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GEOLOGICAL AND NATURAL HISTORY SURVEY
Meredith E. Ostrom, State Geologist and Director

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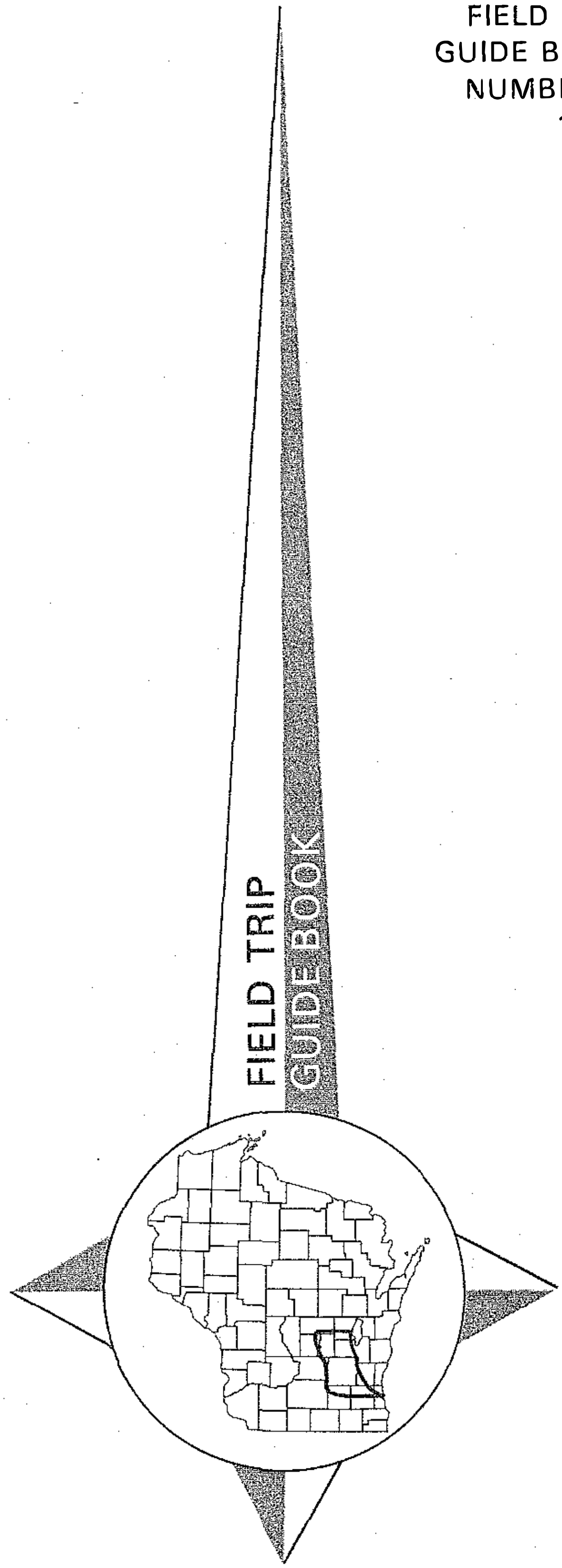

PRECAMBRIAN INLIERS IN SOUTH–CENTRAL WISCONSIN

Prepared for:
TWENTY-FOURTH ANNUAL MEETING
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OMISSIONS

Field Trip Guide Book Number 2 - Precambrian Inliers in South-Central Wisconsin

In preparation for publication, the bar scales were inadvertently left off the following figures.

Figure 14 (p. 59)	Photomicrograph of Marcellon rhyolite ash-flow tuff. Horizontal dimension, 3.3 mm.
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Field Trip Guide Book
Number 2

University of Wisconsin-Extension
GEOLOGICAL AND NATURAL HISTORY SURVEY
Meredith E. Ostrom, State Geologist and Director

PRECAMBRIAN INLIERS IN SOUTH-CENTRAL WISCONSIN
(companion volume to Geoscience Wisconsin Volume 2)

With contributions by

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INTRODUCTION

Eugene I. Smith[1]

For the past seventy years very little attention has been paid to the igneous rock in the Fox River Valley. At the turn of the century well known geologists such as Irving, Chamberlin, Weidman. Leith and Hobbs described these isolated exposures of Precambrian rock. Between 1907 and 1972 few geological studies were initiated. The last major field trip to visit these Precambrian rocks was conducted by A. Leith in 1935 for the Kansas Geological Society. While the geology that will be shown to you on this Lake Superior Institute field trip is based for the most part on geological studies completed since 1972, descriptions of the Observatory Hill rhyolite and the Waterloo Quartzite rely considerably on the earlier work. This field trip is intended to introduce you to the rock types and the rock fabric formed during a major post-Penokean igneous event (1765 m.y. ago) and to demonstrate the structural style of a post-Penokian deformation (1650 m.y. ago?). The field trip stops are arranged in stratigraphic order from oldest to youngest (fig. 1). Since the exposures are on the flank of the Wisconsin Arch, travelling to the southeast off the crest of the arch conveniently exposes younger units.

The first stop is at the Flynn's Granite Quarry. Here fine-grained granophyric granite is cut by granite porphyry and metabasalt dikes. The granite probably is the subvolcanic equivalent of the rhyolites to be viewed at stops 2, 3, and 4.

Observatory Hill (stop 2) is formed by a sequence of steeply dipping porphyritic rhyolite ash-flow tuffs which erupted from source chambers now represented by granite cropping out to the northwest (Flynn's Quarry, Montello and Redgranite). The rhyolite is cut by fine- and coarse-grained rhyolite dikes and is surrounded by exposures of Cambrian sandstone.

Stops 3 and 4 (The Marcellon and Marquette rhyolites) display the fabric and mineralogy of the texturally variable rhyolites. In the volcanic section sparsely-porphyritic plagioclase-bearing rhyolite commonly alternates with porphyritic quartz, plagioclase, alkali feldspar rhyolite. The rocks show fabrics common to ash-flow tuffs that have undergone compaction, welding and late-stage primary laminar flowage (eutaxitic and spheruloidal textures and large flow folds).

The Waterloo Quartzite (stop 5), the youngest exposed Precambrian rock in south-central Wisconsin, is folded into a broad eastward plunging syncline. The nose of the structure lies in the Portland area near the quarry visited during stop 5.

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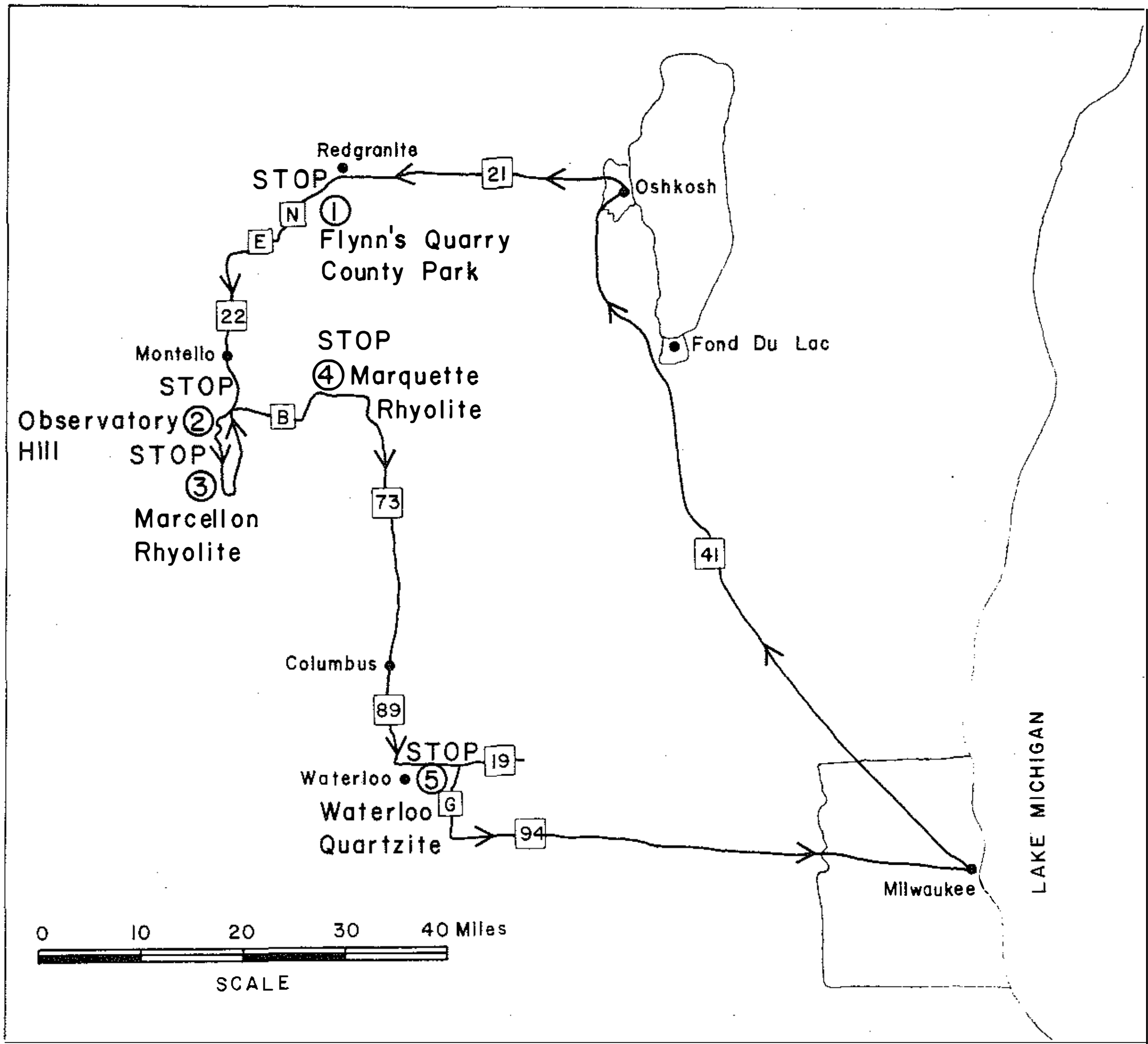

Figure 1. Route for the Lake Superior Institute field trip to the south-central Wisconsin Precambrian rhyolite and granite inliers.

I thank Pattie Fields-Troha for typing draft copies of these stop descriptions and Jill Ann Hartnell for drafting the figures. Diane Pyper made many useful editorial corrections that helped smooth out the rough spots. I also thank Frank Luthur (University of Wisconsin-Whitewater) for an informative discussion on the metamorphic rocks from Waterloo.

Participants on this trip will traverse the scenic, glaciated countryside of southeastern and south-central Wisconsin to study isolated exposures of Precambrian granite, rhyolite, and quartzite that project through a cover of Paleozoic rocks and Pleistocene drift (Fig. 1).

Board bus at 6:30 P.M. sharp on Friday May 12, 1978 in the front of the Pfister Hotel (Headquarters for the 24th Annual Lake Superior Institute). Our route of travel will follow U.S. 41 to Oshkosh, Wisconsin. A geological roadguide for this part of the trip is provided. Overnight accommodations will be at the Pioneer Inn, on the west shore of Lake Winnebago in Oshkosh

On Saturday May 13, 1978, board the bus in front of the Pioneer at 8:00 A.M. sharp. The guidebook includes a geologic roadguide for the field trip route, as well as detailed information on each of the geologic stops. This field excursion will terminate at the Pfister Hotel in Milwaukee about 6:30 P.M.

A companion volume to this Geoscience Wisconsin Volume 2, contains papers by Smith (1978c), Van Schmus (1978) and Haimson (1978) on the geology, ages, and engineering properties of the granites, rhyolites and quartzites.

Friday, May 12, 1978

Geologic Road Log for U. S. 41 from the Intersection of Wisconsin 74 Menomonee Falls at the North Edge of Waukesha County to Oshkosh, Wisconsin (junction Wisconsin 21)

Richard A. Paull[1] and Rachel K. Paull[2]

U. S. 41 trends north-northwesterly through the glaciated Eastern Ridges and Lowlands Province of Wisconsin. The orientation of this route is such that it cuts obliquely across the strike of the Paleozoic formations. From south-southeast to the north-northwest, these units include Silurian dolomite, Upper Ordovician Maquoketa Shale, and the Middle Ordovician Platteville-Galena formations. However, the bedrock along the highway is largely obscured by Wisconsinan (Woodfordian and the younger Valderan) glacial deposits. An exception exists along the crest of the prominent Niagaran (Silurian) escarpment, where glacial deposits are thin.

Woodfordian glacial features are well-displayed along U. S. 41. Included are a recessional moraine related to retreat of the Lake Michigan lobe, kames and kettles associated with the spectacular Kettle Interlobate Moraine, and well-formed drumlins within the area occupied by the Green Bay lobe. Deposits that accumulated in Glacial Lake Oshkosh when retreat of the last Wisconsinan (Valderan) ice tongue blocked northeastward drainage into Green Bay are also traversed.

Details on the geology encountered along U. S. 41 are provided in the geologic road log that follows. We hope this will help to make your journey more enjoyable. Mileages in the road log are cumulative, with mileage increments between each entry included in brackets.

Mileages

0 (2.0) — Wisconsin 74 exit from U. S. 41 to downtown Menomonee Falls. Continue northwest on U. S. 41 and 45 toward Oshkosh, the location of our "watering hole" for this evening.

Lime Kiln Village Park is about one mile west in the heart of the business district of Menomonee Falls. Here, the Silurian dolomite forms a small falls on the Menomonee River. Dolomite was quarried here for lime production as early as the 1850's, and three historic kilns are preserved within the park. Glacial striae on the Silurian bedrock in the vicinity of the kilns establish an east-west flow direction for advance of the Lake Michigan glacial lobe during the Woodfordian.

2.0 (5.0) — Waukesha/Washington county line. Enter Washington county in an area of folling countryside, on the northwestern edge of the intensely

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[2]The University of Wisconsin-Madison, Madison, Wisconsin; and Alverno College, Milwaukee, Wisconsin

urbanized, greater Milwaukee area. This region was last glaciated during the Woodfordian by the advance of the Lake Michigan lobe. The outermost (oldest) of a series of three, major ridge-forming recessional moraines (Lake Border Moraines), which parallel the shore of Lake Michigan in the Milwaukee area, trends through this area.

To the west, one catches glimpses of the irregular hills of the Woodfordian interlobate moraine that developed between the Lake Michigan lobe on the east and the Green Bay lobe on the west. This is the Kettle Interlobate Moraine, which trends north-northeast from Walworth County to Kewaunee County to form the glacial backbone of eastern Wisconsin. Northwest-trending U.S. 41 is on a collision course with this prominent topographic feature.

7.0 (1.0) Wisconsin 167 (Holy Hill Road) exit; continue on U.S. 41 and 45. Holy Hill, a prominent kame topped by a picturesque church, is located about 7 miles west of here within the heart of the Kettle Interlobate Moraine.

8.0 (4.0) U.S. 45 exit to West Bend; continue north on U.S. 41.

12.0 (1.0) The highway ascends the eastern edge of the Kettle Interlobate Moraine, and leaves the lowland occupied by the Lake Michigan lobe during the Woodfordian advance. This country is higher and more irregular, with kettles and abundant locally derived erratics of light-colored Silurian dolomite.

13.0 (1.0) Wisconsin 60 exit to Slinger and Hartford within the Kettle Interlobate Moraine.

14.0 (0.4) The Hilltop Restaurant on the west side of the highway is well named, for it occupies the crest of the Kettle Interlobate Moraine. The scenic kettle and kame topography that characterizes this region formed when the Green Bay and Lake Michigan glacial lobes stagnated along their junction during the Woodfordian. As the ice at the melting edges of these juxtaposed lobes began to thin, sediment-laden meltwater flowed down cracks and holes in the ice to provide a source for subglacial streams. Meltwater also cascaded over the ice surface into the widening abyss between the tongues. Here, large chunks of ice were buried in the outwash sands and gravels. The resulting maze of crevasse fills, moulin kames, eskers, outwash fans, and kettles is superimposed on a dual complex of ridges which had previously formed as lateral moraines.

14.4 (0.9) Little Switzerland Ski Hill, to the west of the highway at the edge of Slinger, utilizes a prominent moulin kame. The internal makeup of a similar kame is revealed in an abandoned sand and gravel operation about 0.1 mile north of the ski hill. The gravel in this kame is well-stratified, and it includes an abundance of light-colored Silurian dolomite cobbles and a few large boulders. Other well-formed kames are present east of the highway.

Mileages

15.3 (1.7)	Junction U.S. 41 and Wisconsin 144. Continue north on U.S. 41.
17.0 (0.8)	Junction U.S. 41 and County K. The highway descends from the Interlobate Moraine toward the lowland area occupied by the Green Bay lobe during the Woodfordian ice advance.
17.8 (3.5)	The sand and gravel pit west of the highway is on the northwestern edge of the Kettle Interlobate Moraine. This is one of many such operations that exploit the abundant resource of water-washed sand and gravel within this unique morainal complex. The route ahead traverses gently rolling, poorly-drained ground moraine. Tamaracks flourish in some of the wetter areas.
21.3 (1.7)	Junction U.S. 41 and Wisconsin 33; continue north on U.S. 41. The route crosses a recessional moraine that formed as the Woodfordian Green Bay lobe paused during its retreat.
23.0 (4.0)	Wayside east of the highway is in an area of swampy, rolling ground moraine.
27.0 (2.5)	This high area provides an excellent overview of scenic, irregular countryside. An abundance of erratics in the till here is documented by stone fences that line some fields, and by rock piles in others.
29.5 (0.6)	Junction U.S. 41 and Wisconsin 28. Continue north on U.S. 41.
30.1 (1.9)	Dodge/Washington county line. Enter Dodge County in an area dominated by large, well-formed drumlins. Erratics in fence rows and farmyards testify to the stony nature of this till.
32.0 (0.4)	Wayside east of the highway.
32.4 (1.6)	Wayside west of the highway.
34.0 (2.4)	Junction U.S. 41 and Wisconsin 67. Continue north on U.S. 41. The route ahead gradually climbs the gentle (2°-5°), easterly dipslope of the resistant Silurian dolomite. However, the bedrock in this region is covered by a swarm of broad, low drumlins that create a gently rolling landscape.
36.4 (1.0)	Junction U.S. 41 and Wisconsin 49. Continue north on U.S. 41.
37.4 (1.4)	Fond du Lac/Dodge county line. Enter Fond du Lac County.
38.8 (0.5)	Sand and gravel operations on both sides of the highway utilize a local area of outwash deposits.
39.3 (2.7)	Roadcut on the west side of the highway exposes Silurian dolomite where glacial deposits are thin. The proximity of bedrock to the

surface has facilitated the development of numerous dolomite quarries in this general area. This rock is an excellent dimension stone, but most of it is crushed for agricultural lime and road building. However, some is kilned to produce chemical lime.

This high point provides a good view of the north-northeasterly trending Kettle Interlobate Moraine along the skyline to the east. A lowland region, developed on relatively nonresistant Middle and Upper Ordovician rocks, lies to the west.

42.0 (0.6) Large quarries in Silurian dolomite are located east and west of U.S. 41.

42.6 (2.0) This is the edge of the Silurian (Niagaran) escarpment, and it provides a fine view of the Ordovician lowland ahead. This excarpment (or cuesta) is the most significant bedrock feature in eastern Wisconsin. It emerges from a thick cover of glacial deposits a few miles northeast of Milwaukee, and trends north-northeast as a prominent cliff along the east side of Horicon Marsh and Lake Winnebago. From here, the escarpment persists northeastward to form the rocky spine of the Door Peninsula. It continues across Lake Michigan as a string of bedrock islands before it rises as the rugged Garden Peninsula of Upper Michigan.

The route ahead descends toward the Ordovician lowland through an area of gently rolling ground moraine.

44.6 (0.6) The highway in this vicinity crosses the ill-defined terminal moraine of the latest Wisconsinan (Valderan) ice advance of the Green Bay lobe.

The wooded edge of the Silurian escarpment is visible along the skyline to the east.

45.2 (1.8) Junction U.S. 41 and Wisconsin 175 to Fond du Lac, at the south end of Lake Winnebago. Continue northwest on U.S. 41.

Lake Winnebago, with a surface area of 215 square miles and a maximum depth of 21 feet, is the largest inland lake in Wisconsin. It sprawls for 28 miles along the west edge of the Silurian escarpment, and is situated in an area underlain by relatively nonresistant Middle and Upper Ordovician rocks. This lowland extends from Green Bay southwestward through Lake Winnebago, Horicon Marsh, and over a low drainage divide into the broad valley now occupied by the Rock River. During the Pleistocene, the Green Bay lobe advanced and retreated along this route numerous times. The ice, in part confined by the resistant Silurian escarpment, scoured the Ordovician bedrock and deposited a variety of glacial landforms. During northeastward regressions of the Woodfordian and Valderan glaciers, drainage along the lowland into Green Bay was temporarily blocked by the retreating wall of ice. A vast lake, termed Glacial Lake Oshkosh, formed from the meltwaters impounded behind the youngest (Valderan) of these icy dams. At this time, the site of Fond du Lac was under 40 to 60 feet of water. Eventually Green Bay became ice free, and Glacial Lake Oshkosh drained into Lake Michigan via the

Mileages

Fox River. Lake Winnebago is a remnant of this feature, surviving in a shallow irregularity on the floor of this ancient water body.

Cross east branch of Fond du Lac River.

47.0 (1.8) Junction U.S. 41 and U.S. 151. Continue north on U.S. 41. The route ahead traverses a relatively subdued area underlain by sediments deposited in Glacial Lake Oshkosh.

48.8 (4.2) Junction U.S. 41 and Wisconsin 23. Continue northwest on U.S. 41.

The wooded Silurian escarpment continues to dominate the horizon to the east.

53.0 (4.0) Wayside west of the highway, as U.S. 41 curves northward.

57.0 (1.7) Highway ascends to reddish, rolling Valderan ground moraine at the western edge of Glacial Lake Oshkosh.

58.7 (3.2) Fond du Lac/Winnebago county line. Enter Winnebago County in an area of rolling ground moraine. There is a good view to the east of the Silurian escarpment along the far shore of Lake Winnebago. The route from here to Oshkosh traverses reddish sediments deposited in Glacial Lake Oshkosh.

61.9 (0.7) Wayside east of the highway.

62.6 (2.7) Junction U.S. 41 and Wisconsin 26. Continue north on U.S. 41 through a subdued area underlain by flat-lying glacial lake deposits.

65.3 (2.9) Junction U.S. 41 and Wisconsin 26 and 44 to Oshkosh. Continue north on U.S. 41. Oshkosh, on the west shore of Lake Winnebago, is developed on the ancient floor of Glacial Lake Oshkosh.

68.2 Junction U.S. 41 and Wisconsin 21. The geologic roadguide for the Precambrian inliers field trip begins at this intersection, and continues westward on State 21.

END OF LOG - HAVE A PLEASANT EVENING!

Saturday, May 13, 1978

Geologic Road Log for a Field Excursion to Precambrian Rhyolite and Granite Inliers of South-Central Wisconsin

Rachel K. Paull[1] and Richard A. Paull[2]

This road log starts at the intersection of U. S. 41 and Wisconsin 21 on the northwestern edge of Oshkosh, Wisconsin, and terminates in Milwaukee, Wisconsin at the junction of I-94 with I-43 (U. S. 141) and I-794 (see Fig. 1).

The route of travel on this trip is due west from Oshkosh for 26 miles to Redgranite, and then south-southwest nearly to Portage (Marcellon inlier). Since we detour to look at two Precambrian inliers, this leg involves about 50 miles of travel. From here, we proceed northeast to a rhyolite inlier near Marquette; a distance of 20 miles by road. After a 5 mile segment to the east, our route trends south for 40 miles. From immediately north of Waterloo, we travel eastward for 7 miles to the Waterloo Quartzite, and then south for 8 miles to reach Interstate 94 at Lake Mills. After a fast 50-mile run to the east, we are back in Milwaukee. In all, we will cover 206 miles, make 5 geologic stops, and even stop for lunch (Fig. 1). It will be a busy day!

This odyssey through east-central Wisconsin traverses parts of two of the four major physical provinces recognized in Wisconsin. However, in the area covered by this field excursion, the features of both provinces are masked by young glacial deposits. The Eastern Ridges and Lowlands parallels Lake Michigan. This province contains a sequence of generally north-south striking, Ordovician through Devonian formations, with the older rocks to the west. Differences in resistance of these units result in broad, subdued ridges alternating with lower areas. The Central Plain is a lowland region, developed on Upper Cambrian sandstones, that lies to the west of the Eastern Ridges and Lowlands.

Within the general region of the Central Plain covered by this trip, there are ten localities where Precambrian granite and rhyolite project through a cover of Lower Paleozoic rocks and unconsolidated Pleistocene deposits. The igneous rocks in these inliers are dated at 1765 m.y. old, and they probably formed during the waning stages of the Penokean orogeny. Granite inliers lie northwest of the area where rhyolite is exposed. Although the field relations are not established at present, the rhyolite and granite are generally believed to be comagmatic. If so, the granite is a subvolcanic equivalent of the extrusive rhyolite.

After accumulation of the rhyolite, a thick sequence of Precambrian quartz sandstone and other sedimentary rocks was deposited. After deposition, these rocks and the underlying rhyolite were subjected to an intensive episode of folding, possibly 1650 m.y. ago. Detailed information on the Precambrian history of this region is provided by Eugene I. Smith in the next section of this guidebook.

The five stops on this field excursion provide an opportunity to examine each of the major Precambrian rock types described above. However, rhyolite receives the most emphasis, with three stops devoted to an examination of this diverse rock type.

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The glacial geology of east-central Wisconsin is also spectacular, and quite varied. The trip begins in an area occupied by the youngest Wisconsinan (Vanderan) ice advance, and by lakes which formed during the retreat of this ice. However, most of the route traversed is within the region covered by an older Wisconsinan (Woodfordian) advance of the Green Bay lobe. Deposits formed by this icy tongue include large expanses of glacial lake sediments, recessional moraines related to the retreat of this lobe, outwash sands and gravels, scenic kettle lakes, and some of the best drumlin swarms in the world. All of these features combine to make this region a glacial showcase, and a most pleasant place to spend a field day.

We hope the geologic roadguide that follows makes your trip more enjoyable. Mileages are cumulative, with mileage increments between each entry provided in brackets. Detailed geologic information for each stop is provided by Eugene I. Smith in the next section of this guidebook. It would be beneficial if you would read the detailed descriptions of each area before we stop.

Mileages

0 (2.2) — Start of Geologic Road Log at intersection of U. S. 41 and Wisconsin 21 at the northwestern edge of Oshkosh, Wisconsin. Proceed west on State Highway 21.

Oshkosh is located on the west shore of Lake Winnebago, the largest inland lake in Wisconsin. This shallow lake is a remnant of Glacial Lake Oshkosh, a much larger Pleistocene water body formed when the retreating Valderan ice blocked northeastward drainage along the Green Bay lowland into Lake Michigan. The route ahead traverses lacustrine sediments that accumulated in Glacial Lake Oshkosh.

2.2 (2.6) — Enter an area of higher, gently rolling countryside. This is a Valderan ground moraine and outwash complex that once stood as an island in Glacial Lake Oshkosh.

4.8 (2.2) — Descend from the morainal "island" onto the flat floor of Glacial Lake Oshkosh. Here, the lake sediments are sufficiently well-drained to be intensively farmed.

7.0 (0.7) — This subdued ridge is the western edge of the gentle, east-dipping, Middle Ordovician (Platteville-Galena formations) cuesta. The route ahead descends through the Middle Ordovician St. Peter Sandstone onto a relatively flat surface developed on dolomites of the Lower Ordovician Prairie du Chien Group. However, the bedrock in this area is obscured by glacial deposits.

7.7 (0.3) — Enter Omro on the Fox River. The Fox flows northeasterly to join the southeasterly flowing Wolf River drainage in Lake Butte des Morts. This shallow lake is another remnant of Glacial Lake Oshkosh, and it drains into Lake Winnebago at Oshkosh.

Mileages

The Middle Ordovician St. Peter Sandstone is quarried for foundry sand a few miles south of here near Waukau. This sand is trucked to Berlin for processing, but from 1870-1878, the St. Peter in this area supplied a glass factory in Omro.

8.0 (0.5) The park on the south bank of the Fox River represents intelligent use of the flood plain. Unfortunately, such foresight was not exercised when downtown Omro was developed.

8.5 (2.5) Junction Wisconsin 21 and 116 at the west edge of Omro. Continue on State 21, and cross the Fox River. The route ahead parallels the north side of the swampy Fox River valley for the next few miles.

11.0 (2.8) Another area of rolling Valderan moraine that once stood as an island in Glacial Lake Oshkosh.

13.8 (2.0) Intersection Wisconsin 21 and County K. The gentle ridge just east of this intersection is the easterly-dipping, western edge of the Lower Ordovician Prairie du Chien escarpment. As such, it serves to define the boundary between the Eastern Ridges and Lowlands and the Central Plain.

The bedrock underlying the Central Plain is predominantly sandstone of Late Cambrian age. However, the bedrock in this vicinity is covered by glacial lake sediments.

A quarry developed in the Prairie du Chien dolomite is immediately southeast of this intersection. The glacial deposits here are thin along the edge of the cuesta.

15.8 (1.3) Waushara/Winnebago county line. Enter Waushara County.

17.1 (2.0) Tamarack bogs, like the one north of the highway, are common in poorly-drained localities throughout this region.

19.1 (1.8) The truck-farming area south of the road was a former tamarack bog. When drained by ditching, the peaty bog soils are highly productive. A remnant of the former habitat still exists along the west edge of the tilled land.

The prominent line of northeasterly trending ridges about 3 miles northwest of here is part of the Woodfordian morainal complex. These ridges, which mark the western edge of Glacial Lake Oshkosh, are older than the patches of Valderan till previously traversed.

20.9 (0.3) Junction of Wisconsin 21 with 49. Continue west on 21.

21.2 (5.2) Good view to the northwest of the hilly Woodfordian drift. The pinkish to red soils adjacent to the road are lacustrine sediments that accumulated in Glacial Lake Oshkosh. Poor drainage and numerous tamarack swamps are characteristic of this lowland area.

Mileages

26.4 (1.3) Enter Redgranite and Junction with County N. Proceed west on County N toward Lohrville.

Redgranite was once the site of a thriving quarry operation and a pickle factory. The pickle factory might prosper again, but the quarry is permanently abandoned. Now flooded, it is the focus of a city park.

This quarry, adjacent to Wisconsin 21 a few blocks northwest of here, employed about 260 workers in 1909 to produce hand-trimmed granite paving blocks for a few cents apiece. With the average trimmer producing up to 300 blocks per day, four trains were required to haul the daily output southward to the booming towns of Milwaukee, Chicago, and St. Louis. Quarrying declined rapidly after 1915, when concrete became the preferred road building material. However, other uses of granite allowed a more modest operation to continue until the pit was closed in 1931. By this time, the quarry occupied 7 acres and extended downward to a depth of 200 feet.

As the name of the town indicates, the rock exposed here is a reddish granite. It is fine-grained and granophyric in texture, and leucocratic in composition, with quartz and alkali feldspar comprising 90% to 98% of the rock. Subordinate minerals include biotite (altered to chlorite), sphene, hornblende, muscovite, and zircon. This granite, like others exposed in this general area, is dated at 1765 m.y. old. A well-exposed, greenish-black, vertical dike of fine-grained metabasalt trends northeasterly across the lake. This dike is about 5 feet wide, and it has sharp contacts with the granite.

The Precambrian bedrock at this locality was polished and striated by westerly moving Woodfordian ice.

27.7 (0.3) Enter the village limits of Lohrville, once a thriving center for granite quarrying. County N turns south.

28.0 (0.1) County N turns west. An abandoned, small quarry north of the road exposes a medium-to coarse-grained, reddish granite.

28.1 (0.1) The Lohrville Stone Company north of the highway occupies a building constructed from local granite. The piles of glacial erratics gathered together by this firm suggest that these are a more important commodity today than the local bedrock.

28.2 (0.1) County N turns south. The large, glacially-smoothed knob of granite north of the highway establishes that Pleistocene deposits are thin in this area.

28.3 (0.8) Depart Lohrville as County N turns westward.

Mileages

29.1 (0.6) STOP 1 at Flynn's Quarry County Park south of the highway. This park, like the one at Redgranite, is developed around a flooded granite quarry. The park road is an old quarry road, which loops around the lake before returning to County Highway N.

Details on the geology at this stop are described by Eugene Smith in the next section of this guidebook. Unfortunately, only 30 minutes is available to examine this interesting locality!

After stopping, continue westward on County N. The route ahead passes through a low area occupied by tamarack bogs before ascending to higher, better-drained, Woodfordian ground moraine.

29.7 (0.5) County N turns southward along an irregular, rolling morainal ridge. The till is studded with large, locally-derived granitic erratics.

30.2 (0.2) Enter community of Spring Lake. County N turns west.

30.4 (0.3) Junction County N and F in Spring Lake. Turn northward on N.

30.7 (4.1) Junction County N and Z. Turn southwesterly on N and leave Spring Lake, through an area of rolling sandy till within the Woodfordian morainal complex. Large glacial erratics of local derivation are common in the fields adjacent to the highway, and several kettle lakes are present in this general area.

The attractive countryside between here and Neshkoro is part of the Woodfordian Green Lake recessional moraine. As such, it has little value for agriculture, but it is highly prized as recreational land for city dwellers who want to be weekend "tree farmers." The pine plantations that enhance this landscape are the result of their endeavors.

34.8 (0.5) Waushara/Marquette county line. Enter Marquette County. Pine Bluff is located about 3 miles west of here. This prominent landmark is a glacially-smoothed, elliptical knob of coarse-grained, gray to pinkish granite that rises more than 100 feet above the swampy lowlands along the White River. The granite of this inlier is lithologically and genetically related to the granites exposed in the Redgranite-Lohrville and Montello areas.

Glacial striations on the bedrock at this locality trend about N65°W.

35.3 (0.7) Junction County N and E. Turn west on County N and E in an area where sand dunes formed on top of the sandy Woodfordian drift.

36.0 (0.5) Junction County N and E with Wisconsin 73. Turn south on State 73 and County E.

36.5 (0.7) Cemeteries on both sides of the highway provide ample evidence of the monument-quality of central Wisconsin granites.

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37.2 (0.4)	Cross White River in downtown Neshkoro.
37.6 (1.3)	Junction Wisconsin 73, and County E and N. Turn west on E and N. The route ahead leaves the lowland occupied by the White River and traverses a scenic, rolling upland within the Woodfordian morainal complex.
38.9 (1.6)	Junction County N and E. Continue west on E.
40.5 (2.6)	There are several kettle lakes of various sizes developed nearby in sandy, glacial outwash. This is another region with low agricultural potential, which is rapidly being converted to recreational "farms."
43.1 (0.4)	Junction County E and Wisconsin 22. Turn south on E and 22.
43.5 (0.6)	Central Wisconsin granite headstones dominate the cemetery east of the highway.
44.1 (0.3)	Junction County E and Wisconsin 22. Continue south on 22. The route ahead traverses sandy, rolling, Woodfordian ground moraine.
44.4 (4.0)	Cross Mecan River, one of many fine trout streams in central Wisconsin.
48.4 (2.9)	Peat swamps along the highway were drained and developed as muck farms. The route ahead traverses a stony till formed into broad, low drumlins with a general east-west orientation. This better-drained land supports a growth of pine and cedar.
51.3 (1.6)	The sand and gravel pit east of the road is developed in Woodfordian outwash. Kettles are also present in this area.
52.9 (0.5)	Enter the city of Montello.
53.4 (0.3)	Junction of Wisconsin 22 with 23 in Montello. Turn west on Wisconsin 22 and 23.
53.7 (0.1)	Quarries north of the highway exploited a ridge of fine- to medium-grained, red to grayish-red granite to produce monument stone, paving blocks, building stone, and crushed rock. When this granite was selected for the tomb of U.S. Grant in New York City, business boomed. By 1910, activity peaked, with some 200 workers employed. In later years, business declined until the last quarry closed in 1976, after nearly 100 years of operation. The longevity of operations at this locality was facilitated by well-developed vertical joints that allowed the rock to be removed in large "precut" blocks.
	The granite of this inlier is granophyric and leucocratic like those exposed in the Redgranite-Lohrville area and at Pine Bluff. It is also of the same age (1765 m.y. old). Several near-vertical dikes

of greenish-black, fine-grained metabasalt up to 5 feet thick cut the granite, and are well exposed in the quarries.

Well drilling adjacent to the granite ridge discloses that this monadnock stood more than 200 feet above the general level of the Precambrian surface prior to transgression of the Late Cambrian sea (see article by Eugene I. Smith in this guidebook).

Glacial striae on the bedrock surface indicate that the Woodfordian ice moved westerly across this area.

53.8 (0.5) Junction Wisconsin 22 and 23. Turn south on State 22.

54.3 (0.4) Cross the Fox River once again. The Fox flows northeasterly to reach Lake Winnebago, and ultimately Lake Michigan at Green Bay. We first crossed it about 46 miles ago, at Omro.

The Fox was part of the historic canoe highway across Wisconsin. Although used by Indians for centuries, it was "popularized" by Marquette and Joliet on their historic journey from Lake Michigan to the Mississippi. A flood of explorers, missionaries, trappers, and traders soon paddled after them. The Fox is dammed just upstream from here to deepen and enlarge Buffalo Lake. The locks visible from the highway were part of a navigation scheme originally designed to link the North Atlantic (via the Great Lakes) with the Gulf of Mexico (via the Wisconsin River and the Mississippi). Shifting sandbars along the shallow Wisconsin River ruled against this plan from the beginning.

A canal at Portage, Wisconsin was started in 1838 to eliminate the 1.5 mile land bridge between the headwaters of the Fox and the Wisconsin River. This project was finally completed in 1876, but the cost of maintaining a channel in the Wisconsin River proved prohibitive, and the project was soon abandoned.

54.7 (1.8) Leave Montello and the lowland along the Fox River, and proceed into an area of rolling, Woodfordian ground moraine.

56.5 (1.7) The prominent, wooded hill about 4 miles to the southwest is Observatory Hill, the highest point in Marquette County, with an elevation of 1080 feet. This will be the locale of our second stop.

58.2 (1.5) The truck farms in this flat area utilize fertile soils deposited in a glacial lake, which formed when northeasterly drainage was blocked by the retreating Woodfordian ice.

59.7 (0.2) Junction Wisconsin 22 and County B. We will return to this intersection in a few hours, and go east on B after making a large loop. Continue south on State 22 in an area of pitted sandy outwash. Gravel pits in this area are testimony to the water-washed purity of these deposits.

59.9 (0.9) Junction Gem Road and Wisconsin 22. Turn east on Gem Road. Our immediate destination is Observatory Hill, about 2 miles southwest

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of here. To reach our objective, we must circle this promontory, and approach from the west.

A small kettle is located northwest of the highway.

60.8 (1.4) Large glacial erratics of local derivation litter the field north of the road.

62.2 (0.2) Junction 14th Road and Gem Road. Turn west (left) on 14th Road.

62.4 (1.0) Junction 14th Road and 13th Road. Turn south (left) on 13th Road in an area of rolling ground moraine. At long last, we are closing in on Observatory Hill!

63.4 (0.5) An irrigation well west of the road encountered Precambrian porphyritic rhyolite, lithologically identical to exposures on Observatory Hill, at a depth of 300 feet.

63.9 (0.4) Junction 13th Road and Gillette Ave. Proceed southeasterly (straight ahead) on Gillette Ave. and ascend the flank of Observatory Hill.

64.3 (1.1) STOP 2 for Observatory Hill rhyolite. This bedrock hill, which rises about 250 feet above the level of the surrounding landscape, has a core of resistant rhyolite flanked by medium-to coarse-grained, friable, iron-stained Upper Cambrian sandstone. Locally, this sandstone grades into a conglomerate that contains clasts derived from the Precambrian bedrock.

Glacial striae on the rhyolite vary from N45W to N74W, and record the movement of ice over and around this resistant knob.

A detailed description of the rocks at this locality is provided by Eugene Smith in the next section of this guidebook. Since only 60 minutes is allocated for this stop, we should proceed with enthusiasm!

NOTE: Since this road dead ends about 0.4 mile ahead, backtrack northwesterly to the intersection of Gillette Road and 13th Road. The logged mileage that follows assumes a turn-around at the dead end of Gillette Road after this stop.

65.4 (0.7) Intersection of Gillette Road and 13th Road. The bedrock of the high, wooded hill west of this intersection is Upper Cambrian sandstone with no rhyolite exposed. Turn south on 13th Road.

66.1 (0.2) 13th Road turns sharply to the west in an area of rolling countryside formed by a Woodfordian recessional moraine. Pine plantations, cedars, and oaks accentuate the beauty of this glacial landscape.

66.3 (0.4) Junction 13th Road and Gillette Drive. Continue west on Gillette. NOTE: It seems that the Gillettes are important in this country!

66.7 (1.5) A low bedrock ridge north of the road is the Taylor Farm rhyolite locality. The well-jointed, porphyritic rhyolite exposed here is similar to that found on Observatory Hill. However, the high bedrock hill of sandstone northeast of here separates these two localities. Glacial striae on this rhyolite document a general N70W direction of ice flow for the Green Bay lobe of Woodfordian ice at this locality.

68.2 (0.2) Junction Gillette Drive and County F. Turn south on County F.

68.4 (1.4) LUNCH STOP at John Muir County Park on Ennis Lake.

John Muir, a distinguished naturalist and a prime mover in the establishment of our national park system in 1890, was born in Scotland in 1838. His family came to Wisconsin to farm the land across the lake from this memorial park when he was only a boy of 11. He grew up on this beautiful kettle lake (called Fountain Lake in those days), and it proved to be a significant ingredient in the development of his love of nature.

The importance of this lake to Muir is well documented on page 96 of his autobiography, "The Story of My Boyhood and Youth" (University of Wisconsin Press, 1965).

"Our beautiful lake, named Fountain Lake by father, but Muir's Lake by the neighbors, is one of the many small glacier lakes that adorn the Wisconsin landscapes. It is fed by twenty or thirty meadow springs, is about half a mile long, half as wide, and surrounded by low finely-modeled hills dotted with oak and hickory, and meadows full of grasses and sedges and many beautiful orchids and ferns. First there is a zone of green, shining rushes, and just beyond the rushes a zone of white and orange water-lilies fifty or sixty feet wide forming a magnificent border. On bright days, when the lake was rippled by a breeze, the lilies and sun-spangles danced together in radiant beauty, and it became difficult to discriminate between them.

On Sundays, after or before chores and sermons and Bible-lessons, we drifted about on the lake for hours, especially in lily time, getting finest lessons and sermons from the water and flowers, ducks, fishes, and muskrats. In particular we took Christ's advice and devoutly "considered the lilies" - how they grow up in beauty out of gray lime mud, and ride gloriously among the breezy sun-spangles."

After lunch, continue south on County F through an area of rolling, sandy drift. Immediately to the west, the north-flowing Fox River parallels the highway.

69.8 (1.7) Junction County F and O. Turn east on County O. The rolling, sandy, ground moraine contains large erratics scattered about. Differences in drainage are clearly reflected in the vegetation, with tamaracks in swampy places, and oaks and plantation pines on the higher, well-drained soils.

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71.5 (1.4) Junction County O and 13th Road. Turn south on 13th Road.

72.9 (0.7) Knights Lake, on the east side of the road, occupies a small kettle.

73.6 (0.4) Junction 13th Road and 14th Road. Turn south (right) on 14th Road. This road curves eastward immediately ahead.

74.0 (0.9) Junction 14th Road and Dalton Road at the Marquette/Columbia county line. Turn south (right) on Dalton Road and enter Columbia County, through rolling country with some land suitable for agriculture.

74.9 (0.2) Junction Dalton Road and County CM. Turn southwesterly (right) on County CM in an area with abundant erratics. We will backtrack to this intersection after Stop 3.

75.1 (0.4) A well on the A. Uchtung farm on the right side of the road reached Precambrian rhyolite at a depth of 390 feet. Drilling continued 170 feet into the rhyolite.

75.5 (0.6) Junction County CM and Monthey Road. Turn south (left) on Monthey Road.

76.1 (0.1) Exposure of Middle Precambrian Marcellon rhyolite east of the road. This is one of four isolated exposures of rhyolite in this immediate area.

76.2 (0.7) STOP 3 at Marcellon rhyolite locality. This scenic exposure is a glacially rounded and polished knob that rises nearly 70 feet above the surrounding countryside. Glacial striae indicate a westerly direction for Woodfordian ice flow at this locality.

A detailed description of the geology to be observed here is supplied by Eugene Smith in the next section of this guidebook. Unfortunately, we have only 45 minutes for an examination of this interesting exposure.

After studying the rock here, turn around and backtrack northward along Monthey Road.

76.9 (0.6) Junction Monthey Road and County CM. Turn northeast (right) on CM.

77.5 (2.7) Junction CM and Dalton Road. Continue northeastward on CM through rolling, glacial countryside.

80.2 (0.6) Junction County CM and Wisconsin 22. Turn north (left) on State 22 and cross Columbia/Marquette county line. Enter Marquette County once again.

80.8 (0.2) State Historical Marker on the east side of the highway is entitled "John Muir Country," and it describes his sojourn in this area. It also includes this meaningful quote of Muir's:

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"Everybody needs beauty as well as bread;
places to play in and places to pray in,
where nature may heal and cheer, and give
strength to body and soul alike."

81.0 (1.2) The house west of the road is a showplace for samples of Wisconsin fieldstone, the trade name for glacial erratics.

82.2 (3.6) Wisconsin 22 climbs onto a highland littered with glacial erratics.

85.8 (3.5) Junction Wisconsin 22 and County B. Turn east on County B, in a region of sandy outwash occupied by gravel pits. The route ahead is characterized by numerous swamps, some of which are drained for muck farming. Higher areas support pine plantations.

89.3 (0.7) Marquette/Green Lake county line. Enter Green Lake County.

90.0 (3.1) The poorly drained lowland north of the road is part of the extensive Grand River Wildlife Area. When the retreating Woodfordian ice dammed the northeastward flowing drainage of the Fox and Grand rivers, a glacial lake formed in this area. In time, it filled with meltwater, and overflowed westward into the Wisconsin River. However, continued retreat of the Green Bay lobe of the Woodfordian ice restored northeasterly drainage, and this lake was emptied. However, Lake Puckaway and Buffalo Lake exist as remnants of this ancient water body.

93.1 (0.3) Junction County B and H. Continue northeasterly (left) on B and H.

93.4 (2.4) Junction County B and H. Turn north on County H. The high, wooded hill to the northeast of this intersection is Bartholomew Bluff. It is a bedrock feature composed of Upper Cambrian formations capped by resistant Lower Ordovician dolomite of the Prairie du Chien Group. The route ahead traverses the east edge of an area of poorly-drained, glacial lake deposits now occupied by the Grand River Marsh.

95.8 (0.5) The bedrock hill immediately northwest of the road is one of several isolated rhyolite exposures, which trend northwestward from here for about one mile. In all, there are seven rhyolite knobs in this general area. These features stood several hundred feet above the general Precambrian erosional level as monadnocks, prior to transgression of the Upper Cambrian sea (see article by Eugene I. Smith in this guidebook).

96.3 (0.3) STOP 4 at an exposure of the Marquette rhyolite. The cedar-covered, glacially-smoothed, bedrock knob west of the highway rises about 100 feet above poorly-drained tamarack swamps to the north. A similar exposure lies immediately east of the road.

Glacial striations and chatter marks on the bedrock indicate that the Woodfordian ice generally moved westward at this locality. However, measurements vary from N57W to N86W.

An analysis of the rhyolite at this stop is provided by Eugene Smith in the next section of this guidebook. About 60 minutes are available to study the exposures at this locality.

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After examining the rhyolite, continue northeasterly on County H.

96.6 (1.0) Junction County H and KK. Turn east (right) on H and KK. The route ahead traverses rolling ground moraine studded with numerous erratics. The shape of the east-west trending drumlin south of the road establishes that ice movement in this area was to the west.

97.6 (3.8) Junction County H, KK, and B. Continue straight ahead (east) on County H. The route ahead traverses scenic, glacial countryside with some agricultural potential. Lake Puckaway, an enlargement of the Fox River, is occasionally visible to the north.

101.4 (2.1) Junction County H and Wisconsin 73. Turn south (right) on State 73. The route ahead traverses rolling agricultural land.

103.5 (0.3) Junction Wisconsin 73 and 44. Continue south on 73 and 44.

103.8 (0.6) Enter Manchester, a hilltop community astride the Green Lake recessional moraine. This prominent glacial feature, which trends north-northwestward and south-southeastward from here, formed as the Green Bay lobe of the Woodfordian ice paused during retreat.

104.4 (0.4) Leave Manchester in an easterly direction. The boundary between two major physical provinces trends northeast-southwest through this area. The Central Plain, to the northwest, is a subdued region characterized by Upper Cambrian bedrock. The Eastern Ridges and Lowlands, with younger bedrock, occupies the region to the east and southeast. However, this division is ill-defined here because of the thick cover of young glacial deposits.

104.8 (0.4) Junction Wisconsin 73 and 44. Turn south on State 73 in an area of rolling agricultural land.

105.2 (1.6) Cross Grand River.

106.8 (0.7) The highway intersects a drumlin that trends east-west. The blunter, east-facing nose of this drumlin indicates westerly ice movement in this area.

107.5 (1.8) Lake Maria, east of the highway, lies along the trend of the Green Lake recessional moraine.

109.3 (0.6) Green Lake/Columbia county line. Enter Columbia County in an area where intensively farmed drumlins stand above flat, low areas that are poorly drained. When drained, these lowlands are productive muck farms.

109.9 (2.9) Several roadcuts in the next 0.5 mile expose thin-to medium-bedded Lower Ordovician dolomite of the Prairie du Chien Group. Some of these bedrock exposures form the cores of drumlins.

112.8 (2.0) The high-voltage power lines crossing the highway come from a large, coal-fired power plant at Portage. This facility utilizes Wisconsin River water as a coolant.

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114.8 (0.5)	Junction Wisconsin 73 and 33. Continue south on 73.
115.3 (1.0)	Enter Randolph.
116.3 (0.2)	Leave Randolph.
116.5 (13.0)	Cross Columbia/Dodge county line, as Wisconsin 73 turns east, and then south. Enter Dodge County. The route ahcad traverses rich agricultural land developed on a swarm of broad, well-formed, southwesterly-trending drumlins.
129.5 (1.3)	Junction Wisconsin 73 and U.S. 151. Continue south on State 73.
130.8 (0.9)	Dodge/Columbia county line. Enter Columbia County and the city of Columbus. Cross southeasterly flowing Crayfish River.
131.7 (0.6)	Junction Wisconsin 73 and 89 in Columbus. Turn south (left) on Wisconsin 89.
132.3 (3.0)	Leave Columbus. The route ahead traverses intensively farmed, rolling, glacial countryside.
135.3 (4.8)	Columbia/Dane county line. Enter Dane County. Broad, well-shaped drumlins here trend southwesterly.
140.1 (1.4)	Dane/Dodge county line. Enter Dodge County in an area with occasional drumlins.
141.5 (0.7)	Stop sign at junction of Wisconsin 89 and County T. Proceed straight ahead (east) on Dalman Road.
142.2 (1.0)	Junction Dalman Road and County I. Turn south (right) on County I.
143.2 (1.0)	Village of Portland and junction with Wisconsin 19. Turn northeast on State 19, and leave Portland.
144.2 (0.3)	Cross Maunesha River.
144.5 (0.1)	Knobs of glacially-smoothed, Middle Precambrian Waterloo Quartzite lie north and south of the highway. These exposures are two of about a dozen quartzite knobs that protrude through the glacial drift in this general area. All of the exposures are smoothed by glacial action, and some have small potholes developed on the upper surfaces. This quartzite is quite similar to that exposed in the well-known Baraboo syncline, about 35 miles to the northwest. Like the Baraboo Quartzite, ripple marks cross bedding, and conglomeratic beds are also present within the thick quartzite sequence in this area.

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The structure here is an easterly plunging syncline. This folding, as at Baraboo, may have occurred 1650 m.y. ago.

Measurements of glacial striae indicate that the ice flowed about S20W at this locality.

144.6 (0.3) STOP 5 at the abandoned John O'Laughlin quarries in the Waterloo Quartzite.

The quartzite at this stop is described by Eugene Smith in the next section of this guidebook. About 30 minutes is allotted to assimilate the geology at this locale.

144.9 (1.7) Junction Wisconsin 99 and Hubbleton Road. Proceed east on Wisconsin 19.

About 1 mile north along Hubbleton Road, in the ditch along the eastern edge of the road, an isolated exposure of Paleozoic conglomerate is present. This conglomerate, which contains rounded Waterloo Quartzite boulders up to 6 feet across, is probably a local facies of the Middle Ordovician St. Peter Sandstone. It is also one of the few Paleozoic exposures in this general area.

About 0.5 mile straight north of the St. Peter conglomerate locality, at the junction of Maunesha Creek and the Crawfish River, is Stony Island. This is another glacially rounded mass of Waterloo Quartzite. Here, several pegmatite dikes up to 3.2 feet thick intruded the quartzite after folding. These dikes were dated by L.T. Aldrich and others in 1959 as 1444 m.y. old.

The route ahead traverses more drumlin county, although the agricultural potential is not as good as it was east of Portland.

146.4 (0.4) Easterly dipping ledge of Middle Precambrian Waterloo Quartzite adds interest to the lawn of the farmhouse south of the highway. Intermittent exposures indicate that this ledge persists southward along strike for almost a mile.

147.0 (0.3) Another exposure of Waterloo Quartzite is visible about 100 yards north of the highway.

147.3 (0.5) Junction Wisconsin 19 and County G (north). Continue east on 19.

Exposures of brecciated Waterloo Quartzite cemented by milky quartz are located about 0.75 mile to the north. Additional exposures of quartzite are present in the vicinity of Mud Lake, about 5 miles north-northeast of here along County G.

147.8 (0.5) Dodge/Jefferson county line. Enter Jefferson County.

148.3 (2.4) Hubbleton and junction Wisconsin 19 and County G. Turn south (right) on G in a broad area of flat, poorly-drained muck soils located between intensively farmed drumlins. Where ditched, the muck soils are also cultivated.

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150.7 (2.1) County G continues southward through drumlin country.

152.8 (1.4) The low ridge of Waterloo Quartzite in the field about 150 yards east of the highway is sometimes referred to as the Lake Mills exposure. The quartzite here is light blue to gray in color, and it is composed almost entirely of coarse, interlocking quartz grains with rare mica. Primary foliation (bedding) strikes N. 50° W. and dips 70° northeast on the south limb of the Waterloo syncline.

154.2 (2.0) Junction County G and Wisconsin 89. Turn south on Wisconsin 89 through good drumlin country.

156.2 (1.8) Junction Wisconsin 89 and Interstate 94. Turn east on I-94 toward Milwaukee.[1]

The I-94 route from the Lake Mills-Waterloo interchange to Milwaukee is entirely within the Eastern Ridges and Lowlands physical province, and the highway trends at right angles to the general strike of the Paleozoic formations. Consequently, the bedrock along the route ranges from Middle Ordovician formations on the west to Silurian dolomite on the east. However, these rocks are largely obscured by Woodfordian glacial deposits.

The glacial geology encountered along I-94 between here and Milwaukee is spectacular. The orientation of the route is such that the interstate cuts most glacial features essentially at right angles. From west to east, these include well-developed drumlin fields, outwash plains, the Kettle Interlobate Moraine with numerous scenic lakes, and recessional moraines of the Lake Border morainic system. Other significant attractions along this route include: the Lapham Peak overlook high in the Kettle Moraine, and the subcontinental divide, which separates drainage destined for the North Atlantic via the St. Lawrence from that which flows to the Gulf of Mexico via the Mississippi.

158.0 (2.0) Eastbound rest area in an area of rolling ground moraine.

160.0 (1.0) I-94 crosses the Crawfish River, a tributary to the Rock. Aztalan State Park is 1.5 miles south on the west bank of this river. In addition to Late Woodland Indian effigy mounds, this park contains a two-tiered pyramidal mound, and a partly restored stockaded village identified with the Middle Mississippi culture. When the site was first described in 1837, it was named Aztalan in the hope that the cultural remains preserved here were those of Mexican Aztecs. To reach the park, use the Lake Mills exit and then turn east on County B.

161.0 (1.0) Westbound rest area, in an area of ground moraine and low-lying drumlinoid hills.

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[1] The remainder of this geologic road guide is published with permission of Kendall/Hunt Publishing Company, Dubuque, Iowa, and it should not be duplicated by any means without written permission.

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162.0 (1.0) I-94 crosses the Rock River. The Rock marks a general vegetation divide between native hardwood forests to the east, and oak savannas and prairies to the west. Some think the river formed a barrier to prairie fires, thus preserving the forests to the east.

Jefferson, 6.5 miles to the south at the junction of the Crawfish and Rock rivers, experienced a short-lived, geology-related, land boom about 1840. A federally-assisted project was planned to construct a canal from Lake Michigan at Milwaukee to the Rock River near Jefferson. Some construction was actually accomplished before the million-dollar project was abandoned. Meanwhile, land values had sky-rocketed in Jefferson as the prospect of a connection between the Mississippi River and the Great Lakes seemed imminent. Land promoters arrived, and a steamboat made it up the Rock River from St. Louis. Tracts of swampland were bought by local residents and newcomers at inflated prices, in the hope that great profits would result when the canal was completed. The land promoters left town with well-laden carpetbags before news of the abandonment of the canal plans reached southern Wisconsin.

163.0 (6.0) Exit Wisconsin 26 to Watertown, Johnson Creek, and Jefferson, within the Jefferson County drumlin field. Where the interstate cuts through a drumlin, the roadcuts have been carefully sodded over to conceal the internal character of the sandy and clayey till. However, at the northwest corner of this intersection, behind the service station and restaurant, an excavated drumlin is exposed.

169.0 (4.0) Irregular ground moraine assumes symmetry and order as the highway traverses a classic drumlin field, produced by the Green Bay lobe of the Woodfordian ice advance. These drumlins trend essentially north-south, but nearer to Madison the orientation is southwesterly.

Poorly drained areas and tamarack swamps flank many of the drumlins.

173.0 (2.0) Wisconsin 135 exit.

175.0 (3.0) Jefferson/Waukesha county line. Enter Waukesha County. The drainage in this rolling countryside is poor, and farm fields must be ditched. Numerous tamarack swamps with red osier dogwood are lingering evidence of the boreal climate of the Pleistocene.

178.0 (4.0) Wisconsin 67 exit to Oconomowoc and Dousman. The interstate now traverses outwash and proglacial lake sediments in an area once occupied by the Green Bay lobe during the Woodfordian ice advance. To the east, the view of the Interlobate Moraine looming above the flat outwash surface is impressive. A few overgrown kettles are adjacent to the highway on the south side. To the north, rising above the flat outwash plain, an incongruous landform resembles the classic moulin kames of the northern Kettle Moraine. This is the artifically-created ski hill near Oconomowoc.

182.0 (1.0) An exit on County CC provides a side trip to view the Kettle

Interlobate Moraine from the observation tower on Lapham Peak. This tower provides an excellent overview from the highest vantage point in the southern Kettle Interlobate Moraine. To the west is Genesee Flat. To the east is the glacial spillway described at mile 184. Several scenic, glacial lakes are also visible.

To reach Lapham Peak, go south on County CC (Kettle Moraine Scenic Drive) about 1.8 miles to a crossroad. Turn left (east) onto Government Hill Road. Continue about 0.7 mile to a small park that includes the Lapham Peak observation tower. The tower for state station WHAD is also located here. A marker at 1233 feet of elevation, on a glacial erratic boulder in the park, is dedicated to one of Wisconsin's earliest geologists and naturalists: "Increase A. Lapham, Eminent scientist and useful citizen."

The route ahead crosses a region of pitted (kettled) outwash deposits, and many kettle lakes dot the landscape. Nagawicka Lake, immediately north of the highway, is such a lake. Other examples are Upper and Lower Nemahbin lakes, which sandwich the interstate about 1 mile west of here. The ice blocks which formed these lake basins were derived from the Green Bay lobe along the western edge of the Interlobate Moraine.

183.0 (1.0) The interstate approaches the crest of the Interlobate Moraine. A small ski area south of the highway utilizes part of this slope. From the crest of this ridge, the radio tower and observation tower on Lapham Peak are visible south of the highway.

The Kettle Interlobate Moraine, which trends northeasterly across Wisconsin for about 130 miles, from Walworth to Kewaunee counties, is the premier glacial feature in Wisconsin. It is probable that the resistant Silurian dolomite influenced the position of the interlobate deposits in this area, by retarding the spread of the Green Bay lobe.

Within this morainal complex, the country is rolling and rugged, with abundant knobs and kettles. This feature formed during the Woodfordian glacial advance by a juxtapositioning of the terminal moraines of the Green Bay and Lake Michigan lobes. Between these icy walls, complex drainageways developed, and meltwaters reworked some of the morainal materials. The resultant deposits are a mixture of sand, gravel, boulders, and clayey till. Much of the coarser material was derived from the Silurian dolomite, but igneous and metamorphic rock types from far to the north are also present.

184.0 (1.0) Wisconsin 83 exit. This highway follows low ground along an abandoned drainage channel which carried the last meltwater that drained southward through this part of the Kettle Interlobate Moraine. Water drained down this .25 mile wide valley until it reached Wales, about 3 miles to the south, where it cut through the Interlobate Moraine to flow west. Gravel outwash terraces flank this drainage, and a remnant of a high terrace is visible on the east side of this valley.

Mileages

185.0 (1.0)	Pewaukee Lake lies to the north. The church at Holy Hill, on a kame perched high on the Interlobate Moraine, is also visible to the north on a clear day. Pewaukee Lake occupies a preglacial river valley which was scoured into the Upper Ordovician Maquoketa Shale. This ancient valley was blocked by morainal debris deposited along its eastern margins by the Lake Michigan lobe during the Woodfordian ice advance.
186.0 (2.0)	Ground moraine deposits in this area are thin. North of the highway on the west edge of the Tumblebrook golf course, there is a small quarry in Silurian dolomite. Glacial striae on bedrock in this area indicate that ice movement was west-southwest. South of the road, the names of a subdivision (Pebble Valley), and a farm (Stoney Hill), bear testimony to the character of the morainal material.
188.0 (3.0)	Exit County G to Pewaukee. A drumlin field lies south of the highway for the next several miles. These east-west trending drumlins are composed of sandy clay till that contains abundant boulders.
191.0 (1.0)	Exit County F. West of this intersection, the route crossed the Pewaukee River, which is tributary to the Fox. This valley is paralleled by outwash terraces, which are commercial sources of sand and gravel in this area.
192.0 (2.0)	Exit Wisconsin 164 to Sussex and Waukesha. East-west trending drumlins are north and south of the highway. Colonel Dunbar, while visiting Waukesha in 1869, drank from some of the springs which issue from the glacial drift, with high amounts of dissolved calcium magnesium bicarbonate. Upon deciding that the local mineral waters had eliminated his "incurable ailments," he began to advertise his cure nationwide, and Waukesha soon became a fashionable health spa. Although this fad waned after about 30 years, bottled spring water is still a Waukesha product. Waukesha is located on the Fox River. Outwash terraces along this river are important commercial sources for sand and gravel. Since the glacial drift is quite thin in this region, Silurian dolomite is extensively quarried along the valley of the Fox from the Waukesha area northward to Sussex, Lannon and Menomonee Falls.
194.0 (3.0)	Exit U.S. 18 (Blue Mound Road) to Waukesha and Wisconsin State Patrol Headquarters.
197.0 (2.0)	Exit Moorland Road. The flat terrain here is poorly drained, clay-rich ground moraine. Ditching and channelization were required for the extensive development of the land north of the highway. The golf course to the south represents a more intelligent land use. A few isolated patches of moraine, and several east-west trending drumlins rise above the generally swampy ground. The route ahead descends a prominent ridge, which is part of the

Woodfordian Lake Border recessional moraine system. Sunny Slope Road traverses this ridge crest, which forms the drainage divide between Lake Michigan and the drainage basin of the Fox River. The Fox flows southward parallel to the Woodfordian moraines to reach the Illinois River, and ultimately the Gulf of Mexico via the Mississippi.

199.0 (2.0) Milwaukee/Waukesha county line. Enter Milwaukee County. Exit I-894 (U.S. 45) south to Chicago and U.S. 45 north to Fond du Lac. The Milwaukee County Zoo is northwest of this intersection.

202.0 (2.0) Exit Wisconsin 181 (84th Street). The Wisconsin State Fair Park grounds and an Olympic-size outdoor ice rink are southeast of this junction. The interstate traverses Wisconsinan (Woodfordian) ground moraine and recessional moraines of the Lake Border system. The highway here is essentially parallel to the east-west direction of ice movement, and consequently the morainic ridges trend north-south. About 100 feet of glacial deposits, primarily a boulder clay till, overlie Silurian dolomite in this area.

204.0 (1.0) U.S. 41 exit (north and south). Milwaukee County Stadium, home of the Milwaukee Brewers and also the site of the Milwaukee games of the Green Bay Packers, is just west of this junction. The large hill southwest of the stadium is a Silurian dolomite exposure on the grounds of the U.S. Veterans Administration Hospital.

205.0 (1.0) Route parallels the industrial complex along the east-west trending Menomonee River valley. Three large, glass domes in Mitchell Park are visible to the south. One contains a display of vegetation native to a desert environment, another features tropical plants, and the last houses local flora and is used for special flower shows.

206.0 Junction I-94 with I-43 (U.S. 141) and I-794. The Milwaukee Harbor is to the southeast, toward the highrise Harbor Freeway bridge along the lakeshore.

Three rivers merge at the Milwaukee Harbor. The Menomonee River flows from the north and west, the Milwaukee River comes from the north, and the Kinnickinnic River originates to the west and south.

Milwaukee grew from three settlements that were originally separated by these rivers. Walker's Point, east of the Kinnickinnic River, is now dominated by the towering clock of the Allen Bradley Company. The Milwaukee River flowed between Kilbourntown on the west and Juneautown to the east.

The high smokestack to the east is part of the Jones Island Metropolitan Sewage Plant. Here, sewage sludge is dried and converted to Milorganite, a commercial fertilizer.

Jones Island, an artificially breached peninsula, also contains a tanker pier, cargo terminals and a heavylift wharf, and is headquarters for the Port of Milwaukee. Milwaukee's inner harbor was developed by an enlargement of the lower Kinnickinnic River, and it serves as the service and wintering area for part of U.S. Steel's iron ore carrier fleet.

END OF LOG

Proceed through downtown Milwaukee to the Pfister Hotel.

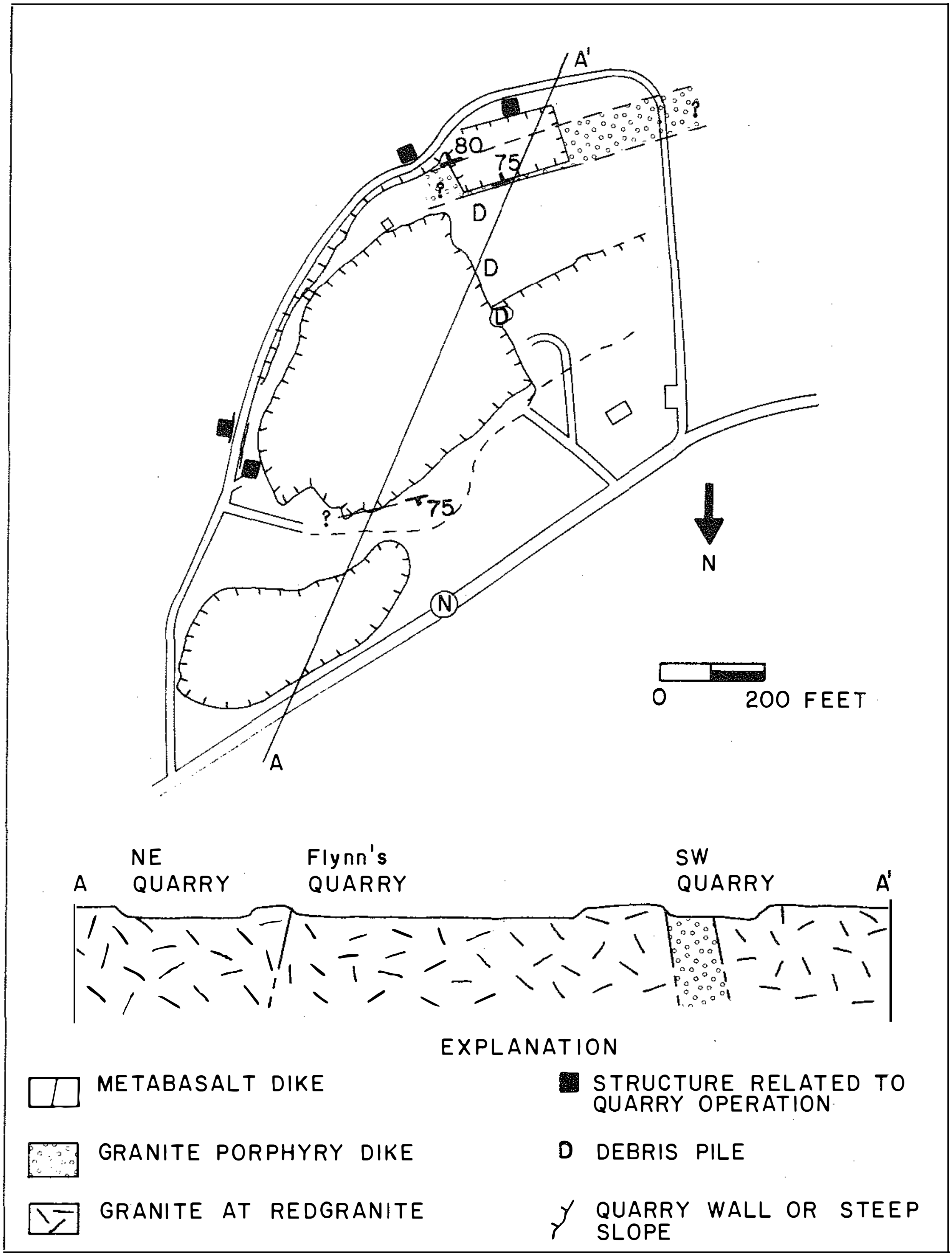

Figure 2. Pace and compass map of Flynn's Quarry County Park, Waushara County.

Geologic Stop Descriptions

Eugene I. Smith[1]

STOP 1 - GRANITE AND RELATED INTRUSIONS AT FLYNN'S QUARRY COUNTY PARK

Location: All exposures at this stop are reached by an easy walk from the Parking area (Fig. 2).

Description:

Granite

Fine-to medium-grained red (granophyric) granite with micropegmatitic and myrmeketic texture is exposed in three quarries within the boundaries of Flynn's Quarry County Park (Fig. 2). Quartz and alkali feldspar compose 90 to 98 percent of the rock, with biotite (partially or wholly altered to chlorite), sphene, hornblende, muscovite and zircon as subordinate minerals. The granite for the most part is texturally homogeneous. Locally however, grain alignments and fine-grained bands (dikes?) are observed. The mineralogy and texture of the granite (especially the intergrowths of quartz and alkali feldspar) suggest that it is a shallow intrusion.

Granite Porphyry Dike

In the northeast quarry, the granite is cut by a 200 m wide east trending granite porphyry dike (strike east-west, dip 75° to the south). The dike rock is characterized by large (5 mm) alkali feldspar phenocrysts set in a fine-grained matrix of quartz, biotite and chlorite. The finely disseminated chlorite gives the matrix of the dike rock a green color, thus making it easily distinguishable from the red granite. The contact between granite and dike rock is clearly visible on a ledge on the north wall of the northeast quarry (Fig. 3). In detail, the contact bends in and out, suggesting some assimilation of granite during intrusion. Fragments (xenoliths) of granite are found within the dike near the contact; also feldspar phenocrysts are concentrated and weakly aligned in the granite porphyry dike at the contact.

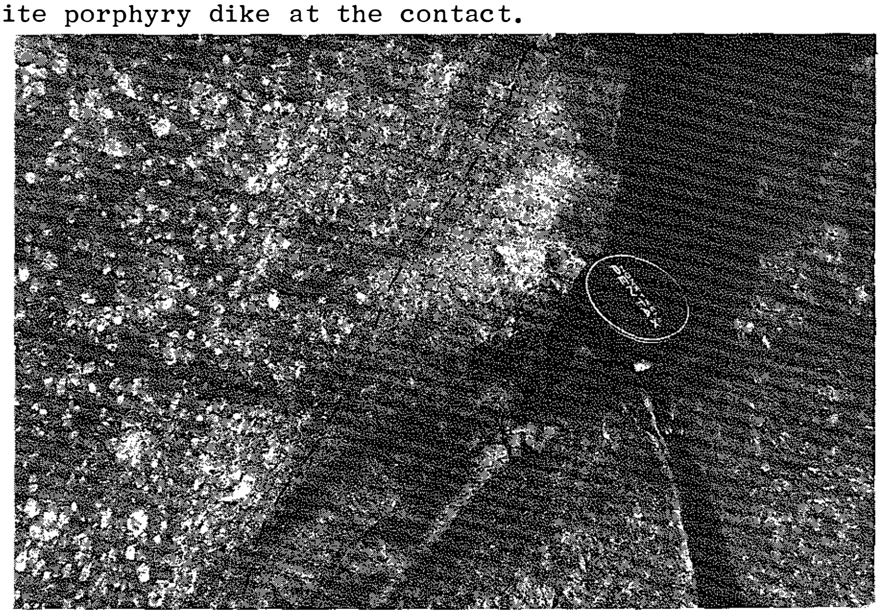

Figure 3. View of the contact between the granite porphyry dike and granite in Flynn's Quarry County Park (dashed line traces contact). Note that the feldspar phenocrysts are concentrated and weakly aligned in the dike rock near the contact.

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Chemically, the dike is a less differentiated phase of the granite. It is lower in SiO_2, and K_2O and higher in Al_2O_3, FeO + Fe_2O_3 and CaO when compared to the Flynn's Quarry granite (Table 1, analyses 18 and 31). In terms of trace elements the dike is higher in Ba, and has a lower Rb/Sr ratio than the granite.

Metabasalt Dike

On the north wall of the main quarry, the granite is cut by a thin (2 m wide) metabasalt dike striking N. 80 E. and dipping 70° to the south (Fig. 2). The dike rock is fine grained and has a distinctive green color on both weathered and fresh surfaces. In thin section, the metabasalt displays intergranular texture with laths of plagioclase enclosing mats of epidote, clinozoisite and iron oxide. The contact between the metabasalt and granite is clearly observed on a ledge just above water level (Fig. 4). Here lenses of granite are completely enclosed by stringers of metabasalt. Except for these lenses, no granite fragments were noticed within dike rock. These contact relationships suggest that the metabasalt intruded primarily by the dilation of country rock.

Comparison of Flynn's Quarry Granite to Granite in Nearby Areas:

Redgranite to Pine Bluff- Granites and Dikes

Granites similar in mineralogy and texture to that at Flynn's Quarry are exposed in discontinuous outcrops from the city of Redgranite to Pine Bluff (Fig. 5). Dikes of metabasalt trending east-west and approximately N. 45E. cut the granite in many localities. One of the most easily visited of these dikes forms a distinct ridge jutting into the quarry lake north of S.T.H. 22 in downtown Redgranite (just north of Griffs' Cafe). A coarse-grained diorite dike cuts granite in a small quarry in the N 1/2, Sec. 27, T.18 N. R. 11 E. (Fig. 5). The dike is about 5 m thick and trends N. 40 E. (dip vertical). In thin section, flow-aligned plagioclase laths surround clots of chlorite and epidote.

Montello Granite

Another granite similar in lithology to that at Flynn's Quarry and at Red Granite is located in the city of Montello (Buckley, 1898). There is also an exposure to the east of Montello in the SE 1/4, Sec. 9, T. 15 N., R. 10 E. This granite was extensively quarried from 1880 to 1976. President Grant's sarcophagus in New York City is carved from Montello Granite. The rock in the Montello quarry is a red granite composed of intergrown quartz and alkali feldspar crystals (myrmeketic and micropegmatitic textures are common) with chlorite, biotite, and euhedral zircon as accessory minerals. Attempts to date this rock by the fission-track technique failed because an insufficient number of zircon grains were separated and most of the separated zircons were metamict. The Montello granite is cut by thin metabasalt dikes (plagioclase and sausserite as dominant minerals) which trend northeast, north-south and northwest. Quarry faces at Montello are commonly bounded by these dikes. The metabasalt dikes are closely sheared at their margins; several dikes are sheared throughout. The granite commonly shows a dark red bake zone extending 2 to 5 cm inward from the intrusive contacts, also small grains of pyrite are more common in granite near metabasalt than farther away from the granite-dike contacts.

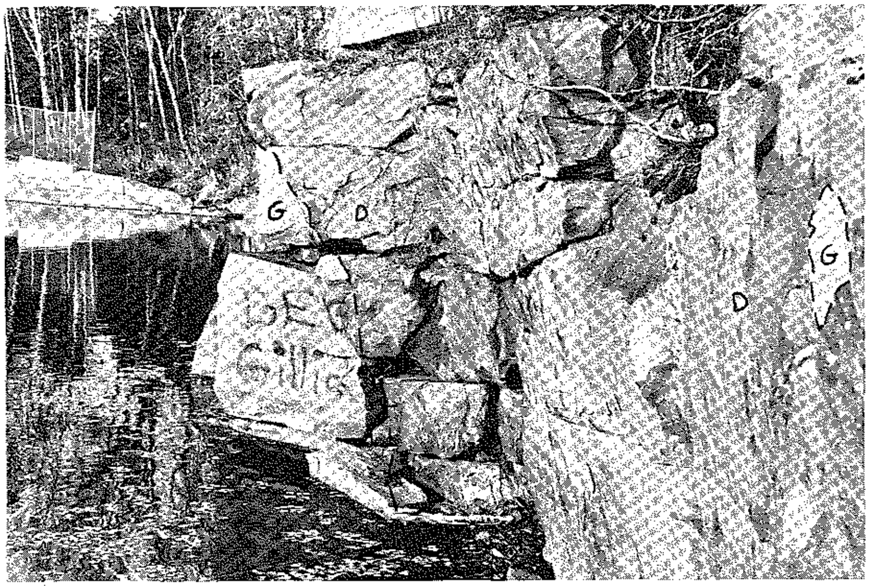

Figure 4A. View of a thin metabasalt dike that cuts granite in Flynn's Quarry County Park. The dike in this view is 2 meters thick. The southern contact (left) dips about 10° to the north (dashed line). Granite (G) to the north of the dike appears as a window in the dike rock (D).

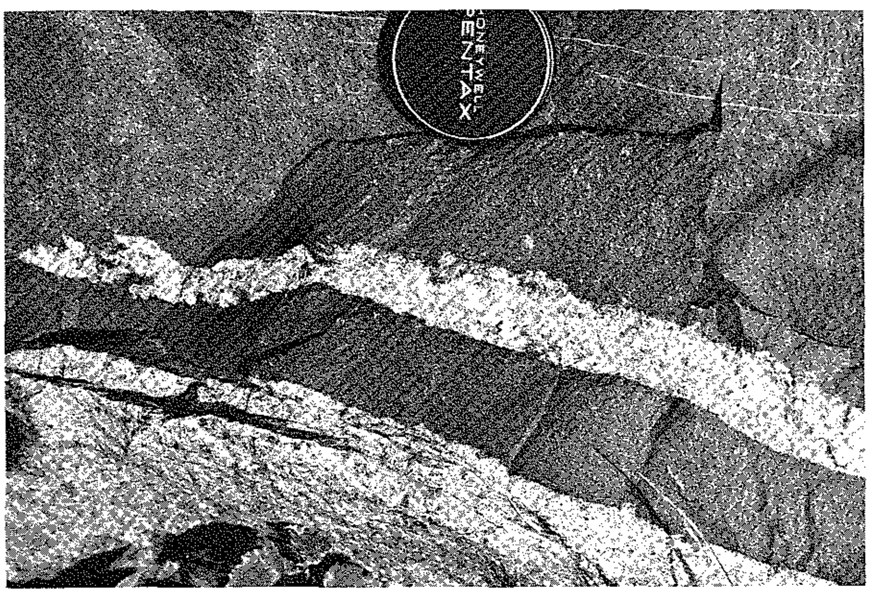

Figure 4B. Close-up of the contact between the metabasalt dike and granite. Basalt intruded granite along closely spaced joints.

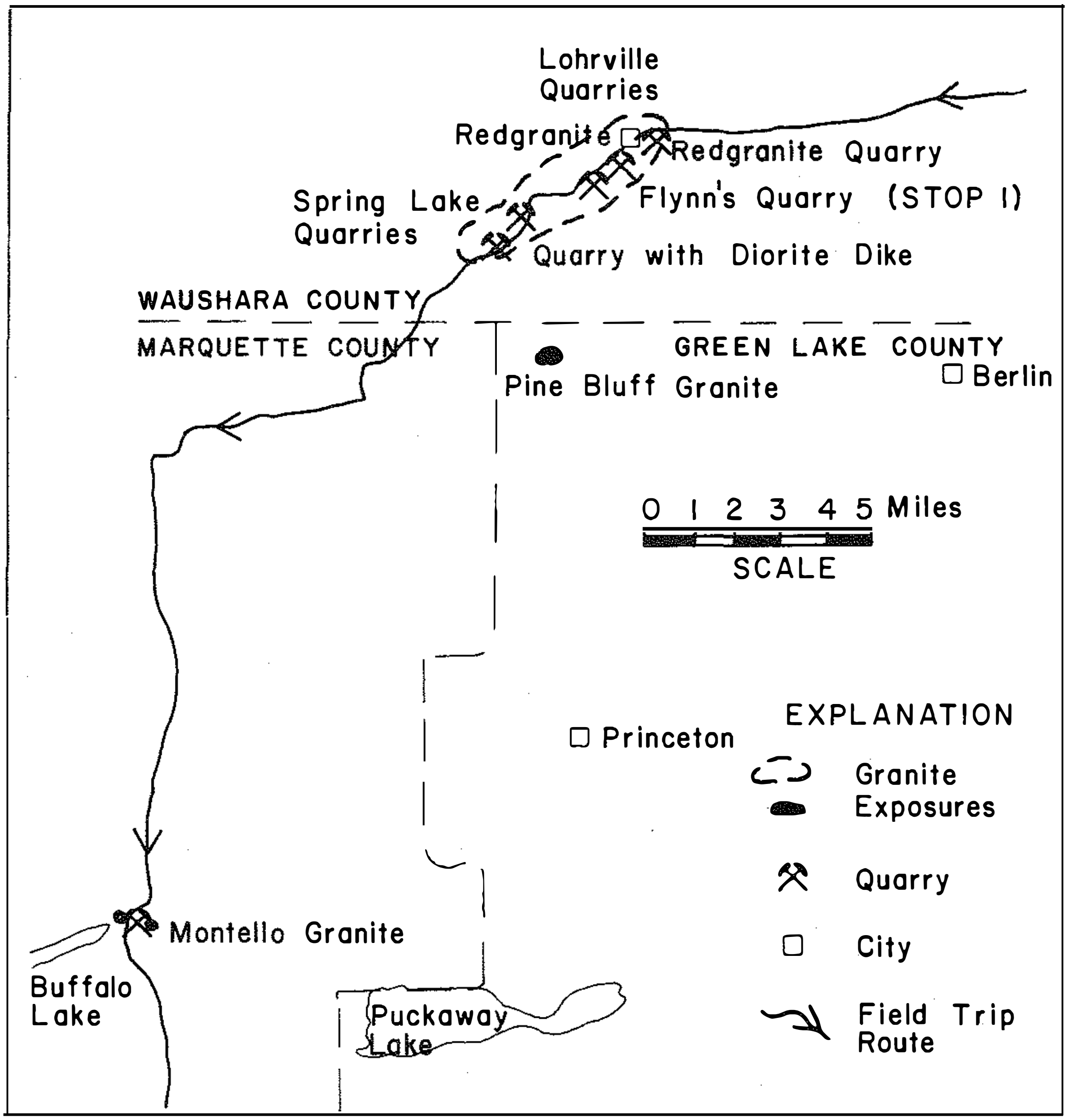

Figure 5. Detailed route map from Redgranite to Montello showing granite exposures and locations of important quarries.

Chemical Comparisons:

The granite at Redgranite (and presumably Flynn's Quarry) is similar in chemistry, mineralogy and age to that at Montello, except for noticably higher amounts of Cu and Cr in the Montello Granite, (Table 1, analyses 14 and 18). These similarities indicate that the granites are comagmatic and that they formed during the same intrusive event. Studies of cuttings from deep wells show that granite lithologically similar to that exposed at Redgranite and Montello occurs in the basement over a large area of south-central Wisconsin. These rocks probably form a large late-Penokean or post-Penokean (1765 m.y. old) composite batholith which is exposed only in the Redgranite area and at Montello (Smith, 1978c).

The similarity of the granites at Montello and Redgranite was noted long ago by Weidman (1904) who labelled these rocks the Waushara Granite. Emmons (1940) also suggested the presence of a large batholith in central Wisconsin. However, he did not distinguish between the older Penokean aged granites in central Wisconsin (Wausau area) and the younger granites in south-central Wisconsin.

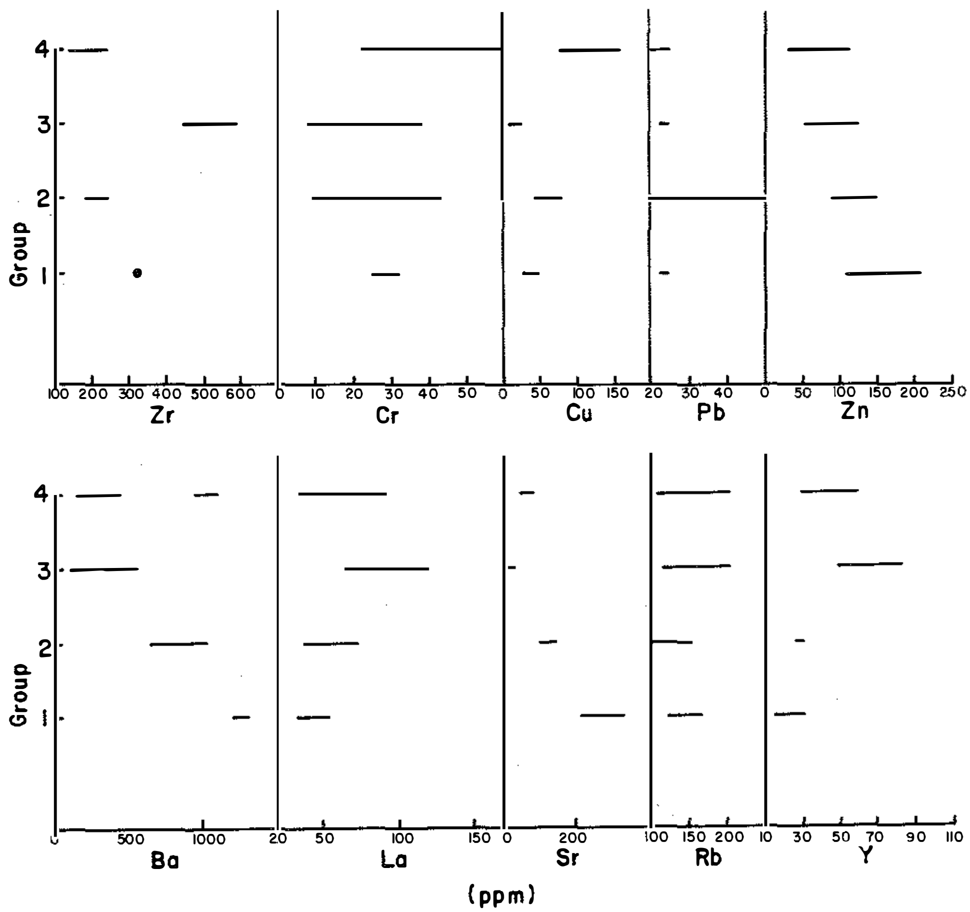

Figure 6. Some elemental concentrations for the four chemical groups (from Smith, 1978a). Bars indicate the range of values for each chemical group. Dot indicates that the data point is based on one analysis.

Relationship of Granites to Rhyolite:

The Redgranite and Montello Granites are similar in major and minor element chemistry and age to the rhyolites exposed to the south (stop 2 for example) (see table 1 , analyses 4-29; and Fig. 6; and Smith, 1978c by Van Schmus, 1978. These similarities strongly suggest that the granites and rhyolites are comagmatic. In other words, the granites may represent the magma chambers from which the rhyolite ash-flow tuffs were erupted. Later, granite intruded its own volcanic cover engulfing much of the rhyolite. Surviving rhyolite exists as roof pendants within the granite.

Table 1.

NEW CHEMICAL ANALYSES FOR CENTRAL WISCONSIN INLIERS AND IGNEOUS ROCKS IN THE BARABOO AREA

	1	2	3	4	5	6	7	8	9	10
		GROUP 1					GROUP 2			
SiO2	69.28	70.61	70.26	71.79	71.81	72.95	71.11	73.07	72.85	71.85
TiO2	0.42	0.37	0.30	0.28	0.26	0.25	0.28	0.28	0.27	0.29
Al2O3	13.90	14.29	14.10	14.46	14.29	13.77	14.68	14.65	13.88	14.32
Fe2O3	1.37	0.92	0.86	1.40	1.57	1.69	1.67	1.60	1.13	0.68
FeO	2.89	2.03	2.66	0.86	0.90	0.72	0.84	0.69	1.09	1.82
MnO	0.14	0.11	0.10	0.07	0.06	0.06	0.06	0.06	0.05	0.09
MgO	0.90	0.34	1.02	0.30	0.20	0.26	0.26	0.13	0.27	0.26
CaO	1.68	1.61	1.48	1.34	1.15	0.91	1.11	0.94	1.09	1.25
Na2O	4.17	4.45	4.29	3.48	4.14	3.88	4.00	3.78	3.58	3.68
K2O	4.33	3.78	3.69	4.63	4.54	4.46	4.35	4.21	4.53	4.52
H2O+	0.92	0.92	1.32	1.25	1.09	0.73	1.21	0.78	0.96	0.78
H2O-	0.07	0.04	0.04	0.09	0.05	0.04	0.06	0.06	0.05	0.08
P2O5	0.18	0.08	0.17	0.08	0.09	0.04	0.09	0.05	0.10	0.08
TOTAL	100.25	99.55	100.29	100.03	100.15	99.76	99.72	100.30	99.85	99.70
B	20	24	25	28	33	20	20	28	22	20
Ba	1300	1350	1200	690	650	590	650	690	630	720
Co	3	3	3	3	3	3	3	3	3	3
Cr	32	15	25	5	10	11	10	11	10	12
Cu	30	20	50	120	55	60	45	55	55	45
La	49	55	31	35	40	35	45	47	40	42
Mo	10	10	10	10	10	10	10	10	10	10
Ni	12	10	10	10	10	10	10	10	10	10
V	7	3	6	6	8	9	10	6	8	5
Y	32	38	15	30	22	28	30	30	22	30
Zr	320	440	320	200	230	210	240	210	230	200
Pb	28	22	22	40	30	45	30	40	35	45
Rb	165	154	120	152	125	137	134	138	130	116
Sr	210	212	324	105	97	97	137	95	130	150
Zn	210	190	110	130	70	145	105	105	70	115
Sc	5	5	5	-	-	-	-	-	-	-

Table 1. (Continued)

	11	12	13	14	15	16	17	18	19	20
	GROUP 2 (Continued)				GROUP 3					
SiO2	71.22	71.64	72.27	72.33	75.83	75.09	73.73	76.14	75.30	75.60
TiO2	0.24	0.28	0.30	0.28	0.21	0.21	0.29	0.24	0.19	0.17
Al2O3	14.15	14.36	13.83	13.62	11.92	12.33	12.09	11.79	12.04	12.59
Fe2O3	1.53	1.84	1.51	1.94	1.08	1.08	1.83	1.10	1.04	0.99
FeO	0.70	0.65	1.08	0.68	0.98	1.12	1.34	0.88	1.04	0.71
MnO	0.12	0.07	0.08	0.07	0.07	0.08	0.11	0.02	0.06	0.03
MgO	0.15	0.28	0.24	0.29	0.06	0.04	0.04	0.09	0.04	0.04
CaO	2.03	1.37	1.61	1.27	0.53	0.39	0.36	0.45	0.33	0.13
Na2O	3.14	4.07	3.87	4.70	3.43	3.76	3.50	3.16	4.65	4.46
K2O	4.66	3.74	3.72	3.73	5.45	5.58	6.03	5.65	4.63	4.95
H2O+	1.94	1.50	1.51	1.16	0.54	0.49	0.36	0.58	0.33	0.47
H2O-	0.05	0.09	0.07	0.05	0.01	0.00	0.01	0.01	0.03	0.02
P2O5	0.07	0.10	0.09	0.10	0.01	0.01	0.00	0.01	0.00	0.00
TOTAL	100.00	99.99	100.18	100.22	100.12	100.18	99.69	100.12	99.68	100.16
B	29	26	26	20	25	20	20	20	22	22
Ba	730	630	750	650	440	410	390	390	115	545
Co	3	3	3	3	3	3	3	3	3	3
Cr	11	9	8	7	38	23	27	8	13	16
Cu	55	55	72	50	23	22	26	9	22	25
La	45	35	37	37	78	90	120	95	72	65
Mo	10	10	10	10	10	10	10	10	10	10
Ni	10	10	10	10	10	10	10	10	10	10
V	7	12	12	10	5	5	5	5	5	5
Y	27	28	22	27	70	71	85	65	49	49
Zr	190	200	210	270	420	590	550	590	450	480
Pb	50	40	40	35	22	23	22	28	19	28
Rb	155	116	102	75	190	152	152	202	117	120
Sr	126	126	135	106	25	31	11	21	5	28
Zn	120	115	85	120	55	125	115	65	105	95
Sc	-	-	-	-	3	3	3	3	3	3

Table 1. (Continued)

	21	22	23	24	25	26	27	28	29
	MARCELLON							BARABOO	
SiO2	75.68	78.25	75.55	76.63	71.99	71.80	73.77	73.83	72.76
TiO2	0.12	0.11	0.14	0.12	0.26	0.32	0.14	0.16	0.22
Al2O3	12.46	11.05	12.21	11.38	13.57	13.74	12.35	13.33	13.34
Fe2O3	0.68	0.95	0.42	0.97	1.93	1.30	1.01	0.96	1.77
FeO	1.09	0.84	1.71	1.13	0.88	1.72	1.81	1.21	0.72
MnO	0.13	0.07	0.17	0.12	0.11	0.11	0.13	0.07	0.12
MgO	0.12	0.16	0.29	0.13	0.37	0.58	0.39	0.31	0.18
CaO	0.36	0.29	0.45	0.62	1.10	0.85	0.94	0.43	0.45
Na2O	3.66	3.66	2.82	3.16	4.34	4.43	3.26	2.51	4.39
K2O	5.00	3.72	5.16	4.66	4.91	4.49	4.92	5.28	5.25
H2O+	0.57	0.70	0.85	0.59	1.20	0.60	1.25	1.43	0.77
H2O-	0.04	0.09	0.04	0.01	0.08	0.04	0.04	0.05	0.08
P2O5	0.07	0.09	0.06	0.06	0.03	0.13	0.07	0.08	0.01
TOTAL	99.98	99.98	99.87	99.58	100.77	100.11	100.08	99.65	100.06
B	40	25	20	35	30	20	22	27	35
Ba	240	160	180	240	970	1050	410	1100	950
Co	3	3	3	3	5	3	3	3	5
Cr	54	44	62	41	15	58	58	25	22
Cu	95	115	160	80	40	105	110	42	45
La	47	35	50	45	90	52	42	49	80
Mo	10	10	10	10	10	10	10	10	10
Ni	5	11	5	5	5	5	5	10	5
V	5	5	5	5	8	5	5	3	5
Y	50	42	52	50	60	35	38	31	33
Zr	200	180	200	190	150	220	160	240	140
Pb	22	19	180	14	22	18	19	5	25
Rb	131	108	165	130	102	110	108	205	115
Sr	72	61	61	46	95	176	82	110	62
Zn	100	130	105	110	102	135	110	35	115
Sc	5	5	5	5	7	7	5	5	7

Table 1. (Continued)

	30	31	32	33	34	35	36	37
				DIKES				
SiO_2	63.92	72.10	60.59	48.94	49.47	52.02	60.72	56.21
TiO_2	0.94	0.30	0.93	0.99	0.94	1.27	0.99	1.33
Al_2O_3	15.65	12.74	16.47	17.84	14.77	15.84	15.72	13.20
Fe_2O_3	1.92	1.06	1.61	2.21	1.46	2.66	1.13	1.95
FeO	4.38	2.21	4.50	6.56	7.42	7.72	5.86	6.66
MnO	0.20	0.12	0.18	0.19	0.19	0.21	0.19	0.14
MgO	1.40	0.09	1.77	6.57	7.05	4.78	1.89	5.10
CaO	1.58	1.08	3.86	9.59	6.54	7.87	3.94	6.01
Na_2O	4.71	3.12	4.27	3.25	4.59	3.23	3.90	3.09
K_2O	3.34	6.12	3.27	1.11	1.09	1.66	3.31	2.56
H_2O+	1.51	0.73	1.50	2.97	5.57	1.96	1.43	2.34
H_2O-	0.11	0.03	0.11	0.12	0.18	0.10	0.10	0.14
P_2O_5	0.31	0.04	0.48	0.31	0.36	0.34	0.46	0.98
TOTAL	99.97	99.74	99.54	100.29	99.63	99.66	99.64	99.71
B	20	20	50	25	15	33	22	70
Ba	1050	1170	1200	660	680	950	1250	1100
Co	3	3	4	24	20	20	7	37
Cr	12	26	16	42	155	27	20	150
Cu	65	16	70	50	77	75	32	80
La	40	88	68	10	21	29	33	95
Mo	10	10	10	10	10	10	10	10
Ni	10	10	6	24	19	10	16	51
V	15	5	92	240	240	270	55	260
Y	25	63	28	11	14	31	32	45
Zr	200	590	220	75	86	180	240	620
Pb	30	19	25	28	15	20	22	21
Rb	113	180	105	38	55	154	155	75
Sr	218	56	514	642	270	419	420	625
Zn	75	110	180	180	170	190	220	160
Sc	-	3	20	27	25	24	16	23

Table 1. (Continued)

	38	39	40	41	42	43
SiO2	69.76	68.44	70.22	71.20	67.60	76.17
TiO2	0.37	0.50	0.35	0.47	0.44	0.17
Al2O3	13.77	14.20	14.26	14.90	15.10	12.05
Fe2O3	0.76	1.46	0.94	1.72	1.75	0.96
FeO	2.25	2.99	2.47	1.60	2.24	1.00
MnO	0.13	0.17	0.19	---	---	0.03
MgO	0.43	0.62	0.34	0.72	1.10	0.11
CaO	2.30	2.02	1.30	0.71	2.10	0.26
Na2O	3.95	4.78	4.48	1.70	1.95	3.76
K2O	3.55	3.06	3.76	5.98	4.95	4.27
H2O+	2.12	1.11	1.07	0.70	1.60	0.63
H2O-	0.03	0.04	0.06	0.40	0.90	0.07
P2O5	0.11	0.13	0.09	---	---	0.06
TOTAL	99.53	99.52	99.53	100.38	100.62	99.53
B	17	20	20	18	25	16
Ba	990	1250	1400	550	450	165
Co	3	5	5	3	25	3
Cr	28	15	25	45	17	45
Cu	135	110	90	410	370	155
La	40	29	40	33	35	55
Mo	20	20	20	20	20	20
Ni	10	5	5	10	17	10
V	5	22	5	40	35	17
Y	22	29	30	20	20	26
Zr	280	260	270	220	220	340
Pb	25	---	---	10	40	16
Rb	105	72	84	190	180	95
Sr	205	420	275	26	79	26
Zn	97	---	---	110	205	120
Sc	---	10	5	6	6	5

Table 1. Explanation

Number	Sample Number	Description
1.	179	Coarse-grained rhyolite dike on Observatory Hill.
2.	180	Contact zone of coarse-grained rhyolite dike on Observatory Hill.
3.	183	Baxter Hollow Granite.
4.	89	Marquette rhyolite (unit G) from Noble's Quarry. Samples 4-14 are keyed to figure 45.
5.	102	Marquette rhyolite (unit G).
6.	106	Marquette rhyolite (unit G).
7.	101	Marquette rhyolite (unit F).
8.	100	Marquette rhyolite (unit E).
9.	103	Marquette rhyolite (unit D).
10.	104	Marquette rhyolite (unit D, massive phase).
11.	91	Marquette rhyolite (unit C).
12.	92	Marquette rhyolite (unit B).
13.	98	Marquette rhyolite (unit B).
14.	99	Marquette rhyolite (unit B).
15.	107	Montello Granite.
16.	108	Observatory Hill rhyolite.
17.	109	Endeavor rhyolite.
18.	110	Granite at Redgranite collected in Flynn's Quarry.
19.	112	Berlin rhyolite.

Table 1. Explanation (Continued)

20.	114	Utley rhyolite.
21.	173	Marcellon rhyolite (unit A). Sample numbers 21-27 are keyed to figure 33.
22.	176	Marcellon rhyolite (unit A).
23.	174	Marcellon rhyolite (unit B).
24.	161	Marcellon rhyolite (unit B).
25.	145	Marcellon rhyolite (unit C).
26.	175	Marcellon rhyolite (unit C).
27.	178	Marcellon rhyolite (unit D).
28.	182	Caledonia Church rhyolite (south limb of the Baraboo Syncline).
29.	147	Baraboo rhyolite from the NE ¼, sec. 23, T. 12 N., R. 7 E.
30.	105	Marquette andesite dike (figure 45).
31.	111	Granite porphyry dike from Flynn's Quarry County Park.
32.	148	Marcellon andesite dike (figure 33).
33.	177	Marcellon basalt dike (figure 33).
34.	153	Metabasalt dike at Montello (collected from quarry just north of S.H. 23).
35.	154	Metabasalt dike at Redgranite (from quarry city of Redgranite).
36.	155	Diorite dike from granite quarry near Spring Green (NE ¼, sec. 27, T. 18 N., R. 11 E.).
37.	184	Denzer diorite

38.	192	Dacite dike at Marquette (figure 45).
39.	190	Dacite dike at Marquette (figure 45).
40.	191	Dacite dike at Marquette (figure 45).
41.	210	Dacite dike in the Utley Quarry.
42.	211	Andesite dike in the Utley Quarry.
43.	193	Taylor Farm rhyolite.

All major element analyses on Table 6 (except #41 and 42) were made using conventional wet-chemical methods (K. Aoki, analyst). Major element analyses 41 and 42 were done by O. Joensuu. Trace element analyses (Rb, Sr, Pb and Zn) by atomic absorption spectrometry (O. Joensuu, analyst). All other trace elements by optical emission spectrography (O. Joensuu, analyst). The results for Zr are accurate to ± 10%. Sr and Rb are accurate to ± 5% of the amount present except for low Sr (less than 20 ppm) which is accurate to ± 10% of the amount present.

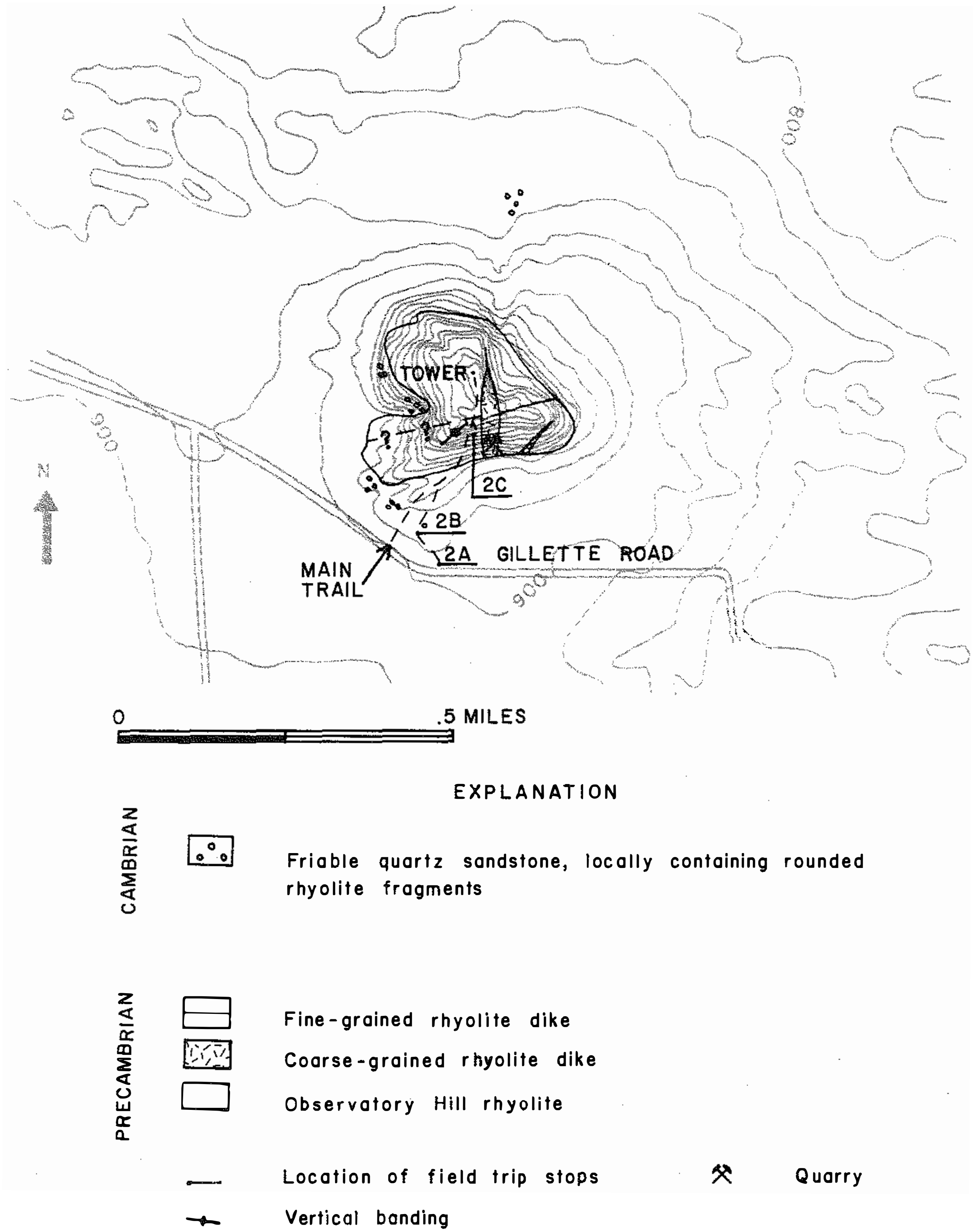

Figure 7. Geologic map of Observatory Hill adapted from Hobbs and Leith (1907). Approximate locations of field trip stops are superimposed. Contour interval 20 feet between 800 and 960 feet; above 960 feet the interval is 10 feet. Contour lines between 900 and 960 feet are approximately located.

STOP 2 - RHYOLITE AT OBSERVATORY HILL

Location:

Observatory Hill (Hobbs and Leith, 1907) is one of five porphyritic rhyolite inliers in south-central Wisconsin (others are at Endeavor, Taylor Farm, Utley and Berlin). The hill is formed by steeply dipping flows of quartz-and alkali feldspar-bearing rhyolite tuffs, cut by coarse-grained and fine-grained rhyolite dikes. Observatory Hill is surrounded by outcrops of Upper Cambrian sandstone and conglomerate (Fig. 7).

The traverse to the summit of Observatory Hill will follow an easy but sometimes indistinct trail. Please stay together during the climb. It is quite easy to become lost on the slopes surrounding Observatory Hill.

Description:

Stop 2A

The climb to the summit of Observatory Hill begins at exposures of Cambrian sandstone just to the east of the bend in Gillette Road (north side of road) (Fig. 7). The outcrop at this stop is about 300 m to the south of rhyolite outcrops on Observatory Hill and is composed of a friable reddish-brown quartz sandstone. No fragments of rhyolite are found here; they are quite common, however, in sandstone exposures closer to the rhyolite ledges.

Stop 2B

Walk from stop 2A to the northwest over the low rise to the first northeast trending valley (Fig. 7). Note the outcrops of Cambrian sandstone and conglomerate on the southeast side of the valley (Fig. 8). A conglomerate bed in this exposure is approximately 40 cm thick and contains rhyolite fragments lithologically similar to rhyolite cropping out 200 m to the north. The fragments within the conglomerate are rounded and reach 10 cm in size (Fig. 9). Occasionally, quartzite is found as small rounded pebbles in the conglomerate. The source of these clasts may be in the large area of quartzite to the northeast of Observatory Hill (Smith, 1978c) or from vein quartz within the rhyolite.

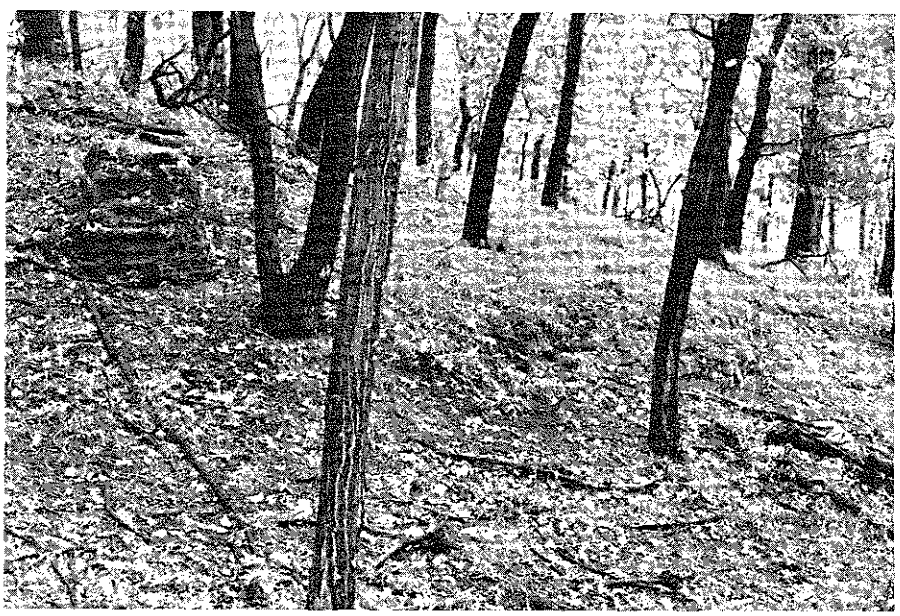

Figure 8. View of Cambrian sandstone outcrops at stop 2B on the south flank of Observatory Hill.

Figure 9A. Close-up of a conglomerate layer interbedded with Cambrian sandstone at stop 2B. In these bands, fragments are angular (compare with Fig. 9B). Most of the fragments are porphyritic rhyolites similar to those cropping out on Observatory Hill.

Figure 9B. View of large rhyolite fragments (up to 10 cm in size) in a conglomerate layer at stop 2B. In this band, fragments are rounded (compare with Fig. 9A).

On Observatory Hill exposures of conglomerate containing rhyolite pebbles are usually restricted in occurrence to a zone 5 to 20 m wide about the rhyolite ledges. The conglomerate layer at Stop 2B is located an unusually large distance from rhyolite exposures (200 m), and its deposition probably reflects a relatively short lived and highly energetic event. In the Baraboo region Dott and Dalziel (1970) reported large boulders of Baraboo Quartzite entrapped within Cambrian sandstone. They envisaged transport of cobbles and boulders by waves and strong currents generated by violent tropical storms that pounded the Baraboo islands during Cambrian time. Observatory Hill probably existed as a small island in late Cambrian time and was probably also hit by violent tropical storms. Strong currents generated during these storms are probably responsible for the transport of rhyolite fragments away from the Observatory Hill island, thus forming the conglomerate band observed at Stop 2B.

Stop 2C

From Stop 2B climb the ridge above the sandstone exposure and join a trail running along the crest of the ridge. Follow this trail to where it joins the main trail and then continue up the hill on the main trail (Fig. 7).

Note the first outcrops of rhyolite to your left and straight ahead. There is at least 500 feet of relief on the Precambrian surface in the vicinity of Observatory Hill. Just ahead rhyolite exposures are at an elevation of 1080 feet. About 1200 m to the northwest of Observatory Hill, rhyolite was encountered in an irrigation well at a depth of 300 feet (480 feet above sea level).

Cross into the rhyolite exposures and continue to the trail junction. Follow the trail to the right (south). The fork to the left (north) goes to the summit where a lookout tower was once located in the early 1920's (Fig. 7). The ruins of the tower can still be observed along the inscriptions carved into the rhyolite by several of the workers who manned the tower.

Follow the trail (south) to a large area of bare rock which forms the sharp southern edge of Observatory Hill (hereafter called the south bluff). From the south bluff the Marcellon rhyolite exposures (20 km to the south) and the Baraboo Hills (30 km to the southwest) can be easily seen on a clear day. At this stop, we will examine the Observatory Hill rhyolite and a coarse-grained rhyolite dike.

Observatory Hill Rhyolite

The Observatory Hill rhyolite is typical of porphritic rhyolites exposed in south-central Wisconsin. It contains phenocrysts of quartz ($<$1 mm in size and rounded) and pink to white alkali feldspar (1 to 5 mm in size) set in a dark gray to black matrix. On close examination, the matrix of the rhyolite shows faint flow structure formed by flattened shards and pumice fragments. In general, these bands dip steeply and strike N. 50°E. The rhyolite is an ash-flow tuff and is remarkably texturally homogenous over the entire hill.

Petrographic studies indicate that the rhyolite is composed of pheno-crysts of quartz and alkali feldspar set in a coarsely devitrified ground-mass. The quartz is anhedral and is usually strained (7%). Some of the quartz is deeply embayed. Alkali feldspar (23%) is probably orthoclase and may display carlsbad twinning. Accessory minerals are chlorite, biotite (?), epidote, iron oxide and zircon. The matrix commonly contains aligned and flattened Y shaped and cuspate shards.

In terms of major and minor element chemistry, the rhyolite belongs to chemical group 3 (Table 1, analysis 16; Fig. 6), of Smith (1978a) and is therefore similar in chemistry to granophyric granites and porphyritic rhyolites in the Fox River Valley. The group 3 rhyolites and granites are distinguished from other south-central Wisconsin igneous rocks by high SiO_2, K_2O/Na_2O, La, Zr, Y and Rb/Sr; and low CaO, Al_2O_3 and Ba (Table 1).

Coarse-Grained Rhyolite Dike

A coarse-grained rhyolite dike strikes north south across Observatory (Fig. 7). The dike is about 70 m wide at the south bluff but pinches out to the north. A thin (15 m thick) dike of similar coarse-grained rhyolite strikes N. 50 E. across the southeast slopes of Observatory Hill. These dikes were originally identified by Hobbs and Leith (1907) who referred to them as granite dikes.

The contact between the dike and the Observatory Hill rhyolite is well displayed on the east edge of the south bluff. The contact shows complex interfingering of dike rock into Observatory Hill rhyolite (Fig. 10) and in locality a rhyolite zenolith is found in dike rock close to the contact. Locally the Observatory Hill rhyolite is intensely fractured near the contact (Fig. 11). Also, quartz veins are concentrated on either side of the contact.

Extending 5 to 10 m into the dike from the intrusive contact is a fine-grained contact zone (chill zone?). The rock in this zone is gray-green in color and contains large plagioclase phenocrysts.

Petrographic studies of the dike rock of the contact zone reveal subhedral zoned plagioclase phenocrysts (30%) with cores altered to sausserite and unaltered rims, subhedral alkali feldspar (5%), fractured and broken quartz (3%) and small subhedral feather-like grains of biotite (1%). The matrix is a microbreccia containing fragments of fine-grained rhyolite, basalt and eutaxitic rhyolite.

At this locality also notice the glacial polish and grooving. Here glacial striations trend N. 70° W.

Walk to the east of the south bluff to the first major outcrop. Here rhyolite in the central part of the dike is well exposed. This rhylite is similar in mineralogy to that of the contact zone, but differs by having a coarser-grained matrix than the contact-zone rock. Also, it is pink to red in color in outcrop, not green in color like the contact-zone rock. Petrographic examination indicates that plagioclase is the dominant phenocryst (46%). Alkali feldspar is present in micropegmatitic intergrowths with quartz (21%). Quartz, in addition to its occurrence in alkali feldspar-quartz

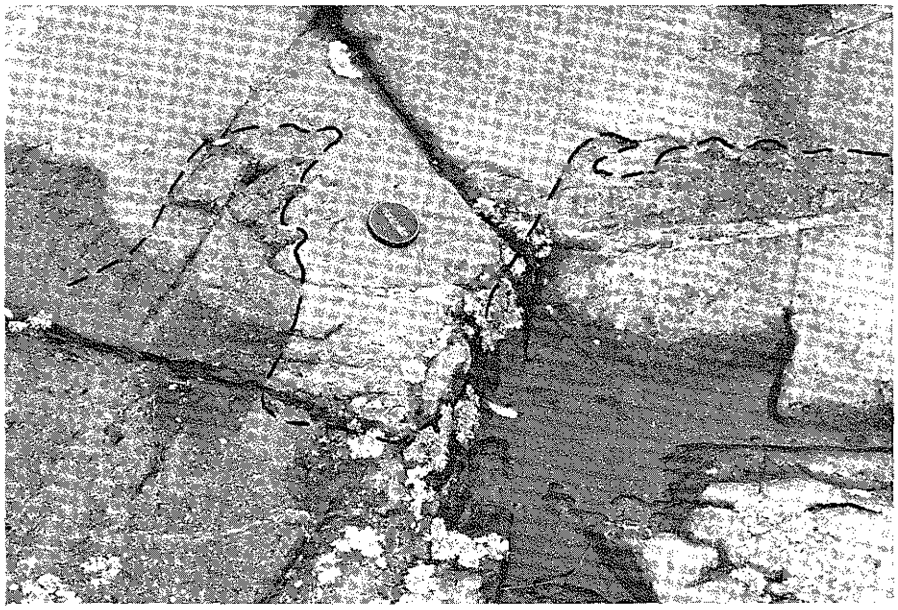

Figure 10. View of the contact between the coarse-grained rhyolite dike (below), and the Observatory Hill rhyolite (above). Note the fingers of coarse-grained rhyolite extending into the Observatory Hill rhyolite (dashed line). Also noteworthy are the numerous veins of quartz that roughly parallel the contact.

Figure 11. Close-up view of the shattering of the Observatory Hill rhyolite at the contact with the coarse-grained rhyolite dike.

intergrowths, is present as small anhedral phenocrysts (2%). Accessory minerals (10%) include chlorite in irregular clots, epidote, clinozoisite, and iron oxide. These minerals are set in a finely devitrified groundmass (21%).

This dike and a fine-grained granite at Baxter Hollow (Gates, 1942) are similar in chemistry, and form chemical group 1 of Smith (1978a) (Table 1, analyses 1 and 2; and Fig. 6). The rocks are distinguished from the other granites and rhyolites in the Fox River Valley and Baraboo area by higher TiO_2, CaO, Ba, V and Sr and by lower SiO_2 and Rb.Sr ratio. Both the Observatory Hill rhyolite and the Baxter Hollow Granite are younger than the Fox River Valley and Baraboo rhyolites. Baxter Hollow Granite intrudes rhyolite (Gates, 1942) but its relationship to the overlying Baraboo Quartzite is unclear (Dott and Dalziel, 1972). This stratigraphic and chemical evidence suggests that the intrusion of the Baxter Hollow Granite and the Observatory Hill rhyolite was a discrete igneous event that occurred after the emplacement and folding of the widespread rhyolite ash-flow sheets.

The coarse-grained rhyolite dike was quarried for a short time at the turn of the century. This operation is evidenced by a large area of broken dike rock located just below and to the east of the south bluff.

Labradorite Porphyry Dike

Hobbs and Leith (1907) reported an east-trending "labradorite porphyry" dike just to the north of the south bluff. A careful search for this dike revealed an east-trending fine-grained quartz-feldspar rhyolite dike about 5 m in width. This dike is truncated by the north-trending coarse-grained rhyolite dike as is the "labradorite porphyry" dike described by Hobbs and Leith. In terms of location, orientation and stratigraphy, it is almost certainly the same dike mapped by them. In thin section, this rock contains rounded and embayed quartz phenocrysts (2%) and alkali feldspar with perthitic texture (altered to sericite and dusted with iron oxide) (3%). These minerals occupy a fine-grained matrix (devitrified) with iron oxide accentuating a crude banding (95%). The only evidence of metabasalt on Observatory Hill is found on the south bluff. Here a green metabasalt that occurs in an outcrop only 3 m long and 0.3 m wide may intrude rhyolite.

Other Exposures of Porphyritic Rhyolite:

Other exposures of porphyritic rhyolite (Endeavor, Utley, Berlin, and Taylor Farm) are mineralogically, texturally, and chemically similar to the rhyolite at Observatory Hill. However, common in the Utley rhyolite are zones of spherulites and lithophysae, also disk-shaped coarse-grained inclusions may represent recrystallized collapsed pumice. Rhyolite is locally sheared at Berlin (Weidman, 1898) and slickensided surfaces are found at Utley (Gram, 1947). Rhyolite at Utley is intruded by rhyolite, dacite and metabasalt dikes.

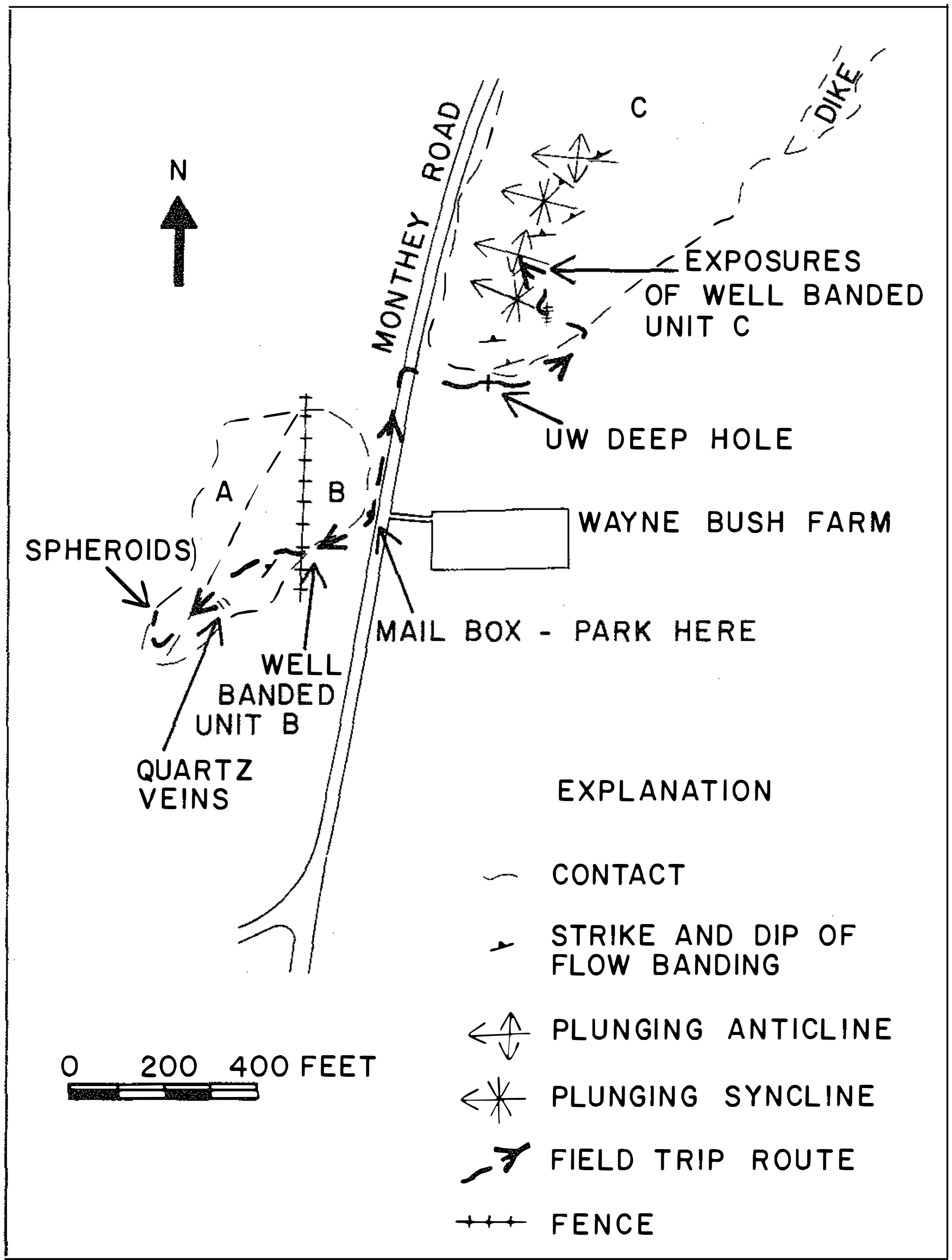

Figure 12. Route map for traverses at the Marcellon rhyolite exposures. Letters A, B, C refer to Marcellon rhyolite unit numbers (see text and Fig. 13).

STOP 3 - THE MARCELLON RHYOLITE-SPHEROIDAL TEXTURES

Location:

To reach the outcrops of spheroidal rhyolite we will walk into the woods (west) at the mail box located across Monthey Road from the Wayne Bush Farm. This traverse requires a bit of climbing on bare rock that becomes quite slippery during wet weather. Wear proper field boots and take considerable care while on this traverse.

This stop will illustrate several of the textural types of rhyolite in the Marcellon inlier. See Figure 12 for the traverse route. The rhyolite exposures to the east of Monthey Road are described in a supplemental stop.

Introduction to the Marcellon Rhyolite: The Marcellon inlier (Hobbs and Leith, 1907; Smith, 1978a) is composed of texturally variable rhyolites similar in chemistry and lithology to rhyolites at the Marquette exposure (Stop 4), and in the Baraboo area. The Marcellon inlier is formed by four mineralogically and chemically distinct ash-flow tuffs folded into a northeast striking asymmetric (and possibly overturned) antiform (Fig. 13). The western limb of the antiform strikes N. 50° E. and dips 50-85° to the northwest. The eastern limb also strikes N. 50° E. but dips steeply (80° to vertical) to the southeast. The rhyolite flows are cut by a northeast trending andesite dike and by an east trending basalt dike (Table 1, analyses 32 and 33). The andesite dike cuts the basalt dike and is therefore younger.

The structurally highest unit (unit A) at Marcellon is a sparsely porphyritic plagioclase (1%), quartz (2%), alkali feldspar (2%) rhyolite characterized by abundant large spherulites (up to 15 cm in diameter) composed of radiating fibers of alkali feldspar and quartz. On the eastern flank of the fold, spherulites are less distinct and smaller, but still conspicuous. Structurally below unit A is a rhyolite (unit B) which contains sparse quartz (6%), alkali feldspar (4%) and plagioclase (1%) phenocrysts in a banded matrix with occasional faint spherulitic growths. Several samples show perlitic cracks in the matrix. Unit C is characteristically well banded and contains plagioclase as the dominant phenocryst (14-18%). Banding in unit C is continuous and relatively consistent in orientation (N. 50°E.) but locally broad westward plunging flow folds are exposed. Several lenses of spherulitic rhyolite lie parallel to banding and have sharp contacts with nonspherulitic rock. Unit C on the eastern flank of the fold is similar in mineralogy to rock on the western flank, but it lacks conspicuous banding. The core of the antiform is formed by a rhyolite (unit D) which contains phenocrysts of quartz (2%), plagioclase (15%) and alkali feldspar (2%) in a fine-grained devitrified groundmass with numerous shards, flattened pumice and perlitic fractures (Fig. 14). All units at Marcellon are interpreted as ash-flow tuffs.

Evidence for the northeast striking antiform at Marcellon includes: (a) the symmetric pattern of lithologies on the geologic map (Fig. 13); (b) structural data (orientation of banding within the rhyolite) which indicates that the western part of the structure strikes N. 50° E. and dips to the northwest; the eastern part also strikes northeast, but dips steeply to the southeast. (c) The chemical correlation of lithologically similar rhyolite from the western flank to the eastern flank of the structure. Similarities in

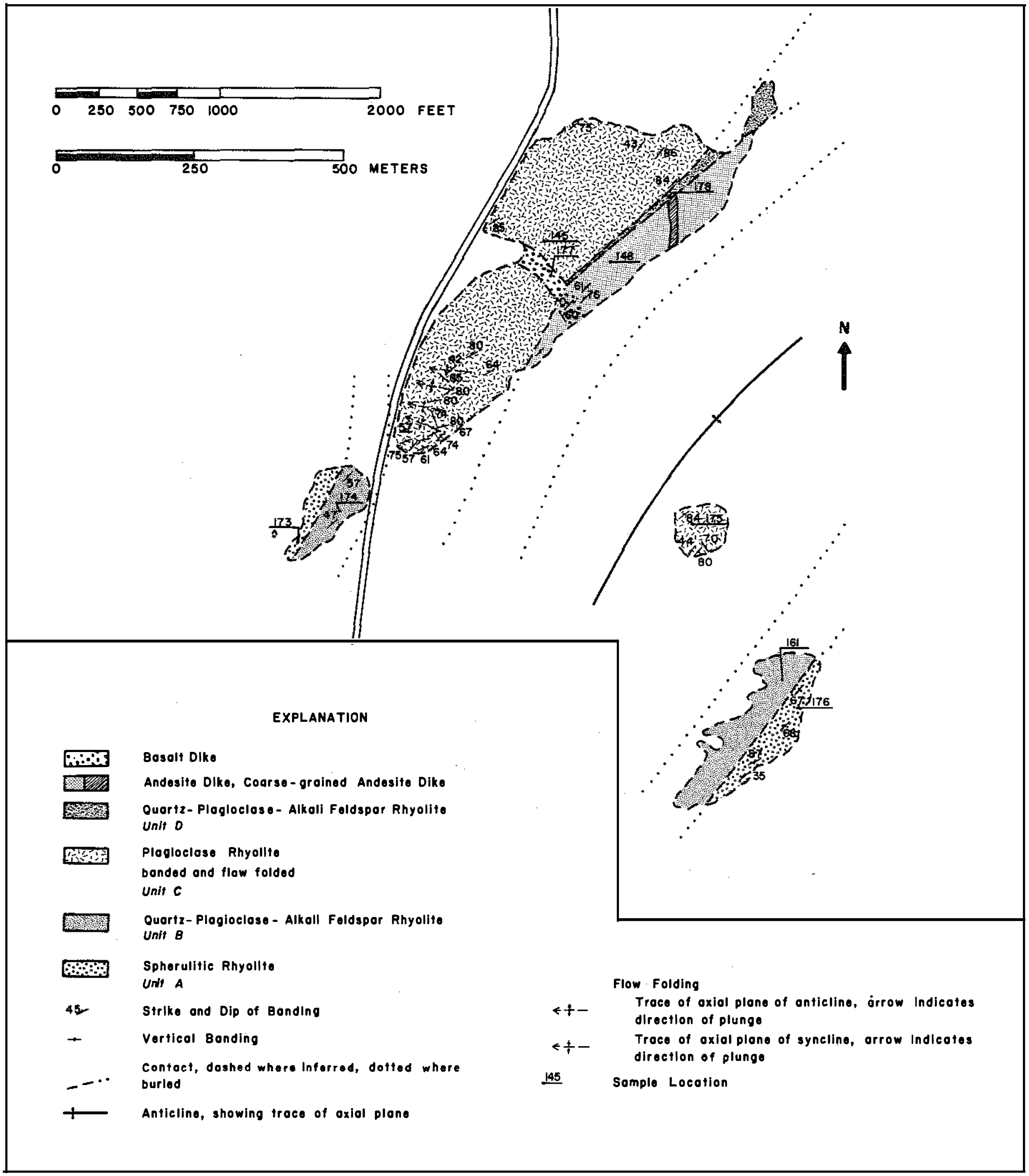

Figure 13. Geologic map of the Marcellon inlier (adapted from Smith, 1978a).

Figure 14. Photomicrograph of cuspate and Y-shaped shards in the Marcellon rhyolite ash-flow tuff (unit D). Bar scale is 1 mm long.

the Rb-Sr ratios of lithologically similar units (Table 1, analyses 21-27) suggest that they are stratigraphically equivalent. For example, both spherulitic rhyolite exposures (unit A) show similar Rb/Sr values. Similar groupings are apparent for units B and C. Unit D (Quartz-plagioclase-alkali feldspar) can be distinguished from the other quartz-bearing rhyolites by a lower Rb/Sr ratio and higher Ba, CaO, and FeO + Fe_2O_3 (2.82% as compared with a 1.77-2.13 %). Also, unit C is different from the other rhyolites by having a higher Ba content (Fig. 15).

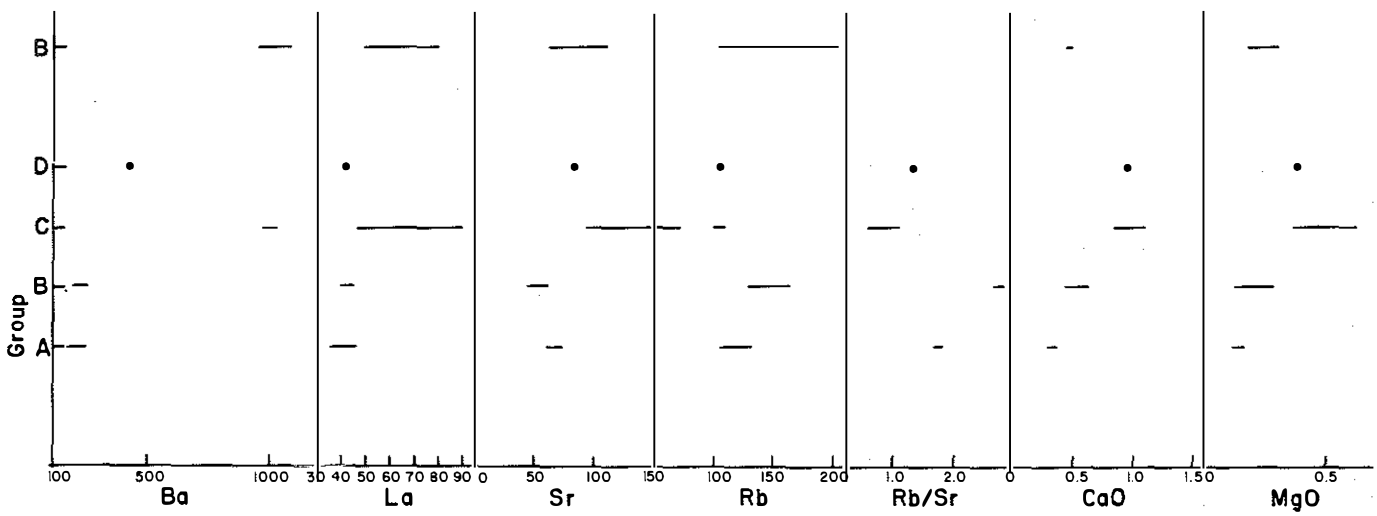

Figure 15. Stratigraphic variation in elemental concentrations for the Marcellon rhyolite. Ba, La, Sr and Rb are in ppm; CaO and MgO are in weight percent. For comparison, elemental concentrations for the Baraboo rhyolites (B) are also plotted (from Smith, 1978a).

Marcellon Traverse: Walk into the woods to the west at the mailbox located across Monthey Road from the Wayne Bush Farm. See Figure 12 for the traverse route.

Unit B

Note the well-banded unit B rhyolite to your right in the exposure just to the west of Monthey Road (Fig. 12). The bands are discontinuous and are formed by collapsed pumice fragments and shards. At this exposure, bands strike N. 50° E. and dip to the northwest at 50° to 70°; thus indicating the orientation of the west limb of the Marcellon antiform. Band orientation is remarkably consistent in this area, but several broad folds interrupt this pattern. In several places unit B is spherulitic.

Walk to the southwest along the margin of the bluff. Cross the barbed-wire fence and climb to the crest of the bluff (Fig. 12). As you ascend, note the lichen growing in grooves in differentially weathered unit B rhyolite (the grooves are parallel to the banding described above). At the crest of the bluff notice the glacially polished and striated surface (striations trend N. 70° W.). Also noteworthy are the large veins of milky quartz on the south flank of the bluff. One quartz vein is 20 cm wide and over 6 m long.

Cross the summit of the hill and descend to its base (you should now be on the west side of the hill and almost at its end) (Fig. 12). Notice that as the hill is traversed from east to west the banding so common in unit B disappears and that the rock becomes highly charged with spheroids (characteristic of unit A). This change marks the contact between unit B and unit A.

Spheroidal Texture

Unit A is a poorly-banded ash-flow tuff with a spheroidal texture (Figure 16). Banding trends N. 20°E. to N. 30° W. and may swirl about spheroids or may be truncated by them. Three important types of spheroids are present in this exposure.

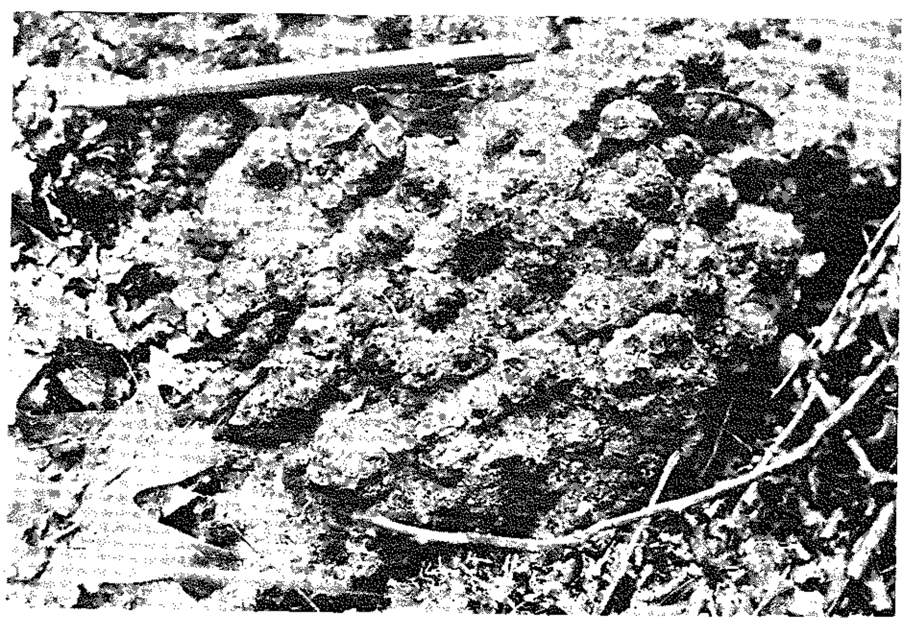

Figure 16. View of weathered spherulites in the Marcellon rhyolite (unit C). These spherulites are identical to those observed in unit A.

(1) Spherulites composed of radiating fibers of quartz and alkali feldspar (Fig. 17). A small alkali feldspar crystal may be present in the core of the spheroid. In outcrop they appear massive and may be broken. Spherulites commonly form by the devitrification of volcanic glass, and commonly occur in the densely welded vitric basal zone of an ash-flow cooling unit.

Spherulites are also quite common in felsic lava flows.

(2) Spheroids with concentric bands. In thin section they are composed of alternating concentric bands of coarsely and finely devitrified glass (Fig.18). These spheroids may be concretionary lapilli (??).

(3) Lithophysae with hollow cores and in many cases with drusy quartz lining the cavity wall. These spheroids may not have a central cavity. In thin section many of them have a core of epidote, and/or quartz (Fig. 19).

The spheroids have cross sections that are nearly circular (average ratio of length of minor to major axis = 0.71 ± 0.11). The cross sections of these spheroids may be regarded as strain ellipses, and their nearly circular shape suggests that these rhyolites were not strongly deformed. Also supporting this suggestion is the overall freshness of the rhyolites (there is little evidence for medium- or high-grade metamorphism, and original textures are preserved in the matrix). Also considering their age, these rocks are remarkably fresh in terms of their chemistry (Smith, 1978a).

Deep Well: Return to Monthey Road. Walk from the Bush Farm to the tree covered hill just to the north of the farm (Fig. 12). The outcrop of well-banded unit C at the base of the hill was the site of a deep hole drilled by B. Haimson and students from the University of Wisconsin-Madison. Two hundred and ninety-seven feet of core was recovered before drilling had to be stopped because of the extreme hardness of the rock (Haimson, 1978). The hole penetrated banded unit C. and then entered a poorly banded rhyolite mineralogically identical to unit C. This poorly banded rock is most probably a textural variant of unit C. and may represent a separate ash-flow cooling unit. Also, a 1 m thick metabasalt dike trending N. 26°E. was intersected at a depth of 132 feet in the hole.

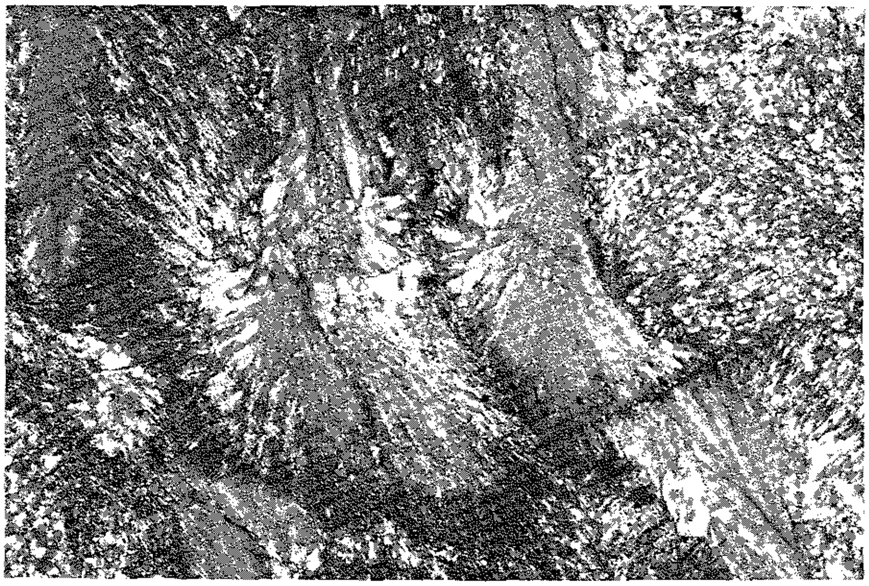

Figure 17. Photomicrograph of spherulitic texture in the Marcellon rhyolite unit A. These spherulites are composed of radiating fibers of quartz and alkali feldspar. Bar scale in 1 mm long.

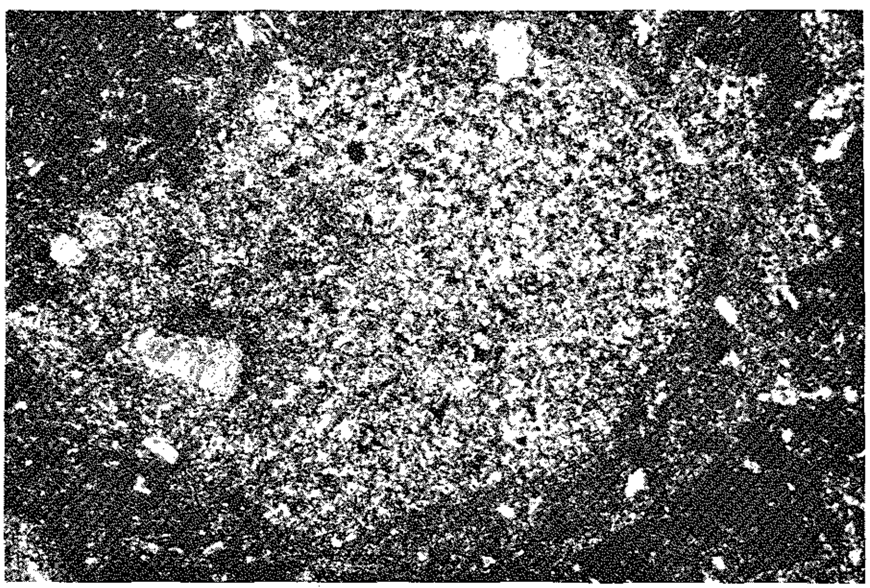

Figure 18. Photomicrograph of a spheroid with concentric bands. Core is composed of coarse-grained quartz and alkali feldspar; rim is formed by fine-grained quartz and alkali feldspar. Several spheroids show alternating bands of coarse- and fine-grained material. Bar scale is 1 mm long.

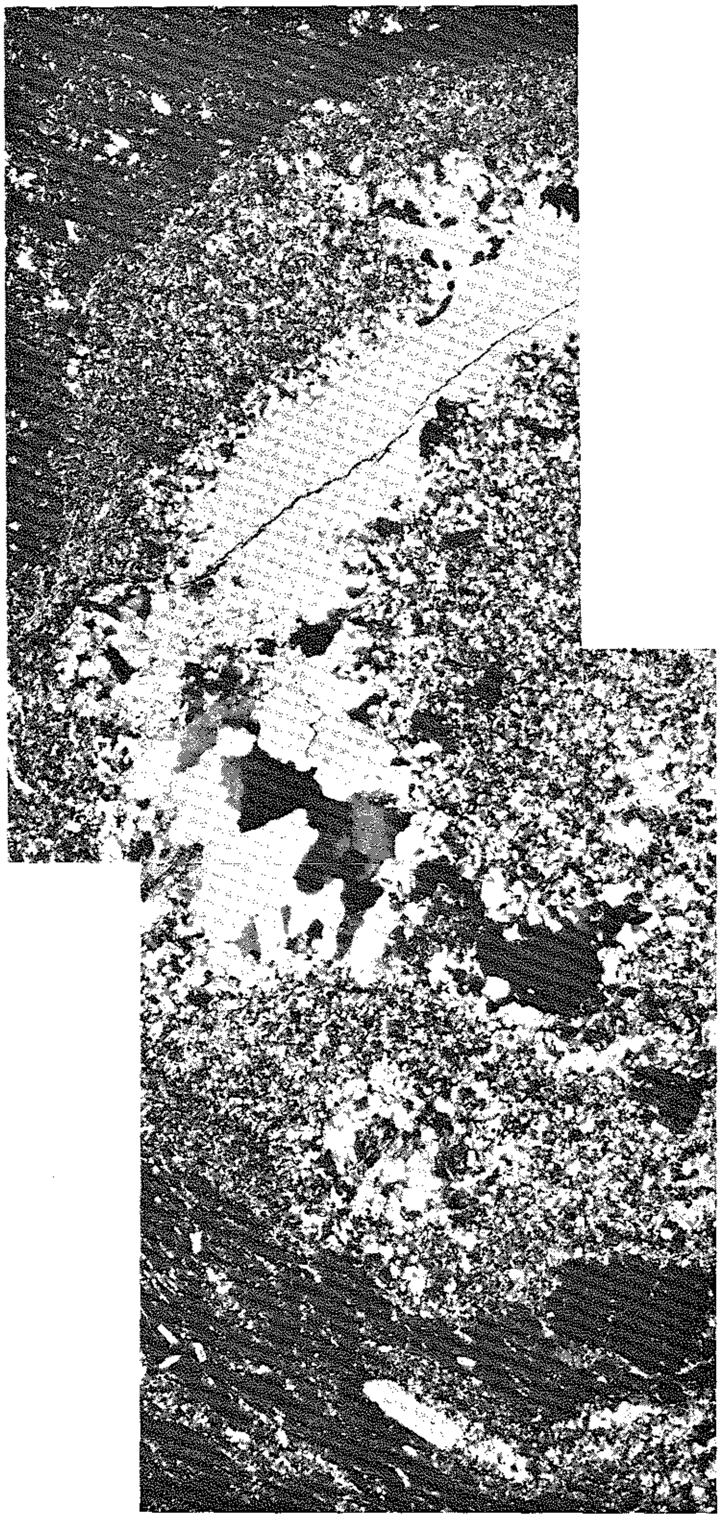

Figure 19. Photomicrograph of a spheroid with a core of coarse quartz and epidote. Quartz grains are interlocking and probably grew in a cavity. The core is off-center within the spheroid and is surrounded by a band of fine-grained quartz and alkali feldspar. Many of the spheroids are more intricate and have alternating bands of fine- and coarse-grained alkali feldspar and quartz about the core. These structures may be lithophysae. Bar scale is 1 mm long.

Supplemental Stop - Flow Structures in the Marcellon Rhyolite:

This stop illustrates structures and textures in unit C. From the Bush Farm walk to the north on Monthey Road to the tree covered knob (Fig. 12). Turn right (east) on the dirt road (just south of the hill). Walk past the drilling site (described in Stop 3) and continue walking for about 70 m (Figure 12). Turn left (north) into the trees and follow the "canyon" to the bare steep exposure on the right (a distance of about 50 m, on the way, you should pass a large red granite erratic). The textures described below are located on this exposure.

Unit C is a well-banded rhyolite containing plagioclase (15-25 %) as the dominant phenocryst. The unit strikes N. 30° E. and dips steeply 50° to 80° to the northwest (this exposure is on the west limb of the Marcellon antiform). Bands are discontinuous and are in general lighter-colored than the matrix (Fig. 20). Many bands have a dark medial line, and in places they are observed to bend about phenocrysts. The bands were formed during primary flowage and compaction of an ash-flow tuff by shearing and compaction of pumice and shards.

Banded ash-flow tuffs similar to those observed here are quite common in outflow deposits about Tertiary volcanic centers (Schmincke and Swanson, 1967; Deal and Rhodes, 1976). When viewed perpendicular to the foliation plane, these Tertiary ash-flow tuffs display strong lineation formed by flattened pumice (Fig. 21). The axial ratio of pumice may be 20 to 1 on the flow plane, and as high as 200 to 1 on the plane normal to the flow surface and parallel to the direction of flow. Where pumice shows a high degree of stretching and flattening the rock may resemble a flow-banded lava, but the presence of glass shards and the discontinuous nature of the bands suggests instead that the rock is a highly foliated ash-flow tuff (Smith, 1978b).

The banding at this locality is folded into a series of broad anticlines and synclines that plunge steeply (50° to 80°) to the west. Fold amplitudes are as great as 30 m and wavelengths vary up to 10 m. In most cases where a fold nose is observed, the plunge of the fold axis parallels the dip of unit C as a whole. Fold limbs are themselves folded into antiforms and synforms that plunge steeply to the west (Fig. 22). These minor folds have amplitudes of up to 10 m and wavelengths that vary from several centimeters to several meters. Flow bands on fold limbs may truncate each other, also fold crests may not completely close, forming fanning patterns (Fig. 23).

The folds are interpreted as ramp structures formed during the flowage of an ash-flow tuff. In detail they are formed by compressional buckling and thrusting of the upper part of an ash-flow cooling unit over a more fluidal interior (Smith, 1978b). In Tertiary ash-flow tuffs ramp structures are broad warps in the flow foliation that resemble large folds in felsic lavas. Amplitudes are up to 50 m and wavelengths vary from several meters to tens of meters. Many are asymmetric with gentle limbs dipping 10° to 30° sourceward, and are convex upward (Schminke and Swanson,1967).

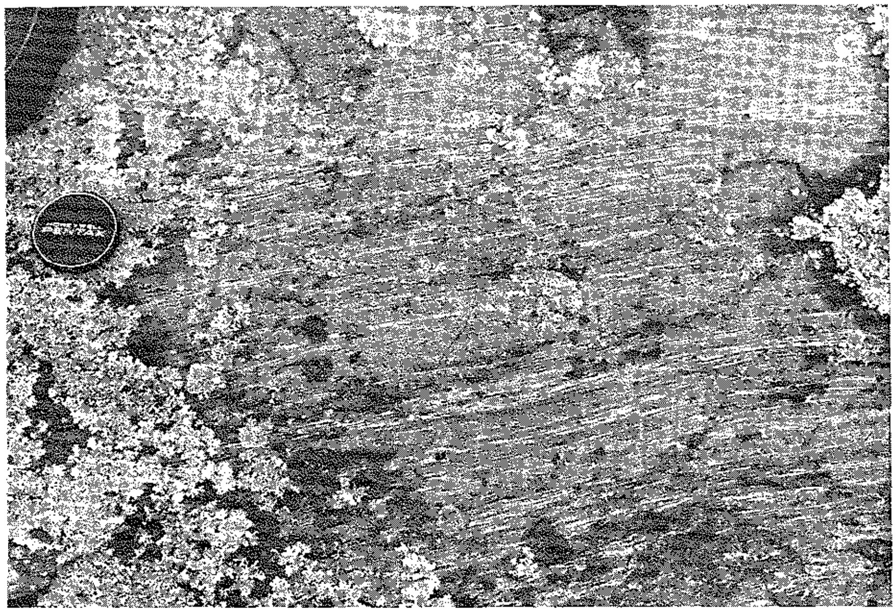

Figure 20. Highly flattened and sheared pumice and shard fragments forming a pronounced lineation in the Marcellon rhyolite (unit C). The bands are discontinuous and are in general lighter colored than the matrix. Note that several bands trend to form about cavities and phenocrysts.

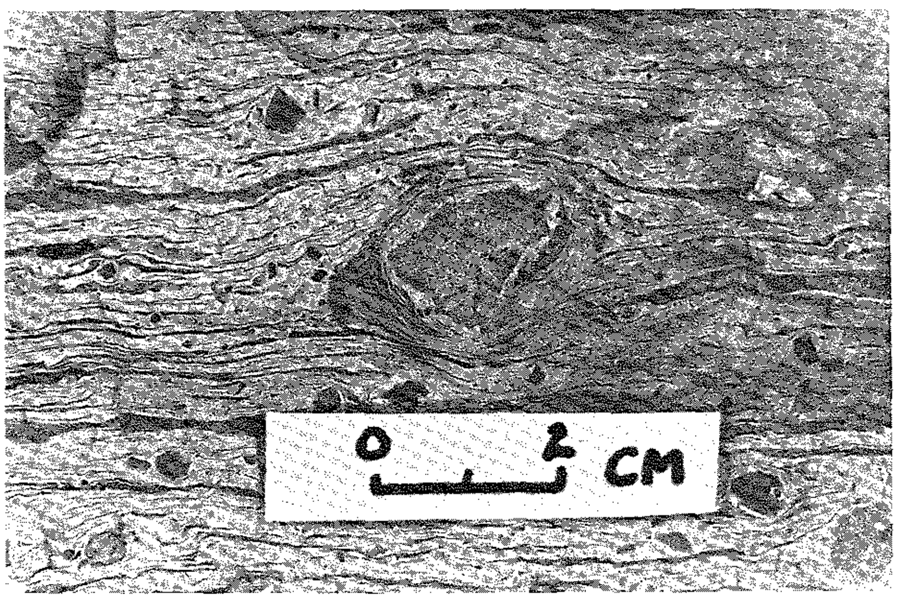

Figure 21. Close-up of lineation formed by highly flattened and stretched pumice in the Tertiary A. L. Peak Tuff, San Mateo Mountains, New Mexico. The strong lineation formed during the late-stage laminar flowage of the ash flow. Also note the numerous rotated inclusions.

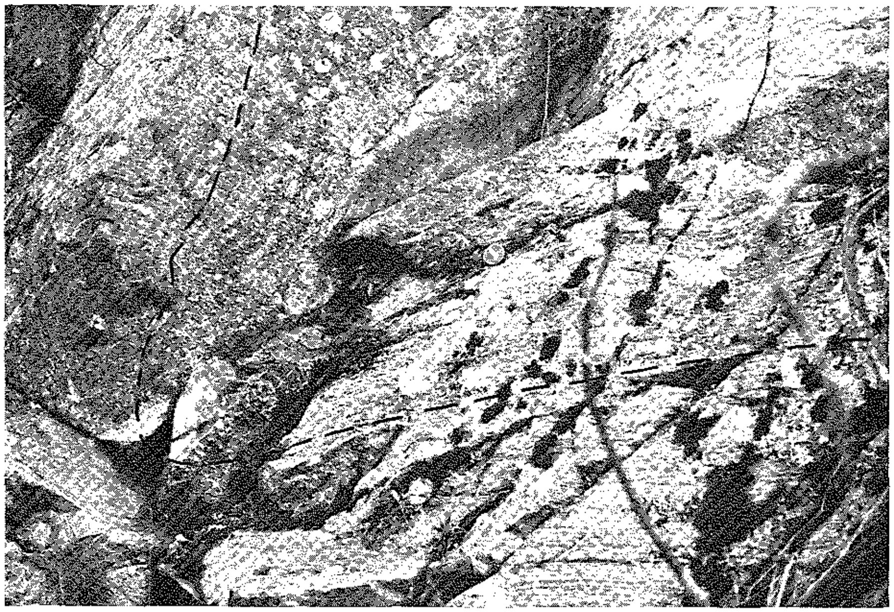

Figure 22A. A large steeply plunging flow fold in the Marcellon rhyolite (unit C). The fold axis strikes N. 50° W. and plunges 85° to the west. The plunge of the fold axis parallels the dip of unit C as a whole. Dashed line traces the limbs of the fold.

Figure 22B. A small fold in the Marcellon rhyolite (unit C). This structure probably formed during primary flowage of the ash-flow tuff. Its axis strikes east-west and plunges 60° to the west.

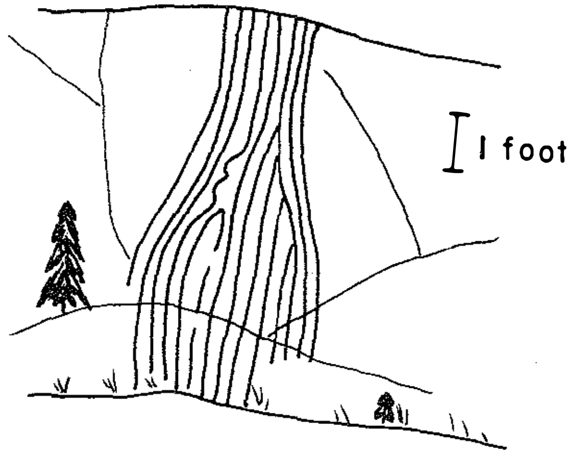

Figure 23A. Sketch of a fold in the Marcellon rhyolite unit C where fold crest does not completely close producing a fanning pattern. Also note truncation of banding.

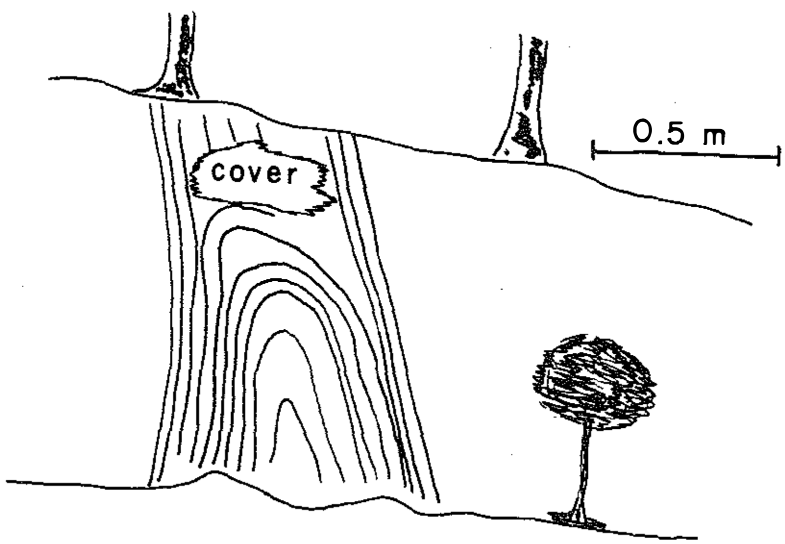

Figure 23B. Sketch of a large fold in Marcellon rhyolite unit C. Fold plunges steeply to the west (left).

STOP 4 - THE MARQUETTE RHYOLITE (NORTH OF COUNTY HIGHWAY H)

Location: The stratigraphy and fabric of the Marquette rhyolite to the north of County Highway H will be examined at this stop. A supplemental stop views banding, pumice lenses and a block-flow breccia in exposures to the south of County H on Ingall's knob. See Figure 24 for traverse routes.

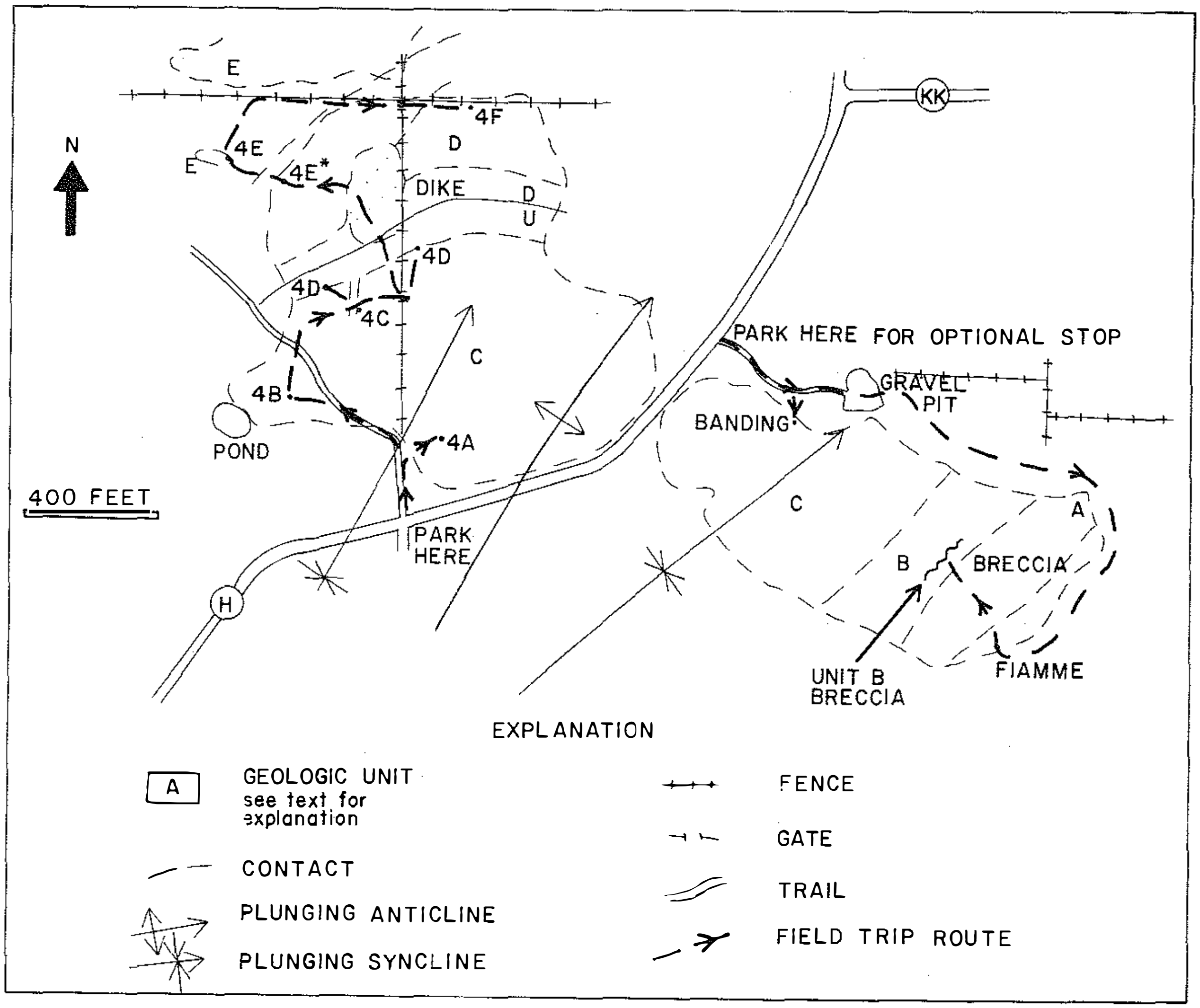

Figure 24. Route map for traverses at the Marquette rhyolite exposure.

Introduction to the Geology of the Marquette Exposure:

The rhyolite at Marquette (Pretts, 1895; Hobbs and Leith, 1907; Smith and Hartlaub, 1974; Smith 1978a) occupies seven small hills surrounded by Pleistocene sediments and Paleozoic sedimentary rocks (Fig. 25). The extensive cover prevents reliable field correlation of units from hill to hill, and since most contacts are obscured, relative age of the Marquette units can only be inferred by noting their stratigraphic position within major folds. Correlations depicted on the geologic map (Fig. 25) are based primarily on chemical

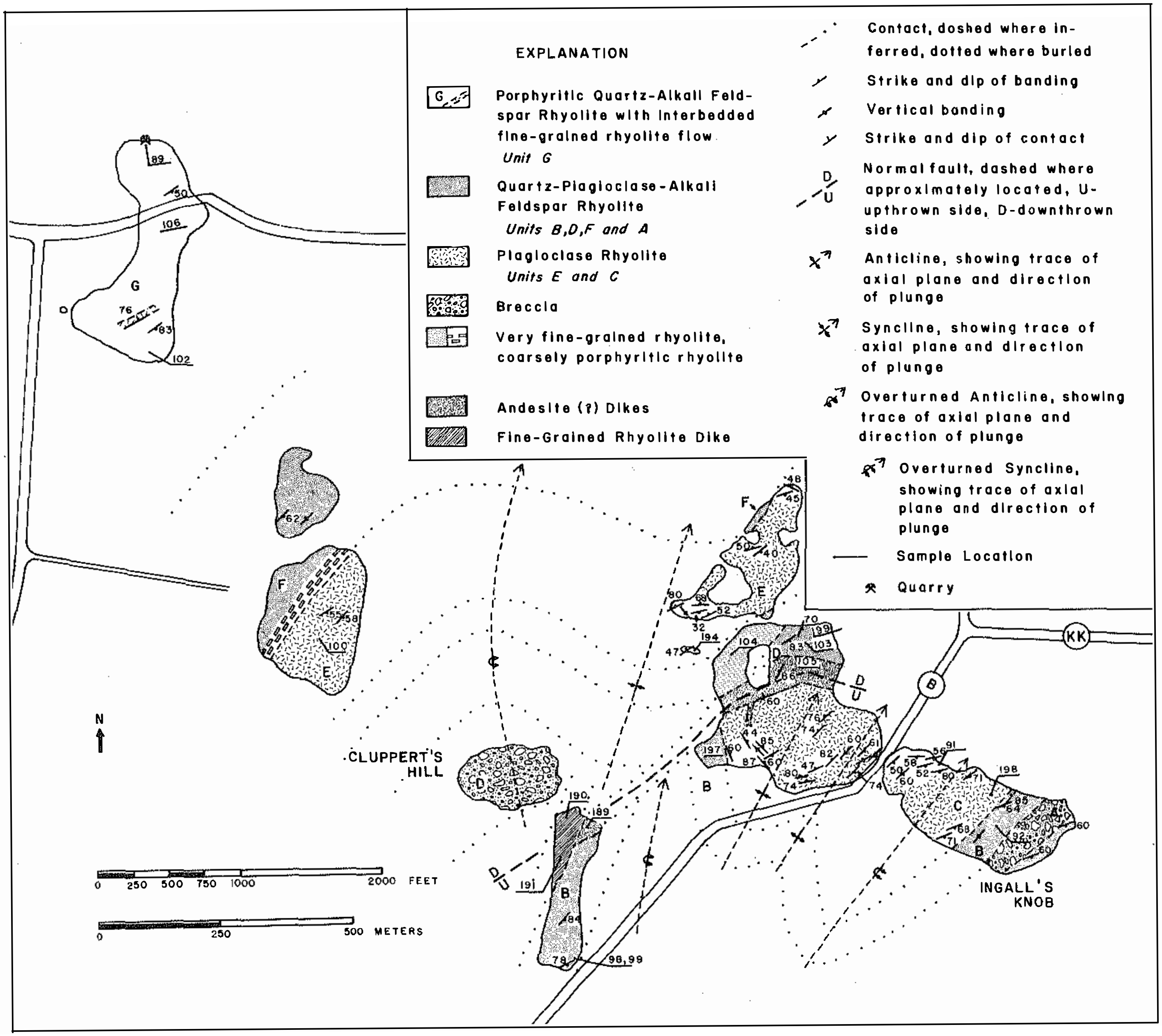

Figure 25. Geologic map of the Marquette Inlier (adapted from Smith, 1978a).

and petrographic similarities.

The inlier is formed by seven mineralogically and chemically distinct volcanic flows, ash-flow tuffs, and breccias. The units lettered A to G from southeast to northwest are broadly folded into a series of normal and overturned anticlines and synclines with an average wavelength of 300 m. The fold axes strike N. 20° to N. 40° E. and plunge to the northeast. These folded rhyolite units are cut by a 100 m thick andesite dike (Table 1, analysis 30) which was intruded along a northeast trending normal fault. The fault is downthrown to the north, and the displacement, calculated by estimating the amount of structural shortening, probably does not exceed 600 m. The structures to the north of the fault have a one to one correspondence to those to the south, except that they are displaced to the southwest. While the map shows simpler structural patterns to the north of the fault then to the south, this difference is probably due to poor structural control to the north of the fault.

The youngest rock in the inlier is a northeast trending fine-grained massive dacite dike, 35 m thick, which cuts the fault and the andesite dike (Table 1, analyses 39 and 40). The dike is similar to unit C in lithology (fine-grained with plagioclase as the dominant phenocryst), but it is distinguished from unit C on chemical grounds (Fig. 26).

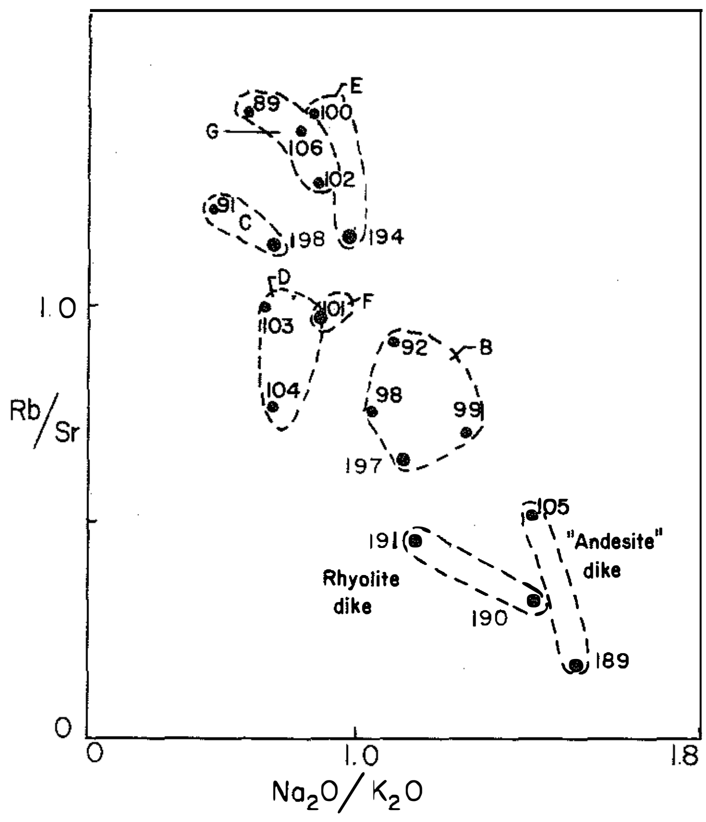

Figure 26. Rb/Sr-Na_2O/K_2O plot for Marquette inlier samples. This plot demonstrates that mineralogically similar rhyolites can be distinguished on the basis of Rb/Sr and Na_2O/K_2O ratios. Also note the cyclic change in Rb/Sr ratio. Plagioclase-bearing rhyolites (unit C and E) have Rb/Sr greater than 1, whereas quartz-plagioclase-alkali feldspar rhyolites (units B, D, and F) have Rb/Sr less than 1. Unit G is the quartz-alkali feldspar-plagioclase rhyolite (from Smith, 1978a).

Unit G is a thick (1000 m) quartz (10 %), alkali feldspar (commonly perththitic) (16 %) and plagioclase (7 %) rhyolite porphyry. Except for minor variations in phenocryst abundance and faint banding, the unit is texturally homogeneous. Shard-like forms were observed in the matrix of unit G, indicating that it is an ash-flow tuff. A fine-grained rhyolite is interbedded with unit G, and crops out near the south end of the unit G exposure.

The 6 units lying to the southeast of unit G are texturally variable, with banded, fine-grained and porphyritic varieties common. Most of the units show evidence of brecciation and micro-brecciation. Coarse breccia is found on the southeast margin of Ingall's Knob where clasts of porphyritic and fine-grained red to black rhyolite exceed 10 m in size. Unit D on Cluppert's Hill is also extensively brecciated. Eutaxitic texture is well displayed in several of the units.

Each unit in the Marquette inlier has distinguishing chemical and mineralogical characteristics which are used to correlate units between exposures (Fig. 46, Table 1, analyses 4-14). Units A, B, D, and F are porphyritic plagioclase (18 to 27%), quartz (2 to 8%), and alkali feldspar (1 %) rhyolites with 20 to 36 % total phenocrysts. Unit B is distinguished from the other quartz bearing rhyolites by Na_2O/K_2O greater than 1.0 and low Rb/Sr (0.64 - 0.92). Unit D and Unit F are similar in both major and minor element chemistry. Unit D, however, contains in its upper part a 100 m thick massive phase; a similar massive rock is not associated with unit F. To date, no chemical studies have been made on unit A. Units C and E are fine-grained (10 to 15 % phenocrysts) with plagioclase as the dominant phenocryst. Unit E is distinguished from unit C by lower CaO.

Noteworthy is the cyclic change from phenocryst-poor plagioclase rhyolite (units C and E) to phenocryst-rich three-mineral rhyolite (units B, D, and F). This cyclic variation in mineralogy is also reflected in trace element chemistry (Table 1, analyses 4-14); for example, Rb/Sr ratios vary from 1.45 to 1.23 for units E and C and from 0.71 to 1.0 for units F, D, and B (Fig. 26).

Chemical and flow direction data (Smith, 1978a) show that all of the Marquette units are comagmatic and that all flows erupted from a source to the northwest of the present outcrops. This evidence suggests that cyclic variation in chemistry, mineralogy, and texture reflect eruption from a differentiating source. Fine-grained units probably represent eruption from fractionated crystal-poor magma. On the other hand, more highly porphyritic varieties may represent eruption from zones of crystal accumulation within the source chamber. The lower Rb/Sr ratios in phenocryst and feldspar rich units (F, D and B) may be explained by a model where Sr is concentrated into the crystallizing feldspar and Rb is enriched in the liquid phase. As a consequence phenocryst and feldspar rich units would have lower Rb/Sr than the fine-grained, feldspar-poor varieties (units C and E) which formed from fractionated, crystal- and feldspar-poor magma.

Alternately, fine-grained and phenocryst-rich pairs may represent compositionally zoned ash-flow sheets with the phenocryst-rich unit at the top and the fine-grained unit at the base. Zoned ash-flow tuffs commonly show an upward increase in MgO, CaO, Al_2O_3, TiO_2 and Sr/Rb and may vary in composition from quartz latite at the top to rhyolite at the base (for example see Smith, 1960; Ratte and Steven, 1964; Smith and Bailey, 1966; Noble and Hedge, 1969; and Rhodes, 1976). Phenocryst abundance, and xenolith abundance and size usually increase upward, with pumice commonly showing reverse zonation (Sparks, 1976). Within one ash-flow sheet the transition from phenocryst-poor to phenocryst-rich tuff can be abrupt (Noble, 1970). Marquette units F and E may together represent a single compositionally zoned ash-flow sheet with unit E the differentiated fine-grained base and unit F the less differentiated phenocryst-rich top. Grouping of units D and C is doubtful since they are separated by a fault and by an andesite dike. More detailed field and chemical data must be obtained before this model can be properly evaluated.

The Marquette Rhyolite Traverse:

Stop 4A - Unit C

Walk due north from the locked gate on the north side of County Highway H, then turn to the woods (east) to the first exposure (see Fig. 24 for the route).

This exposure is formed by a plagioclase-bearing rhyolite ash-flow tuff (unit C). It contains small (up to 5 mm in size) anhedral to subhedral plagioclase laths set in a black fine-grained matrix that is streaked reddish brown. Unit C is commonly well banded, and may also display spherulitic and brecciated texture. At this locality, bands stand out prominently due to differential erosion. The bands form the reddish-brown streaks, and under careful scrutiny they are observed to be composed of discontinuous lenses of collapsed pumice and shard fragments. The banding trends N. 60 E. and dips 85° south or is vertical. Since this exposure is on the south flank of a northeast plunging syncline, a dip to the north is expected. This deviation is probably due to flow folding in the ash-flow tuff (see the supplemental stop at the Marcellon rhyolite for further discussion of flow folding).

Stop 4B - Unit B

This stop is just to the west of an old stone fence (Fig. 24) constructed about 1900 as part of the old Driblow farm.

Unit B is a porphyritic quartz, plagioclase, alkali feldspar-bearing rhyolite with a reddish-brown to black matrix. Quartz is rounded and clear and may be up to 3 mm in size. Plagioclase is pink to white in color and occurs in laths up to 6 mm in size; some grains show prominent albite twinning. Alkali is difficult to identify in hand specimen. On weathered surfaces faint banding and minor brecciation are observed. This quartz-bearing rock is distinguished from other quartz-bearing rhyolites in the Marquette inlier by its higher Na_2O/K_2O ratio. Unit B is the only sodic rhyolite in the inlier (Fig. 26). Unit B changes in lithology laterally. On Ingalls Knob (south of Highway H) quartz is small and rarely observed in outcrop whereas quartz is large and easily identified in unit B exposures to the north of HighwayH.

The contact between unit B and unit C trends No. 10° W. and passes to the south and east of this stop. Many of the large blocks observed just to the south of our present position are breccias with an assortment of fragment types. It is doubtful, however, whether these blocks are in place.

Stop 4C - Small Andesite Dike Intruding Unit C Rhyolite

Traverse due north from Stop 4B to the low outcrops across the field in the trees (just to the north of the Bee Hives) (Fig. 24). At this stop a fine-grained variety of unit C is cut by a thin andesite dike (an off-shoot of the main northeast trending dike). The andesite and rhyolite are at first difficult to distinguish from one another in the field. The following characteristics will aid in their identification. Unit C rhyolite breaks irregularly with a splintery surface. Sparse small plagioclase laths are the dominant phenocryst. Jointing produces straight breaks and angular corners in the rock. The andesite contains small plagioclase laths (1/2 mm) set in a fine-grained matrix with a characteristic greenish hue. Jointing produces irregular breaks and rounded corners in the dike rock. A fresh surface of the rhyolite reflects light from numerous planes, and thus "twinkles" when rotated in direct sunlight. Partially separated splinters of rock are lighter in color than unbroken rock and form grooves on the broken surface. In contrast, the andesite has a smooth and dull freshly exposed surface.

In several places, a very fine banding is observed in the andesite and trends (N. 45° E.) obliquely to the strike of the dike. These bands may be flow bands sheared into this orientation after dike emplacement. Alternately they may reflect a rock cleavage formed during the folding of these rocks.

Stop 4D (Optional) - The Contact Between the Andesite Dike and Unit C Rhyolite

Since the size of this exposure is small, it will not be visited on the field trip. It is of considerable interest, however, because it displays one of the few exposed contacts in the inlier.

From Stop 2C walk to the east across the field to the gap in the north-trending fence (Fig. 24). The exposure (piled with rock) encountered on the way is composed of unit C rhyolite cut by numerous quartz veins. After passing through the gap in the fence proceed through the forest (bearing N. 10 E.) to the first rock ledge. The contact between rhyolite and andesite is exposed on top of this ledge where a juniper tree with shallow roots has toppled exposing a fresh rock surface (the tree was uprooted during a major ice storm in April, 1976). The intrusive contact trends N. 87° E. and dips 60° to the north. This dip probably reflects the inclination of a northeast-trending normal fault (later intruded by the dike) (Fig. 25). The difference between rock types is subtle (see discussion under Stop 4C). The contact is sharp; no xenoliths of rhyolite are found within the dike and no contact effects are observed in the rhyolite. This dike is fine-grained and shows little change in grain size from contact to center. In thin section, the texture of the dike rock is intergranular to ophitic with a framework of sausseritized plagioclase laths and clots set in a patchy matrix of iron oxide and epidote-clinozoisite. Both andesite and rhyolite are jointed with N. 60° E. and N. 40° W. as important directions.

Another exposure that displays the contact between the andesite dike and unit C rhyolite can be reached by walking through the trees from Stop 4C (bearing N. 10° W.) to an exposure piled with rock (Fig. 24). The contact here trends N. 80 E. and dips 65° to the north. Piled on top of the exposure are rocks moved to this location from the cleared field to the north. Most of the blocks are massive unit D rhyolite. This rock is similar in outward appearance to unit C, but it can be distinguished quickly in the field from the other fine-grained units by the bell-like sound emitted when hit by a hammer. Also the rock breaks with a distinctive "breaking glass" sound.

Stop 4E - Massive Unit D, and Unit E

See Figure 24 for directions from Stop 4D to this locality.

For orientation stand at point 4E* (see Fig. 24) and look to the northwest; the contact between unit D and unit E trends N. 30° E. through the grass-covered depression before you. Unit E lies on the rock ledge to the northwest.

Massive unit D rhyolite is very fine grained near its contact with unit E, but becomes noticeably coarser in grain size to the south. Plagioclase altered to sausserite occurs in glomeroporphyritic clots and is the dominant phenocryst. Phenocrysts are set in a devitrified matrix that contains coarser-grained pod-shaped areas (pumice fragments?). Broken spherulites are also observed in the matrix. Unit D locally displays fine striations that are similar to those in the andesite dike (see description of Stop 4D). These striations strike (N. 30°E.) parallel to the contact between units D and E but dip obliquely to it (80° south for the striations as compared to 60° north for the contact).

Unit D at this location is similar in lithology to the fine-grained variety of unit C observed at Stop 4C; it however, splinters like glass when broken and commonly rings like a bell when hit by a hammer. This fine-grained rock has chemical characteristics that distinguish it from other fine-grained Marquette rhyolites (Fig. 26).

Walk across the grass covered depression to the low rock ledge of banded unit E rhyolite. The contact between unit D and unit E trends northeast through this depression. Banding in unit E is formed by discontinuous white to pink streaks that represent pumice fragments and shards sheared and compressed during late-stage primary flowage and during post-depositional compaction and welding. Bands may be up to 50 cm long, but are usually less than 5 mm in width. Commonly they bend about phenocrysts. Bands strike N. 53°E. and dip 47° to the west.

On the southwest corner of the outcrop near the base of the unit, unit E grades into a spherulitic rhyolite. Spherulites are as large as 3 cm in diameter.

To the west, the outcrops are covered by a drumlin elongated in an east-west direction. This orientation reflects the movement of the Green Bay Lobe (Woodfordian) from east to west in this area.

Stop 4F (Optional) - Porphyritic Unit D

From Stop 4E walk north to the east-trending fence, then follow the fence eastward (300 m) to the north-south fence (Fig. 24). Outcrops encountered to the north of the east-trending fence are of unit E rhyolite, blocks in the field to the south are fine-grained unit D rhyolite. Continue walking along the fence to the first exposure. Note the angular blocks of rock to the north of the fence. Here a wide assortment of rhyolite lithologies is found. These blocks were probably transported by ice a short distance.

Unit D is gray on weathered surfaces but pink on freshly broken fractures. In hand specimen abundant phenocrysts of rounded quartz up to 3 mm in size and subhedral feldspar (plagioclase and alkali feldspar) up to 5 mm in length are easily identified. In thin section the rock contains large rounded and embayed quartz (10%), subhedral grains of sausseritized plagioclase (8%), and orthoclase with perthitic texture (14%). Banding in unit D at this locality is faint; band trends vary from N. 7° E., 70° east to N. 50° E, 85° southeast (deviation due to flow folding?).

Unit D is easily distinquished from unit B, particularly by differences in Na_2O/K_2O ratio (the ratio is greater than 1 for unit B and less than 1 for unit D). Also, unit D contains a 100 m thick massive phase (stop 4E); a similar massive phase is not associated with unit B (or in fact with unit F, the other quartz, plagioclase, alkali feldspar-bearing rhyolite unit).

SUPPLEMENTAL STOP - MARQUETTE RHYOLITE ON INGALL'S KNOB

Highlights of this stop include the well-banded unit C, and pumice lenses and breccia in unit A.

Unit C - Banding: Park at the entrance to the Ingall's Knob gravel pit (see Fig. 24). Walk along the dirt road toward the gravel pit and then bear right (south) to the outcrops of dark rhyolite clearly visible on the flanks of Ingall's Knob. These outcrops are composed of well banded unit C rhyolite (Fig. 27) .

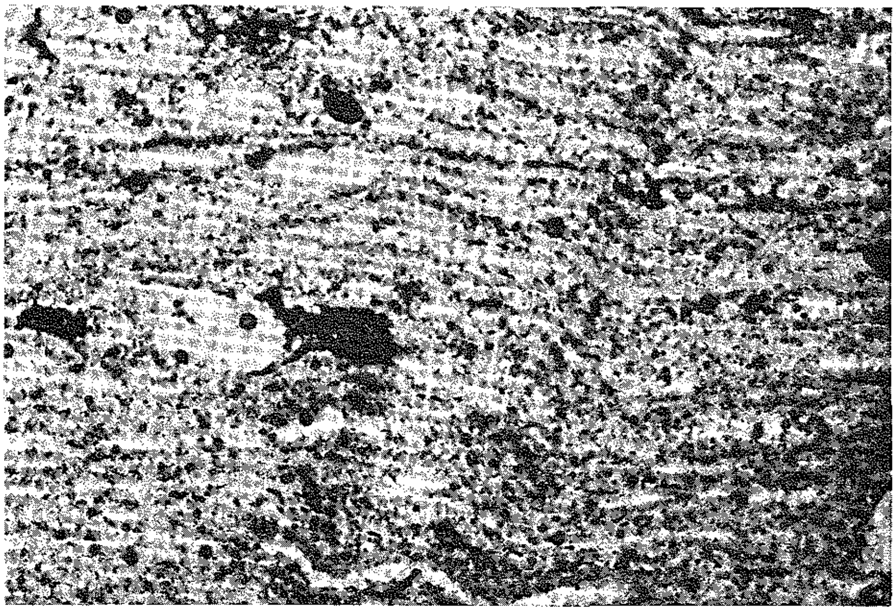

Figure 27. Photomicrograph of highly flattened and crenulated shards in the Marquette rhyolite (unit C). Flattening probably occurred during primary movement of the ash flow. Folding may have occurred during flowage or during later deformation. Bar scale is 1 mm long.

The bands are discontinuous and are formed by sheared and collapsed pumice fragments. Banding strikes N. 50°E. and dips 70° to 80° to the south; bands are locally folded. The rock in this locality also contains lenses of breccia and spherulitic rhyolite.

Unit A - Fiamme (Pumice Lenses): Walk to the end of Ingall's Knob (see Fig. 24) and climb directly up the rock face. The rock forming the bluff on the southeast end of Ingall's Knob is a porphyritic quartz, orthoclase, plagioclase-bearing rhyolite ash-flow tuff showing nicely developed fiamme (the black lens-like features in the rock). The fiamme are collapsed pumice fragments and are elongated parallel to the strike of unit A (N. 50°E.). They have an average axial ratio of 12 $\pm$ 8/1 (based on the measurement of 50 fiamme).

In thin section, unit A rhyolite contains rounded and embayed quartz (10%), alkali feldspar with perthitic texture (8%), partially sausseritized plagioclase (5%), and iron oxide (tr). The matrix is finely devitrified but contains bands that are more coarsely recrystallized. Flow texture is common with shard-like forms aligned and locally bent about phenocrysts of quartz and feldspar (Fig. 28). One small mafic xenolith was identified in thin sections.

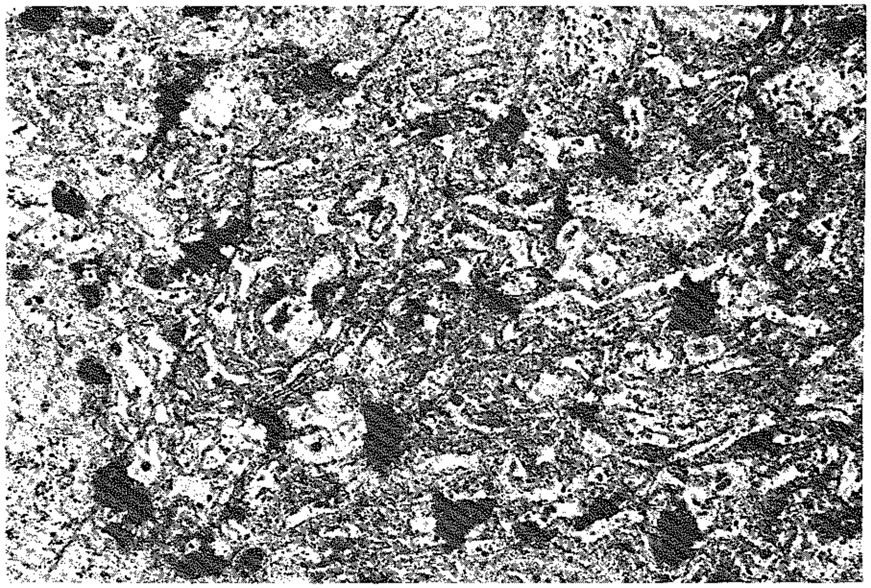

Figure 28. Photomicrograph of flattened shards in the Marquette rhyolite ash-flow tuff (unit A). Shards are aligned and locally bent about phenocrysts of quartz and feldspar. Bar scale is 1 mm long.

Unit A - Breccia: The change in slope above the rock face marks the contact between the top of unit A ash-flow tuff (below) and the base of unit A breccia (above). This contact varies in orientation between N. 40°E. and N. 30°W., but in general trends N. 50°E. The wavy nature of this contact suggests that it is an unconformity.

Unit A breccia is poorly sorted and is approximately 50 m thick. It is crudely banded with large clasts and matrix fragments elongated in a N. 50°E. direction (parallel to the strike of unit A). Along the route of this traverse, a crude size sorting is observed with large fragments concentrated toward the upper part of the unit. This size sorting, however, is not characteristic of the unit as a whole. In other locations, large fragments of rhyolite are found throughout the unit. On our route, breccia near the base of the unit contains small (less than 30 cm in size) dark-colored porphyritic rhyolite fragments. Only a few of the fragments are quartz-bearing rhyolites. Toward the top of the unit the fragments become huge; one block is 33 m long in a N. 50°E. direction and is 12 m wide. Most of the larger fragments are similar in lithology to the quartz-bearing unit A ash-flow tuff. However, three other rock types are present; 1)banded rhyolite with small white feldspar, 2) banded rhyolite with large (5mm) white feldspar, and 3) massive rhyolite with small quartz and alkali feldspar phenocrysts. The matrix of the breccia is gray in color on weathered surfaces. In thin section the matrix is microbrecciated with crystal, rock and angular shard fragments aligned in the N. 50°E. direction.

Breccia Exposure at the Summit of Ingall's Knob: Details of the relationship between fragments and matrix are revealed in an exposure at the summit of Ingall's Knob (Fig. 29). The largest fragment at this location is a porphyritic (black in color) rhyolite composed of quartz and alkali feldspar phenocrysts. It is 5 m wide and over 10 m long in the N. 50°E. direction. Contacts between it and the breccia matrix (gray in color) are sharp. Note the smaller fragments of black rhyolite in the matrix on both sides of the larger black-colored rhyolite fragment. These fragments probably are pieces of rhyolite that broke off the larger fragment during transport. Just to the north there is a large red fragment impregnated with quartz veins. The size of this fragment is difficult to estimate because of extensive cover. Notice the smaller red-colored fragments in the matrix just to the south of the red clast. The red fragment is a porphyritic rhyolite similar in mineralogy to the black fragments. Both fragment types are similar in mineralogy to the unit A ash-flow tuff.

Origin of the Breccia: In order to explain the origin of this breccia in the following observations must be accounted for:

1. The matrix of the breccia may show a crude layering that resembles a flowage texture. Smaller fragments, crystals and shards are aligned in the N. 50°E. direction.

2. Many of the larger clasts have unequal dimensions in section and have their long axes oriented in the N. 50°E. direction.

3. There are a wide variety of clast types. Many of the larger fragments are similar in lithology to the unit A ash-flow tuff.

4. There is only a slight suggestion of size sorting in the deposit.

5. Many of the fragments are very large (up to 33 m long).

The unit is similar in overall fabric to mud-flow breccias or lahars commonly interbedded with ash-flow tuffs and lavas in Tertiary and Holocene volcanic piles, in terms of poor sorting and fragment size (Parsons, 1968; Smith, 1976b). However, mud-flow breccias usually do not contain elongated or oriented fragments, and the matrix does not show flow structure. The unit may instead represent a pyroclastic-flow breccia (that is, a block avalanche or block-flow deposit). Modern examples of this type of deposit are described by Aramaki (1963) and Parsons (1968) from Asama Volcano in Japan. Modern block-flow deposits may erupt initially as ash flows and then during emplacement may pick up large fragments from the surface over which they travel. Also, fragments from the walls of the vent and cognate pumice are often incorporated. The matrix of the Holocene block-flow deposits around Asama Volcano may be crudely banded and is commonly composed of fine ash and dust. These breccia units extend as far as 18 km from Asama Volcano and vary in thickness from 40 cm to 10 m (Parsons, 1968).

There are many similarities between the Holocene pyroclastic-flow breccias about Asama Volcano and the unit A breccia; consequently, I suggest that the

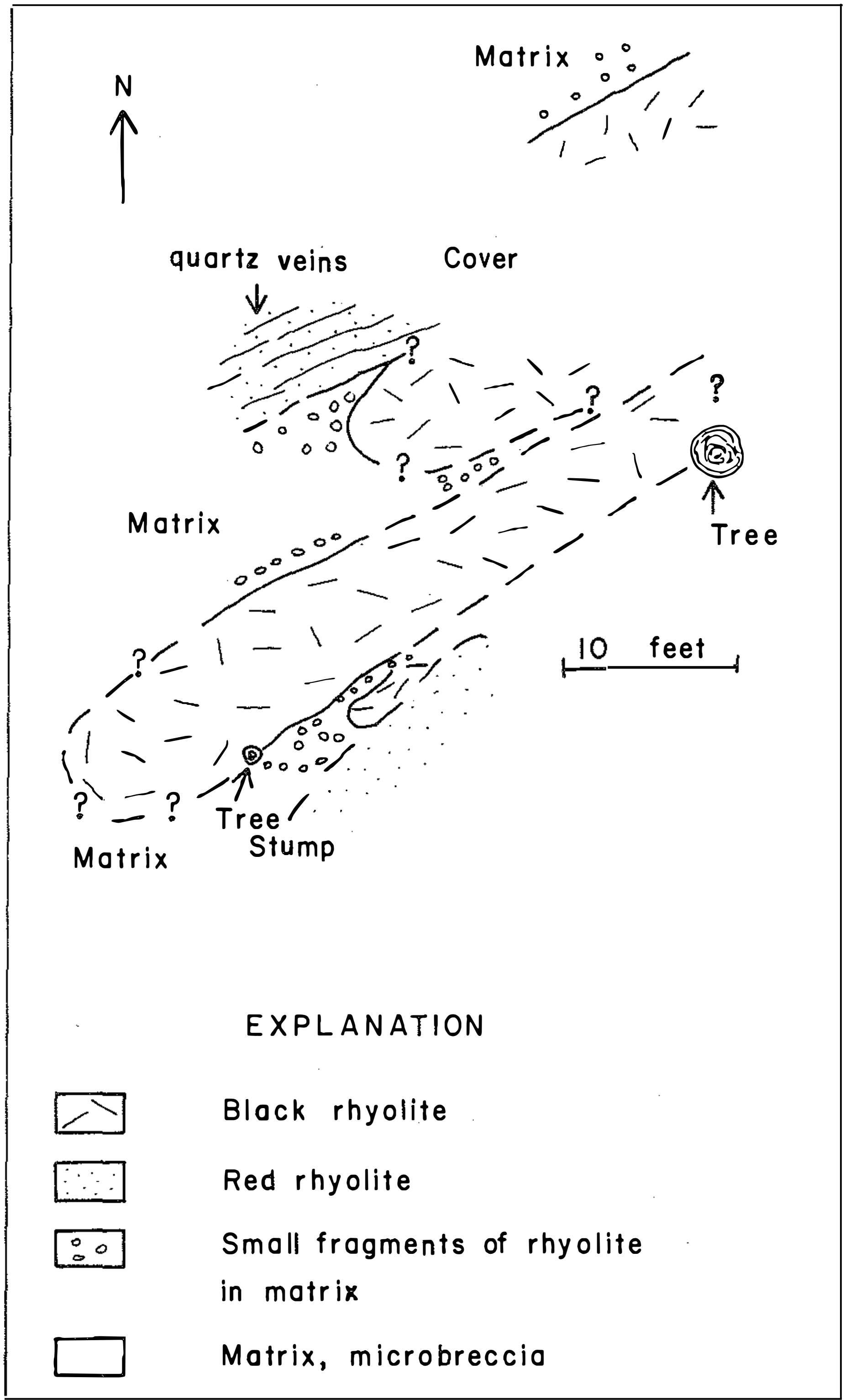

Figure 29. Sketch map of an exposure of unit A breccia on Ingall's Knob.

unit A breccia is a pyroclastic- or block-flow breccia and not a mud-flow deposit.

Unit A-Unit B Contact

The contact between unit A and unit B on Ingall's Knob is gradational. The basal part of unit B contains numerous beds and lenses of breccia that grade into unit A breccia. Just to the northwest of the outcrop of unit A breccia (described in detail above) is a good exposure of brecciated unit B (Fig. 24). This lens of breccia is separated from massive unit B by a thin (2 m wide) sheared zone. Unit B breccia at this exposure is monomictic. This is in contrast to other unit B breccia lenses, and the unit A breccias that are polymictic.

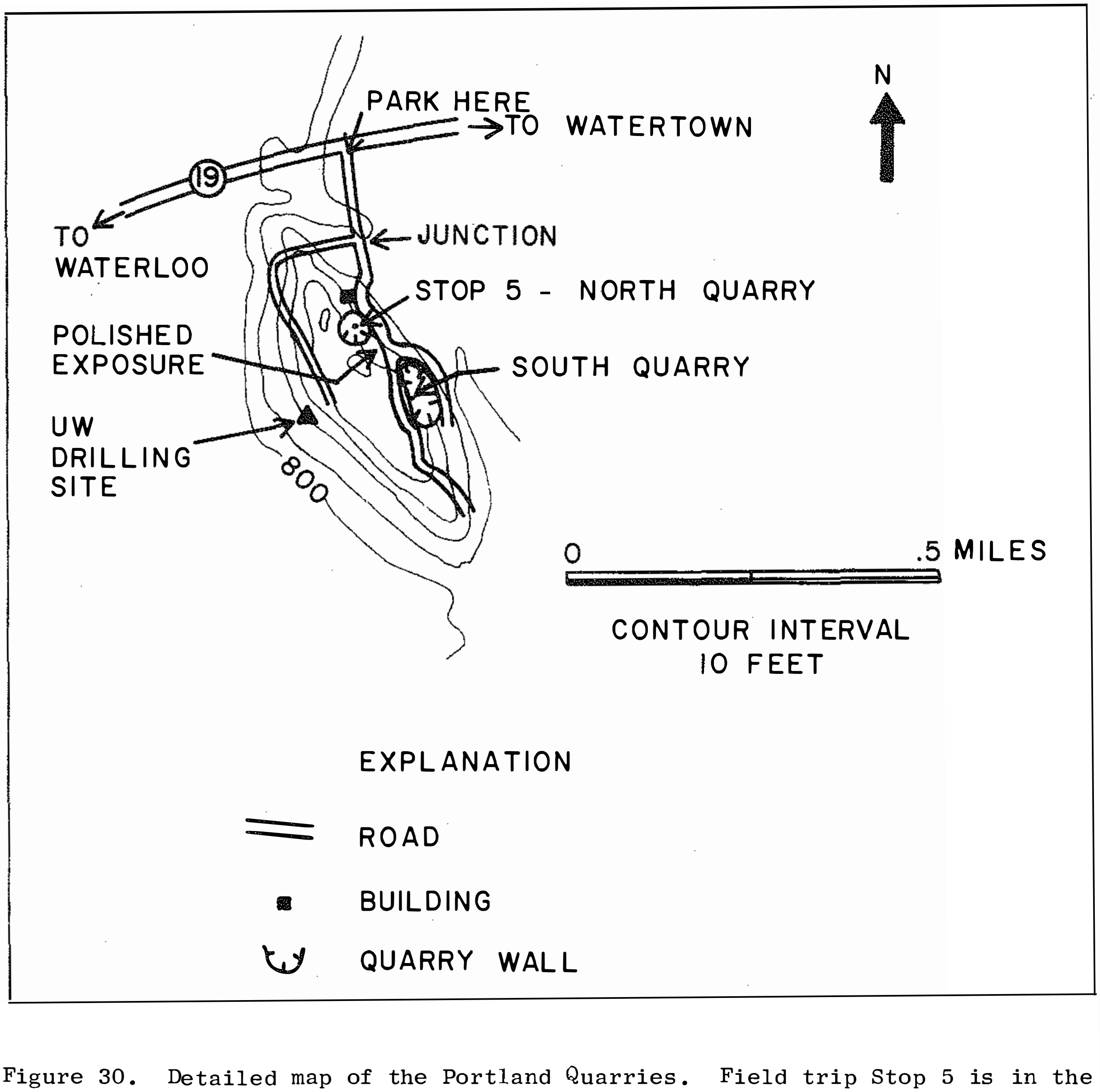

Figure 30. Detailed map of the Portland Quarries. Field trip Stop 5 is in the north quarry. South quarry should be entered from the east.

STOP 5 - WATERLOO QUARTZITE NEAR PORTLAND

This stop illustrates the lithology of the Waterloo quartzite, the youngest major Precambrian rock unit in south-central Wisconsin. These outcrops are at the extreme southeastern edge of the exposed Precambrian shield in Wisconsin.

Location: From the locked gate on the south side of S.T.H. 19, walk south toward the John O'Laughlin Quarries (this area is a Department of Natural Resources hunting preserve). At the road junction take the left fork. The right fork leads to the site of the University of Wisconsin's two deep drill holes, about 900 feet of core was obtained from one of them. Drilling was terminated before intersecting the base of the quartzite (see Haimson, guide 1978). Walk past the large corrugated iron building and then turn west (right) and walk about 70 m through the trees to the quarry (see Fig. 30 for route).

Introduction: The Waterloo Quartzite is probably stratigraphically equivalent to the Baraboo and Barron Quartzites in Wisconsin and to the Sioux Quartzite in Minnesota and South Dakota (Dott and Dalziel, 1972). In south-central Wisconsin the quartzite sheet lies stratigraphically above late-Penokean aged rhyolites and granites and is mainly preserved as infolds into the igneous basement. The absolute age of the quartzite can only be determined by indirect means. At Baraboo the quartzite overlies rhyolites that are similar in chemistry to those rocks in the Fox River Valley dated at 1765 m.y. old. This date is the maximum age of the quartzite. Both the rhyolite and overlying quartzite were deformed during an event suggested by Smith (1978a) to have occurred 1650 m.y. ago. This date is the Rb-Sr apparent age of the Fox River Valley igneous rocks (Van Schmus and others, 1975). These data suggest that the Baraboo-Waterloo Quartzite was deposited on an eroded rhyolite-granite basement between 1765 and 1650 m.y. ago. A pegmatite dike with coarse quartz, feldspar and muscovite crystals that cuts the Waterloo Quartzite (on Rocky Island - NW $\frac{1}{4}$, Sec. 27, T. 9N., R. 13E.) has been dated at 1440 m.y. old by the Rb-Sr method (Aldrich and others, 1959). Also, muscovite from a phyllite bed in the Waterloo Quartzite has been dated at 1410 m.y. old by the K-Ar technique (Goldich and others, 1966). These dates place a minimum age on the deposition of the quartzite.

At Waterloo, the dominant rock is a red to gray vitreous quartzite composed of 75 to 98% SiO_2. Quartz is present as interlocking and strained sand-sized grains (Fig. 31). Muscovite in the matrix of the quartzite commonly displays lepidoblastic texture, and with increasing amounts of mica the rock may grade into a foliated quartzite. Occasionally, thin phyllite layers are found interbedded with the quartzite. Bands of andalusite schist were identified in core recovered from the deep well drilled just to the east of the quarries (Haimson, 1978). The andalusite is partially altered to sericite. The assemblage andalusite-muscovite-quartz suggests that the quartzite was locally, if not regionally, metamorphosed to the upper part of the greenschist facies. An amphibolite dike was also encountered in the well (Haimson, 1978).

In the Waterloo area the quartzite forms a broad east-plunging syncline (Buell, 1892, Warner, 1904, Sumner, 1956) which is almost entirely buried by Ordovician and Cambrian sedimentary rocks (Fig. 32). Outcrops to the north of Lake Mills (NE $\frac{1}{4}$, Sec. 25, T. 8N., R. 13E.) define the south limb of the structure. Here bedding dips to the north at 50°. The apparent nose of the fold is in the Portland area (the area of Stop 5). Here the strike of bedding changes from N. 30°W. (in the south) to N. 30°E. (in the north) defining a broad concave eastward arc; the nose of the syncline. Strike and dip measurements are a bit erratic in this area suggesting that the structure in the nose of the syncline is complex. The north limb of the syncline is exposed near Mud Lake where quartzite strikes N. 80°E. and dips steeply to the south. The north limb may extend as far to the east as Hartford in Washington County (Sumner, 1956).

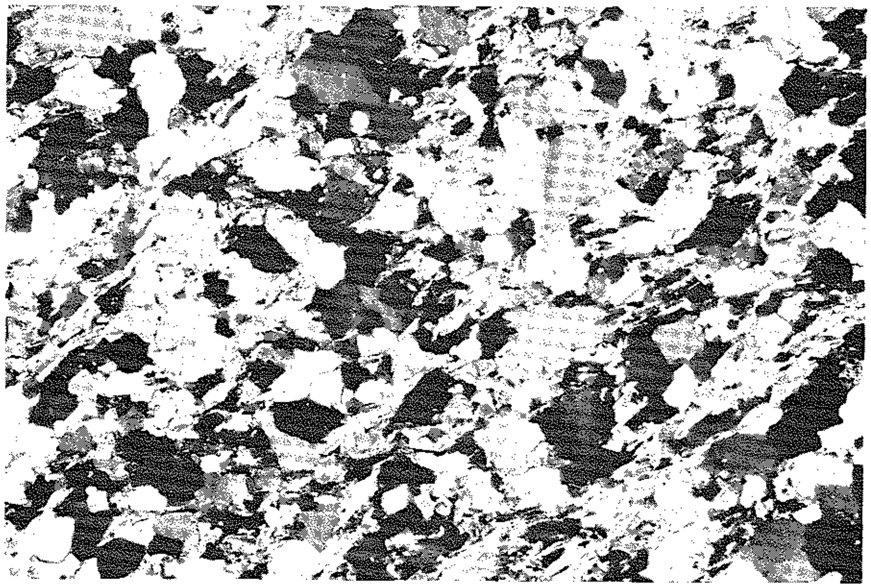

Figure 31. Photomicrograph of the Waterloo Quartzite from the Portland Quarry. Interlocking and strained quartz grains are interrupted by aligned laths of muscovite. With increasing amounts of muscovite the rock grades into a foliated quartzite and finally a phyllite or schist. Bar scale is 1 mm long.

The quartzite at Waterloo is well jointed with N. 40°E. and N. 80°E. directions common (also N. 70°W. as a minor direction). However no detailed studies of the rock fabric in the Waterloo area have been undertaken. Thick layers of phyllite, so common in the upper part of the Baraboo Quartzite, are lacking in the Waterloo Quartzite. Phyllite beds at Waterloo are thin (rarely thicker than 25 cm) and commonly pinch out over a lateral distance of 10 to 20 m. Primary structures such as bedding planes, cross bedding and conglomerate beds are common, and ripple marks are occasionally observed. The unravelling of the structural history of the Waterloo Quartzite is crucial to the understanding of the 1650 m.y. old event.

The Waterloo Quartzite is overlain by Cambrian sandstones that locally contain large rounded boulders of quartzite. About 3 km north of Stop 5 (Fig. 32), blocks of quartzite 1 meter in size are embedded in Cambrian sandstone close to the quartzite exposures; the size of the clasts decreases rapidly until just 700 m from the sandstone-quartzite contact the Cambrian sandstone is fine grained and friable and contains no quartzite fragments (Buell, 1892).

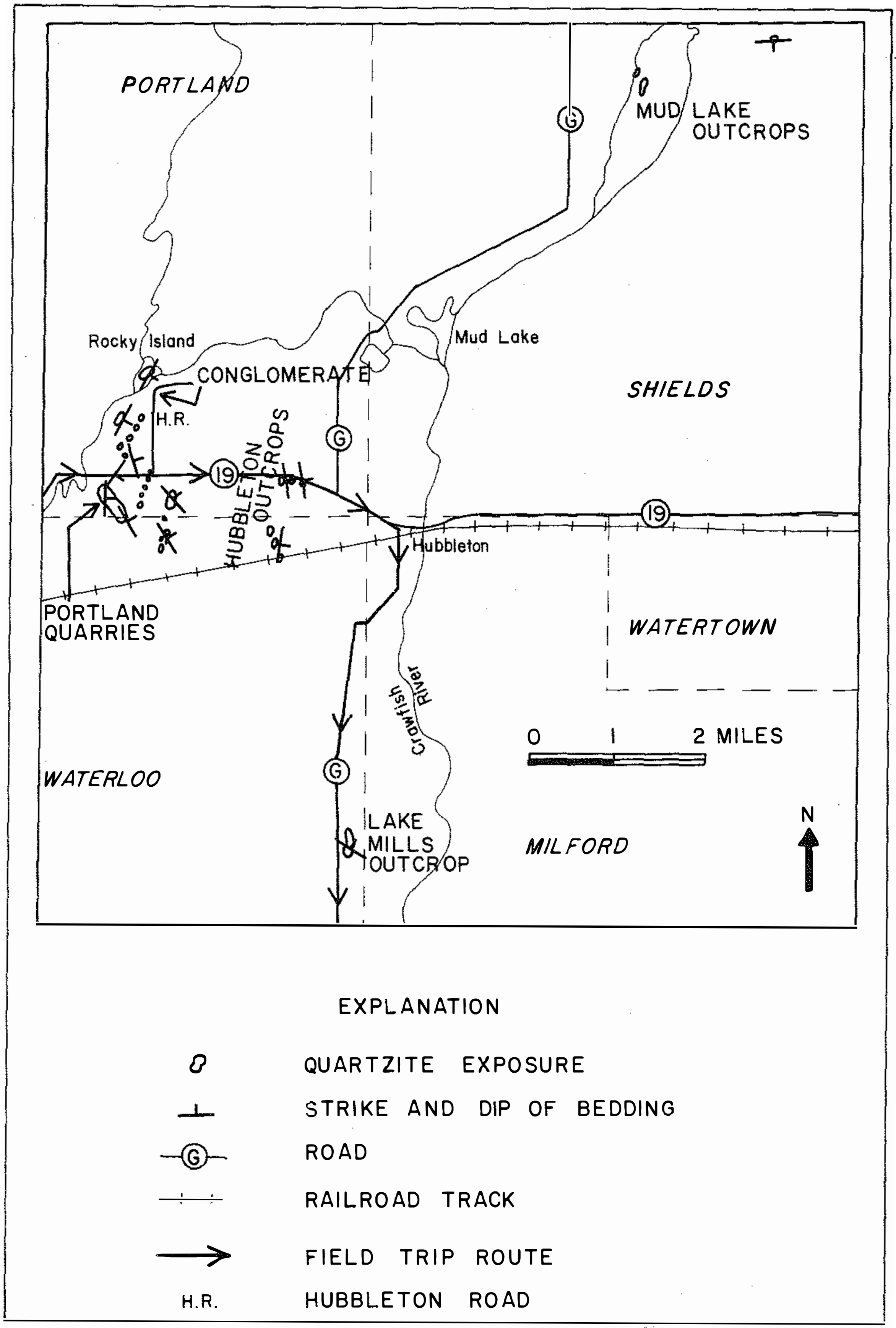

Figure 32. Detailed route map through the Waterloo Quartzite area. Stop 5 is at the Portland Quarries. Map adapted from Buell (1892).

If the Paleozoic sedimentary rocks and the Pleistocene sediments were stripped from the Waterloo area, the quartzite would stand as an arcuate ridge (concave to the east) 500 to 900 feet above the surrounding Precambrian surface. For example, to the north of the city of Waterloo, quartzite is intersected in deep wells at 135 feet above sea level. Just 2 miles to the east, quartzite is exposed at the Portland quarries at an elevation of 860 feet (see Smith, 1978c).

Only one deep well has penetrated quartzite. This well located near Reesville in western Dodge County penetrated 500 feet of quartzite before entering a mica-rich rock described by Thwaites (1940) as a gneiss or a schistose quartzite.

Studies of well cuttings show that the Waterloo Quartzite is part of a large area of quartzite extending from Waterloo to Milwaukee and north to Fond du Lac (Smith, 1978c). Thwaites (1940) reported iron-bearing shale interbedded with this large quartzite sheet.

Stop Description: After entering the quarry, walk to its steep south wall. The rock in this quarry is typical of Waterloo Quartzite in the Portland area. It is coarsely recrystallized and is rich in muscovite. Bands of conglomerate are common and contain quartzite fragments up to 3 cm in size. Conglomerate bands strike N. 35°E. and dip 42° to the south. On the western part of the quarry wall a 25 cm thick phyllite lens is exposed (Fig. 33). The phyllite thins to 3 cm and eventually pinches out to the west. Color banding that represents primary bedding parallels conglomerate layers. Cross bedding is observed just above the phyllite lens (Fig. 33). Dott and Dalziel (1972) report a mean current direction of 165 degrees (S. 15°E.) for the Waterloo Quartzite based on measurements of 38 cross sets. This compares with a direction of 171 degrees measured for the Baraboo Quartzite (Dott and Dalziel, 1972). Common current directions for these two quartzites strongly suggest that the Baraboo and Waterloo Quartzites are correlative.

In outcrops just to the south of the quarry, foliated quartzite is highly polished and grooved (due to glaciation). Grooves trend N. 20°E. Foliation and cross bedding (?) impart a swirl-like pattern to the outcrop. In places the foliated quartzite has weathered out in a series of low ridges each about 1 cm high (Fig. 34).

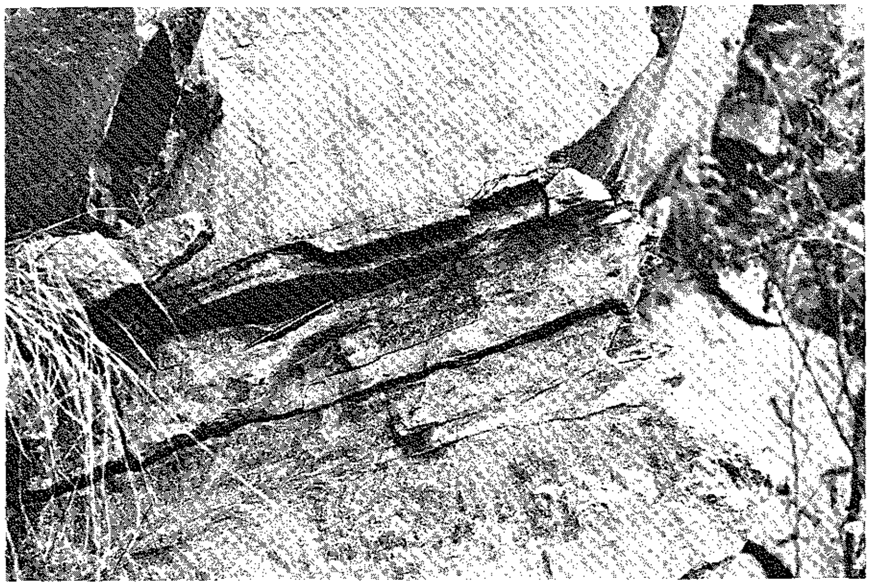

Figure 33. View of a thin phyllite layer (between arrows) interbedded with quartzite at the Portland Quarry (Stop 5). Note the crossbedding in the quartzite just above the phyllite bed.

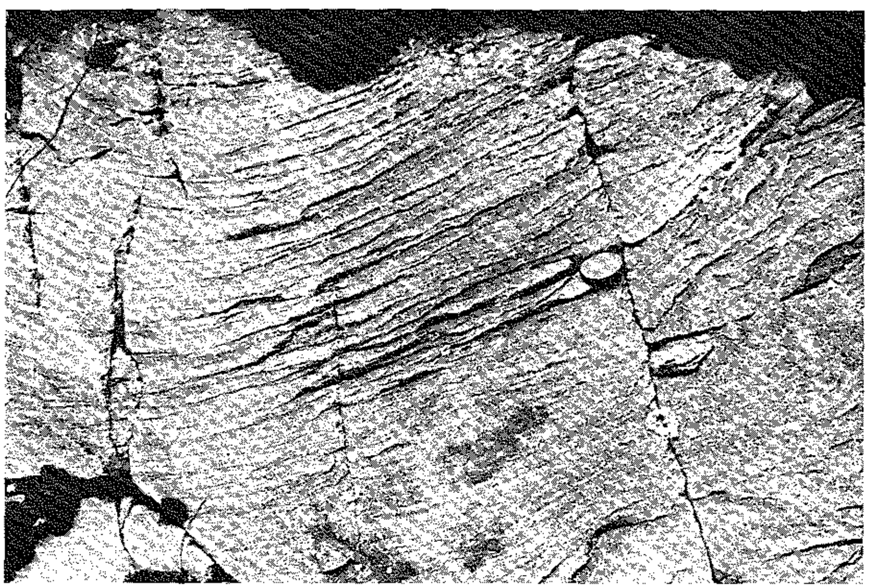

Figure 34. Close-up view of foliated Waterloo Quartzite located just to the south of the quarry visited at Stop 5. Foliation planes are weathering out here into a series of low steps each about 1 cm high.

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