD data outweighs the usefulness of surface RD data for age differentiation.

The Casa Diablo soil has the strongest development for Tahoe equivalent soils in this portion of the eastern Sierra Nevada. Although the possibility exists that Casa Diablo is pre-Tahoe, some local factors may help account for the 6% clay increase in this profile and its absence in other Tahoe profiles. Volcanic lithologies are common in this drainage and these would have higher rates of clay production than would granitic lithologies. Tephra deposits mantle much of the topography and these could weather rapidly to clay which could infiltrate into the soil. Yet another factor is that the parent material is initially slightly higher in clay content than are most eastern Sierra Nevada tills and this alone would promote faster clay production (Birkeland, 1974). Finally, a somewhat higher precipitation than is present in other drainage could accelerte the rate of clay production. If it is accepted from the soil, grusification and rind data for volcanic clasts that the Casa Diablo Till is probably of Tahoe age, then the 6% clay increase from the Cox to the Bt horizon is a maximum for post-Tahoe soils in this part of the eastern Sierra Nevada.

The Casa Diablo-Tahoe correlation based on our RD data suggests that a portion of Tahoe Glaciation occurred between 0.062 ± 0.013 and 0.126 ± 0.025 my ago. On the other hand, if the Casa Diablo Till is older than the Tahoe, the bracketing dates require that Tahoe deposits are either (1) missing along Mammoth Creek, or (2) within the oldest of Curry's Group B moraines. However, our RD data suggest that Curry's Group B moraines are indeed an undifferentiated unit which correlates with the Tioga Glaciation. Furthermore, there are no compelling reasons why Tahoe till should not be present in the area studied. Therefore, we accept the new Casa Diablo dates, and feel the RD data support the Casa Diablo-Tahoe correlation as well as the Group B-Tioga correlation.

CHAPTER IV

Road log from Mammoth Creek to Sawmill Canyon (N)-Bloody Canyon

R. M. Burke

This is a short note to provide limited roadside view information between stops 2 and 3. No attempt has been made to provide a thorough roadside guidebook as several excellent publications exist to fill this need. The works of Wahrhaftig and others (1965), Sharp (1972), Smith (1976), and Lipshie (1976) are sufficiently detailed and diverse to allow the traveler a unique opportunity to create his/her own self guided tour along this segment of the Sierra Nevada escarpment. This note is intended to identify only the most prominent features seen by the driver when traveling at 50 mph. The route is seen on figures IV-1 and IV-2.

Mileage

On highway 203 from Mammoth Lakes to stop 2 you were able to view the spectacular sets of moraines deposited at the mouths of Sherwin, Laurel, and Convict Creeks. The different lithologies between the Sherwin (granitic) and Laurel (metamorphic) drainages are reflected by the present day vegetation cover on the glacial deposits; Sherwin Creek moraines are forested, Laurel Creek moraines are not forested.

0.0 Turn northwest onto highway 395 from highway 203.

You will be driving through beautiful Jeffrey Pine Forest, the largest such forest in the world (Smith, 1976, p. 21). The ground is littered

Figure IV-1. Topographic map of the route between stops 2 and 3, part II of field trip. Base maps are the Mt. Morrison, Cowtrack Mtn., and Mono Craters 15-minute quadrangles.

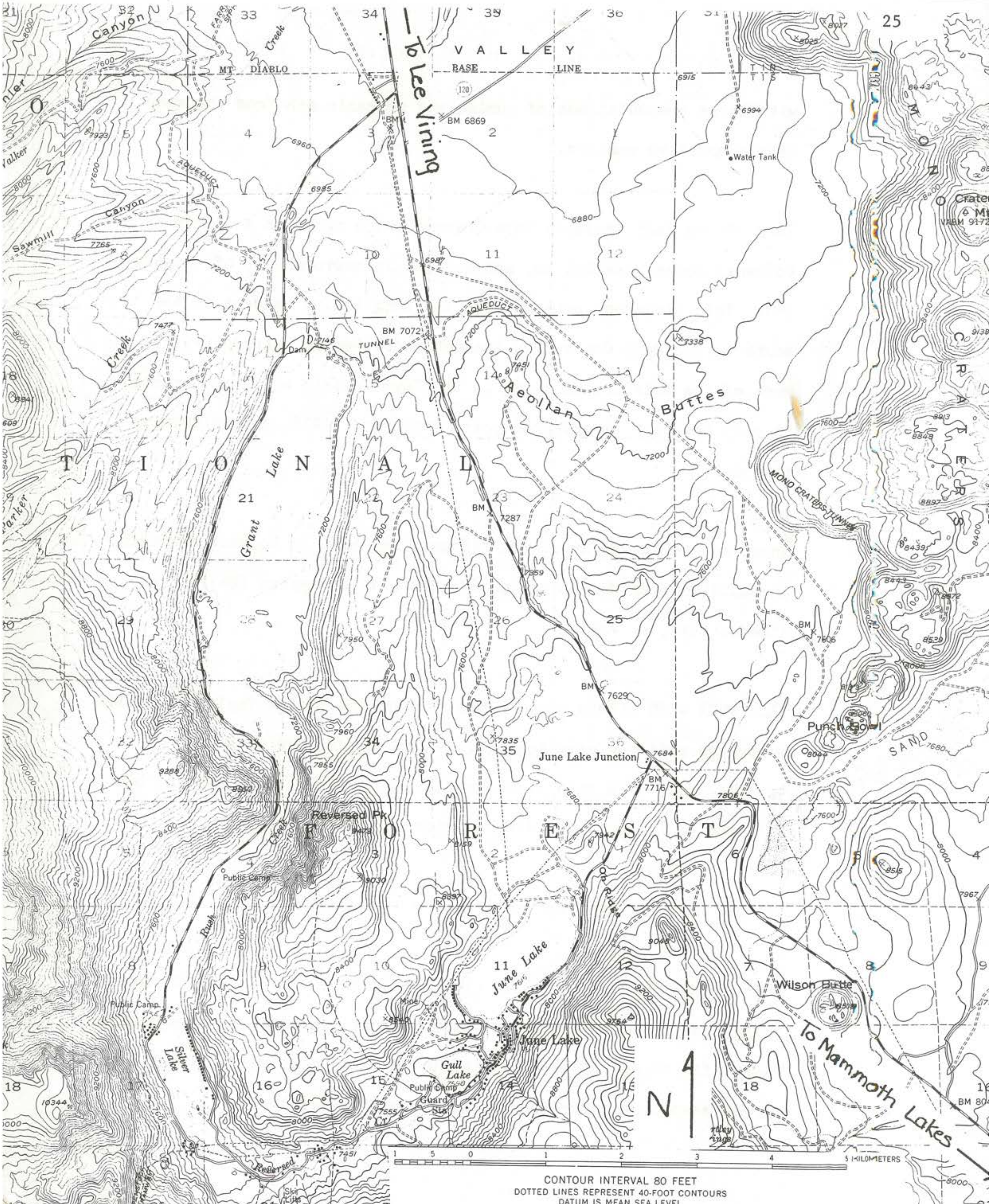


Figure IV-2. Topographic map of the route between stops 2 and 3, part II of field trip. Base map is the Mono Craters 15-minute quandrangle.

with large accumulations of pumice and volcanic ash from the many nearby eruptive centers.

5.3 Turn-off to left leads to Inyo Craters which occur in a lineament of volcanic domes parallel to, and about 5 kilometers west of, highway 395. This lineament extends from the Long Valley caldera in the south to the Mono Craters in the north (Bailey and others, 1976). Much of the volcanic activity in the Inyo Craters area has occurred in only the past few hundred years (see Wood, 1976, and references therein).

5.4 Ahead and to the right of the highway, the hill is Lookout Mountain, an obsidian plug dome dated at 673,000 ± 14,000 years (Bailey and others, 1976, p. 729).

7.1 REST AREA - 20 minute stop. This is the last toilet facility we will encounter until we camp tonight. If you don't have water for tonight, this is a good place to fill up. We will be close to, but will not go through, Lee Vining prior to making camp.

7.3 Reenter highway 395 from Rest Area.

7.6 Owens River Road turnoff. If time and traffic permit, we will make a brief stop at this locality to point out and discuss the type Deadman Pass Till (Curry, 1966). The saddle in which this deposit is located can be seen on the skyline to the southwest (left).

9.0 Crestview Caltrans Station. We have been in the Long Valley Caldera all morning and are now leaving this feature as we climb to Deadman Pass summit.

11.6 Straight ahead is a view of Wilson Butte, a Holocene obsidian dome.

13.8 On the right side of highway 395 is an explosion pit apparently caused by a phreatic explosion. The large notch carved into the far wall formed in only a few hours as the result of a pipeline break during construction of the Los Angeles aqueduct (Smith, 1976, p. 23).

14.2 Sharp corner to the left around a good exposure of Bishop Tuff.

15.0 Roadcut in right lateral Tahoe-age moraine of June Lake (Putnam, 1949).

15.1 Roadcut in right lateral Tioga-age moraine of June Lake (Putnam, 1949).

This straight stretch in highway 395 affords the first view of Mono Basin, with moraines surrounding Grant Lake and Parker Creek dominating the view.

15.3 June Lake Junction. Outcrops and deposits seen for the next few miles consist of Bishop Tuff, Basalts of June Lake, and Tioga, Tahoe, and older(?) tills of June Lake Basin (Putnam, 1949).

15.8 The view to the right is of the obsidian domes and flows making up the mostly Holocene-age Mono Craters. We will be in several localities for photographs of these features, so a special camera stop will not be taken here.

19.5 To the right of highway 395 are the Mono Craters domes and flows (3:00), and Mono Lake (1:00). To the left of highway 395 is a good view of the type Mono Basin moraines (10:00).

21.4 CAREFUL - BAD INTERSECTION - We turn left onto the Grant Lake-Silver Lake-June Lake Road.

21.6 Directly ahead is a good view up Sawmill Canyon (N) outlined by the type locality Mono Basin moraines. Stop 3 is on the right lateral moraine (Chapter V).

CHAPTER V

Relative Dating techniques and reevaluation of the glacial deposits along Sawmill Canyon (N)-Bloody Canyon

R. M. Burke and P. W. Birkeland

The majority of this chapter is taken from Burke and Birkeland (1979) and is reproduced here with the permission of Quaternary Research and the Uiversity of Washington. All references of this material should be made to the original paper. The soil chemical data are recently out of our lab and not included in Burke and Birkeland (1979). See Chapter XIII for a brief discussion of the soil chemistry data. Figure V-1 shows the location of stops 3-7 to view the right lateral moraines of the type Mono Basin (3), unforested Tahoe (4), forested Tahoe (5) Tenaya (6), and Tioga (7) as mapped by Sharp and Birman (1963). These stops will be used to demonstrate RD methods and to discuss our results compared with those of the original workers and with your efforts today. For this reason, the first part of this chapter contains a short background on relative dating along the Sierra Nevada and introduces the RD methodology we apply.

Introduction to relative dating along the eastern Sierra Nevada

Use of semi-quantitative weathering data for age differentiation of glacial deposits along the eastern Sierra Nevada started with the pioneer work of Blackwelder (1931). However, relative dating (RD) techniques now widely used by many Quaternary workers result from the more recent work of Sharp and

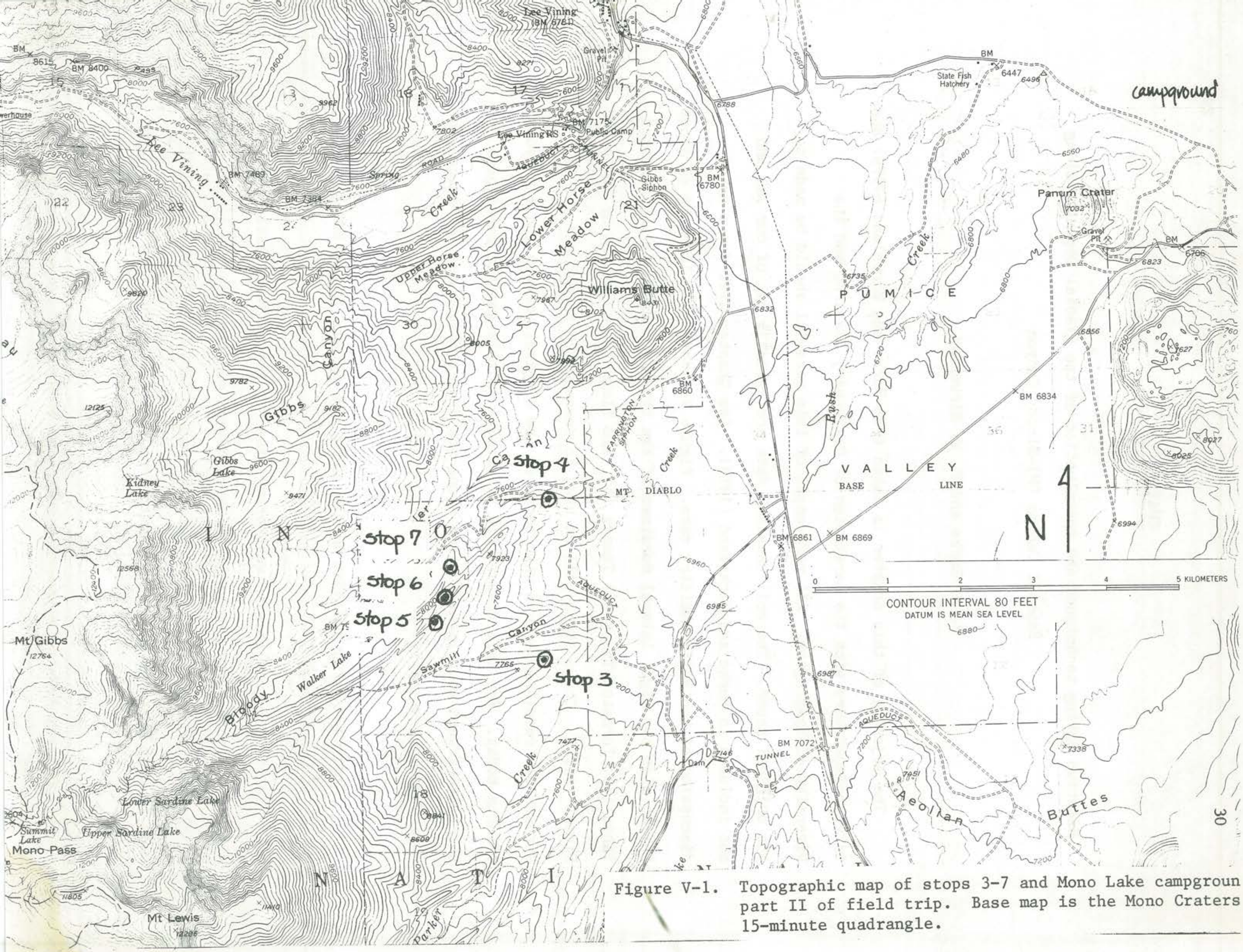


Figure V-1. Topographic map of stops 3-7 and Mono Lake campgroun part II of field trip. Base map is the Mono Craters 15-minute quadrangle.

Birman (1963), Birman (1964), and Sharp (1969, 1972) in the Sierra Nevada, and indeed these works from the basis for the stratigraphic nomenclature and approximate ages presently used for Sierra Nevada glacial deposits. The eastern Sierra Nevada was picked as a major study area in our efforts to advance RD techniques because of extensive previous work (Wahrhaftig and Birman, 1965; Bateman and Wahrhaftig, 1966). The work presented in this paper is part of a larger study to evaluate soil and weathering characteristics as correlation criteria for Quaternary deposits, and to evaluate rates of weathering over parts of the western U.S.A.

RD is based upon the premise that certain weathering parameters are time dependent, and therefore they can be used to delineate episodes of deposition. The need to understand and to use RD techniques arises from the scarcity of radiometric dating control for many surficial Quaternary sequences. In the past, stratigraphic sequences often have been subdivided on a single weathering characteristic. An example is rock weathering; however, it may be difficult to effectively use this criterion in other areas where the rock types are different. Hence , we apply several RD techniques in an attempt to determine which parameters provide the best data for till subdivision locally and for correlation over a larger area. This multi-parameter approach reduces the possibility of mistakes in subdivision and correlation due to local (non-temporal) variation of a key parameter, and was best summarized by Blackwelder (1931, p. 880): "Of all these criteria only a few can usually be applied in any one place. One of them alone affords only a tentative opinion, but when several of them all point to the same conclusion confidence is much strengthened." Our approach was to obtain quantitative data on several weathering and soil phenomena for each major deposit. The number of measurements per deposit, however, has to be sufficiently limited so that the data can be effectively incorporated into a mapping program. As expected, no one phenomenon is universally useful in till differentiation; however, some are more consistent than others and a few apparently do not work in the Sierra Nevada. In contrast to our approach, some workers in the past have made multiple measurements on a deposit of a few parameters, and then used an average value for age assignment. This latter approach has the advantage of producing lots of the same type of data and thus assessing the variability of a parameter within a single moraine. A shortcoming of our approach may be that we do not have data on "within moraine" variability. However, gathering data on a variety of parameters may be as effective in age determination as increasing the number of measurements on only a few parameters. This will remain to be further tested in the future.

Study sites were selected which had been well studied previously and within which there were minimal differences in non-temporal weathering and soil forming factors; in this way we sought to increase the probability that variations in RD data reflect different durations of weathering. The four valleys of this study are Sawmill Canyon of the Owens River drainage (designated Sawmill Canyon (S)), Mammoth Creek, the Sawmill Canyon (N)-Bloody Canyon ara near Mono Lake, and Green Creek. A total of 58 man days were spent in collecting the weathering and soils data during July and August of 1975 and 1976.

The data generated in this study suggest a revision of the stratigraphic nomenclature presently used in the Sierra Nevada. In a previous paper (Birkeland and others, 1976) we have given preliminary comments on the entire glacial sequence; however, discussion herein will be limited to deposits presently designated as Tioga, Tenaya, Tahoe, Mono Basn and Casa Diablo in age (Table III-1). A major conclusion of our work is that our RD data support only a two-fold subdivision of post-Sherwin, pre-Neoglacial deposits rather than the above five-fold subdivision.

Environmental Factors

The environmental factors which influence weathering rates and soil formation are similar for most valleys of this study (Table V-1).

The setting of the deposits in Sawmill Canyon (S) is atypical of the other three areas in that the deposits occur within the confines of the bedrock valley walls, and are vegetated by a mixed conifer forest with an understory of the Great Basin sage community. The deposits of the other three valleys lie beyond the range front and are generally occupied mostly by the Great Basin sage community.

Lithology is a most important variable which must be minimized if variations in RD data are to be considered time dependent. Weathering parameters are measured on medium- to coarse-grained granitic rocks. These usually are classified as granodiorite or quartz monzonite with a biotite content ranging from four to eight percent (Kistler, 1966; Moore, 1963; Rinehart and Ross, 1964). In general, the rocks are similar enough in grain size and mineralogy (see Kistler, 1966; Moore, 1963; and Rinehart and Ross, 1964) that correlation based on RD techniqus should be possible from valley to valley.

Relative Dating Techniques

Of the many RD data that can be collected on morainal deposits, we collected only those that could be readily quantified and that showed the most

Table V-1. Environmental data for the four study areas, Sierra Nevada.

Locality	Elevation (meters)	Granitic Bedrock Lithology[a]	Mean Annual[b] Temp	Pct	Vegetation[b]
Sawmill Canyon (S)	2075-2635	granodiorite, quartz monzonite	7°C	35cm	mixed conifer forest, Great Basin sage community
Mammoth Creek	2270-2440	granodiorite, quartz monzonite	8°C	50cm	Great Basin sage community, Jeffery Pine forest
Sawmill Canyon (N) - Bloody Canyon	2195-2530	quartz monzonite	8°C	45cm	Great Basin sage community, mixed conifer forest
Green Creek	2225-2450	granodiorite	7°C	40cm	Great Basin sage community

[a]taken from Moore(1963), Rinehart and Ross(1964), and Kistler(1966).

[b]taken from U.S. Weather Bureau(1964), and Storer and Usinger(1963). Data given are interpolated for altitude from nearby weather stations and thus contain a ± error of unknown magnitude.

promise for age differentiation based upon our prior experiences. A brief definition of our RD criteria follows, along with some potential problems. These definitions are taken or modified from Blackwelder (1931), Nelson (1954), Birman (1964), Sharp (1969, 1972), Birkeland (1973), Carroll (1974), and Shroba (1977).

Weathering Criteria: Moraine Surface Boulders

(1) Fresh to weathered ratio: Fifty boulders of at least 30 cm diameter are randomly selected at each site. A boulder is considered weathered if 50% or more of the exposed surface exhibits single grain mineral relief. A weathered boulder is rough to the touch and a fresh boulder feels smooth.

(2) Pitted to non-pitted ratio: Fifty boulders are counted at random and each is considered to be pitted if its surface has one or more concave depressions of more or less circular shape, apparently caused by granular disintegration. Pitting and weathering counts are made separately because boulders that are weathered are not necessarily pitted and vice versa.

(3) Pit depth: The depth of a pit is measured from the bottom of the pit to the present surface of the boulder, and is thus a minimum measure of total pitting. Measurements are listed in the following two ways: (1) the maximum pit depth for the deposit, and (2) the average value for the deepest pits on the first 25 boulders classified as pitted.

Using a definition of weathering which combines our first three techniques, Clark (1967) found the exposure to wind and height above local vegetation to be strong controlling factors of boulder weathering. By selecting data collection sites along the flattest segments of moraine crests in the same kind of vegetational cover, we have attempted to reduce the variability of these controlling factors between data sets, within any single drainage.

(4) Maximum height of resistant mafic inclusion: The measurement here is the distance between the top of the inclusion and the average position of the adjacent rock surface.

(5) Rind to no rind ratio: A rind is a zone of weathered rock, recognized by a discoloration, that parallels the outer surface of the rock. For each count, 25 granitic cobbles are broken open and the presence or absence of a rind is recorded.

(6) Average rind thickness: In the above count each rind is measured to the nearest mm (0.1 mm for volcanic rocks), and including the zeros, a mean rind thickness for the 25 clasts is calculated.

(7) Hammer-blow weathering ratio: At each site, 50 boulders are struck with a hammer and classified as fresh, weathered, or grusified. A boulder is fresh if it gives a sharp ringing sound, weathered if it gives a dull thud, and grusified if it disintegrates when struck. This method is less discriminating of age than the fresh to weathered technique described above.

(8) Surface Boulder Frequency (SBF): The total number of boulders with a diameter greater than 50 cm are counted within a 30 m by 6 m rectangle along the crest of a moraine. In an effort to minimize the effect of boulder frequency variability along a single moraine, the rectangle is placed where there visually appears to be a maximum boulder concentration. Previous workers (Blackwelder, 1931; Sharp and Birman, 1963; Birman, 1964; Dickinson, 1968; and Sharp, 1969, 1972) relied in part on SBF to recognize and map glacial deposits of different age in the eastern Sierra Nevada. Our SBF data, however, do not allow us to make such distinctions. Reasons for the failure may be that too few counts were made by us, or that the 50-cm minimum diameter may have been too large. Other workers have used a 30 cm minimum diameter. A major problem with this technique is where to take such counts, as Rahm (1964)

and Clark (1967) demonstrate that variation can be a function of original deposition. Our data do not resolve this problem.

(9) Granitic boulder to non-granitic boulder ratio: The measurement is made on 50 boulders greater than 50 cm in diameter. Non-granitic rock types are more resistant to weathering and should proportionally increase with time. Sharp (1969, 1972) found this technique useful when applied to a set of moraines along the same side of a single valley. We found the technique non-discriminating, but as with SBF this may again result from too few counts to eliminate internal variation in the original deposit.

(10) Split to non-split ratio: At each site, 50 boulders are classified as split or non-split. A split boulder is one which appears to have broken along a planar crack since emplacement, by a mechanism other than spalling. This technique has been successfully applied in some areas of the Rocky Mountains (Shroba, 1977), but failed to discriminate among deposits in the present study.

(11) Oxidized, to partially oxidized, to unoxidized ratio: Fifty granitic boulders are classified on the basis of their surface discoloration. An oxidized boulder exhibits total surface discoloration (commonly 10YR hues), a partially oxidized boulder is discolored to a lesser extent in either hue or surface area, and an unoxidized boulder exhibits no oxidation.

Weathering Criteria: Subsurface Features in Roadcuts or Hand-dug Pits.

(12) Grusified granitic boulders: Below the ground surface, boulders with 30 cm diameter or greater are considered grusified if they exhibit intense granular disintegration throughout. Boulders are classified as either fresh, grusified and unoxidized, or grusified and oxidized.

(13) Soil properties: Soil properties are measured in the field and analyzed by standard laboratory techniques. Pits are dug along moraine crests in places considered to be free of excessive erosion or deposition. Field properties include horizonation, color, texture, consistence, structure, pH, and presence of other diagnostic pedologic features such as clay films or carbonate. Laboratory analyses are particle size distribution, percent loss on ignition (approximate organic matter), pH, and dry color. The soil horizon nomenclature follows Soil Survey Staff (1975) and Birkeland (1974). B horizon denotes a color B horizon, equivalent to a cambic horizon, and Bt denotes an increase in pedologic clay relative to the C horizon. Cox horizons are less oxidized than B horizons and numbered successively with increasing depth to denote diminishing degrees of oxidation. Roman numerals indicate various parent material layers.

An extensive literature documents the usefulness of soil stratigraphy in interpreting the Sierra Nevada Quaternary deposits (Birkeland, 1964, 1967; Morrison, 1965; Janda, 1966; Janda and Croft, 1967; Curry, 1968, 1971; Birkeland and Janda, 1971; Shlemon, 1971; Harden and Marchand, 1977). Our soils data are often inconclusive and do not always support the age differentiation of other data. This could be due to some combination of the slow rate of weathering of granitic materials in the local climate, and the rate of removal by erosion of the uppermost soil horizons. We presently have no means of assessing the latter effect.

Moraine Morphology

(14) Width and slope angles: Although greatly controlled by unknown conditions of original deposition, the general cross-sectional shapes of moraines are measured in an attempt to describe the degree of preservation

since deposition. The measurements taken are inner and outer slope angles, along with crest width. Although useful in the Rocky Mountains (Miller, 1971), the measurements of this study did not produce a useful set of data for age differentiation; perhaps a more detailed shape analysis or sampling program is needed.

One important problem with some RD methods is that different workers cannot produce the same numbers, even though they are trying to use the same definition of the feature measured. We find that reproducibility between workers varies with the RD method. Within our own group of colleagues, we are reasonably consistent in measuring subsurface rock weathering and soil features. However, surface weathering features are more difficult to reproduce between workers. Therefore, all rock weathering data reported here were collected by Burke. Birkeland collected data on some parameters, and although his numbers differed from Burke's they resulted in the same weathering breaks and thus, the same subdivision of deposits.

Defining a Glaciation Using RD Techniques

Once the data are collected for a set of moraines the next task is to determine how much of a variation from one deposit to another constitutes a glaciation, and how much constitutes a stade. People working in quaternary stratigraphy of glacial deposits probably can be grouped into the "splitters" and the "lumpers." Splitters would make the maximum subdivision of the sequence, probably at the stade level, based perhaps on subtle variations in weathering characteristics, on moraine position, and other features such as cross-cutting moraine relationships. Many unit names might be given these deposits, but because the variations in RD features from one deposit to the other are at most subtle, and cross-cutting relationships may only be of local significance, valley-to-valley correlation can be either difficult, non-existent, or forced. Lumpers, on the other hand, require more gross changes in RD features before a subdivision is attempted; changes of enough magnitude that the major breaks in soil and weathering features can be consistently recognized by many workers from valley to valley. In this context, we are lumpers. The major question is how great a change in RD data is needed before we propose a new unit. No unique numerical change is adequate for all the data collected, but for many of the RD data on adjacent moraines we prefer a change by a factor of two in the numerical values before considering deposition to have occurred in different glaciations. Commonly, not all features will double or halve, and some will not change at all. However, because many factors can be invoked to suggest that most of the data collected are a minimum for the age of the till, those data of those RD methods that give the greatest differences between adjacent moraines might better reflect the true age differences. When the data are treated in this way, we probably are separating out first-order glaciations, rather than second-order fluctuations within first-order glaciations (Porter, 1971). It is these first-order features that can be recognized and correlated, and therefore deserve the assignment of formalized names.

GLACIAL DEPOSITS OF SAWMILL CANYON (N) - BLOODY CANYON

Introduction

The cross-cutting and nested morphological relationships of moraines along Sawmill Canyon (N) - Bloody Canyon (Figs. V-2 and V-3) have long been

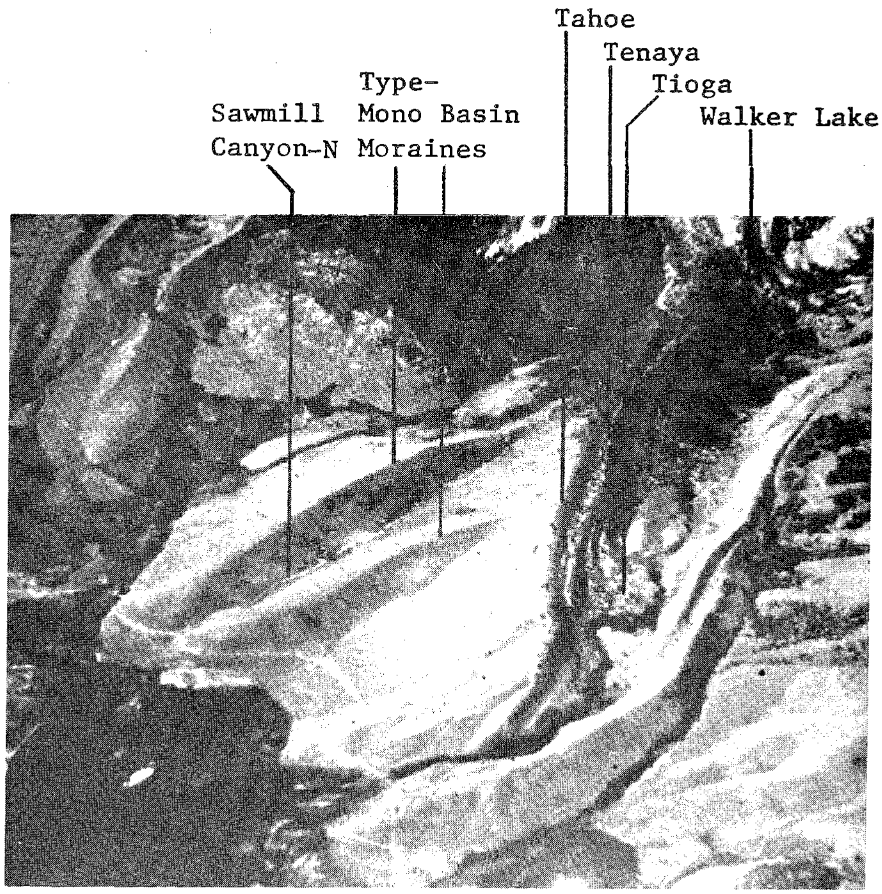


Figure V-2. Moraines of the Sawmill Canyon (N)-Bloody Canyon area, illustrating the cross-cutting relationships of the Mono Basin and Tahoe moraines and the nested relationships of the Tahoe and younger moraines. Age assignments from Sharp and Birman (1963).

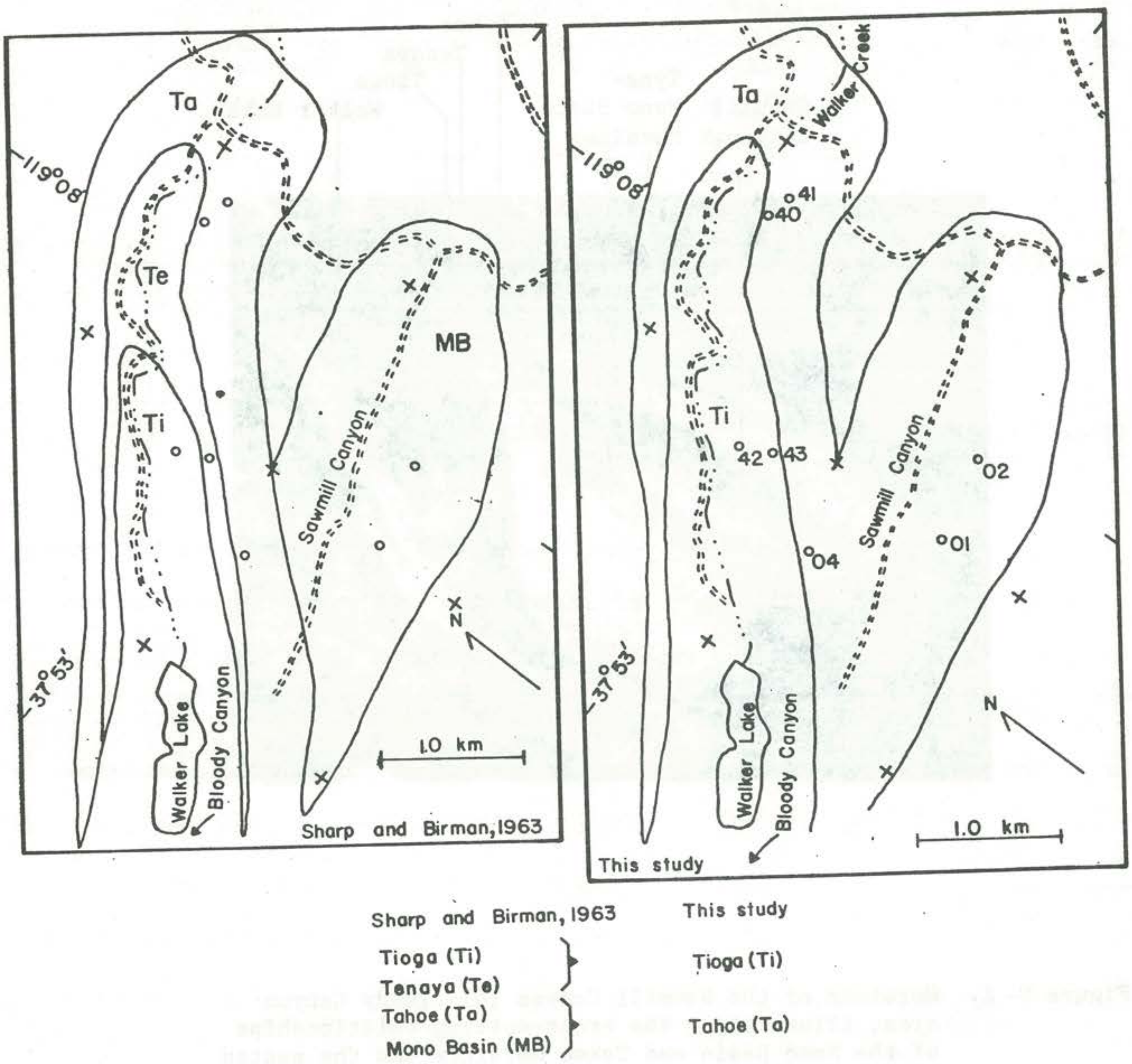


Figure V-3. Glacial deposits in the Sawmill Canyon (N)-Bloody Canyon area according to Sharp and Birman (1963) and this study. The base map is the Mono Craters 15-minute quadrangle, California. See Appendix B to correlate stop numbers to site numbers.

discussed (McGee, 1885; Russell, 1887; Putnam, 1949). Sharp and Birman (1963) subdivided these moraines using semi-quantitative data into a four-fold subdivision of Mono Basin, Tahoe, Tenaya, and Tioga. This valley contains the type locality of Mono Basin Till and one of the first Tenaya Tills described east of the Sierra Nevada crest. In contrast, Putnam (1949, p. 1291) and Kistler (1966) recognized only Tioga and Tahoe deposits, and this is in line with our conclusions.

Tioga Glaciation

The small sharp crested moraines along Walker Creek--the Tioga and Tenaya of Sharp and Birman (1963)--which are superposed on the inner slopes of the massive Tahoe moraines (Fig. V-2) can be demonstrated by RD data to be quite similar to each other and significantly younger than the Tahoe moraine (Fig. V-4a and Table V-2). Weathering data are consistent between the post-Tahoe moraines and all values are at least one-half those for the Tahoe deposits. The soils developed upon the two post-Tahoe moraines are nearly identical (Figs. V-4b, 5, and 6; Table V-3). Both soils have a thin surficial layer of ash mixed with till which in turn overlies till. Partial-size analyses show no obvious pedogenic clay buildup; however, the very slight clay increase toward the top of the profiles could result from weathering, or it could reflect eolian influx. Granitic boulders are fresh throughout the soils.

Tahoe Glaciation

In order to compare the Tahoe and the Mono Basin Tills of Sharp and Birman (1963), the following data collection sites were established: (1) Two

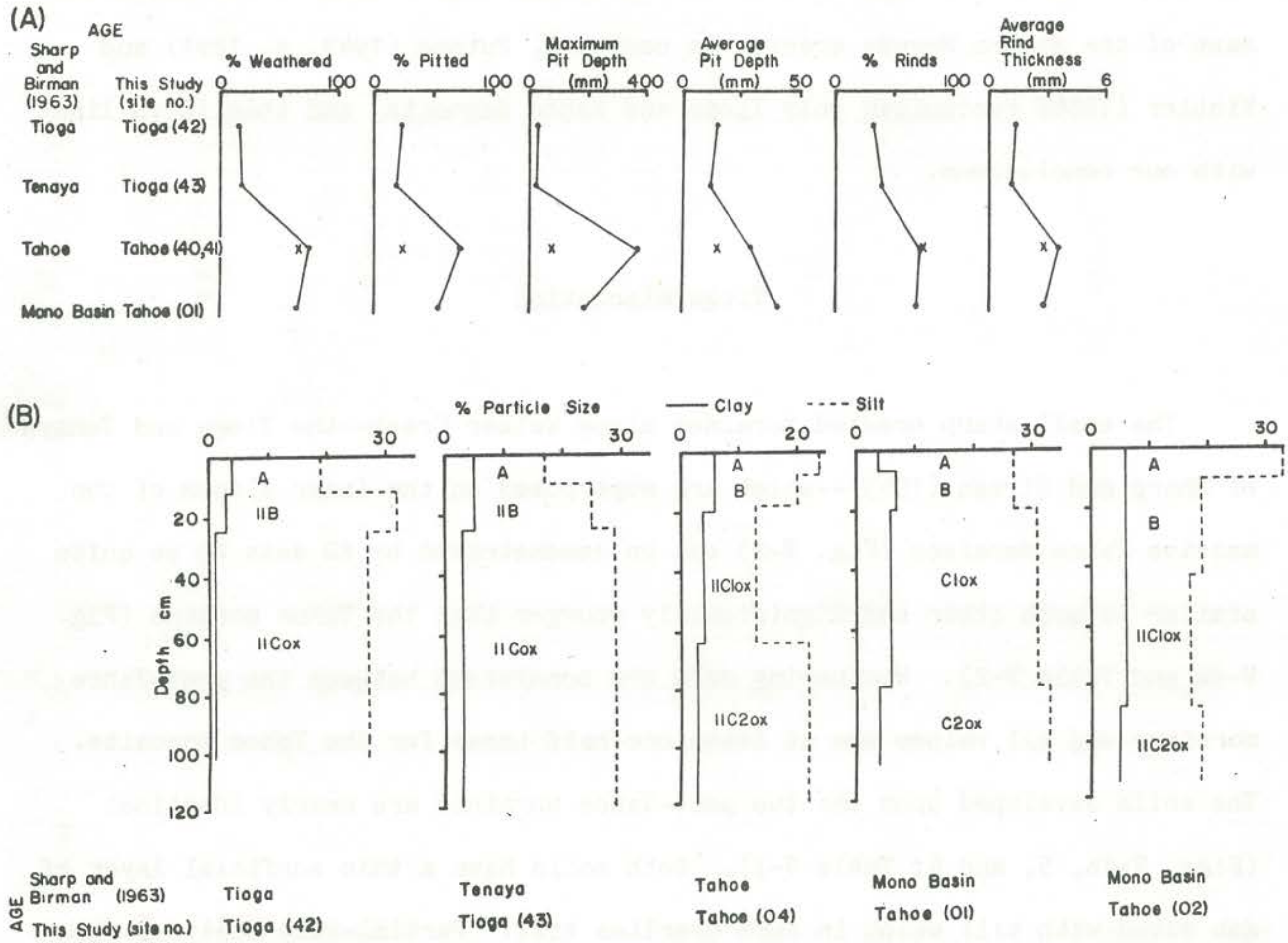


Figure V-4. Selected RD (A) and soil (B) data for deposits in the Sawmill Canyon (N)-Bloody Canyon area. Complete data and actual numbers are given in tables V-2 and V-3. The x in (A) represents data for site 04 on the forested portion of the major Tahoe moraine. See Appendix B to correlate stop numbers to site numbers.

Table V-2. Weathering and morphological data for Sawmill Canyon(N)-Bloody Canyon tills.

Valley	Age, site number: This study	Age, site number: Original Study	% Weathered	% Pitted	Maximum Pit Depth mm	Average Pit Depth mm	Maximum Height of Mafic Inclusions mm	% Rinds	Average Rind Thickness mm	Fresh: Weathered: Grus by hammer blow	SBF	% Granitic Boulders[a]	% Split	Oxidized: Partially Ox: Unoxidized[b]	Moraine Morphology: Moraine Width (meters)	Moraine Morphology: Distal Slope (degrees)	Moraine Morphology: Proximal Slope (degrees)
Sawmill Canyon(N)-Bloody Canyon	Ti/42	Ti	18	22	28	15	-	32	1.4	50:0:0	53	78	16	-	8	24	28
			12	22													
	43	Te	22	18	20	12	-	40	1.2	50:0:0	38	94	12	-	10	25	25
			12	16													
	Ta/04 forested	Ta	62	26	80	15	-	76	2.9	45:5:0	33	76	32	5:31:14	15-20	22	27
			70	22	-	-	-	-	-	43:7:0	33	76	60	-	-	-	-
	40	Ta	80	68	120	30	-	80	4.2	43:6:1	43	84	26	2:33:15	20	20	26
			82	74													
	41	Ta	64	74	370	28	-	68	3.1	45:5:0	60	94	28	5:34:14	19	14	21
			82	80													
			74	62													
	01	MB	62	56	190	41	-	68	2.6	38:13:0	48	56	42	7:27:16	35-40	19	18
			64	52	-	-	-	72	3.1	37:13:0	66	68	42	-	20-25	16	20
			64	52													

[a]The non-granitic component consists of volcanic and metavolcanic rocks.

[b]Where only two numbers appear, the count was oxidized: unoxidized boulders only.

[c]A dash (-) represents no data available.

Table V-3. Soil data for Sawmill Canyon (N)-Bloody Canyon tills.

Location	Site number	Age[a] Previous Study	Age[a] This Study	Horizons[b]	Depth (cm)	Color[c]	Texture[d]	Estimated % gravel	% < 2 mm fraction Sand	Silt	Clay	pH[e]	% Organic Matter[f]	Remarks
Sawmill Canyon (N)-Bloody Canyon	42	Ti	Ti	A	0-12	10YR 6/3.5	LS	75-90	77	19	4	5.7	4	The A horizon appears to have an eolian ash(?) mixed with the till.
				IIB	12-25	10YR 7/2.5	SL	75	65	32	3	6.3	1	
				IICox	25-102+	10YR 7/2 to 2.5Y 7/2	LS	75	72	27	1	6.5	0	
	43	Te	Ti	A	0-10	10YR 4.5/3	LS	50	78	17	5	5.6	12	The A horizon appears to have an eolian ash(?) mixed with the till. The IICox is indurated by silica(?) cement.
				IIB	10-25	10YR 5.5/3	SL	50	70	25	5	6.3	2	
				IICox	25-120+	10YR 7/2.5 to 2.5Y 7/2	LS	50	68	29	3	6.5	0	
	04	Ta	Ta	A	0-8	10YR 6/3	SL	75-90	71	24	6	5.8	2	A and B horizons appear to have eolian ash(?) mixed with the till. Cox horizons are slightly indurated by silica(?) cement.
				B	8-20	10YR 7/3	SL	75-90	74	20	6	5.5	1	
				IIClox	20-64	2.5Y 7/3	LS	75-90	83	13	4	5.6	0	
				IIC2ox	64-120+	2.5Y 8/2.5	LS	75-90	75	22	3	5.5	0	
	01	MB	Ta	A	0-7	2.5Y 6/3	SL	75-90	70	27	4	6.2	2	This is the type locality of Mono Basin Till. Entire comment from site 04 applies here also.
				B	7-20	10YR 6/3	SL	75-90	66	27	7	6.5	1	
				Clox	20-80	10YR 7/3 to 2.5Y 7/3	SL	75-90	64	31	6	6.5	1	
				C2ox	80-107+	2.5Y 7.5/2	SL	75-90	63	33	4	6.5	0	

[a]Age of previous study is based upon works of Dalrymple (1964)-Sawmill Canyon (S), Curry (1971)-Mammoth Creek, Sharp and Birman (1963)-Sawmill Canyon (N)-Bloody Canyon, and Sharp (1972)-Green Creek. Age assignments are Tioga (Ti), Tenaya (Te), Tahoe (Ta), Mono Basin (MB), and Casa Diablo (CD).

[b]Nomenclature follows Soil Survey Staff (1975) and Birkeland (1974).

[c]Colors are dry, determined on less than 2 mm fraction.

[d]Textural designations are loamy sand (LS), sandy loam (SL), and sand (S).

[e]pH determinations are by meter on a 2:1 water to soil mixture.

[f]Organic matter determined by loss on ignition, corrected for structural water loss by subtracting loss on ignition of organic free silt + clay fraction.

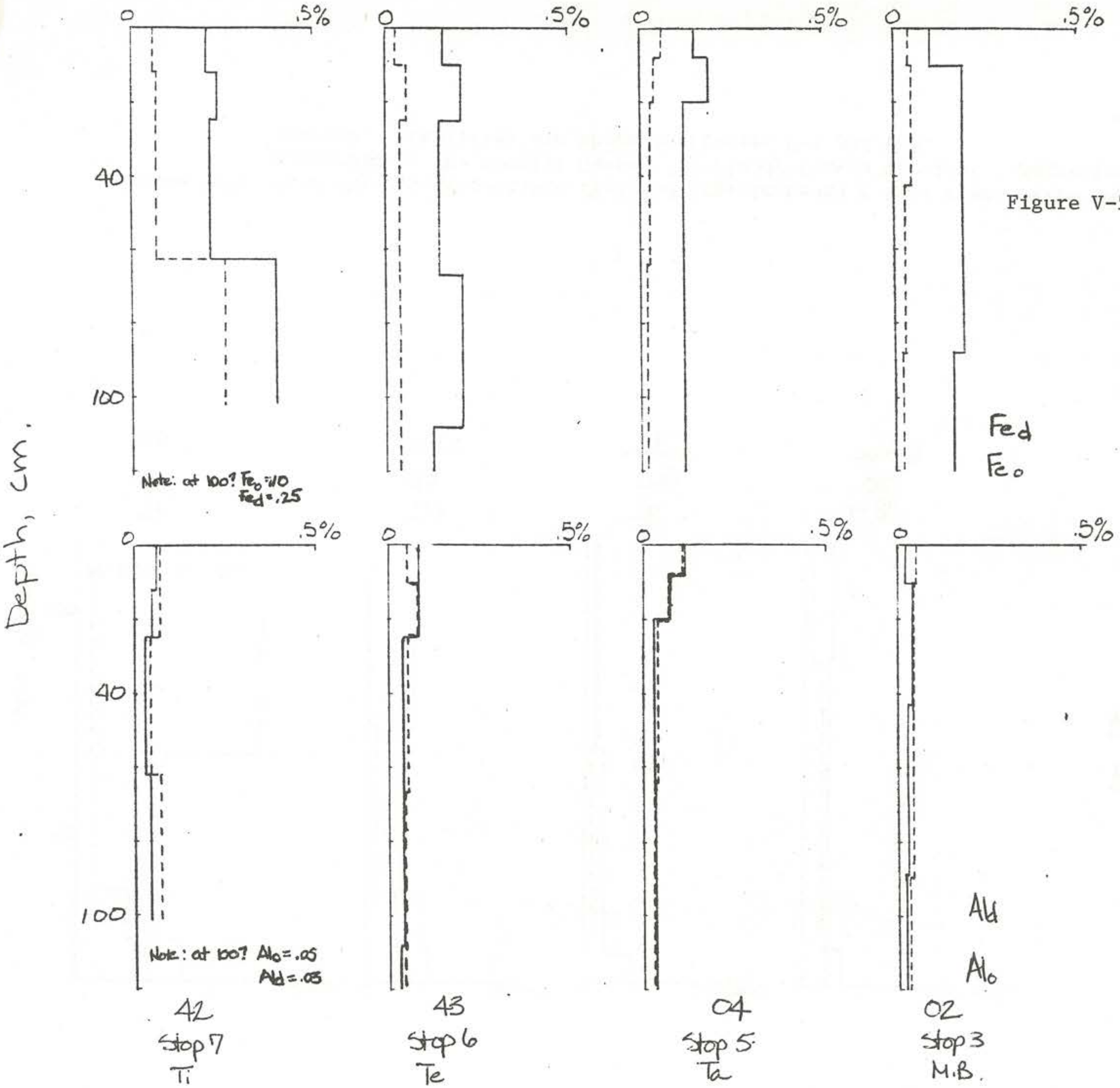


Figure V-5. Oxalate (o)- and dithionite (d)-extractable Fe and Al trends with depth for the soils developed on the Sawmill Canyon (N)-Bloody Canyon moraines. Magnetics have been removed. Localities are shown on figures V-1 and V-3.

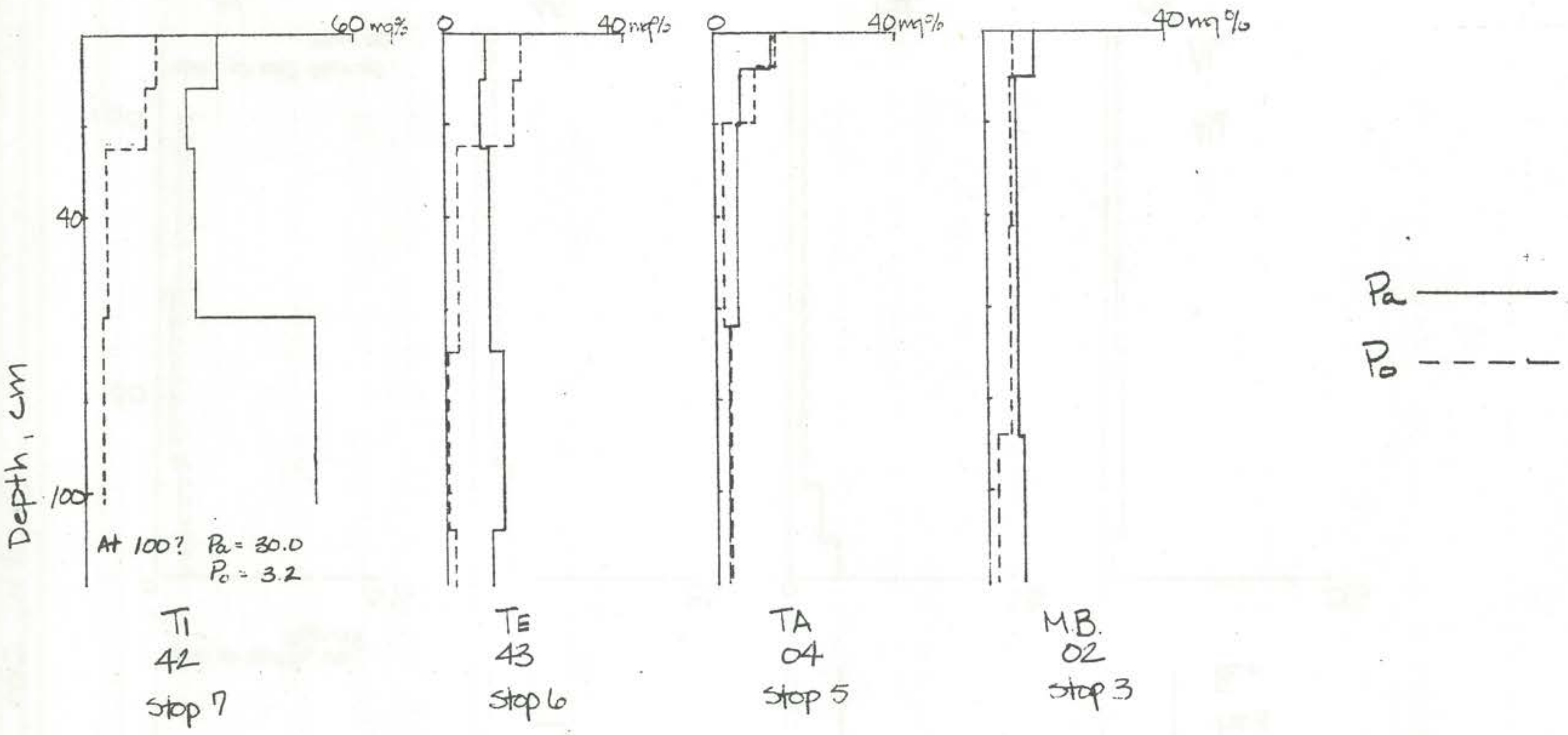


Figure V-6. Acid (H_2SO_4)-extractable (Pa) and organic-bound P (Po) trends with depth for soils developed in the Sawmill Canyon (N)-Bloody Canyon moraines. Magnetics have been removed. Localities are shown on figures V-1 and V-3.

sites (01 and 02) (stop 3) in sagebrush vegetation on the right lateral type Mono Basin moraine; (2) one site (04) (stop 5) in forest vegetation on the major right lateral Tahoe Moraine; (3) one site (40) (stop 4) in sagebrush vegetation on the same Tahoe moraine as site 04; and (4) one site (41) (stop 4) in sagebrush vegetation on a smaller Tahoe lateral moraine (Fig. V-3). These vegetational differences are considered crucial to our interpretation of the ages of the deposits.

If one compares certain RD data for the sage covered type Mono Basin moraine with similar data for the forested Tahoe moraine, an apparent age difference may be argued (Fig. V-4a). However, for reasons given below, surface RD data should be compared only when collected under similar vegetation. The best comparative data in this study are for non-forested conditions. Indeed, comparisons of RD data collected from comparable sage-covered sites on Mono Basin and Tahoe moraines suggest that the age difference between these landforms is not great, in spite of their pronounced cross-cutting relationships. We believe that spalling related to past forest fires could explain the different values derived for forested and sage-covered sites along the Tahoe moraine. As has been suggested by Blackwelder (1927) and demonstrated in stratigraphic studies by Birkeland (1973) and Meierding (1977), forest fires limit the usefulness of comparing surface weathering data between forested and non-forested areas. The atypical weathering data of the forested Tahoe moraine is probably due to the freshing effect brought about by the spalling of boulders during ancient forest fires. This is supported by the high probability of a past fire history along the eastern Sierra Nevada (Schroeder and Buck, 1970).

Subsurface data do not suggest a great difference in age between the Mono Basin and Tahoe Tills. The post-Mono Basin soil has been discussed previously by Birkeland and Janda (1971), and they stated that it does not have properties which indicate a greater age than the nearby post-Tahoe soil (Birkeland and Janda, written communication in Wahrhaftig and Sharp, 1965, p. 84). The data here suggest that soil development in both Mono Basin and Tahoe Tills is minimal. One post-Mono Basin profile (site 01) exhibits a very slight clay increase in the B horizon, but the other does not (Fig. V-4b). For comparison, the soil in Tahoe Till also has a very slight clay increase in the A and B horizons, relative to the Cox horizons. These clay increases are believed to represent some combination of eolian influx and in situ weathering. Neither the Mono Basin nor Tahoe Tills have good exposures; however, the soil pit of site 02 on the Mono Basin moraine has a 50 cm boulder which is totally grusified and weakly oxidized, and smaller boulders in both moraines are commonly grusified. Thus, because both Tahoe and Mono Basin deposits have weak soil development and partial grusification, the deposits cannot be differentiated on the basis of subsurface parameters.

The morphology of the Mono Basin moraines appears to be the only criteria which may support a significant time difference between Mono Basin and Tahoe deposits. Although slopes are similar, the Mono Basin moraine has a wider crest than the Tahoe moraine (Table V-2). In addition, a skyline profile of the two moraines (Fig. V-7) shows the Mono Basin moraines to have less relief than Tahoe moraines, and this may suggest smoothing with time. In summary, whereas some morphologic data suggest a time break between the Mono Basin and Tahoe moraines, our RD and soil data do not adequately demonstrate two mappable units.

Two other lines of reasoning deserve mentioning for they have been used to support a relatively large hiatus between the times of Mono Basin and Tahoe deposition. One line of reasoning is the time reportedly needed for Walker

Figure V-7. Skyline profile of the Mono Basin and Tahoe moraines as defined by Sharp and Birman (1963). The photo was taken from the right lateral Mono Basin moraine, Walker Creek lies beyond the Tahoe moraine.

Creek to breach the left lateral Mono Basin moraine so that younger glacial advances went to the northeast rather than following the path of Mono Basin ice. Sharp and Birman (1963, p. 1084) state: "That the Tahoe laterals are superimposed across the upper ends of the abandoned moraines of Sawmill Canyon is adequate testimony to a considerable age difference." We would like to suggest that moraine breaching could be accomplished while ice occupies the valley, thus allowing ice-marginal streams to overtop and cut through lateral moraines. After the ice snout retreated above the Tahoe breach, readvance could be channeled to the northeast. A second line of reasoning proposed by Curry (1968) and Clark 1972) suggests enough time to allow for a vertical fault motion of about 120 m (Curry) and 60 m (Clark) between Mono Basin and Tahoe deposition. The evidence for postulated faulting is indirect, and the time required for the proposed offset is unknown. The latter line of reasoning is expressed in more detail by Clark (Chapter VI, this guide book). As important as these lines of reasoning are, we do not feel they are presently as conclusive as our RD data for delineating separate mapping units.

Discussion

The RD data given here suggest that only glacial deposits of two different ages are present. The confidence of this statement is strengthened by the fact that most of the data collected seem to point to the same conclusion. Confidence would be increased, however, if we had more data on subsurface granitic clast weathering. The previously mapped Tenaya seems best included with the Tioga. There is, however, more of a problem with the Tahoe and the Mono Basin. If both are studied under similar vegetation covers, they are quite similar; they only look dissimilar when the forested Tahoe is compared with the sagebrush covered Mono Basin. One problem though is that the sagebrush covered Tahoe moraines are near the terminal positions, and it was argued earlier that clasts in these positions might be more weathered than clasts in lateral moraines of the same age. At the present time, we cannot solve these arguments without extensive trenching, but we do know that fire can be an important factor in destroying surface weathering features. Unfortunately, the transition from forest to sage takes place at about the same position as one might expect the "terminal" effect to show up. At the present time, we consider the fire hypothesis to be the most plausible and so group the Mono Basin and Tahoe into the Tahoe Glaciation, and suggest a change of Sharp and Birman's (1963) unit boundaries as shown in Figure V-3. The cross-cutting relationships could, in this case, be used to show the duration of the Tahoe instead of an indication of two different glaciations.

CHAPTER VI

Range-front faulting: Cause of the difference in height between Mono Basin And Tahoe moraines at Walker Creek

Malcolm M. Clark

One unusual characteristic of the type Mono Basin moraines at Sawmill Canyon (N), as defined by Sharp and Birman (1963) and discussed by Burke and Birkeland (1979), is that their crests are 50 to 70 m lower than the crests of the overriding Tahoe and Tioga moraines at similar downvalley distances (see stops 3-MB, 5-Ta, and 7-Ti of figure V-1). Indeed, the truncated crests of the Mono Basin moraines are at about the same elevation as the adjacent bottom of Bloody Canyon. Along the east front of the Sierra Nevada, such a relation is anomalous for moraines of similar downvalley extent. Range-front faulting between the times of deposition of the Mono Basin and Tahoe moraines seems to be the most likely cause of this anomaly (Curry, 1968, p. 42X; Clark, 1972). This hypothesis suggests, but does not require, a lengthy interval between the deposition of the Mono Basin and Tahoe moraines at Walker Creek.

The geometry of these moraines is unusual on the east slope of the Sierra Nevada. Adjacent crests of lateral moraines deposited from most glaciers of similar extent (such as Tahoe and Tioga) on the east slope are within roughly 15 m of the same elevation except near a terminus; where differences in elevation exist, Tahoe crests are generally higher than the Tioga crests. These small height differences between Tahoe and Tioga moraines are an expectable result of the quasiplastic behavior of ice (which causes successive glaciers in the same channel to differ only slightly in thickness, regardless of extent) and of the fact that Tioga glaciers of the Sierra Nevada were generally 80 to 90% as extensive as Tahoe glaciers (Clark, 1967, Table 3). Among the Tioga-Tahoe moraines that display these height-extent relations are those at Rock, Reversed, Lee Vining, Virginia, Green, Robinson, and Molybdenite Creeks, on the Little Walker River, and at Fallen Leaf Lake. Because the Mono Basin moraines of Sawmill Canyon (N) resulted from a glacial advance inter-mediate in extent between the Tioga and Tahoe advances and have about the same gradient as the Tahoe and Tioga moraines, their relative position--more than 50 m lower than the adjacent Tahoe and Tioga crests--indicates that something unusual has happened

Analogous relations between moraines at Pine, McGee, and Parker Canyons suggest an explanation for the situation in Sawmill Canyon (N). Although these canyons do not contain recognized Mono Basin moraines, at each canyon Tioga moraines show the same anomalous relation to Tahoe moraines as the Tahoe-Tioga moraines of Bloody Canyon do to the adjacent Mono Basin moraines. At each of these canyons Tioga moraines are higher than the adjacent, more extensive Tahoe moraines--by 35 m at Pine and Parker Creeks, and by 50 m at McGee Creek. At Pine and McGee Creeks, the explanation seems simple: post-Tioga normal faulting along the range front has clearly offset Tioga moraines by 13 m at Pine Creek and by 25 m at McGee Creek. If displacement also took place across the same faults during the period between the Tahoe and Tioga glaciations, this displacement would account for the unusual elevation of the Tioga above the Tahoe crest (Clark, 1972). Figure VI-1 shows how range-front faulting could cause younger glacial advances (such as the Tioga) to deposit moraines above older, larger moraines (such as the Tahoe) on the downthrown block

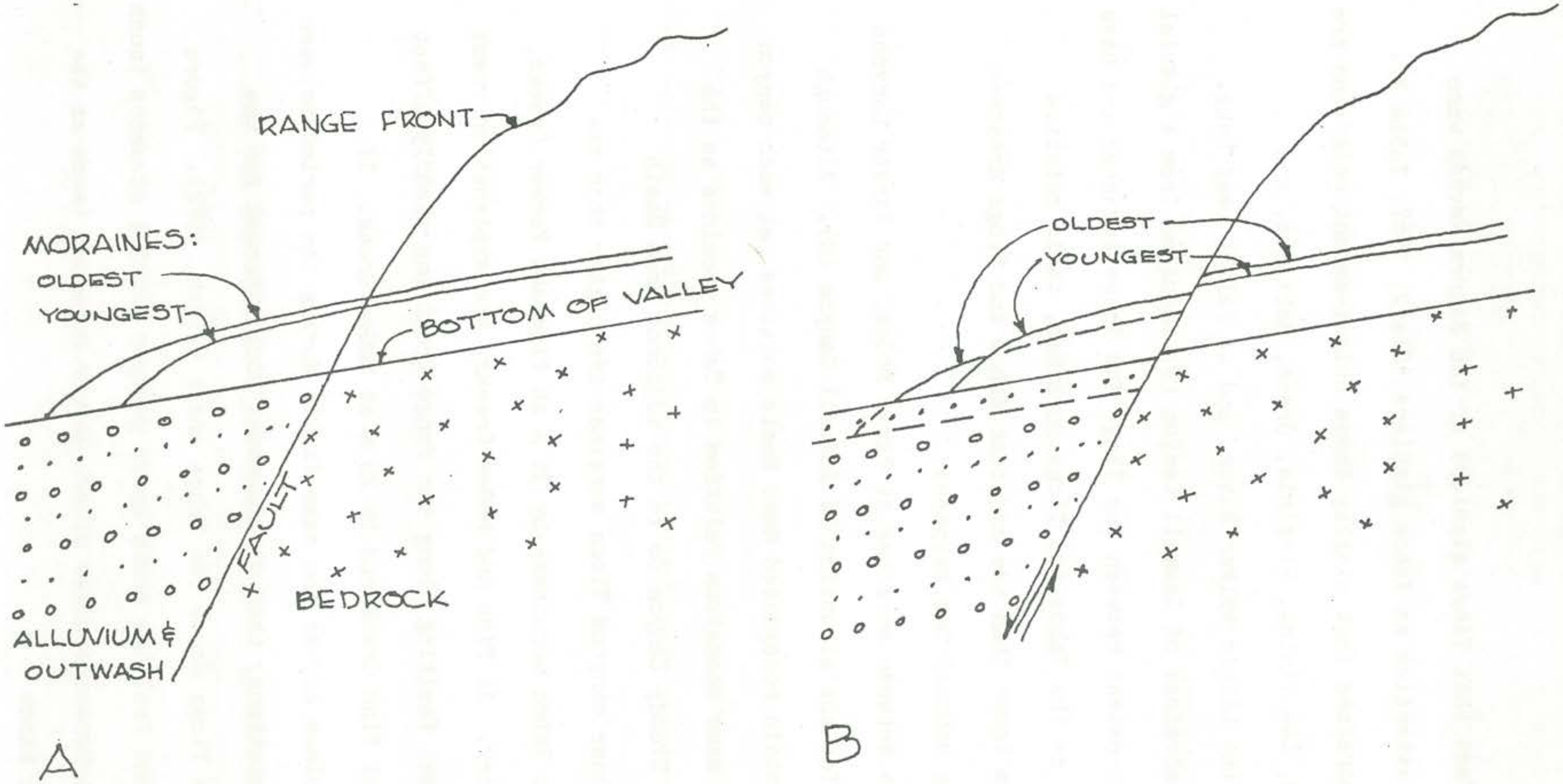


Figure VI-1. Cross section of moraines at a range-front fault. A, Normal arrangement of moraines deposited during a period without fault displacement. B, Anomalous arrangement of moraines deposited during a period of several fault displacements. Alluviation (which includes outwash) on downthrown block after faulting is much greater than corresponding deepening of bedrock glacial channel in upthrown block and elevates younger, smaller moraines above older, larger moraines on the downthrown block.

Although the moraines in Parker and Bloody Canyons show no obvious evidence of Holocene faulting, a fault that indicates Quaternary activity crosses both canyons along the range front (Kistler, 1966). Late Pleistocene displacement on this fault could account for the anomalous elevation of the Tioga above the more extensive Tahoe moraines at Parker Creek. From 50 to 70 m of displacement on this fault between the times of deposition of the Mono Basin and Tahoe moraines could also account for the present elevation of the Tahoe above the Mono Basin moraines of Sawmill Canyon (N). This hypothesis explains the similarities in length, width, and slope and the dissimilarity in height between the Tahoe and Mono Basin moraines at Walker Creek. In addition, landsliding, deposition, or displacement related to faulting could supply the mechanics for diversion of the Tahoe glacier in Bloody Canyon away from the earlier course of the Mono Basin advance down Sawmill Canyon (N).

Although the 50 to 70 m of fault displacement at Walker Creek suggests a lengthy interval between deposition of the Mono Basin and Tahoe moraines, it does not require that they derive from different glaciations. The Holocene displacement rate of 25 m in 10,000 yr. at McGee Creek, for example, would produce the offset at Walker Creek in 20,000 to 30,000 years. This time is shorter than many current estimates for the duration of a glacial period.

CHAPTER VIII

Roadlog from Mono Lake to Green Creek

R. M. Burke

This short note is to provide limited roadside viewing information between the campsite on Mono Lake and stop 8 in the Bridgeport Basin. As with Chapter IV, this is not intended to be a thorough roadside geologic guidebook, but rather a quick comment on some of the more prominent features. The route is primarily seen on figure VIII-1 with the northern part on figure XI-1.

As we leave the Mono Lake campground and proceed toward highway 395, Mono Lake, the tufa mounds of Mono Lake, and the obsidian domes of Mono Craters dominate the view. A summary of Mono Lake is presented in Chapter VII.

The origin of the tufa deposits has ben discussed in some detail by Dunn (1963). After demonstrating that the waters of Mono Lake are essentially CA^{++} free, he concluded "that much of the tufa lining the shores of alkaline lakes which is often attributed to algae or to wave agitation (with loss of CO_2) is probably formed as the result of mixing waters." That is, cold spring water approximately saturated wth $CaCo_3$ are rising into the Ca^{++} free warmer lake water and resulting in precipitation of the tufa mounds because the Ca^{++} "cannot exist in water of the composition found in Mono Lake". He also considered other factors that work in the right direction for tufa mound buildup: (1) the higher temperatures in the lake relative to spring waters causing a decrease in $CaCo_3$ solubility, (2) algal action, an important inducement to initial precipitation according to Scholl and Taft (1964), and (3) pH charges. A combination of these factors has apparently attributed to these towers marking the former lake levels.

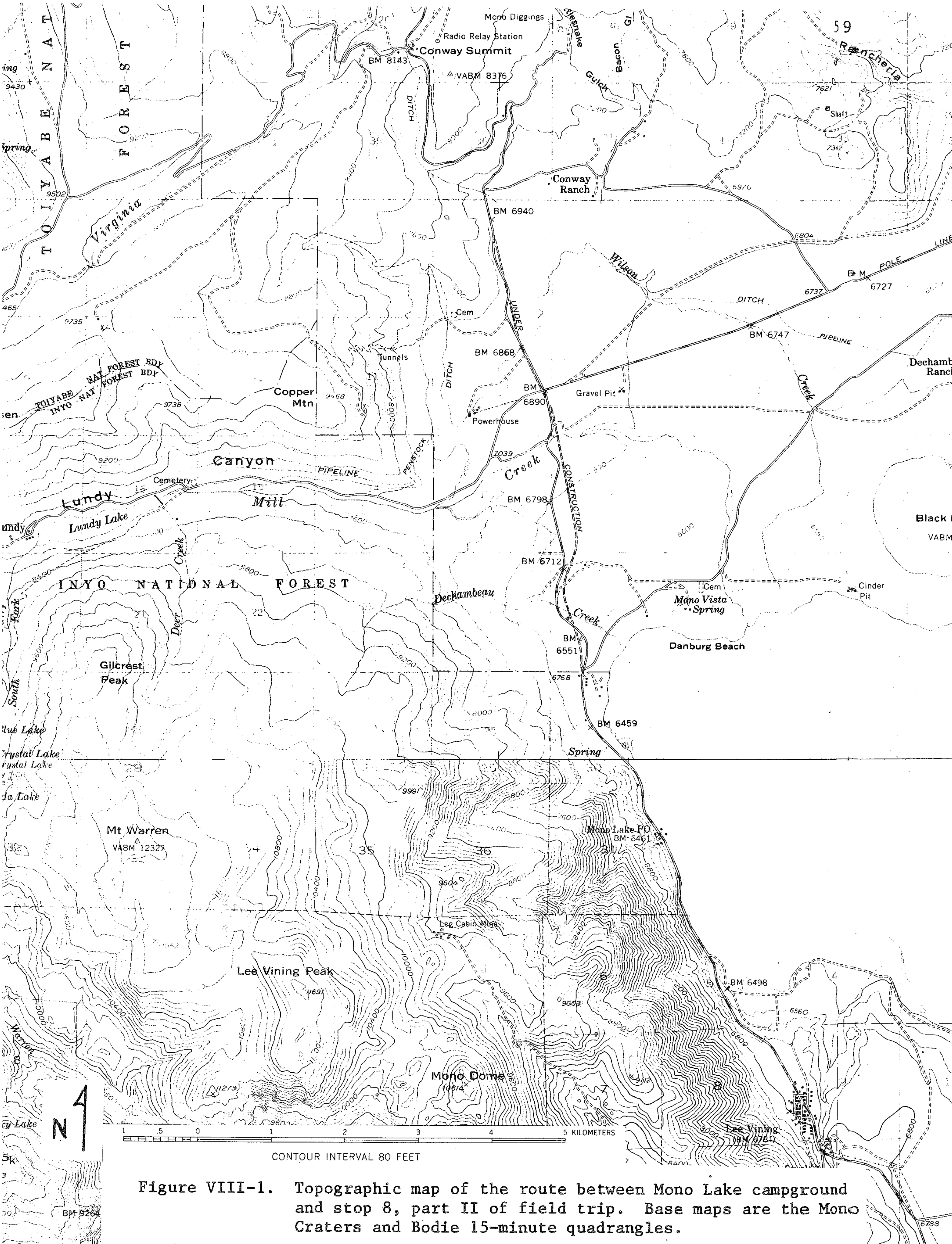


Figure VIII-1. Topographic map of the route between Mono Lake campground and stop 8, part II of field trip. Base maps are the Mono Craters and Bodie 15-minute quadrangles.

There is an extensive literature dealing with many phases of the Mono Crater. This literature has been concisely summarized by Wood (1977) and should be consulted for specific details. The available literature is diluted here to a few general statements. The Mono Craters occupy the northern portion of the fracture zone extending from the Long Valley caldera and along the Inyo Crater chain. Between our campsite and highway 120 are Panum Crater and an adjacent vent, both sources of tephra that has been dated from only a few hundred years (Wood, in prep.). The oldest exposed Mono Crater dome is, at most, a few tens-of-thousands of years old. The composition of these domes and flows is generally rhyolite. The eruptive sequence resulting in one of the Mono Crater forms is summarized by Wood (1977) from his work and the earlier literature; he states "The initial stage forms an explosion crater rimmed by tephra. This is followed by extrusion of a dome on the crater floor, and, if extrusion continues, it overflows the tephra rim to form a coulee that may extend several kilometers from the vent." (Wood, 1977, p. 89). Tephra layers from these volcanic centers help to date Holocene deposits within the Sierra Nevada and Great Basin.

Mileage

0.0 Intersection of highways 395 and 120 (to the west--Tioga Pass turnoff) for those people needing gasoline, you should buy it in Lee Vining. To the north, stations may be closing before the trip terminates. We will regroup on Conway Summit (mile 13.0) prior to our first stop of the day.

4.1 The faulted Tahoe moraines of Lundy Canyon-Mill Creek are visible straight ahead.
Visible for the next few miles are lacustrine deposits of Lake Russell, alluvial fans and debris flows from the Sierras, shorelines carved by Lake Russell, and tufa deposits--some left as horizontal bands outlining the former shoreline.

9.3 The crystalline bedrock is the Granitic Rocks of Rattlesnake Gulch which is a granite body grading locally into quartz monzonite and granodiorite (Chesterman and Gray, 1975). Note the excellent examples of tor-like features.

10.1 Deeply eroded exposures of granitic bedrock and an abundance of tor-like features can be seen.

11.9 This is a beautiful overview of Mono Lake and Mono Basin from which many of the previously discussed features can be observed. The parking area on the left side of the highway can be dangerous to get into when headed north. For those people desiring a quick camera stop, I recommend you proceed up the hill, turn around safely and return to this vantage point. We will regroup on Conway Summit (mile 13.0) prior to our first stop of the day.

12.6 To the right is a most impressive cut into Sherwin(?) till and interbedded glaciofluvial deposits (Sharp, 1972).

13.0 Conway Summit. We will stop here to regroup prior to proceeding to stop 8 in the Sherwin(?) till.

For the next 5 miles, roadcuts will be in Sherwin(?) deposits, and Tertiary Rocks of the Rancheria Tuff Breccia. Tahoe moraines can be seen along of Virginia Creek (paralleling highway 395) and the plateau-like surface to the west of Virginia Creek is Sherwin(?) till.

18.1 Stop 8 to view soil formed in Sherwin(?) till (Chapter IX and X, loc. 3).

19.3 Intersectin of Bodie turnoff. Roadcuts on either side of the road are in dacite of the Willow Springs Formation dated at about 8 m.y. (M. L. Silberman in Chesterman and Gray, 1975).

21.4 Turn off to Green Creek and stops 9-12.

CHAPTER IX

Soils and subsurface rock weathering features of Sherwin and pre-Sherwin glacial deposits, eastern Sierra Nevada, California

by

P. W. Birkeland and R. M. Burke

Soil development and subsurface rock weathering of Sherwin and pre-Sherwin Tills were studied in the Sherwin type area and near Bridgeport, California to determine useful characteristics for distinguishing these deposits from those of Tahoe age, and to test these characteristics as tools of correlation. Comparison of stable surface sites indicates that soils formed in Sherwin Till have much better developed Bt horizons, than soils formed in Tahoe Till, as shown by horizon thickness, clay content, clay films, and redness. Grusification of granitic clasts is about the same in Sherwin and Tahoe Tills, but metamorphic and volcanic clasts are much more weathered in the Sherwin deposits. The best soil development in deposits mapped as Sherwin is near Bridgeport, but correlation with the type area remains uncertain. Soils formed in the type Sherwin Till are less developed than those near Bridgeport, probably because the soils are younger, having formed on an exhumed surface since the erosion of the overlying Bishop Tuff. Data on a buried soil in the upper part of the type Sherwin Till, overlain by the Bishop Tuff, help confirm Sharp's (1968) estimate of the age of the Sherwin Glaciation at about 0.75 m.y. The type Sherwin Till buries a soil formed in still older till exposed in Rock Creek gorge, and a minimum time for the latter soil to have formed is estimated to be about 100,000 years.

INTRODUCTION

This study was intended to contribute more information on the use of relative dating methods to subdivide tills in the central part of the eastern Sierra Nevada, Californa. Much of the work in the Sierra Nevada has focused on the differentiation of Pleistocene tills with morainal form. From younger to older, this sequence of tills has been named Tioga, Tenaya, Tahoe, Mono Basin and Casa Diablo. We recently have reexamined this till sequence using a variety of relative dating methods, and suggest that the above 5-fold sequence can usually be simplified to a 2-fold sequence of major advances termed Tioga and Tahoe (Burke and Birkeland, 1979). The latter terminology is applied here. The data most useful in the above work are collected on surface and subsurface rock weathering features; features of soil development proved rather disappointing in subdividing the deposits. In this paper we examine the methods useful in the differentiation of Tahoe deposits from pre-Tahoe deposits. Because surface rock weathering features are quite advanced in Tahoe deposits, and in places the data overlap with that for Sherwin and pre-Sherwin tills (e.g. Sharp, 1969), we concentrated on subsurface rock weathering and soil morphology. Our goals were: (1) to identify criteria that would clearly differentiate Tahoe deposits from pre-Tahoe deposits; and (2) to see if the relative dating data could be useful in subdividing and correlating pre-Tahoe deposits. The emphasis was on field criteria backed by relatively simple laboratory analyses, so that these could be easily integrated into a mapping program. We feel we have been successful in goal (1), but only have had limited success in goal (2). Furthermore, the basic conclusions here differ little from those presented earlier by Sharp (1968, 1972); indeed, they support his work and add more quantitative data to those presented by him. It should be pointed out that this study differs slightly from an earlier one with somewhat similar goals (Birkeland and Janda, 1971), in that the soils are here described in more detail, and we were able to locate sites that display stronger soil development.

Study Area

For this study we selected what we consider to be the key exposures of Sherwin and pre-Sherwin till in the central part of the eastern Sierra Nevada. Although much of the area was reported on by Blackwelder (1931), the detailed work defining the key sites has been done by Sharp (1968, 1972). In Rock Creek drainage (Fig. 1) at the type locality of the Sherwin Till, the study sites include surface and buried soils formed in the Sherwin Till and a buried soil formed in a pre-Sherwin till. Near Bridgeport, two surface soils formed in Sherwin or pre-Sherwin till, or till-like deposits, were studied in the Green, Dunderberg and Virginia Creeks drainages.

Environmental Setting

The factors important to soil formation in this region have been given by Sharp (1968, 1972) and Birkeland and Janda (1971), so they are only briefly summarized here. Rock type varies from predominantly granitic lithologies in the Rock Creek area to granitic and metavolcanic lithologies, with some andesite, in the Bridgeport area. Vegetation is generally sagebrush and short grasses. Mean annual precipitation varies from about 24 cm in the Rock Creek area, to 32 cm or slightly higher in the Bridgeport area, with most of the precipitation coming during the fall and winter months. Mean annual temperature is about 7-8° C.

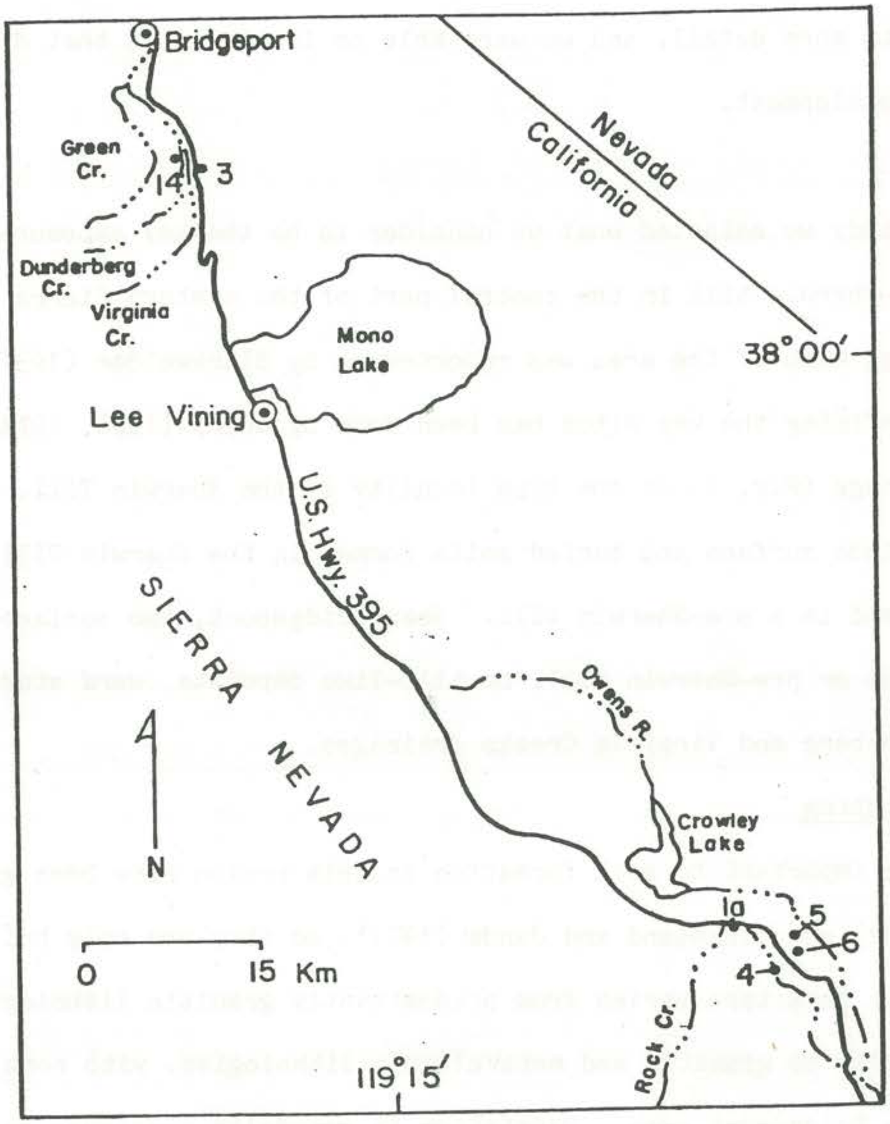


Figure IX-1. Location of soils studied in the east-cantral Sierra Nevada. The east-facing range front is generally paralled to, but west of, U.S. Highway 395. Locality numbers correspond with sites discussed in the text and data given in table 1.

Ages of Glacial Deposits

The ages of eastern Sierra Nevada glacial, deposits have been reviewed recently by Birkeland and others (1976) and Burke and Birkeland (1979), the data essential to this study is repeated here. Tioga Till probably was deposited between 10,000 and 30,000 BP. Tahoe Till is considered to be intermediate in age between basalts dated by K-Ar at 62,000 ± 13,000 BP and 126,000 ± 25,000 BP; the soil and weathering features could represent a duration of about 100,000 years. The next oldest major till is the Sherwin Till. At the type locality the Sherwin Till underlies the Bishop Tuff (Sharp, 1968), for which there is a mean K-Ar date of 0.71 my (Dalrymple and others, 1965) that is supported by zircon fission-track dating (Izett and Naeser, 1976). By adding the assumed time it took to form the soil in the till buried by the tuff to the age of the tuff, Sharp (1968) put the age at about 0.75 my. A still older diamicton of probable galcial origin in the same area has been called the McGee Till, and it rests on a basalt dated by K-Ar at 2.6 my.

RESULTS

Soils formed in Tahoe and Tioga Tills

As a point of reference for this study, we first will briefly describe the post-Tahoe and post-Tioga soils and sub-surface rock weathering. Soils are weakly to moderately developed in tills considered by us to be of Tahoe age, and in general the soil descriptions follow those of Birkeland and Janda (1971). The soils are usually oxidation profiles with subdivided Cox horizons; perhaps some horizons would meet the color or textural requirements of a cambic B horizon (Soil Survey Staff, 1975), but in our opinion most would not. The soil formed on the Casa Diablo Till at the type locality considered to be of Tahoe age (Burke and Birkeland, 1976), has a moderately developed Bt horizon that meets the criteria for an argillic horizon (Soil Survey Staff, 1975). Granitic clasts commonly are grusified within the post-Tahoe soil profiles, and in places grusified clasts occur beneath the profile in the Cn horizon. In addition, many grusified clasts near the surface are oxidized to brownish colors. In contrast, although post-Tioga soils can have oxidation profiles similar to those of post-Tahoe soils, no Bt horizons have been located and granitic clasts usually are not weathereed.

Pre-Sherwin buried soil in Rock Creek gorge

Sharp (1968) reported on a locality in Rock Creek gorge in which it looked as if Sherwin Till overlay an older till, with a deeply weathered reddish zone developed in the upper part of the buried deposit (loc. 4, Fig. 1). He favored the idea that the reddish zone was a buried soil, and speculated that the lower till might be McGee in age. Our interpretation is in close agreement with that of Sharp.

The red weathered zone has all the attributes of a buried soil (Working group on the origin and classification of paleosols, 1971; Valentine and Dalrymple, 1976). The overlying Sherwin Till has an unoxidized matrix, grusified but not oxidized granitic clasts and is in sharp contact with the underlying weathered zone. In contrast, clasts within the underlying weathered zone are grusified and oxidized brown, a feature common to soils formed in Tahoe Till. There are two buried Bt horizons within the weathered zone that are recognized on the basis of color, slight increases in clay content relative to the underlying Cox horizons, and clay films (loc. 4, Table 1). We do not know why there are two buried B horizons; that is, (1) were there two periods of till deposition separated by soil formation, or (2) is the upper B horizon the result of colluviation of a thick soil not exposed in the cut. The outcrop is too limited to give a good answer. The B horizons do not meet the criteria for an argillic horizon (Soil Survey Staff, 1975), for even though they possess clay films, the differences in the percent clay between the B horizons and the Cox horizons are less than 3 percent. We realize that this is a change in the definition of the argillic horizon because the A and B horizons are to be compared on clay content. Buried soils, however, rarely have A horizons preserved, so comparison of A and B horizons is impossible. Our suggestion in these cases is to apply the same clay-increase criteria to the B and C horizons if one can be reasonably certain that the C horizon material approximates the parent material for the B horizon.

The above properties for the reddish weathered zone are distinctly pedological in origin rather than being features, such as ground-water alteration, attained after burial by Sherwin Till. The weathered zone thus points to a hiatus of considerable duration between deposition of the two tills. A minimum time for the hiatus probably is the time that has elapsed between deposition of Tahoe Till and the present, perhaps 100,000 yr. Any more detailed age assignment is unwarranted, because position in the landscape strongly influences soil development, and the position of the buried soil in the paleo-landscape is unknown.

Soil in type Sherwin Till

In an earlier study (Birkeland and Janda, 1971), a Bt horizon was not recognized in the type Sherwin Till. The site for that study was west of Rock

Table IX-1: Data on pre-Tahoe soils, eastern Sierra Nevada 1/

Locality	Horizon	Depth, cm	Color (dry)	Particle-size distribution, % sand	silt	clay	Gravel, %	Organic matter,%	pH
Buried soil in pre-Sherwin till, Rock Creek gorge (Loc. 4, Fig. 1) 2/	Cn		2.5Y 7/3	73.3	17.9	8.8	90	0	7.1
	IIB2tb	0-54	7.5YR 5.5/5	59.2	31.2	9.6	10	0.6	7.3
	IICoxb	54-104	2.5Y 7/3.5	62.1	30.6	7.3	10	0.6	7.7
	IIIB2tb	104-144	10YR 6/4	58.0	28.5	13.5	50	0.4	7.7
	IIICoxb	144-444	2.5Y 6/3	62.5	25.5	12.0	50	0.5	7.8
	IIICnb	13 m below "0" depth	2.5Y 5/3	66.3	22.0	11.7	50-75	0.4	8.4
Surface soil in type Sherwin Till (loc. 5 Fig. 1) 3/	B2t	0-45	10YR 4/4	67.5	12.5	20.0	50-75	0.6	6.7
	B3t	45-80	10YR 4/3	69.1	8.5	22.4	50-75	0.3	6.8
	Cox	80-100+	2.5Y 5/3	67.4	19.6	13.0	50-75	0.4	7.1
Surface soil in type Sherwin Till (loc. 6, Fig. 1) 4/	A	0-9	10YR 4/3	82.9	11.1	6.0	0	1.1	6.1
	IIB1	9-24	10YR 5/4	75.3	14.4	10.3	75-90	0.6	6.6
	IIB2t	24-80	10YR 4/6	69.5	16.2	14.3	75-90	0.1	6.8
	IIB3t	80-94	10YR 6/4	71.3	16.3	12.4	75-90	0.2	6.8
	IIIC1ox	110-138	10YR 6/5	72.0	18.1	9.9	50-75	0.4	6.9
	IIIC2ox	138-238	10YR 6/4.5	80.1	13.6	6.3	50-75	0.2	7.0
	IVC3ox	238-263	7.5YR 6/7	69.0	23.9	7.1	50-75	0.4	7.6
	IVCn	263+	2.5Y 7/3	69.3	23.8	6.9	50-75	0.2	7.8
Soil in type Sherwin Till buried by Bishop Tuff (Loc. 1a, Fig. 1) 5/	C1oxb	0-83	2.5Y 5/3.5	87.2	6.6	6.2	0	0.3	7.0
	C2oxb	83-120					0		
	IIC2oxb	120-165	2.5Y 5/3	86.7	6.8	6.5	10	0.3	6.9
	IIC3oxb	165-210	5Y 6/2	82.7	11.9	5.4	90	0.1	6.5
	IICnb	210+	5Y 7/2	89.1	7.9	3.0	90	0.2	7.1

Table IX-1: Data on pre-Tahoe soils, eastern Sierra Nevada 1/ (continued)

Locality	Horizon	Depth, cm	Color (dry)	Particle-size distribution, % sand	silt	clay	Gravel, %	Organic matter,%	pH
Soil in Sherwin(?) Till (Lox. 14, Fig. 1) 6/	B2t	0-35	5YR 6/6	33.4	30.0	36.6	10	0.2	6.0
	B3	35-75+	7.5YR 7/6	48.9	32.7	18.4	10	0.4	6.2
Soil in Sherwin(?) Till (loc. 3, Fig. 1) 7/	A	0-7	10YR 6/3	52.3	36.9	10.8	50-75	1.4	6.7
	B1	7-15	7.5YR 4.5/3	46.9	33.9	19.2	50-75	1.0	6.5
	IIB21t	15-43	5YR 5/4	28.6	31.2	40.2	50-75	0.4	6.7
	IIB22t	43-100	5YR 5/3.5	38.9	27.6	33.5	50-75	0.8	6.7
	IIB23t	100-130	5YR 4/4	44.4	26.1	29.5	50-75	0.5	6.4
	IIB24t	130-160	5YR 4/4	38.5	26.7	34.8	50-75	0.3	6.2
	IIB31	160-180	7.5YR 5/4	45.0	28.1	26.9	50-75	0.8	6.5
	IIB32	200-220	7.5YR 5/4	55.6	24.9	19.6	50-75	0.7	7.5
	IIB33	240-260	7.5YR 5/4	55.5	25.1	20.4	50-75	0.6	7.6
	IIB34	280-300	7.5YR 5/4	51.0	27.2	21.8	50-75	0.7	7.3
	IIIC1ox	320-340	10YR 8/3	54.3	26.5	19.2	10-20	0.5	7.6
	IIIC2ox	360-380	10YR 7/3	51.9	27.9	20.2	10-20	0.6	7.5
	IIIC3ox	400-420	10YR 6/3	54.9	28.9	16.2	10-20	0	7.5

Footnotes to Table IX-1

1/ Parent material layering (I, II, etc.) is recognized on abrupt particle-size variation, that is considered to be of geologic origin, in either the gravel or non-gravel content. Colors are for dry, sieved (< 2mm) samples. Particle-size classes follow the U.S.D.A. Gravel percent, It is a visual estimate, by volume, determined in the field. Organic matter is weight loss at 450°C for 2 hours, with a correction for crystal-lattice water loss. pH was taken with a soil:water ratio of 1:2.5. Soil horizon nomenclature for Cox and Cn horizons follows Birkeland (1974), and clay film description follows Soil Survey Staff (1951).

2/ Soil described and collected in roadcut 0.5 km south of the bridge over Rock Creek along the Sherwin Grade, at the boundary between sections 11 and 12, T. 5 S., R. 30 E., Casa Diablo Mountain, California 15-minute quadrangle. Description is for the northern part of the southern of 2 outcrops of "old red till" of Sharp (1968, fig. 8).

Remarks: The Cn is Sherwin Till, and included granitic clasts are weathered flat-to-the-face, and are virtually unoxidized (10YR 6/1). In contrast, boulders to 144 cm depth in the buried soil are grusified throughout and oxidized (maximum oxidation color: 7.5YR 6/8). Grusified granitic clasts are slightly oxidized in the IIICoxb horizon. Clay films are few and thin in the IIB2tb horizon, and common and moderately thick in the IIIB2tb. IIICnb collected 18 m south of the rest of the profile, south of the fault shown by Sharp (1968, fig. 8); granitic clasts there are fresh.

3/ Soil described and collected in shallow artificial cut at the summit of hill x7264 feet, in the center of section 1, T. 5 S., R. 30 E., Casa Diablo Mountain, California 15-minute quadrangle.

Remarks: Vegetation is sagebrush and short grasses with some piñon pine. Included granitic clasts are grusified and oxidized. Clay films in the B2t are common and moderately thick, and seem to be less common in the B3t.

4/ Soil described and collected in the large west-facing roadcut of the southbound lane of U.S. Highway 395, 1.6 km southeast of the Little Pumice Cut of Sharp (1968, fig. 1), and just north of the connecting lane between the south- and northbound lanes of the highway. NW 1/4 of Section 12, T. 5 S., R. 30 E., Casa Diablo Mountain, California 15-minute quadrangle.

Remarks: Vegetation is mainly sagebrush and short grasses. Granite clasts are grusified throughout, those in the soil are oxidized, whereas those in the Cn till are not. Clay films in the Bt horizons are moderate to few and thin.

5/ Soil described and collected in the Big Pumice Cut of Sharp (1968, figs. 1 and 3), 17 m west of the first occurrence of Sherwin Till in the cut. SW 1/4 of Section 34, T. 4 S., R. 30 E., Casa Diablo Mountain 15-minute quadrangle.

Remarks: Parent material I seems to be colluvium, II and III are till. Many granitic clasts throughout the cut are grusified and those in the uppermost 4 m of the till are oxidized to 2.5Y 6/3.

6/ Soil described and collected at "old red soil" locality shown in Figure 6 of Sharp (1972), south-central part of Section 34, T. 4 N., R. 25 E., Bodie, California 15-minute quadrangle.

Remarks: Vegetation is sagebrush and short grasses. Clay films in the B2t are abundant, thick, and 2.5YR 6/3 (moist).

7/ Soil described and collected from roadcut about 0.1 km north of where the 7200-foot contour intersectd U.S. Highway 395 in Section 35, T. 4 N., R. 25 E., Bodie, California 15-minute quadrangle. A power line crossed the highway here in 1975. Uppermost 100 cm of soil was described in a roadcut along the abandoned road just east of, and parallel to, U.S. Highway 395, and the rest of the soil described in U.S. Highway 395 roadcut.

Remarks: Vegetation is sagebrush and short grass. Granitic clasts are grusified and oxidized throughout the soil and they have a maximum oxidation color of 10YR 6/8. The percent of grusified stones decreases with depth. Many metamorphic and volcanic clasts can be cut through with a pick. Clay films in the Bt horizon are common and moderately thick. The subordinate horizon nomenclature below 100 cm depth reflects various sampling intervals.

Creek in till mapped as Sherwin by both Blackwelder (1931) and Sharp (1968). The soil was sampled at as high an altitude as possible to reduce the possibility of the site having been once buried by the Bishop Tuff. The fact that a Bt horizon was not found probably can be ascribed to erosion at the site.

In this study we sampled two surface soils formed in the type Sherwin Till. One soil (loc. 5, Fig. 1) is at an altitude slightly below the top of the Bishop Tuff located 1 km to the north. However, because Sharp (1968) maps a patch of pumice northeast of and only 20 m lower than the soil, chances are good that Bishop Tuff did cover the site. The soil, therefore, most likely reflects pedogenesis in the exhumed till since removal of the tuff. The soil has a strongly developed Bt horizon (loc. 5, Table 1), which would be classed as an argillic horizon because the clay content in the Bt is nearly twice that in the Cox horizon. Granitic clast weathering is typical for deposits of Tahoe age or older.

The other surface soil (loc. 6, Fig 1) is a site that was also buried by the Bishop Tuff, so pedogenesis is mainly that since erosion of the tuff. This soil (loc. 6, Table 1) has many properties in common with that described above for the locality 5. In particular, the combination of B horizon thickness, clay content of the Bt horizon relative to the C horizon, oxidation colors, and weathering of granitic clasts are quite similar at both sites. This similarity could mean that: (1) both soils have formed for a similar length of time since removal of the tuff; or (2) it is an artifact of erosion at only one site; or (3), the soils are approaching steady-state conditions in development and they would look similar despite a great difference in age. For reasons to be given later, it is unlikely that steady-state conditions can be demonstrated for these soils. Their similarity probably is a function of the time since the till was exhumed from beneath the tuff, in addition to subsequent erosion.

These soils can be put into a time framework with respect to the other soils already discussed. B-horizon development exceeds that of soils in Tahoe Till, so the duration of time necessary to form them probably exceeds 100,000 years. Comparing the surface soils in Sherwin Till with the buried soil in pre-Sherwin till in Rock Creek gorge, there is better textural development in the former but better color development in the latter. At present we cannot make any time discrimination between the development of reddish color versus that of clay buildup for these three sites. We suspect that clay content might be the better indicator of age, and thus the two surface soils in Sherwin Till would have required longer periods of time to form than the buried soil in Rock Creek gorge.

A buried soil in the type Sherwin Till at the contact with the overlying Bishop Tuff also was studied. Sharp (1968), studied these relationships in detail and concluded that the character of the buried soil was intermediate between that of post-Tioga and post-Tahoe soil. From this he concluded that the Sherwin Till weathered for a few tens of thousands of years before being buried by the tuff; thus, he put the age of the Sherwin at about 0.75 my. We studied the Little Pumice Cut of Sharp (1968, Fig. 6) and found the soil relationships not to be clearcut, so concentrated our efforts on the buried soil in the Big Pumice Cut of Sharp (1968 Fig. 3; loc. 1a, Fig. 1, this study).

The buried soil exposed in the Big Pumice Cut is essentially a weakly oxidized Cox profile slightly over 2 m thick (loc. 1a, Table 1). The oxidation colors are less intense that those for many profiles in both Tioga and Tahoe Tills. The granitic clast grusification, however, seems to be as well developed as in many exposures of Tahoe Tills. Hence, the suggestion of Sharp (1968) that this soil seems to have properties intermediate between those formed in Tioga and Tahoe Tills seems justified.

Soils in Sherwin (?) Till near Bridgeport

Soils formed in the pre-Tahoe tills of the Virignia, Dunderberg and Green Creek drainages are the most strongly developed soils encountered in this study. Sharp (1972) tentatively grouped these tills with the Sherwin, but queried the designation because correlation with the type locality is uncertain. The soil at locality 14 (Fig. 1) is the "old red till" of Sharp (1972), and that at locality 3 (Fig. 1) was previously studied by Birkeland and Janda (1971; soil samples 8 and 43), and by Sharp (1972) who considered the parent material to be outwash.

Both soils are characterized by Bt horizons with the highest clay contents, the best developed clay films, and the reddest hues in the study area (locs. 14 and 3, Table 1). In addition, the weathering of subsurface clasts in the soil at locality 3 is extreme. The main difference between these two soils is a thinner Bt horizon at locality 14, but this could be due more to erosion than to a difference in age. Locality 3 is the more stable of these two sites, and this is reflected by the depth to which the B2t and B3 horizons extend. We were not able to definitely determine the parent material for the soil at locality 3, but the high clay content seems to rule out a well-sorted fluvial deposit; however, a mudflow origin cannot be ruled out. Of the soils examined along the central part of the eastern Sierra Nevada by Birkeland and colleagues over the past 16 years, these seem to be the best developed soils formed in till or till-like deposits.

CONCLUSIONS

The soil data presented confirm many of the findings of Sharp (1968, 1972), and add some quantitative soil data as supportive material. The soil formed in the Sherwin till buried by the Bishop Tuff and exposed in the Big Pumice Cut (loc. 1a), may only have required a few tens of thousands of years to form, in support of Sharp's (1968) suggested age of about 0.75 m.y. for the Sherwin Glaciation. The weathering of granitic clasts at the same site may argue in favor of a longer time for the hiatus, but some of the grusification could postdate the emplacement of the Bishop Tuff. Strongly developed surface soils formed in Sherwin Till at the type locality (locs. 5 and 6) are similar, perhaps because of similar pedological and erosional histories since removal of the Bishop Tuff. Steady-state arguments probably cannot be invoked to explain the similarity in these two profiles because soils farther north near Bridgeport are much better developed. The soils near Bridgeport are the best developed for the area. The reason for this could be that: (1) they represent the total development expected for reasonably stable sites over 0.75 m.y.; or (2) the material in which they formed could be pre-Sherwin in age; or (3), the presence of volcanic, metavolcanic and other metamorphic lithologies could increase the rate of clay formation and red-color buildup relative to that for soils formed in deposits of predominantly granitic lithologies. Hence, we agree with Sharp's (1972) call for caution in the correlation among these very old deposits on relative age dating criteria. The oldest soil studied could be the buried soil in Rock Creek gorge. Sharp (1972) remarked on the similiarity between this latter oil and the red soils near Bridgeport (loc. 3 and 14, this study); we disagree with this statement as the two surface soils show many more strongly developed pedological features than does the buried soil. If, however, it can be shown that the parent materials for the soils at localities 3 and 14 are pre-Sherwin, then it is possible that these soils are the surface equivalent of the buried soil in Rock Creek gorge, and the difference in development would then be attributed primarily to differences in duration of exposure to soil-forming processes.

Correlation with more distant areas in California is even less certain than within this relatively restricted area. The maximum soil development and rock weathering reported on here have distinct similarities to those for pre-Tahoe tills near Lassen Peak (Crandell, 1972) and Hobart Till near Truckee, if indeed the Hobart Till can be proven to predate the Donner Lake Till (see Birkeland and Janda, 1971, Table 1, footnote 5). For now it seems that soil morphology and rock weathering characteristics can be used to group tills into a broad pre-Tahoe age designation, but subdivision within this grouping will have to await detailed study of a sequence of deposits in which post-depositional erosion can be demonstrated to be minimal.

ACKNOWLEDGMENT

We are grateful to Rolf Kihl for the laboratory data, and to R. P. Sharp and R. R. Shroba for reviewing this manuscript. The work was supported by U.S. Geological Survey Grant No. 14-08-0001-G-202.

CHAPTER X

Preliminary remarks on chemical data for soils formed on Sherwin and pre-Sherwin glacial deposits, eastern Sierra Nevada, California

P. W. Birkeland, A. L. Walker, and R. M. Burke

This short note is to accompany the previous paper, and add some soil chemical data that have just recently come out of our lab. The analyses are as follows:

a. Oxalate extract: Thought to mainly extract the amorphous and some organic bound Fe and Al (designated Fe_o and Al_o).

b. Dithionite extract: thought to extract the total free Fe and Al (crystalline, amorphous, and organic bound; designated Fe_d and Al_d).

c. Phosphorous fractions: in sulfuric acid extractable-P_a (in apatite and sorbed at oxide surfaces), and organic bound-P_o.

The expected trends are for Fe and Al fractions to build up with time, and for P_o to increase with time at the expense of P_a. Ideal trends are not always obtained; in fact the only good trend is in Fe_d. Some preliminary conclusions can be made (Table X-1 and Figure X-1, X-2, and X-3):

1. The soil formed in the Sherwin Till, buried by the Bishop Tuff (loc. 1a, Chapter IX) exhibits few trends, and is thus similar to soils formed in Tioga and Tahoe Tills.
2. Relict soils formed form Sherwin Till at the type locality (locs. 5 and 6, Chapter IX) also do not show very striking trends, especially for soils considered to be that old.

Table X-1: Chemical data for soils formed on Sherwin and pre-Sherwin glacial deposits

Field locality*	Horizon	Feo	Fed	Alo	Ald	Pa	Po
Buried soil in pre-Sherwin till, Rock Creek Gorge (loc. 4)	Cn	.18	.40	.05	.03	36.4	0.4
	IIB2tb	.06	1.01	.07	.07	5.3	5.5
	IICoxb	.06	.56	.06	.04	3.7	2.8
	IIIB2tb	.06	.64	.07	.05	12.5	2.2
	IIICoxb	.04	.58	.07	.04	61.8	--
	IIICnb	.03	.54	.07	.04	65.4	1.8
Type Sherwin Till (loc.5)	B2t	.08	.34	.09	.04	40.7	3.4
	B3t	.10	.35	.10	.04	38.1	3.7
	Cox	.05	.34	.08	.02	41.7	2.2
Type Sherwin Till (loc. 6)	A	.10	.31	.08	.05	35.2	7.0
	IIB1	.08	.33	.08	.04	29.2	6.6
	IIB2t	.07	.41	.08	.04	40.9	5.9
	IIB3t	.04	.36	.07	.03	38.0	5.0
	IIIC1ox	.05	.54	.07	.01	42.2	4.4
	IIIC2ox	.04	.28	.06	.01	46.7	--
	IIIC3ox	.09	2.02	.06	.02	34.8	15.0
	IIICn	.03	.30	.06	.03	58.6	--
Type Sherwin (buried by Bishop Tuff), Loc. 1a)	C1oxb	.03	.22	.05	.04	20.5	4.8
	C2oxb + IIC2oxb	.05	.21	.05	.03	16.6	3.6
	IIC3oxb	.15	.20	.05	.04	18.8	4.6
	IICnb	.02	.14	.02	.02	18.0	0.4
Sherwin Till (loc. 14)	B2t	.07	3.52	.11	.12	4.1	15.2
	B3	.02	.16	.07	.09	2.2	8.7
Sherwin(?) Till (loc. 3)	A	.11	.78	.07	.05	27.6	10.3
	B1	.11	.38	.08	.03	50.9	--
	IIB21t	.10	1.10	.13	.09	8.2	21.1
	IIB22t	.09	1.21	.11	.10	11.3	17.4
	IIB23t	.08	.86	.12	.09	23.3	16.5
	IIB24t	.08	.85	.12	.09	19.3	16.4
	IIB31	.09	.77	.10	.09	23.6	17.1
	IIB32	.12	1.31	.10	.12	38.0	9.6
	IIB33	.07	1.71	.10	.17	21.3	8.7
	IIB34	.06	1.43	.10	.14	23.8	11.2
	IIIC1ox	.03	1.10	.09	.09	4.3	21.2
	IIIC2ox	.05	.82	.11	.09	4.9	14.8
	IIIC3ox	.05	1.27	.08	.12	18.9	9.9

* Numbers are keyed to figure IX-1.

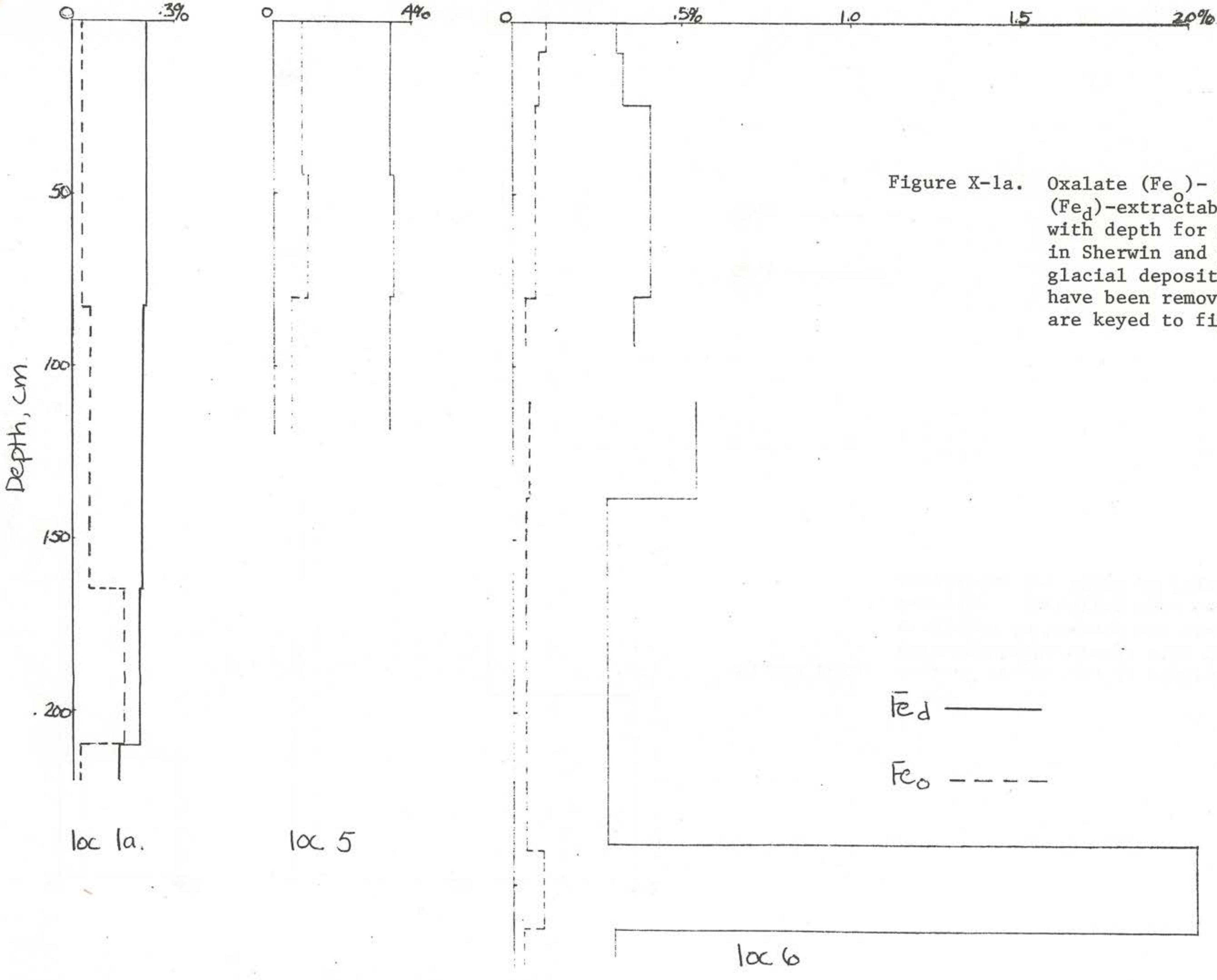


Figure X-1a. Oxalate (Fe_o)- and dithionite (Fe_d)-extractable Fe trends with depth for soils developed in Sherwin and pre-Sherwin glacial deposits. Magnetics have been removed. Localities are keyed to figure IX-1.

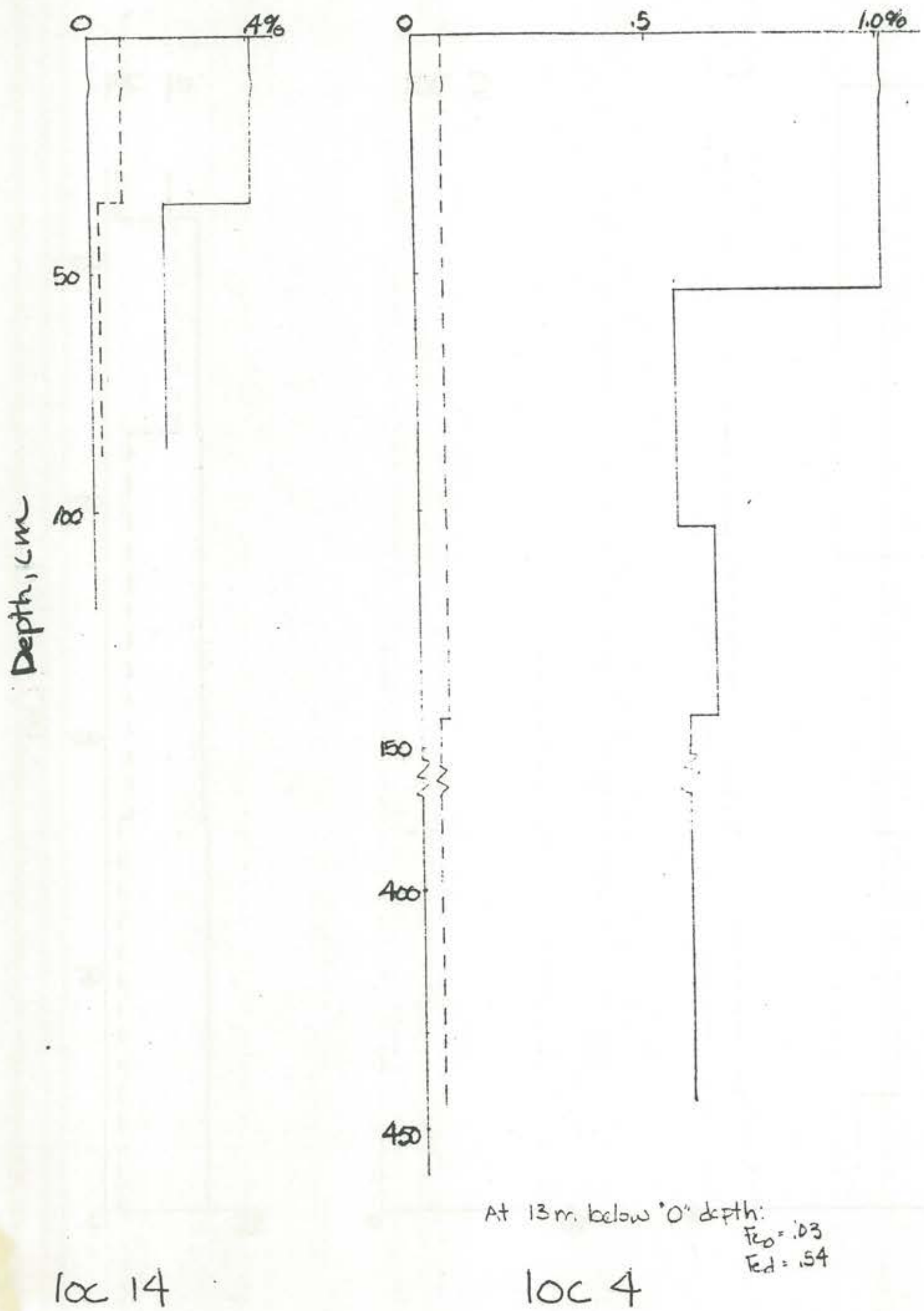


Figure X-1b. Oxalate (Fe_o)- and dithionite (Fe_d)-extractable Fe trends with depth for soils developed in Sherwin and pre-Sherwin glacial deposits. Magnetics have been removed. Localities are keyed to figure IX-1.

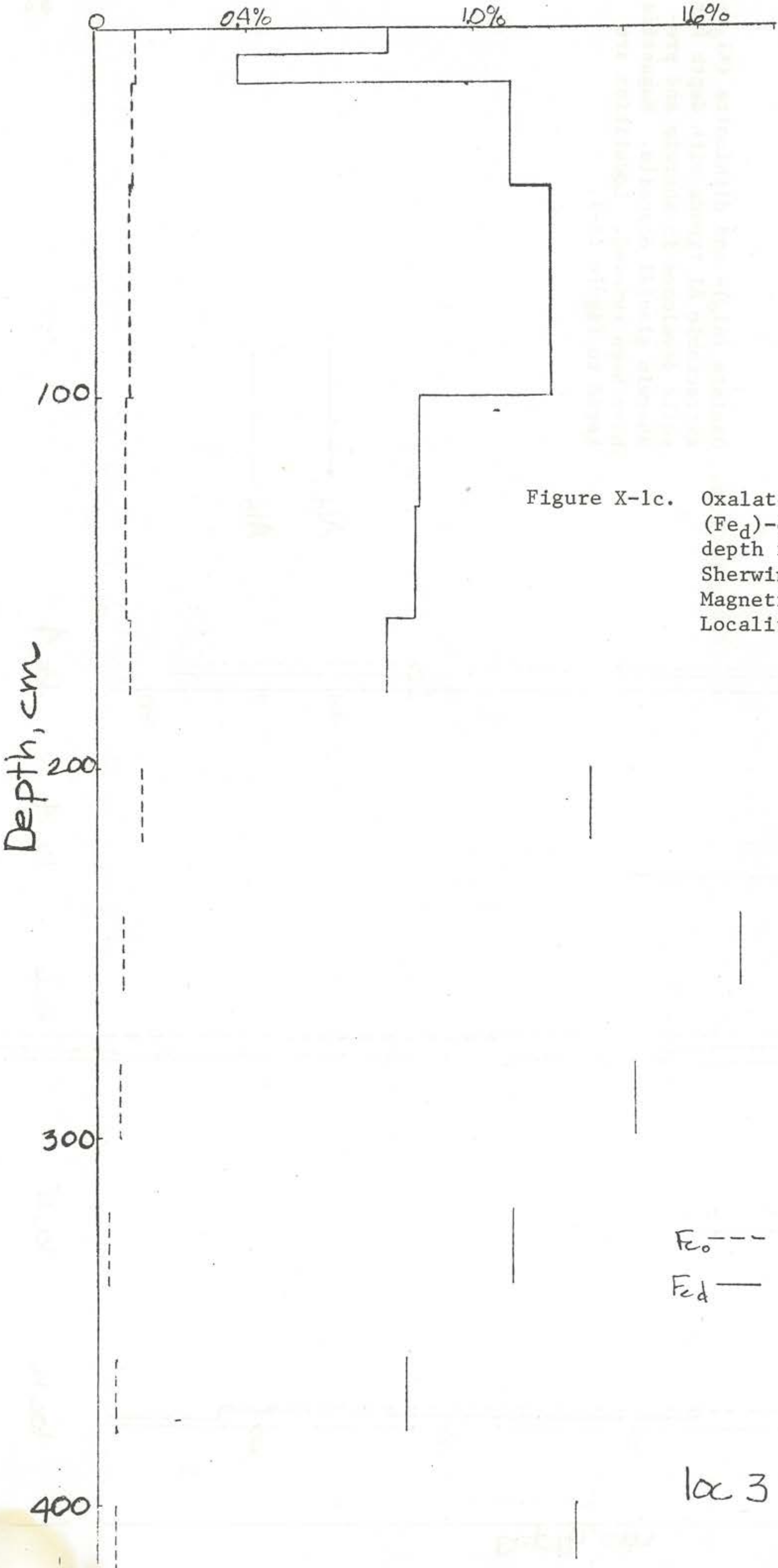


Figure X-1c. Oxalate (Fe_o)- and dithionite (Fe_d)-extractable Fe trends with depth for soil developed in Sherwin (?) glacial deposit. Magnetics have been removed. Locality is keyed to figure IX-1.

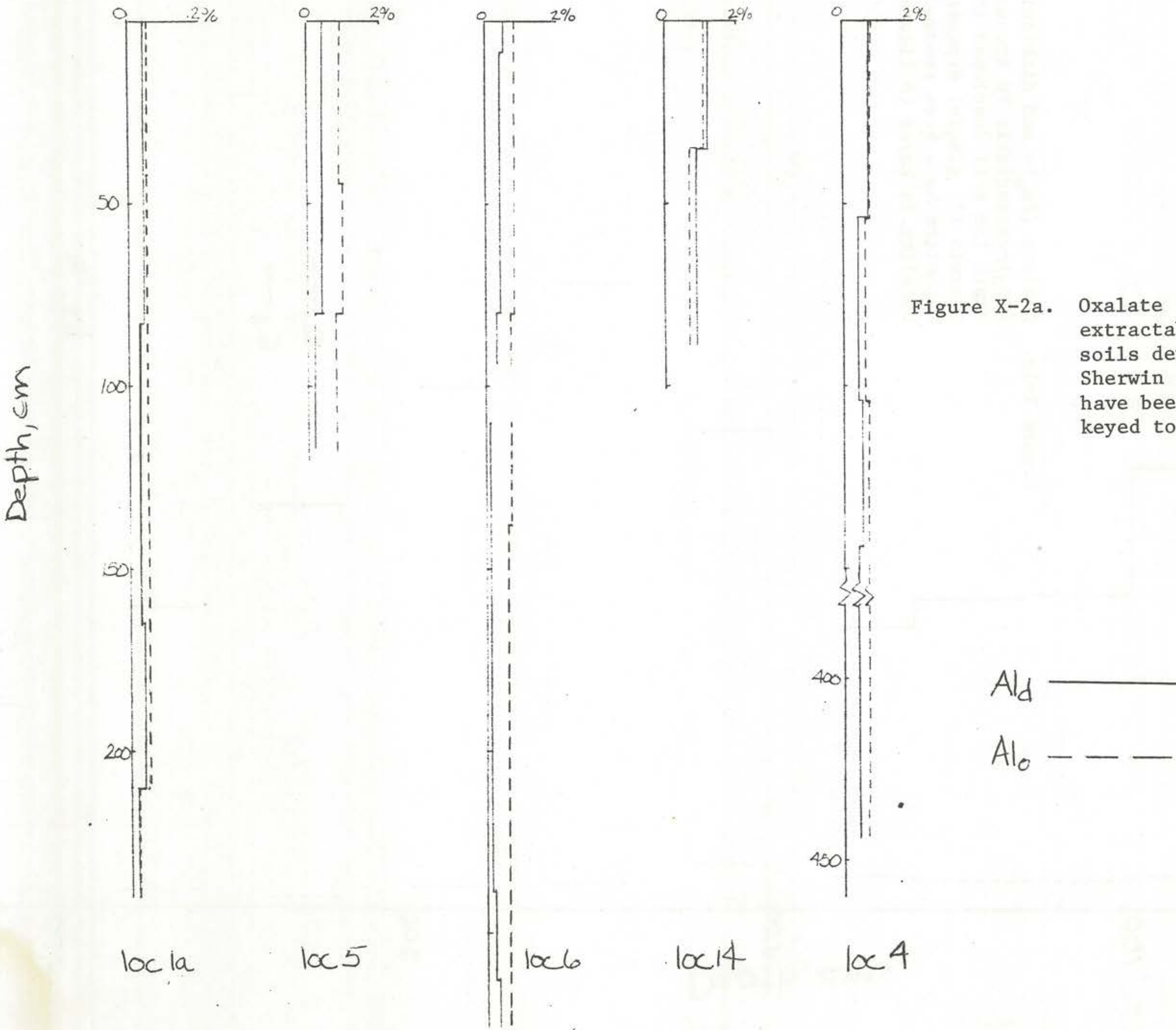


Figure X-2a. Oxalate (Al_o)- and dithionite (Al_d)-extractable Al trends with depth for soils developed in Sherwin and pre-Sherwin glacial deposits. Magnetics have been removed. Localities are keyed to figure IX-1.

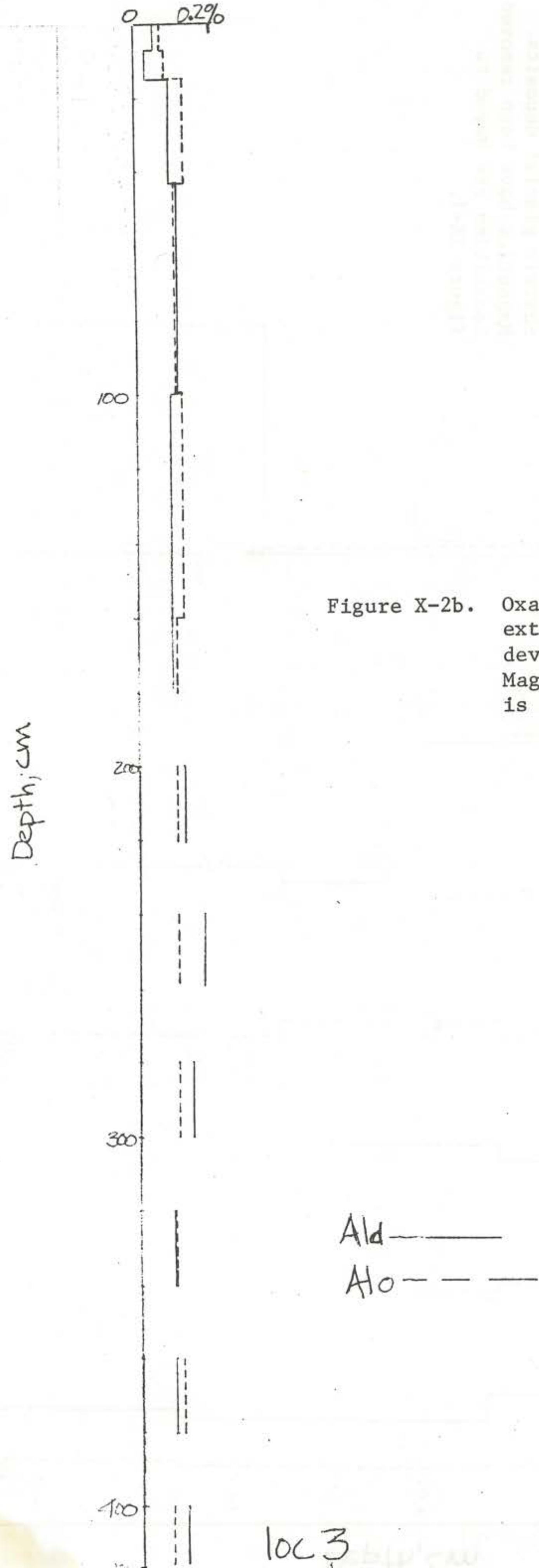


Figure X-2b. Oxalate (Al_o)- and dithionite (Al_d)-extractable Al trends with depth for soil developed in Sherwin (?) glacial deposit Magnetics have been removed. Locality is keyed to figure IX-1.

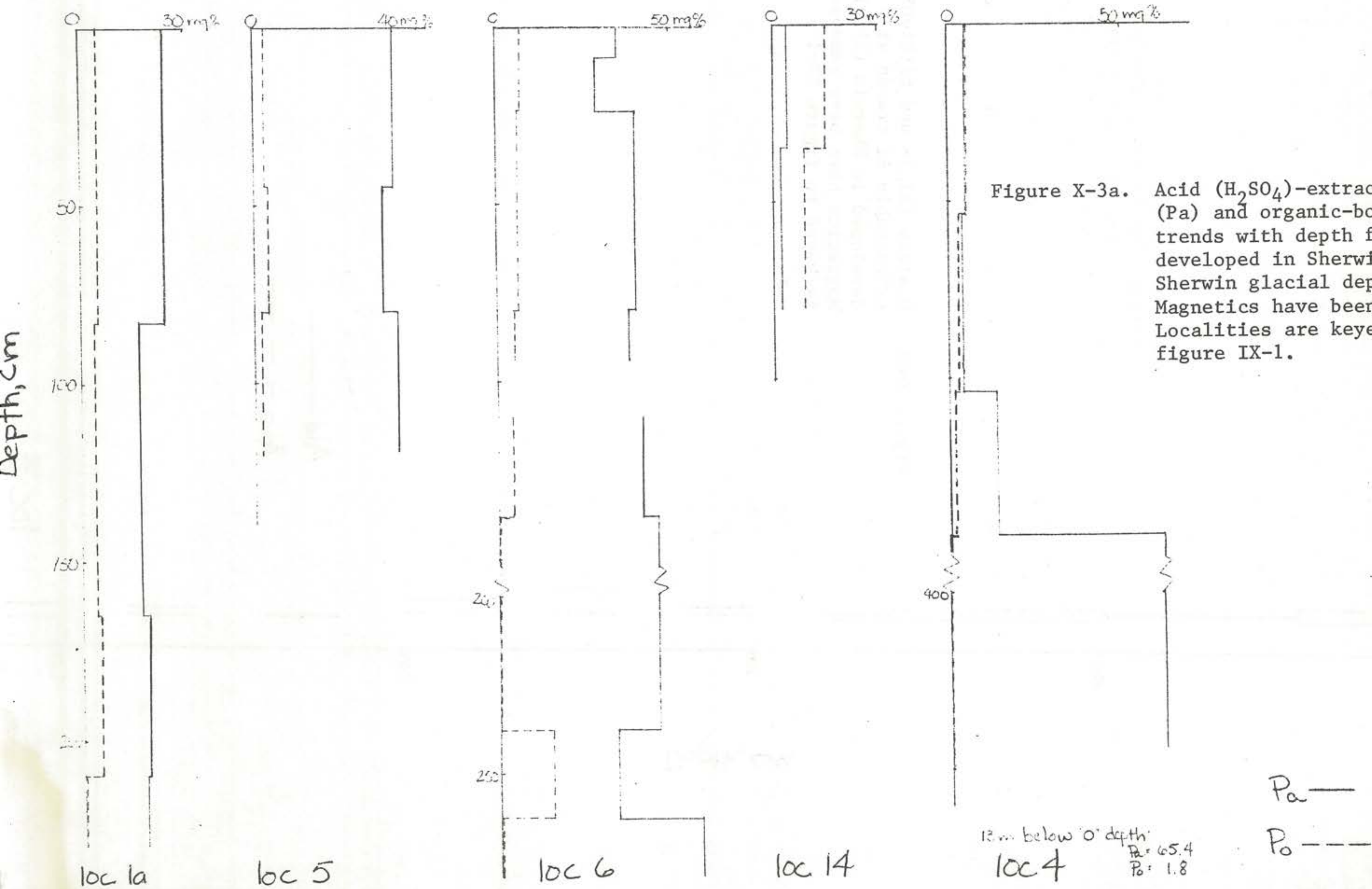


Figure X-3a. Acid (H_2SO_4)-extractable (Pa) and organic-bound P (Po) trends with depth for soils developed in Sherwin and pre-Sherwin glacial deposits. Magnetics have been removed. Localities are keyed to figure IX-1.

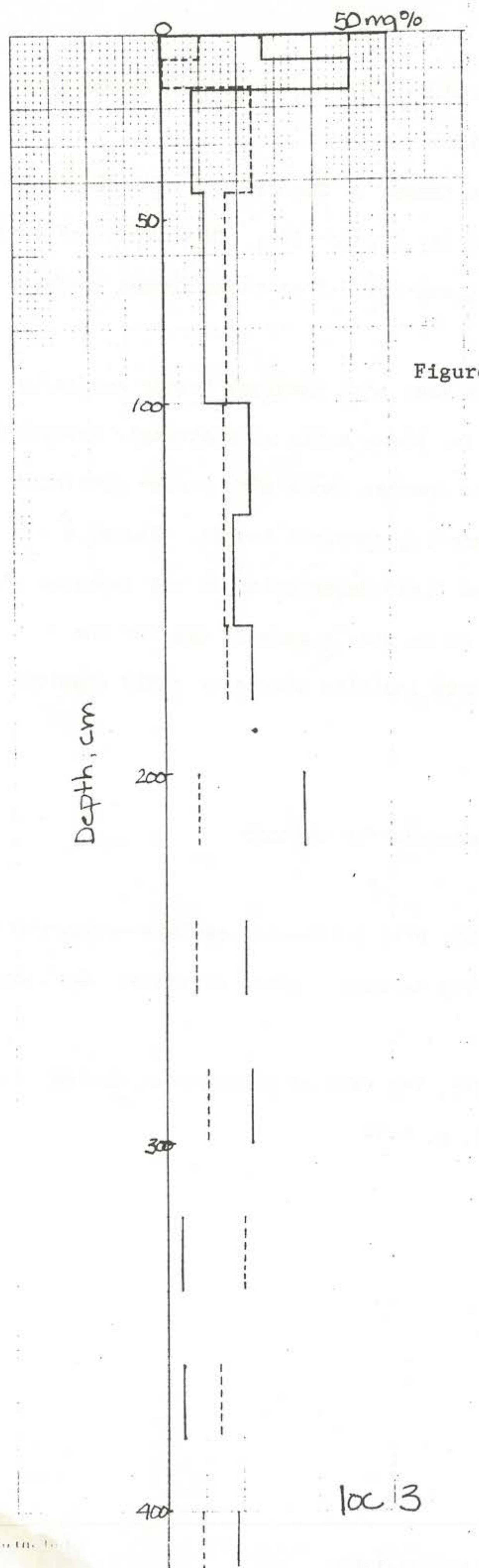


Figure X-3b. Acid (H_2SO_4)-extractable (Pa) and Organic-bound P (Po) trends with depth for soil developed in Sherwin (?) glacial deposit. Magnetics have been removed. Locality is keyed to figure IX-1.

3. The data for the pre-Sherwin buried soils(s) in Rock Creek Gorge (loc. 4, Chapter IX) also do not show striking trends.

4. The best buildup is Fe_d for soils formed in Sherwin (?) till deposited in the Bridgeport Basin (locs. 3 and 14, Chapter IX). This amount of buildup seems adequate to differentiate these soils from those formed in Tahoe and Tioga Tills.

The main conclusion here is that some soil chemical trends generally parallel the soil morphology. That is, those soils with strongly developed morphology have a marked Fe_d pattern, whereas those with lesser developed morphology show little, if any, diagnostic chemical trends. Hence, a preliminary conclusion is that a good field description is not improved with laboratory data if all one wants to do is give a general age for the deposit. Perhaps the semi-arid climate inhibits storng or rapid chemical differentiation.

General references for methods

McKeague, J. A., and Day, J. H., 1966, Dithionite--and oxalate--extractable Fe and Al as aids in differentiating various classes of soils: Can. Jour. Soil Sci., v. 46, p. 13-22.

Walker, T. W., and Syers, J. K., 1975, The fate of phosphorous during pedogenesis: Geolderma, v. 15, p. 1-19.

CHAPTER XI

Relative dating of the post-Sherwin glacial deposits along Green Creek

R. M. Burke and P. W. Birkeland

The majority of this chapter is taken from Burke and Birkeland (1979) and is reporduced here with the permission of Quaternary Research and the University of Washington. All references of this material should be made to the original paper. The soil chemical data are recently out of our lab and not included in Burke and Birkeland (1979). See Chapter XIII for a brief discussion of the soil chemistry data. Figure XI-1 shows the location of stops 8-12. Stop 8 and 12 are to view Sherwin(?) deposits which are discussed in Chapters IX and X as localities 3 (stop 8) and 14 (stop 12). Stops 9, 10, and 11 are to look at deposits mapped, respectively, as Tioga, Tenaya, and Tahoe by Sharp (1972). We will use these stops to further demonstrate our use of RD parameters, to compare our results with that of others, and to allow you to try your hand at correlation with the moraines studied yesterday at Sawmill Canyon (N) - Bloody Canyon.

Introduction

The glacial deposits of Bridgeport Basin have been mapped in part by Blackwelder (1931) and in detail by Sharp (1972). In the Green Creek drainage, Blackwelder recognized tills of the Tioga, Tahoe, and Sherwin Glaciations but gave little data in support of the three age assignments. Sharp (1972), on the basis of field relationships and semiquantitative

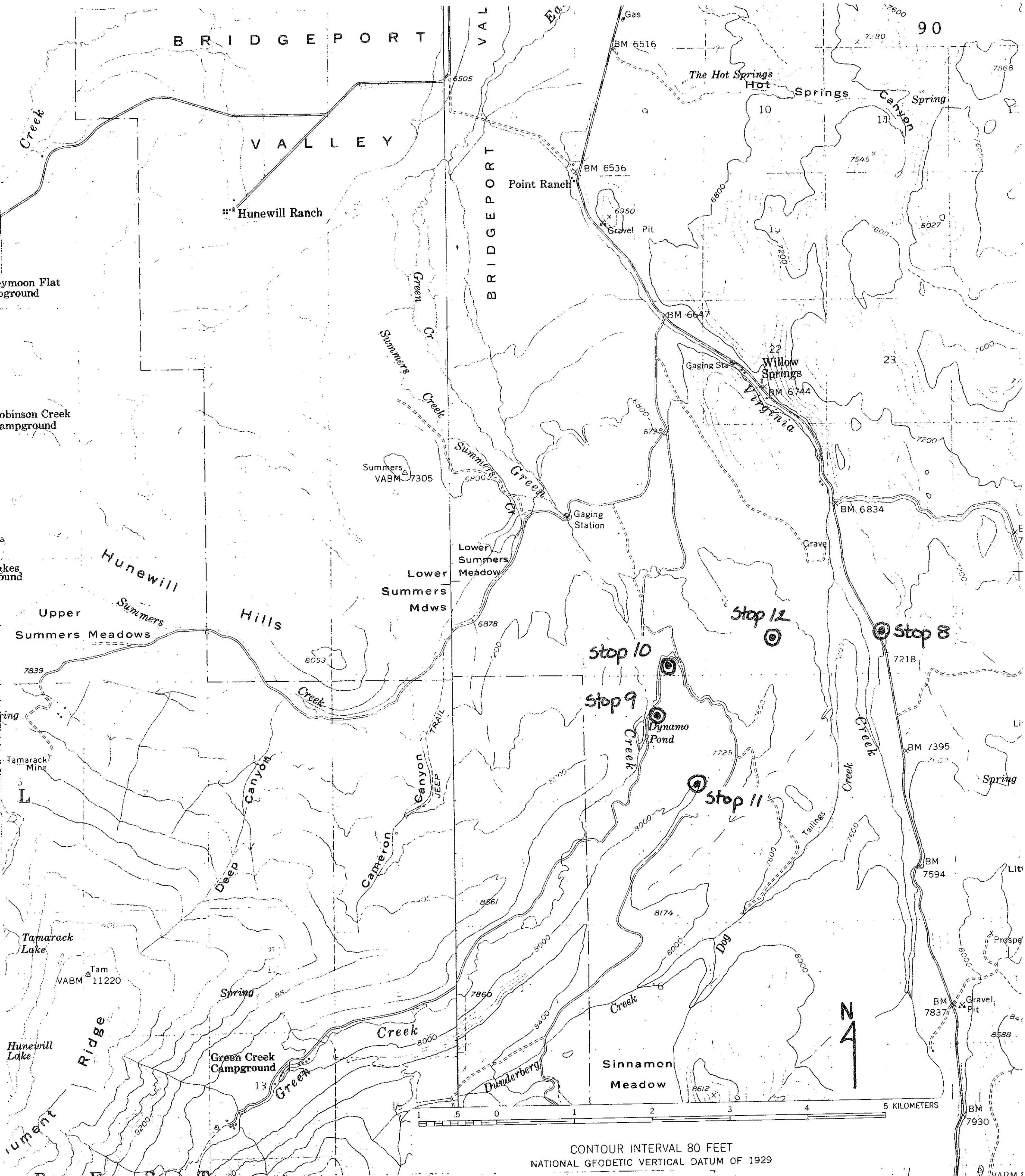


Figure XI-1. Topographic map of the continuation of the route between Mono Lake campground and stop 8 (see Fig. VIII-1) plus all stops for day 2 of part II of the field trip. Base maps are the Bodie and Matterhorn Peak 15-minute quadrangles.

weathering data recognized five ages of till--Tioga, Tenaya, Tahoe, Mono Basin, and Sherwin (Fig. XI-2), and much of this is supported by the work of Dickinson's group (1968).

Tioga Glaciation

Two moraines assigned to the Tioga Glaciation by Sharp (1972) were selected for our study (Fig. XI-2). Site 25 will be visited today at stop 9. The RD parameters which have been shown to delineate weathering breaks most consistently in other valleys as well as surface oxidation data, indicate that both sites are of the same age (Fig. XI-3a and Table XI-1).

Soils for these two moraines are similar, both being weakly developed A/B/Cox profiles (Fig. XI-3b and Table XI-2). There is slight, if any, pedogenic clay buildup within the profiles. Subsurface grusification is minimal and similar between both sites (Fig. XI-4). Therefore, our data support Sharp's (1972) Tioga age assignment to this set of multiple moraines.

Tahoe Glaciation

Data collection sites were established along the crest of the major right lateral Tahoe moraine (site 22. stop 11), and along two right lateral Tenaya moraine crests near stop 10, (site 24d, Fig. XI-2). The Tahoe and Tenaya moraines along Green Creek have similar morphology and weathering characteristics (Fig. XI-3a and Table XI-1). These moraines are substantially more weathered than the adjacent Tioga deposits and the RD data are comparable to those for Tahoe moraines in other drainages.

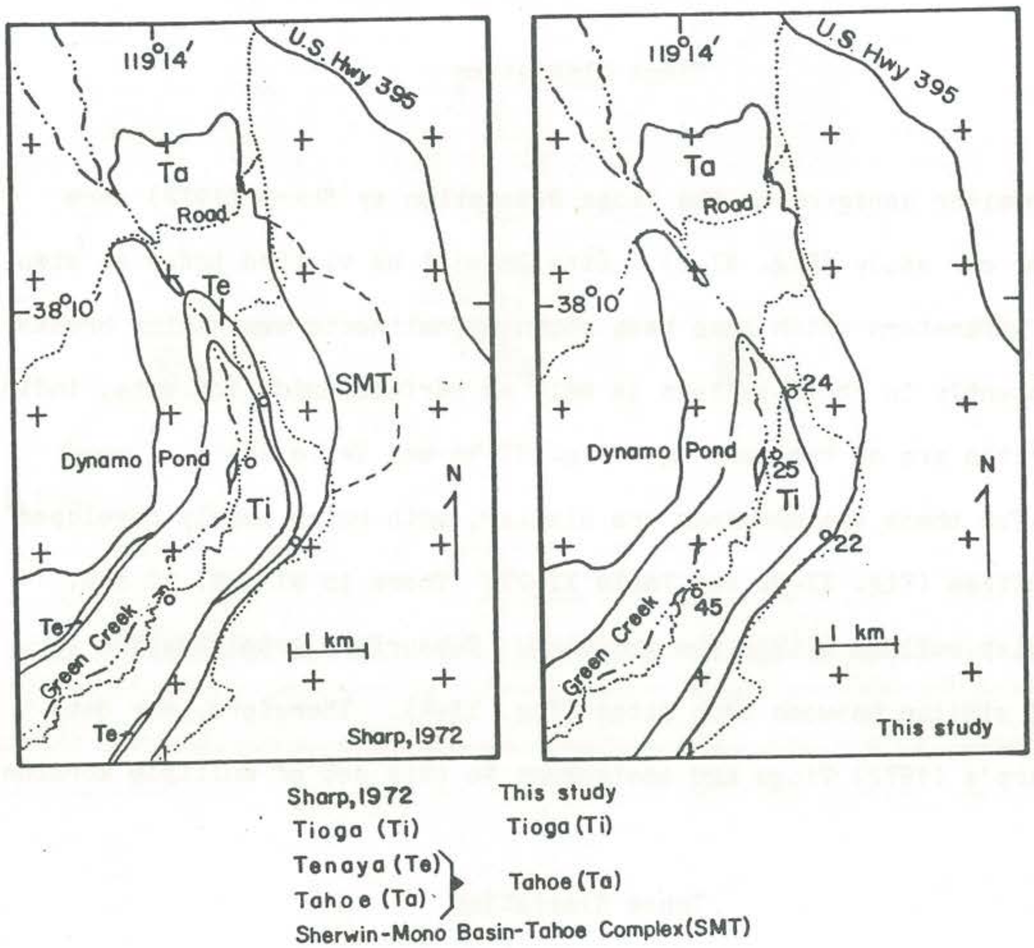


Figure XI-2. Glacial deposits along Green Creek according to Sharp (1972) and this study. The 'SMT' unit is not shown on the right hand map because not enough work was done on it. The base map is the Bodie 15-minute quadrangle, California. See Appendix B to correlate stop numbers to site numbers.

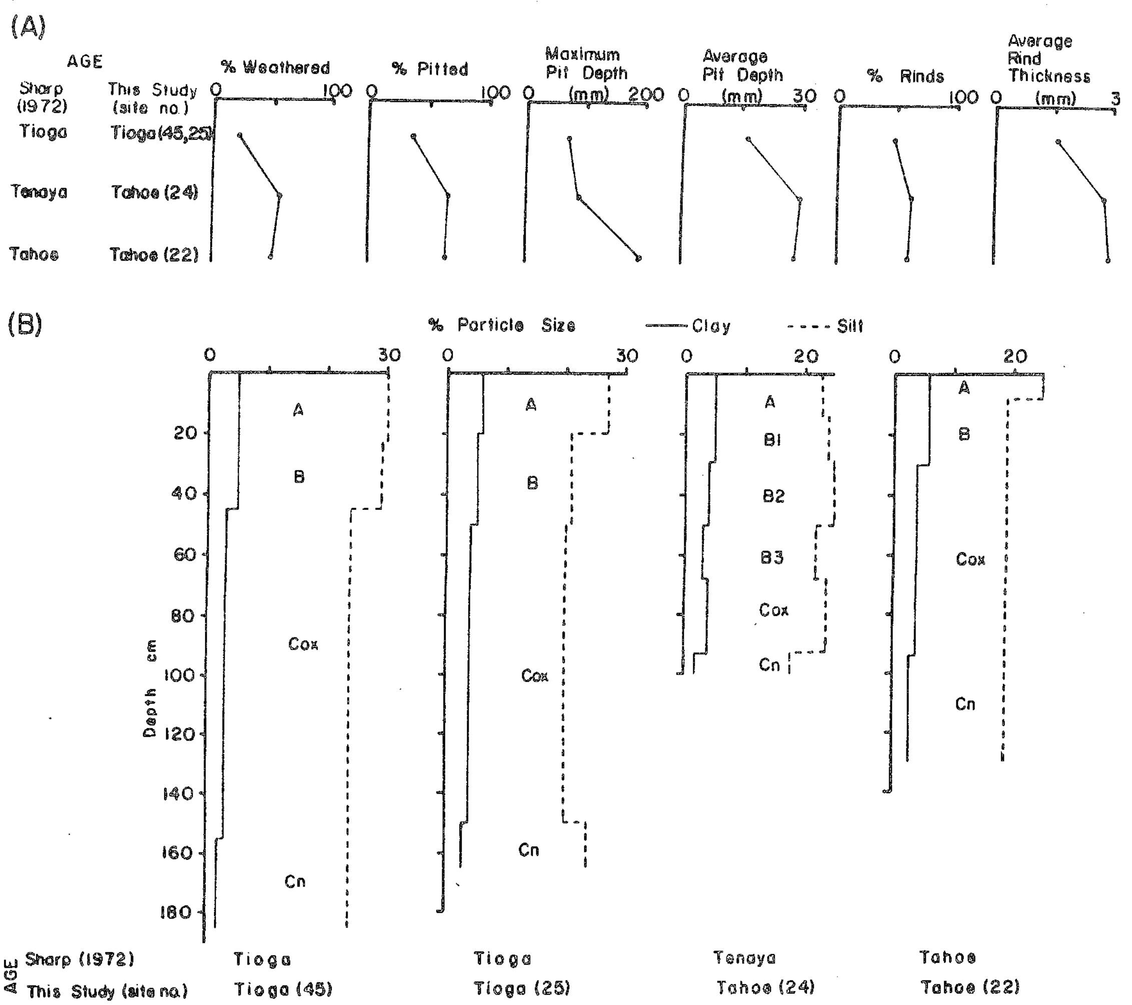


Figure XI-3. Selected RD (A) and soil (B) data for deposits along Green Creek. Complete data and actual numbers are given in tables XI-1 and XI-2. See Appendix B to correlate stop numbers to site numbers.

Table XI-1. Weathering and morphological data for Green Creek tills.

Valley	Age, site number: This study	Age, site number: Original Study	% Weathered	% Pitted	Maximum Pit Depth mm	Average Pit Depth mm	Maximum Height of Mafic Inclusions mm	% Rinds	Average Rind Thickness mm	Fresh: Weathered: Grus by hammer blow	SBF	% Granitic Boulders[a]	% Split	Oxidized: Partially Ox: Unoxidized[b]	Moraine Morphology: Moraine Width (meters)	Moraine Morphology: Distal Slope (degrees)	Moraine Morphology: Proximal Slope (degrees)
Green Creek	Ta / 24	Te	58	72	95	27	70	62	2.5	45:5:0	154	82	24	6:35:9	3	-	15
			52	60	-	31	-	60	2.6	47:3:0	77	90	10	7:31:12	-	-	-
			60	72													
			54	68													
	22	Ta	46	58	195	25	115	60	3.2	43:7:0	57	86	4	5:29:16	30	16	19
			50	72		26	-	56	2.6	46:4:0	-	92	16	-	-	-	-
			50	64													
			48	64													
Green Creek	Ti / 45	Ti	16	42	65	14	-	48	1.9	47:3:0	103	84	10	1:14:35	-	-	-
	25	Ti	26	36	55	17	-	44	1.5	48:2:0	70	84	10	4:18:28	5-20	13	20
			20	34													

[a] The non-granitic component consists of volcanic and metavolcanic rocks.

[b] Where only two numbers appear, the count was oxidized: unoxidized boulders only.

[c] A dash (-) represents no data available.

Table XI-2. Soil data for Green Creek tills.

Location	Site number	Age[a] Previous Study	Age[a] This Study	Horizons[b]	Depth (cm)	Color[c]	Texture[d]	Estimated % gravel	% < 2 mm fraction Sand	Silt	Clay	pH[e]	% Organic Matter[f]	Remarks
Green Creek	22	Ta	Ta	A	0-8	10YR 5.5/3	SL	50-75	69	25	6	6.3	2	Cn(?) may be a C2ox horizon.
				B	8-30	10YR 5/4	LS	50-75	76	19	6	7.0	1	
				Cox	30-94	2.5Y 6/3	LS	50-75	77	19	4	7.2	0	
				Cn(?)	94-130+	2.5Y 8/2	LS	50-75	78	19	3	7.9	0	
	25	Ti	Ti	A	0-20	10YR 4/3	SL	75-90	67	27	6	7.0	5	Upper portion of profile may have slight eolian influx.
				B	20-50	10YR 5/3	SL	75-90	74	21	5	6.9	1	
				Cox	50-150	2.5Y 6/3	LS	75-90	75	20	4	6.6	1	
				Cn	150-165+	5Y 7/2.5	SL	75-90	73	24	3	6.5	0	
Green Creek	45	Ti	Ti	A	0-23	10YR 5/3.5	SL	50	65	30	5	6.0	2	
				B	23-45	10YR 5/4	SL	50	66	29	5	6.5	1	
				Cox	45-155	10YR 6/3.5	LS	50	73	24	3	6.7	0	
				Cn	155-185+	2.5Y 6/3.5	LS	50	74	24	2	6.9	0	
	24	Te	Ta	A	0-14	10YR 4.5/3	SL	50-75	72	23	5	6.0	3	
				B1	14-29	10YR 5/3.5	SL	50-75	71	24	5	6.3	1	
				B2	29-50	10YR 6/4	SL	50-75	71	25	4	6.7	0	
				B3	50-68	2.5Y 6/3	LS	50-75	74	22	3	6.8	0	
				Cox	68-93	2.5Y 7.5/3	SL	50-75	72	24	4	6.8	0	
				Cn	93+	5Y 7/2	LS	50-75	80	18	2	7.1	0	

[a]Age of previous study is based upon works of Dalrymple (1964)-Sawmill Canyon (S), Curry (1971)-Mammoth Creek, Sharp and Birman (1963)-Sawmill Canyon (N)-Bloody Canyon, and Sharp (1972)-Green Creek. Age assignments are Tioga (Ti), Tenaya (Te), Tahoe (Ta), Mono Basin (MB), and Casa Diablo (CD).

[b]Nomenclature follows Soil Survey Staff (1975) and Birkeland (1974).

[c]Colors are dry, determined on less than 2 mm fraction.

[d]Textural designations are loamy sand (LS), sandy loam (SL), and sand (S).

[e]pH determinations are by meter on a 2:1 water to soil mixture.

[f]Organic matter determined by loss on ignition, corrected for structural water loss by subtracting loss on ignition of organic free silt + clay fraction.

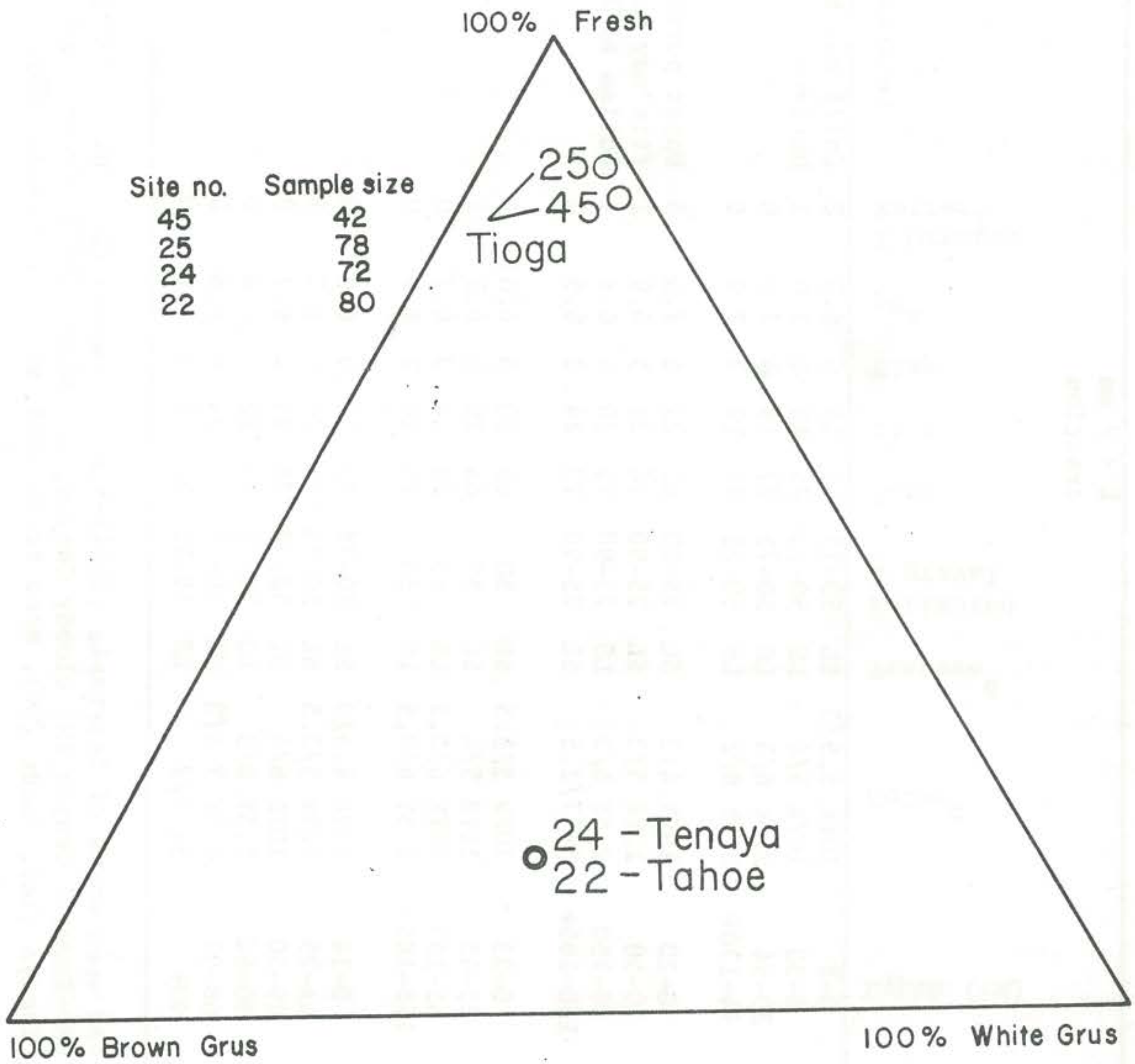


Figure XI-4. Plot of fresh:white grusified:brown grusified subsurface granitic clasts exposed in roadcuts in moraines along Green Creek. Brown grus relates to stones that are both grusified and oxidized, whereas white grus relates to stones that are grusified but not markedly oxidized. Brown grusification denotes a greater amount or intensity of weathering. The names shown are those of Sharp (1972), and the site numbers are those of this study. See Appendix B to correlate stop numbers to site numbers.

Data on the soil profiles of sites 24 (Sharp's Tenaya) (stop 10) and 22 (Sharp's Tahoe) (stop 11) show little variance from the post-Tioga soils (Figs. XI-3b,XI-5, XI-6 and XI-7; Table XI-2). The oxidation of these soils is not substantially redder nor deeper than that of post-Tioga soils (Table XI-1). In contrast, the depth of oxidation was used by Sharp (1972) to help differentiate Tioga and Tahoe Till, but part of this variation could be that his Tahoe Till site seems to be on a slope (Sharp, 1972, Fig. 6). Soil profiles on both Tenaya and Tahoe moraines show intense grusification and oxidation of granitic boulders which is very similar to Tahoe deposits in other valleys, and very much different from that in post-Tioga soils (Fig. XI-4).

Discussion

Data collected by Dickinson's group (1968) and Sharp (1972) appear to suggest that the Tahoe and younger glacial deposits along Green Creek record three separate glaciations In contrast, our data suggest that this sequence records only two glaciations and that the Tenaya deposits of previous workers can reasonably be considered a product of the Tahoe Glaciation (Fig. XI-3). We do not know how to solve this dilemma of two vs. three glaciations at the present time. It essentially comes down to comparing the different RD methods used; that is, whether or not increasing the number of sample sites of a few RD parameters is to be preferred over getting data from more parameters, including that for the subsurface, on fewer sites.

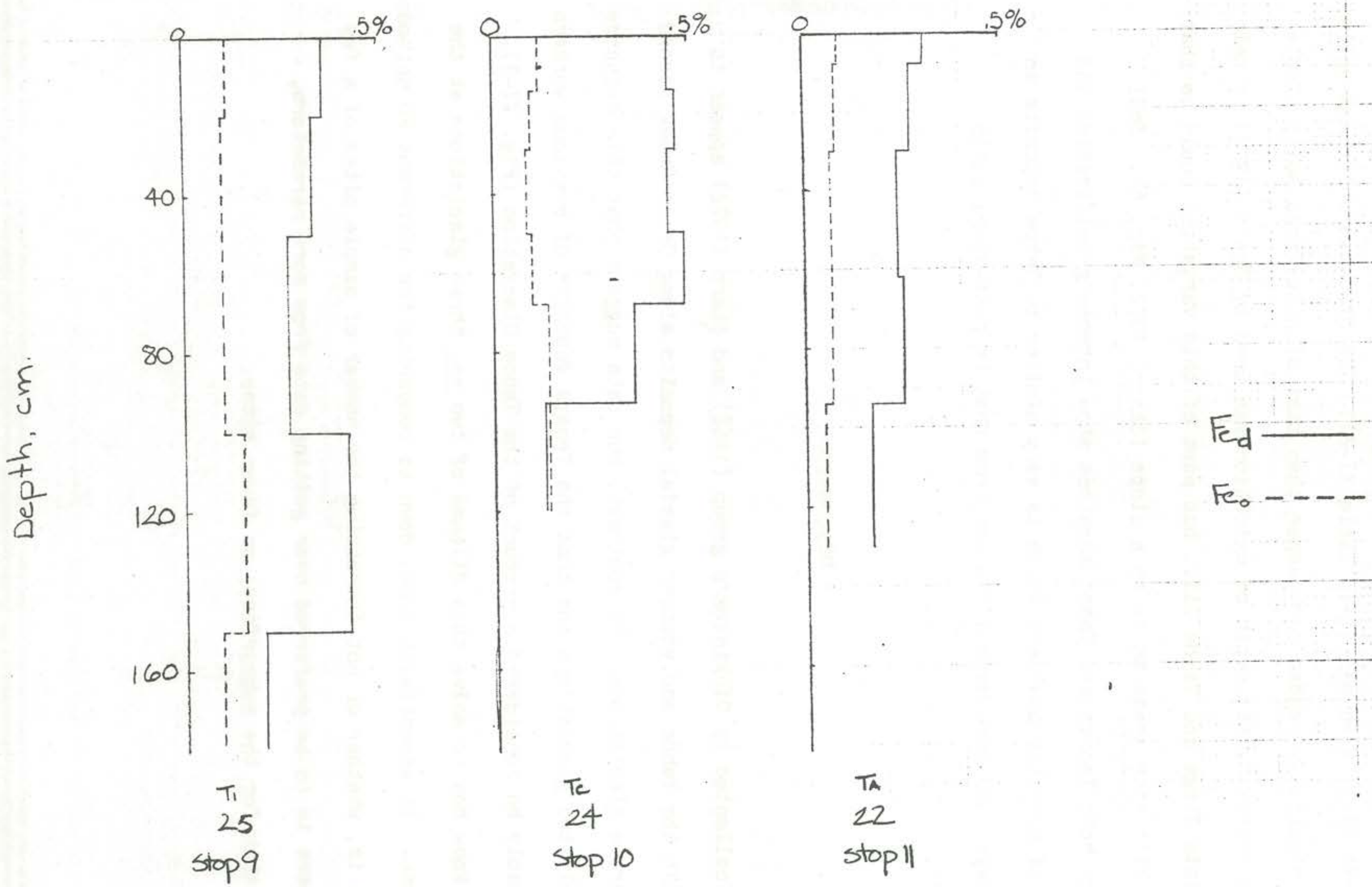


Figure XI-5. Oxalate (Fe_o)- and dithionite (Fe_d)-extractable Fe trends with depth for soils developed in the Green Creek glacial deposits. Magnetics have been removed. Localities are shown on figures XI-1 and XI-2.

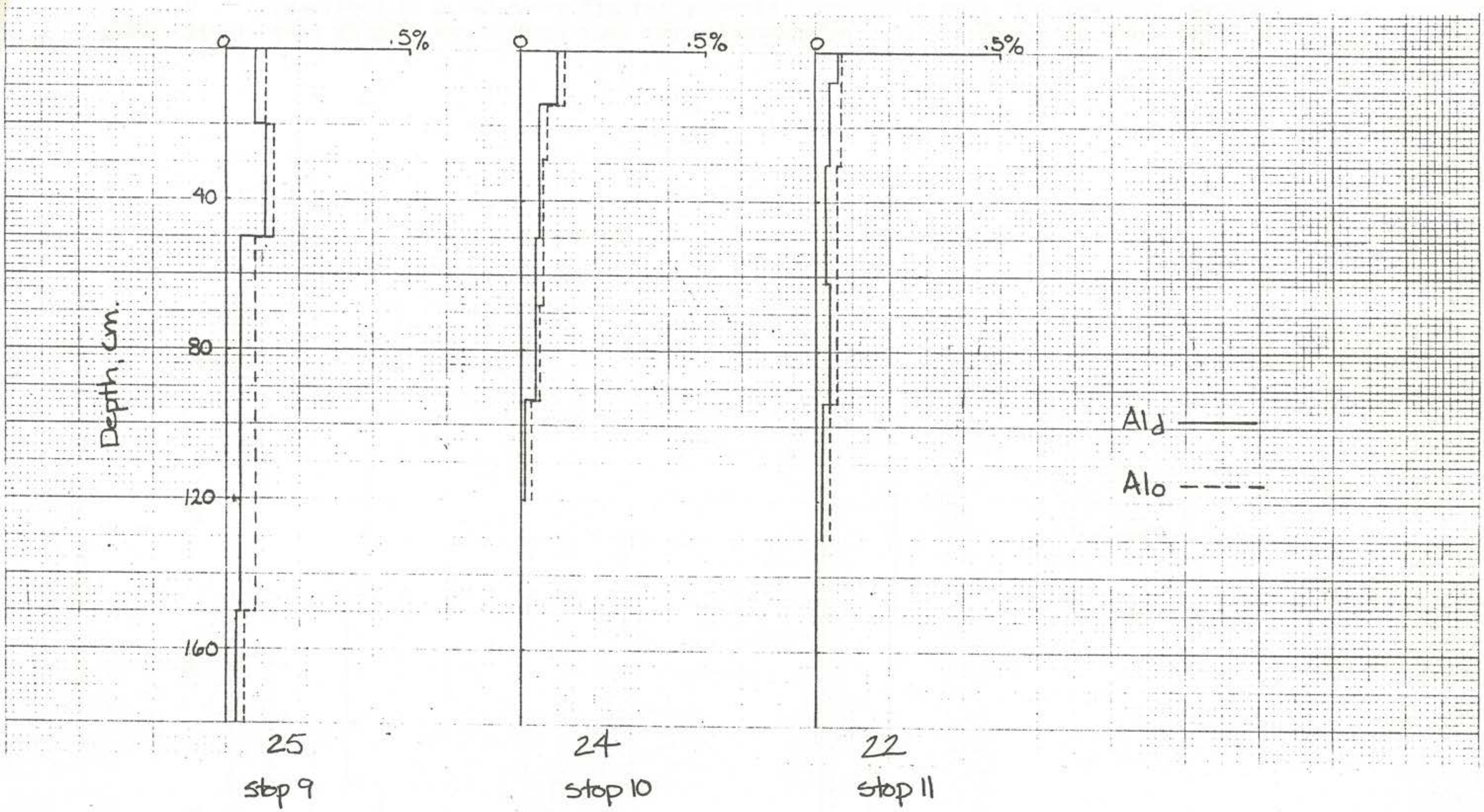


Figure XI-6. Oxalate (Al_o)- and dithionite (Al_d)-extractable Al trends with depth for the soils developed in the Green Creek glacial deposits. Magnetics have been removed. Localities are shown on figures XI-1 and XI-2 .

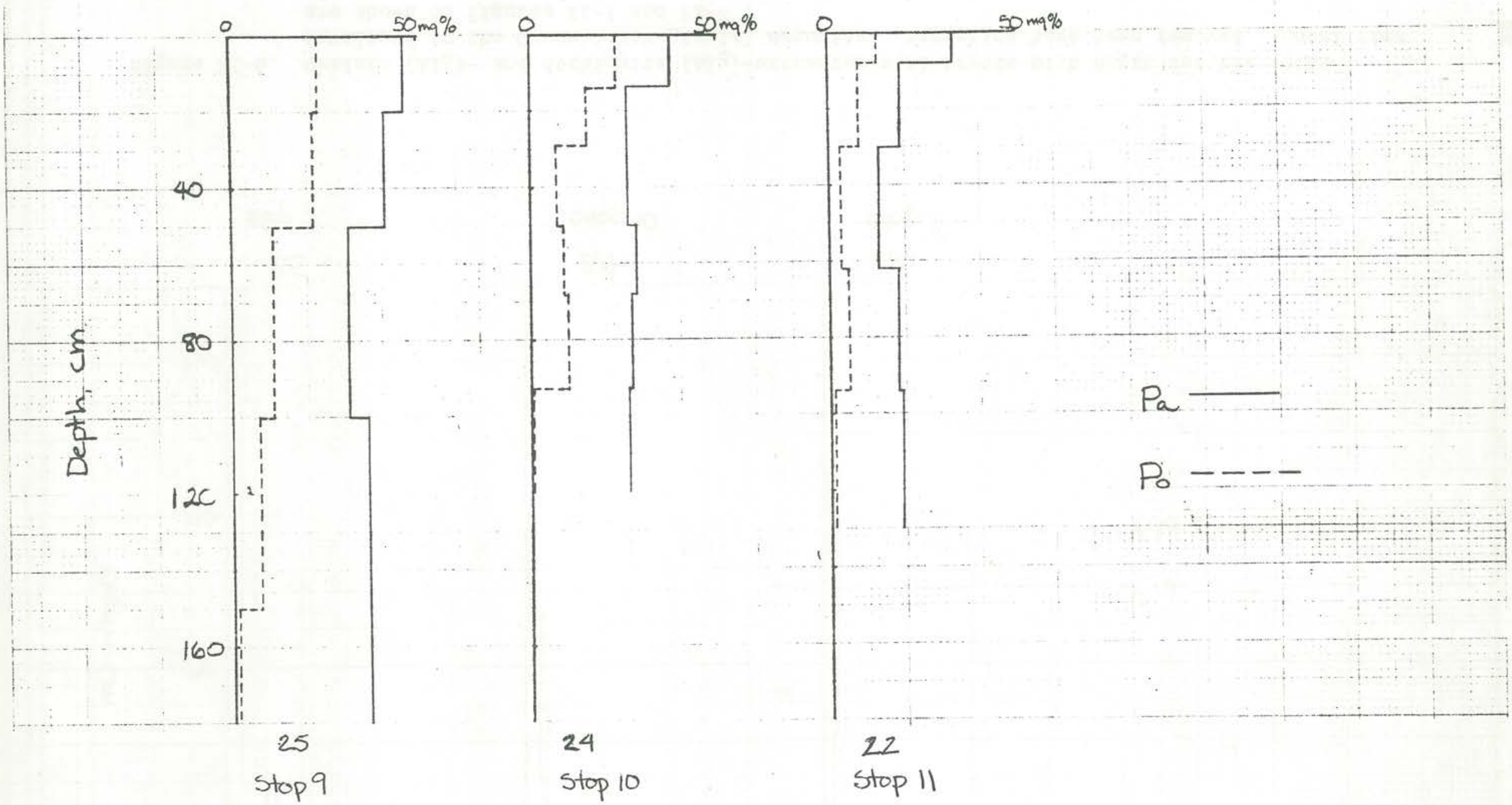


Figure XI-7. Acid (H_2SO_4)-extractable (Pa) and organic-bound (Po) P trends with depth for soils developed in Green Creek glacial deposits. Magnetics have been removed. Localities are shown on figures XI-1 and XI-2.

CHAPTER XII

Summary of the relative dating philosophy and the glacial stratigraphy along the eastern escarpment of the Sierra Nevada

R. M. Burke and P. W. Birkeland

The majority of this chapter is taken from Burke and Birkeland (1979) and is reporduced here with the permission of Quaternary Research and the University of Washington. All references of this material should be made to the original paper.

REGIONAL CRITERIA FOR FORMALLY NAMING GLACIATIONS

From the work in the four study areas (Sawmill Canyon (S), Mammoth Creek, Sawmill Canyon (N) - Bloody Canyon, and Green Creek) we recognize that the limited sensitivity of RD techniques only allows a delineation of first-order glaciations, and that these in all likelihood will not delineate units of stadial rank (Porter, 1971). For example, RD data can suggest an indistinguishable closeness in the ages of moraines which by cross-cutting or nested relationships obviously represent pulsations of the ice front. Whereas some might argue that each pulsation is a glaciation or a stade, and give it a formal name, we contend that the main use of names is for subdivisions of deposits that can be consistently recognized and distinguished from other deposits by the same and/or other worker. Thus, RD data presently provide acceptable data upon which mapping can be carried on from valley to valley using a formal stratigraphic nomenclature. In contrast to providing formal names for first-order events, second-order events can be informally designated as older or younger, or outer and inner, and used in local sequences, which in time may or may not be shown to correlate from valley to valley.

The question still remains, however, as to which RD data best define a mapping unit, and how much of a difference is expected before assigning deposits to different glaciations. The most consistent RD data are weathering, pitting, rind development and subsurface weathering. For different age assignments we at least expect to combine major variations in the conditions of granitic boulders with major variations in some surface weathering feature. If, however, soil development and subsurface grusification both suggest an age different from surface weathering, we favor the subsurface data and look for an explanation for the anomalous surface data. The magnitude of change needed in surface data to recognize separate glaciations is a doubling of at least some data. Finally, we suggest that only two first-order post-Sherwin Pleistocene Glaciations can be demonstrated in the four valleys studied. These are here correlated with the Tahoe and Tioga Glaciations (Table XII-1).

Tioga vs. Tahoe Deposits

Obvious morphological differences which exist between Tioga and Tahoe are that Tioga moraines are commonly less massive but more completely preserved than Tahoe moraines. Along the moraine crest (Fig. XII-1), the percent of weathered granitic boulders in Tioga deposits is generally less than 30% compared to about 50% or more in Tahoe moraines. In no valley does the percent pitted boulders exceed 50% on Tioga moraines, but seldom is it less than 50% on Tahoe moraines. Pitting is fairly subtle on Tioga moraines, but

Table XII-1: Correlation of glacial deposits in four valleys, eastern Sierra Nevada

Sawmill Canyon (s)	Mammoth Creek	Sawmill Canyon (N) Bloody Canyon	Green Creek	R. D. correlation
(Dalrymple, 1964)	(Curry, 1971)	(Sharp and Birman, 1963)	(Sharp, 1972)	(Burke and Birkeland, 1979)
Tioga	Tioga	Tioga	Tioga	Tioga
Tenaya	Tenaya	Tenaya	Tenaya	
Tahoe	Tahoe	Tahoe	Tahoe	Tahoe
Pre-Tahoe	Mono Basin	Mono Basin	Mono Basin	
	Casa Diablo			

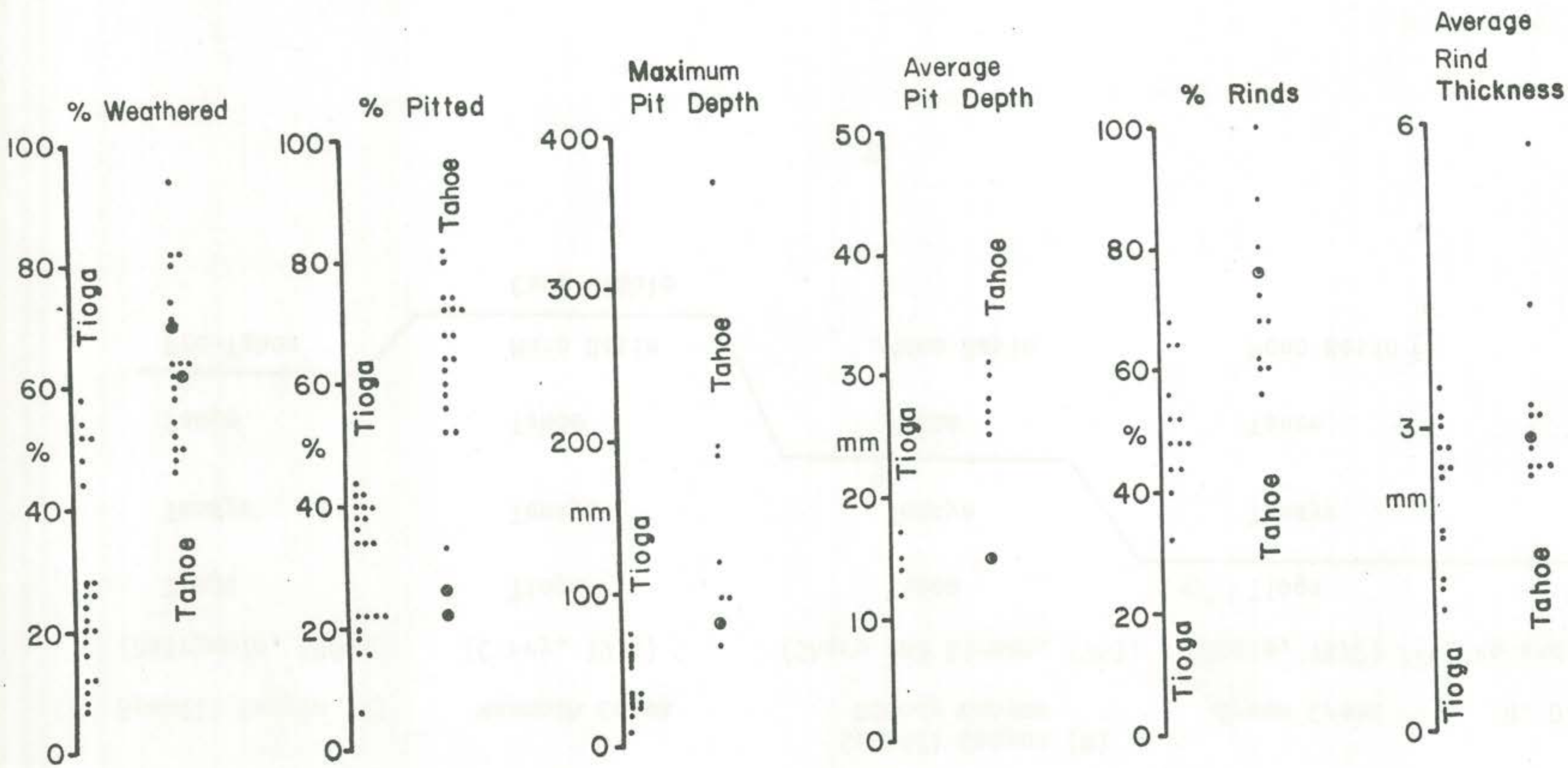


Figure XII-1. Composite of the best surface RD data from the four valleys. Data are given in tables III-2, V-2, XI-1, and appendix C. The overlap in Tioga-Tahoe data is either unexplained, due to the overlap in data for Mammoth Creek drainage, or due to the inclusion of data from forested (⊖) Tahoe sites.

results in grotesque boulder forms on Tahoe deposits (Fig. XII-2); in addition, maximum Tioga pit depths are considerably less than those of Tahoe age. Where average pit depth was measured (Sawmill Canyon (N) - Bloody Canyon and Green Creek) it supports the Tioga and Tahoe age designation based on other data. The percent of boulders with weathering rinds and the average rind thickness work well for subdivision within a drainage, but overall comparisons of absolute numbers are less useful. Mafic inclusions in the granitic clasts on Tioga moraines are generally weathered in relief to less than 50 mm, whereas a relief in excess of 100 mm is common for boulders on Tahoe moraines. Other surface RD parameters are not consistently useful in separating the two units.

It is worth stressing that when surface RD data from the four valleys are grouped together (Fig. XII-1), there is an expected overlap in the values. The important thing, however, is to compare values in a single valley. If overlap in some data persists, one has to judge which could give an erroneous age, given the environment. If too many surface RD data conflict in age assignment, as at Mammoth Creek, subsurface RD data have to be considered before age assignment is attempted.

Subsurface data also are diagnostic in subdividing the Tioga and Tahoe deposits. The most consistent criterion is the weathered condition of the granitic clasts, for those in post-Tioga soils generally are fresh whereas those in post-Tahoe soils are generally grusified and oxidized to some extent (Fig. XII-3). In contrast, few of the soil profile descriptions support the age difference between the Tioga and Tahoe deposits. Oxidation is slightly more intense in some post-Tahoe soils than in post-Tioga soils. Most profiles of both ages display a slight clay increase toward the surface that could result from a combination of primary mineral weathering and downward

A

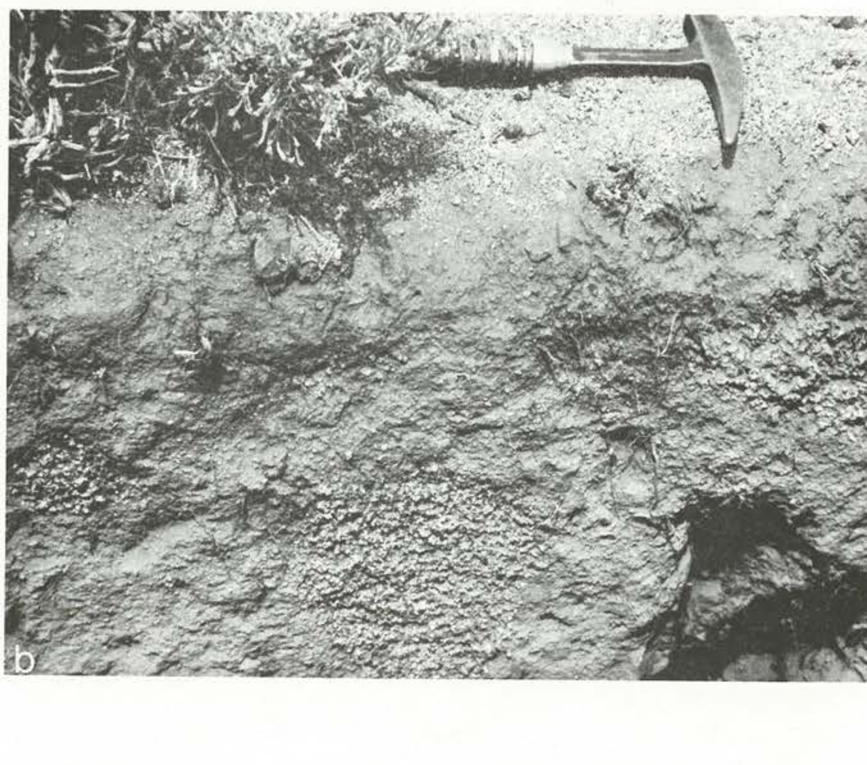
B

Figure XII-2. Typical appearance of surface granitic boulders on Tioga (A) and Tahoe (B) moraines. The Tioga example is from site 20, Mammoth Creek, and the Tahoe example is from site 41, Sawmill Canyon (N)-Bloody Canyon.

A

0
A
12 cm
IIB
25 cm
IICox

B



0
A
8 cm
B
30 cm
Cox

Figure XII-3. Typical post-Tioga (A) and post-Tahoe (B) soils. Note that in (A) the subsurface granitic boulders are fresh whereas in (B) they are grusified. The post-Tioga soil is developed at site 42, Sawmill Canyon (N)-Bloody Canyon, and the post-Tahoe soil at site 22, Green Creek.

translocation of eolian fines; it is doubtful a pattern that is so consistent can be solely due to parent material variations. Bt horizon development did help in discriminating the Casa Diablo Till from the younger tills in Mammoth Creek. If the tentative correlation of Casa Diablo deposits with Tahoe deposits is correct, the implied rate of development of the textural B horizon in this soil is matched only by that of a buried probably post-Tahoe soil in the eastern Carson Range along the Reno-North Lake Tahoe road (illustrated in Birkeland, 1974, Fig. 8-10). Soil clay mineralogy has previously been shown to be an ineffective tool for stratigraphic age assignment of many of these deposits (Birkeland and Janda, 1971).

The Problem of the Tenaya and Mono Basin

Before this study, considerable debate has focused on the question as to where the Tenaya Glaciation of Sharp and Birman (1963) best fits in the glacial sequence of the eastern Sierra Nevada. The date of Sharp and Birman (1963), Birman (1964), Sharp (1969, 1972) and Dickinson's (1968) group show the Tenaya to be separable from both the Tioga and the Tahoe. On less data than those presented by the above workers, others have suggested that deposits of the Tenaya should be considered as an early advance of the Tioga Glaciation (Morrison, 1965; Smith, 1968; Birkeland and Janda, 1971). Our data here indicate that in at least three drainages the Tenaya is not readily separated from the Tioga, whereas in a fourth it is not separable from the Tahoe. Our suggestion is to drop the Tenaya as a first-order glaciation until further work is done.

The Mono Basin Glaciation of Sharp and Birman (1963) presents a similar problem in that Mono Basin Till has been shown to be quite similar to Tahoe

Till at the Mono Basin type locality, if both are compared under sagebrush vegetation. Furthermore, the weathering characteristics of both deposits are similar to the deposit that both Sharp (1972) and we agree is Tahoe in the Green Creek drainage. Our tentative suggestion is to not use the Mono Basin terminology until more localities have been restudied.

CONCLUSION

E. B. Blackwelder, R. P. Sharp, and J. H. Birman have made very important contributions not only to the Sierra Nevada glacial sequence, but also the development of RD techniques to date deposits where absolute dating methods do not apply. We view our work here only as a further step in the refinement of both aspects of the work pioneered by them. Indeed, the reason this area was picked as one in which to refine RD techniues was because of their previous high quality work in the area. We feel we have demonstrated a refinement in the tecnhiques, with the by-product being that we offer an alternative to some of the age assignments for the deposits. This multiparameter approach to relative dating suggests that only two major groups of post-Sherwin pre-Neoglacial tills, here grouped into the Tioga and Tahoe Glaciations, can be mapped. Deposits previously mapped as Tenaya seem best grouped with the Tioga in some drainages, but with the Tahoe in at least one drainage. Hence, we do not know how to define the Tenaya on RD data. In Sawmill Canyon (S) and Mammoth Creek, our outermost Tioga deposit is slightly more weathered than other Tioga deposits and could be the Tenaya of other workers. The type Mono Basin Till clearly was deposited prior to the major Tahoe moraine of the Sawmill Canyon (N) - Bloody Canyon area; however, under similar vegetation conditions, the data suggest no great age difference between the two deposits, and so we lump both into the Tahoe Glaciation. The type Casa Diablo Till has characteristics not unlike the Tahoe deposits of other valleys and so it also is tentatively correlated with the Tahoe Glaciation. We therefore suggest mapping only multiple Tioga and Tahoe deposits until better criteria for further subdivision are developed.

Problems remain in the use of RD methods, such as the necessary differences in data to justify different age assignments, operator variance, and how RD features are preserved and used for age indication in spite of erosional alteration of the land form. Because of this, we restate our contention (Birkeland and others, 1976) that the answers to questions brought up lie in the field, and any worker seriously considering a correlation with the east-central Sierra Nevada should visit the key sites in the field.

CHAPTER XIII

Preliminary remarks on chemical data for soils formed in post-Sherwin glacial deposits, eastern Sierra Nevada, California

R. M. Burke, A. L. Walker, and P. W. Birkeland

This short note expresses preliminary thoughts on the recently derived soil chemical data (Table XIII-1) that have been visually preprinted in Chapters III, V, and XI. The analyses are the oxalate extraction, dithionite extraction and phophorous fractions as outlined in Chapter X.

The expected results are a continual buildup of the trends expressed by the soils developed in Holocene deposits (Chapter II). However, expected trends are not realized on these Pleistocene soils. Preliminary observations are as follows:

1, Post-Tioga and post-Tahoe soils that appear similar based upon a good description of the field morphology cannot be differentiated on the basis of more detailed laboratory analyses.

2. Rates of chemical change in the soils formed on the Sierra Nevada cirque deposits are not reflected in the soils formed in older deposits along the range front. This might be explained by either: (a) a much drier environment which has not been appreciably wetter in the past, (b) a retardation of obvious chemical activity caused by a high amount of silicic volcanic detritus from Mono and Frye Craters, or (c) erosion of the upper part of the post-Tioga and post-Tahoe soils. The difference in trends cannot be explained by steady-state arguments as explained in (3).

Table XIII-1.--Chemical data for soils on deposits along Mammoth Creek, Sawmill Canyon(N)-Bloody Canyon and Green Creek

Valley	Site No.	Stop No.	Horizon	Depth(cm)	Feo	Fed	Alo	Ald	Pa	Po
Mammoth Creek	03	2	A	0-8	.35	.49	.10	.09	-	-
			B1	8-23	.21	.63	.11	.07	-	-
			B2t	23-88	.12	.54	.07	.05	-	-
			Cox	88-129	.10	.52	.06	.04	-	-
			Cn	129-135+	.09	.50	.03	.03	-	-
			Fr. till	Ca.500	.06	.40	.05	.02	-	-
Bloody-Sawmill(N)	42	7	A	0-12	.06	.21	.07	.06	30.0	16.6
			IIB	12-25	.07	.24	.07	.05	23.2	14.2
			IICox-top½		.07	.22	.04	.03	24.6	5.4
			IICox-lower½	25-102+	.26	.40	.07	.04	51.4	4.2
			IICox @ 100 cm		.10	.25	.05	.03	30.0	3.2
	43	6	A	0-10	.03	.16	.05	.08	9.6	17.4
			IIB	10-25	.06	.21	.08	.08	8.6	15.8
			IICox-top½		.04	.15	.05	.04	10.4	3.4
			IICox lower½	25-120+	.04	.21	.04	.04	13.4	-
			IICox 108-120		.04	.13	.04	.03	10.6	2.2
	04	5	A	0-8	.04	.10	.05	.02	11.4	6.2
			B	8-20	.05	.19	.04	.04	7.2	5.8
			IIC1ox	20-64	.03	.19	.04	.03	7.4	5.2
			IIC2ox	64-120+	.02	.16	.03	.02	8.0	2.4
	02	3	A	0-10	.06	.15	.11	.11	13.2	13.8
			B	10-43	.04	.19	.07	.07	6.4	9.8
			IIC1ox	43-88	.03	.12	.04	.03	5.4	2.6
			IIC2ox	88-115+	.02	.12	.03	.03	3.4	3.0
Green Creek	25	9	A	0-20	.11	.36	.11	.08	45.8	22.8
			B	20-50	.10	.33	.13	.11	41.4	21.5
			Cox top½	50-150	.10	.27	.08	.04	31.3	10.8
			Cox lower½		.15	.42	.08	.04	35.9	7.2
			Cn	150-165+	.09	.20	.05	.03	36.4	1.0
	24	10	A	0-14	.12	.45	.12	.10	37.6	23.3
			B1	14-29	.10	.47	.07	.05	26.1	15.5
			B2	29-50	.09	.45	.06	.05	26.1	6.8
			B3	50-68	.10	.49	.06	.04	28.3	9.0
			Cox	68-93	.14	.36	.05	.04	27.1	10.2
			Cn	93+	.14	.13	.03	.01	26.2	-
	22	11	A	0-8	.09	.31	.07	.06	32.8	13.1
			B	8-30	.08	.27	.07	.04	18.7	8.2
			Cox top½	30-94	.07	.24	.06	.03	13.1	2.6
			Cox lower½		.07	.25	.06	.04	18.3	5.0
			Cn	94-130+	.05	.14	.04	.02	19.8	1.4

3. Although chemical analyses do not generally allow differentiation of post-Tioga and post-Tahoe soils, maximum buildup is less than those on Sherwin(?) deposits (Chapter X), suggesting soil development rates may be retarded, but have not reached steady state conditions.
4. For potential differentiation of these deposits, Al extracts appear to be the weakest of the 3 elements.
5. Variation of some buildups is consistently greater between valleys than between varying age deposits within a single valley. For example, Fe_d, Pa and Po values of Green Creek do not vary much between sites but are consistently greater than those of Sawmill Canyon (N) - Bloody Canyon which also do not vary much between sites.
6. Again, as with field properties, and physical properties, the soil developed in type Casa Diablo Till shows the strongest post-Tahoe development based upon Fe buildup. At depth, the Fe_o values drop to values similar to those in Cn horizons of other post-Tioga and post-Tahoe soils, but Fe_d remains slightly higher than in other soils. This may reflect a parent material with an initially greater source of Fe (extracted as crystalline Fe), that is not yet altered at depth by pedalogic processes (lower values of amorphous Fe_o).
7. Where some trends appear to defy known stratigraphic age relationships Fe_d of Green Creek soils could suggest Tioga is older than Tahoe--they may define the limit to which soil chemical trend-age relationships are useful along the eastern Sierra Nevada.

The main conclusion is, as it was in Chapter X, that some soil chemical trends parallel the soil morphology. This once again points out that in the semi-arid environment along the eastern Sierra Nevada, relative age assignment may not become more detailed as one goes from good field descriptions to more detailed chemical analyses.

CHAPTER XIV

The problem of correlation with the Tahoe-Truckee area

P. W. Birkeland and R. M. Burke

In 1976 we attempted to use relative dating (RD) and soils data to reexamine in reconnaissance fashion the well-known sequence of moraines in the Tahoe-Truckee area. The western shore of Lake Tahoe was one of the regions used by Blackwelder (1931) to define the glacial sequence of the Sierra Nevada. Blackwelder (1933) presented detailed site locations of both Tioga and Tahoe deposits, and later the area was mapped by McAllister (1936). Despite the higher precipitation and forested conditions of the Tahoe-Truckee area, there are striking similarities in some of the RD data between it and the central Sierra Nevada.

Tahoe and Tioga moraines occur northwest of Angora Lookout (McAllister, 1936; see Fallen Leaf Lake, California 15-minute quadrangle; or Fig. 1 of Wahrhaftig, 1965). The surface weathering characteristics of the two moraines are difficult to evaluate because of a full lichen cover on the boulders and a dense forest cover. However, a maximum pit depth of 150 mm and 58% weathered granitic boulders on the Tahoe moraine contrasts with minimal pitting and only 30% weathered boulders on the Tioga moraine. Although most of the surface weathering data might be suspect due to possible forest fire freshening, the Tahoe-age assignment is supported by subsurface characteristics. Some grusification and oxidation of the granitic boulders are present within the post-Tahoe soil, and slight oxidation (2.5Y 6/v) extends to a depth of greater than 150 cm. Although the RD data are not unambiguous, they tentatively support a Tahoe-age assignment for the older moraine.

The high moraine between Emerald Bay and Cascade Lake directly south of Inspiration Point (Stop 1, Fig. 7-1 of Wahrhaftig, 1965) is mapped as Tahoe, and it is flanked to the northwest by a Tioga moraine (McAllister, 1936). The surface RD data distinguish between the two moraines. The boulders on the Tahoe moraine have pit depths up to 380 mm and are 90% weathered, whereas those on the Tioga moraine are minimally pitted and only 22% weathered. However, the subsurface RD data do not support the age assignment based upon surface RD data. The post-Tahoe soil is very similar to the post-Tioga soil and neither have grusified granitic boulders.

An important site which appears to have Tioga Till superimposed over Tahoe Till (C. Wahrhaftig, written commun., 1975) occurs in a Highway 89 roadcut northeast of Cascade Lake (locality E, Fig. 7-1 of Wahrhaftig, 1965). The cut exposes about 8 m of Tioga Till, the lower half of which appears to have been fluvially reworked, overlying a pre-Tioga till having slight matrix oxidation (5Y 6.5/2d) but without a buried soil profile. A count of fresh:grusified:grusified and oxidized produced ratios of 49:1:0 and 2:22:26 for the Tioga and pre-Tioga tills respectively. The two morainal crests southeast of Cascade Lake have been mapped as Tioga and Tahoe (McAllister, 1936; Wahrhaftig, 1965, Fig. 7-2). However, surface weathering features are similar on both crests, an observation also noted by C. Wahrhaftig (written commun., 1975). In addition, the soil and condition of subsurface granitic clasts are similar on both crests. All of this suggests that both moraines are Tioga and there is therefore no surface expression of the buried pre-Tioga till. Although the older till in the roadcut has the subsurface boulder weathering features we expect of a Tahoe deposit, without morainal form or knowledge of the degree of soil development and the amount of surface weathering which occurred between the deposition of the two tills, all we can conclude is that the buried till is Tahoe or older. In short, the correlation of the deposits along Lake Tahoe to those in the east-central Sierra Nevada requires additional work.

We also employed our multiparameter RD techniques to reexamine the work of Birkeland (1964) near Truckee. Our work indicates some problems in the original age assignments and again a need for more work before correlations of the pre-Tioga units with the east-central Sierra Nevada units are considered sound. For example, the deposit exposed in the large I-80 freeway cut west of Truckee (SE 1/4, NE 1/4, Sec 16, T17N, R16N of the Truckee California 15-minute quadrangle) is mapped as Tahoe by Birkeland (1964), but the granitic clasts are seldom grusified. The deposit is best correlated with the Tioga Glaciation, as suggested by weathering rind data of Colman (1977). The Tahoe-Donner housing subdivision has produced a new roadcut at the junction of Andermatt and Wolfgang roads (on the Truckee quadrangle this is near the western margin of the map on boundary of sections 30 and 31, T18N, R16E) that exposes a deposit originally mapped as the outermost right lateral Tahoe moraine of Prosser Creek. However, the soil profile shows pedologic and rock weathering features similar to those of the type Donner Lake Till (Birkeland, 1964). Several alternatives seem possible to explain this confusion: (1) the original mapping is in error and the till should be assigned to the Donner Lake Glaciation; (2) the Donner Lake Till was deposited during the Tahoe Glaciation as the latter is defined by Burke and Birkeland (1979) for the east-central Sierra Nevada; or (3) the Donner Lake Till (and the till of this cut) is indeed pre-Tahoe and we have yet to discover an adequate exposure of Tahoe Till. If the Donner Lake Till is pre-Tahoe, a possible Tahoe moraine might be the highest left lateral moraine north of Donner Lake in which grusified granitic clasts are exposed in roadcuts on Ski Slope Way (Tahoe-

Donner subdivision) on the north-facing slope of the moraine. This alternative is tentatively supported by the limited data given in Table XIV-1. However, all of these alternative are met with serious problems too complex for presentation at this time. For example, should the soil formed in Tahoe glacial deposits be expected to be more like that formed in Tahoe outwash near Verdi, Nevada (Birkeland, 1968) or not? The point of this short discussion is to caution others that correlation of pre-Tioga units between the Truckee area and the east-central Sierra Nevada requires more work.

Table XIV-1: Limited RD data for Truckee area

Site number:	7680121	7680119	7680222
Location:	Type Donner Lake Till	Donner-Tahoe Subdivision	North Fork Prosser Cr.
Mapped Age:	Donner Lake	Tahoe Moraine	Tioga
Comments:		Forest Fire Area	
OX: Part. ox: unox		2:30:18	1:27:22
Split: Nonsplit		2:48	12:38
Spall: Nonspall		42:8	23:27
Granitic: Nongranitic		42:8	45:5
SBF (total blds > 50 cm in 30mx6m)		18	65
Pit: Nonpit		4:46	8:42
Pit depths		30	undulating
FR: WX		36:14	42:8
Rinds(m) Basalts	n=17	n=11	n=9
	$\bar{x}$ =.76	$\bar{x}$=.45	$\bar{x}$=.20
Rinds (m) Andesites	n=14	n=25	n=11
	$\bar{x}$=.84	$\bar{x}$=.92	$\bar{x}$=.25

*Mapped ages are from Birkeland (1964), data are those collected by Birkeland and Burke in 1976.

Appendix A

Correlation between numbered stops and locality numbers used in text, figures and tables - Part I of field trip, Chapters I and II.

Stop	Locality number
1	1
2	8
3	9, 10
4	3
5	4, 5
5a	11
6	7
7	13, 14
8	15

Appendix B

Correlation between numbered stops and locality numbers used in text, figures and tables -Part II of field trip.

Stop	Chapter	Drainage	Locality number
1	III	Mammoth Creek	20
2	III	" "	03
3	IV	Sawmill Canyon (N)- Bloody Canyon	01, 02
4	V	" "	40, 41
5	V	" "	04
6	V	" "	43
7	V	" "	42
8	IX	Green Creek	loc. 3 (Chapters IX and X)
9	XI	" "	25
10	XI	" "	24
11	XI	" "	22
12	IX	" "	loc. 14 (Chapters IX and X)

Appendix C. Weathering and morphological data for Sawmill Canyon (S) tills.

Valley	Age, site number: This study	Original Study	% Weathered	% Pitted	Maximum Pit Depth mm	Average Pit Depth mm	Maximum Height of Mafic Inclusions mm	% Rinds	Average Rind Thickness mm	Fresh: Weathered: Grus by hammer blow	SBF	% Granitic Boulders[a]	% Split	Oxidized: Partially Ox: Unoxidized[b]	Moraine Morphology: Moraine Width (meters)	Distal Slope (degrees)	Proximal Slope (degrees)
Sawmill Canyon (S)	Ti / 07	Ti	52	40	23	–[c]	20	52	2.6	47:3:0	23	88	84	–	30–50	12	18
	08	Te	52	38	28	–	20	56	2.8	46:4:0	40	86	60	20:30	8	22	25
			58	38	25	–	–	52	2.6	46:4:0	84	98	62	–	–	–	–
	10	Ta	54	40	35	–	15	48	3.0	48:2:0	66	94	52	11:42	3–4	29	30
			44	44	30	–	–	64	3.4	47:3:0	39	74	82	–	–	–	–
	Ta / 11	pre-Ta	94	82	95	–	5	100	5.8	26:22:2	24	96	21	20:13	25–35	27	22

[a]The non-granitic component consists of volcanic and metavolcanic rocks.

[b]Where only two numbers appear, the count was oxidized: unoxidized boulders only.

[c]A dash (-) represents no data available.

Appendix D. Soil data for Sawmill Canyon (S) tills.

Location	Site number	Age[a] Previous Study	Age[a] This Study	Horizons[b]	Depth (cm)	Color[c]	Texture[d]	Estimated % gravel	% < 2 mm fraction Sand	Silt	Clay	pH[e]	% Organic Matter[f]	Remarks
SC (N)-Bloody Canyon	02	MB	Ta	A	0-10	2.5Y 7/2.5	SL	50-75	61	33	6	6.6	1	Same moraine as site 01, with same comments applying.
				B	10-43	10YR 8/3	SL	75-90	75	19	6	6.6	1	
				IIClox	43-88	10YR 8/2	LS	90	77	17	6	6.2	1	
				IIC2ox	88-115+	2.5Y 8/2	LS	90	76	19	5	6.3	0	

[a]Age of previous study is based upon works of Dalrymple (1964)-Sawmill Canyon (S), Curry (1971)-Mammoth Creek, Sharp and Birman (1963)-Sawmill Canyon (N)-Bloody Canyon, and Sharp (1972)-Green Creek. Age assignments are Tioga (Ti), Tenaya (Te), Tahoe (Ta), Mono Basin (MB), and Casa Diablo (CD).

[b]Nomenclature follows Soil Survey Staff (1975) and Birkeland (1974).

[c]Colors are dry, determined on less than 2 mm fraction.

[d]Textural designations are loamy sand (LS), sandy loam (SL), and sand (S).

[e]pH determinations are by meter on a 2:1 water to soil mixture.

[f]Organic matter determined by loss on ignition, corrected for structural water loss by subtracting loss on ignition of organic free silt + clay fraction.

REFERENCES CITED

Adam, D. P., 1967, Late-Pleistocene and Recent palynology in the central Sierra Nevada, in Cushing, E. J., and Wright, H. E., Jr., eds., Quaternary Paleocology: INQUA Congress VII, Proceedings 7, Yale University Press, New Haven, Connecticut, p. 275-301.

Bailey, R. A., Dalrymple, G. B., and Lanphere, M.A., 1976, Volcanism, Structure and Geochronology of Long Valley Caldera, Mono County, California: Journal of Geophysical Research, v. 81, p. 725-744.

Bateman, P. C., and Wahrhaftig, Clyde, 1966, Geology of the Sierra Nevada: California Division of Mines and Geology Bulletin 190, p. 107-172.

Benedict, J. B., 1967, Recent glacial history of an alpine area in the Colorado Front Range, U.S.A., I. Establishing a lichen-growth curve: Journal of Glaciology, v. 6, no. 48, p. 817-832.

Birkeland, P. W., 1964, Pleistocene glaciation of the northern Sierra Nevada, north of Lake Tahoe, California: Journal of Geology, v. 72, p. 810-825.

_____, 1967, Correlation of soils of stratigraphic importance in western Nevada and California, and their relative rates of profile development in Morrison, R. B., and Wright, H. E., Jr., eds., Quaternary Soils, INQUA Congress VII, Proceedings 9: Desert Research Institute, Reno, Nevada, p. 71-911.

_____, 1968, Correlation of Quaternary Stratigraphy of the Sierra Nevada with that of the Lake Lahontan area, p. 469-500 in R. B. Morrison and H. E. Wright, Jr., eds., Means of correlation of Quaternary successions: International Association of Quaternary Research, VII Cong., Proc. v. 8.

_____, 1973, Use of relative age-dating methods in a stratigraphic study of rock glacier deposits, Mount Sopris, Colorado: Arctic and Alpine Research, v. 5, p. 401-416.

Birkeland P. W., 1974, Pedology, weathering, and geomorphological research: New York, Oxford, 285 p.

Birkeland, P. W., and Janda, R. J., 1971, Clay mineralogy of soils developed from Quaternary deposits of the eastern Sierra Nevada, California: Geological Society of America Bulletin, v 82, p. 2495-2514.

Birkeland, P. W., Burke, R. M., and Yount, J. C., 1976, Preliminary comments on Late Cenozoic Glaciations in the Sierra Nevada, in Mahaney, W. C., ed., Stratigraphy of North America: Proceedings of a Symposium: Stroudsburg, Dowden, Hutchinson, and Ross, Inc., p. 283-295.

Birkeland, P. W., Walker, A. L., Benedict, J. B., and Fox, F. B., 1979, Morphological and chemical trends in Soil Chronosequences: Alpine and Arctic Environments: Agronomy Abstracts, p. 188.

Birman, J. H., 1964, Glacial geology across the crest of the Sierra Nevada: Geological Society of America Special Paper 75, 80 p.

Blackwelder, Eliot, 1927, Fire as an agent in rock weathering: Journal of Geology, v. 35, p. 134-140.

_____1931, Pleistocene glaciation in the Sierra Nevada and Basin Ranges: Geological Society of America Bulletin, v. 42, p. 865-922.

_____, 1933, Eastern slope of the Sierra Nevada: XVI International Geological Congress, Guidebook 16, p. 81-102.

Burke, R. M., and Birkeland, P. W., 1979, Reevaluation of multiparameter relative dating techniques and their application to the glacial sequence along the eastern escarpment of the Sierra Nevada, California: Quaternary Research, v. 11, no. 1, p. 21-51.

Carroll, Tom, 1974, Relative age dating techniques and a late Quaternary chronology Arikaree Cirque, Colorado: Geology, v. 2, p. 321-325.

Chesterman, C. W., and Gray, C. H., Jr., 1975, Geology of the Bodie Quadrangle, Mono County, California: Map sheet 21, California Division of Mines and Geology, scale 1:48,000.

Clark, M. M., 1967, Pleistocene glaciation of the drainage of the West Walker River, Sierra Nevada, California: Ph.D. Thesis, Stanford University, California, University Microfilms, Inc., no 68-6401, Ann Arbor, Michigan, 170 p.

_____, 1972, Range-front faulting: Cause of anomalous relations among moraines of the eastern slope of the Sierra Nevada, California: Geological Society of America Abstracts with Programs, v. 4, p. 137.

Colman, S. M., 1977, The development of weathering rinds on basalts and andesites and their use as a Quaternary dating method, Western United States: Ph.D. Thesis, University of Colorado, 235 p.

Crandell, D. R., 1972, Glaciation near Lassen Peak, northern California: U.S. Geological Survey Profesional Paper 800-C, p. C179-C188.

Curry, R. R., 1966, Glaciation about 3,000,000 years ago in the Sierra Nevada: Science, v. 154, p. 770-771.

_____, 1968, Quaternary climatic and glacial history of the Sierra Nevada, California: Ph.D. Thesis, University of California, Berkeley, University Microfilms, Inc., no. 68-13896, Ann Arbor, Michigan, 238 p.

_____, 1969, Holocene climatic and glacial history of the Central Sierra Nevada, California, in "United States Contributions to Quaternary Research" (S. A. Schumm and W. C. Bradley, eds.), p. 1-47: Geological Society of America Special Paper 123.

_____, 1971, Glacial and Pleistocene history of the Mammoth Lakes Sierra, California--a geologic guidebook: Montana Department of Geology Geological Serial Publication 11, Missoula, Montana, 49 p.

Dalrymple, G. B., 1964, Potassium-argon dates of three Pleistocene interglacial basalt flows from the Sierra Nevada, California: Geological Society of America Bulletin, v. 75, p. 753-758.

Dalrymple, G. B., Cox, Allan, and Doell, R. R., 1965, Potassium-argon age and paleomagnetism of the Bishop Tuff, California: Geological Society of America Bulletin, v. 76, p. 665-674.

Dickinson, W. R., 1968, Semiquantitative "Glacial Measures", Bridgeport Basin, California: Unpublished report of the "1968 Stanford Geological Survey under the direction of William R. Dickinson."

Dunn, J. R., 1953, The origin of the deposits of tufa at Mono Lake: Journal of Sedimentary Petrology, v. 23, p. 18-23.

Harden, J. W., and Marchand, D. W., 1977, The soil chronosequence of the Merced River area, in Singer, M. J., ed., Soil development, geomorphology, and Cenozoic history of the northeastern San Joaquin Valley and adjacent areas, California: Guidebook for the joint field session of the American Society of Agronomy, Soil Science Society of America and the Geological Society of America, Chapter VI: Davis, California, American Society Agronomy, p. 22-38.

Izett, G. A., and Naeser, C. W., 1976, Age of the Bishop Tuff of eastern California as determined by the fission-track method: Geology, v. 4, p. 587-590.

Janda, R. J., 1966, Pleistocene history and hydrology of the San Joaquin River, California: Ph.D. Thesis, University of California, Berkeley, University Microfilms, Inc., no. 67-5086, Ann Arbor, Michigan, 425 p.

Janda, R. J., and Croft, M. G., 1967, The stratigraphic significance of a sequence of non-calcic brown soils formed on the Quaternary alluvium of the Northeastern San Joaquin Valley, California, in Morrison, R. B., and Wright, H. E., Jr. eds., Quaternary Soils: INQUA Congress VII, Procedings 9, Desert Research Institute, Reno, Nevada, p. 157-190.

Kistler, R. W., 1966, Geologic map of the Mono Craters Quadrangle Mono and Tuolumne Counties, California: U.S. Geological Survey Map GQ 462, scale 1:62,500.

Lipshie, S. R., 1976, Geologic Guidebook to the Long Valley-Mono Craters region of eastern California: Geologic Society of UCLA, Los Angles, 184 p.

Matthes, F. E., 1960, Reconnaissance of the geomorphology and glacial geology of the San Joaquin Basin, Sierra Nevada, California: U.S. Geological Survey Professional Paper 329, 62 p.

McAllister, J. F., 1936, Glacial history of the area near Lake Tahoe: Stanford University unpublished M.A. thesis.

McCulloch, D. S., 1963, Late Cenozoic erosional history of Huerfano Park, Colorado: Ph.D. Thesis, University of Michigan, University Microfilms, Inc., no. 63-6922, Ann Arbor, Michigan, 158 p.

McGee, W. J., 1885, On the meridional deflection of ice streams: American Journal of Science, v. 29, p.386-392.

McKeague, J. A., and Day, J. H., 1966, Dithionite--and oxalate--extractable Fe and Al as aids in differentiating various classes of soils: Canadian Journal of Soil Sciences, v. 46, p. 13-22.

Meierding, T. C., 1977, Age differentiation of till and gravel deposits in the upper Colorado River Basin: Ph.D. Thesis, University of Colorado, 353 p.

Miller, C. D., 1971, Quaternary glacial events in the Northern Sawatch Range, Colorado: Ph.D. Thesis, University of Colorado, 86p.

-----, 1969, Chronology of neoglacial morains in the Dome Peak area, North Cascade Range, Washington: Arctic and Alpine Research, v. 1, p. 49-66.

Moore, J. G., 1963, Geology of the Mount Pinchot quadrangle, southern Sierra Nevada, California: U.S. Geological Survey Bulletin 1130, 152 p.

Morrison, R. B., 1965, Quaternary geology of the Great Basin, in The Quaternary of the United States, Wright, H. E., Jr., and Frey D. G., eds.: Princeton, Princeton University Press, p. 265-285.

Nelson, R. L., 1954, Glacial geology of the Frying Pan River drainage, Colorado: Journal of Geology, v. 62, p. 325-343.

Porter, S. C., 1971, Fluctuations of late Pleistocene alpine glaciers in western North America, in Turekian, K. K., ed., The late Cenozoic glacial ages: New Haven, Yale University Press, p. 307-329.

Putnam, W. C., 1949, Quaternary geology of the June Lake district, California: Geological Society of America Bulletin, v. 60, p. 1281-1302.

_____, 1962, Late Cenozoic geology of McGee Mountain, Mono County, California: University of California Publications, Geological Science v. 40, p. 181-218.

Rahm, D. A., 1964, Glacial geology of the Bishop area, Sierra Nevada, California (abs.): Geological Society of America Special Paper 76, p. 221.

Rihehart, C. D., and Ross, D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California, with a section on a gravity study of Long Valley, by L. C. Pakiser: U.S. Geological Survey Professional Paper 385, 106 p.

Russell, I. C., 1887, Quaternary history of Mono Valley, California: U.S. Geological Survey 8th Annual Report, Part 1, p. 261-394.

Scholl, D. W., and Taft, W. H., 1964, Algae, contributors to the formation of calcareous tufa, Mono Lake, California: Journal of Sedimentary Petrology, v. 34, p. 309-319.

Schroeder, M. J., and Buck, C. C., 1970, Fire Weather: Agricultural Handbook no. 360, Washington, U.S. Department of Agriculture, 229 p.

Sharp, R. P., 1968, Sherwin Till-Bishop Tuff geological reltionships, Sierra Nevada, California: Geological Society of America Bulletin, v. 79, p. 351-364.

_____, 1969, Semiquantitative differentiation of glacial moraines near Convict Lake, Sierra Nevada, California: Journal of Geology, v. 77, p. 68-91.

_____, 1972, Pleistocene glaciation, Bridgeport Basin, California: Geological Society of America Bulletin, v. 83, p. 2233-2260.

_____, 1972, Geology field guide to Southern California: Dubuque, Iowa, Kendall/Hunt Publishing Co., 181 p.

Sharp, R. P., and Birman, J. H., 1963, Additions to the classical sequence of Pleistocene glaciations, Sierra Nevada, California: Geological Society of America Bulletin, v. 74, . 1079-1086.

Sheridan, M. F., 1971, Guidebook to the Quaternary geology of the east-central Sierra Nevada: XVI Field Conf., Rocky Mtn. Sec., Friends of the Pleistocene, 60 p.

Shlemon, R. J., 1971, The Quaternary deltaic and channel system in the central Great Valley, California: Association of American Geograhers, Annals 61, p. 427-440.

Shroba, R. R., 1977, Soil development in Quaternary tills, rock-glacier deposits, and taluses, Southern and Central Rocky Mountains: Ph.D. Thesis, University of Colorado, 424 p.

Smith, G. I., 1968, Late Quaternary geologic and climatic history of Searles Lake, southeastern California, in Morrison, R. B., and Wright, H. C., eds., Means of Correlation of Quaternary successions: Salt Lake City, Utah University Press, p. 293-310.

Smith, G. S., ed., 1976, Mammoth Lakes Sierra: a handbook for roadside and trail, 4th ed.: Palo Alto, Genny Smith Books, 147 p.

Soil Survey Staff, 1951, Soil Survey Manual, USDA Handbook 18: U.S. Government Printing Office, Washington, ___ p.

_____, 1975, Soil Taxonomy. USDA Handbook 436. U.S. Government Printing Office, Washington, 754 p.

Storer, T. I., and Usinger, R. L., 1963, Sierra Nevada natural history: Berkeley, University of California Press, 374 p.

U.S. Weather Bureau, 1964, Climatography of the United States no. 86-4, decennial census of United States climate: Climatic summary of the United States--Supplement for 1951-1960-California, 216 p.

Valentine, K. W. G., and Dalrymple, J. B., 1976, Quaternary buried paleosols: A critical review: Quaternary Research, v. 6, p. 209-222.

Wahrhaftig, Clyde, 1965, Tahoe City to Emerald Bay in Wahraftig, Clyde, Morrison, R. B., and Birkeland, P. W., eds., Guidebook for Field Conference I, Northern Great Basin and California: Nebraska Academy of Sciences, Lincoln, Nebraska, p. 59-71.

Wahrhaftig, Clyde, and Birman, J. H., 1965, The Quaternary of the Pacific mountain system in California <u>in</u> Wright, H. E., Jr., and Frey, D. G., eds., The Quaternary of the United States: Princeton, Princeton University Press, p. 299-340.

Wahrhaftig, Clyde, and Sharp, R. P., 1965, Sonora Pass Junction to Bloody Canyon, <u>in</u> Wahrhaftig, Clyde, Morrison, R. B., and Birkeland, P. W., eds., Guidebook for Field Conference I, Northern Great Basin and California, International Quaternary Association: Lincoln, Nebraska, Academy of Sciences, p. 71-84.

Walker, T. W., and Syers, J. K., 1975, The fate of phosphorous during pedogenesis: Geolderma, v. 15, p. 1-19.

Wood, S. H., 1975, Holocene stratigraphy and chronology of mountain meadows, Sierra Nevada, California: Ph.D. dissertation, Pasadena, California Institute of Technology, University Microfilms, Inc., no. 99374636, 180 p.

_____, 1977, Distribution, correlation, and radiocarbon dating of late Holocene tephra, Mono and Inyo Craters, eastern California: Geological Society of America Bulletin, v. 88, p. 89-95.

_____. in prep., Panum Crater tephra dated 640 ± 40 radiocarbon yrs. B.P., Mono Craters, California.

Working group on the origin and nature of paleosols, 1971. Criteria for the recognition and classification of paleosols, <u>in</u> Yaalon, D. H. (ed.), Paleopedology: International Society Soil Science and Israel University Press, Jerusalem, p. 153-158.

RELATIVE WEATHERING DATA

Stop no: ____________ Deposit and location: ______________________________

Soil Characteristics: ____

State of subsurface clasts: lithology: ________; est. % wxed ____________; wxing depth __________

max size of wxed clasts: ________; max oxidation of clasts ____________

Moraine morphology: width (M) ________ inner ∢ ________ outer ∢ ________

Split 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

Non spit 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

Granitic 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

Non Granitic 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

SBF-30X6m-visual max - min diameter = ________ Total blds count 1 ________ Count 2 ________

granitic 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

non grantiic 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

Pitted 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

Non Pitted 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

Pit Depths ____ ____ ____ ____ ____ ____ ____ Depths ____ ____ ____ ____ ____ ____ ____

ROCK TYPE: ________ n = ________ x̄= ________ ROCK TYPE: ________ n= ________ x̄= ________

Fresh 123456789012345678901234567890123456789012345678901234567890 = ____ min diam = ____
Wxed 123456789012345678901234567890123456789012345678901234567890 = ____

Fresh 123456789012345678901234567890123456789012345678901234567890 = ____ min diam = ____
Wxed 123456789012345678901234567890123456789012345678901234567890 = ____

Hammer Blow GWR:Fr 123456789012345678901234567890123456789012345678901234567890 = ____
Wxed 123456789012345678901234567890123456789012345678901234567890 = ____
Grus 123456789012345678901234567890123456789012345678901234567890 = ____

*Rinds 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____
No Rinds 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____
depth: ____ ____ ____ ____ ____ ____ ____ depth: ____ ____ ____ ____ ____ ____ ____

Rock type: ________ n: ________ x̄: ________ Rock type: ________ n: ________ x̄: ________

Height Mafic inclusions ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

Height veinlets ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

Surface boulder oxidation:

ox 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

part ox 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

unox 123456789012345678901234567890 = ____ 123456789012345678901234567890 = ____

miscellaneous: ____

Est. age in my opinion: ________ Name of operator ______________________________(print neatly)

I would like to have these data compiled along with the data of others on the FOP trip and subsequently receive summary information to be printed and distributed to all participants handing in data. Yes /___/ No /___/

*To minimize destruction of the outcrop we request this be a test of how a group of people measure the same rinds - therefore, please measure those rinds already broken open and placed in "rind piles" - please protect these sites.

SAMPLE SOIL DESCRIPTION SHEET

Site No.__________ Date__________ Time__________ Weather______________ Described by ________________

Location____

Geomorphic Surface____

Elevation__________ Slope__________ Aspect __________ Erosion ______________

Vegetation ____

Climate ________________________ Sampling Method (roadcut,backhoe,etc)____________

Parent Material ________________ Estimated Age __________________________

Depth cm	Horizon	Color	Structure	Est. % Gravel	Consist-ence	Texture	pH	Miscellaneous (roots,pores,clay films,concretions,boundary)