DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I–650

DESCRIPTION OF MAP UNITS

HOLOCENE

ALLUVIAL DEPOSITS

Fine-grained humic alluvium—Gray to gray-brown humic silt, sand, and clay underlying floodplains, marshes, and depressions in Pinedale Till (pt). Locally overlies Pinedale outwash or stream deposits (ps, pg, pgs, psg). In basin of Nez Perce Creek and around Norris Geyser Basin, deposits are light-brown or gray clay derived from nearby areas of hydrothermal alteration. Contain thin lenses of sand composed mostly of sinter. About 1–10 feet (0.3–3 m) thick

fa

Stream gravel—Light-gray to gray-brown poorly sorted well-rounded weakly bedded sand, gravel, and cobbles. Clasts predominantly of rhyolite or tuff; a few are of andesite or basalt. Deposits underlie floodplain of Yellowstone River and form local terraces 10–20 feet (3–6 m) above it. They also occur locally on Central Plateau

sg

Alluvial and lacustrine sand—Light-gray moderately sorted angular to subrounded well-bedded sand and some silt in Norris Geyser Basin. Composed chiefly of hydrothermally altered tuff of Yellowstone Group and siliceous sinter. Includes deposits of siliceous sinter around hot springs

als

COLLUVIAL DEPOSITS

Solifluction deposit—Buff fine- to coarse-grained stony silty sand; contains numerous subrounded to subangular pebbles, cobbles, and boulders. Deposits have very subdued lobate form, and steep convex fronts 10–15 feet (3–4.6 m) high. Are developed along spring zone at outer margin of Pinedale kame terrace deposits along Gibbon River. Are associated with spring deposits, but too small to show on map, are widespread along contact between Pinedale kame gravelly sand (pkgs) and underlying lake sediments of late Bull Lake age along valleys of streams flowing into Hayden Valley from the south

sd

HYDROTHERMAL DEPOSITS

Diatomaceous silt—Deposits of siliceous diatom silt composed mostly of siliceous diatom tests. May contain lenses of sand along streams. Deposits are chiefly downstream from nearby thermal springs and area along Gibbon River, especially in Elk Park and Gibbon Meadows. About 2–12 feet (0.6–3.7 m) thick

ds

Siliceous sinter—White to light-gray deposit of amorphous opaline silica forming sinter around geysers, cones and cones on rims of active and inactive hot springs and geysers in and around Elk Park and Gibbon Meadows. Local internal structure perpendicular to bedding. Deposits include some alluvial debris; sand composed chiefly of small flat angular sinter fragments. As much as 50 feet (6 m) thick

si

PINEDALE GLACIATION

GLACIAL DEPOSITS

Till and glacial rubble—Gray-brown to gray stony sandy silty till (pt), forms compact unsorted unsized. Stones related to angular, chiefly of rhyolite. In the southern half of the quadrangle, till contains sparse erratics of basalt and andesite from Absaroka Range. In Hayden Valley and on Central Plateau, the erratics are of basalt and andesite from the Washburn Range to the northeast and of granite and gneiss from the northeastern part of Yellowstone National Park. West of Solfatara Plateau to Norris Geyser Basin the erratics are chiefly of basalt and andesite from the Washburn Range. In the northwest part of the quadrangle, the erratics are of granite, gneiss, and intrusive and sedimentary rocks from the Gallatin Range to the north, and of obsidian from the area of Obsidian Cliff, also to the north. In the area of Norris Geyser Basin, and to the south and west, there are also erratics of chalcedonic sinter, derived mostly from the northern part of Norris Geyser Basin and west of Elk Park. The till is mostly ground moraine, 5–20 feet (1.5–6 m) thick, but locally forms morainal ridges as much as 50 feet (12 m) high. Soil on the till is weakly oxidized and commonly less than 1 foot (0.3 m) thick. Glacial rubble (pr) is a thin mantle of stony sandy debris, mostly locally derived but containing a few erratics. It is mainly on glaciated uplands in western and northwestern parts of the quadrangle

pt
pr

ICE-CONTACT DEPOSITS

Lake deposits—Light-gray to brownish-gray poorly sorted crudely to moderately well-bedded sand (pks), gravel (pkg), sandy gravel (pksg), and gravelly sand (pkgs). Thickness a few feet to as much as 50 feet (15 m). Cemented by hydrothermal silica locally in thermal areas. Deposits characterized by great variation in texture, sorting, and stratification, by postdepositional faulting and, locally, by crevasse-fill ridges and kettles. They form kame terraces around stagnant ice basins in valleys and valley reentrants. South of Hayden Valley, they underlie an extensive hummocky area characterized by numerous large collapse depressions and, by ice-contact scarps along its northern margin. Along the east side of Gibbon Canyon, deposits form a long ice-contact delta in which the forested beds dip upriver

pks
pkg
pksg
pkgs

LACUSTRINE DEPOSITS

Lake sediments—Gray- to blue-gray weathering buff massive to laminated locally varved silt (pl) containing minor thin laminae of fine sand along Alum Creek at east edge of quadrangle. Light-gray to white thin-bedded silt and hydrothermal clay (pp) with associated beds of gray sand and rhyolitic gravel along east side of highway in Gibbon Canyon. Plant debris in clays has radiocarbon age of 9,640±200 years (W–964) (Lavin and others, 1965), suggesting deposit formed in late Pinedale time. Gray to buff crossbedded medium sand (psl) forms beach deposit 20 feet (6 m) above east shore of Beach Lake

pl
psl

Ice-dammed lake sand—Light-gray medium to fine well-sorted; local silt layers. Crossbedded pebbly beach sand at base. Thin veneer of gravel and cobbles containing clasts of rhyolite, basalt, and andesite at top. Deposits overlap Pinedale Till (pt), merge laterally with contact gravelly sand (pkgs), and overlie lake sediments (bl) of late Bull Lake age. They occur only in southwestern part of Hayden Valley. About 50 feet (15.2 m) thick

pksl

ALLUVIAL DEPOSITS

Outwash and stream deposits—Gray to light-brown moderately sorted and stratified unconsolidated sand (ps), gravel (pg), sandy gravel (psg), and gravelly sand (pgs). The last is chiefly of rhyolite. Deposits form terraces 20–40 feet (6–12 m) above streams in valleys and fill upland basins and outwash channel floors. Most are 10–20 feet (3–6 m) thick. Similar deposits (pfg) form gently sloping alluvial fans where streams open into basins or valleys

ps
pg
psg
pgs
pfg

COLLUVIAL DEPOSITS

Talus deposit—Angular to subangular blocky rubble, mostly of rhyolite, forming cones and sloping sheets of debris at base of cliffs. Deposits as much as 50 feet (12 m) thick, sparsely vegetated, and inactive

pta

Talus-flow deposit—Lobate mass of talus-like material extending downslope from toe of a talus. Indicates forward movement of the mass by flowage. Deposits inactive at present

ptf

Block rubble—Irregular sheet of angular blocks 1–4 feet in diameter lacking matrix and derived from underlying rhyolite flow. Slopes gentle to steep. 2–10 feet (0.6–3 m) thick

prb

Colluvium—Gray to gray-brown sandy debris and angular to subangular blocks derived from nearby bedrock. Mapped only above upper limit of Pinedale glacial erratics on Gibbon Hill, where deposit is all of gray rhyolite, and on uplands to east, where deposit is all of pumice or obsidian. A few boulders of local gray rhyolite, having a possible glaciated shape, were found at the top of Gibbon Hill, a rhyolite dome (Rrd). No glacially shaped stones were found on the upland to the east, underlain by pumice rock and obsidian of the Gibbon River rhyolite flow (Rgr)

pco

Landslide deposit—Lobate mass of large and small angular blocks of rhyolite in sandy matrix. Extends downslope from cliff source. Gradational laterally and abruptly into kame sandy gravel (pksg) or gravelly sand (pkgs) terrace deposits. Surface of deposit along Spruce Creek characterized by numerous hummocks and kettles; local relief as much as 80 feet (24.4 m); some individual rhyolite blocks more than 100 feet (30.5 m) long

pls

HYDROTHERMAL DEPOSITS

Hydrothermal-explosion deposit—Yellowish-gray loose to compact mixture of angular rock fragments as much as 18 inches (46 cm) in diameter and subround stone mostly pebble size sparsely scattered in a nonbedded matrix of sorted silty matrix. Angular fragments and most stones are of tuff of Yellowstone Group; a few stones of obsidian. Material mostly hydrothermally altered locally since deposition; encloses a shallow crater. Believed to be of hydrothermal-explosion origin, possibly under water (Muffler, White, and Truesdell, 1971). Single deposit found by D. E. White and L. J. P. Muffler in western part of Norris Geyser Basin

phe

BULL LAKE GLACIATION, LATE STADE

GLACIAL DEPOSITS

Till (in stratigraphic sections 9 and 10 only)—Gray compact mixture of subangular to subround stones as much as 4 inches (10 cm) in diameter in unsorted sand matrix. Stones chiefly of rhyolite and altered rhyolite, but some are erratics of basalt and andesite, a few striated. Sand chiefly of rhyolite minerals and numerous accessory minerals of obsidian. Deposits overlie Hayden Valley rhyolite flow (Rh) and underlie varved lake silt (bl) of late Bull Lake age in Hayden Valley. In Norris Geyser Basin, lenses of till near base of lower part of ice-contact deposits (bkgs). Thickness 1–8 feet (0.3–2.4 m)

bt

Glacial rubble—Thin discontinuous mantle 0–5 feet (0–1.5 m) thick of subangular to subround gravel, cobbles, and boulders in a sandy matrix on uplands in southern part of quadrangle. Material mostly of rhyolite, but includes erratics of basalt and andesite locally. May include some alluvial products. Soil, where preserved, consists of an oxidized horizon 2–3 feet (0.6–1 m) thick

br

ICE-CONTACT DEPOSITS

Kame deposits—Light-brownish-gray to brown poorly sorted crudely to well stratified rhyolitic sandy gravel (bkg), forming ridge in eastern part of Hayden Valley. Cemented by silica, locally altered by hydrothermal activity; contains erratics of basalt and andesite. Light-pinkish-gray to gray poorly sorted irregularly bedded rhyolitic sandy gravel (bkgs) in Norris Geyser Basin. In northern part of basin, deposits contain layers of till in lower part. Gray medium-grained rhyolitic sand (bks) forms knob west of Elk Park. Deposit characterized by long forset beds, but has channel-and-fill, somewhat gravelly topset beds that contain subangular to subround fragments of chalcedonic sinter. All of these deposits are locally mantled by Pinedale Till or erratics. Thickness as much as about 100 feet (30.5 m)

bkg
bkgs
bks

Sediments of Otter Creek—Gray diatomaceous silt grading westward into gray to rusty silica-cemented gravelly sand; exposed along bed of Otter Creek between 1.3–1.7 miles (2.1–2.6 km) west of Highway 14. Silt is brecciated in the northwest part of the deposit; it contains angular grains of obsidian and pumice, pods and fracture fillings of angular pumice and obsidian sand, and scattered pebbles of rhyolite. Gravelly and locally poorly sorted with sharp changes in texture and bedding; composed of angular to subangular grains of obsidian, quartz, sanidine, pumice, and rhyolite; a few spherulites and glass shards. Gravel chiefly of rhyolite, mostly ¼ to 2 inches (0.6–5.1 cm) in diameter; a few cobbles as much as 6 inches (15 cm) in diameter and having alteration rinds ¼ inch (0.6 cm) thick. Where the gravelly sand merges abruptly with a silica-cemented glassy breccia consisting of angular to subangular fragments and masses of angular pebble-to-cobble-sized shattered obsidian in a dense pale-gray fine-grained glass sand and shard matrix. This rock, in turn, grades westward abruptly into the fore beds of the forset beds of the Solfatara Plateau rhyolite flow (Rs). The sediments lie topographically above, but are not in contact with, the Hayden Valley rhyolite flow (Rh), which is exposed downstream and underlies the Solfatara Plateau rhyolite flow elsewhere

oc

LACUSTRINE DEPOSITS

Ice-dammed lake silt—Bluish-gray weathering brownish gray compact massive to laminated locally varved silt with local interbeds of gray fine to medium sand. Underlies most of Hayden Valley, where it locally overlies Bull Lake Till (stratigraphic sections 9 and 10). Mantled by a thin veneer of Pinedale erratics and patches of Pinedale Till (pt). South of Hayden Valley, the lake silt overlies the sediments of Otter and Alum Creeks where it is mantled by thick Pinedale ice-contact deposits. Extends north from Hayden Valley east and west of Yellowstone River. Deposits attain an altitude of 7,980 feet (2,432 m) along their western margin; range in thickness from 20 to about 200 feet (6–61 m). They overlie the Solfatara Plateau (Rs) and Hayden Valley (Rh) rhyolite flows in Hayden Valley and extend along the valley of the Yellowstone River to the north

bl

Ice-dammed lake sand—Light brownish gray to brown unsorted, nonbedded to crudely stratified rhyolitic sand containing scattered angular to subangular pebbles. Underlies hills around hydrothermal basin southwest of Paintpot Hill. Composed of rhyolite, obsidian, perlite, and fine granular glass of local derivation. Contains no erratics but is overlain by Pinedale Till containing chalcedonic sinter and other erratics from the north. Some rhyolite pebbles, hydrothermally altered prior to deposition, are derived from Paintpot Hill, an altered rhyolite dome. Others may be derived from altered parts of the Nez Perce Creek(?) rhyolite flow (Rn?), which the deposits locally overlap. However, the abundant fresh grains and fragile irregular blebs of obsidian and perlite, and the large quantity of granular glass are derived from the Gibbon River rhyolite flow (Rgr), which underlies most of the deposits. The sediments are moderately to strongly cemented with silica except in areas of acid alteration. Around hot springs and fumaroles, all of the material is altered, and the obsidian and perlite have been leached, leaving numerous small cavities. Acid alteration is also responsible for erosion of the present basin in the deposits. At and below an altitude of 7,720 feet (2,352 m), the deposits are clean medium- to well-sorted flat-bedded to crossbedded fine to coarse sand; hard and well cemented with silica. These deposits occur east, southeast, and west of Paintpot Hill and north of the trail to Artists Paintpots. Like those at higher altitudes, they contain abundant obsidian, perlite and glass, though those east of Paintpot Hill are mostly altered by hydrothermal activity. At stratigraphic section 12, west of Paintpot Hill, the uppermost part of the sediments, at an altitude of about 7,500 feet (2,287 m) contains layers of black, sandy, silicified, mixed and broken plant debris. Total thickness of deposits ranges from about 30 feet (9 m) to about 170 feet (52 m)

bsl

INTRA-BULL LAKE INTERVAL

LACUSTRINE DEPOSITS

Lake silt—Bluish-gray weathering buff massive to thinly laminated silt, containing abundant small pumice and perlite fragments, glass shards, and diatoms. Exposed beneath, and is intricately infolded and injected into, base of Hayden Valley rhyolite flow (Rh) along Grand Loop Road—at and just south of Chittenden Bridge (stratigraphic section 7), along the east side of Yellowstone River south of Chittenden Bridge, and along Otter Creek 1 mile (1.6 km) west of the highway crossing. This unit (bil) is included in the upper part of the unit called sediments of Upper Falls (uf) along Yellowstone River to the north of Chittenden Bridge and along Cascade Creek (stratigraphic sections 2, 3, 4, 5). Maximum exposed thickness of the silt in this quadrangle is about 25 feet (7.6 m)

bil

INTRA-BULL LAKE INTERVAL, EARLY STADE OF BULL LAKE GLACIATION, AND PRE-BULL LAKE TIME

LACUSTRINE DEPOSITS, CHIEFLY

Sediments of Upper Falls—Sequence of sediments, chiefly lacustrine, exposed along the valley of Cascade Creek and Yellowstone River. In this quadrangle, the sediments comprise ten units, from top to bottom as follows:

uf

1. Sandstone—Gray medium- to coarse-grained moderately silica cemented; mostly of rhyolite and obsidian, but contains numerous pumice particles; shallow channel-and-fill cross-bedding characteristic of a near-shore lake deposit. Along north-trending sector of Cascade Creek, at an altitude of about 7,880 feet (2,402 m), the sand is cemented to quartzite along its contact with the overlying Hayden Valley rhyolite flow (Rh). It extends as irregular quartzite veins up into the flow, where it was injected when the lava entered the lake and overrode the then soft sand. Unit is as much as 15 feet (4.6 m) thick.
2. Silt—Gray greenish-gray pink or buff massive to laminated. This unit, from 0 to 15 feet (0–4.6 m) thick, is the same as the lake silt (bll) of the intra-Bull Lake interval south of Chittenden Bridge. In vicinity of the sharp bend in the canyon of Cascade Lake where they merged and grew into all known exposures of this unit is lacking and the Hayden Valley flow, intensively perlitized, rests directly on contorted greenish-gray silt containing abundant small pumice pebbles. In several places, gray-buff, hard brittle baked silt extends as thick irregular seams as much as 100 feet (30.5 m) up into the flow, where it was injected when the lava flowed over the soft silt. These units below the silt are not exposed in this sector of the canyon.
3. Varved silt—Gray; varved pairs each about ½ inch (1.3 cm) thick; total thickness about 2½ feet (0.8 m). Exposed only on south side of canyon of Cascade Creek at old dam about ½ mile (0.8 km) west of highway.
4, 5, 6. (Undivided) Sand—Gray coarse massive to irregularly bedded; uncemented to moderately cemented by silica. Grains chiefly of rhyolite, some hydrothermally altered, and obsidian. Local silt seams in upper part. Contains a few pebbles of rhyolite, andesite, and basalt in lower part. Thickness 6–10 feet (1.8–3 m). Sediment of Upper Falls (uf) mapped along Yellowstone River are chiefly cemented ledges of this sand. The sand is exposed beneath the overlying silt at Chittenden Bridge (stratigraphic section 7) but not farther south along Yellowstone River.
7. Gravel—Angular to subround pebbles and cobbles, coated with dark-iron oxide, in silty sand matrix. Chiefly of rhyolite, but some of andesite and basalt; some altered, indicating glacial transport. Deposit commonly only a few inches thick (stratigraphic section 4). Gravel is at base of unit and rests with angular unconformity on older sedimentary units.
8. Pumiceous lake sand—Gray medium sized silty poorly sorted pumice sand. Exposed only at altitude of 7,960 feet (2,426 m) at stratigraphic section 5, where it is 5 feet (1.5 m) thick. Composed chiefly of lake-transported pumice aggregates in silt and hydrothermal clay matrix.
9. Stream gravel—Composed wholly of rhyolite. Exposed only in stratigraphic section 2.
10. Pumiceous tuff (tuf) (Tuff of Bluff Point?)—Compact, massive; consists of pumice and obsidian chunks as much as ½ inch (1.3 cm) in size, in a finer pumice matrix. Exposed only at stratigraphic section 5, where it is 4 feet (1.2 m) thick; rests disconformably on Canyon rhyolite flow (Rc).

Sediments of Upper Falls, between Canyon flow and Hayden Valley flow in this quadrangle, are 22–75 feet (6.7–23 m) thick

HYDROTHERMAL DEPOSITS

Chalcedonic sinter—White, light-gray or pink, hard layered chalcedony. Layers ¼–¼ inch (0.3–1.3 cm) thick, are locally separated by thin irregular cavities, some filled with quartz; in places layers are very compacted. Layering is irregular and indistinct near contact with underlying rock; locally becomes a nodular structure of chalcedony and massive quartz containing irregular casts of sand or fragment fillings, some still extant, especially along partings. Base of deposit is a mixture of altered sand and rock fragments in a chalcedony-quartz matrix. According to White and others (1956) chalcedonic sinter was originally ordinary opaline sinter deposited around hot springs for a long time in an area of thermal activity under which conditions the opaline sinter was converted to chalcedonic sinter

ch

BEDROCK

Bedrock—The quadrangle is underlain entirely by Quaternary volcanic rocks. These have been mapped and stratigraphically subdivided by R. L. Christiansen and H. R. Blank, Jr. (1972; U.S. Geol. Survey, 1972; Christiansen, 1975,) from whose work the inset map of rhyolite flows is derived. We have mapped the outcrops of these rocks because their stratigraphic and (or) physiographic relation to the Quaternary sediments contributes to our interpretation of the Quaternary glacial and lacustrine history. Potassium-argon dates are by J. D. Obradovich.

Rgr
Rs
Rh
Rn
Rsp
Re
Rw
Rbo
Rm
Rc
Rrd
R

The northwest rim of a large caldera, about 600,000 years old, trends northeast across the northern part of the quadrangle, north of Canyon Creek and along the crest of Solfatara Plateau (see index map). All the rhyolite flows and domes are younger than this caldera. The Gibbon River rhyolite flow (Rgr) (K–Ar age about 87,000 years) lies on the caldera rim in the northwest part of the quadrangle. Its western margin forms much of east rim of Gibbon Canyon. Southwest of Paintpot Hill it is overlapped by cemented lake deposits of late Bull Lake age. The Solfatara Plateau rhyolite flow (Rs) underlies the Solfatara Plateau and extends south to Hayden Valley and west across the Central Plateau. It yielded a K–Ar age of about 99,000 years, and overlies the Hayden Valley rhyolite flow (Rh), from which two K–Ar dates of about 97,000 and 103,000 years were derived. The frontal breccia of the Solfatara Plateau flow merges with the sediments of Otter Creek (oc), and probably was extruded against a glacier of late Bull Lake age. The flow is overlain by till (bt) and varved lake silt (bl) of late Bull Lake age. The Hayden Valley rhyolite flow (Rh) extends eastward from the Central Plateau across Hayden Valley and the east edge of the quadrangle. Near Chittenden Bridge and along Cascade Creek the flow is perlitized, and involuted with lake silt (bll) of the intra-Bull Lake interval, where in turn overlies varved silt and glacial gravel of early Bull Lake age. The Nez Perce Creek rhyolite flow (Rn) (K–Ar age about 143,000 years) rests on the Spruce Creek rhyolite flow (Rsp) in the central part of the quadrangle. A flow that may be a part of the Nez Perce Creek and is mapped as Nez Perce Creek(?) rhyolite flow (Rn?) (Christiansen, 1975) yielded a K–Ar age of 157,000 years. The flow erupted against the caldera rim at Gibbon Canyon along whose eastern wall it is exposed beneath the younger Gibbon River rhyolite flow (Rgr). At the north end of the canyon it protrudes from beneath the Gibbon River flow to form the ridge between the canyon and Paintpot Hill. Its stratigraphic relation to other flows and to the tuff of Bluff Point is unknown. The Spruce Creek flow rests on the Elephant Back rhyolite flow (Re), which underlies most of the southern part of the quadrangle. The Elephant Back flow yielded a K–Ar age of about 150,000 years, but rests on the West Thumb rhyolite flow, K–Ar dated at about 143,000 years. The West Thumb rhyolite flow (Rw) crops out in the southeast corner of the quadrangle. The Nez Perce Creek, Spruce Creek, Elephant Back, and West Thumb rhyolite flows represent a succession of eruptions closely related in time. The tuff of Bluff Point (Rbp) crops out as a welded tuff dipping steeply to the west against the Mary Lake rhyolite flow on the escarpment west of Mary Lake. It also crops out in the canyon of Nez Perce Creek to the southwest. The tuff at the base of stratigraphic section 5 in the canyon of Cascade Creek may represent a nonwelded facies of the tuff of Bluff Point. The Mary Lake rhyolite flow (Rm) (K–Ar age about 158,000 years) is exposed at and west of Mary Mountain. The oldest rhyolite extrusives in the quadrangle are three small domes (Rrd) on the wall of the caldera in area of Gibbon Hill, and the Canyon rhyolite flow (Rc) (K–Ar age about 590,000 years) which lies just inside the caldera rim, and crops out along Cascade Creek. The oldest rock (R) in the quadrangle is a tuff of the Yellowstone Group, K–Ar dated at 600,000 years. It was erupted at the time of development of the caldera. The tuff forms the west wall of Gibbon Canyon and underlies much of the northwest part of the quadrangle.

STRATIGRAPHIC SECTIONS

Units, separated by slashes, are shown in descending order; numbers represent thickness in feet (metres in parentheses). Sections demonstrate stratigraphic relations of units having too small a surface area to be shown on the map. Numbered units of uf (sediments of Upper Falls) are those described in text.

1. 3 (0.9) pt/2 (0.6) bl/2 (0.6) br (early Bull Lake age)/8 (2.4) Rc
2. 30 (9.1) pt/12 (3.7) uf (unit 1)/37 (11.3) uf (units 2 and 3, mostly covered)/11 (3.3) uf (units 4–6, undivided)/0.4 (0.12) uf (unit 7)/9 (2.7) uf (unit 8, silt)/8 (2.4) uf (unit 8, sand)/3 (0.9) uf (unit 9, stream gravel)
3. 25 (7.6) Rh/15 (4.6) uf (unit 1)/6 (1.8) uf (unit 2)
4. 100 (30.5) Rh/10 (3) uf (unit 2)
5. 40 (1.2) Rh/3 (0.9) uf (unit 2)/2.8 (0.85) uf (unit 3)/5 (1.5) uf (units 4–6, undivided)/0.5 (0.15) uf (unit 7)/5 (1.5) uf (unit 8)/4 (1.2) uf (unit 10, Rbp?)/4 (1.2) Rc
6. 40 (12.2) Rh/28 (6.3) uf, undivided, mostly lake sand/15 (4.6) Rc
7. 8 (2.4) Rh/26 (7.9) bll/4 (1.2) uf (units 4–6, undivided)
8. 2 (0.6) pco, colluvium/3 (0.9) pt/6 (1.8) involuted and crumpled lake silt mixed with pt/21 (6.4) bl, thickly varved
9. Pinedale erratics/25 (7.6) bl/4 (1.2) bt/15 (4.6) Rh
10. 6 (1.8) pt/10 (3) bl/2 (0.6) bt/10 (3) Rh
11. 6 (1.8) psl/36 (11) pl/17 (5.2) psl/zone of erratics/3 (0.9) bl
12. 35 (10.7) bsl/8 (2.4) Rgr

SURFICIAL GEOLOGIC HISTORY

INTRODUCTION

The Norris Junction quadrangle lies in the central part of Yellowstone National Park. It is chiefly occupied by the Central Plateau and its extension to the northeast, the Solfatara Plateau. These plateaus are drained eastward by tributaries of the Yellowstone River, which enters its Grand Canyon at Chittenden Bridge, and westward by Gibbon River and Nez Perce Creek. The plateaus are underlain by a series of Quaternary rhyolite flows erupted within and along the rim of a large caldera, mentioned under "Bedrock." Four basins are partly or wholly enclosed by the steep margins of the flows. The Norris Geyser Basin and Gibbon Geyser Basin lie on the rim of the caldera; the basins of Nez Perce Creek and Hayden Valley lie within the caldera. Each basin is the locus of significant hydrothermal activity, the most spectacular being that in Norris Geyser Basin. The uplands along the northern border of the quadrangle form the southern margin of the Washburn Range, which lies just north of the caldera rim.

PLEISTOCENE GLACIATIONS

During at least three Pleistocene glaciations—from oldest to youngest: Sacagawea Ridge, Bull Lake, and Pinedale—great icecaps covered most of Yellowstone National Park (Richmond, 1970; Pierce, 1970; Waldrop, 1970), and, locally, evidence is found for still older Pleistocene glaciations. However, only deposits of the Bull Lake and the Pinedale Glaciations are recognized in this quadrangle. During each glaciation, an icecap flowed in a generally westward direction across the quadrangle from sources in the drainage basin of Yellowstone Lake to the southeast. In Pinedale time, the lake-basin icecap merged in the northeastern part of the quadrangle with ice overflowing to the south from a very large west-flowing glacier in the drainage of the Lamar and Yellowstone Rivers to the North. In the northwestern part of the quadrangle, it also merged with ice flowing southward from the Gallatin Range and adjacent uplands to the east.

PRE-BULL LAKE TIME

According to Christiansen and Blank (1972), a widespread tuff of the Yellowstone Group was erupted about 600,000 years ago, during development of the large caldera whose northern rim trends northeast across the northern part of the quadrangle. (See small map.) A large lake existed in the caldera following its development. Deposits of this lake occur in the Canyon Village quadrangle, adjacent to the east. The Canyon rhyolite flow (Rc) (K–Ar age about 590,000 years) was extruded into the lake along the caldera rim in the northeastern part of the quadrangle. Three rhyolite domes (Rrd) were also extruded on the caldera rim in the northwestern part.

After development of the caldera, but during pre-Bull Lake time, hot springs deposited opaline sinter in the northwestern part of Norris Geyser Basin and West Elk Park. This probably took place during an interglacial age. Subsequently, the opaline sinter was buried for a long time by younger sediments, possibly of glacial origin. While buried, the opaline sinter was reconstituted by hydrothermal activity (White, Brannock, and Murata, 1956) to form the present deposits of chalcedonic sinter (ch).

There is evidence of glaciation in Yellowstone National Park just prior to about 160,000 years ago. However, we found no pre-Bull Lake glacial deposits in this quadrangle.

About 158,000 years ago, the Mary Lake rhyolite flow (Rm) was erupted within the caldera in the central part of the quadrangle. Somewhat later, about 155,000 years ago, the tuff of Bluff Point (Rbp) (former Shoshone Lake Tuff Member) was erupted in association with the development of a caldera at the site of the present West Thumb of Yellowstone Lake (Christiansen and Blank, 1972). The pumiceous tuff (unit 10) at the base of the sediments of Upper Falls (uf) at stratigraphic section 5 may be the tuff of Bluff Point. The welded facies of the tuff is inclined against the steep front of the Mary Lake flow southwest of Mary Lake. Eruption of the tuff was followed about 10–15 thousand years later by the eruption of a series of thick rhyolite flows, including the West Thumb flow (Rw), Elephant Back flow (Re), Spruce Creek flow (Rsp) and Nez Perce Creek flow (Rn). (See index map.) These flows, all about the same age, built up the Central Plateau to its present height and separated the original caldera lake into two drainages. One, to the east, was occupied by lakes in and north of present Hayden Valley and in the basin of Yellowstone Lake. The other, to the west, was in the drainage of the present Firehole and Gibbon Rivers. The pumiceous lake sand (unit 8) of the sediments of Upper Falls (uf) at stratigraphic section 5 was deposited in the lake that lay in and north of present Hayden Valley.

The Nez Perce Creek(?) rhyolite flow (Rn?), considered by Christiansen (1972) to be a part of the Nez Perce Creek flow (Rn), extended into the area of Gibbon Canyon. It flowed against cliffs of the 600,000-year-old tuff that formed the wall of the caldera (along present Gibbon Canyon) and probably dammed a lake upstream. If so, the altitude of the flow front at the head of Gibbon Canyon suggests that the surface altitude of the lake may have been at about 7,600 feet (2,317 m). At this altitude, the lake would have extended north into the area of Gibbon Meadows, Elk Park, and Norris Geyser Basin. No deposits of the lake have been identified. Outflow from the lake would have been along the contact between Nez Perce Creek(?) flow and the tuff of the caldera rim. A paleocanyon, ancestral to present Gibbon Canyon, may have been eroded, but no remnant of such a paleocanyon was found.

BULL LAKE GLACIATION

The Bull Lake Glaciation in Yellowstone National Park comprised two distinct widespread glacial advances separated in time by a nonglacial interval when glaciers were absent from the basin of Yellowstone Lake. During both advances, icecaps nearly covered the entire park. At both times, the ice that covered this quadrangle originated as valley glaciers in the Absaroka Range east and south of Yellowstone Lake. The glaciers flowed into the basin of Yellowstone Lake where they merged and grew into all known parts of this ice sheet. Where it is lacking and the Hayden Valley flow, intensively perlitized, rests directly on contorted greenish-gray silt containing abundant small pumice pebbles. In several places, gray-buff, hard brittle baked silt extends as thick irregular seams as much as 100 feet (30.5 m) up into the flow, where it was injected when the lava flowed over the soft silt. These units below the silt are not exposed in this sector of the canyon.

EARLY STADE

Before the eruption of the Hayden Valley (Rh) and Solfatara Plateau (Rs) rhyolite flows, a lake basin occupied the area east of the Central Plateau from the south side of Hayden Valley north to Canyon Creek. The early Bull Lake icecap invaded this basin from the southeast and gradually thickened against the slopes to the west and north. The ice deposited a thin layer of gravel containing erratics of basalt and andesite, some striated, on preexisting lake sediments. The gravel is exposed at stratigraphic section 5 and was found by digging at stratigraphic section 2. It is also exposed at stratigraphic section 1 where it rests on the Canyon rhyolite flow and contained, when examined by us, a striated boulder of basalt about 8 inches (20 cm) in diameter. Pebbles and small cobbles of rhyolite, andesite, and basalt occur in the lower part of the lake sand overlying the gravel (stratigraphic section 5). We infer that they were ice-rafted during the recession of early Bull Lake ice. Varved silt above the lake sand (stratigraphic section 5) was also deposited in the lake during recession of the ice.

As discussed below, the glacial gravel of early Bull Lake age is overlain by lake deposits that are overlain in turn by the Hayden Valley rhyolite flow (Rh), whose average K–Ar age is about 100,000 years. The early stade of Bull Lake Glaciation therefore ended before about 100,000 years ago.

INTRA-BULL LAKE INTERVAL

Following recession of the early Bull Lake icecap, an open lake again occupied the lake basin east of the Central Plateau. Its deposits were chiefly massive to laminated silt (bil and unit 2 of uf) which underlies and interfingers with crossbedded lake sand, a near-shore facies of the lake, along the canyon of Cascade Creek (unit 1 of uf, stratigraphic sections 2 and 3). The shore of the lake probably lay against the slopes of the Canyon rhyolite flow (Rc) at an altitude of about 7,800 feet (2,377 m).

About 100,000 years ago, the Hayden Valley rhyolite flow (Rh) (K–Ar dated at about 97,000 and 103,000 years) erupted from the Central Plateau into the lake. Exposures along the north-trending sector of Cascade Creek show where it flowed across the near-shore lake sand, which was locally squeezed up into fractures in its base, and down a steep underwater slope into the silt. Exposures on the floor of the canyon of Cascade Creek near its head show where the flow invaded the soft silt, infolding and injecting it up into the flow as much as 80 feet (24.4 m) and baking it to a pale-buff color. Along the east side of Yellowstone River, about 1 mile (1.6 km) south of Chittenden Bridge, similar injections of the silt show as white zones extending up into the dark flow rock. The flow itself, upon entering the lake, was intensely hydrated to granular perlite, which is extensively exposed along the canyon of Cascade Creek and at the bend in the highway just south of Chittenden Bridge. At the latter locality, a large involution of silt in the perlitized flow is well exposed. Everywhere beneath the flow the silt contains abundant chunks and grains of pumice, erupted just prior to eruption of the flow itself.

LATE STADE

The late Bull Lake icecap invaded the quadrangle from the southeast and spread northwest and west across it. In the northwest corner of the quadrangle it may have abutted another icecap flowing south and southwest from the Gallatin Range to the north. In the southwestern part of the quadrangle, Bull Lake glacial rubble (br) is preserved on uplands above the upper limit of younger Pinedale Till. In Hayden Valley, till (bt) of late Bull Lake age, or a layer of stones containing erratics of basalt and andesite, overlies the Hayden Valley rhyolite flow (Rh) (stratigraphic sections 9, 10, and 11). The glacial deposits are therefore younger than about 100,000 years. They are overlain by a widespread younger varved silt (bl) of late Bull Lake age.

The Solfatara Plateau rhyolite flow (Rs) (K–Ar age about 99,000 years) erupted in part over the Hayden Valley flow. Its abnormally convex shape along the western and northern margins of Hayden Valley suggests that it erupted against the late Bull Lake glacier. This hypothesis is supported by the unusual character of the sediments of Otter Creek (oc), exposed in the narrow valley of Otter Creek between two lobes of the flow; in particular by the abrupt transition of the flow-front breccia into the sediments and by the pattern of fractures, filled by a granular glassy matrix, that shatter large and small obsidian fragments in both the breccia and the sediments. Also of significance is the predominance of pumice and obsidian in the sediments, the admixture in the sediments of rock foreign to the flow-front breccia, such as hydrothermally altered and fresh stony rhyolite, and the sharp changes in texture and bedding characteristic of the sediments. These features suggest explosive cooling in contact with late Bull Lake ice or ice-marginal water. If so, the late Bull Lake glacier lay in this area about 99,000 years ago. The sediments were found only at the margin of the Solfatara Plateau flow.

Numerous ice-contact deposits were formed during recession of the late Bull Lake icecap. In the northwestern part of the quadrangle, a large kame, composed mostly of cemented, well-sorted lake sand (bks), that displays long foreset beds dipping to the west, was deposited on the flank of the upland west of Elk Park. At the top of the kame are beds of channel-and-fill crossbedded coarse sand containing a little gravel. Pebbles of chalcedonic sinter in the gravel are derived from outcrops of the sinter immediately to the north and are distinct from a variety of Pinedale erratics on the deposit. They suggest local drainage from the north over the stagnating ice. In the thermal area of Norris Geyser Basin, the ice probably stagnated and melted rapidly, for the area contains extensive deposits of hydrothermally altered and cemented ice-contact gravelly sand (bkgs). These deposits are overlain by unaltered or little altered unconsolidated Pinedale till and ice-