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David Fountain

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METAMORPHIC CORE COMPLEXES AND LOW-ANGLE FAULTS OF NORTHEASTERN WASHINGTON

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ABSTRACT

Amphibolite-facies metamorphic rocks of northeastern Washington commonly are mylonitic and are restricted to the Okanogan, Kettle, and Spokane domes. Along the margins of the domes cataclasis and attendant local chloritization of mylonitic rocks appear to be related to Tertiary low-angle faults that contain unmetamorphosed Eocene volcanic and sedimentary rocks in their upper plates. The present structural relief of the domes probably is due to later Tertiary folding.

INTRODUCTION

Three domes containing mylonitic, high-grade metamorphic rocks occur in northeastern Washington and are at least locally bounded by low-angle faults (Fig. 1). At least 25 such domes, termed metamorphic core complexes (Coney, 1980), occur from northern Mexico to southern British Columbia (Davis and Coney, 1979). Those in Washington are the southern extent of the Shuswap domes of British Columbia.

This paper is a summary of the geology of metamorphic core complexes in Washington and their attendant low-angle faults. Figure 1 complements the larger scale map of the Kettle and Okanogan domes in the field trip guide (Cheney and others, this volume); it also supplements preliminary maps of the Kettle dome and northeastern Washington by Cheney (1980) that were published before the existence of many of the low-angle faults was known. Because space does not permit a full review of the evidence here, the reader is referred to

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Editor's Note: References cited in this paper can be found at the end of the next paper in this volume by Cheney and others.

Explanation of Figure 1:

Names (and sources of data) for the faults are as follows:

BCF = Bacon Creek fault (Wright, 1949; Parker and Calkins, 1964; Muessig, 1967; Cheney, unpublished mapping, and reinterpretation of Muessig, 1967, and Staatz, 1964).

CF = Columbia River fault (Yates, 1971).

CT = Chesaw thrust (McMillen, 1979; Cheney, unpublished mapping; reinterpretation of Fox, 1978, Rinehart and Fox, 1972, 1976, Pearson, 1967, 1977, and Parker and Calkins, 1964).

DMF = Drummer Mountain fault (reinterpretation of Parker and Calkins, 1964).

JJF = Jumpoff Joe fault (Miller and Clark, 1975).

KRF = Kettle River fault (Rhodes and Cheney, 1981).

LLF = Long Lake fault (reinterpretation of Staatz, 1964).

MCT = Myers Creek thrust (McMillen, 1979).

NF = Newport Fault (Miller, 1971, 1974a, 1974b, 1974c, 1974d; Bond, 1978).

NRF = Nespelem River fault (Staatz, 1964).

OF = Okanogan fault (Snook, 1965).

OLF = Omak Lake fault (Snook, 1965).

SF = Sherman fault (Muessig, 1967; Cheney, unpublished mapping).

SPF = St. Peter fault (Parker and Calkins, 1965).

Unnamed fault west of BCF is from Pearson (1967).

Inferred faults are based upon the following criteria: metamorphic discontinuities, brecciated or chloritic rocks, very well-jointed and muscovitic granitic rocks, Tertiary rocks dipping into crystalline rocks, and the outcrop pattern of dikes of Scatter Creek rhyodacite. Data are from the authors cited in the indices of geologic mapping shown in Figure 3 of Cheney (1980) and Cheney and others (this volume).

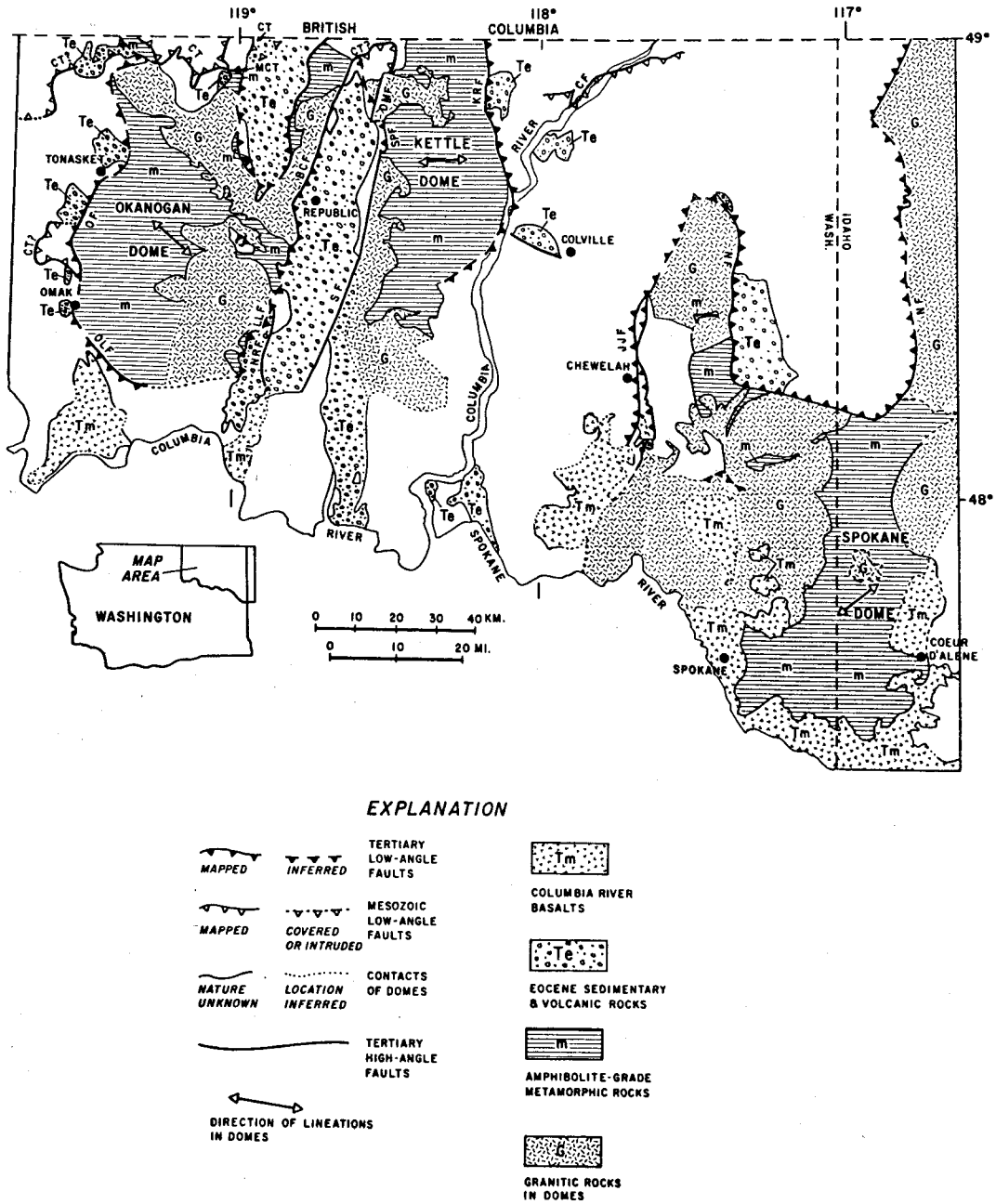


Figure 1. Map showing the location of Kettle, Okanogan and Spokane domes in northeastern Washington.

the references in Figure 1 for documentation of the low-angle faults. Similarly, indices of geological mapping in the Okanogan and Kettle domes are part of Figure 2 of Cheney and others (this volume) and Figure 3 of Cheney (1980) for the Spokane dome.

ROCKS AND STRUCTURES WITHIN THE DOMES

Most of the metamorphic rocks within the domes are of sillimanite-grade. They may be pre-Paleozoic, possibly pre-Beltian (Cheney, 1980; Reynolds and others, 1981). However, K/Ar cooling dates in the Okanogan dome show th t at least some of the metamorphism is late Cretaceous (Fox and others, 1976, 1977).

Along the shallow-dipping western margin of the Okanogan dome and eastern margin of the Kettle dome, both orthogneisses and paragneisses have foliations that usually dip less than 30° and are concordant with lithologic contacts. Mylonites are increasingly abundant toward the margins of the domes and have a slickenside or mineral lineation along the foliation plane. In compositionally layered rocks, the gently dipping mylonitic foliations are axial planar to isoclines. The strike of the lineations is amazingly constant within a dome but varies from dome to dome (Fig. 1).

Along the shallow dipping margins of the domes, the metamorphic rocks are both mylonitic and cataclastic, as are pre-Tertiary granitic plutons. In contrast, Eocene granitic batholiths are not mylonitic but are cataclastically deformed within a few hundred meters of the margins of the domes. Cataclasis and attendant discontinuous chloritization cut the mylonitic rocks and are spatially related to the low angle Tertiary faults shown in Figure 1. Greenschist facies (rather than sillimanite-grade) metamorphic rocks and unmetamorphosed Eocene volcanic and sedimentary rocks occur in the upper plates of these faults. Compared to the shallow-dipping margins, the steeper eastern margin of the Okanogan dome and western margin of the Kettle dome have more steeply dipping metamorphic rocks, more batholithic rocks, and almost no mylonites.

The best known of the low-angle faults bounding the domes are the synformal Newport fault (Miller, 1971) on the northern margin of the Spokane dome and the Kettle River fault on the northeastern margin of the Kettle dome (Rhodes and Cheney, 1981). Other known and inferred low-angle faults are shown in Figure 1. The existence of the inferred faults is based upon the criteria listed in Figure 1. Parts of the Bacon Creek fault are inferred to be intruded and obscured by hypabyssal intrusions of Scatter Creek rhyodacite.

The antiformal structure of the Kettle dome is best illustrated by the map pattern of the metamorphic rocks but is also defined by the foliations (Cheney, 1980). The antiformal nature of the Spokane dome is best outlined by the foliations of the metamorphic rocks shown by Griggs (1973). The eastern portion of the Okanogan dome is comprised of granitic plutons (Fox and others, 1976, Fig. 2), which impart a map pattern that might be interpreted as antiformal. The low-angle Tertiary faults consistently dip away from the domes; this antiformal pattern (Fig. 1) suggests that the faults may have been folded by the event that caused the domes.

STRUCTURES OUTSIDE OF THE DOMES

North of the Okanogan dome, McMillen (1979) recognized the Chesaw thrust on the basis of greatly flattened and locally mylonitic and lineated greenschist-facies rocks and associated ultramafic and silica-carbonate rocks. Rocks in the upper plate are characteristically greenstones or Triassic carbonate rocks and conglomerates containing clasts of limestone, chert, and phyllitic rocks. These characteristics are used to infer extensions of the Chesaw thrust west and northeast of the Okanogan dome (Fig. 1).

Rocks along the Chesaw thrust are contact metamorphosed by the Cretaceous(?) Buckhorn Mountain pluton (McMillen, 1979). Thus, the Chesaw thrust may be about the same age as, and might be the cause of, the mylonitic rocks in the metamorphic core complexes. If so, the variable strike of the lineations from dome to dome requires an additional explanation.

A major syncline involving the Eocene volcanic and sedimentary rocks, as well as pre-Tertiary rocks of greenschist facies, occurs in the Republic area (Wright, 1949). This Sanpoil syncline (Muessig, 1967) has about the same strike and structural relief as the Kettle dome and the adjacent part of the Okanogan dome. A smaller syncline, involving the same three Eocene formations that are in the Sanpoil syncline, occurs on the northeastern side of the Kettle dome. Thus, the intervening Kettle dome and the Kettle River fault and the other domes and low-angle faults probably owe their structural relief to post-Eocene arching (Cheney, 1980). The Sanpoil syncline, which is bounded on the west by the low- to high-angle Bacon Creek fault, has also been known as the Republic graben (Staatz, 1964; Muessig, 1967).

CONCLUSIONS

Amphibolite-facies metamorphic rocks of northeastern Washington are restricted to three metamorphic core complexes. Instead of being diapirically emplaced gneiss domes as has been previously suggested (Fox and others, 1976; Okulitch and others, 1977), the metamorphic rocks appear to have been juxtaposed against lower grade and unmetamorphosed rocks along low-angle, post-middle Eocene faults. The present structural relief of the domes probably is due to later Tertiary doming; this implies that Tertiary low-angle faults may be part of a folded décollement of regional extent and that the structural lows, instead of being grabens, are synformally folded upper-plate rocks.

ACKNOWLEDGEMENTS

We thank R. J. Stewart for critically reviewing an earlier draft of this article and Mobil Oil Corporation for defraying the cost of the drafting of Figure 1.

GEOLOGICAL EXCURSION OF HIGH-GRADE METAMORPHIC ROCKS AND LOW-ANGLE FAULTS OF THE KETTLE AND OKANOGAN DOMES, WASHINGTON

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INTRODUCTION

The purpose of this field trip is to examine the high-grade metamorphic rocks and low-angle faults of the Kettle and Okanogan domes in the Okanogan Highlands of northeastern Washington. These domes are broad north-trending arches of predominantly sillimanite-grade metasedimentary rocks and orthogneisses intruded by Mesozoic and Eocene granitic rocks of batholithic dimensions. The metamorphic rocks and Mesozoic plutons are mylonitically and cataclastically deformed in the upper structural levels of the domes, but the Eocene granitic rocks are only cataclastically deformed. The rocks of the domes are bounded by greenschist-grade Paleozoic and Mesozoic metamorphic rocks, Mesozoic and Tertiary plutons, and unmetamorphosed Eocene volcanic and sedimentary rocks.

More than 25 such terranes, or metamorphic core complexes occur, in the North American Cordillera from Mexico to British Columbia. A number of these are described in Crittenden and others (1980). The locations of core complexes in northwestern U.S. and southern B.C. (Shuswap domes) are shown in Figure 1.

The Shuswap domes have been characterized as Mesozoic to Tertiary diapiric gneiss domes (Fox and others, 1977) cut by high-angle faults, which formed grabens in which local sections of Tertiary sedimentary and volcanic rocks were deposited. More recently, suggestions have been made that Tertiary rocks are of regional extent (Pearson and Obradovich, 1977), that the metamorphic rocks

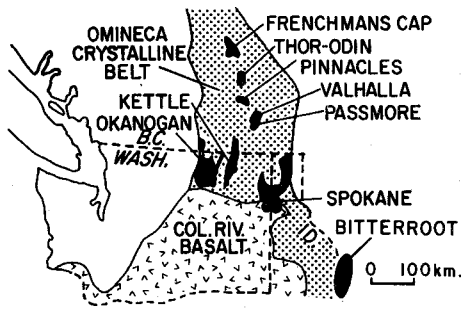
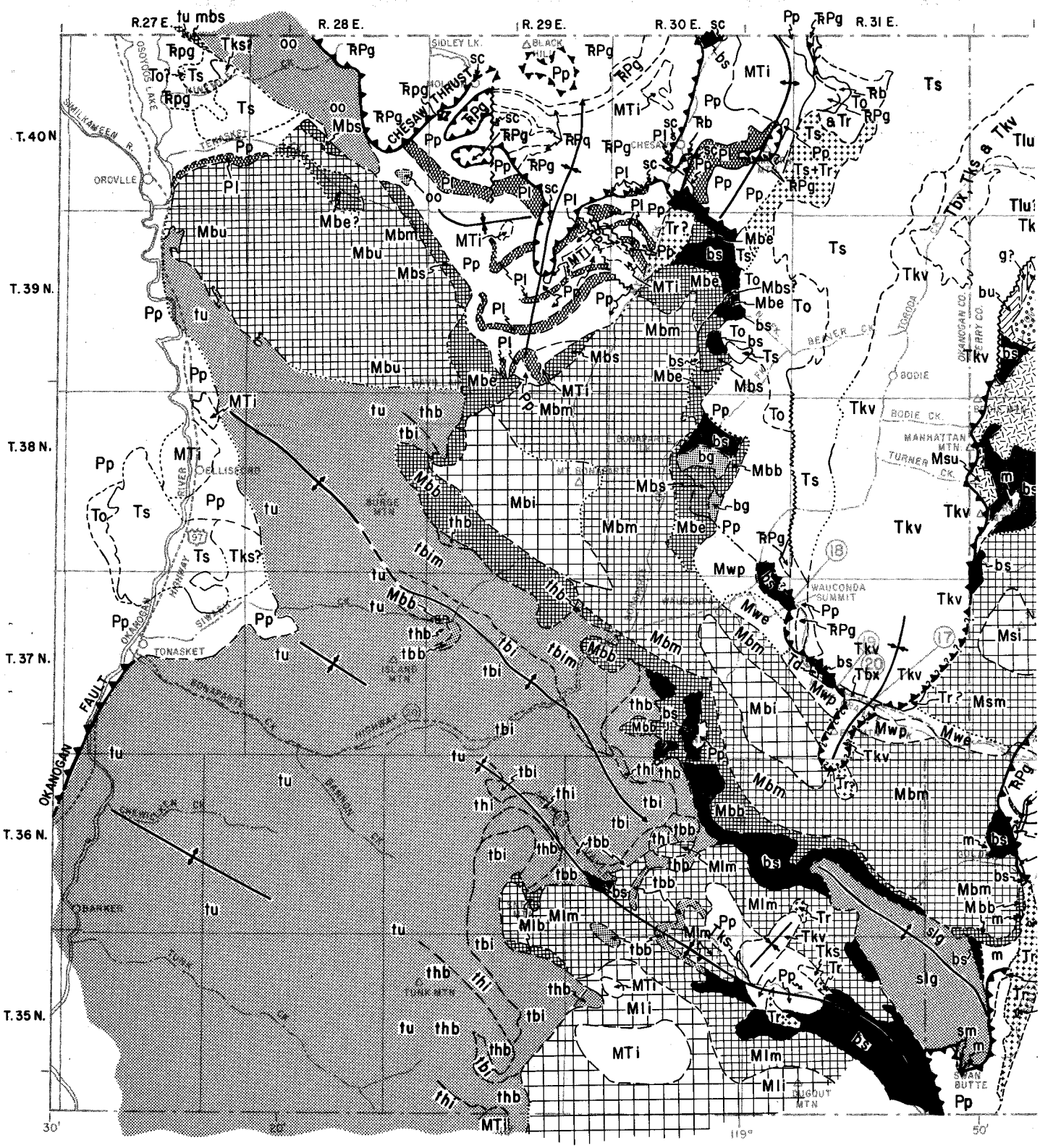


Figure 1. Location map of domes (metamorphic core complexes) in northwestern U.S. and British Columbia. Domes are shown in black.

are pre-Paleozoic(?) crystalline basement exposed in the cores of post-Eocene folds, and that the contact between these high-grade metamorphic rocks and other rocks is tectonic instead of intrusive (Cheney, 1980; Rhodes and Cheney, 1981). These and other hypotheses will be examined on this trip.

Figure 2 is a geological map of the portions of the Kettle and Okanogan domes traversed by this field trip. Capitalized abbreviations in the road log refer to units on the map. Because most of the area has only been mapped in reconnaissance scale (1:62,500 or smaller), the nature, extent, and significance of many geological features are still controversial. Because space does not permit a detailed description of the geology, the reader is referred to Cheney (1980), Rhodes and Cheney (1981), and the companion article to this field guide (Cheney and others, this volume).

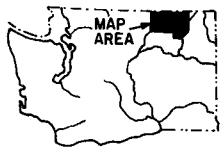
This field guide is divided into two parts. The first part (day one) is a road log from the junction of U.S. Route 395 and State Route 20 (Barney's Junction) to Republic via Deer Creek Summit. The second part (day two) is a road log from Republic to Barney's junction via Wauconda. If all stops are included, both parts can be completed in two long days. The stops are numbered on Figure 2.



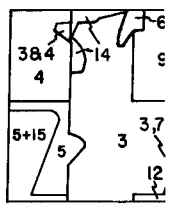
N

(22) FIELD TRIP STOP NUMBERS OF CHENEY, ET. AL., 1981

INDEX MAP



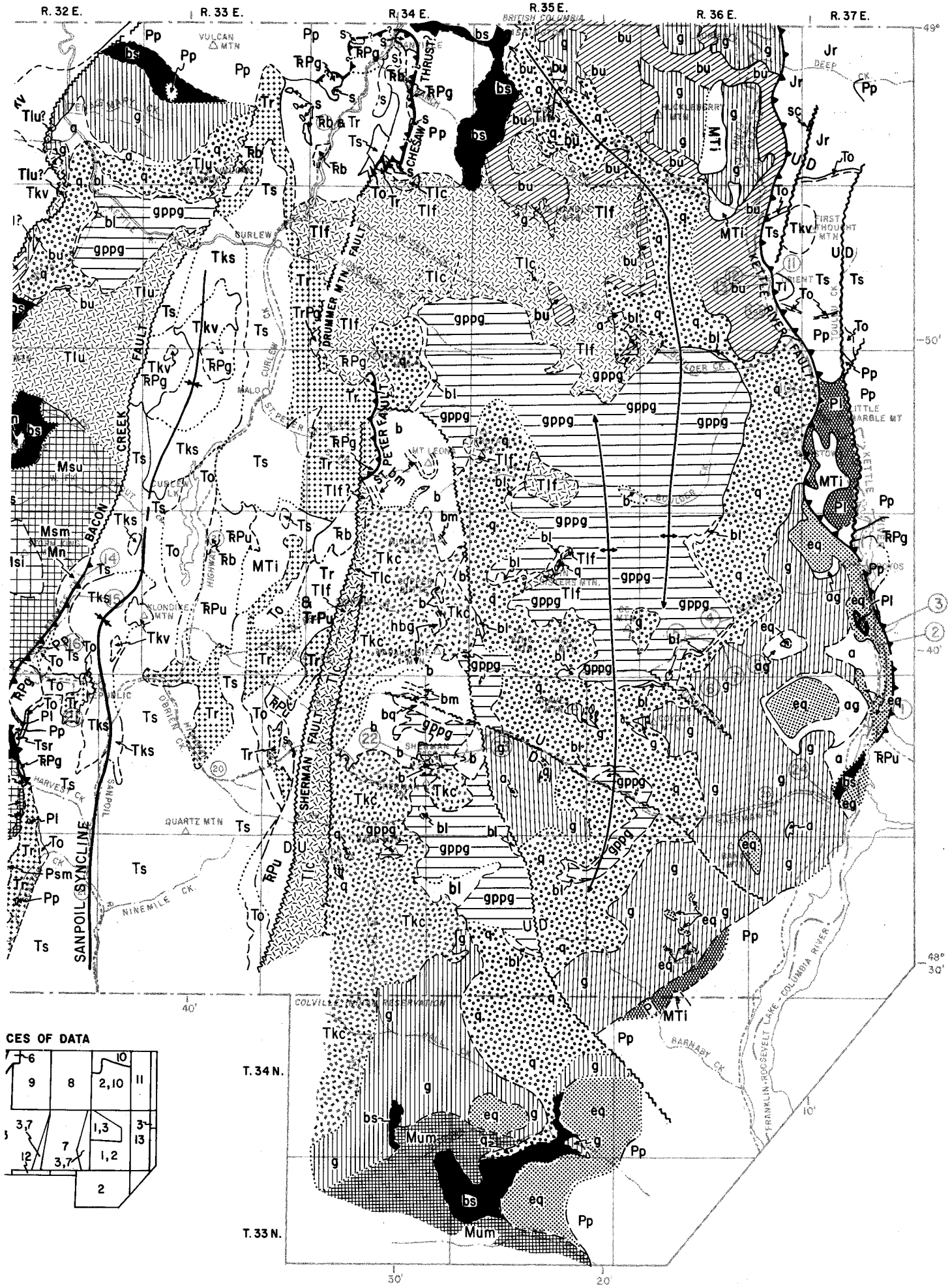
SOURCES

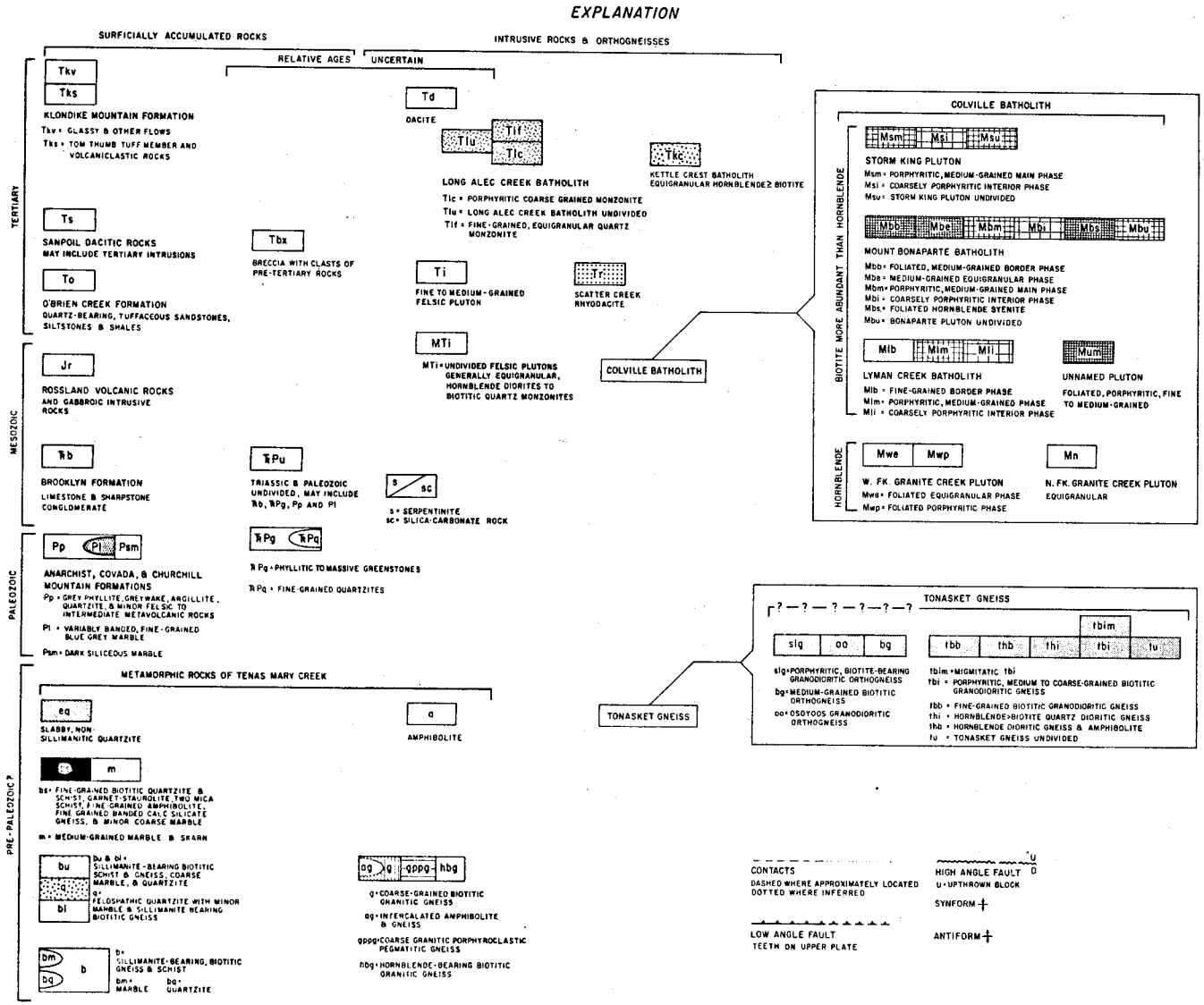


0 6 mi

0 10 km

1/81


R. 32 E.
R. 33 E.
R. 34 E.
R. 35 E.
R. 36 E.
R. 37 E.
49°
50'
40'
48°
30'
10'
20'
30'
T. 34 N.
T. 33 N.
BRITISH COLUMBIA
VULCAN MTN
SURLEW
BACON CREEK FAULT
SANPOIL SYNCLINE
QUARTZ MTN
NINEMILE CK.
KLONDIKE MTN
SHERMAN FAULT
THRUST
DRUMMER MTN. FAULT
ST. PETER FAULT
KETTLE RIVER FAULT
COLVILLE INDIAN RESERVATION
FRANKLIN ROOSEVELT LAKE
COLUMBIA RIVER
BARNABY CK.
CES OF DATA


EXPLANATION
SURFICIALLY ACCUMULATED ROCKS
INTRUSIVE ROCKS & ORTHOGNEISSES
RELATIVE AGES
UNCERTAIN
TERTIARY
MESOZOIC
PALEOZOIC
PRE-PALEOZOIC?
Tkv
Tks
KLONDIKE MOUNTAIN FORMATION
Tkv = GLASSY & OTHER FLOWS
Tks = TOM THUMB TUFF MEMBER AND VOLCANICLASTIC ROCKS
Ts
SANPOIL DACITIC ROCKS
MAY INCLUDE TERTIARY INTRUSIONS
To
O'BRIEN CREEK FORMATION
QUARTZ-BEARING, TUFFACEOUS SANDSTONES, SILTSTONES & SHALES
Jr
ROSSLAND VOLCANIC ROCKS AND GABBROIC INTRUSIVE ROCKS
TRb
BROOKLYN FORMATION
LIMESTONE & SHARPSTONE CONGLOMERATE
Pp
Pl
Psm
ANARCHIST, COVADA, & CHURCHILL MOUNTAIN FORMATIONS
Pp = GREY PHYLLITE, GREYWAKE, ARGILLITE, QUARTZITE, & MINOR FELSIC TO INTERMEDIATE METAVOLCANIC ROCKS
Pl = VARIABLY BANDED, FINE-GRAINED BLUE GREY MARBLE
Psm = DARK SILICEOUS MARBLE
METAMORPHIC ROCKS OF TENAS MARY CREEK
eq
SLABBY, NON-SILLIMANITIC QUARTZITE
bs
m
bs = FINE-GRAINED BIOTITIC QUARTZITE & SCHIST, GARNET-STAUROLITE TWO MICA SCHIST, FINE-GRAINED AMPHIBOLITE, FINE GRAINED BANDED CALC SILICATE GNEISS, & MINOR COARSE MARBLE
m = MEDIUM-GRAINED MARBLE & SKARN
bu
q
bl
bu & bl = SILLIMANITE-BEARING BIOTITIC SCHIST & GNEISS, COARSE MARBLE, & QUARTZITE
q = FELDSPATHIC QUARTZITE WITH MINOR MARBLE & SILLIMANITE BEARING BIOTITIC GNEISS
bm
b
bq
b = SILLIMANITE-BEARING, BIOTITIC GNEISS & SCHIST
bm = MARBLE
bq = QUARTZITE
Td
DACITE
Tlu
Tlf
Tlc
LONG ALEC CREEK BATHOLITH
Tlc = PORPHYRITIC COARSE GRAINED MONZONITE
Tlu = LONG ALEC CREEK BATHOLITH UNDIVIDED
Tlf = FINE-GRAINED, EQUIGRANULAR QUARTZ MONZONITE
Tkc
KETTLE CREST BATHOLITH
EQUIGRANULAR HORNBLENDE≥ BIOTITE
Tbx
BRECCIA WITH CLASTS OF PRE-TERTIARY ROCKS
Ti
FINE TO MEDIUM-GRAINED FELSIC PLUTON
Tr
SCATTER CREEK RHYODACITE
MTi
MTi = UNDIVIDED FELSIC PLUTONS GENERALLY EQUIGRANULAR, HORNBLENDE DIORITES TO BIOTITIC QUARTZ MONZONITES
TRPu
TRIASSIC & PALEOZOIC UNDIVIDED, MAY INCLUDE TRb, TRPg, Pp AND Pl
TRPg
TRPq
TRPg = PHYLLITIC TO MASSIVE GREENSTONES
TRPq = FINE-GRAINED QUARTZITES
s
sc
s = SERPENTINITE
sc = SILICA-CARBONATE ROCK
a
AMPHIBOLITE
ag
q
gppg
hbg
q = COARSE-GRAINED BIOTITIC GRANITIC GNEISS
ag = INTERCALATED AMPHIBOLITE & GNEISS
gppg = COARSE GRANITIC PORPHYROCLASTIC PEGMATITIC GNEISS
hbg = HORNBLENDE-BEARING BIOTITIC GRANITIC GNEISS
COLVILLE BATHOLITH
BIOTITE MORE ABUNDANT THAN HORNBLENDE
Msm
Msi
Msu
STORM KING PLUTON
Msm = PORPHYRITIC, MEDIUM-GRAINED MAIN PHASE
Msi = COARSELY PORPHYRITIC INTERIOR PHASE
Msu = STORM KING PLUTON UNDIVIDED
Mbb
Mbe
Mbm
Mbi
Mbs
Mbu
MOUNT BONAPARTE BATHOLITH
Mbb = FOLIATED, MEDIUM-GRAINED BORDER PHASE
Mbe = MEDIUM-GRAINED EQUIGRANULAR PHASE
Mbm = PORPHYRITIC, MEDIUM-GRAINED MAIN PHASE
Mbi = COARSELY PORPHYRITIC INTERIOR PHASE
Mbs = FOLIATED HORNBLENDE SYENITE
Mbu = BONAPARTE PLUTON UNDIVIDED
Mlb
Mlm
Mll
LYMAN CREEK BATHOLITH
Mlb = FINE-GRAINED BORDER PHASE
Mlm = PORPHYRITIC, MEDIUM-GRAINED PHASE
Mll = COARSELY PORPHYRITIC INTERIOR PHASE
Mum
UNNAMED PLUTON
FOLIATED, PORPHYRITIC, FINE TO MEDIUM-GRAINED
HORNBLENDE
Mwe
Mwp
W. FK. GRANITE CREEK PLUTON
Mwe = FOLIATED EQUIGRANULAR PHASE
Mwp = FOLIATED PORPHYRITIC PHASE
Mn
N. FK. GRANITE CREEK PLUTON
EQUIGRANULAR
TONASKET GNEISS
?—?—?—?—?—?
slq
oo
bg
tbim
tbb
thb
thi
tbi
tu
slq = PORPHYRITIC, BIOTITE-BEARING GRANODIORITIC ORTHOGNEISS
bg = MEDIUM-GRAINED BIOTITIC ORTHOGNEISS
oo = OSOYOOS GRANODIORITIC ORTHOGNEISS
tbim = MIGMITATIC tbi
tbi = PORPHYRITIC, MEDIUM TO COARSE-GRAINED BIOTITIC GRANODIORITIC GNEISS
tbb = FINE-GRAINED BIOTITIC GRANODIORITIC GNEISS
thi = HORNBLENDE>BIOTITE QUARTZ DIORITIC GNEISS
thb = HORNBLENDE DIORITIC GNEISS & AMPHIBOLITE
tu = TONASKET GNEISS UNDIVIDED
CONTACTS
DASHED WHERE APPROXIMATELY LOCATED
DOTTED WHERE INFERRED
LOW ANGLE FAULT
TEETH ON UPPER PLATE
HIGH ANGLE FAULT
U = UPTHROWN BLOCK
D
SYNFORM
ANTIFORM

ROAD LOG

FIRST DAY

BARNEY'S JUNCTION TO REPUBLIC, WASHINGTON

Cumulative Mileage

0.0 STOP 1 (Barney's Junction): Eastern Granitic Gneiss (Cheney, 1980, p. 465 and 469)

Park cars in the parking lot at Barney's Junction and walk 0.2km. north through the roadcut in interlayered amphibolite and biotitic gneiss (unit AG on map).
Note the following:

1. East-trending lineations which are so characteristic of the metamorphic rocks of the Kettle dome
2. Light gray-green aphanitic mylonitic zones, which are restricted to the upper structural levels of the dome
3. Boudinaged pegmatites containing broken feldspars
4. Isoclinal recumbent folds with axial planes parallel to the foliation (but with almost no axial plane foliation); these are thought to be first generation folds. At the northeastern end of the cut note the ellipsoidal pattern of small pegmatites probably caused by refolding of earlier noncylindrical folds during extension in the direction of the lineation.

Drive northward on U.S. Route 395.

0.5 Kifer road on west. Excellent exposures of the eastern quartzite (EQ) occur in quarries up this road. Continue northward on Rt. 395.

1.0 Excellent outcrops of black amphibolite which is structurally above the eastern gneiss and below the eastern quartzite to be seen at Stop 2.

2.9 STOP 2: Eastern Quartzite (Cheney, 1980, p.470)

Park in front of fire danger sign, cross the barbed wire fence and walk 110° to knob of quartzite west of railroad tracks.

The eastern quartzite (unit EQ on map) has unusually abundant and well developed, open to tight, concentric folds plunging gently northwestward. These have been described in detail by Donnelly (1978). They probably are second generation folds (later than the recumbent isoclinal folds seen at Stop 1). Note the truncation structures.

Drive northward on U.S. Route 395.

3.1 Amphibolite. Note folds at north end of roadcut.

3.3 Turn right on road to Kamloops Island and cross the bridge.

3.5 Turn left into Kamloops Island Campground and drive to far end.

3.7 STOP 3: Margin of the dome (good lunchstop)(Cheney, 1980, p.473)

Note the rusty weathering eastern quartzite in the road cuts along U.S. Route 395. The top of the hill is capped by gray fine-grained marble (unit Pl on map). The marble is a remnant of the low-grade rocks preserved on the flank of the dome and is inferred to be a klippe of the Kettle River fault.

Return to U.S. Highway 395.

4.5 U.S. Highway 395, turn right (north).

8.0 Turn left (west) onto Deadman Creek Road.

10.9 Eastern gneiss on north side of road.

11.7 Jackknife Mountain Road on right; bear left (straight ahead).

12.0 Take left fork (Deadman Creek Road).

14.5 Go left over bridge on South Fork Deadman Creek Road.

14.6 Turn left on South Deadman Face Road.

14.8 STOP 4: Granitic, Porphyritic, Pegmatitic Gneiss (Cheney, 1980, p.476, Wilson, 1980).

Stops 4 through 8 will examine the rocks structurally below those seen at Stop 1. Only the pelitic rocks that are inferred to be the structurally lowest in the dome will not be seen (see Stops 22 and 26).

The pegmatite gneiss (unit GPPG) is unusual at this stop in that it contains folia of biotitic gneiss and amphibolite; this is probably because the upper contact of the gneiss with pelitic rocks is just a few meters above. Elsewhere this gneiss commonly has irregular pegmatitic patches a meter or two in diameter. Note the eastward trending lineations. Compare the gneiss with the eastern gneiss at Stop 8.

The GPPG commonly is the lowest unit exposed in the dome; note that it has a large area of outcrop (Fig. 2).

14.9 Marble on right.

15.6 Graphitic, sulfidic marble containing tight, nearly isoclinal folds with refolded axes.

16.0 STOP 5: Quartzite-dominated sequence (Cheney, 1980, p.469, Wilson, 1980)

The marbles in unit BL of the map are unusually well exposed along this road. This phlogopitic marble contains diopside, graphite, and pyrite. Note the following:

1. Isoclinal folds
2. Ellipsoidal structures indicative of reorientation of earlier axes into the direction of extension.
3. Boudinage of pegmatite, marble, and a thin pelitic unit

16.3 STOP 6: Quartzite-dominated sequence (Cheney, 1980, p.469; Wilson, 1980)

Sillimanite-bearing gneisses are map unit BL. Regionally this rock type is more abundant than marble in unit BL.

Note the bold outcrops on CC Mountain to the northwest across Deadman Creek; the lower 2/3 of the mountain are GPPG; the upper 1/3 is quartzite (Q).

16.9 Hoodoo Mountain road on right, stay left.

17.2 Quartzite in ditch.

17.7 STOP 7: Quartzite-dominated sequence (Cheney, 1980, p.469, Wilson, 1980).

Sillimanite-bearing biotitic feldspathic quartzite of map unit Q has the uncommon occurrence of muscovite and sillimanite. No sillimanite has yet been discovered in the muscovitic eastern quartzite (EQ).

The quartzite at Stop 7 is unusually micaceous and slabby; elsewhere layers commonly are 0.3 to 1.0 m thick. The quartzite is unusually thin (200 m) at this locality; elsewhere it is 650 m or more thick.

17.9 Lowest outcrop of eastern gneiss.

18.1 STOP 8: Eastern Granitic Gneiss (Cheney, 1980, p.469; Wilson, 1980)

Biotitic eastern gneiss is typical of map unit G. Note the lack of mylonitic seams that are in this gneiss at Stop 1; we are at the base of the gneiss about 800 meters structurally lower than Stop 1. The gneiss extends to the skyline (and beyond) of the ridges to the east and south.

Note that compared to GPPG, this gneiss is better foliated but lacks the large feldspars and pegmatitic patches.

18.5 End of road, turn around and return to U.S. Highway 395.

28.9 Junction of Deadman Creek Road and U.S. 395; turn left (north).

34.1 Barstow

34.8 Fine-grained marble in cliffs to west and across the Kettle River to the east.

35.4 STOP 9: Fine-grained marble (Cheney, 1980, p.474).

The parking at this stop is terrible. Look for the two wide spots.

This brecciated fine-grained, finely banded marble is similar to that

seen from Stop 3 and to that underlying Little Marble Mountain across the Kettle River to the east. Note the difference between the grain sizes of this marble and that in the dome at Stop 5. The sheared and brecciated chloritic and dioritic dikes suggest that the marble is in the greenschist facies.

Because the contact with the metamorphic rocks of the Kettle dome is only 0.5 km to the west, such rocks may be only a couple of hundred meters below Stop 9.

36.2 Hodgson Road on left (west).

36.3 STOP 10: Kettle River fault (Rhodes and Cheney, 1981)

Permission for access and parking must be obtained from the residents. Walk northward on the dirt road and path east of the corral. Stay on the path down to the river.

The west bank of the river is underlain by chloritic calc-silicate gneisses, chloritic granitic gneisses, marbles, and quartzites of map unit BU. Note the recumbent fold near the path, boudins, and the numerous small faults with only a few centimeters of displacement. The folds and boudins are related to a period of plastic deformation that preceeded the chloritization and brecciation that accompanied the Kettle River fault. Chloritic rocks such as these are confined to the highest levels of the dome.

Note the unusual westerly dip of the rocks. During periods of low water, an antiformal axis can be seen in mid-stream, the metamorphic rocks on the east bank are horizontal to easterly dipping.

On the east bank of the river white weathering, fine-grained marble overlies gray fine-grained, foliated marble, which in turn overlies a strongly boudinaged zone of intercalated chloritic calc-silicate gneiss and gray fine-grained marble. Chloritic gneisses occur in the rapids and on the adjacent eastern bank.

This zone of chloritic gneiss and fine-grained marble is inferred to be the Kettle River fault, which is the contact between the high-grade rocks of the dome and the lower grade cover rocks.

Return to cars (please stay on paths) and continue northward on U.S. 395.

37.3 Calc-silicate gneisses (with pegmatites), quartzites, and pelitic gneisses of BU unit.

37.5 Boulder Creek Road on left (west).

39.9 Turn right into Orient and proceed to eastern abutment of bridge.

40.3 STOP 11: Tertiary pluton

Chloritically altered granitic rocks are intrusive into the Eocene Sanpoil volcanic rocks. Presumably the chloritic alteration is related to the

Kettle River fault.

Recross bridge and return to Orient.

40.7 STOP 12 (Orient): First Thought Mountain

Park in parking lot of Orient school, walk north to knobs of dolomitic marble and granitic gneiss (map unit BU). Note the chloritic granitic rocks across the Kettle River to the east (Stop 11). The contact of the high-grade rocks is in the valley between Stops 11 and 12.

Note First Thought Mountain. This is a syncline cut by high-angle faults and the low-angle contact of the Kettle dome. The same Tertiary rocks in the Republic area are in a similar structural position with respect to the Bacon Creek fault.

Return to junction with U.S. 395.

50.3 STOP 13 (Orient): Hornblende Diorite.

Examine the Orient weather station and then walk to U.S. 395 to see the hornblende diorite which is mostly massive. In places it is well foliated and lineated and contains isoclinal folds. Apparently this unit was emplaced late in the deformation which produced the foliation and lineation.

Return to cars and turn left (south) onto U.S. 395 to cross the Kettle River Range.

52.7 Turn right (west) on the Boulder-Deer Creek Road (Curlew 25 miles). Watch out for cattle on this road for the next 24 miles.

53.3 Under the bridge to the left are amphibolites, marbles, and granitic gneiss with stretched xenoliths (map unit BU).

53.5 End of pavement.

54.7 Bear right (South Boulder Road on left); for the next 6 miles the road ascends through GPPG, BL, and Q with some dikes of the Long Alec Creek batholith.

63.6 Outcrops for the next 11 miles are Long Alec Creek batholith (52 m.y.).

64.9 Deer Creek Summit, descend western slope of Kettle River Range.

65.6 Beginning of pavement.

75.8 Stop sign, go straight; Long Alec Creek road is on left; the road to Curlew is on the right.

75.9 Bear right at yield sign and cross the railroad tracks.

76.1 State Route 21, turn left (south) toward Republic.

SECOND DAY

REPUBLIC TO BARNEY'S JUNCTION VIA WAUCONDA

Cumulative Mileage

0.0 From junction of Clarke Avenue and the Curlew Lake Road turn left (west) toward the Knob Hill mine. The rocks for the first half mile are the basal Tom Thumb tuff member of the Klondike Mountain Formation. T e road then enters Eureka Gulch in Sanpoil volcanic rocks on the east and dikes of Scatter Creek on the west. Most of the former mines in Eureka Gulch produced flux (quartz) and only by-product gold; the flux was used in the now defunct Northport smelter. North of Knob Hill mill, the outcrops are coarse to fine-grained volcaniclastic rocks of the Tom Thumb member.

3.1 At the junction with the Swamp Creek Road, bear right.

4.4 STOP 14: Bacon Creek fault. (Muessig, 1967, Plate 1)

Park just north of the junction of the Barrett Creek Road with the Swamp Creek Road (County highway 218). This stop involves a strenuous hike to the south end of the granitic knob 300 feet above the Swamp Creek Road. Scramble to the top of the knob and then work back downhill, looking at the altered rocks (and trying to assess the dip of the fault).

STOP 14A:

Virtually unaltered granitic rock occurs on the back side of the knob. The small quartz grains in the feldspar megacrysts and the 5 mm size of the hornblende may be useful in distinguishing the altered rocks below.

The views from the top of the knob include the following:

1. The northeast trending valley is the trace of the Bacon Creek Fault.

2. Eastward along the Barrett Creek Road, Muessig (1967) mapped Sanpoil volcanic rocks (minimum age 50 m.y.) generally north of the road and Klondike Mountain volcanic rocks (minimum age 41 m.y.) south of the road.

3. The mountains in the distance to the east are the Kettle River Range on the western margin of the Kettle dome.

4. To the west, the wooded hills are underlain by the biotitic granitic rocks of the Okanogan dome.

Descend the knob by staying on the south side of the outcrops.

STOP 14B

About 20 m below the summit look at the well cleaved (dips about 45^{o}SE)

pink granitic rock that is cut into rhomboids by chloritic seams. The long axial planes of the rhomboids also dip about 45°SE. Note the other veinlets that cut the chloritic seams.

Descend by staying south of the outcrop and then traverse northward to its base.

STOP 14C

The pink chloritic rocks have a penetrative planar fabric that dips about 40°SE.

STOP 14D

Fifteen meters above the Swamp Creek Road is an almost unaltered fine-grained granitic rock.

STOP 14E

On the west side of the Swamp Creek Road is a very slabby and limonitic weathering outcrop of variably bleached, fine-grained granitic rock.

STOP 14F

On the east side of the Barrett Creek Road and variably brecciated and sheared Sanpoil volcanic rocks. Note the shear zone that dips about 40°SE. The shear zones and breccias seem to outline tectonic lenses.

Cross the fence at the south end of the outcrop and speculate on the fragmental texture on the weathered surface of the rocks.

Drive south on the Swamp Creek road.

4.6 Continue south at the junction of Swamp and Barrett Creek Roads. Sheared granitic rocks occur on the right hand (northwest) side of the road for the next mile.

4.65 Bold outcrops with nearly concoidal fractures on the northwestern side of the road are brecciated granitic rocks. Because volcanic rocks are on the southeastern side of the road, the road is on the trace of the fault.

5.2 STOP 15: Easterly dipping quartz veins

Turn left off the Swamp Creek road onto the remnant of the road to the Tom Thumb mine. Walk up the road 0.5 km to the first prospect pit. The total ascent is 200 feet.

Beyond the first switchback are poor outcrops of sheared and argillically altered rocks. The rocks in the third outcrop appear to have a relict volcanic texture.

In the dump below the old shaft (Rebate mine) are beautiful examples of banded, very fine-grained vein quartz typical of epithermal gold-silver

deposits. Much of the vein quartz is brecciated.

Contour northwesterly to the second prospect pit and observe the quartz vein greater than 1 m thick that dips 35°SE. Presumably this is the vein that was encountered in the shaft.

Climb northeasterly above the shaft and observe the fragmental texture in the Sanpoil volcanic rocks.

Continue southward on Swamp Creek road.

5.3 Sheared granitic rocks on the southeast side of the road for the next 0.5 miles.

5.7 Bear right at the junction of the Swamp Creek road with the paved road to the Knob Hill gold mine and Republic. Faults and veins in and around the mine dip northeasterly to northwesterly and are thought to be related to the Bacon Creek fault (Wright, 1949; Full and Grantham, 1968). Volcaniclastic rocks of the Tom Thumb member of the Klondike Mountain Formation occur for the next 0.6 miles up the paved road.

Sheared granitic rocks occur along the northwest side of the Swamp Creek road for the next mile.

5.9 About ¼ mile SE of here, Day Mines, Inc., drilled a hole that was collared about 200 feet above the valley floor. At 1353 feet this vertical hole encountered 16 feet of brecciated limestone before bottoming in 233 feet of brecciated pink, chloritic granitic rocks similar to Stops 14B and 14C. Thus, the dip of the Bacon Creek fault here is 45°SE or less.

8.3 Turn right (northwest) off the Swamp Creek road onto U.S.F.S. Road 386.

8.6 STOP 16: Bacon Creek fault zone (Cheney, 1980, p.479).

Parking is poor here; walk 150 m up mine road.

The phyllitic and quartzitic rocks at the mine presumably are Paleozoic. In the trench leading to the adit, the rocks have numerous shears dipping about 25°SE. In the trench, and especially in the open cut above, are generally angular blocks less than 2 m long of quartzite and fine-grained marble in the sheared phyllitic rocks. The trench and adit are inferred to be in the Bacon Creek fault zone.

Continue up USFS Road 386.

8.75 Poor outcrop of unaltered fine-grained equigranular granitic rock with closely spaced joints. This outcrop indicates that the Bacon Creek fault is between here and Stop 16.

8.9 Turn around and return to the Swamp Creek road.

9.5 Turn right (south) at the junction of U.S.F.S. Road with the Swamp Creek Road.

10.2 Turn right (west) at the junction with State Route 20.

10.5 On the south are outcrops of fine- to medium-grained greenstone, suggesting that the Bacon Creek fault is to the west. The outcrops for the next 5 miles are in hornblende-bearing granitic rocks, which are minor rock types within the slightly foliated biotitic quartz dioritic to quartz monzonitic plutons of the "Colville batholith."

13.0 Okanogan County line.

16.7 STOP 17: Sweat Creek Campground: Rest stop; good water at pump.

On the hill northeast of the campground are columnarly jointed, glassy black flow rocks typical of the upper portion of the Klondike Mountain formation (minimum age 41 m.y.).

Return to State Route 20 and continue westward past Wauconda Summit.

21.4 Wauconda Summit.

21.7 STOP 18: Contact between high-grade and low-grade metamorphic rocks.

Examine the presumed upper Paleozoic phyllite and fine-grained quartzite near the driveway and then walk westward down State Route 20. Do not cross the fence.

Approximately 100 m west of the quartzite, fine-grained marble, which is common in the phyllitic rocks, crops out north of the fence.

About 130 m west of the limestone, amphibolite occurs at the fence line; another 20 m to the west are outcrops of garnet-staurolite, two-mica schist. Speculate on the nature and orientation of the contact between the rocks of different metamorphic grade.

Continue westward on State Route 20.

24.9 Wauconda P.O., Store, and Restaurant: turn around and drive eastward on State Route 20.

28.1 Cross the contact between the garnet-staurolite, two-mica schist plus amphibolite and the lower grade rocks of Stop 18. Descending eastward from Wauconda Summit, we will again enter the higher grade rocks.

28.4 Wauconda Summit. The road traverses greenstones for the next ½ mile and then passes through gray phyllites.

29.3 Dumps of gray phyllite on the right (west) are part of the old Wauconda gold camp.

30.1 Sparse outcrops on the left (east) are predominantly amphibolite. Unfortunately the contact with the structurally overlying lower grade rocks is concealed.

31.0 A small porphyritic intrusion of unknown age with spectacular flow banding is on the right (south). Non-flow banded portions with columnar

jointing parallel the flow banding. Approximately 100 m to the east on the northern side of the road, porphyritic rocks intrude brecciated rocks (as will be seen at Stop 19).

31.9 STOP 19: brecciated granitic rocks

Medium-grained hornblende-bearing granitic rock is cut by numerous breccia dikelets and hair-line fractures. At the west end of the southern side of the road cut, an unbrecciated porphyritic dike similar to the rocks at Mile 31.0 cuts the brecciated granitic rocks. On the hillside to the north a breccia of predominantly hornblende-bearing granitic rock xtends to the base of the cliff (which is glassy, flow-banded flows of the Klondike Mtn. Formation). The breccia will be seen at Stop 20.

Similarly, but less intensely brecciated granitic rocks occur as much as 1.1 miles east and 3 miles northwest (south of the low-grade matamorphic rocks of Wauconda Summit). The metamorphic discontinuity of Stop 18 and at Mile 30.1, plus the brecciated granitic rocks, may define the trace of a low-angle fault.

Return to cars and continue eastward on State Route 20.

32.5 STOP 20: Tertiary breccia (Cheney, 1980, p.479).

Stop approximately 80 m west of Mile Post 293 and walk 0.2 miles east along the highway observing an unsorted and unstratified breccia. The clasts are predominantly hornblende-bearing granitic rock. The number of non-granitic clasts increases eastward in the road cut; one block of amphibolite is about 2 m long.

Cheney (1980) suggested that this breccia may be tectonic. However below the cliffs north of Stop 21 the breccia contains a sandy lens 7 m long and 0.3 m wide with layers 5 to 8 cm thick. Furthermore, no discrete shear zones have been found in the breccia.

If this breccia is sedimentary, it may be a previously unrecognized formation. It does not contain the black phyllitic chips that are so characteristic of the presumably basal Tertiary O'Brien Creek Sandstone. Nor does it contain volcanic clasts as would be expected if it were correlative with, or younger than, the Sanpoil volcanic rocks.

Return to cars and proceed eastward on State Route 20.

33.0 Sweat Creek Campground (Stop 17): rest stop and water.

36.8 Ferry County Line.

41.0 STOP 21: Tertiary rocks and fault zone of the Republic district.

Park at wide spot at the crest of the hill overlooking the road cut just west of Republic.

From the top of the hill eastward to the creek the basal O'Brien Creek Formation, with its characteristic black phyllite chips is intruded by

dikes of Scatter Creek rhyodacite. The dikes have feldspar phenocrysts (greater than 1 cm), which appear to be characteristic of the Scatter Creek. Both the O'Brien Creek and the Scatter Creek are faulted, pyritic, and hydrothermally altered. (Note the evidence of a former gold mine.)

Coarse pyroclastic rocks of the basal part of the Tom Thumb tuff member of the Klondike Mountain Formation crop out east of the creek. The argillic alteration of the Klondike Mtn. and O'Brien Creek Formation probably is due to weathering of the disseminated pyrite associated with gold mineralization.

The juxtaposition of the Klondike Mtn. Formation against the O'Brien Creek Formation without any intervening Sanpoil lavas implies that the creek is the trace of a fault. This fault was named the Republic fault by Muessig (1967), who described additional evidence for it.

Continue eastward on State Route 20.

41.6 At the blinker in downtown Republic turn right, staying on State Route 20.

42.0 Unaltered fine-grained tuff with leaf fossils crops out on the southern edge of town. This is the Tom Thumb tuff.

42.2 At the junction of State Routes 20 and 21 turn left (east) on 20. The brownish weathering knobs for the next 9 miles are the Sanpoil dacitic rocks.

44.8 At the junction of State Routes 20 and 21 bear right (east) on 20.

49.6 Walker Creek Road on left (north).

49.9 Outcrops for the next 1/2 mile are massive white sandstones interbedded with dark siltstones and shales of the O'Brien Creek Formation.

51.0 This valley marks the high-angle Sherman fault. The fault separates the Tertiary formations and low-grade metamorphic rocks on the west from the granitic rocks (that intrude the western limb of the Kettle dome) on the east. The granitic rocks commonly are chloritic adjacent to the fault.

57.2 STOP 22 (Sherman Pass): Kettle Crest batholith, GPPG, and pelitic rocks.

Sherman Pass (altitude 5575 feet) is the highest pass in Washington that is open to vehicular traffic in the winter.

On the south side of the road is the weakly foliated quartz dioritic border phase (note xenoliths and screens of metamorphic rocks) of the Tertiary Kettle Crest batholith intrusive into the metamorphic rocks of the Kettle dome.

Walk to the easternmost outcrops on the northern side of the pass to see GPPG (and compare with Stop 4). Walk westward on the bench above the highway to study the contact of GPPG with westerly dipping sillimanite-bearing biotitic gneisse and amphibolite. The steep dips here are unusual in the Kettle dome but are characteristic of its western margin.

Unfortunately the relative structural positions of the GPPG and the sillimanitic pelitic rocks cannot be determined here, but the map pattern to the north indicates that GPPG may be the structurally higher unit.

A 1/2 mile walk northward along the Kettle Crest trail starts in quartz diorite and passes into sillimanitic pelitic rocks with weakly radioactive, boudinaged pegmatites. At the power lines is a good view westward across the Republic structural low; the jagged peaks in the farthest distance are in the Pasayten Wilderness.

Return and continue eastward on State Route 20.

58.2 U.S.F.S. Recreation area (campground and scenic view).

59.2 Unmarked side road on the left within a curve.

59.7 STOP 23: Pegmatites

Park on the shoulder and walk 0.2 miles down the highway to boudinaged pegmatites with broken feldspars in sillimanite-bearing biotitic migmatites. These rocks are believed to be beneath the GPPG. Although the pegmatites are some of the most biotitic and radioactive in the dome, the quartz is not dark gray to black.

Continue eastward on State Route 20.

60.3 Huge biotite-poor pegmatite on left (north).

61.3 South Sherman Road on right (east).

61.7 Albian Hill Road on left (north).

63.3 GPPG in former stream channel on northern side of road.

69.8 S. Sherman Creek Road on right (south).

76.2 At the junction with the road to Inchelium bear left on State Route 20.

77.0 STOP 24: Eastern gneiss

An excellent exposure of eastern gneiss occurs in the road cut. Compare with GPPG of Stops 4 and 22 and with the eastern gneiss of Stops 1 and 8.

Return to cars and continue to Barney's Junction.

78.5 This black amphibolite is above the eastern gneiss. Note ductile deformation zones near north end of outcrop.

80.4 Barney's Junction (junction of State Route 20 and U.S. 395) is where the field trip commenced and now ends.

END OF FIELD TRIP

ACKNOWLEDGEMENT

We thank Mobil Oil Corporation for defraying the cost of drafting Figure 2.

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QUATERNARY GEOLOGY OF THE SPOKANE AREA

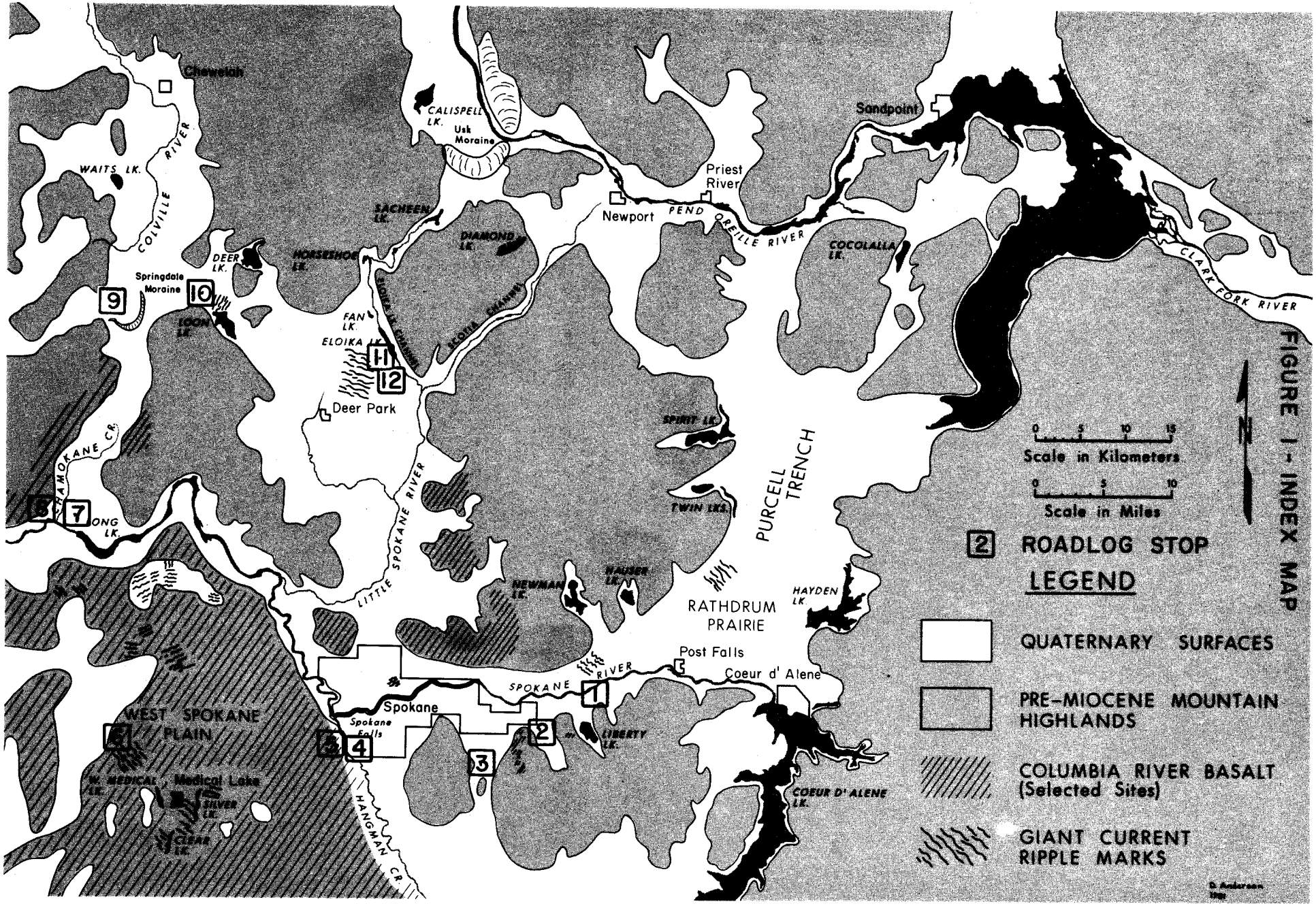
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INTRODUCTION

Repeated flooding from Glacial Lake Missoula produced many of the Quaternary geological features in Spokane and surrounding areas. This trip visits some sites in Spokane and then proceeds west to a giant current-ripple site on the west Spokane Plain in the northern channeled Scablands. It continues north across the Spokane River at Long Lake Dam to the late Wisconsin terminal moraine near Springdale and then east into the Little Spokane River Basin (a major floodway for Lake Missoula floods) where the trip terminates approximately 20 miles (32 km) north of Spokane (Fig. 1).

The broad Quaternary geologic picture of catastrophic flooding in northeastern Washington was first recognized by Bretz (1923) who elaborated more fully on his ideas in a series of papers, the last of which appeared in 1969 (Bretz, 1969). Reconnaissance studies relating catastrophic flooding and glaciation are summarized in Richmond and others (1965) and Conners (1976). More detailed studies begun by us in 1978 are modifying many earlier views concerning the timing, number, and areal extent of floods and glaciers (Kiver and others, 1979; Stradling and others, 1980; Kiver and Stradling, 1981; also unpublished work by Kiver and Stradling).

Glacial Lake Missoula was impounded near the mouth of the Clark Fork River by the Purcell Trench ice lobe (Fig. 1). Failure of the ice dam produced floodwaters that flowed through the Rathdrum reach into Spokane and/or through the Little Spokane River Basin into the Spokane River down-valley from Spokane (Fig. 2). Water impounded by ice near Grand Coulee, 45 miles (72 km) west of the area shown in Fig. 1, or by ice near the Spokane-Columbia River confluence, produced lakes whose surface elevations were at times at least 2,200 feet (671 m) in elevation and covered the Spokane area. Thus, many sediments in the Spokane valley and elsewhere were deposited by floods pouring into ice-dammed lakes.


Chewelah
WAITS LK.
COLVILLE RIVER
CALISPELL LK.
Usk Moraine
Sandpoint
Priest River
Newport
PEND OREILLE RIVER
SACHEEN LK.
DIAMOND LK.
DEER LK.
HORSESHOE LK.
COCOLALLA LK.
CLARK FORK RIVER
Springdale Moraine
9
10
LOON LK.
FAN LK.
ELOIKA LK.
SCHEUERMAN CHANNEL
REGINA CHANNEL
11
12
Deer Park
SPIRIT LK.
PURCELL TRENCH
SPOKANE CR.
5
7
ONG LK.
LITTLE SPOKANE RIVER
TWIN LKS.
NEWMAN LK.
HAUSER LK.
HAYDEN LK.
RATHDRUM PRAIRIE
Post Falls
Coeur d' Alene
SPOKANE RIVER
1
WEST SPOKANE PLAIN
Spokane
Spokane Falls
2
3
4
LIBERTY LK.
N. MEDICAL LK.
Medical Lake
SILVER LK.
CLEAR LK.
HANGMAN CR.
COEUR D' ALENE LK.
0 5 10 15
Scale in Kilometers
0 5 10
Scale in Miles
2 ROADLOG STOP
LEGEND
QUATERNARY SURFACES
PRE-MIOCENE MOUNTAIN HIGHLANDS
COLUMBIA RIVER BASALT (Selected Sites)
GIANT CURRENT RIPPLE MARKS
D. Anderson 1969
FIGURE 1 - INDEX MAP

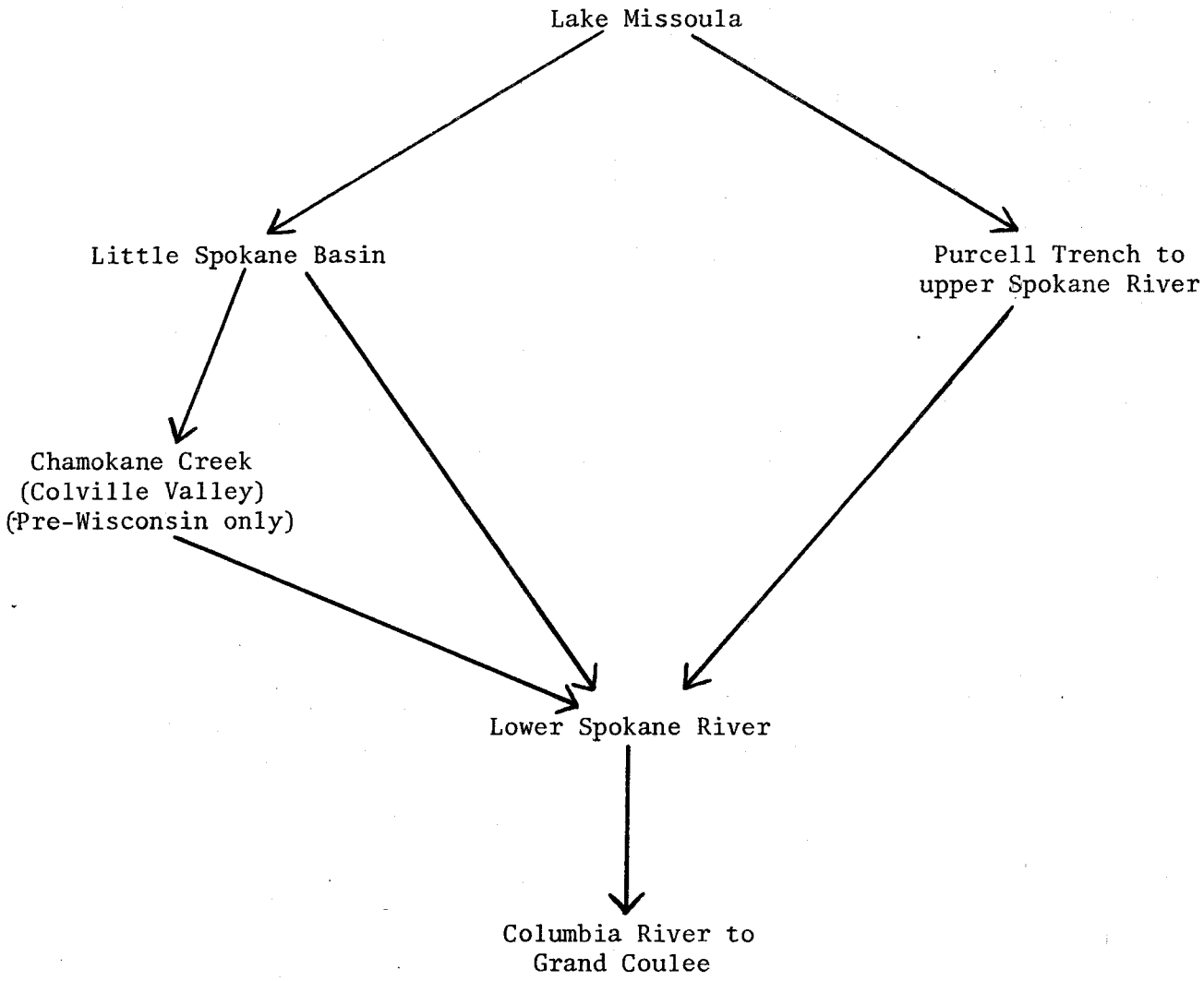


Figure 2. Generalized flow chart for Lake Missoula floodwaters in the northern Columbia Plateau

The generalized sequence of Quaternary events for northeastern Washington shown in Table 1 was determined partly by noting the relation of glacial and flood sediments to the extensive terrace system along the Columbia and Spokane rivers (Fig. 3) and partly from radiometric and tephrochronology dating (Stradling and Kiver, 1981; Kiver and Stradling, 1981, and unpublished data). The maximum recognizable extent of ice in the Colville Valley (Fig. 1) is at the Springdale terminal moraine. The moraine post-dates a large flood or floods that spilled into the Colville-Chamokane Valley through a pass near Loon Lake from the Little Spokane River Basin. Outwash terraces grade from the moraine to the 1700 feet (518 m) T_4 - T_5 terraces (Fig. 3) in the Spokane and Columbia River valleys. The presence of Mount St. Helens set "s" ash in an equivalent terrace just downstream from Grand Coulee Dam indicates that the terrace and its associated moraine are about 13,000 years old. The T_4 - T_5 terraces are in turn cut by lower and younger terraces containing flood sediments. Thus, catastrophic flooding younger than the Springdale moraine must have occurred.

TABLE 1. GENERALIZED SEQUENCE OF QUATERNARY EVENTS, NORTHEASTERN WASHINGTON

Age		Event
Holocene		Modern streams entrench their channels
	Unnamed glaciation	Catastrophic, valley-confined flood from Little Spokane River basin
Late Wisconsin	Springdale glaciation	Flood in Little Spokane River basin, backfloods into Spokane area, overland floods
	McCoy Lake glaciation	Last major flood down Purcell Trench, overland floods
Early Wisconsin or Pre-Wisconsin	Unnamed	Flood down Purcell Trench, overland floods
Pre-Wisconsin	Unnamed	Overland floods, Little Spokane and Chamokane Valleys flooded

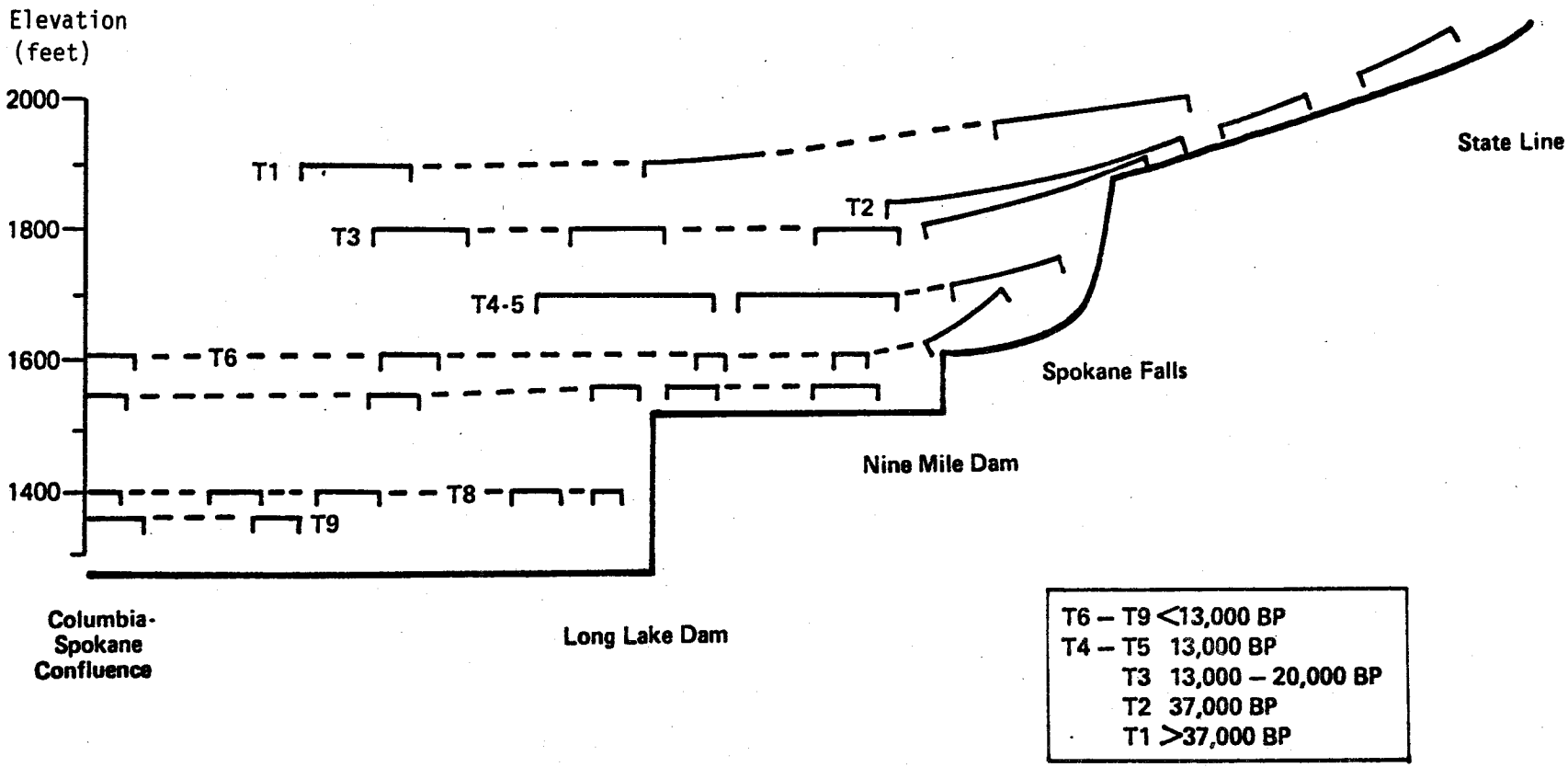


Figure 3. Spokane valley - GENERALIZED TERRACE PROFILES

The maximum recognizable ice extent in the Little Spokane River Basin is at Eloika Lake (Fig. 1) and is older than 32,610 ± 1,480 radiocarbon years. The moraine was post-dated and probably pre-dated by catastrophic floods coming through the same channel system. The Eloika Lake, Scotia, and other channels, as well as the Pend Oreille River Valley, were ice free in late Wisconsin time south of a terminal position near the present town of Jared (manuscript in preparation with Richard Waitt) along the Pend Oreille River. This allowed most of the late Wisconsin Lake Missoula floodwaters to flow westward and then south through the Horseshoe Lake, Scotia, and other channels into the Little Spokane River Basin and thence into the Spokane River downvalley from Spokane (Fig. 2). Thus, the Rathdrum reach was a less important floodway during late Wisconsin time except for floods contemporaneous with the McCoy Lake glaciation (Table 1).

Evidence for the maximum extent of ice in the Purcell Trench is sparse because of extensive erosion by catastrophic floods. Masses of sediment damming tributary valleys in Spokane were considered early Wisconsin (Bull Lake or pre-Fraser) ice margin deposits by Weis (1968) and Richmond and others (1965). Flint (1936; 1937) and Conners (1976) identified nearly all of these deposits as outwash. Their streamlined form, topographic position, and sedimentary structures are identical to the catastrophic-flood bars (Fig. 4) of unquestioned origin in the Channeled Scablands. Thus, these critical deposits were mapped by us as late Wisconsin flood deposits (Kiver and others, 1979).

Late Wisconsin floods were multiple, with at least thirteen distinct floods each separated by a few decades. The evidence for this occurs mostly along Latah (Hangman) Creek (Kiver and Stradling, 1981; and Rigby, 1981) and in the Little Spokane River Basin where varved and other lacustrine sediment sets are interbedded with flood deposits.

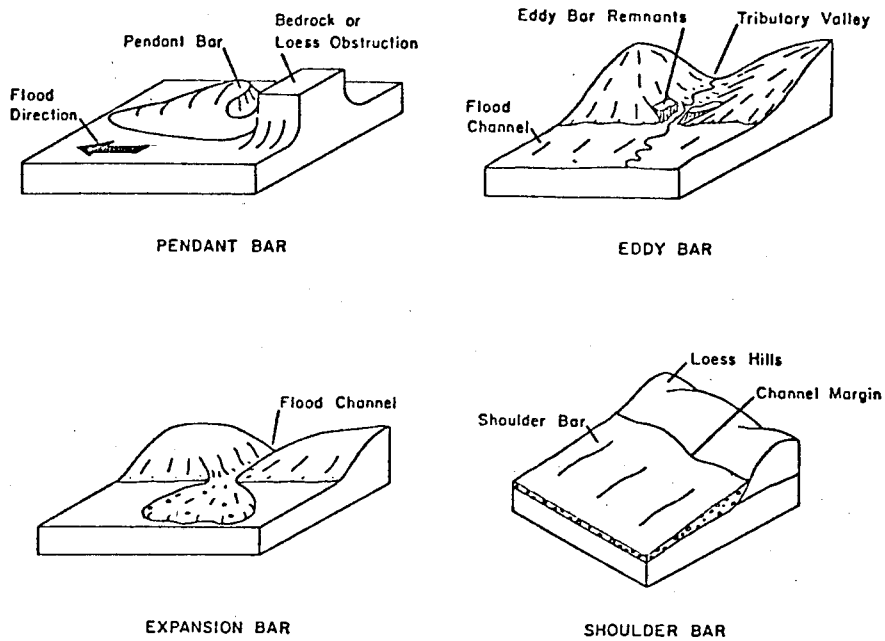


Figure 4. Catastrophic flood bar forms (after Rigby and others, 1979).

ROAD LOG

Cumulative Mileage

0.0 Spokane. Downtown Holiday Inn parking lot. Go north on Division, turn west on Second Avenue, and turn south on Browne. Enter east ramp for Interstate 90. Flows representing the Miocene Grande Ronde and Wanapum Basalt formations of the Columbia River Basalt Group along with basal and interbedded Latah Formation sediments are locally exposed along the edges of the Spokane Valley. They overlie Precambrian metasediments, high-grade metamorphic rocks, and Mesozoic granitic rocks.

5.3 Large gravel pit to the south is in Lake Missoula flood deposits of late Wisconsin age. A number of similar deep pits reach the top of the Spokane aquifer and are of great concern to local environmental groups and planners. Most of the Quaternary deposits in the Spokane Valley are late Wisconsin flood deposits of McCoy Lake age (Table 1). Some early Wisconsin flood deposits also occur locally.

7.6 Roadcuts through rounded flood-gravel deposits.

8.2 Topographic rise on south is a pendant bar trailing downvalley from Carlson Hill. The bar contains westerly-dipping foreset beds. Most of the Spokane Valley floor above Spokane Falls has flood gravels showing a distinct flood-streamed morphology including pendant and shoulder bars (Fig. 4). Some of these flood bars dam tributary valleys and form lakes along the Spokane Valley margin and were originally thought to be ice-margin deposits or kame deltas of early Wisconsin age (Flint, 1936, 1937; Weis, 1968; and Conners, 1976). Giant current-ripple trains in the Spokane Valley and Rathdrum Prairie to the east in Idaho provide strong evidence for catastrophic floods.

14.0 Saltese Flat pendant bar visible south of road.

15.3 Leave Freeway at exit 296. Turn right towards Liberty Lake. End of pendant bar on left by clubhouse and flood-scoured Precambrian rocks on right. Floodwaters piled up on the downvalley side of Liberty Lake tributary valley and were highly erosive as they swept back into the Spokane Valley.

16.3 Turn left onto Sprague Avenue. Road traversed sands deposited in an eddy during late Wisconsin catastrophic flooding.

18.4 Liberty Lake on right is held in by eddy-pendant bar complex of late Wisconsin age. Road ascends towards Cable Creek, a flood channel pass at 2,580 feet (787 m) elevation. Floodwaters were above the pass or about 700 feet (213 m) above the present valley floor.

20.2 Turn left onto Green Ridge drive.

21.6 STOP 1: On Kramer Hill. Turn left and park. General view of Spokane and its connection with the southern end of the Purcell Trench to the east. Floodwaters from Lake Missoula poured through the Purcell Trench and raced through the Spokane valley (Figs. 1 and 2) here at a mean velocity of 53.7 feet/sec (16.4 m/sec) and a maximum discharge of 7.52 x 10^8 cubic feet per second (2.1 x 10^7 cubic meters per second) (Baker, 1973; p. 30). Downstream glaciers blocked the Columbia and the Spokane Rivers at least once creating a 100 feet (31 m) or more deep lake in the Spokane area.

The top of Kramer Hill (2,785 feet; 849 m) is very near the high-water level of 2,620 feet (799 m) estimated for this area by Baker (1973). The elevation of the Spokane River in this reach is approximately 2,100 feet (640 m) and the glacial lake stood at about 2,200 feet (671 m) during at least some of late Wisconsin time.

Liberty Lake just below and to the west is held in by a prominent pendant-eddy bar at the mouth of the valley as is Newman Lake directly north from Kramer Hill and across the Spokane valley. Typically, pendant bars in these positions have a prominent downstream nose and a narrow valley about 450 feet (317 m) wide between the nose and flood-scoured west wall of the tributary valley.

Directly in front and just west of the Newman Lake pendant bar are giant current-ripples. Like most giant ripples, they are best seen on airphotos. Retrace route to Sprague Avenue.

26.9 Turn left on Liberty Lake Road. Proceed south past Liberty Lake on Molter Road and follow flood pass over Carlson Hill. Floodwaters during the McCoy Lake and older glaciations swept over the margins of the Spokane valley up to approximately 2,700 feet (823 m) elevation.

29.1 Turn right and descend toward Saltese Flats, a historically drained marsh.

30.1 Turn right onto Henry Road.

31.4 Pendant-eddy bar complex blocks the north end of Saltese Flat.

33.0 Turn left on Eigth Street. Route traverses top of pendant bar.

34.2 Turn left on Barker Road.

34.4 STOP 2: Th/U activity in caliche from road cut on left indicates a minimum age of 11,000 ± 2,000 years for the pendant bar sediments. Based on volcanic ash clasts and discrete ash beds found in flood deposits in the Channeled Scablands, as well as studies of terraces in

the Spokane and Columbia Rivers, most of the flood deposits in Spokane are believed to date from two glacial episodes; one 13,000 years ago and an earlier late Wisconsin advance (Stradling and Kiver, 1981; and unpublished data). Turn around and proceed north to Appleway Avenue.

35.6 Turn left on Appleway.

37.7 Turn left on Sullivan Road. Road ascends edge of large pendant bar that blocks the Mica and Opportunity spillover channels. These channels are the first spillovers leading south from the Spokane Valley into the Channeled Scablands beyond. The two channels join to the south and spilled over at 2,480 feet (756 m) near the town of Mica.

39.8 Turn right on 32nd Street. Route traverses eddy bar deposits behind pendant bar. The mica channel is east of the pre-Tertiary hill to the south and the Opportunity channel is on the west.

42.6 Flood-scoured pre-Tertiary rock on west side of tributary valley visible ahead.

43.7 Turn left onto Bowdish Road. Cross Dishman-Mica Road.

44.0 STOP 3: Chester sandpit. This pit lies at the entrance to the Opportunity spillover channel that leads to the Channeled Scablands. The last major spillover probably occurred during the McCoy Lake glaciation and deposited the lower massive sand unit. Overlying the sand are rhythmically-bedded, silt and fine-sand sediments similar to, and perhaps equivalent to, the Touchet Beds of southeastern Washington. If so, the upper unit would be about 13,000 years old. Low-energy conditions here were due mostly to the floodwaters backwashing up from the Little Spokane River and insufficient depth to allow a major spillover. Large boulders which were present on the surface until about 1970 are believed to have been ice-rafted to the site. Return to Dishman-Mica Road and proceed north to Sprague Avenue. Note again flood-scoured pre-Tertiary rock west of road where floodwaters piled up and then flowed rapidly away.

48.1 Turn left on Sprague Road.

49.1 Turn left on Park Road. Route climbs flank of pendant bar behind pre-Tertiary outcrop.

49.7 Turn right on 8th Avenue. Follow surface of pendant bar.

50.7 Descend point or nose of pendant bar.

51.1 Turn left on Carnahan Road by large gravel pit in flood deposits. Ascend Glenrose spillover channel.

52.1 Turn left on Glenrose Road.

52.7 Turn right on 29th Street. Road leads westward crossing Glenrose channel and rises onto a scabland surface at about 2,340 feet (713 m) elevation.

57.2 Turn left onto High Drive.

58.0 STOP 4: Park on right at turnout. Latah (Hangman) Creek Valley below is the only major tributary in Washington joining the Spokane River from the south. The valley follows a major northwest-trending lineament that extends about thirty-four miles (54 km) from Tekoa to the Spokane River and eighteen miles (29 km) along the Spokane River to Tumtum. Across the valley to the southeast is the Marshall Creek Valley that leads to Cheney and was a major spillover channel (2,300 feet; 701 m elevation) into the Channeled Scablands. Floodwater deposits were partially protected from erosion in the Latah Creek Valley and evidence for at least the last two major intervals of catastrophic flooding during the McCoy Lake (?) and Springdale Glaciations is preserved. At STOP 5 in the valley below is an excellent exposure of flood sediments and interbedded varves that presents strong evidence for multiple flooding during McCoy Lake (?) time. Continue south on High Drive.

59.4 Turn right on Hatch Road. Bear right and descend east wall on Latah Creek Valley. Route descends through mostly flood sediments. Prominent terrace remnants are crossed at 2,020 feet (616 m) and 1,960 feet (598 m) elevations.

61.7 Turn right on Route 195. Note exposures of rhythmically-bedded flood and lacustrine sediments on right.

63.3 Latah Formation interbed exposed on left; STOP 5 is massive outcrop on undercut bank east of Latah Creek.

64.0 STOP 5: Turn right onto gravel road beyond bridge. Park and cross Latah Creek if water level permits. The outcrop contains rhythmically-bedded flood sediments (McCoy Lake (?) age) interbedded with varved clays and silt and unconformably overlain by slackwater sediments probably equivalent to the 13,000 year old Touchet Beds of southeastern Washington. The thirteen cyclic sand units in the lower unit (James Rigby, personal communication) probably represent turbidity flows into the glacial lake occupying the Spokane Valley and its tributaries. Rip-up clasts of varved clays and silts commonly occur in the lower part of flow units and up to forty-two varves separate turbidite units. Turbidity current activity partially or completely removed and deformed many lacustrine interbeds. Coarse gravel layers (up to boulder-size clasts) near the top of the lower unit probably represent lowered glacial lake levels and resulting subaerial exposure that allowed higher enery conditions during some floods. The significance of the rhythmic slackwater deposits in the upper unit is unknown but Waitt (1980) believes that the Touchet Beds represent about forty multiple floods from Glacial Lake Missoula. Continue west on Route 195.

66.5 Take Wenatchee (Route 2) exit to I-90.

67.4 Landslide blocks of basalt developed on Latah interbeds on left. Note highway department has removed toe of slide to install pipeline.

68.1 Exit freeway and follow Route 2 signs.

69.3 Excellent columnar jointing developed in basalt flows along highway. Road follows thin and discontinuous cover of flood sediments overlain by a very thin layer of loess. This extensive, relatively flat area is known as the west Spokane Plains. A number of giant ripple trains are developed on this surface. Thin loess cover, limited soil development, and the presence of Mount St. Helens set "s" ash in the flood sediments suggests recent flood activity.

78.9 Descend into Deep Creek valley. Holocene dune sands on east wall contain interbedded Mazama ash.

80.6 Turn left on Espanola Road. Proceed south to McFarlane Road.

81.6 Turn right on McFarlane Road. Route follows flood surface into area of giant current ripples.

82.8 STOP 6: Gravel pit in giant current marks. Lower section contains crudely bedded sand and gravel overlain by a white calcereous layer. Unconformably overlaying the lower unit is a middle unit of gently dipping sand layers with an ash couplet of Mount St. Helens "s" (13,000 yrs B. P.) ash in finer layers near the top. A coarse flood gravel overlies the middle unit and a one meter thick loess layer caps the section. Return to gravel road and continue west.

83.9 Turn right on McEneany Road. Loess thickens dramatically. Numerous ice-rafted rocks of different lithologies overlie thick loess.

85.3 Turn left on Route 2. Route crosses thick loess with some flood channels cut into bedrock.

89.6 Enter Reardan.

90.2 Turn right on Route 231 toward Ford. Road crosses flood channel and enters loess-covered area.

95.8 Road descends through basalts of Spring Canyon.

99.2 Large (transverse) flood bar to the east deposited as floodwaters spilled over from the Channeled Scablands above.

100.6 Directly ahead is a very large pendant bar about four miles (6.4 km) long behind granite ridge to the east. The mouth of Chamokane Creek Valley (an extension of the Colville Valley) is notched in the north wall of the Spokane Valley directly ahead.

103.1 Coarse gravels exposed in the 1,700 feet (518 m) terrace.

103.8 Turn right toward Long Lake Dam. Lunch stop along river. Return to Route 231 and turn right.

105.5 Turn right (east) on paved road. Road follows 1,520 feet (463 m) flood terrace and rises onto the 1,700 feet (518 m) outwash-flood terrace.

106.5 STOP 7: Viewpoint by Long Lake Dam. The dam is about 190 feet (58 m) high. Long Lake reservoir is at a normal pool elevation of 1,531 feet (468 m) and the reservoir behind Little Falls below Long Lake Dam has a normal elevation of 1,357 feet (414 m). The prominent basalt cliff on the skyline due south of the dam is at an elevation of 2,360 feet (719 m). Chamokane Creek to the northwest is an underfit stream draining the large valley (not visible from this location) that leads northward to the Springdale moraine.

The Spokane River formerly followed a more northerly course but was pushed southward by outwash deposits from Chamokane Creek and by deposition of a very large flood bar behind the pre-Tertiary bedrock walls of Chamokane Creek 3.5 miles (5.6 km) upstream from here. The river cut through the Quaternary deposits and Miocene basalt and was superposed onto the underlying Cretaceous granite that provides the footings of Long Lake Dam. Across the river is a large north-trending granite ridge with flood sediments deposited downvalley from it in pendant bars. The main pendant bar is four miles (6.4 km) long and is best seen by examining topographic maps. Smaller pendant bars on top of the main bar are visible from here.

Scabland topography, including giant ripple trains, occur on top of the Miocene basalt (2,360 feet; 719 m elevation) forming the prominent south wall of the Spokane Valley here. Scabland features also occur on the north rim west of Long Lake Dam at about 2,400 feet (732 m) elevation.

Six prominent terrace levels occur in this general area. The highest level (Fig. 3, T_1) is about 1,940 feet (591 m) elevation that includes an unknown thickness of later flood deposits. Thus, the original terrace level is questionable but most likely correlates with early Wisconsin (37,000 yrs. B. P.) or McCoy Lake (13,000 to 20,000 yrs. B. P.) deposits. An 1,800 feet (549 m) terrace (Fig. 3, T_3) upstream and on the south side of the river correlates with terrace levels near McCoy Lake (fifteen miles (24 km) downvalley form west edge of Fig. 1) and in the Columbia River valley overlain by glacial till. This terrace and its associated till is believed to be 13,000 to 20,000 years old.

The dominant terraces here are the approximately 13,000 year old 1,720 feet (524 m) and 1,700 feet (518 m) paired terraces (T_4, T_5, Fig. 3). The viewpoint parking lot is on the 1,700 feet (518 m) terrace. The terrace contains glacial-lacustrine sediments and outwash traceable up Chamokane Creek to the Springdale Moraine and is overlain by distinct

bars and sediments derived from floodwaters emerging from the Little Spokane River valley (Fig. 1). The T_4-T_5 terrace and lower flood terraces in the Little Spokane River truncate higher flood terraces along the main Spokane River Valley up valley from here, indicating that major late floods used the Little Spokane basin floodpath rather than the Rathdrum-Spokane route in very late Wisconsin time.

The 1,520 feet (463 m) terrace that the road followed before ascending to the 1,700 feet (518 m) terrace by the parking area is overlain by shoulder and pendant bars. These later floods did not seriousl, erode older landforms suggesting that they were probably run-of-the-river rather than overland floods.

The lowest nearby terrace is the 1,420 feet (433 m) lacustrine terrace locally overlain by flood sediments but lacking distinct flood bars here. The terrace continues underneath the waters of Long Lake and terminates about three miles (4.8 km) upstream. Thus, the upper end of the glacial lake in which this terrace formed was nearby. Return to Route 231.

107.5 Turn left onto Route 231.

107.6 Turn right onto gravel road.

108.5 Cross Chamokane Creek, enter Spokane Indian Reservation land, and park near top of the hill.

108.6 STOP 8: Chamokane Creek exposure. Roadcut extends from about 1,370 feet (418 m) at creek level to 1,520 feet (463 m) at top of terrace. Lower, varved sediments overlain by varved clay with interbedded sand units which are overlain by sand and gravel layers of glacial-fluviatile and catastrophic flood origin (Fig. 5). Continue along gravel road.

108.8 Turn right on Martha Boardman road.

109.8 Road is on 1,720 feet (524 m) elevation outwash terrace. Road proceeds north up Chamokane Creek valley (Walker Prairie) on Spokane Indian Reservation land.

110.9 Note the double terrace here probably related to two glacial advances or ice positions farther upvalley.

111.8 Sand dunes visible at 10:00 on higher terrace remnant.

113.2 Turn right on Ford highway.

114.1 Turn left on gravel road. The road follows the higher outwash terrace northward. Walker Prairie has extensive landslides on its margins where Yakima Basalt overlies the Latah Formation. Some of the landslides moved two miles away from the present edge of the basalt plateau. The basalt plateau to the west is capped by very old glaciolacustrine

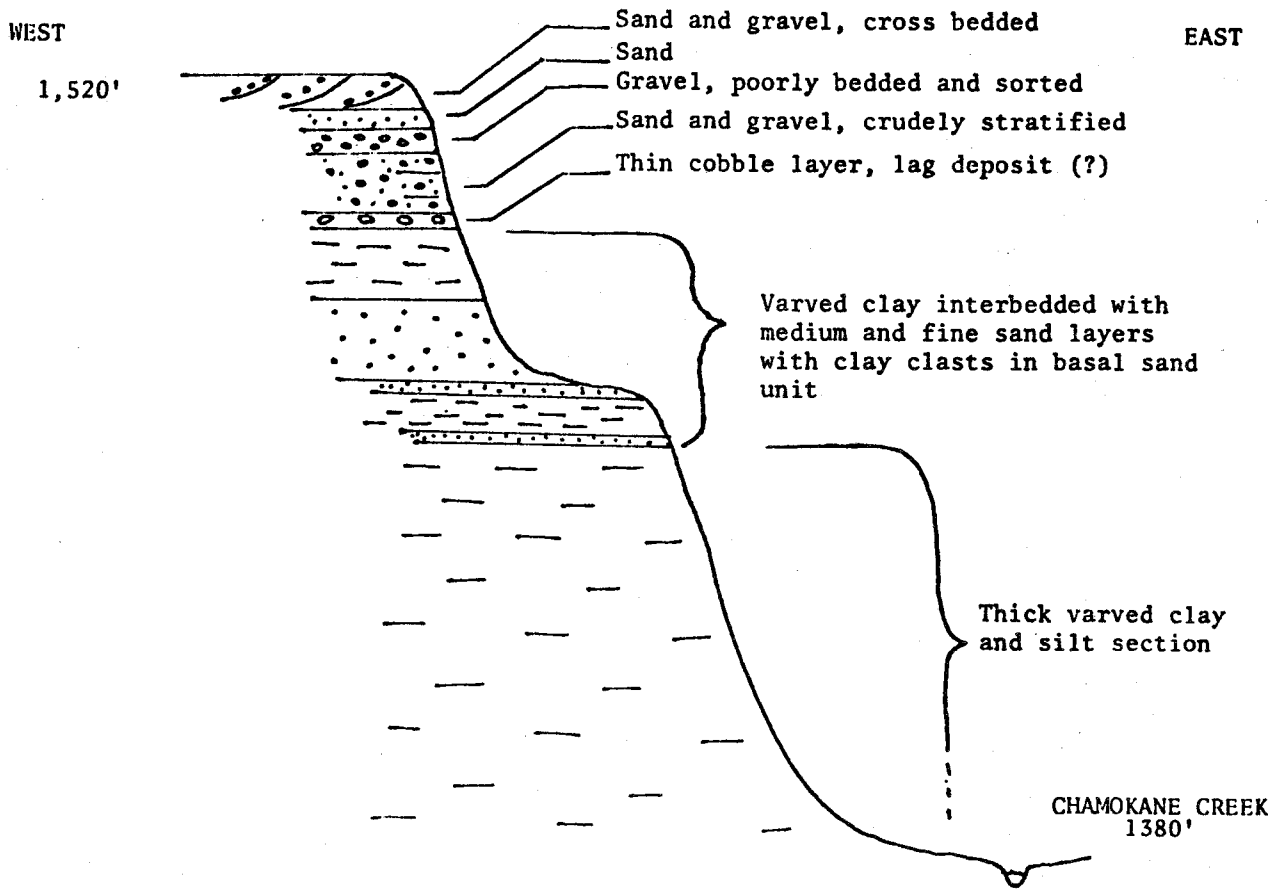


Figure 5. Diagrammatic cross section of Chamokane Creek exposure in SE ¼ sec. 10, T. 27 N., R. 39 E. (mile 108.6).

(?) and glaciofluviatile (?) deposits at elevations between 2,460 - 2,500 feet (750 - 762 m).

123.1 Turn left on Route 231 towards Springdale. Road climbs from lower fluviatile terrace along Chamokane Creek onto outwash terrace. The outwash terrace elevation increases from 2,000 feet (610 m) to 2,060 feet (628 m) by Springdale.

127.0 Late Wisconsin Springdale moraine marking the terminus of the Colville ice lobe on left. No evidence of glaciation south of this moraine exists in Chamokane valley unless the old deposits on the high basalt plateau west of Chamokane Creek contain outwash or ice-contact deposits.

127.4 Enter Springdale, bear left at intersection.

128.6 Turn left on Hunters Road. Moraine straight ahead. Road follows edge of moraine and basalt cliff to south.

130.3 Equinox Food Exchange.

131.1 Narrow canyon created by position of late Wisconsin moraine.

131.3 View of Camas Valley. A large lake was created by the ice dam in the narrow canyon farther back along the road.

132.2 STOP 9: Turn right into sand and gravel pit. These sediments were probably deposited as a kame delta in a lake dammed by Springdale-age glaciers. The top of the hill containing these sediments is at an elevation of 2,360 feet (720 m), compared to the 2,240 feet (683 m) elevation at the top of the moraine blocking the canyon. Thus, the ice must have extended at least 80 feet (24 m) higher than the moraine. The valley floor is underlain by late Wisconsin glaciolacustrine sediments.

132.4 Return to highway and proceed back to Springdale.

138.6 Turn left on east edge of town on Route 292 towards Deer Lake. This old flood channel follows Sheep Creek toward Loon Lake and the Little Spokane River Basin. The mouth of Sheep Creek by Springdale is blocked by a low late Wisconsin lateral moraine that post-dates the flood through Sheep Creek channel. Pre-Tertiary bedrock along the suspected flood route is very deeply weathered suggesting that catastrophic flooding probably occurred during pre-Wisconsin time. An outwash terrace in the Sheep Creek channel cuts a higher flood terrace and is traceable to the east edge of the Colville lobe near Deer Lake.

139.5 Poorly-bedded sand and gravel in roadcut is part of the 2,400 feet (732 m) flood terrace along Sheep Creek. This terrace is traceable to Loon Lake and northward where it dams the west side of Deer Lake.

141.5 Road follows a giant-current-marked surface on the 2,400 feet (732 m) terrace downvalley from the deeply-weathered pre-Tertiary knob ahead.

142.4 Road descends through glaciofluviatile deposits and modern alluvium. Flood terrace and road rise to 2,420 feet (738 m) level ahead.

142.9 Turn right onto secondary road (Shore Acres Road).

143.3 STOP 10: Turn left into gravel pit in flood terrace just west of Loon Lake. Floodwaters from the Little Spokane Basin flowed westward through a channel north of Loon Lake Mountain, into the Sheep Creek valley, and then into Chamokane valley by Springdale. Highly indurated, calcium-cemented lower gravels are probably pre-Wisconsin in age. Rhythmic sedimentation characterized by finer silt and sand lenses suggests multiple flooding or surges of floodwater during a single flood. A nearby gravel pit by the railroad bridge crossing Route 292 exposes at least two clay units interbedded in flood gravels indicating multiple flooding. The lower unit contains at least twenty-five varves suggesting that at least that number of years separated two catastrophic floods. Other sites associated with the high flood surface (Deer Park surface) in the Little Spokane basin show similar sedimentologic evidence. The upper limit of the glacial lake that occupied the Little Spokane basin must exceed 2,400 feet (732 m) which is the highest known elevation of lacustrine sediments in the Little Spokane basin. Return to gravel road and turn left.

144.3 Intersection with Route 292. Turn right toward the town of Loon Lake. Route leads across giant current marks and into the unnamed channel north of Loon Lake Mountain that was a major spillway for older Little Spokane Basin floods.

145.3 Intersection with Route 395. Continue straight ahead.

145.6 Mazama ash (?) in gravel pit to right. Continue east through major channel connecting Loon Lake with the Little Spokane Basin. Pre-Tertiary rocks along the channel are very deeply weathered.

148.9 Intersection with Deer Lake Road; bear right. Gravel pit to south has flood gravels displaying westerly inclined crossbeds.

149.4 Deeply weathered, highly indurated gravels.

150.1 Clay pits in deeply weathered bedrock.

151.3 Road leads onto high surface in Little Spokane Basin (elev. 2,358 feet; 719 m).

152.7 Road on left leads to Porcupine Pass, a high (2,760 feet; 841 m) flood and perhaps meltwater pass from the Horseshoe Lake area in the Eloika lake channel to the Little Spokane River Basin. Striated pebbles and cobbles occur in the Porcupine Pass channel.

153.2 Turn left onto Davis Road.

154.3 Turn right on Sherman Road. The road leads south along the truncated edge of an expansion bar (Fig. 4). Glaciers from the Pend Oreille Valley to the north and floodwaters from Lake Missoula flowed through the Eloika Lake channel into the Little Spokane basin. Low ridges on the surface to the east mey be early or pre-Wisconsin moraines overlain by flood deposits. Extensive areas between and beyond the suspected moraines are covered by giant current ripples.

156.0 Turn left onto Bridges Road toward Eloika Lake. Road leads across giant current ripples (elev. 2,228 feet; 679 m).

158.8 STOP 11: Gravel pit on left (Fig. 6). Massive sand overlain by sand containing two units of varved sediments. Organic material collected from the coarse flood gravel near the top of the section has not yet been dated but is probably early Wisconsin in age.

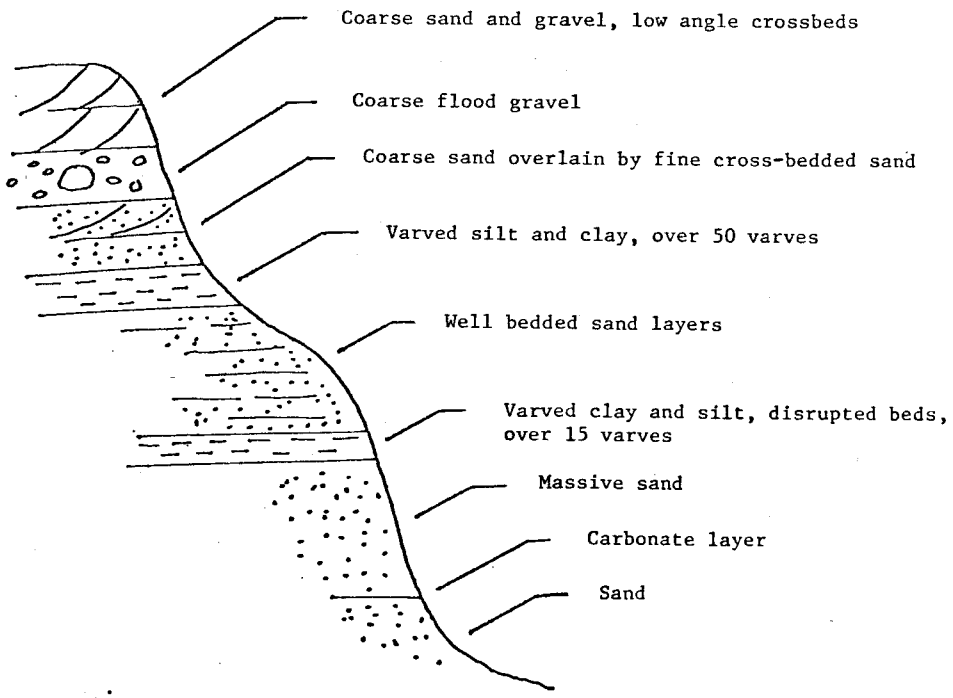


Figure 6. Diagrammatic section of 30' (10m) exposure near Eloika Lake in SE ¼, sec. 8, T. 29 N., R. 43 E (mile 158.8)

159.0 Eloika Lake is rimmed by an early Wisconsin or older terminal moraine eroded by subsequent floods (see p.31).

160.4 Note large erratic boulders on surface.

161.6 Intersection, Route 2. Turn left. Road climbs on top of large pendant-expansion bar. Extremely large boulders on both sides of the road are only on surface of the flood bar.

162.6 STOP 12: Turn right into large gravel pit and park by locked gate. Note very large granite erratics on undisturbed surfaces surrounding pit and large boulders occasionally strewn on pit floor. In the back part of the pit is a "super" erratic about 15 feet (5 m) long.

The large erratics are probably of glacial origin and reworked by floodwaters. Floodwaters from the Eloika Lake channel and those from Diamond Lake joined a few miles north of here. Some of the floodwaters turned north by Sacheen Lake and surged down the ice-free parts of the Pend Oreille valley at least to an area near Ione where organic material in flood deposits is dated as 41,900 ± 3,300 years old (W.S.U. 2488).

The last major floods through the Little Spokane Basin probably used the topographically lower Scotia Channel (Fig. 1) a few miles east of here. The channel follows the main branch of the Little Spokane River which is cut through a mountainous area into the Pend Oreille valley near Newport. The final cutting of this transverse channel combined with ice-free conditions near Newport subsequently diverted most of the west-flowing floodwaters through the Scotia channel.

Proceed south on Route 2 to Spokane.

End of Road Log

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GEOLOGY OF THE STEPTOES AND PALOUSE HILLS OF EASTERN WASHINGTON, A ROADLOG OF THE AREA SOUTH OF SPOKANE, WASHINGTON

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INTRODUCTION

This roadlog is a circuit through the steptoes and Palouse Hills of eastern Washington (Figure 1) and is designed for a self-guided trip. The stratigraphic section for the area is illustrated in Figure 2.

The steptoes of eastern Washington are the peaks of a mountain range that was formed in Late Cretaceous and Cenozoic time and then nearly buried by the Miocene Columbia River basalts. Individual steptoes are composed of metasedimentary rocks of the Belt Supergroup of Late Precambrian age. The Columbia River basalts and younger sediments of Pleistocene and Recent age mask the structure of the underlying metasedimentary rocks. Although the area has been mapped by Griggs (1973a), briefly described in an abstract by Griggs (1973b), and discussed in a paper by Savage (1973) no detailed sedimentologic studies have been made of the eastern Washington Belt Supergroup metasediments.

ROAD LOG

Cumulative Mileage

0.0 Starting Point; U.S. Hwy 195 at the south side junction of the two off ramps from U.S. I-90 on the west of Spokane. Proceed south on U.S. Hwy. 195.

1.0 Grande Ronde basalt exposed in road cut on right. Priest Rapids basalt forms rim of Hangman Creek Valley.

1.7 Railroad overpass.

2.2 Clastic deposits, sands, gravels and varves of the Missoula Floods exposed in stream cut along Hangman Creek to left.

2.6. Large cutbank along Hangman Creek to the left. The lower 2/3 of the exposure consists of repeated sequences of varves and sands and gravels of the Missoula Floods. There are up to 25 varves in individual sequences. Many of the sands and gravels channel into underlying deposits and contain ripup clasts of the varves. The overlying 1/3 of the exposure contains coarse cobbles in dark-colored gravels and sands interbedded with light-colored fine-grained sands and silts of the Missoula Floods (17,500 to 13,000 B.P.).

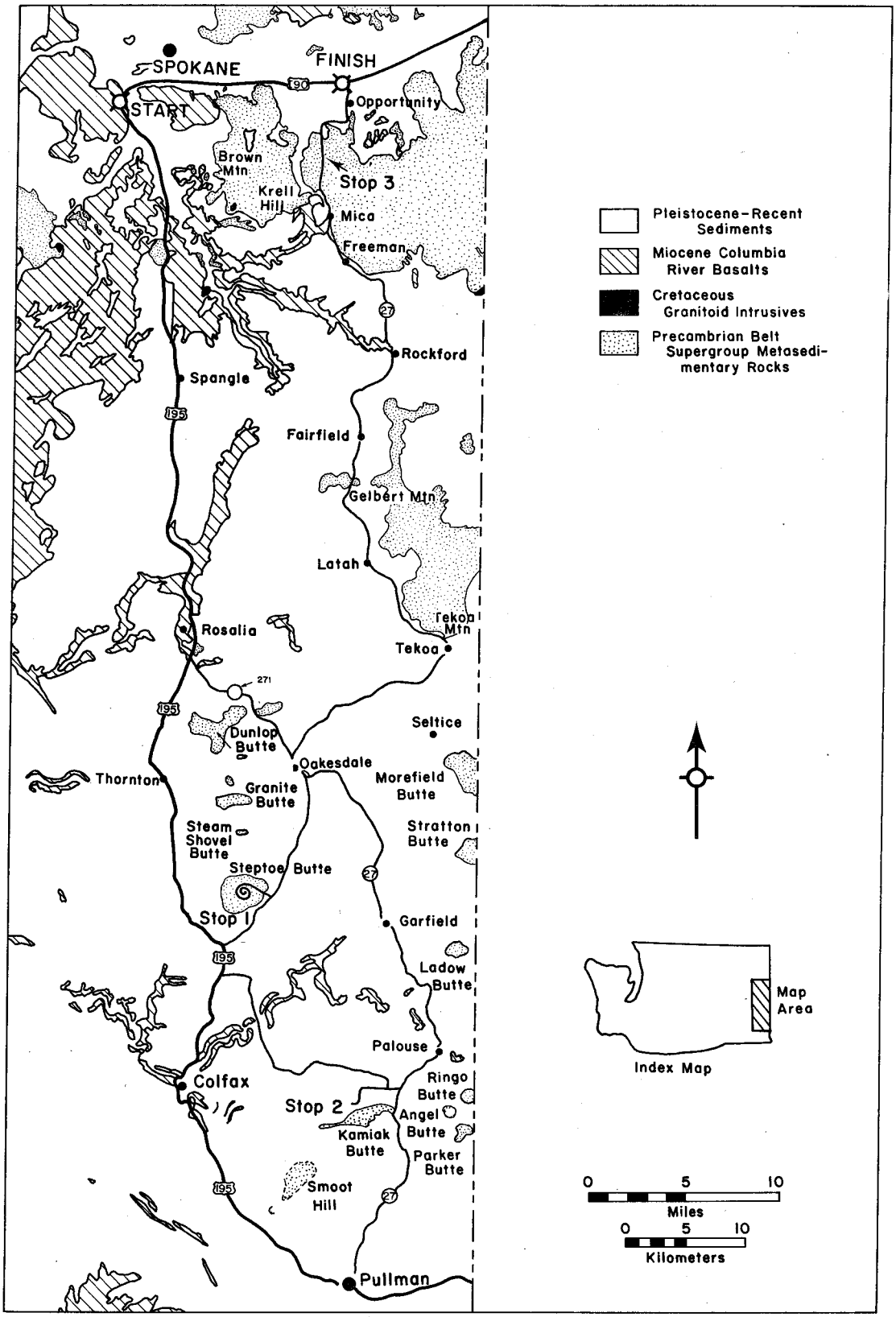


Figure 1. Generalized geologic and highway map showing field trip stops. Geology compiled from Griggs (1973b), Kiver and others (1979), Swanson and others (1979) and Webster (1979).

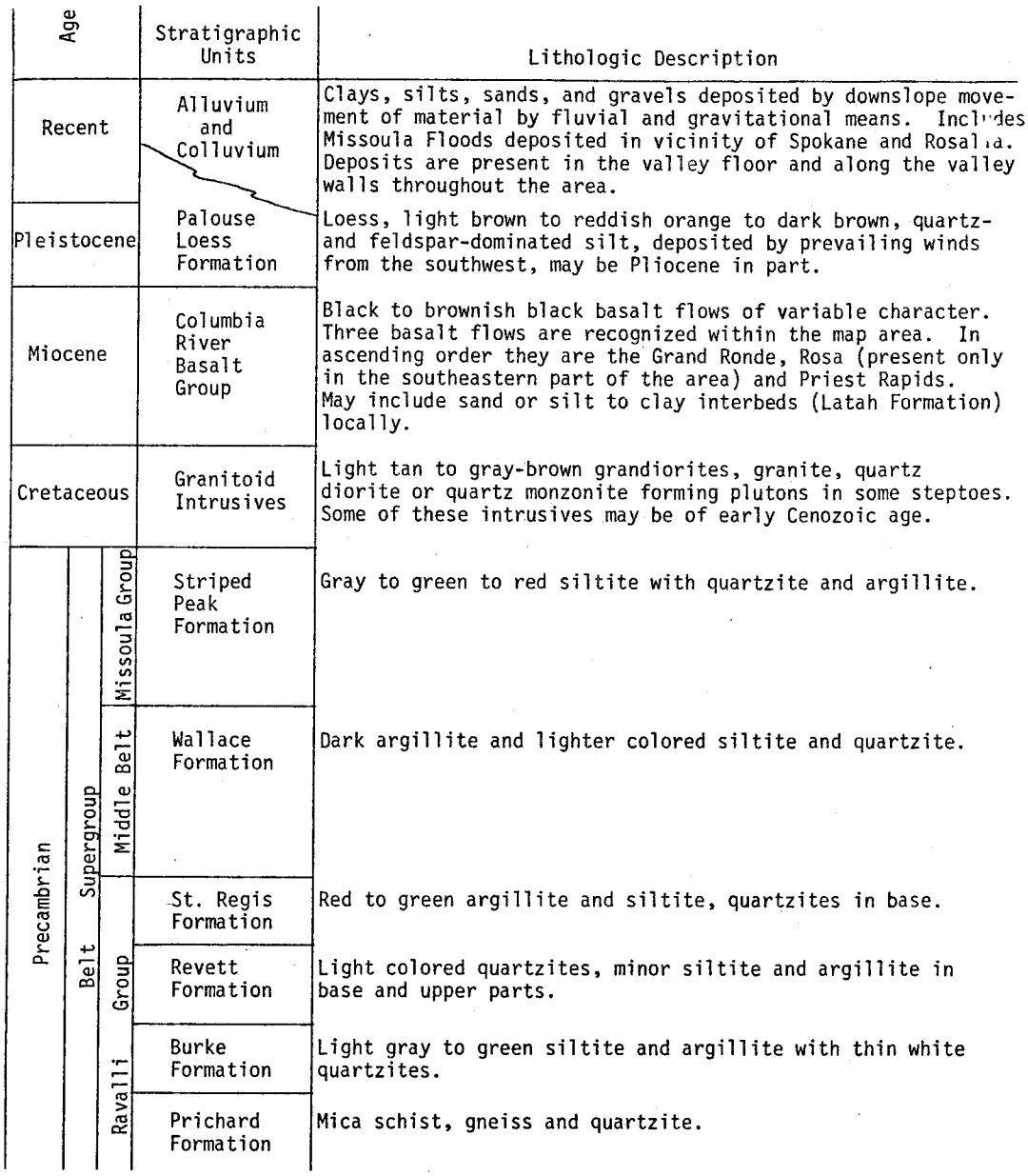


Figure 2. Generalized geologic section of the Steptoe-Butte area south of Spokane

4.2 Missoula Floods sequence of lake varves and sands and gravels visible in stream cuts to the left for the next one-half mile.

4.7 Grande Ronde basalt and interbed of sand (Latah Formation) in road cut to right.

5.5 Leaving Hangman Creek Valley as the highway proceeds up Mullen Hill. The old Mullen Road, which extended from Portland, Oregon to western Montana serving the mining camps of western Montana and northern Idaho, dropped into the Spokane area near this point. Traces of the roadway and cultural features are clearly visible in parts of the Scablands of eastern and central Washington to the west.

6.6 Hangman Creek Valley diverging to the left at 10:00; Krell Hill (Prichard Formation, Belt Supergroup) with the broadcasting towers on it at 9:00.

6.8 Priest Rapids basalt in road cuts, both sides of highway.

9.1 Shasta Mountain (Prichard Formation) visible at 9:00.

9.3 Quartzite and weathered phyllites and argillites of the Prichard Formation in road cut to right.

10.0 Top of Priest Rapids basalt; elevation approximately 2,465 feet. Mima mounds are visible at various places among the conifers for the next 3.5 miles.

11.3 Quarry in Priest Rapids basalt at 9:00.

13.7 Southern limit of the extensive conifer cover. South of here conifers will be found in patches, generally on the north-facing slopes or in deeper stream valleys cut into the Columbia River basalts. On several geologic maps the tree line observed here is incorrectly shown as the southern extent of the Spokane lobe of the Pleistocene glaciation. The true southern extent of the glacial front is nearly 30 miles north of Spokane. As you continue across the overpass note the Mima mounds on both sides of the road.

15.0 Junction, Spangle Road, continue south on U.S. 195.

For the next 35 miles we will travel across loess of the Palouse Formation overlying Columbia River basalts and Recent alluvial sediments of local drainages. At higher elevations mountains and buttes composed of Belt Supergroup strata will be fleetingly visible in the distance to the east. This area received between 2.5 and 7.5 cm of ash from the May 18, 1980 eruption of Mount St. Helens. Pockets of the gray ash are visible at numerous places along the trip, especially in the bar-ditch.

Agricultural products from this area include wheat, barley, peas, lentils, rape, mustard, sun-flowers, grass seed, alfalfa, and hay.

24.0 Plaza turnoff. Continue south on U.S. 195.

25.6 Tekoa Mountain (Striped Peak Formation, Belt Supergroup) visible in distance at 11:00.

25.9 Priest Rapids basalt in road cuts on both sides of road.

26.5 Mima mounds in the sparse conifer cover at 9:30.

27.6 Crossing North Pine Creek, Recent alluvium. Old highway U.S. 195 follows the bluff to the left. Pillow basalts (mottled orange and brown) of the Priest Rapids flow overlie a sand interbed immediately above the road level. Grande Ronde basalts are present beneath the modern alluvium and base of the valley walls.

29.7 Cross Pine Creek.

30.0 Rosalia turnoff, continue south on U.S. 195.

30.7 Priest Rapids basalt in road cut to left.

31.3 Railroad overpass. Quartzite, schist and gneiss of the Prichard Formation are exposed in the railroad cut to the left.

31.6 Bear right leaving U.S. 195 on off ramp.

31.9 Stop, turn left on Washington State Hwy 271 toward Oakesdale.

33.8 The rounded loess-covered knob at 12:00 (elevation 2,883 feet) probably consists of metasedimentary rocks of the Prichard or possibly Striped Peak Formation. These knobs project above the basalt surface (an elevation of approximately 2,500 feet in this area) but lack exposures of the bedrock. Many such knobs or hills will be observed throughout the remainder of this trip.

35.4 Quarry in Priest Rapids basalt to left.

35.6 Railroad crossing; quarry in Priest Rapids basalt to left.

37.4 Granite Butte formed of quartzites, probably belonging to the Revett or Burke Formations at 3:00 with the top of Steptoe Butte visible in the distance.

40.3 Junction, bear right onto Washington State Hwy 27 into Oakesdale.

40.6 Entering Oakesdale; railroad crossing just ahead.

40.8 Stop, turn left, continuing on Washington State Hwy 27.

41.1 Railroad crossing.

41.5 Junction, bear right onto Steptoe Butte State Park road; railroad crossing.

43.8 Steptoe Butte visible at 12:30.

48.6 Turn right toward Steptoe Butte.

49.5 Entering Steptoe Butte State Park.

50.4 Revett Formation, quartzite, exposed in road cut to left.

50.9 Quarry in Revett Formation, quartzite, to left. Poor to excellent exposures of the quartzites are present in the road cut from here to the summit of the butte.

52.8 STOP 1: Summit, Steptoe Butte.

Steptoe Butte is the type steptoe "an island-like area in a lava flow" as defined by Russell (1901, p. 23). The butte has long been a landmark for travelers and residents of the area. It provides an excellent view of other buttes of the area. Proceeding in a clockwise direction commencing from the north (as though you were facing the removed monument plaque) the following buttes are recognizable: Steam Shovel Butte (foreground), Granite Butte just beyond, Krell Hill (broadcasting towers, in distance); Shasta Butte at 12:45; Tekoa Mountain at 1:15; Plummer Butte (sharp peak in distance) at 1:30; Mission Mountain at 2:00-3:00; Ladow Butte at 3:20; Moscow Mountain in the distance with Ringo, Parker and Angel Buttes in the foreground at 4:00; Kamiak Butte with Smoot Hill to right end at 5:00. The area to the east is the heart of the Palouse Hills. On a clear day the Blue Mountains are visible on the skyline to the south, 6:00-7:00.

In general, in the steptoes the northern buttes are composed of older Belt metasedimentary rocks and southern buttes are younger Belt metasedimentary rocks. Younger intrusives are present in several of the buttes (i.e. Smoot Hill).

Steptoe Butte is muscovite-bearing metaquartzite of the Revett Formation, Ravalli Group. The metaquartzite is generally reddish brown but may be white or tan; grain size ranges from 0.5 mm to 3.0 mm. Accessory minerals are muscovite, ranging from 1% to 10% and trace amounts of magnetite and limonite. Thin sections reveal that the quartz grains typically have interlocking sutured boundaries and undulose extinction. Overgrowths are present but not common on subangular to subrounded original grain shapes. Relict crossbedding is present in roadside exposure on the north and east sides of the butte. White to clear quartz veins, up to 8 cm in width, cut the metaquartzite throughout the butte area. Structurally the butte is a southwesterly plunging faulted syncline.

Steptoe Butte is named for Lt. Col. E.G. Steptoe who, with 159 men under his command, was attacked by a large band of Spokane, Palouse and Couer d'Alene Indians near Rosalia on May 17, 1858. In defeat he escaped to the southeast through the present site of Oakesdale turning south to the Snake River (Steptoe Canyon south of Colton, Washington) where the Wawawai Indians helped him across the Snake to elude the pursuing victors.

On this butte Cashup Davis built a hotel as a tourist attraction in the late 1800's. He operated the hotel a few years until his death after which it was abandoned and ultimately burned.

Return to Steptoe Butte State Park Road.

57.0 Turn right onto Steptoe Butte State Park Road toward Colfax.

58.5 Quarry in Priest Rapids basalt to left.

60.8 Bear left at Y.

62.1 Junction, turn left onto U.S. 195 toward Colfax.

62.5 Junction, turn left onto Dry Creek road.

63.2 Quarry in Priest Rapids basalt to left.

64.1 Turn right onto Glenwood road.

66.3 Begin descent into the North Fork Canyon of the Palouse River; numerous exposures of the Columbia River basalts will be visible in road cuts and along the canyon walls. Here three basalts are recognized, the Grande Ronde, Rosa and Preist Rapids flows, in ascending order. The Rosa flow dies out between here and Rosalia where the Priest Rapids flow overlies the interbed which in turn overlies the Grande Ronde basalt.

66.8 Railroad crossing.

67.1 Begin ascent out of canyon.

68.1 Junction, stop, turn left onto Washington State Hwy 272.

68.2 Bear right at Y toward Kamiak State Park.

68.5 Quarry in Priest Rapids basalt to left.

69.7 Quarry in Priest Rapids basalt to left.

70.4 Tree cover ridge at 12:00 is Kamiak Butte.

71.0 Priest Rapids basalt exposure in barditch to left.

72.0 Hills surrounding this valley project above the basalt surface but are covered with loess. They are probably formed of Belt metasedimentary rocks. The loess in this area may attain thicknesses in excess of 150 feet.

73.4 At 12:00 are Ringo, Angel and Parker Buttes with Moscow Mountain in the background; Kamiak Butte at 2:00.

75.3 Turn, hard right, onto Fugate road.

76.0 Turn left onto Kamiak Butte Park road.

76.6 Blocks of Revett Formation quartzite in road cut to left.

76.8 STOP 2: Parking lot, Kamiak Butte State Park.

Kamiak Butte consists of a fault block of quartzites questionably assigned to the Revett Formation. The block is tilted to the south; it strikes a few degrees north of east and dips 24° south on the eastern end and 56° south on the west end.

Kamiak Butte is primarily quartzite which is most commonly white but may be light gray to bluish or pink to light brown. This quartzite is fine- to course-grained, thickly bedded, hard, dense to friable, and contains small-scale crossbeds locally. Ubiquitous throughout the butte are lenses and layers of metaconglomerate. These metaconglomerates are quite different in the various exposures. For example, in the eastern end of the butte (southerly slope), about 150 meters southwest of the end of the trail, two white to light brown, poorly-sorted, friable metaconglomerates can be observed. A few meters west of the westernmost and tallest television broadcasting tower on the butte a brown, well-sorted, hard metaconglomerate bed can be traced along strike down to the western side of the butte. In this western-most exposure the metaconglomerate has a glossy surface with well rounded moderately-sorted quartz pebbles.

Close to the highest peak in the butte, a mica schist bed containing small crystals of magnetite is present.

The best exposures are in the north slope of the butte, especially across the western end (Fig. 3). A vertical fault paralleling the strike of the beds (N75E) probably occurs along the northern side of the butte. Several rockslides are believed to be present beneath the forest cover on the north side of the butte.

Savage (1973) believes that Kamiak Butte as well as the other buttes in the adjacent area are fault blocks of the Ravalli Group metasediments. He also postulates a shallow water, shoreline-intratidal environment. The authors' preliminary observations agree with Savage's interpretation of the sedimentary environment. However, the age of the quartzites at Kamiak Butte may be early Paleozoic.

Look south from the summit view area. To the southeast Moscow Mountain is in the distance, with Paradise Ridge and Bald Butte to the right. The Palouse Hills are in the foreground. Some of the buildings of the University of Idaho at Moscow and Washington State University at Pullman are visible in front of Paradise Ridge and Bald Butte. Bald Butte consists of granitic gneiss and was recently dated by potassium-argon methods at 69.8 ± 2.6 m.y. (Geochron No. B-4992). Another pod of granite at Viola, Idaho, northwestern end of Moscow Mountain, was dated at 67.8 ± 2.5 m.y. (Geochron No. B-4991). The skyline far to the south is formed by the Blue Mountains (Columbia River basalts) which were uplifted 11-12 m.y. ago.

Kamiak Butte is named for the Yakima Indian Chief, Kamiaken.

Return to park entrance.

77.6 Stop, turn right onto Fugate Road.

78.3 Stop, turn left onto Washington State Hwy 27 towards Palouse.

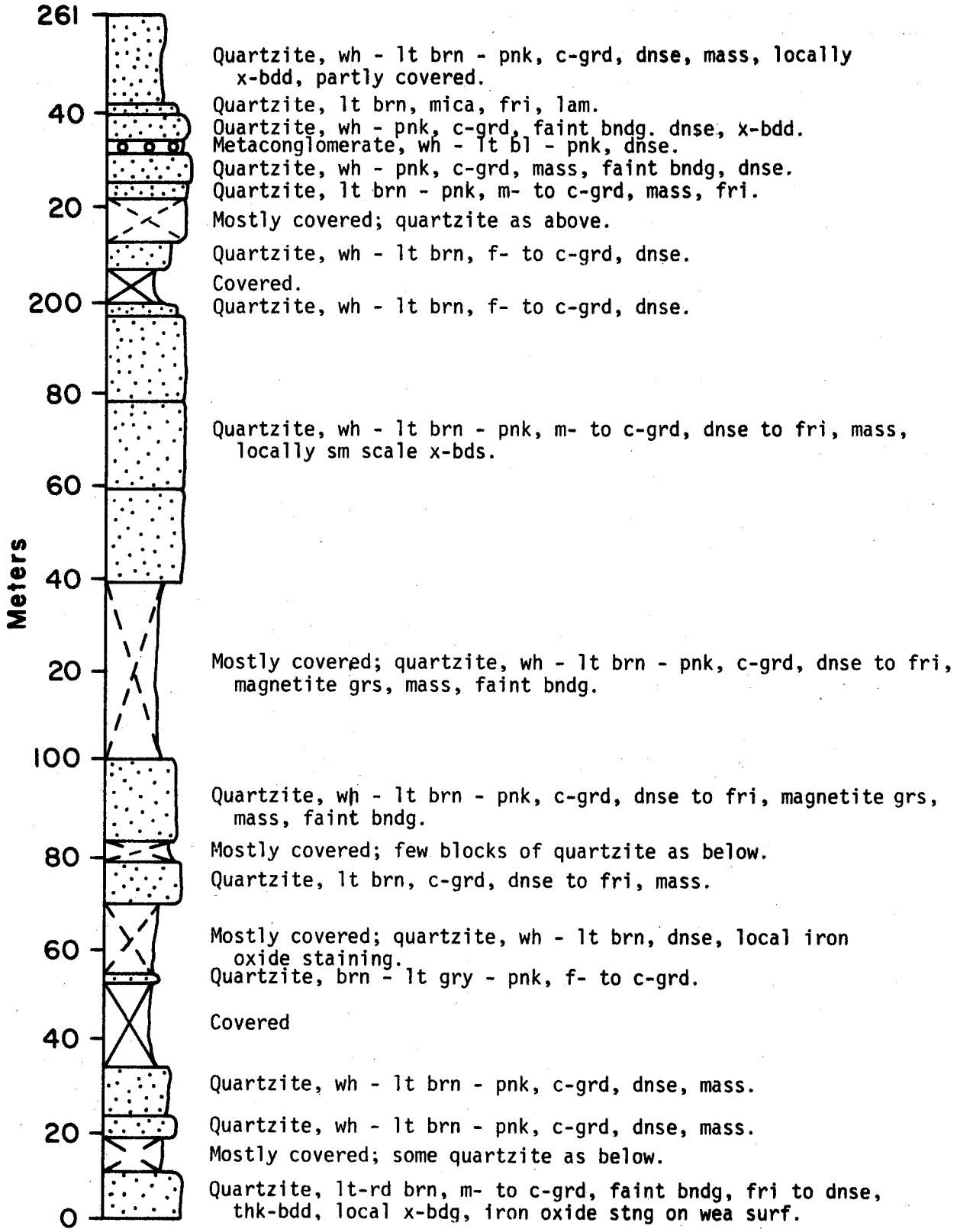


Figure 3. Stratigraphic section for western end of Kamiak Butte.

81.1 Priest Rapids basalt exposed to left. This is the top of the basalt in this area, elevation 2,520 feet.

81.7 Railroad crossing; entering Palouse.

81.9 Cross North Fork Palouse River; continue straight ahead on Washington State Hwy 27.

82.1 Turn left, staying on Washington State Hwy. 27.

82.2 Turn right.

82.6 Railroad crossing; Priest Rapids basalt (uppermost flows) exposed in road cuts, elevation 2,520 feet.

83.0 North Fork Palouse Canyon with alluvial floodplain and quarry in Priest Rapids basalt at 10:30; Kamiak Butte in distance at 9:30. There are good exposures of the Priest Rapids basalt in road cuts for the next 1.6 miles. The base of the valley walls is incised into the Rosa flow.

84.6 Ascending out of North Fork Palouse Canyon.

85.5 Ladow Butte (elevation 3,296 feet) at 12:00; quartzite blocks of the Revett or Burke Formations are present on the north face of the butte. Skyline Ridge at 12:30 in the distance formed of argillites and quartzites of the Striped Peak Formation, Missoula Group. Some trace fossils are present in the argillites along Skyline Ridge drive.

86.3 Entering Cedar Creek Valley; Priest Rapids basalt exposure on far side of valley.

86.8 Quarry in Priest Rapids basalt to right.

87.1 Cross Cedar Creek and leave Cedar Creek Valley.

90.8 Railroad crossing; entering Garfield.

90.9 Railroad crossing.

91.3 Turn right, continuing on Washington State Hwy 27.

92.5 Railroad overpass.

93.1 Tip of Steptoe Butte visible at 9:00.

94.1 Continue straight on Washington State Hwy 27.

95.9 Tekoa Mountain (Striped Peak Formation) at 12:00.

97.3 Railroad crossing.

98.0 Entering Belmont.

100.6 John F. Kelly homestead ranch cabin (founded 1872) to right.

101.3 Railroad overpass.

102.9 Railroad crossing; entering Oakesdale.

103.9 Turn right, continuing on Washington State Hwy 27.

104.1 Turn right, continuing on Washington State Hwy 27.

104.2 Priest Rapids basalt exposed in road cut to left, elevation 2,250 feet.

105.0 View of steptoes along the Washington-Idaho border at 12:00. Close buttes composed of the Striped Peak Formation, more distant buttes formed at wallace, St. Regis, Burke, Revett and Prichard Formations.

107.8 Turn right, continuing on Washington State Hwy 27.

114.8 Entering Tekoa.

115.1 Cross Hangman Creek; railroad crossing.

115.3 Turn left, continuing on Washington State Hwy 27.

115.6 Railroad crossing.

115.7 Stop, turn left, continue on Washington State Hwy 27.

115.9 Pass under railroad trestle.

117.2 Quarry on right contains quartzites of the Striped Peak Formation in the colluvium.

117.3 Priest Rapids basalt exposed along Hangman Creek Valley for next few miles.

119.9 Quartzite of the Striped Peak Formation exposed on hillside to right. Exposures are poor on Tekoa Mountain. The best exposures are on the east side in road cuts and just below the ridge crest.

120.7 Gelbert Mountain at 12:00, Wallace Formation.

122.1 Entering Latah.

123.0 Quarry in Priest Rapids basalt to left, elevation 2,520 feet.

124.0 Quarry in Priest Rapids basalt to left.

125.8 Priest rapids basalt in road cut.

126.5 Railroad overpass.

126.8 Quarries in Priest Rapids basalt on both sides of road.

127.5 Quarry in Priest Rapids basalt to left.

128.0 Argillites of St. Regis Formation exposed to left.

130.3 Entering Fairfield. Driving from Fairfield to Rockford the road cuts are in the Palouse Formation. Shasta Butte (Prichard Formation) is occasionally visible in the distance.

135.8 Priest Rapid basalt exposed along both sides of road.

135.9 Stay to left on Washington State Hwy 27, Rockford to right.

136.0 Pass under railroad overpass.

136.2 Crocc Rock Creek.

136.4 Quarry in Priest Rapid basalt at 11:00.

138.8 Krell Hill (with broadcasting towers), composed of Prichard Formation, in distance at 12:00.

143.9 Krell Hill at 10:00.

144.6 Community of Mica to right; continue on Washington State Hwy 27.

145.0 Tailings from weathered micaceous argillites and schists of Prichard Formation visible to right.

145.3 Weathered micaceous Prichard metasedimentary rocks in road cut to right.

145.8 Dishman road to left, continue on Washington State Hwy 27.

146.9 View across Spokane Valley at 12:00.

147.1 STOP 3: Multiply-deformed gneiss of the Prichard Formation in road cut to left.

148.3 Gneiss cut by quartz dikes in road cut to left.

150.0 Entering Opportunity. Continue on Washington State Hwy for 3.1 miles turning right to go east to Coeur d'Alene, Idaho, or 3.2 miles turning left to Spokane, Washington on U.S. I-90.

End of Road Log

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GLACIAL GEOLOGY

OF CATARACT CREEK AND NORTH WILLOW CREEK VALLEYS

IN THE AREA WEST OF PONY, MONTANA

TOBACCO ROOT RANGE

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INTRODUCTION

This road log describes localities in the Cataract Creek and North Willow Creek valleys, which begin in a group of cirques immediately east of the crest of the Tobacco Root Range near Mount Hollowtop about 10 km southwest of Pony, Montana (Fig. 1 and Fig. 2). The valleys trend northeast and merge about 2.5 km west of Pony. The junction marks the approximate limit of downvalley ice advance in both valleys. This area contains moraines, rock glaciers, and mass-wasted deposits that record Pinedale and Neoglacial events.

Both valleys are characterized by prominent lateral moraines along their northwestern sides. In places these moraines include a series of subparallel ridges representing the accumulation of several advances. An analysis of geomorphic characteristics and soils (soil morphology, particle size, clay mineralogy, heavy minerals, and geochemistry) of these lower valley moraines suggests an early to middle Pinedale age (compare Holmes and Moss, 1955; Madole, 1969; Madole and Shroba, 1979; Mahaney, 1977; Richmond, 1965). These advances may not be separated by enough time to significantly affect weathering characteristics.

Both valley systems also contain younger moraines at higher elevations encircling Mason Lake and Hollowtop Lake only 1.9 km and 1.8 km, respectively, from the cirque headwalls. These deposits have geomorphic and weathering characteristics typical of late Pinedale or early Holocene glaciations (compare Birkeland, 1973; Birkeland and Shroba, 1974; Birkeland and others, 1979; Currey, 1974;

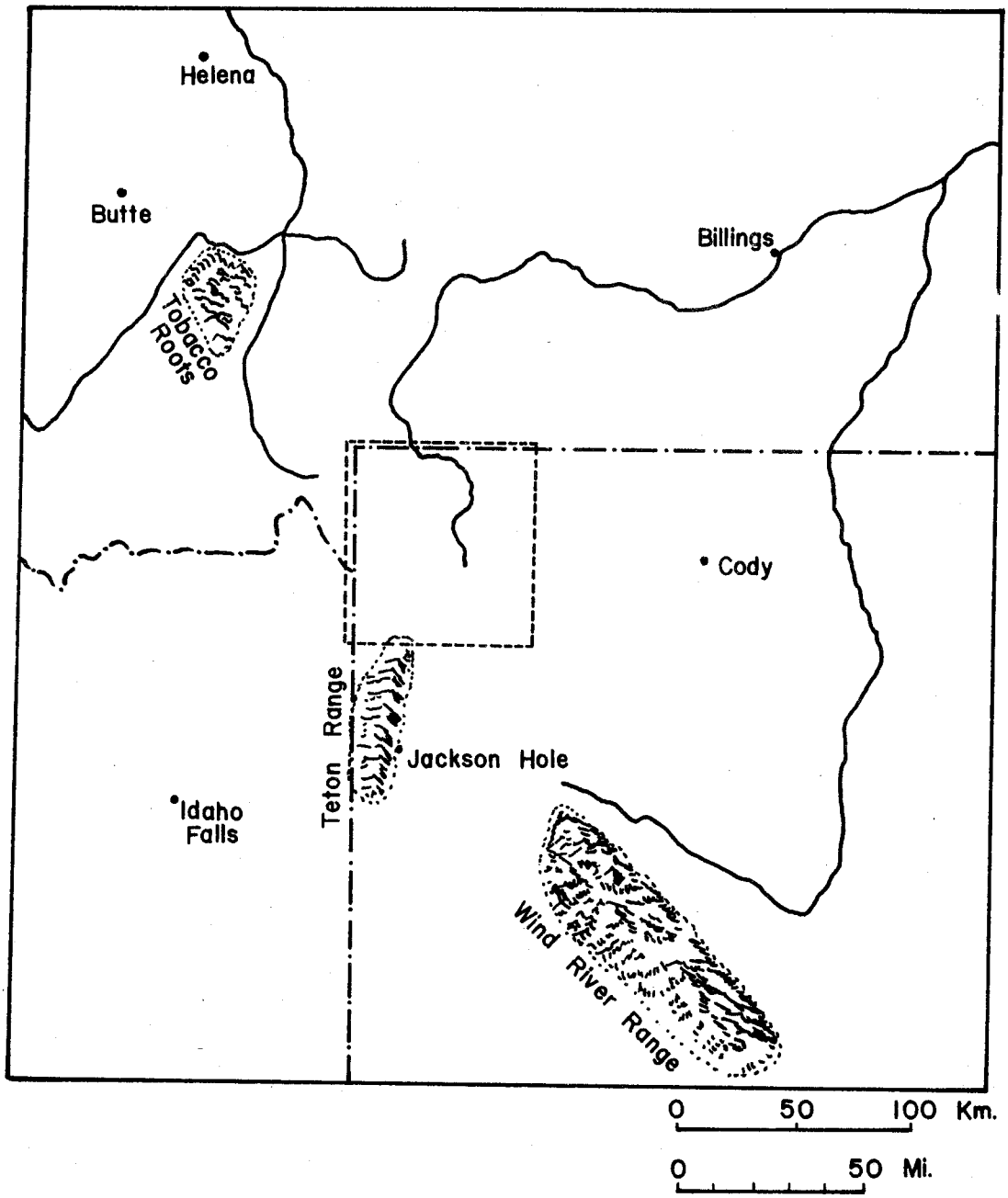


Figure 1. Location map for field trip.

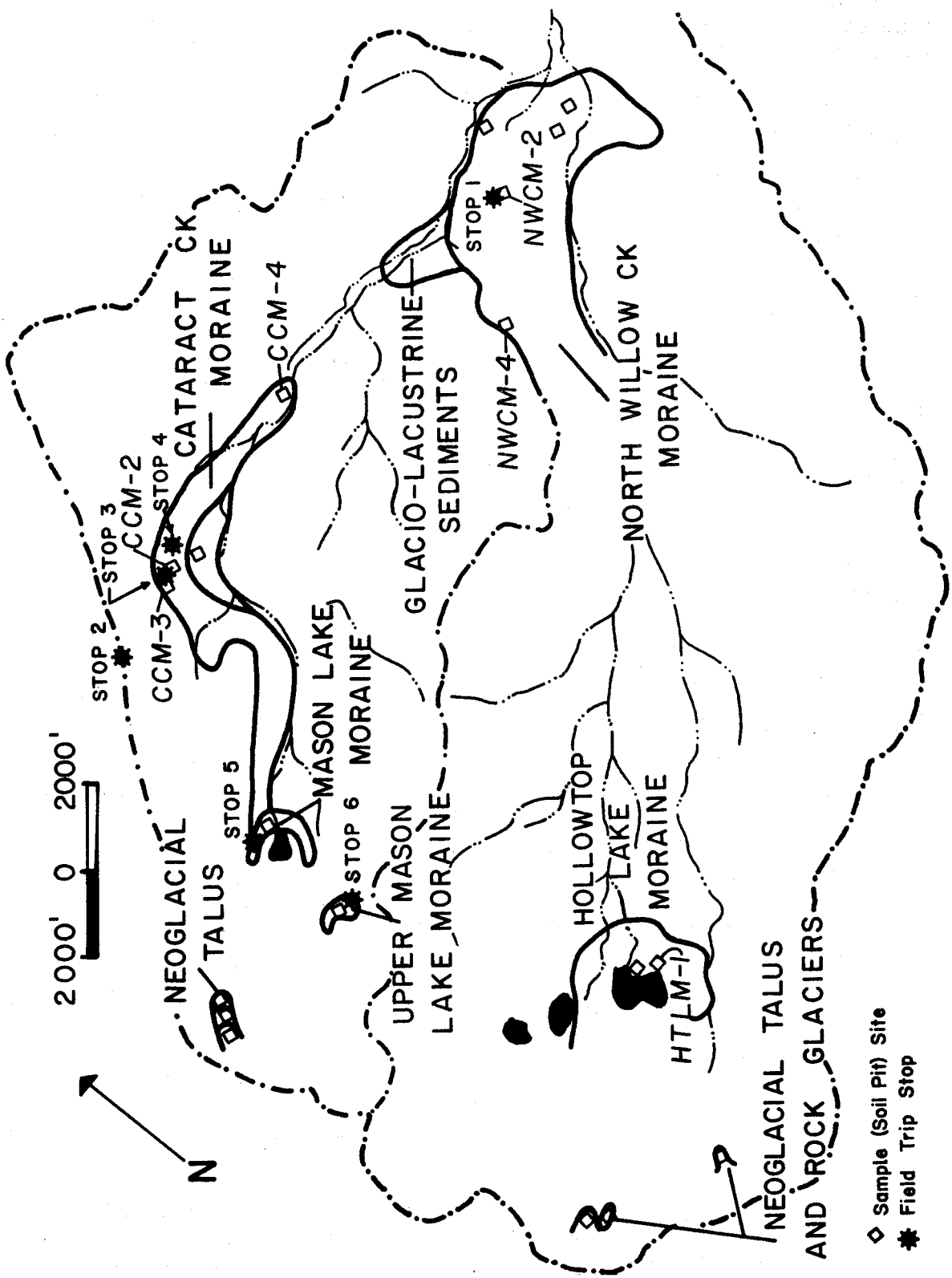


Figure 2. Location map of deposits and landforms in the area west of Pony, Montana.

Holmes and Moss, 1955; Mahaney, 1977; Miller and Birkeland, 1974). In some respects weathering has progressed more here than in the older deposits downvalley because of a greater amount of precipitation at higher elevations.

Within the cirques are multiple levels of rock glaciers, protalus ramparts, and talus lobes and fans. A deposit that is probably a moraine extends around the rim of the cirque at Upper Mason Lake; it may be the only record of a post-Pinedale ice advance in this area. Geomorphic and weathering characteristics indicate that the cirque deposits reflect periods of periglacial activity corresponding with the early Neoglacial, Audubon, and Gannett Peak ice advances elsewhere in the Rocky Mountains (Fig. 3).

The purpose of this fieldtrip will be to examine and discuss early and middle Pinedale glacial land forms and deposits typical of the lower valley moraines as well as mass-wasted features. The trip concludes with an optional hike to higher elevations to examine probable late Pinedale and early Neoglacial deposits.

ROAD LOG

PONY TO UPPER MASON LAKE

Cumulative Mileage	
0.0	Assembly point, Pony Bar (where else to start a fieldtrip?), Pony, Montana. Proceed southwest out of Pony on dirt road.
0.6	Old house formerly used as headquarters of the Boss Tweed gold mine.
1.2	Road junction. Pause to view impressive front of North Willow Creek moraine straight ahead. Then turn right and begin steep ascent up Cataract Creek valley. Careful driving and low gear is required!
1.9	Road is cut into Precambrian crystalline bedrock. Cataract Creek is cutting a gorge to your immediate left. The northern margin of the North Willow Creek lateral moraine forms most of the ridge just south of the creek.
2.0	Road reaches flatter area above gorge. North Willow Creek moraine can be seen to left across Cataract Creek. Ice from North Willow Creek moved over the former divide between the two valleys and pushed northward to the northern valley wall.
2.4	View straight ahead includes dam for Cataract Reservoir. Road begins to ascend to crest of dam. Former workings of Garnet Gold Mine on right.
2.6	STOP 1: Crest of dam. Cataract Reservoir occupies site of Glacial Lake cataract, formed by damming of Cataract Creek by ice spreading northeastward from North Willow Creek. Ice in Cataract Creek valley itself apparently did not reach this far downvalley. Walk across dam to briefly examine exposure of till and then hike to crest of North Willow Creek moraine.

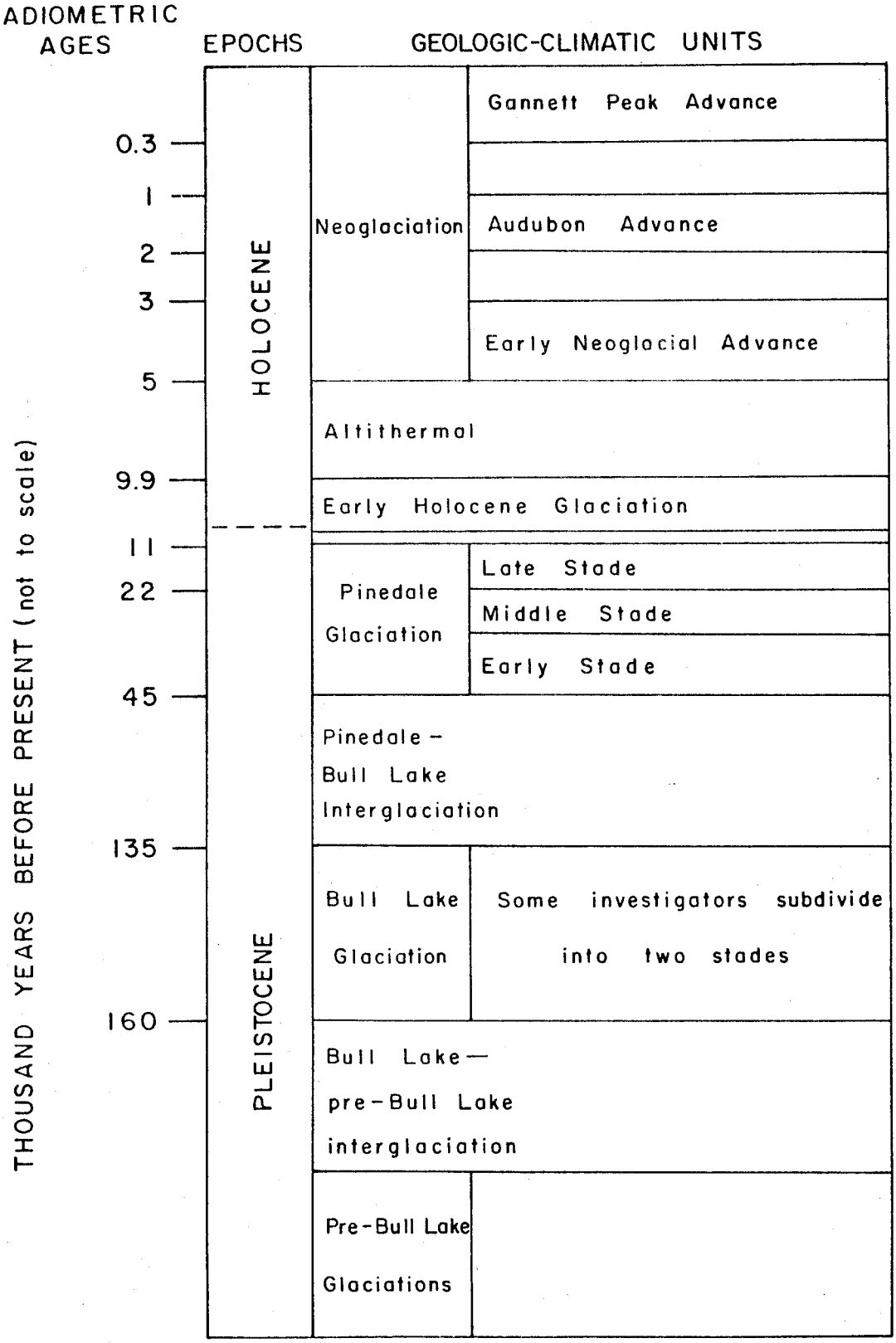


Figure 3. Diagram showing current status of glacial stratigraphy and chronology of the Rocky Mountain region.

The site is located along the crest of the North Willow Creek lateral moraine along the drainage divide between Cataract Creek to the north and North Willow Creek to the south, approximately 1 km (0.6 mi.) from the terminus of the moraine (Fig. 2). This moraine has an unusually bold topographic expression compared to moraines elsewhere in the Tobacco Root Range that are believed to be of the same or very similar age.

The soil pit at this site displays a soil profile and weathering characteristics typical of the North Willow Creek moraine and suggestive of an early to middle Pinedale age for moraines at this elevation (compare Holmes and Moss, 1955; Madole, 1969; Madole and Shroba, 1979; Mahaney, 1977).

Description of Profile

A_1	(0-14 cm) very dark grayish brown (10YR 3/2m), dark brown (10YR 3/3d); gravelly loam (9% clay); fine granular; loose; sharp boundary with
Birh	(14-23 cm) dark brown to brown (10YR 4/3m), yellowish brown (10YR 5/4d); gravelly loam (8% clay); fine angular blocky; compact; gradational boundary with
C	(23-80+ cm) dark brown to brown (10YR 4/3m), light yellowish brown (10YR 6/4d); gravelly loam (6% clay); fine angular blocky; compact

The matrix is dominantly sand (Fig. 4, > 62 μ). Clay content is highest near the surface, with a maximum of only 9% and a clay enrichment due to weathering of only 2 or 3%. The fine silt fraction is somewhat enriched toward the surface but probably not enough to suggest a loess influence.

Enrichment of illite and, to a lesser extent, kaolinite and chlorite occurs in the solum, whereas expandable clay minerals are more abundant below the solum. Clay mineral distribution may be unrelated to weathering and may reflect a change in lithologic composition of the till, although this was not noted in the field, and all clasts from this site are silicic igneous. The geochemical data show a buildup of organic matter in the B horizon and a decrease in free iron oxide with depth. Free iron oxide enrichment is about 0.5%.

The above characteristics serve as a basis for comparison with other sites on moraines of both the same and younger ages. (Data for Figure 4 and other figures in this road log are given in the appendices).

2.8 Proceed upvalley from STOP 1. Road descends steeply to reservoir level that traverses mostly colluvium.

4.1 Crossing over approximate terminal position of ice in Cataract Creek valley. Post-glacial erosion has obscured this position.

4.2 Road begins ascent to right, leaving Cataract Creek. View of Cataract

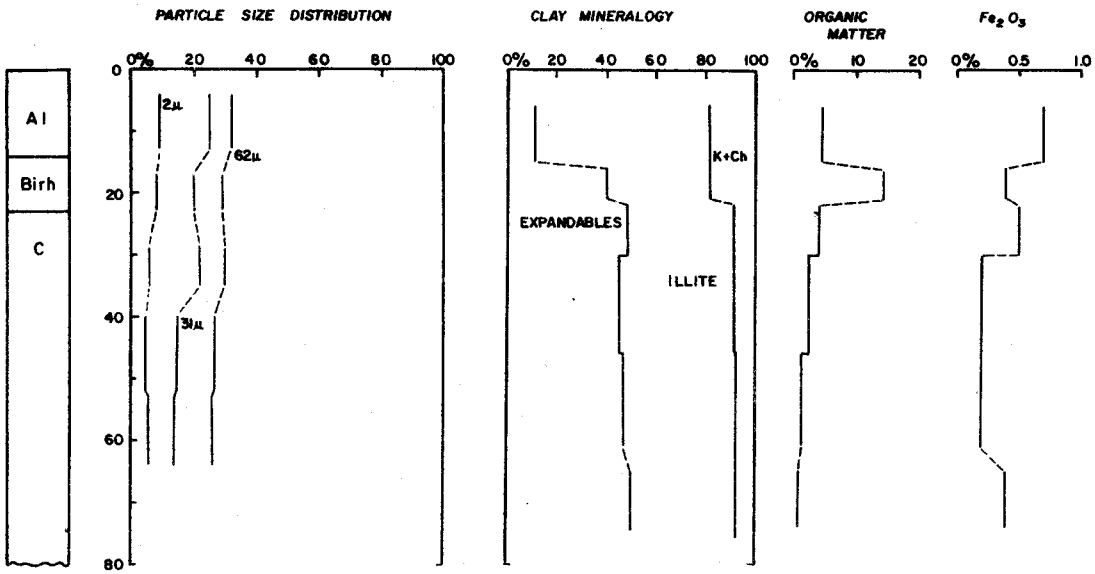


Figure 4. Data plots for North Willow Creek moraine.

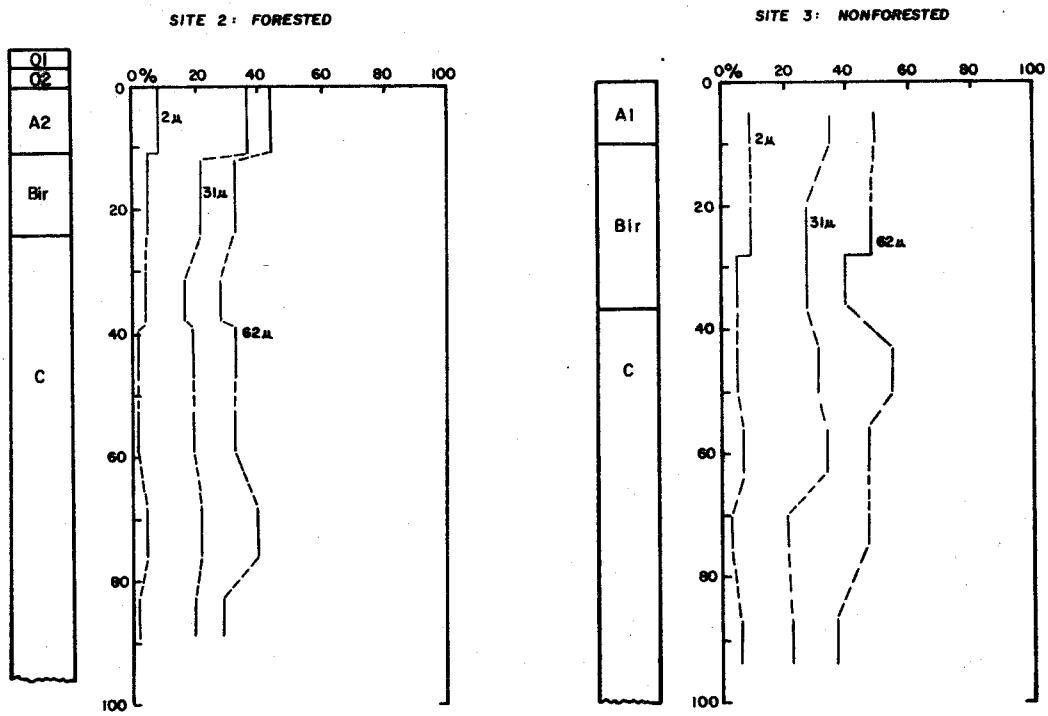


Figure 5. Particle size distribution in profiles of Cataract Creek moraine, sites 2 & 3.

Creek lateral moraine straight ahead. Possible (weather permitting) spectacular views of Mount Hollowtop.

4.4 Switchback to right along base of Lone Wolf deposit whose origin will be discussed at STOP 4. Note its impressive morphology. It is lobate with its distal margin convex southward.

4.7 Switchback to left along approximate crest of upper Cataract Creek lateral moraine. Lone Wolf deposit and Mountain Meadow Mine to left. Lone Wolf Mine high up valley to right. Continue ascent toward divide.

5.0 Forest Service Boundary.

5.2 Crest of upper Cataract Creek lateral moraine near road, modified by several lobate deposits with distal margins convex eastward. Crest of lower Cataract Creek lateral moraine is about 0.2 km to south.

5.4 Junction. Continue on main road to right.

5.8 STOP 2: Drainage divide between South Boulder River drainage to northwest and a part of Cataract Creek watershed drainage to southeast. Overview of the glacial features of Cataract Creek valley. Proceed back down road.

6.2 STOP 3: Junction. Turn right. Short hike to crest of upper Cataract Creek lateral moraine. We will examine two sites on this moraine, one forested, one unforested. The sites are located along the upper part of Cataract Creek lateral moraine about 0.3 km (0.2 mi.) southeast of the drainage divide at STOP 2 (Fig. 2). Site 2 is within the area covered with a coniferous forest, whereas Site 3 is outside the forest under a sagebrush cover. We are interested in assessing any possible influence of vegetative cover on weathering and soil profile development. These sites can also be compared with STOP 1 on the North Willow Creek moraine, which is of about the same age.

The soil colors in the profiles at this stop are noticeably darker than at STOP 1, but at least 50% of the clasts here are derived from metamorphic sources, and this almost invariably results in darker tills than those derived from silicic igneous sources.

Description of Profiles: Site 2

O1 (+6-+3 cm) Needle litter

O2 (+3-0 cm) Decomposed organic matter

A2 (0-11 cm) Dark yellowish brown (10YR 3/4m) yellowish brown (10YR 5/4d); gravelly loam (8% clay); granular; very loose; distinct boundary with

Birh (11-24 cm) Brown to dark brown (10YR 4/3m), pale brown (10YR 6/3d); gravelly loam (5% clay); fine angular blocky; loose, gradational boundary with

C (24-96+ cm) Brown to dark brown (10YR 4/3m), light yellowish brown (10YR 6/4d); gravelly loam (2-4% clay); fine angular blocky; loose

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Site 3

O1	(+6-+3 cm)
O2	(+3-0 cm)
A2	(0-11 cm) Dark brown (10YR 3/3m), dark yellowish brown (10YR 3/4d), gravelly loam (10% clay); granular; loose distinct boundary with
Birh	(10-36 cm) Dark yellowish brown (10YR 3/6m), yellowish brown (10YR 5/6d); gravelly loam (6-9% clay); granular; very loose; gradational boundary with
C	(36-100+ cm) Dark yellowish brown (10YR 4/4m); gravelly loam (4-7% clay); very fine angular blocky; firm

The till matrix at the Cataract Creek moraine sites is somewhat less sandy, with the till at Site 3 unusually rich in silt (Fig. 5). An increase in fine silt toward the top of the profile at Site 2 and possibly at Site 3 suggests an addition of loess to the till. Clay is again highest near the surface, with minimum values (8-10%) typical of early to middle Pinedale sites. Clay enrichment due to weathering is 4 or 5%, slightly more than at STOP 1. This could reflect either a moister environment more favorable for weathering (due to a higher elevation), or a difference in parent material, or both. Note that the clay content of the profile at Site 3, including the parent material, is higher than at Site 2.

Till of the Cataract Creek sites (Fig. 6) contains much more kaolinite + chlorite than till at STOP 1 (Fig. 4). The parent material at Site 2 contains fewer expandable clays than at STOP 1. Data for the parent material at Site 3 are unavailable. Kaolinite + chlorite are enriched in the solum of Site 2, but expandable clays increase in the solum of Site 3. Differences among the three sites probably relate to differences in parent material and weathering environment (primarily climatic and vegetational), but no extensive analyses of these factors has been made.

The non opaque fraction of the heavy mineral suite of the Cataract Creek moraine is overwhelmingly dominated by hornblende (Fig. 7). Hornblende is somewhat depleted (about 7%) by weathering in the solum. The buildup of organic matter at Site 2 is, as expected, within the A horizon (Fig. 7). The B horizon seems to show a slight increase in free iron oxide, and the cation exchange capacity is greatest within the solum.

STOP 4: Short hike to the east along the crest of the upper Cataract Creek moraine to examine lobate deposits interpreted by Jacobs (1967) as proto-cirque moraines and by the authors as mass-wasted features. This is the final stop for those not wishing to hike to Mason Lake.

Below the Cataract Creek moraine Site 2, and along the crest of the moraine (Fig. 2) are several small lobate deposits which demonstrate strikingly fresh morphology. The Mountain Meadow deposit consists of

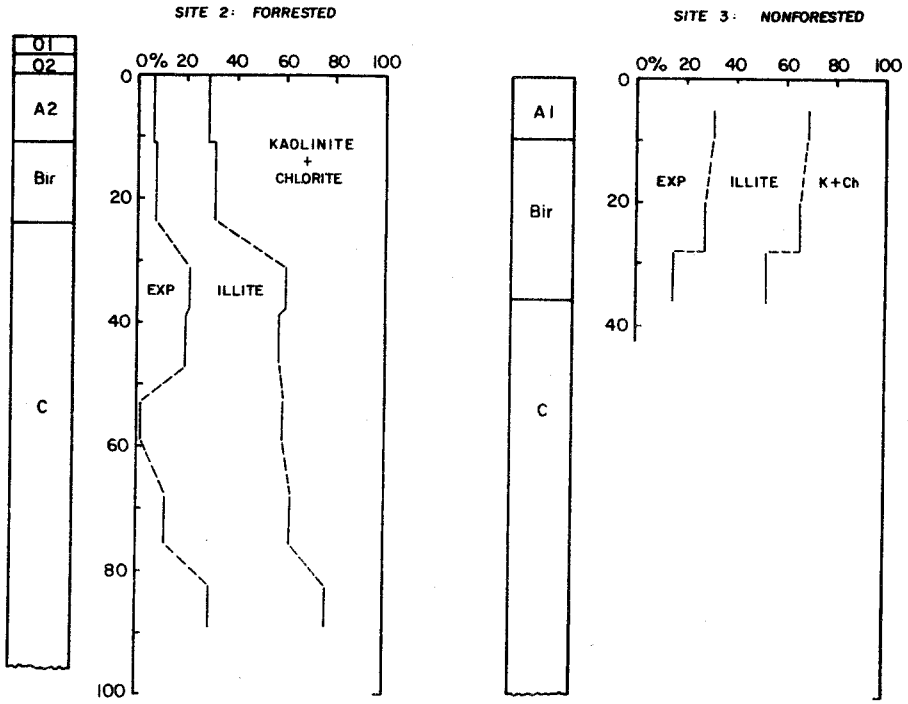


Figure 6. Clay mineralogy in profiles of Cataract Creek moraine, sites 2 & 3.

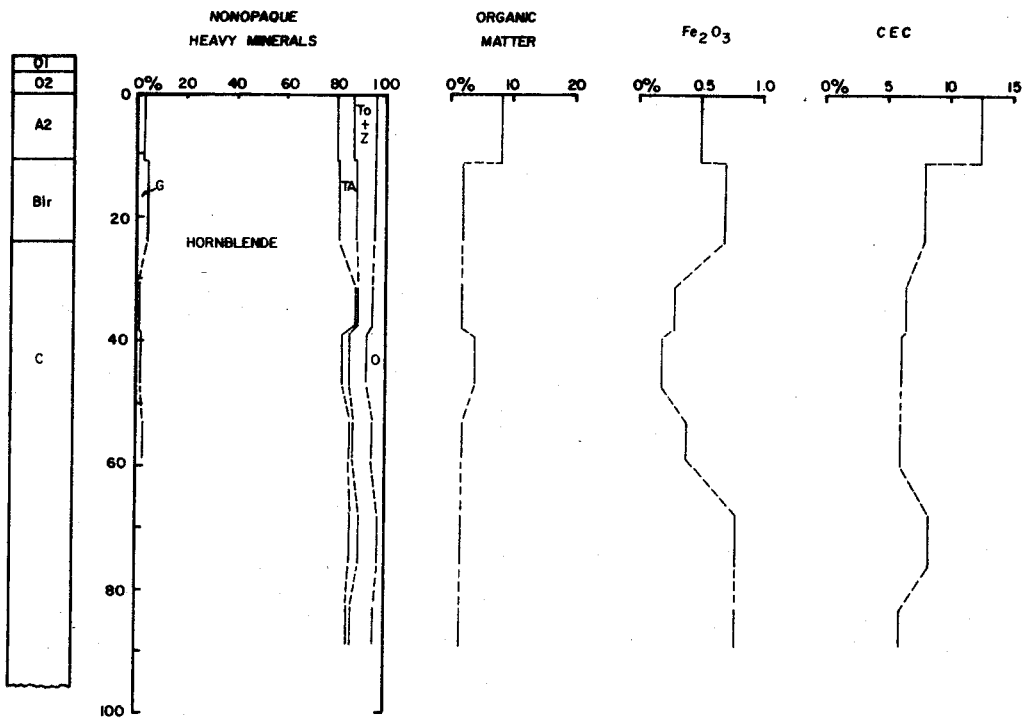


Figure 7. Heavy minerals and geochemistry of Cataract Creek moraine, site 2.

five nested lobes oriented transverse to the crest of the Cataract Creek moraine with distal margins sloping eastward. The Lone Wolf deposit consists mainly of one large lobe whose crest trends roughly parallel to the crest of the Cataract Creek moraine.

In his study of these deposits Jacobs (1967) concluded that the lobes were produced by small (niche) glaciers that originated in what he interpreted as incipient, or protocirques nearby. However, detailed study of the area by the authors indicates that the "protocirques" identified by Jacobs (1967) were never occupied by glacial ice. Furthermore, the morphologic and textural characteristics of the lobes suggest that they are debris flows or earthflows that modified the upper Cataract Creek moraine, perhaps soon after deglaciation of the area. The immediate postglacial age is suggested by soil profiles that demonstrate almost the same degree of soil development as the moraine itself.

Description of Profiles: Mountain Meadow

A1	(0-20 cm) Very dark brown (10YR 2/2m); gravelly silt loam (10% clay); very fine granular; very loose; distinct boundary with
Bir	(20-35 cm) Dark brown (10YR 3/3m), dark yellowish brown (10YR 4/4d); gravelly loam (7% clay); very fine angular blocky; loose; distinct boundary with
C	(35-65+ cm) Dark yellowish brown (10YR 4/4m), yellowish brown (10YR 5/6d); gravelly loam (13% clay) very fine angular blocky; loose

Lone Wolf

A1	(0-19 cm) Brown to dark brown (10YR 4/3d); gravelly silt loam (9% clay); fine, granular; loose; distinct boundary with
Bir	(19-37 cm) Dark yellowish brown (10YR 3/4m), dark yellowish brown (10YR 4/6d); gravelly loam (14% clay); fine granular; loose; gradational boundary with
C	(37-76+ cm) Dark yellowish brown (10YR 4/4m), yellowish brown (10YR 5/6d); gravelly loam (15% clay); fine angular; firm

The matrix of the deposits is highly variable in grain size (Fig. 8), even in the parent material. This variability may be expected in mass-wasted deposits. The enrichment of clay due to weathering is comparable to that demonstrated for soil profiles in the moraine. For those continuing to Mason Lake, return to the cars. Depending on the condition of the road, we may be able to drive part of the way. If not, the hike is approximately 4 km (2.5 mi.) to Mason Lake over a former road (easy hiking).

8.7 STOP 5: Mason Lake moraine. The site is on an apparently late Pinedale moraine which partially dams Mason Lake about 1.1 km (0.7 mi.) outside

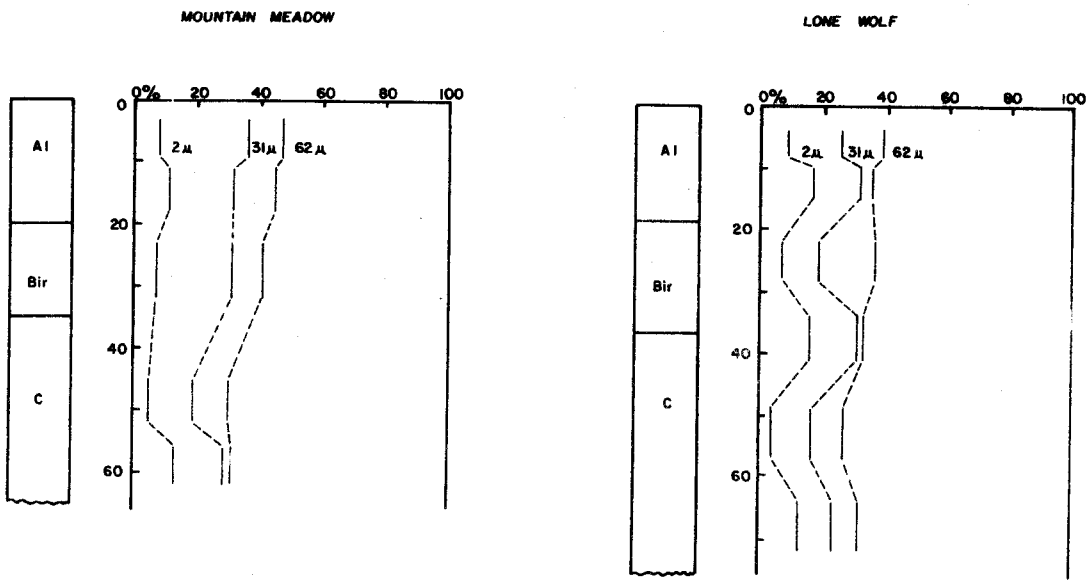


Figure 8. Particle size distribution in profiles of Mountain Meadow and Lone Wolf deposits.

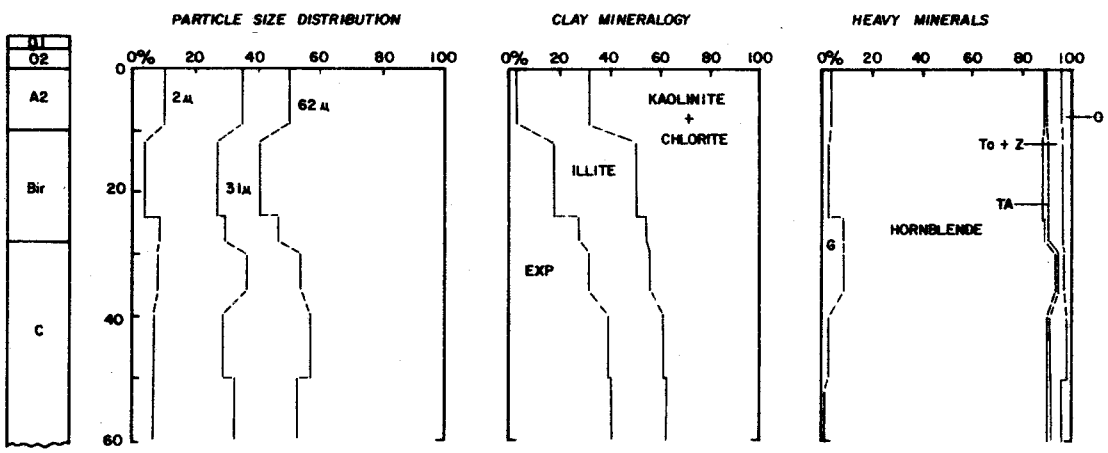


Figure 9. Particle size distribution, clay mineralogy, and heavy minerals in profiles of Mason Lake moraine.

the major cirque at the head of the Cataract Creek valley (Fig. 2). The Mason Lake moraine abuts to the north with the older Cataract Creek lateral moraine. This site displays a soil profile and weathering characteristics typical of late Pinedale deposits located just outside the cirques (compare Birkeland and Shroba, 1974; Currey, 1974; Mahaney, 1977; Miller and Birkeland, 1974).

Description of Profile

O1	(+5-+3 cm) Needle litter, rootlets
O2	(+3-0 cm) Decayed organic matter
A2	(0-10 cm) Dark yellowish brown (10YR 3/4m), dark brown (10YR 3/3d); gravelly loam (12% clay); fine granular; loose; sharp boundary with
Bir	(10-28 cm) Dark yellowish brown (10YR 4/6d); gravelly loam (7% clay); very weak fine angular blocky; loose; distinct boundary with
C	(28-61+ cm) Dark grayish brown (2.5Y 4/2m), olive brown (2.5Y 4/4d); gravelly loam (7% clay); massive; loose

Colors of the solum at this site compare closely with those of Site 2 on the Cataract Creek moraine under similar vegetation. However, the C horizon here is definitely less oxidized (2Y vs. 10YR colors). The till is somewhat less sandy (Fig. 9). Clay reaches a maximum of 10% at the surface then decreases noticeably in the upper B horizon before reaching a secondary buildup in the lower B horizon. Clay enrichment is only 2 or 3%. The solum here is of about the same thickness (28 cm) as at STOP 3.

Distribution of clay minerals also follows a similar pattern, with kaolinite + chlorite enriched in the upper part of the profile. Illite may be similarly enriched but to a much lesser degree. Expandable clay minerals increase with depth.

Hornblende is again the overwhelmingly dominant heavy mineral within the nonopaque fraction. Hornblende depletion is about 4%. Figure 10 shows a slight buildup of organic matter in the A horizon, a slight increase in free iron oxide toward the surface, and a cation exchange capacity that decreases slightly with depth in the solum then increases slightly in the C horizon.

Taken together, weathering characteristics of this site suggest slightly less weathering than at STOP 3. This is to be expected because of the postulated late Pinedale age of this deposit, provided that increased precipitation upvalley does not promote more weathering and override the effect of decreasing age. For those who wish to continue, cross the dam at Mason Lake and hike across the Mason Lake lateral moraine along the south side of the lake and then ascend the steeper trail to Upper Mason Lake. The (very approximately) estimated distance of this hike is 1.5 km (1 mi.).

9.7 STOP 6: Upper Mason Lake moraine. This site is located in deposits that

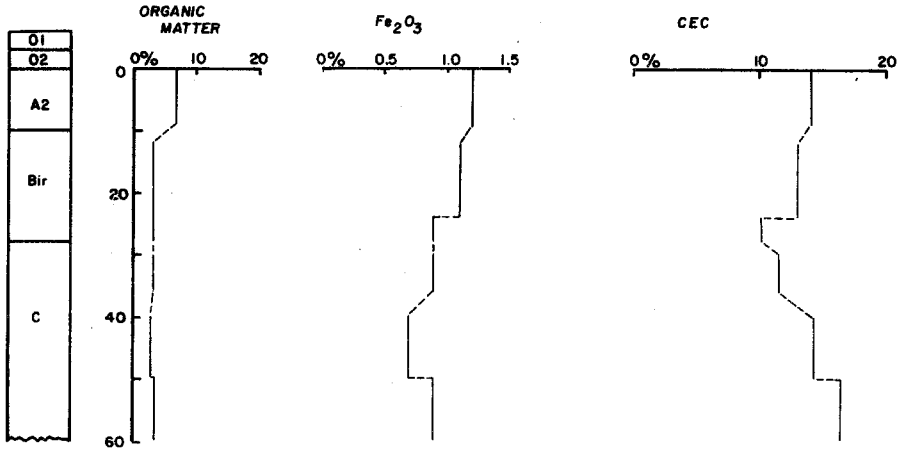


Figure 10. Geochemistry of profile of Mason Lake moraine.

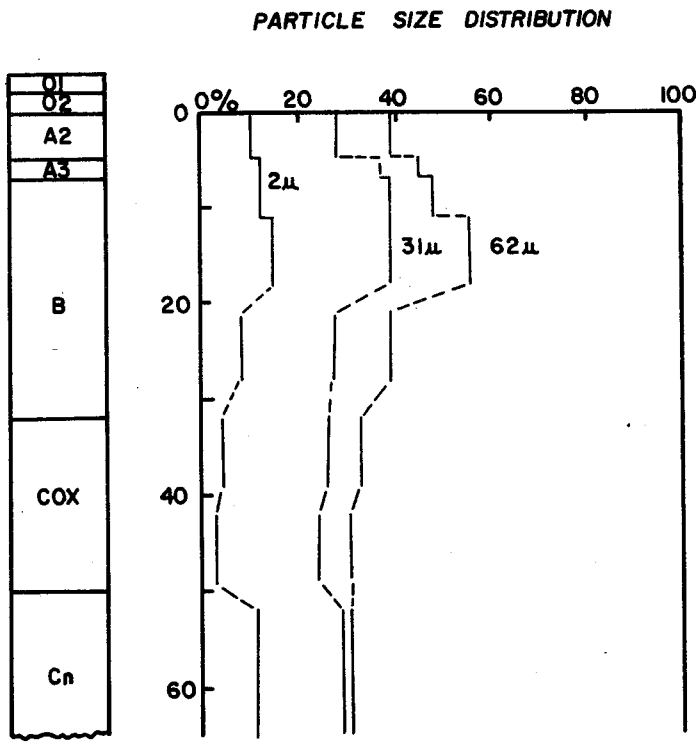


Figure 11. Particle size distribution in profile of Upper Mason Lake moraine.

mantle the bedrock threshold of the cirque containing Upper Mason Lake. The deposit may be colluvium, talus, or till, although the later origin is favored because of the ridgelike character of the deposit. This deposit is probably the only early Neoglacial moraine in the Cataract Creek and North Willow Creek drainage basins. Deposits in other nearby cirques are mostly younger (Audubon and Gannett Peak) rock glaciers, protalus ramparts, and talus.

Description of Profile

O1	(+4-+2 cm) Mostly needle litter
O2	(+2-0 cm) Decayed organic matter
A2	(0-5 cm) Dark yellowish brown (10YR 3/6m), yellowish brown (10YR 5/4d); gravelly loam (10% clay); fine granular; loose; sharp boundary with
A3	(5-7 cm) Dark yellowish brown (10YR 4/6m), brown to dark brown (10YR 4/3d); gravelly loam (12% clay); very fine granular; loose; sharp boundary with
B	(7-32 cm) Dark yellowish brown (10YR 4/6m), yellowish brown (10YR 5/6d); gravelly loam (14% clay); very fine angular blocky; loose; distinct boundary with
Cox	(32-50 cm) Yellowish brown (10YR 5/6 m & d); gravelly loam (5% clay)
Cn	(50-65+ cm) Light olive brown (2.5Y 5/4m), light yellowish brown (2.5Y 6/4d); gravelly loam (11% clay)

Although the data are restricted to soil morphology and particle size distribution (Fig. 11), certain weathering characteristics of this site clearly indicate the superior weathering environment at this higher (2,700 m or 8,750 ft.) and wetter elevation. These include: 1) better defined horizons, 2) thicker solum - 32 cm, 3) a greater clay maximum - 14%, 4) clay buildup in the B horizon, and 5) much greater clay enrichment-about 10%. Obviously greater weathering complicates the task of determining an upvalley relative age sequence based on weathering characteristics!

End Of Road Log

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APPENDIX A. Particle Size Data for Matrix (< 2mm Fraction)

North Willow Creek moraine (STOP 1)

Horizon	Sample Interval	Sand	Coarse Silt	Fine Silt	Clay
A1	4-13 cm	68	7	16	9
Birh	17-23	70	10	12	8
C	29-35	69	9	16	6
	40-52	73	12	10	5
	53-64	74	12	8	6

Cataract Creek moraine, Site 2 (STOP 2)

Horizon	Sample Interval	Sand	Coarse Silt	Fine Silt	Clay
A2	0-11 cm	56	7	29	8
Birh	11-24	67	11	17	5
C	31-38	72	11	13	4
	39-47	67	14	17	2
	53-59	68	13	17	2
	68-76	60	18	18	4
	83-89	71	10	17	2

Cataract Creek moraine, Site 3 (STOP 3)

Horizon	Sample Interval	Sand	Coarse Silt	Fine Silt	Clay
A1	5-10 cm	50	14	26	10
Birh	20-28	52	21	18	9
	28-36	60	12	22	6
C	43-50	44	24	26	6
	56-63	52	13	28	7
	71-75	53	26	17	4
	87-94	63	14	17	6

Mountain Meadow deposit (STOP 4)

Horizon	Sample Interval	Sand	Coarse Silt	Fine Silt	Clay
A1	3-9 cm	53	11	28	8
	11-18	55	14	20	11
Bir	23-32	59	10	24	7
C	45-52	70	11	14	5
	56-62	69	2	16	13

Lone Wolf deposit (STOP 4)

Horizon	Sample Interval	Sand	Coarse Silt	Fine Silt	Clay
A1	4-8 cm	61	13	17	9
	10-15	64	4	15	17
Bir	22-28	63	18	12	7
C	34-41	67	2	15	16
	49-57	73	10	13	4
	64-72	72	4	11	13

Mason Lake moraine (STOP 5)

Horizon	Sample Interval	Sand	Coarse Silt	Fine Silt	Clay
A2	0-9 cm	50	15	25	10
Bir	12-24	59	14	23	4
	24-28	53	17	21	9
C	30-36	46	17	29	8
	40-50	43	28	22	7
	50-60	47	20	26	7

Upper Mason Lake moraine (STOP 6)

Horizon	Sample Interval	Sand	Coarse Silt	Fine Silt	Clay
A2	0-5 cm	61	11	18	10
A3	5-7	55	8	25	12
B	7-11	52	9	27	12
	11-18	45	16	25	14
	21-28	61	12	19	8
Cox	32-39	67	7	22	4
	42-49	69	7	21	3
Cn	52-65	69	2	18	11

APPENDIX B. Relative Amounts of Clay Minerals

North Willow Creek moraine (STOP 1)

Horizon	Sample Interval	Kaolinite + Chlorite	Illite	Expandables	a D.I.Ratio	b E/NE
A1	6-15 cm	17	71	12	4.2	0.4
Birh	16-21	17	42	41	2.4	0.7
C	22-30	7	44	49	6.8	1.0
	30-46	7	47	46	6.7	0.9
	46-61	6	46	48	7.1	0.9
	65-74	6	43	51	6.7	1.0
	75-90	5	42	53	8.2	1.1

a Diffraction intensity ratio: % Illite/% Kaolinite & chlorite
b Expandable/Nonexpandable

Cataract Creek moraine, Site 2 (STOP 3)

Horizon	Sample Interval	Kaolinite + Chlorite	Illite	Expandables	D.I.Ratio	E/NE
A2	0-11 cm	71	22	7	0.3	0.1
Birh	11-21	68	24	8	0.3	0.1
C	31-38	40	38	22	0.9	0.3
	39-47	42	38	20	0.9	0.3
	53-59	41	57	2	1.4	0.2
	68-76	37	50	13	1.3	0.2
	83-89	23	47	30	2.0	0.4

Cataract Creek moraine, Site 3 (STOP 3)

Horizon	Sample Interval	Kaolinite + Chlorite	Illite	Expandables	D.I.Ratio	E/NE
A1	5-10 cm	31	38	31	1.2	0.4
Bir	20-28	34	38	28	1.1	0.4
	18-36	47	38	15	0.8	0.2

Mason Lake moraine (STOP 5)

Horizon	Sample Interval	Kaolinite + Chlorite	Illite	Expandables	D.I.Ratio	E/NE
A2	0-9 cm	68	28	4	0.4	0.04
Bir	12-24	49	33	18	0.7	0.2
	24-28	45	27	28	0.6	0.4
C	30-36	44	24	32	0.6	0.5
	40-50	38	22	40	0.6	0.7
	40-60	36	23	41	0.6	0.7

APPENDIX C. Geochemistry

North Willow Creek moraine (STOP 1)

Horizon	Sample Interval	Organic Matter (%)	Fe_2O_3 (%)	CEC (%)
A1	6-15 cm	4.3	0.7	10.6
Birh	16-21	14.3	0.4	13.5
C	22-30	4.0	0.5	10.9
	30-46	2.4	0.2	7.3
	46-61	1.8	0.2	5.2
	65-74	1.0	0.4	5.7

Cataract Creek moraine, Site 2 (STOP 3)

Horizon	Sample Interval	Organic Matter (%)	Fe_2O_3 (%)	CEC (%)
A2	0-11 cm	8.2	0.5	12.5
Bir	11-24	2.2	0.7	8.0
C	31-38	2.2	0.3	6.6
	39-47	4.2	0.2	6.3
	53-59	2.2	0.4	6.2
	68-76	2.1	0.8	8.4
	83-89	2.0	0.8	6.1

Mason Lake moraine (STOP 5)

Horizon	Sample Interval	Organic Matter (%)	Fe_2O_3 (%)	CEC (%)
A2	0-9 cm	6.7	1.2	14.2
Bir	12-24	3.4	1.1	13.1
	24-28	3.5	0.9	10.3
C	30-36	3.4	0.9	11.8
	40-50	3.1	0.7	14.5
	50-60	3.7	0.9	16.6

APPENDIX D. Heavy Mineral Data

Cataract Creek moraine, Site 2 (STOP 3)

Horizon	Sample Interval	Relative Amounts (%) G	H	To	TA	Z	O	H/To+Z	G/T-+Z	TA/To+Z	H/G	H/TA	Z/To
A2	0-11 cm	2	78	6	7	2	5	10.0	0.3	0.9	32.5	10.8	0.3
Bir	11-24	4	77	5	7	2	5	10.9	0.6	1.1	17.8	10.1	0.3
C	31-38	1	87	4	1	1	6	17.2	0.2	0.2	103.0	103.0	0.2
	39-47	2	81	7	2	1	7	9.9	0.3	0.2	37.0	49.3	0.2
	53-59	3	82	6	2	1	6	14.4	0.4	0.4	32.5	32.5	0.2
	68-76	1	85	6	3	2	3	10.5	0.1	0.4	136.0	27.2	0.4
	83-89	1	83	6	2	3	5	9.3	0.1	0.2	60.5	40.3	0.4

G-garnet, H-hornblende, To-tourmaline,
TA-tremolite-actinolite, Z-zircon, O-other

Mason Lake moraine (STOP 5)

Horizon	Sample Interval	Relative Amounts (%) G	H	To	TA	Z	O	H/To+Z	G/T-+Z	TA/To+Z	H/G	H/TA	Z/To
A2	0-9 cm	4	85	4	1	2	4	15.6	0.8	0.2	20.8	62.3	0.5
Bir	12-24	3	85	4	3	2	3	14.6	0.6	0.6	26.7	26.7	0.4
	24-28	9	80	4	2	2	3	12.2	1.4	0.3	8.9	39.0	0.6
C	30-36	9	85	2	1	1	2	24.2	2.5	0.2	9.7	97.0	0.6
	40-50	3	88	3	1	4	1	14.0	0.4	0.1	32.7	98.0	1.3
	50-60	2	89	2	2	2	3	19.9	0.6	0.4	35.8	44.8	0.8

PLEISTOCENE LANDFORMS AND CHRONOLOGY OF THE LOWER SOUTH BOULDER RIVER VALLEY, MONTANA

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INTRODUCTION

This road log describes some of the major glacial deposits along the lower South Boulder River, a northward-flowing tributary of the Jefferson River located in the northern part of the Tobacco Root Range (Fig. 1). Some of the data presented here have been discussed by Roy and Hall (1979a, b; 1980; 1981), and Roy (1980). These references provide the background data which formed the basis for the proposed glacial chronology used in this presentation.

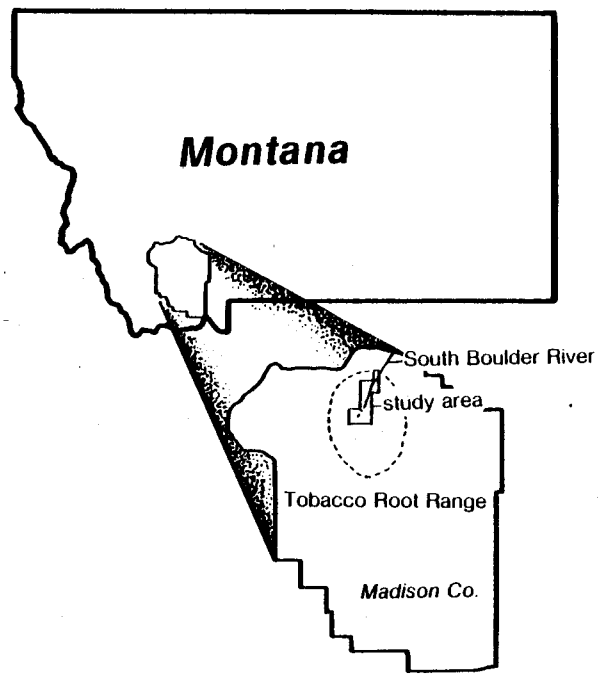


Figure 1. Location of study area.

The South Boulder valley represents the most complete glacial record of the Tobacco Root Range studied to date. Previous studies by Alden (1953), Reshkin (1963), and Jacobs (1967) noted the presence of glacial moraines in the South Boulder valley, but did not establish age relationships. The principal parameter for establishing relative ages in this study was soil development. Comparisons of horizontal development, color, texture and related geochemical data have been used widely to assign relative ages to tills in the Northern and Middle Rocky Mountains (for example, Benedict, 1973; Madole and Shroba, 1979; Mahaney and Fahey, 1976; Miller and Birkeland, 1974).

The lower portion of the study area has glacial deposits representing three glacial stages. The oldest known deposits, of Bull Lake age, are tills at the greatest downvalley distance from the cirque area and at the lowest elevations, approximately 1715 m (5,620 feet). The Pinedale Stage is recorded by a sequence of moraines ranging in elevation from 1,780 m (5,840 feet) to 2,690 m (8,820 feet). There were at least two major advances of Pinedale ice, each characterized by numerous retreats and readvances. The earliest of the major advances (the early Pinedale glaciation) extended farther downvalley than the middle Pinedale glaciation. Nearly 95 percent of the till in the South Boulder valley is of Pinedale age. Glaciofluvial deposits are found throughout the valley but are most extensive at lower elevations.

This road log describes some of the moraines and outwash deposits between the Indiana University Geological Field Station and one of the Pinedale moraines upvalley. The material enclosed here forms the basis for a one-day field trip. At higher elevations, beyond the area covered in this road log, are numerous cirques, glacial lakes, arêtes, moraines and other classical features of alpine glaciation. These landforms are also discussed in the literature cited.

ROAD LOG

Cumulative Mileage

0.0 This road log begins at the Indiana University Geological Field Station located at the intersection of the Pony and South Boulder Roads (Fig. 2). The field station has served as a base of operations for many research projects in southwest Montana. Drive south on the South Boulder Road.

0.5 The road runs across outwash deposits partially covered by colluvium. To the left are two extensive outwash terraces. The upper surface may be of Bull Lake age while the lower surface may be Pinedale in age.

1.8 STOP 1: The South Boulder terminal moraine is to the left (Fig. 2). A cabin is located near the center of this flat-topped mound. This is the only Bull Lake moraine in the study area and was deposited by Bull Lake ice which moved 18 km from the cirques between 135,000 and 160,000 yr BP, based on regional correlations (Roy, 1980; Roy and Hall, 1981). The terminal moraine is topographically subdued and exhibits low relief, probably modified by post-Bull Lake erosion.

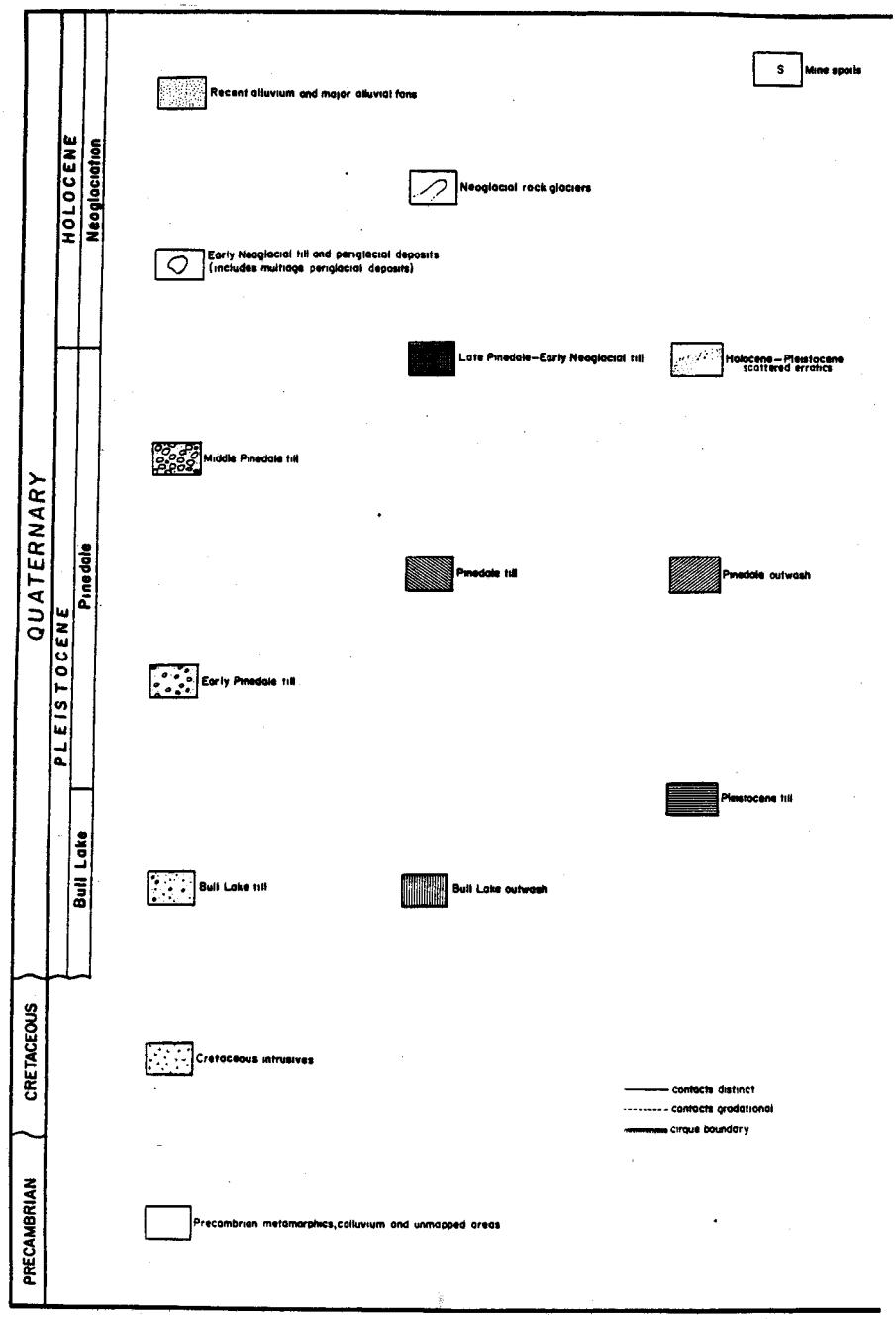


Figure 2a. Explanation for Figures 2, 4, and 6.

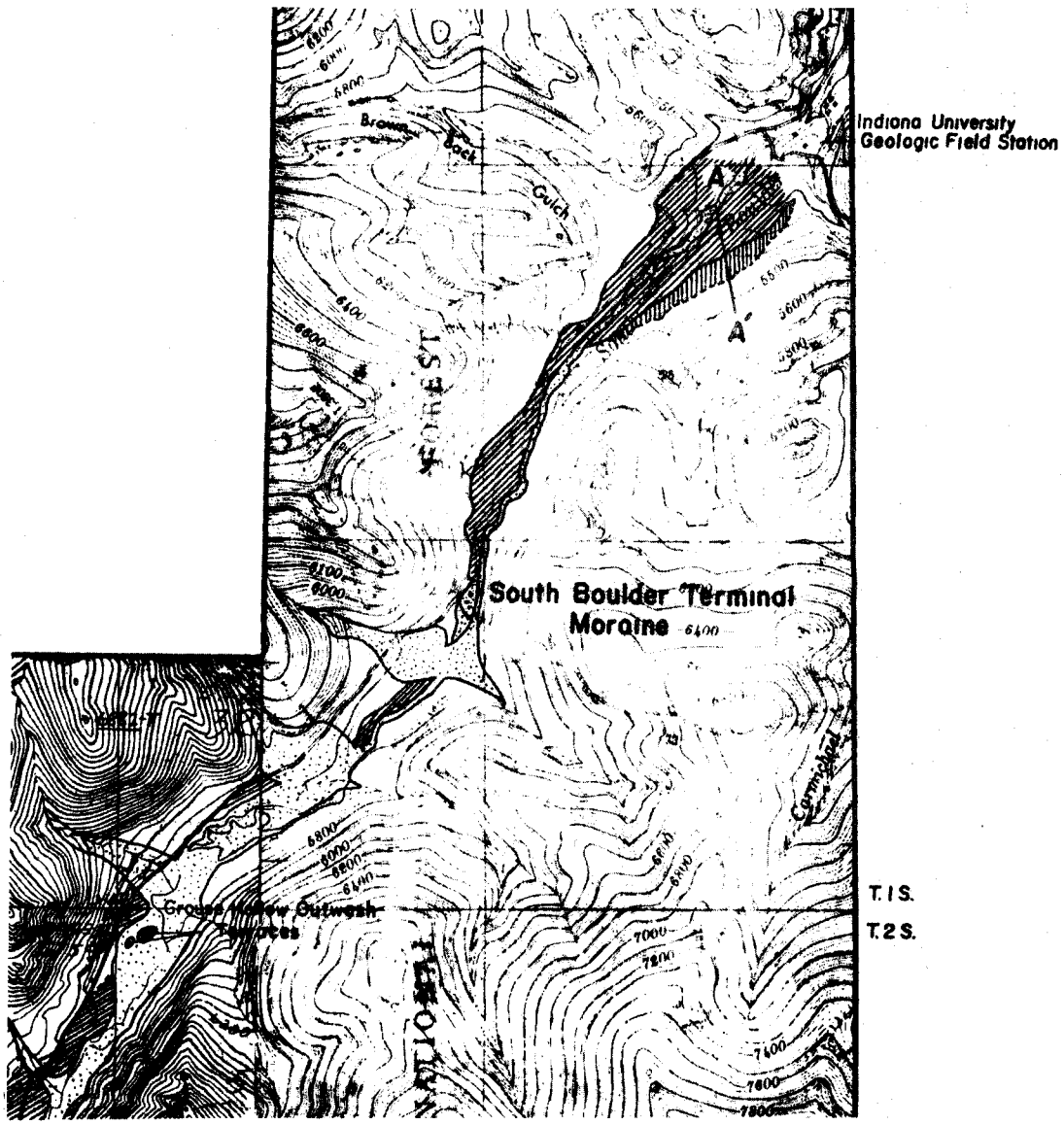


Figure 2b. Geologic map showing the distribution of glacial deposits along the northern portion of the road log. Taken from Roy (1980).

Hand-dug excavations at the crest of the moraine were used to study the post-Bull Lake soil and to collect soil samples for laboratory analysis. One soil pit has been left open for study. The most diagnostic properties differentiating Bull Lake tills from Pinedale tills are the characteristics of the B horizons of the soils. The B horizons of the post-Bull Lake soil at this location (Table 1 and Fig. 3) are clay-rich (having about three times more clay than the underlying C horizons) and exhibit reddish 7.5YR colors resulting from the accumulation of free iron oxides (Fig. 3). Also, soil structure development (Table 1) is strongest in post-Bull Lake soils as compared to the post-Pinedale soils upvalley.

Table 1: Soil Profile of the South Boulder Bull Lake terminal moraine

A_1	(0-16 cm) mollic epipedon; gravelly loam (18% clay) medium subangular blocky to coarse granular to single grain structure; 10YR 4/2 (dry), dark grayish brown; 10YR 3/2 (wet), very dark grayish brown; pH 6.5
$B_{21}tir$	(16-26 cm) agrillic horizon; gravelly loam (19% clay) medium subangular blocky, weak clay skins on peds; 7.5YR 5/6 (dry), strong brown; 10YR 3/3 (wet) dark brown; pH 6.5
$B_{22}tir$	(26-50 cm) gravelly loam to sandy loam, (6-12% clay); medium subangular blocky; 7.5YR 5/6 (dry) strong brown; 7.5YR 4/6 (wet) strong brown; pH 7.0
IIC_1	(50-85 cm) gravelly sand to sand, (3-5% clay); 10YR 5/6 (dry) yellowish brown; 10YR 5/4 (wet) yellowish brown; pH 7.0
IIC_2	(85-(110) cm) loamy sand (3% clay); 10YR 5/4 (dry) yellowish brown; 10YR 4/3 (wet) dark brown; pH 7.0

3.0 Grouse Hollow Outwash terraces (Fig. 2). About 1.2 miles upvalley from the Bull Lake moraine are three conspicuous mounds that could be easily mistaken for moraines. However, a roadcut made through one of the mounds by a recent logging access trail on the left side of the main road reveals clast-on-clast contact, characteristic of outwash. The deposits are remnants of an outwash terrace of Pinedale age that was dissected by post-glacial fluvial erosion.

3.6 Broad outwash plain.

4.2 A heavily eroded and indistinct early Pinedale moraine (the Bridge moraine) is located to the right (Fig. 4).

4.8 Mine spoils to the left.

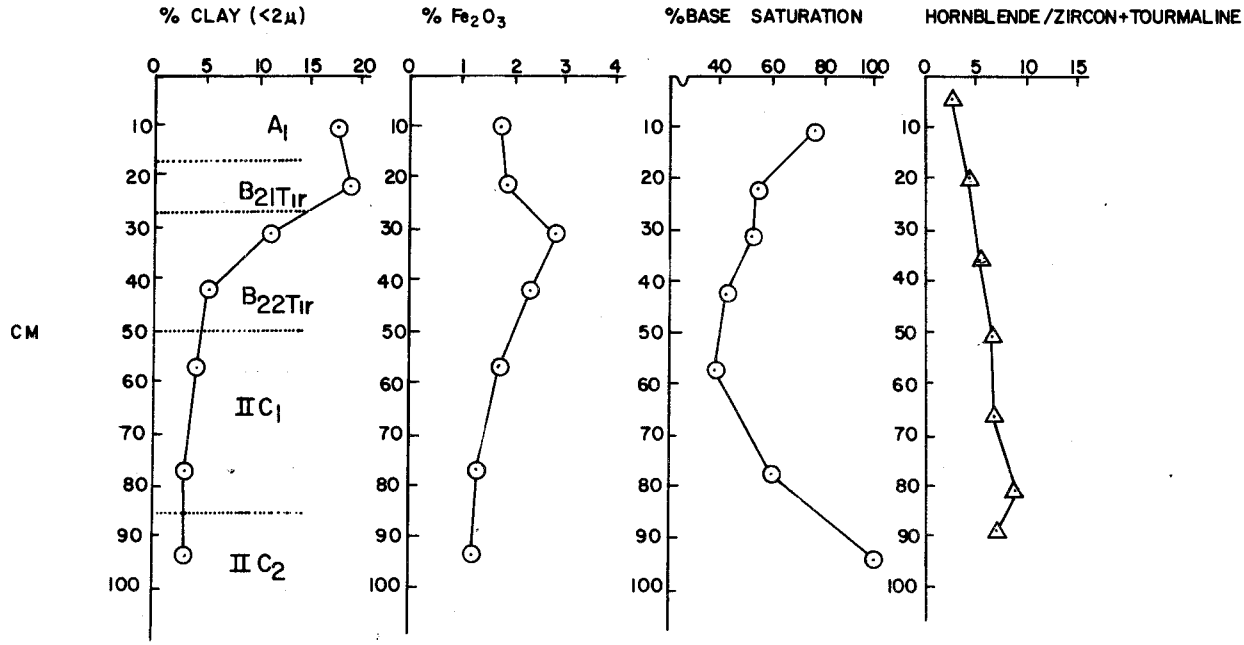


Figure 3. Clay, free iron oxide, base saturation and heavy minerals distribution of the Bull Lake moraine in the South Boulder valley.

5.0 Entrance to the Mammoth community.

5.4 STOP 2: The Mammoth moraine is located to the right across the South Boulder River (Fig. 4). A greenhouse is located near the center of this early Pinedale moraine. Turn right across the bridge. This will lead to a road just below the east side of the moraine.

This till deposit is a severely eroded early Pinedale lateral moraine. The early Pinedale ice which deposited this lateral ridge of till was deflected to the west side of the valley by the bedrock ridge just south of the small community of Mammoth. The overall appearance of this moraine is similar to the older Bull Lake moraine, but there is a profound difference in the degree of soil development between the two sites. The horizons are not as well defined as the older Bull Lake site reflecting an age difference of possibly 100,000 to 125,000 years (Roy and Hall, 1981). The B horizon is poorly developed (Table 2) and lacks the reddish colors found at the older site. The distribution of clay and free iron oxides (Fig. 5) is almost uniform throughout the profile.

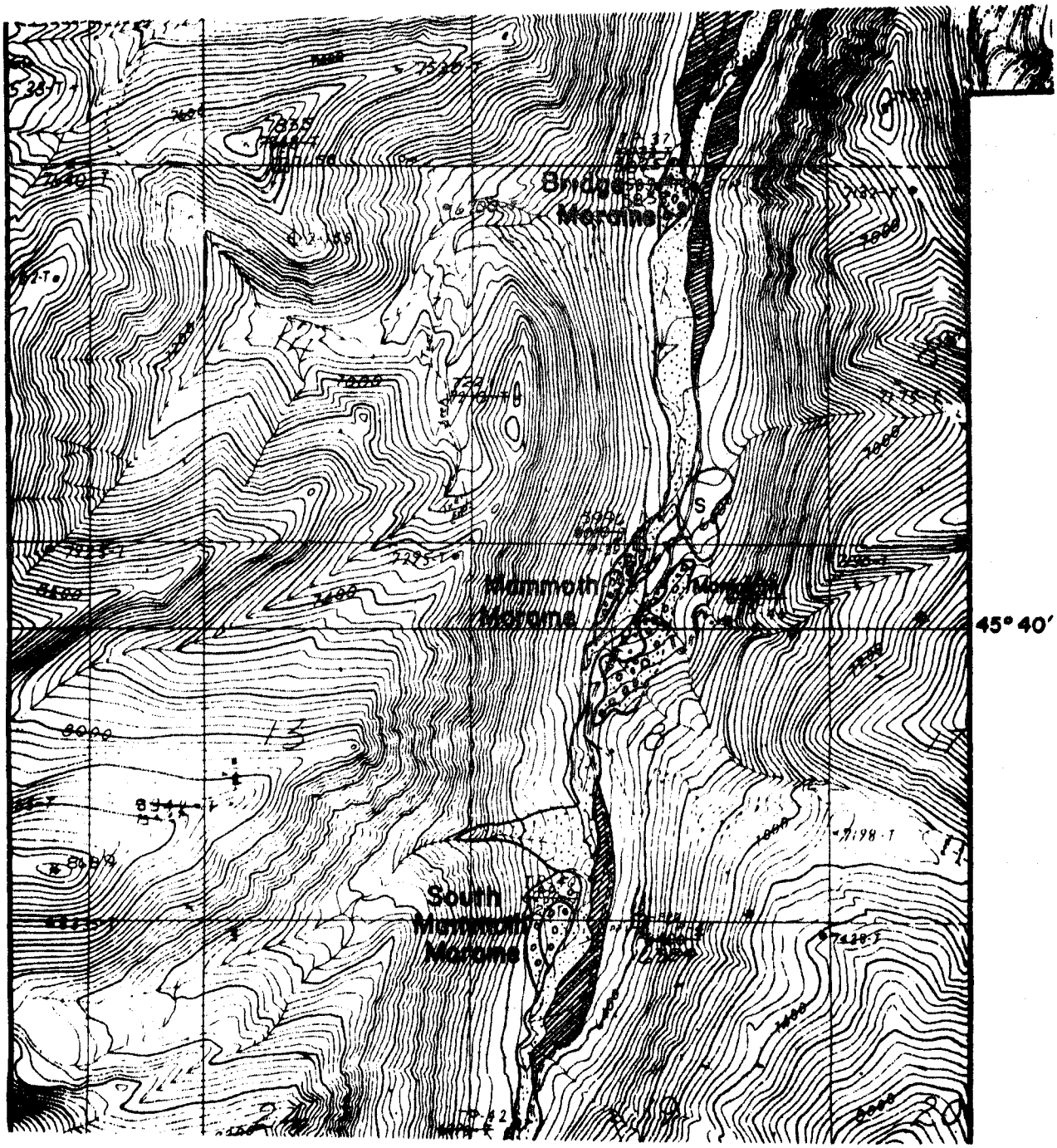


Figure 4. Geologic map showing the distribution of glacial deposits along the central portion of the road log. Taken from Roy (1980). See Fig. 2a for legend.

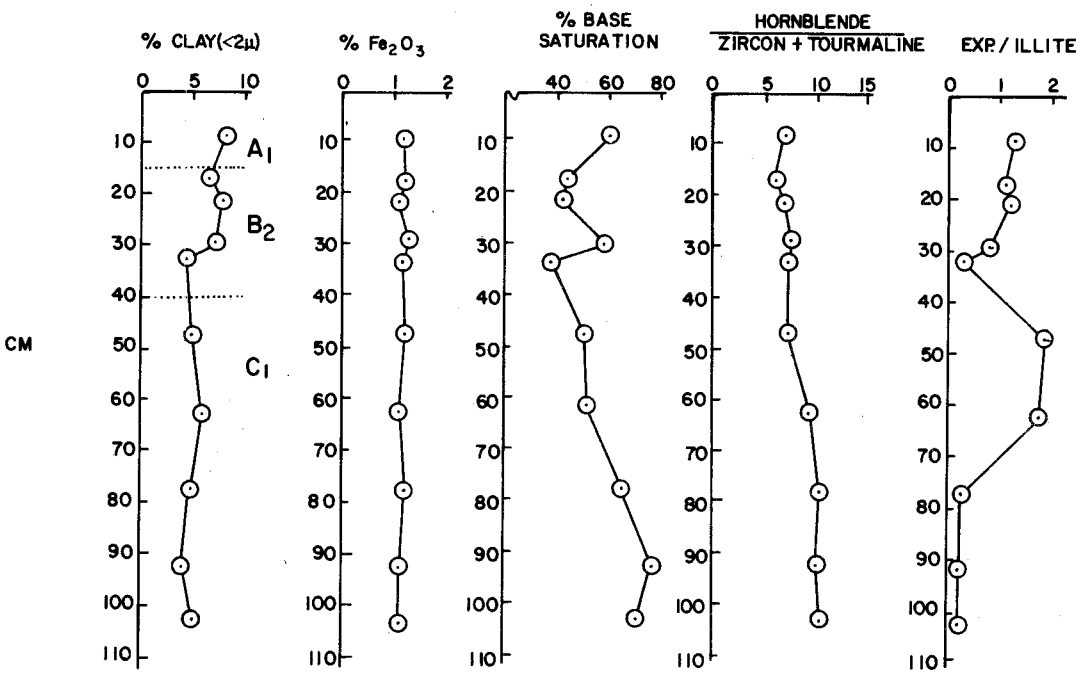


Figure 5. Clay, free iron oxide, base saturation, heavy minerals & clay minerals distributions of the Mammoth moraine (early Pinedale).

7.9 Spring moraine (Fig. 6). This middle Pinedale lateral moraine is the largest moraine in the South Boulder Valley. It is approximately 0.5 km in length and is oriented parallel to the axis of the main valley.

8.4 STOP 3: This is the South Curly Creek moraine (Fig. 6) which is also of middle Pinedale age. Park along the main road. Middle Pinedale moraines are relatively larger than the older Bull Lake and early Pinedale moraines downvalley. Also, the surfaces of the younger tills are more profusely covered with clasts than the older surfaces. However, there are few differences in the soil morphology between early and middle Pinedale tills. An excavation at this site revealed a soil profile (Table 3) similar to the early Pinedale site (Table 2). As with most post-Pinedale soils, the horizonation is weak, often requiring analytical data (Fig. 7) to establish clear horizon boundaries. The boundary between the B horizon and C horizon can be best estimated in the field by looking for subtle color changes in moist hand sample. This lack of distinctive B horizons in typical post-Pinedale soils may have been the basis for the premature conclusion by Jacobs (1967) that B horizons are absent from all soils associated with tills in the South Boulder valley.

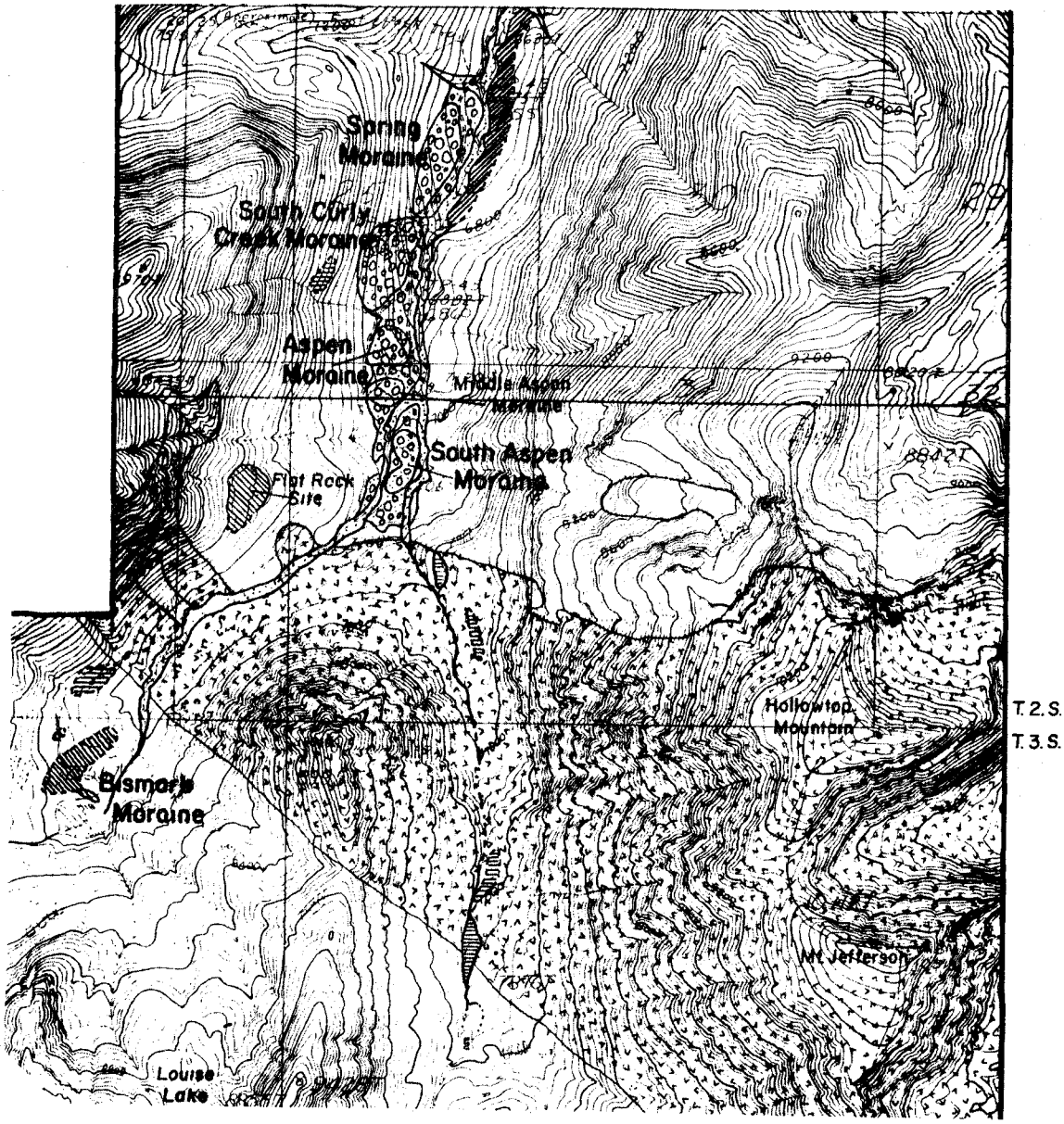


Figure 6. Geologic map showing the distribution of glacial deposits along the southern portion of the road log. Taken from Roy (1980). See Figure 2a for legend.

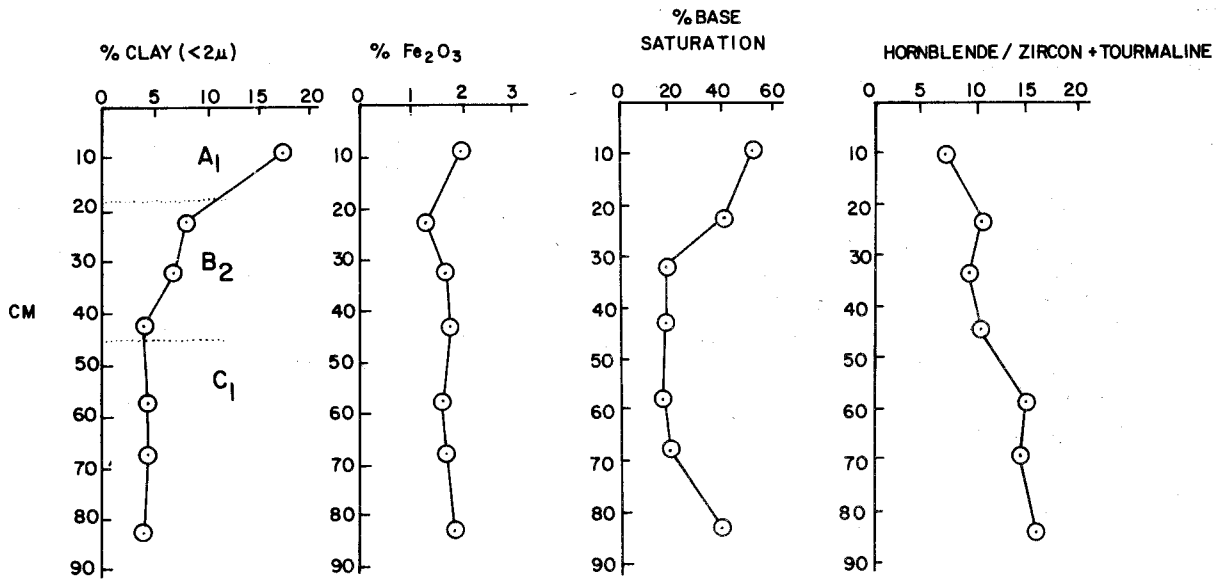


Figure 7. Clay, free iron oxide, base saturation and heavy minerals distributions of the South Curly Creek moraine (middle Pinedale).

Table 3: Soil Profile of the South Curly Creek moraine (middle Pinedale)

A_1	(0-18 cm) mollic epipedon; gravelly loam (19% clay); weak fine subangular blocky to single grain; 10YR 2/2 (dry) very dark brown: 10YR 2/2 (wet) very dark brown; pH 6.0
B_2	(18-45 cm) cambic horizon; gravelly sandy loam (4-8% clay); weak to moderate medium subangular blocky to single grain; 10YR 4/4 (dry) dark yellowish brown; 10YR 3/3 (wet) dark brown; pH 6.0
C_1	(45-(100) cm) gravelly sandy loam (4-5% clay); single grain; 10YR 3/6 (dry) dark yellowish brown; 10YR 3/3 (wet) dark brown; pH 6.0

8.5 Y in road. Turn right.

8.7 STOP 4: The Aspen moraine (Fig. 6) is located to the right. The perimeter of this middle Pinedale moraine is fairly well delineated by a grove of Aspen trees. Park along the road. Note the preserved morainal morphology (i.e., the classical arc-shaped ridge). The soil profile revealed by the excavation at the site (Table 4) has a solum 30 cm in thickness which is 15 cm less than the solum at STOP 3. There is a gradual decrease in solum thickness with decreasing age of till. However, solum thickness is not a strong criteria for relative age dating in this area (Roy and Hall, 1981). There is a substantial amount of clay in the upper 3 cm (Fig. 8) which has been attributed to a loess influence.

Table 4: Soil Profile of the Aspen moraine (middle Pinedale)

A_1	(0-13 cm) umbric epipedon; gravelly silt loam (11-17% clay); crumb to single grain; 10YR 2/2 (dry), very dark brown; 10YR 2/2 (wet) very dark brown
B_2	(13-30 cm) cambic horizon; gravelly sandy loam (5% clay); crumb to single grain; 10YR 3/4 (dry) dark yellowish brown; 10YR 3/3 (wet) dark brown
C_1	(30-(100) cm) gravelly sandy loam (4-6% clay); 10YR 4/4 (dry) dark yellowish brown; 10YR 3/4 (wet) dark yellowish brown

9.1 There are two other small middle Pinedale moraines located near the fork of the river (Middle and South Aspen moraines) which are not readily visible from the road.

9.8 Y in the road. Road to left leads to Bismark Mine. Stay right.

10.3 Y in the road. Turn left towards Bismark Reservoir. This road is moderately rough and it may be necessary during wetter months to park vehicles in the lower valley and walk along the road over the bedrock ridge to the reservoir. Leave by same route as first traveled. Turn right at intersection and head northward.

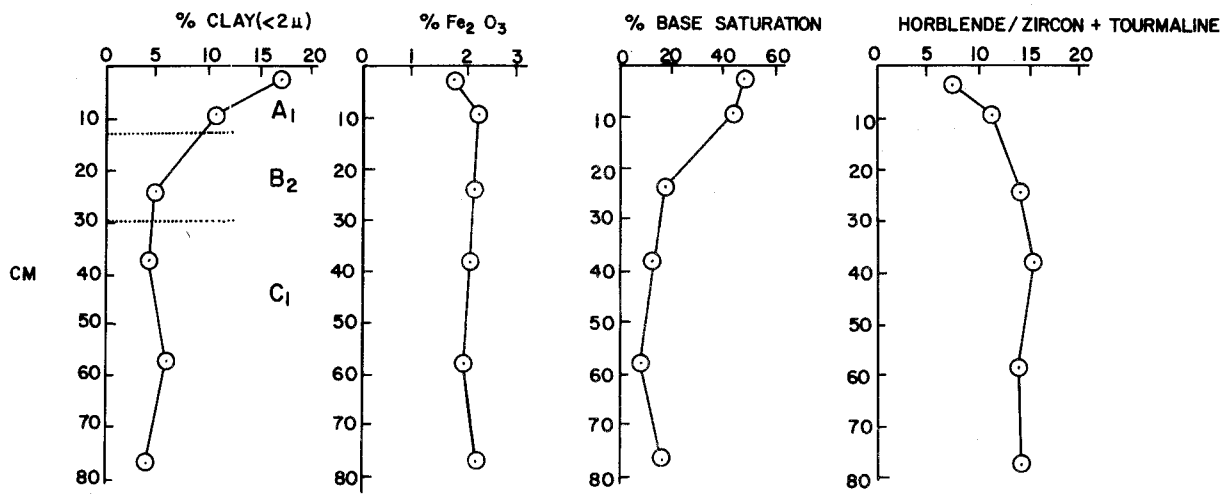


Figure 8. Clay, free iron oxide, base saturation and heavy minerals distributions of the Aspen moraine (middle Pinedale).

10.6 STOP 5: To the left side of the lake is the Bismark moraine, a small ridge of till between the forest boundary and the lake (Fig. 6). The orientation of this moraine is perpendicular to the main valley and it was deposited by ice from the Lake Louise cirque which now contains Louise Lake (Fig. 6). Soil investigations made to determine the relative age of the till presented an enigma with respect to post-Pinedale soil development (Table 5). The soil pit is located along the center of the small ridge. The soil developed here has argillic horizons and reddish colors corresponding to a free iron oxide enrichment of nearly 10 percent (Fig. 9). These data taken together with other relative age parameters including heavy mineral ratios (Roy, 1980) and clay mineral ratios (Roy and Hall, 1981) suggested that this till is as weathered as the Bull Lake till downvalley. However, it is difficult to conceive that this tributary valley would not have also contained Pinedale ice, thus obscuring any Bull Lake tills that may have existed.

The apparent age of this Pinedale till may be the result of its thickness of less than one meter (Fig. 9). The thin vaneer of till is stratigraphically above an eroded pre-Pinedale paleosol with an argillic horizon and a free iron ozide content of 27 percent developed in Precambrian gneiss. Between the till and residual soil is a mixed zone (Fig. 9). Apparently some of the paleosol was incorporated into the till by the Pinedale ice. The high-clay paleosol may have retarded the downward percolation of water, creating a locally perched water table. The excess water may have accelerated the degree of weathering compared to other Pinedale tills. The

free iron oxide content of the paleosol may account for the 7.5YR colors in the post-Pinedale above. Well-developed reddish B_{2t} horizons are unexpected in Pinedale tills. This stop provides the opportunity to study an anomalous post-Pinedale soil and compare this site with the Pinedale sites considered "typical" downvalley.

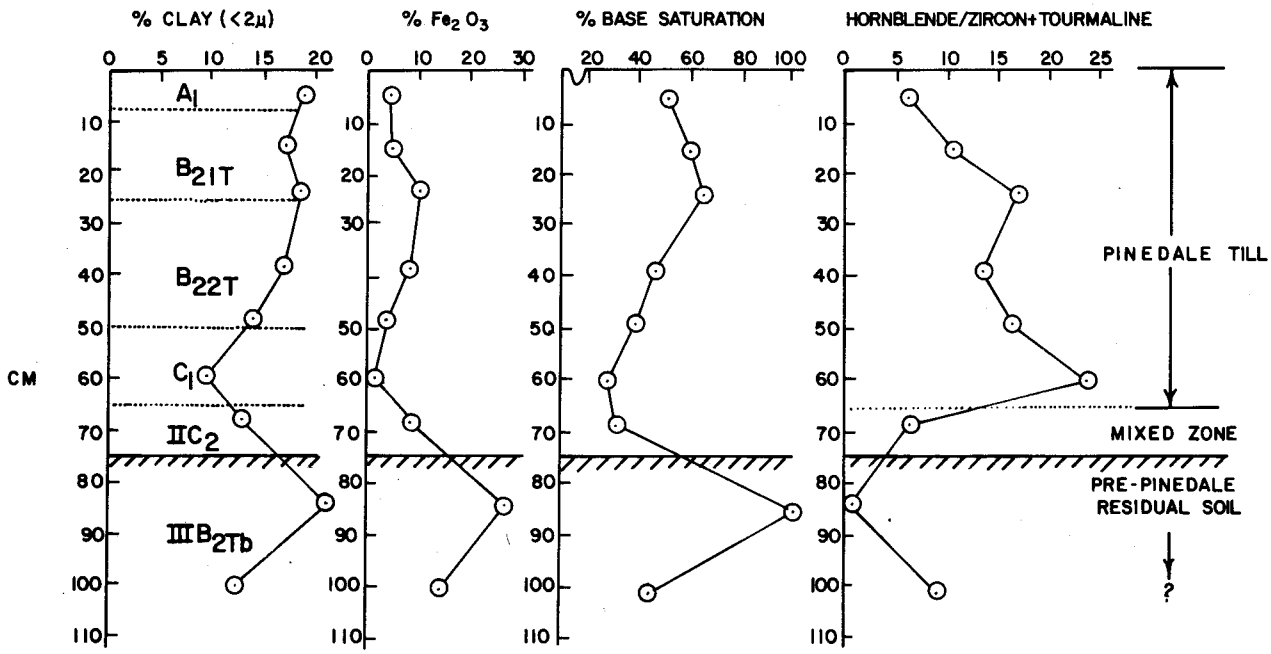


Figure 9. Clay, free iron oxide, base saturation, and heavy minerals distribution of the Bismark moraine (Pinedale).

Table 5: Soil Profile of the Bismark moraine

A_1	(0-8 cm) mollic epipedon; gravelly loam (19% clay); weak medium subangular blocky; 10YR 4/2 (dry) dark grayish brown; 10YR 3.5/2 (wet) very dark grayish brown; pH 6.3
$B_{21}tir$	(8-25 cm) argillic horizon; gravelly loam (17% clay); moderate medium subangular blocky, faint clay skins; 7.5YR 5.5/4 (dry) light brown; 7.5YR 4/4 (wet) brown-dark brown; pH 5.8
$B_{22}tir$	(25-50 cm) argillic horizon; gravelly loam (14-18% clay); moderate medium subangular to angular blocky; 7.5YR 5.5/4 (dry) light brown; 7.5YR 4/4 (wet) brown-dark brown; pH 5.8
C_1	(50-65 cm) gravelly sandy loam (10% clay); coarse subangular blocky; 10YR 6/3 (dry) pale brown; 10YR 3/3 (wet) brown; pH 5.8
IIC_2	(62-75 cm) sandy loam (13% clay); weak coarse subangular blocky; 10YR 6/3 (dry) pale brown; 10YR 3/3 (wet) dark brown; pH 6.5
$IIIB_{2tirb}$	(75-130 cm) loam (12-21% clay); moderate medium subangular blocky; 7.5YR 6/6 (dry) reddish yellow; 7.5YR 5/6 (wet) strong brown; pH 7.0
$IIIC_{1cab}$	(130-(150) cm) gravelly loamy sand; single grain; strong reaction, caliche coatings on rocks; 7.5YR 6/4 (dry) light brown; 7.5YR 5/6 (wet) strong brown; pH 8.0

End of Road Log

ACKNOWLEDGMENTS

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