The geology of the northern flank of the upper Centennial Valley, Beaverhead and Madison counties, Montana

by Matthew Lee Mannick

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Earth Science
Montana State University

Abstract:
The Huckleberry Ridge Tuff of the Yellowstone Group covers a large portion of the north side of the upper or eastern Centennial Valley, southwestern Montana. This ignimbrite is the result of the first major eruptive event (2.0 m.y.) of the Yellowstone caldera. The tuff forms dip slopes on the north flank of the valley lapping eastward against Precambrian rocks near Elk Lake and to the northwest along the West Fork of the Madison River.

The Huckleberry Ridge Tuff in the Centennial area is a composite ash flow sheet composed of two distinct cooling units, each displaying vertical zonation of welding density and phenocryst content.

The upper Centennial Valley is influenced by four major structures: the Madison, Gravelly, and Centennial range front, and Cliff Lake faults. The upper Centennial Valley resulted from the down dropping of a half graben against the Centennial Fault along the Gravelly Range Front and Cliff Lake faults. Observations of Huckleberry Ridge Tuff displacement indicate a minimum post Huckleberry Ridge Tuff offset along the Centennial Fault of 5000 to 6000 feet (1525 to 1830 m) out of a total of approximately 10,000 feet (3050 m).

Variations in depositional thicknesses of the Huckleberry Ridge Tuff indicate a paleotopography which included a major river valley (the ancestral Madison River) that entered the upper Centennial Valley from the north. This drainage can be traced northward into the Madison Valley where it joins the present-day Madison River.

Warm spring activity is present along the Gravelly Range Front Fault and may exist along the Cliff Lake Fault.

A potential geothermal reservoir of substantial dimensions may exist in the channel gravels of the ancestral Madison River in the vicinity of the Cliff Lake Fault beneath the Huckleberry Ridge Tuff.

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ABSTRACT

The Huckleberry Ridge Tuff of the Yellowstone Group covers a large portion of the north side of the upper or eastern Centennial Valley, southwestern Montana. This ignimbrite is the result of the first major eruptive event (2.0 m.y.) of the Yellowstone caldera. The tuff forms dip slopes on the north flank of the valley lapping eastward against Precambrian rocks near Elk Lake and to the northwest along the West Fork of the Madison River.

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INTRODUCTION

Location

The study area is located just north of the Montana-Idaho border about 43 kilometers west of Yellowstone National Park (Fig. 1).

An area encompassing approximately 110 square kilometers located on the north slope of the eastern or upper Centennial Valley (southeasternmost Gravelly Range, Figure 2) was mapped. Data collected from the map area were used to interpret the geology of the Centennial region (study area in Figure 1).

The map area extends northward and westward to the boundary of the Upper Red Rock Lake Quadrangle (Fig. 2) and eastward to the Pleistocene-Precambrian contact east of Elk, Hidden, and Cliff lakes. The southern boundary coincides with the northern edge of the U.S.G.S. geologic map of the southern part of the Upper Red Rock Lake Quadrangle (Witkind, 1976).

Purpose

This study was done in conjunction with a Montana Bureau of Mines and Geology evaluation of the geothermal potential in the Centennial and Madison River valleys. Funding was provided by the Bureau for this paper on the

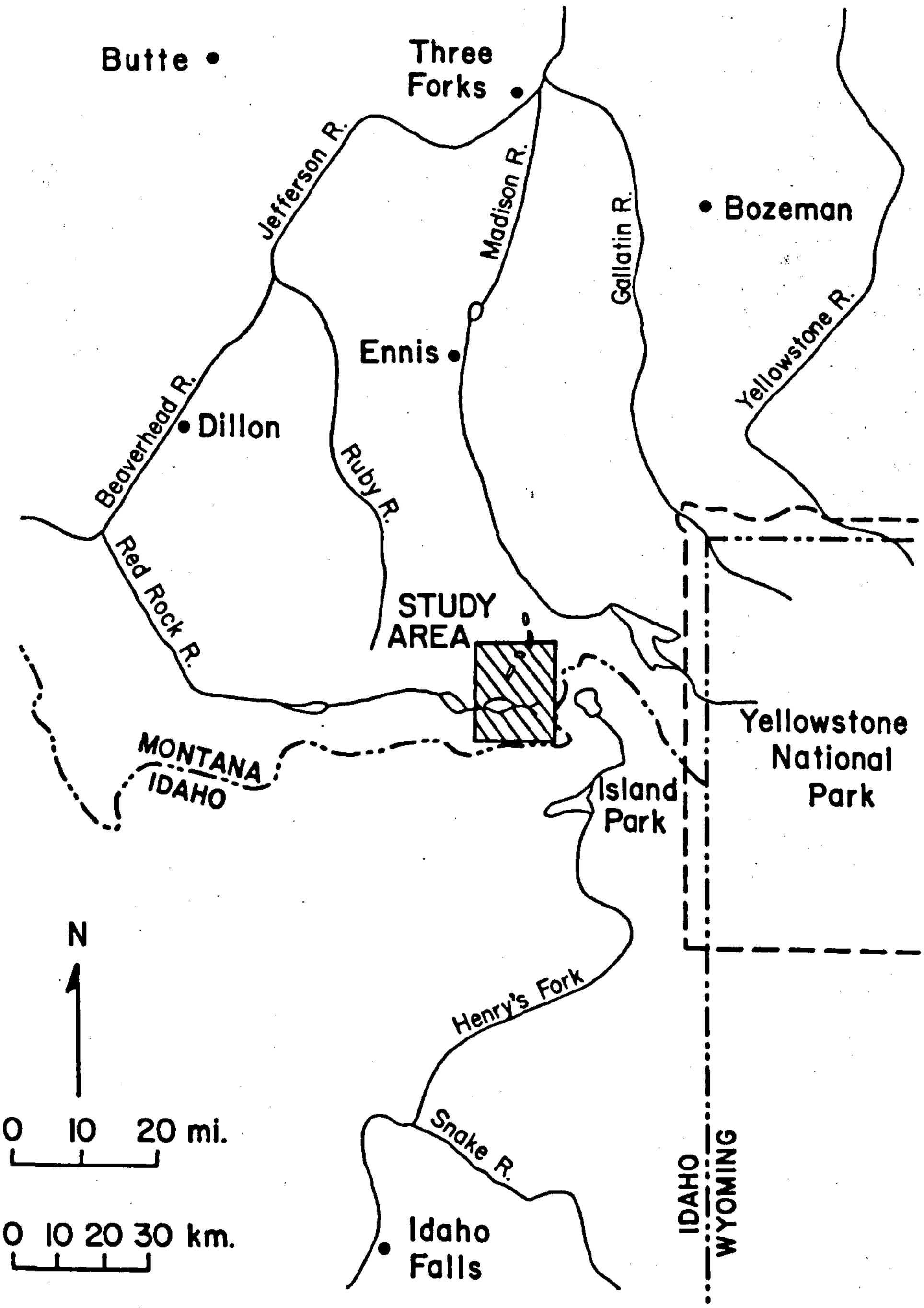


FIGURE 1. Index map.

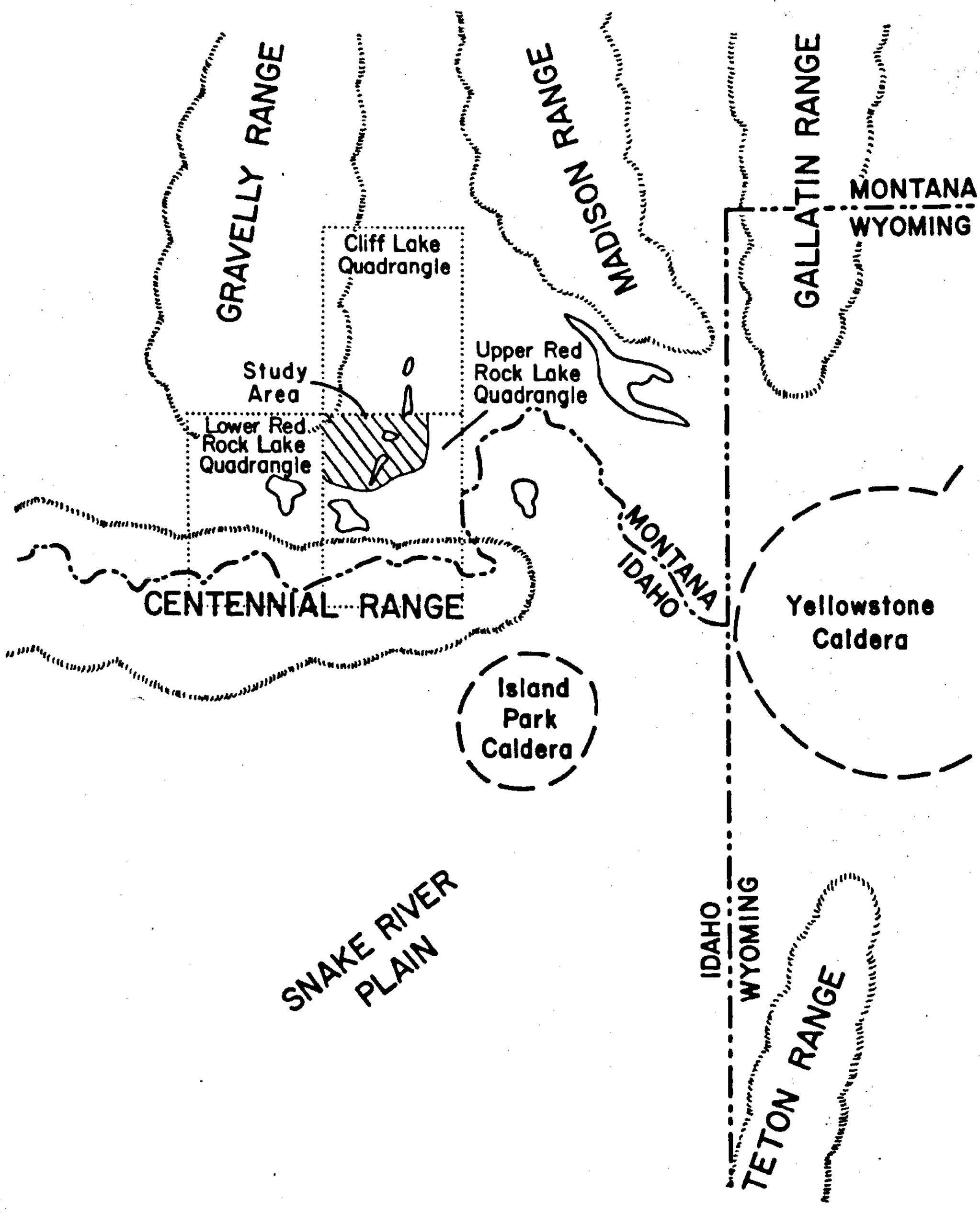


FIGURE 2. Location of map area.

upper Centennial Valley. The structure and volcanic stratigraphy were examined to assist the Bureau in its evaluation of the geothermal systems in the upper Centennial Valley. This evaluation was prompted by the close proximity of the Island Park geothermal field and the presence of warm springs in the Centennial Valley region adjacent to the study area.

Previous Investigations

The Centennial Range and Valley have been examined in little detail previous to this investigation.

Honkala (1949) did the first work on the stratigraphy and general geology of the Centennial region and published additional papers in 1954 and 1960 on the general geology and major structures of the Centennial Mountains and vicinity. These investigations consisted of reconnaissance work generally lacking detail especially when dealing with the volcanic rocks of the region.

The stratigraphy and structure of the Gravelly Range north of the Centennial Valley (Fig. 2) was studied by Mann (1960).

A geologic map of the southern part of the Upper Red Rock Lake Quadrangle, southwestern Montana and adjacent Idaho (Fig. 2) was produced by Witkind in 1976. The map covered a portion of the Centennial Range as well as the floor of the upper Centennial Valley.

Bailey (1977) conducted a geophysical investigation of the seismicity and contemporary tectonics of the Hebgen Lake-Centennial Valley, Montana area.

A portion of the Upper Madison Valley was mapped and evaluated for geothermal potential by Weinheimer (1977 and 1979). This study covered a large part of the Cliff Lake Quadrangle, which is adjacent to and north of the Upper Red Rock Lake Quadrangle (Fig. 2).

The Montana Bureau of Mines and Geology is currently investigating the geology and geothermal potential of the Centennial Valley. Dr. John Sonderegger of the Bureau's hydrology division has been mapping and evaluating geothermal potential in the northern part of the Lower Red Rock Lake Quadrangle (Fig. 2). The Precambrian rocks along the northern flank of the Centennial Valley have been investigated by Dr. Richard Berg of the Bureau. James Schofield conducted a gravity and magnetics study of the Centennial Valley (Upper and Lower Red Rock Lake Quadrangles, Figure 2) as part of a Master of Science degree from the Montana College of Mineral Science and Technology.

Procedure

Field studies of the northern flank of the upper Centennial Valley were undertaken during the summers of 1978 and 1979. Field work consisted of geologic mapping using pace and compass methods aided by air photos. A topographic map with a scale of 1:24000 and contour interval of 20 feet was used as a base for the geologic map.

The volcanic rocks of the area were studied in detail. Volcanic sections were measured using a Brunton compass and Jacob staff and were sampled where lithologies changed. Thin sections were prepared and studied under the petrographic microscope, and correlations of cooling units and the welding variations within them were made from the data. Cross sections were constructed based on interpretations made during the study. Volcanic rocks were sampled at several locations and dated radiometrically (Appendix II) and chemically analyzed (Appendix III). The K-Ar analyses were done at the University of Utah, Department of Geology, and funded by the Montana Bureau of Mines and Geology and the chemical analyses were completed by the Bureau.

ROCK UNITS

Precambrian Rocks

The Precambrian rocks of the upper Centennial region consist of pre-Belt rocks of Precambrian X age (Witkind, 1976). These rocks are exposed along the Centennial Range on the south side of the valley, to the east of Elk, Hidden, and Cliff lakes and west of the West Fork of the Madison River on the north side of the valley (Plate 1).

The Precambrian rocks of the Centennial region consist of low to medium grade metamorphics. These rocks include: gabbro, metadolomite, quartzite, metagranodiorite, amphibolite, and mica schist (Fig. 3). The prominent strike of the foliation is northeast (Witkind, 1972 and 1976).

Paleozoic and Mesozoic Rocks

The Paleozoic and Mesozoic sedimentary sequences are not exposed along the north side of the upper Centennial Valley. The sections may be present at least in part west of Elk and Hidden lakes where they may have been downfaulted and preserved by burial by the Huckleberry Ridge Tuff.

The Paleozoic rocks exposed along the scarp slope of the Centennial Range include marine sediments of the Cambrian through the Permian excluding the Silurian Period

ROCK TYPE	DESCRIPTION
Gabbro	Dark-gray, nonfoliate, coarse-grained; commonly equigranular but locally porphyroblastic with large labradorite metacrysts. Common minerals are labradorite (An_{63}), hornblende, and quartz.
Metadolomite	Light-brown to light-gray, foliated, thick-bedded to massive, and coarsely crystalline. Contains abundant thin to thick quartz beds.
Quartzite	White, light-gray, green, foliate, thin- to thick-bedded, strongly micaceous, medium- to coarse-grained, and equigranular. Bimodal: mostly quartz and muscovite but locally containsminor amounts of microcline, opaque iron minerals, sericite, and chlorite.
Metagranodiorite	Light-gray to gray, foliate, fine- to very coarse-grained, and equigranular. Common minerals are potassic feldspar, hornblende, apatite, sphene, epidote, and opaque iron minerals. Alteration products include sericite and chlorite.
Amphibolite	Dark-gray, strongly foliate, very fine-grained to fine-grained; banded with irregularly alternating laminae of hornblende and quartz-plagioclase. Minor constituents include biotite, apatite, sphene, epidote, zircon, and opaque iron minerals. Alteration products include chlorite, sericite, and calcite.
Mica Schist	Dark-gray to brown, fine- to medium-grained; strongly micaceous; foliate. Major constituents are biotite, quartz, and potassic and plagioclase feldspar. Garnet and staurolite metacrysts are locally common. Accessory minerals include apatite, sphene, zircon, epidote, tremolite, and opaque iron minerals. Common alteration products are sericite, chlorite, and bleached biotite.

FIGURE 3. Precambrian rocks of the upper Centennial Valley.

System	Series	Group	Formation	Description
Permian	Lower Permian		Phosphoria Fm. and Related Permian Rocks	Interfingering units belonging to the Shedhorn Sandstone, Phosphoria Formation, & Park City Formation composed of bedded chert, oolitic phosphatic rock, phosphatic shale, and quartzose sandstones; Carbonate beds at base.
Pennsylvanian	Late Miss. and Penn.		Quadrant Sandstone	Light-brown, fine-grained, quartzose sandstone, locally quartzose; composed largely of angular to subangular quartz grains locally cemented by silica. Contains thin lenticular, light-gray, dense, sandy dolomite beds, 1.2 to 1.5 meters thick, interbedded in upper and basal strata.
			Amsden Formation	Light-gray, medium-bedded to very thick-bedded locally massive, coarsely crystalline dolomite; 5 to 10 cm thick lenses and beds of chert are common.
Missis-sippian	Lower Miss.	Madison	Mission Canyon Ls.	Bluish-gray, thick-bedded to massive, dense limestone beds.
			Lodgepole Limestone	Bluish-gray thin- to medium-bedded limestone that is very fossiliferous and contains much bedded chert.
Devonian	Upper Dev.		Three Forks Formation	Shaly, light-brown to yellow, locally pale-reddish-brown, calcareous thin-bedded siltstone and sandstone.
			Jefferson Formation	Upper member is light-tan thin-bedded dolomite. Lower member is grayish-brown, dense, medium-bedded to massive, vuggy dolomite; locally contains scattered angular fragments of white to gray chert.
Ordo-vician	Upper Ord.		Bighorn Dolomite	Light-gray dolomite in even thin beds 2 to 5 cm thick; faint laminae paralleling the bedding.
Cambrian	Upper Cam-brian		Pilgrim Dolomite	Light-brown to light-gray, thin- and even-bedded, platy dolomite; nodular-weathered surface sparse glauconite grains.
	Middle Cam-brian		Park Shale	Greenish-gray to grayish-red, even-bedded, fissile shale; breaks into minute angular fragments.
			Meagher Limestone	Light-gray to gray even-bedded, thin-bedded limestone; weathers to a crenulated nodular surface. Contains grains and pebbles of Precambrian rocks in basal strata.
			Flathead Sandstone	Reddish-brown, medium-bedded to massive, crossbedded, fine- to coarse-grained, friable sandstone. Locally contains angular to rounded pebbles and cobbles of Precambrian rocks in basal strata.

FIGURE 4. Paleozoic stratigraphy of the Centennial region.

(Fig. 4).

The Mesozoic rocks exposed in the area are of terrestrial as well as marine origin. These include salt and pepper sandstone, quartz sandstone, limestone, claystone, shale, and siltstone as well as reddish and brownish sandstone, siltstone, and claystone (Fig. 5).

Cenozoic Nonvolcanic Rocks

The nonvolcanic rocks of Cenozoic age in the study area are primarily of fluvial and lacustrine origin. These rocks unconformably overlie rocks of Precambrian, Paleozoic, and Mesozoic age in the Centennial region. Cenozoic nonvolcanic rocks both overlie and underlie Pleistocene volcanics unconformably in the region (Plate 1). Several of the following rock descriptions were taken from Witkind (1976).

Tertiary limestone — Pale yellow-brown to light gray, thin to medium bedded, finely crystalline limestone. Unit protrudes up through Pleistocene volcanics to form patchy knobs along the northern flank of the upper Centennial Valley adjacent to the valley fill sediments.

Quaternary lacustrine deposits — Light brown to brown, well sorted, unconsolidated silt and sand.

System	Series	Group	Formation	Description
Cretaceous	Lower Cret.		Kootenai Formation	Consists of a basal conglomerate and conglomeratic "salt and peper" sandstone; a middle light-gray marly limestone and claystone unit; and an upper light-gray marly limestone-claystone bed, containing coiled gastropod molds.
Triassic	Upper Jur.		Morrison Formation	Thin quartzose sandstone beds interlayered with a claystone-siltstone sequence. Sandstone is light-brown, thin- to medium-bedded, lenticular, crossbedded, fine-grained, and friable. Claystone-siltstone sequence consists of varigated grayish-green to pale-red beds.
	Upper and Middle Jurassic	Ellis	Swift Formation	Grayish-brown to greenish-gray, sandy, oolitic limestone, thin- to medium-bedded, and crossbedded; rich in shell fragments and rounded chert grains.
			Rierdon Formation	Light-gray marly limestone that is locally a calcareous claystone.
			Sawtooth Formation	Light-gray, oolitic, thin-bedded limestone containing a few thin light-gray claystone interbeds; fossiliferous, rich in distinctive star-shaped crinoid plates.
Triassic	Lower Triassic		Thaynes Formation	Light-brown thin-bedded limestone; breaks into platy fragments; interbedded chert layers 5 to 10 cm thick.
			Woodside Formation	Reddish-brown, thin-bedded, fine-grained sandstone and shaly siltstone, locally platy; ripple marked.
			Dinwoody Formation	Light-brown to light-gray and yellowish-gray thin- to medium-bedded limestone and calcareous siltstone; platy, even-bedded with many dark-gray shale interbeds; locally fossiliferous (linguloid brachiopods and pelecypods).

FIGURE 5. Mesozoic stratigraphy of the Centennial region.

Quaternary dune sand — Brown, unconsolidated well-sorted quartz sand; frosted angular to subrounded grains.

Quaternary alluvium (Holocene) — Unconsolidated fluvial deposits of silt, sand, and gravel.

Quaternary colluvium (Holocene) — Unconsolidated rubble along the lower portions of steep slopes.

Quaternary displaced Huckleberry Ridge Tuff — Unconsolidated rubble ranging up to boulder size. Formed by the mass wasting of cliffs composed of Huckleberry Ridge Tuff. Large sections of tuff separate from and accumulate at the base of the cliff creating a hummocky topography.

Quaternary displaced basalt — Unconsolidated boulders of basalt found along slopes near the West Fork of the Madison River.

Quaternary sand and gravel deposit — Unconsolidated poorly sorted sand, gravel, cobbles, and boulders that form low mounds or cap small hills. Deposits near Elk Springs may represent material left at the outlet of a former glacial lake in the Centennial Valley as the lake drained northeastward to join the Madison River via the Cliff Lake Fault trench.

Quaternary deposit of coalesced old alluvial fans — Low broad lobate deposit resulting from the coalescence of several old alluvial fans. Composed of unconsolidated fluvial silt, gravel, cobbles, and a few boulders. Coarser material near apexes of fans grades into finer grained materials, such as silt and sand, near distal edges. Probably formed before or during the life of the glacial lake.

Quaternary young alluvial fan deposit — Low lobate deposit of unconsolidated moderately well-sorted silt, sand, gravel, and cobbles at mouths of streams, most of which empty into the Centennial Valley. Constituent rock types reflect bedrock exposed along streams. Precambrian crystalline and Cenozoic volcanic rocks predominate along the north side of the Centennial Valley. Probably formed after glacial lake had disappeared.

Quaternary travertine — Light gray compact travertine found on east shore of Elk Lake (Berg, Personal Communication, 1979).

Cenozoic Volcanic Rocks

The Cenozoic volcanic rocks of the upper Centennial Valley include localized basalts of both Tertiary and Pleistocene age as well as Pleistocene welded tuffs which cover extensive portions of the north flank of the valley

(Plate 1).

Quaternary-Tertiary basalt — Dark gray to black, dense, fine-grained extrusive rock. Locally vesicular, it contains abundant magnetite with sparse olivine phenocrysts. Primarily exposed as thin flows which commonly display columnar jointing. This rock is petrographically similar to the basalt near Elk Lake (Pleistocene basalt) which has been dated at 2.38 million years. These two basalts may be the same age and may have originated from the same magmatic source at depth.

Pleistocene basalt — Dark gray to black, dense, fine-grained extrusive rock. Contains sparse olivine phenocrysts and is locally vesicular. This basalt has been K-Ar dated at 2.38± 0.44 million years by whole rock analysis (Appendix II, C).

This unit is exposed only at the south end of Elk Lake where its depositional relationship with that of the Huckleberry Ridge Tuff is questionable. The basalt occurs as boulder piles and is not exposed in place. The unit appears to have either cut through and flowed over the Huckleberry Ridge Tuff or cut through and flowed over the first cooling unit of the tuff. The basalt appears to have risen from a magma source, possibly related to the Snake River Plain-Yellowstone volcanic system, via the deep-seated Cliff Lake Fault (Plate 1). A similar basalt dated at slightly less than 2.4 million years is known to have originated from this volcanic system in Yellowstone National Park 40 miles (64 km) to the east of Elk Lake (Christiansen and Blank, 1972).

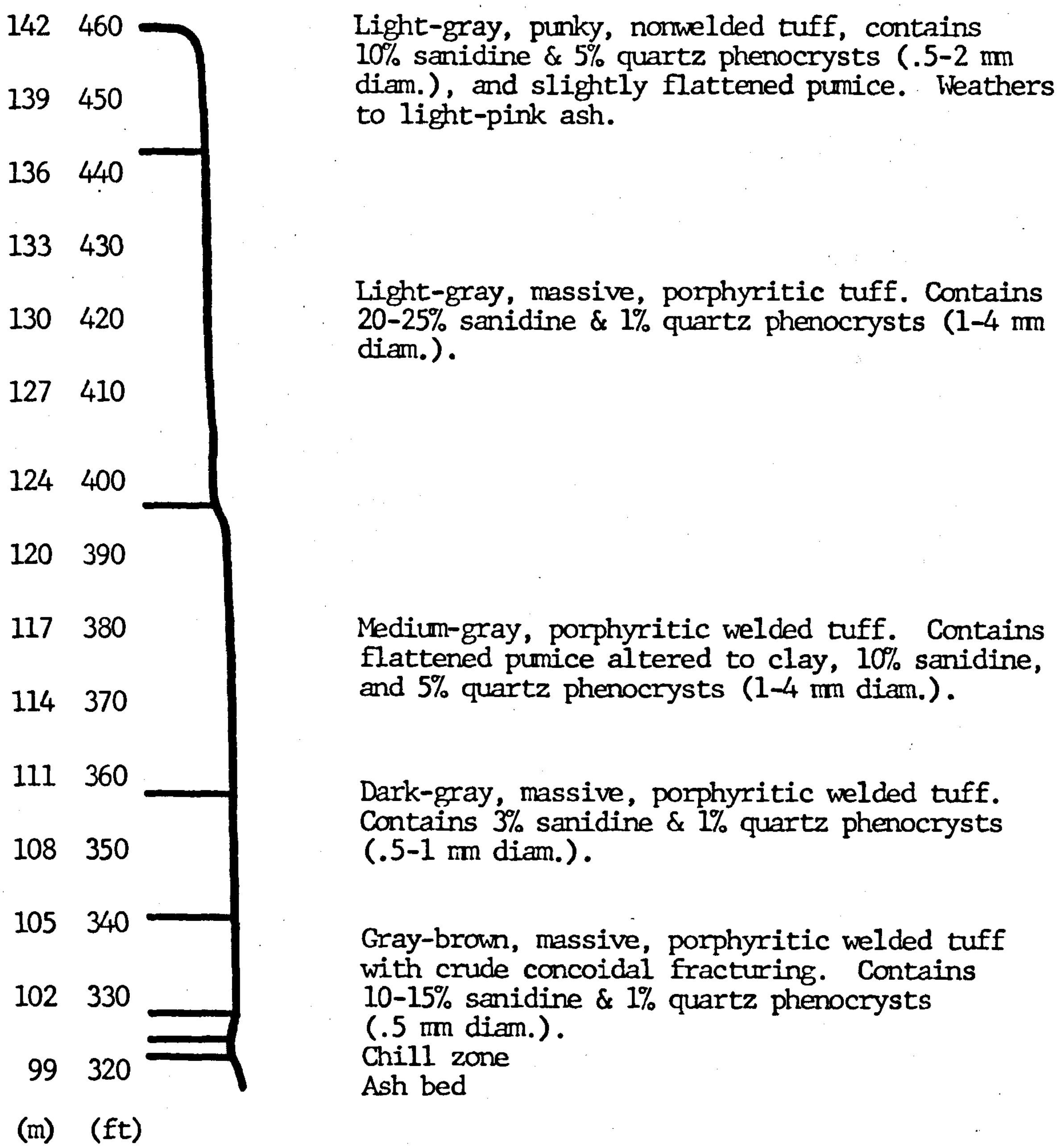
Pleistocene Huckleberry Ridge Tuff — The Huckleberry Ridge Tuff, which originated from the Yellowstone caldera, is the oldest (2.0 m.y.) of the three formations that comprise the Yellowstone Group volcanics of Christiansen and Blank (1972).

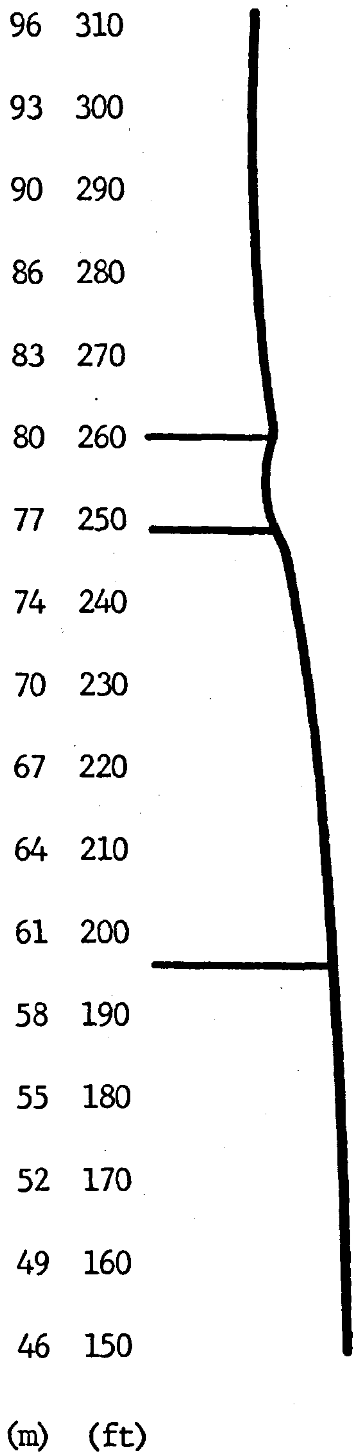
The tuff found in the upper Centennial Valley is petrographically similar to that of the type section of the Huckleberry Ridge Tuff (Christiansen and Blank, 1972). The Huckleberry Ridge Tuff has been subdivided into three members (cooling units of a compound ash flow sheet) at the type section (Christiansen and Blank, 1972), two of which are present in the upper Centennial Valley. The lower cooling unit (Qh_1) in the Centennial Valley can be correlated with the lower member described at the type section and the upper cooling unit (Qh_2) with the middle member. The lower member at the type section contains a thick zone of dense welding beneath a zone of partial welding. Phenocrysts decrease in number toward the top of this member. The lower cooling unit of the tuff in the Centennial region contains a smaller percentage of phenocrysts overall but a similar pattern of welding and phenocryst distribution. The upper cooling unit in the Centennial region is similar to the middle member of the type section with a phenocryst poor zone near the base of the unit. Phenocrysts increase in abundance and size toward the top of the second member of the tuff at both locations. The third and uppermost member of the tuff described at the type section occurs only south of central Yellowstone National Park (Christiansen and Blank, 1972).

K-Ar dates of around 2.0 million years have been attained from the tuff at the following locations (Appendix II, A,B,D,E): 1 mile NNW of Hidden Lake, the south end of Elk Lake, the cliff face on the west bank of the Madison River 2 km north of the mouth of Wall Canyon, and the northeast slope of Flatiron Mountain.

The description (prepared using work of Smith, 1960 as a guide) which follows represents the Huckleberry Ridge Tuff sequence located 1 mile NNW of Hidden Lake (Figs. 6 & 7). A chill zone is present as float at the base of the outcrop (basal Qh_1). The tuff of the chill zone is vitric, partially welded, and contains 3 to 5% sanidine with trace amounts of quartz and olivine phenocrysts all of which range up to 3 mm in diameter. The olivine phenocrysts appear in these pyroclastic rocks of rhyolitic composition as the result of the partial mixing of the bimodal magmatic system beneath the Yellowstone region at the time of eruption. The bimodal system consists of basaltic material beneath magmas of rhyolitic composition (Struhsacker, 1978). Above the basal chill zone is a zone of dense welding 75 meters thick, in which devitrified shards are extremely flattened and deformed (Fig. 8, Photomicrograph A). This portion of the tuff contains 3 to 5% sanidine phenocrysts at the base of the zone which decrease upward to 1 to 2% near the top. Phenocryst size also varies vertically from an average diameter of 1.5 mm near the base to 0.5 mm at the top. The zone of dense welding grades upward into a zone of

FIGURE 6. Huckleberry Ridge Tuff measured section located 1 mile NNW of Hidden Lake (NW¼,NE¼, sec 4, T13S, R1E).



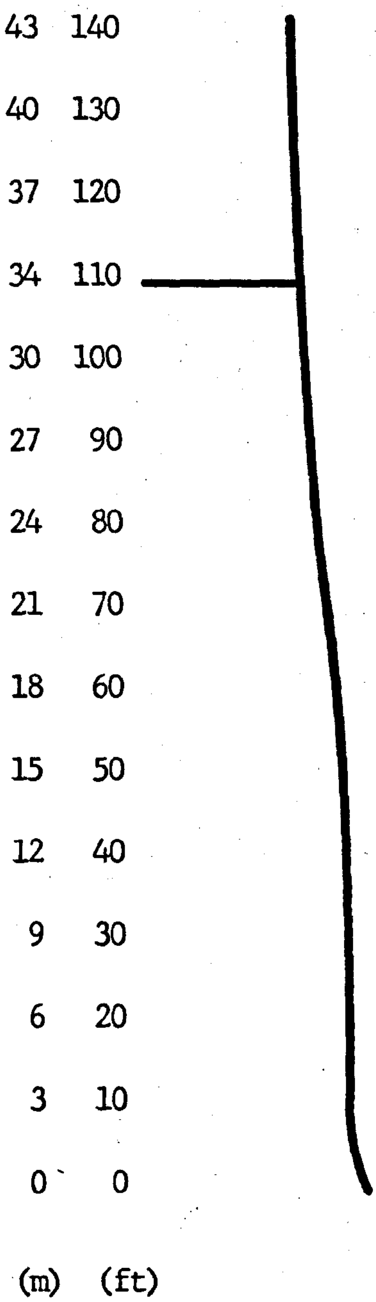


Dark-gray to black, lithophysal welded tuff. Contains 1% sanidine phenocrysts (.2 mm diam.) and spherical vugs filled with secondary feldspar altered to clay.

Reddish-brown welded tuff. Contains 1% sanidine phenocrysts (1mm diam.), flattened pumice fragments, and spherical pockets coated with feldspar altered to clay.

Medium-gray, porphyritic welded tuff. Contains 2% sanidine phenocrysts (.5 mm diam.) and minor vugs filled with feldspar crystals. Weathers to light-gray.

Medium to dark-gray, porphyritic, flow banded welded tuff. Contains 5% sanidine phenocrysts (1.5 mm diam.).



Dark-gray, porphyritic, flow banded welded tuff. Contains 5% sanidine phenocrysts (1.5 mm diam.).

Black, dense, porphyritic, vitric welded tuff resembling obsidian. Contains 5% sanidine phenocrysts (1-3 mm diam.) and rock fragments. This unit seen only at base of cliff.