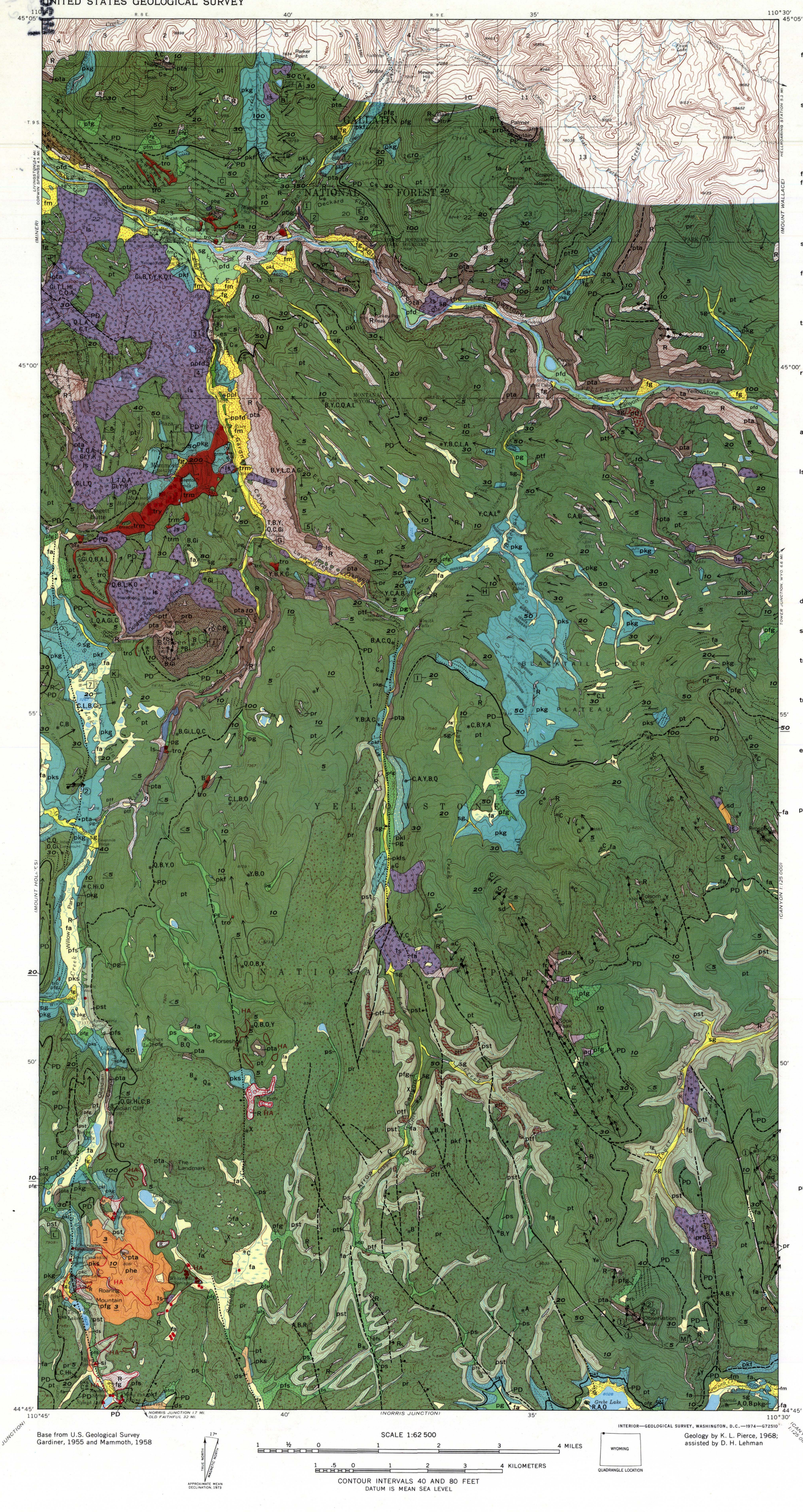
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I-641



Base from U.S. Geological Survey
Gardiner, 1955 and Mammoth, 1958

CONTOUR INTERVALS 40 AND 80 FEET
DATUM IS MEAN SEA LEVEL

Geology by K. L. Pierce, 1968;
assisted by D. H. Lehman

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1974—[illegible]

DESCRIPTION OF UNITS

HOLOCENE

ALLUVIAL DEPOSITS

fa Fine-grained humic alluvium—Silt and subordinate sand, clay, and plant material that underlie wet ground along drainages, in upland depressions or in original depressions on top of rhyolite flows; supports lush stands of tall grasses and sedges. Thickness 3-20 feet.

sg Stream gravel—Tan to gray, moderately sorted, well-bedded gravel with a sand matrix; forms alluvial flats 0-15 feet above the Yellowstone River or within a few feet of the level of the smaller streams. Includes lenses of sand and fine-grained material, especially along smaller streams and in areas of rhyolite tuff. Mostly 5-15 feet thick.

fg **fm** Fan deposits—Fan gravel (fg) is poorly sorted, crudely bedded, locally bouldery; in areas of rhyolite tuff, deposit is mostly angular sand and small pebbles. Muddy fan gravel (fm) is very poorly sorted, with abundant fines derived from clayey bedrock. Deposited by local floods, mudflows, and sheet wash. Thickness 5-50 feet.

COLLUVIAL DEPOSITS

sd Solifluction deposit—Scattered stones in muddy matrix. Unsorted, nonbedded. Formed by flowage of surface layer during thaw. Thickness 5-10 feet.

fr Frost rubble—Abundant cobble-sized rock fragments in a fine-grained matrix on crest of Washburn Range. Seasonal activity is indicated by partly disrupted tundra. Formed by frost mixing, sliding, and solifluction. Thickness 2-5 feet.

ta Talus deposit—Angular rock rubble forming cones or aprons on steep slopes at base of cliffs. Barren except for lichens. Mapped only along Black Canyon and Sheepeater Canyon where modern accumulation noted. Generally 5-20 feet thick.

rb Block rubble—Angular blocks 0.5-5 feet across. Interstices open, but fine-grained matrix present at depth. Barren except for lichens; found near timberline on Bunsen Peak and Palmer Mountain. Derived from frost-heaved andesitic intrusive rocks. Thickness 3-6 feet.

ad Avalanche debris—Boulder- to pebble-sized rock fragments in a fine-grained matrix at base of avalanche chutes. Deposits unsorted, crudely bedded. Thickness 5-10 feet.

ls Landslide deposit—Nonsorted debris in a clayey matrix. Generally results from failure in shaly bedrock. Fresh ridges, depressions, and slump scarps indicate recent movement of most deposits. The slide at The Hoodoos consists of large blocks of older travertine from Terrace Mountain (tro) and the underlying rhyolite tuff that have rotated backward. The extensive areas of landslides north of Mammoth displays a progression from block glide movement (shown by double-hachured scarp symbol) through blocky landslides to earthflows. A large fresh rockslide occurs in the Black Canyon of the Yellowstone. Thickness 10-100 feet.

HYDROTHERMAL DEPOSITS

ds Diatomaceous sediment—White siliceous sediment composed of microscopic diatom shells. Mushy when wet; powdery when dry. Thickness 5-10 feet.

si Siliceous sinter—Nearly white, porous, amorphous silica. Mapped only in southwest corner of area. Mostly 2-10 feet thick.

try Travertine—Light-gray, yellowish- to grayish-weathering calcium carbonate, commonly subhorizontally layered. Younger travertine (try) now being deposited or recently was deposited. Thickness 5 feet to at least 50 feet.

trm Travertine—Similar to younger travertine (try) but no evidence of modern deposition. Deposits not glaciated. Contains caverns tens of feet deep north of Capitol Hill.

EOLIAN DEPOSITS

es Eolian silt and sand—Poorly sorted sand and silt on MacMinn Bench (stratigraphic section 3). Wind-carried from downslope exposures of till and lake sediments. Thickness 3-10 feet.

PINEDALE GLACIATION

GLACIAL DEPOSITS

pt Till—Unsorted, nonstratified, compact mixture of roundstones, sand, silt, and clay deposited by glaciers. Stones mostly subrounded but more faceted than stream gravel. Glacially striated and faceted stones locally common in deposit, but difficult to recognize on surface.

In a belt extending from Mount Everts and Mammoth through Swan Lake Flat to Twin Lakes, the till is gray, calcareous, and clayey with a diversity of cobble-sized erratics (B, C, Gi, Hi, L, Q). In the Washburn Range the till is brown and clayey with stones almost entirely of andesite from conglomerates and breccias of the Absaroka Volcanic Supergroup. On the basalt and tuff bench south of Sheepeater Cliffs the till is tan and consists mostly of basalt cobbles, and tuffaceous sand and silt. In a belt about 4 miles wide bordering the Yellowstone River, the till is mostly brown and clayey, especially in the northern part of the mapped area, and contains abundant boulders of Precambrian crystalline rocks.

Soils developed on Pinedale Till are variable, reflecting differences in parent material and local climate. Soil profiles I, J, and M are on silty noncalcareous till and are shallow and poorly developed. Soil profile K is in clayey parent material and is about 3 feet thick; soil profiles A, B, and L are more than 3 feet thick and show moderate structure development apparently related to the swelling(?) clays present. At lower and more arid sites, soils on calcareous till display a caliche horizon about 2 feet thick; such caliche zones occur beneath A and B horizons totaling 1 foot thick (soil profiles F and H) to more than 2 feet thick (soil profiles D, E, and G).

In much of the northern half of the mapped area the till forms drumloidal topography. End moraines are common just inside the Deckard Flats limit of glaciation (PD). The till has been modified by frost heaving and, on slopes, by solifluction and creep. Generally 5-20 feet thick.

pr Rubble veneer—Thin mantle of rubble in a loose fine-grained matrix on glaciated uplands. Mostly derived, especially by frost processes, from local bedrock, but contains some glacial erratics and other probably glacially moved debris. Terrain underlain by rubble veneer (pr) gradational with and similar in appearance to much of terrain underlain by till (pt), but undisturbed glacial deposits are present only locally in rubble veneer areas. Mapped areas include many small glaciated outcrops of bedrock. Thickness 0-5 feet.

ICE-CONTACT DEPOSITS

pkg **pks** **pkc** **pkf** Kame deposits—Kame gravel (pkg) and sand (pks), moderately well sorted, mostly gray, unevenly bedded with abrupt vertical changes in grain size. Roundstones mostly 2-4 inches in diameter. Deposited by ice-margin streams with ice-contact frontal scarps commonly preserved. Along Obsidian Creek contains obsidian and is unsuitable for concrete aggregate. As indicated by lush vegetation near Amphitheater and Crystal Springs and along Eagle Creek, the mapped kame gravel (pkg) includes either till or lake sediments. Hydrothermally cemented kame sand (pkc) occurs at Roaring Mountain.

Along Bear Creek and in Gardners Hole, kame inwash fan gravel (pkf) is cobbly, well sorted, and bedded; it was deposited against an ice mass by outwash from a glacier upvalley. West of Grebe Lake along south margin of area, deposit (pkf) consists of sand and pebble gravel of hackly rhyolite tuff and is marked by kettles. East of Grebe Lake, deposit (pkf) is poorly sorted mudflow debris derived from Eocene volcanic rocks. Mostly 10-50 feet thick.

LACUSTRINE DEPOSITS

pkl Ice-dammed lake silt—Gray to tan, well-bedded lake silt, sand, and clay deposited in valleys of Lava, Bear, and Obsidian Creeks when blocked by glaciers. Generally concealed by gravel. Near Clearwater Springs, consists of tan silt with thin laminae of brown hydrothermal clay. Mostly 20-100 feet thick.

ppl Proglacial lake sediments—Gray to pink silt and sand in MacMinn Bench area. Coarsely bedded, locally laminated. Some sand displays wavy subhorizontal laminations. Age thought to be early Pinedale because unit grades upward into tan till (stratigraphic section 3) of probably early Pinedale age. Overlain also by Pinedale kame gravel (pkg) (stratigraphic section 4). Thickness 40-80 feet.

ALLUVIAL DEPOSITS

pfd Flood deposits—Buff, coarse boulder gravel, poorly to moderately sorted, poorly bedded; boulders mostly gneiss and basalt and commonly display percussion spalls. Deposits form large longitudinal and midchannel bars as much as 50 feet high and flood-modified alluvial terraces. Flood deposits (pfd) beneath Gardiner contain, just beneath surface, many boulders more than 3 feet across; pockets of sand are also present. In the railroad cut one-fourth mile northwest of Gardiner High School, about 10 feet of large-boulder gravel rests on 20 feet of more sandy gravel. Meandering dry channels cross the surface of alluvial flats south of the confluence of the Gardner and Yellowstone Rivers; there and immediately to the west, the flood deposits may veneer older alluvial deposits. Steep-sided depressions at Crevice Lake and about 3 miles downstream may be the product of flood currents or melting of buried ice blocks. Mostly 10-50 feet thick.

pg **ps** **pfg** **pfs** **pfm** Gravel—Most deposits (pg, ps, pfg, pfs,) are tan to gray, moderately sorted and stratified, and subangular to subrounded. They are mostly locally derived alluvium found along intermittent streams. Near Lava Creek Campground the gravel (pg) is outwash. At the mouth of Sheepeater Canyon the gravel (pg) is cemented by travertine. Stream sand (ps) and fan sand (pfs) in southern part of mapped area are derived from rhyolite tuff and flows and underlie normally dry bottomlands which apparently were modified only by minor surface wash in Holocene time. Muddy fan gravel (pfm) is poorly sorted and derived from clayey bedrock. In most places Pinedale alluvium (pg, ps, pfg, pfs, pfm) is not clearly incised by modern streams, but its coarseness and volume suggest it dates from glacial time. Thickness 5-30 feet.

ppfd Proglacial flood deposits—Gray, locally bouldery gravel. Occurs beneath proglaical lake sediments (ppl) in scarp of MacMinn Bench and protrudes from alluvial fans to south. Two or more beds (stratigraphic sections 3, 4) contain boulders 3-10 feet in diameter. Thick-bedded with many layers of angular cobble and pebble openwork gravel. Larger boulders mostly Quaternary basalt; remainder mostly andesitic volcanic rocks. Glacial-flood origin of parts of unit uncertain; andesitic detritus in lower part of unit may be related to landsliding of Sepulcher Mountain area. Early Pinedale age assignment based on conformable and sequently logical relation to overlying lake sediments (ppl) and till of probable Pinedale age. Thickness 20-125 feet.

COLLUVIAL DEPOSITS

pst Scree deposit of tuff rubble—Hackly small-pebble-sized fragments and local large slabs of stony rhyolite forming sheets over tuff bedrock and aprons or cones farther downslope. Generally covered by open forest. Includes active surface material that locally slides and tumbles downhill against trees and other obstacles. Thickness of sheets 0-5 feet; of aprons and cones 5-30 feet.

ptf Talus-flow deposit—Angular blocks on moderate slopes. Similar to talus, but displays ridges and furrows formed by flowage downhill. In Lava Creek area mostly slabby rubble surrounded by scree deposit of tuff rubble (pst). In Black Canyon formed from Quaternary basalt. Mostly inactive. Mostly 3-10 feet thick.

pta Talus deposit—Angular blocks 0.5-4 feet in diameter. Forms aprons and cones on steep slopes, generally below cliffs. Fine-grained matrix fills voids between blocks and commonly extends to surface where a weak humic soil is developed. Mostly inactive and covered with trees or grass. Thickness 5-50 feet.

prb Block rubble—Similar to Neoglacial block rubble, but inactive and partly forested. Surface blocky, but space between blocks generally nearly filled with fine material. Mapped on Bunsen Peak and Palmer Mountain. Thickness 3-20 feet.

pkls Kame landslide deposit—Rubble in a muddy matrix slumped from valley walls out and down against stagnant glaciers. Mapped along Lava Creek where forms morainelike ice-contact ridges. Thickness 10-100 feet.

HYDROTHERMAL DEPOSITS

phe Hydrothermal explosion deposit—Angular tuff fragments 1-6 inches in diameter in a fine-grained matrix; forms circular deposit 1-2 miles across that thickens towards center where there are explosion craters 50-150 feet deep. Both matrix and fragments hydrothermally altered before emplacement. Occurs on uplands of Roaring Mountain. Thickness increases from 2 feet to about 15 feet towards center of deposit.

PRE-PINEDALE

HYDROTHERMAL DEPOSITS

tro Travertine of pre-Pinedale age—Similar to younger travertine (try) but older travertine (tro) is mantled by glacial till or erratics and predates the Pinedale Glaciation; it forms extensive deposits on Terrace Mountain and on the bench north of Gardiner. Stones from glaciers or reworked from glacial deposits occur in the travertine (tro) in Snow Pass and on the bench north of Gardiner.

PRE-BULL LAKE

ALLUVIAL DEPOSITS

pbg Gravel of pre-Bull Lake age—Well-sorted, coarsely stratified, cobble gravel exposed (stratigraphic sections 1, 2) beneath the basalt flows on Deckard Flats. Roundstones mostly of Precambrian rocks; a few are of tuff. At stratigraphic section 1 and farther up Bear Creek, the lowermost part of the deposit consists of boulders, many as large as 5 feet and some as large as 10 feet in diameter. At stratigraphic section 2 the deposit rests on stream-polished and fluted bedrock. At the east end of Deckard Flats, the deposit (pbg) is a poorly sorted bouldery fanglomerate.

A knob of oxidized gravel (pbg) protrudes into gray Pinedale deposits in a roadcut 1 mile northeast of Gardiner.

og Gravel interbedded with the Osprey Basalt (exposed in stratigraphic section 6 only)—Moderately well sorted gravel composed of cobbles of basalt, tuff, quartzite, and andesitic intrusive rocks. Crops out east of Bunsen Peak where it is interbedded with and underlies a section of about six basalt flows of the Osprey Basalt as redefined by Christiansen and Blank (1972).

hg Gravel beneath Huckleberry Ridge Tuff (exposed in stratigraphic section 5 only)—Pebble and small-cobble gravel consisting of rocks from the Absaroka Volcanic Supergroup and the Bunsen Peak intrusive. Crops out on Mount Everts beneath 2-m.y.-old Huckleberry Ridge Tuff (Christiansen and Blank, 1972).

R Bedrock—(After U.S. Geological Survey map I-711, 1972) Precambrian schists, gneisses, and mineralized and altered rocks occur northeast of the bedrock Gardiner fault (not shown) in the Black Canyon of the Yellowstone region. Mesozoic shales and minor amounts of sandstone occur on and east of Mount Everts. Quaternary basalts form the bench north of Gardiner, Deckard Flats, and the bench from Sheepeater and Lava Creek Canyons to Horseshoe Hill; they crop out discontinuously from the Lava Creek Campground northeast to the Yellowstone River. Quaternary rhyolite tuff underlies the southern part of Mount Everts, the Blacktail Deer Plateau, the Roaring Mountain-Arrow Canyon area, and the Tower Creek area. At and southeast of Obsidian Cliff is the Obsidian Cliff flow (about 176,000 years old) of Roaring Mountain Member of Plateau Rhyolite; one-half mile northeast of Obsidian Lake is the Crystal Spring flow (about 79,000 years old) (K-Ar age dates, J. D. Obradovich, written commun., 1972). Andesitic volcanic and sedimentary rocks of the Eocene Absaroka Volcanic Supergroup form the Washburn Range. Paleozoic and Mesozoic rocks locally crop out in a belt extending from Whiterock Springs northward through Horseshoe Hill to elevation point "8109"

STRATIGRAPHIC SECTIONS

Units, separated by slashes, are shown in descending order; numbers show thickness in feet, except in section 7. Letter symbols represent units listed in Description of Units; where no unit is appropriate, lithology is stated.

1. >50 basalt flows/20 pbg/10 pbg, sandy/bedrock.
2. >50 basalt/0.5 soil, red/3 soil caliche/100 pbg/15 pbg, coarse boulders/bedrock.
3. 3 es/15 pt, gray/25 pt, dark tan/25 pt, tan/80 ppl/30 ppfd, sand, silt, and gravel/30 ppfd, cobbly/30 ppfd, basalt boulders/30 ppfd, angular/15 ppfd, angular, boulders at top.
4. 5 es/75 pkg, sandy/40 ppl/40 ppfd, bouldery/45 ppfd, angular/25 ppfd, basalt boulders.
5. >50 tuff/6 ash/2 hg, sand, red, clayey/5 hg.
6. 180 six basalt flows and local interbeds of gravel (og)/20 og/bedrock.
7. 100 cm peat/128 cm marl with humic layers/0.5 cm volcanic ash/172 cm marl with humic layers/50 cm humic mud/50 cm silt, gray, laminated.

SOIL PROFILES

Soil horizons, separated by slashes, are shown in descending order; numbers give depth in inches below surface. Symbols A, B, and C refer to soil horizons; B_1 B_2 and B_3 refer to subdivisions of B horizon; and C_{ca} refers to carbonate zone in C horizon. Modifiers "moderate" and "strong" show how well structure of B horizon is developed, or how well caliche is developed in C_{ca} horizon. Where no modifier is given, property is weakly developed: that is, the B horizon would generally be regarded as a "color B," or the C_{ca} horizon is developed in calcareous parent material and carbonate has simply been rearranged with only minor translocation.

A. 0–4 A/4–11 B_1, strong/11–23 B_2, strong/23–40 B_3, moderate/C.
B. 0–9 A/9–13 B_1/13–25 B_2, moderate/25–56 B_3/>56 C.
C. 0–18 A/18–28 B/28–>36 C_{ca}, moderate.
D. 0–8 A/8–11 B_1/11–20 B_2, moderate to weak/20–31 B_3/31–>36 C_{ca}.
E. 0–10 A/10–17 B_2/17–28 B_3/28–>36 C_{ca}.
F. 0–2 A/2–11 B/11–35 C_{ca}/C.
G. 0–6 A/6–26 B/26–39 C_{ca}/C.
H. 0–1 A/1–13 B/13–22 C_{ca}/22–43 C_{ca}, moderate/C.
I. 0–11 A/11–15 B/15–38 C, compact/C, loose.
J. 0–1 A/1–14 B/C.
K. 0–3 A/3–34 B/C.
L. 0–12 A/12–23 B_1, moderate/23–38 B_2 strong/C.
M. 0–4 A/4–17 B/C.

SURFICIAL GEOLOGIC HISTORY

INTRODUCTION

This mapped area lies in the north-central part of Yellowstone National Park. The terrain comprises: (1) in the southeast part of the map, the western part of the Washburn Range (elev. 9,300-9,700 feet), (2) in the northern part, the valley of the Yellowstone River (elev. of river, 5,200-5,600 feet) including the Black Canyon of the Yellowstone, (3) in the west-central part, the Gardner River valley, and (4) in most of the remainder, plateaus (elev. 7,000-8,500 feet) dissected by the deep canyons of Lava Creek, Arrow Canyon Creek, and Tower Creek. West of the mapped area lies the Gallatin Range; north and northeast, the northern end of the Absaroka Range (the Snowy Range of previous workers); and south, the Yellowstone plateaus.

PRE-BULL LAKE ALLUVIAL DEPOSITS

All pre-Bull Lake alluvial deposits noted, except for that outcrop 1 mile northeast of Gardiner, are overlain by volcanic rocks whose age is at least approximately known. On Mount Everts (stratigraphic section 5) about 6 feet of sand and gravel (noted by Boyd, 1961, p. 395) is overlain by 2-m.y.-old Huckleberry Ridge Tuff (Christiansen and Blank, 1972). The Eocene volcanic rocks in the gravel indicate that it was probably deposited by a stream draining the present area of Lupine and Blacktail Deer Creeks. No pre-Eocene rocks were noted, such as are common in the Pinedale Till of the area. Thus it is suspected that the gravel is nonglacial and may be preglacial in origin. At the top of the gravel is a reddish clayey silty sand which may be a buried soil.

Preserved beneath the basalts of Deckard Flats (stratigraphic sections 1, 2) is thick gravel almost entirely of Precambrian rocks. This gravel was observed by R. L. Christiansen and me to contain clasts probably derived from the Huckleberry Ridge Tuff. The basalts and gravels are probably between 0.6 and 0.7 m.y. old, for their magnetic polarity is normal and they are correlated with basalts older than the 0.6-m.y.-old Lava Creek Tuff (R. L. Christiansen, oral commun., 1971). Just west of stratigraphic section 2, successively younger basalt flows have buried and preserved a prebasalt terrace scarp about 100 feet high. The size and concentration of boulders in the basal gravels, from stratigraphic section 1 toward Bear Creek, seem unusual in nonglacial Quaternary deposits; they may represent a lag or flood deposit of glacial boulders.

The Osprey Basalt and associated gravels (stratigraphic section 6) postdate canyons cut in 0.6-m.y.-old tuff (Christiansen and Blank, 1972). The quartzite and intrusive rocks in the gravel indicate drainage from part of the Gallatin Range through this area at this time (Boyd, 1961, p. 402).

PRE-PINEDALE TRAVERTINE

Older travertine (tro) is mantled by Pinedale glacial deposits on Terrace Mountain, on the bench north of Gardiner, and at two places south of Sheepeater Canyon. No evidence was found to indicate the travertine to be of pre-Bull Lake age; tentative assignment to the Bull Lake-Pinedale interval seems most reasonable. These travertine deposits indicate the location of pre-Pinedale springs, probably of hot water.

PLEISTOCENE GLACIATIONS

Great icecaps covered most of Yellowstone Park repeatedly during Pleistocene time. These glaciations are (from oldest to youngest): pre-Bull Lake (which probably includes several full-scale glaciations), Bull Lake, and Pinedale.

No distinctly glacial deposits of pre-Bull Lake or Bull Lake age are recognized within the mapped area, but 0.1 mile west of it along the Gardner River, probably Bull Lake Till is exposed beneath Pinedale Till. Compared to the Bull Lake Till the erratics in the Pinedale Till are from a more southerly source, thus indicating that the influence of the Bull Lake icecap on glaciers flowing eastward from the Gallatin Range was less than that of the Pinedale. West and southwest from Yellowstone National Park, the Bull Lake Glaciation was more extensive than the Pinedale, but northward from Yellowstone, the Pinedale appears equally or more extensive.

PINEDALE GLACIATION

The Pinedale glacial history consists of the formation and building of icecaps on the northern Absaroka Range (to the northeast of mapped area), Gallatin (to the west), and Washburn Ranges, and eventually on the Yellowstone Park plateaus (to the south); it culminated in a full-glacial flow regimen with nearly every feature in the mapped area covered by ice. This was followed by a waning of glacial conditions accompanied by variations in the residual influence of ice from different sources.

Early Pinedale advance—Early in Pinedale time, valley glaciers formed west of the mapped area in the Gallatin Range, northeast of the area in the northern Absaroka Range, and probably also in the Washburn Range. Eventually a local icecap became established in the Washburn Range, as recorded by the fresh striations numbered "1" on Observation Peak indicating flow away from the center of the range. At that time a large icecap became established on the northern Absaroka Range north of the park and another one was forming on the plateaus south of the mapped area.

Exposures beneath MacMinn Bench (stratigraphic sections 3, 4) provide evidence for advancing Pinedale glaciers. Glaciers from the Absaroka Range north of the park advanced down the Yellowstone River valley and blocked the Gardner River before glaciers from other sources reached this area. Flood deposits (ppfd) of probable early Pinedale age filled a buried valley beneath MacMinn Bench; they probably represent periodic release of glacially dammed lakes in the Mammoth area, most likely by flotation of the glacial dam. Eventually a lake formed in which were deposited lake sediments (ppl) and then lake sediments containing masses and lenses of tan till. This lake was displaced by a glacier that advanced up the Gardner River valley from the Yellowstone River valley and deposited the tan till (stratigraphic section 3), containing Precambrian erratics from the Yellowstone drainage but no erratics characteristic of the Gallatin Range. Then a glacier pushed down the Gardner River valley, displacing the Yellowstone River valley ice and deposited the overlying zone of dark-tan till (stratigraphic section 3).

While icecaps continued to build on the plateau both south and west of the mapped area, flow of ice across Observation Peak changed from southwestward to northwestward, as indicated by intermediate striations, and then strongly to the north, as indicated by well-developed striations numbered "2." At this time, which I considered approximately the time of glacial maximum or full-glacial conditions, the entire mapped area, except for Palmer Mountain (along the north boundary), was covered by ice.

Under full-glacial conditions a large icecap lay in the southern part of the mapped area. The axis of this icecap trended westward from south of Observation Peak, over Lake of the Woods and beyond the mapped area to Dome Mountain in the Gallatin Range. North of this axis, ice flowed north toward the Yellowstone River valley; south of it, ice flowed southwest toward the Madison Canyon. Glacial scour features were not noted in a band several miles wide beneath the icecap axis, where basal shearing would be minimal. Scour features are increasingly apparent away from the axial belt, as illustrated by the Obsidian Cliff flow. Southeast of The Landmark flow-top ridges and depressions are remarkedly well preserved, as expressed by the areas of "fa" on the map, but northward from the Landmark flow top ridges and depressions become progressively more modified; just north of the Obsidian Cliff flow they are even less apparent on the younger Crystal Spring flow (northeast of Obsidian Lake). The Obsidian Cliff and Crystal Spring flows belong to the Roaring Mountain Member of the Plateau Rhyolite. The distribution of erratics also indicates an icecap axis or divide over this belt with flow away from, and not into, this area; erratics from the Gallatin Range, Washburn Range, northern Absaroka Range, or plateau of rhyolite flows are absent or at least 100 times less common than they are in areas occupied by ice masses from these sources.

Except for the southwestern corner of the mapped area, where flow was to the southwest, flow under full-glacial conditions was toward the Yellowstone River valley. This flow can be divided into four segments: (1) the western segment, (2) the Obsidian Creek-Lava Creek segment, (3) the Washburn Range segment, and (4) the Black Canyon of the Yellowstone segment. These four segments are discussed below.

1. West of the mapped area and along the western boundary as far east as Terrace Mountain, scour features on the higher elements of the topography and drumloidal features in lower areas indicate a north-northeast flow. Erratics (C, Hi) from the south end of the Gallatin Range (5 miles west of Obsidian Cliff) are common in a belt that extends from Sheepeater Canyon to Terrace Mountain—another indication of north-northeastward flow.
2. In the Obsidian Creek-Lava Creek area the glacial scouring and molding of the topography and the scarcity or absence of erratics from the Gallatin, northern Absaroka, and Washburn Ranges (erratics of Q, K, L are locally derived) indicate northerly flow, except for a late-glacial flow pattern around Bunsen Peak. The striations on Bunsen Peak and the complete dominance of Quaternary basalt erratics from the area to the south show that at full-glacial conditions above and south of Bunsen Peak glacial flow was from south to north.
3. East of Lava Creek abundant striations on the Washburn Range indicate northwesterly flow. On Mount Everts exceptionally strong glacial scour features also indicate northwesterly flow.
4. Along the valley of the Yellowstone River in the eastern part of the mapped area scour features indicate a westerly flow. Between Crevice and Cottonwood Creeks striations are well preserved on schist and extend from below to considerably above the Deckard Flats ice limit (PD). From the upper limit of Pinedale Glaciation on Palmer Mountain to the northwest corner of the area, flow was west-northwest down the Yellowstone River valley. Glaciers moving southwest down the valleys of Bear Creek, Crevice Creek, and Cottonwood Creek flowed around to the northwest as they joined the glacier in the Yellowstone River valley.

On Palmer Mountain, ice reached an altitude of about 9,100 feet. Just west of the mapped area on Sepulcher Mountain it reached an altitude of 8,800 feet. At Gardiner, Mont., the ice was at an altitude of about 8,700 feet and was 3,500 feet thick. A deep ice-margin channel now partly filled with talus (pta) occurs at an altitude of 8,500 feet 2.7 miles north of Gardiner. The glacier in the Yellowstone River valley terminated 35 miles downvalley from Gardiner after having been joined on the way by 10 tributary glaciers.

In most of the mapped area, the ice surface was above 9,000 feet. The ice overrode Cook Peak (alt. 9,742 feet) and merged with an equally high glacier from the Obsidian Creek-Lava Creek segment. If ice at least 250 feet thick was needed to produce the striations on Cook Peak, the ice surface there and to the south was higher than 10,000 feet. A similar conclusion is reached by projecting gradients from Gardiner to the source area. The gradient from Gardiner to the glacial terminus is 100 feet per mile; if the same gradient is projected to the icecap axis above Lake of the Woods, the altitude of the ice surface there exceeded 10,000 feet and the icecap was more than 2,000 feet thick there. This projection may be approximately correct, for the normal decrease in gradient towards the icecap axis was probably offset by the marked local increase in gradient where the ice plunged several thousand feet down from the plateaus (alt. 7,000-8,000 feet) northward into the valley of the Yellowstone River (alt. 5,200 feet).

Middle Pinedale recession—A recession from the early Pinedale maximum followed by a readvance to a middle Pinedale maximum occurred in the Yellowstone area and elsewhere in the Rocky Mountains. Evidence for this readvance was not noted in the mapped area, probably because ice levels at that time diminished very little in this, the source area. After the postulated middle Pinedale maximum, glaciers receded, probably in pulses, and ice-margin streams cut into bedrock and glacial deposits.

As the ice level lowered, flow changed, reflecting both topographic effects and the differing capacities of the source areas to continue supplying ice under a waning glacial climate. The following changes in flow, especially the Deckard Flats advance or standstill, illustrate these effects.

As the ice level fell below the crest of the Washburn Range, the ice, instead of flowing across the range, had to flow down the natural slope along Tower Creek, leaving well-developed northeasterly striations that transect northwesterly ones on the ridge along the east boundary of the mapped area.

After ice ceased flowing over the crest of the Washburn Range, an incursion of northern Absaroka Range ice across the northwest flank of the range left Precambrian erratics and striations indicating southwesterly flow below an altitude of 8,800 feet. (Seven of these Precambrian erratic localities are from G. M. Richmond (written commun., 1972).) Farther southwest, nearly stagnant ice lay in the Obsidian Creek-Lava Creek area as indicated by the general absence of Precambrian rocks. This near reversal in flow from full-glacial conditions occurred in part because the icecap on the northern Absaroka Range could better sustain glaciers than the icecap on the 2,000-foot-lower terrain in the Lake of the Woods area. A lower level of this northern Absaroka Range incursion is represented by ice-dammed lake sediments (pkl) and kame gravels (pkg) along Lava Creek and Precambrian erratics just west of Lava Creek.

As the ice level fell below the top of Bunsen Peak, glaciers flowed around it and left flow features and erratics different from those of full-glacial conditions.

Deckard Flats advance—Late in middle Pinedale time, there was a readvance or standstill, here called the Deckard Flats advance for the lateral moraines just upslope from Deckard Flats (east of Gardiner). Deckard Flats end moraines have been removed by subsequent floods on the floor of the Yellowstone River valley, but descending lateral moraines on the south side of the valley indicate that the terminus was near the mouth of Reese Creek, 2 miles northwest of the map boundary. This ice position requires an upvalley recession of about 30 miles from the Pinedale maximum. The Deckard Flats moraines on Deckard Flats and on the travertine bench above Gardiner are more bouldery and have stronger morainal topography than the Pinedale Till upslope. Along Bear Creek, thick inwash fan gravel (pkf) and ice-dammed lake sediments (pkl) were deposited against ice of the Deckard Flats advance.

In Deckard Flats time, Yellowstone River valley ice moved into the Gardner River valley to a point downstream from the deeply kettled kame gravel at the south end of MacMinn Bench. This ice deposited boulders of Precambrian rocks from the Black Canyon of the Yellowstone in the landslide area southwest of Gardiner. At the north end of MacMinn Bench, abundant large Precambrian erratics from the Black Canyon define a band which extends from the north side of Mount Everts into the Gardner River valley where they appear to be associated with the gray, uppermost till at stratigraphic section 3.

On the Blacktail Deer Plateau the Deckard Flats boundary passes around the lower flank of the Washburn Range and descends Lava Creek into Mammoth "hole." It encircles Mount Everts, which was then a nunatak. Extensive kame sand and gravels (pks, pkg) are associated with ice-margin drainage on the Blacktail Deer Plateau. The icecap in the Obsidian Creek-Lava Creek area had apparently vanished, allowing for minor incursion of Deckard Flats ice from both the Gallatin and northern Absraoka Ranges.

Near the western map boundary, ice carrying erratics from the Gallatin Range (Hi, Gi, L, C, Q) moved eastward down the drainages into the western part of the mapped area. Ice-dammed lake deposits (pkl) accumulated in the Roaring Mountain area. Along Obsidian Creek, extensive kame deposits erratics (C, Hi, Q), striations, and small-scale glacial streaming features indicate that Deckard Flats flow was at 60°-90° to the drumloidal topography and transport direction of erratics under full-glacial conditions.

Ice with erratics from the Gallatin Range poured down Sheepeater Canyon and through Golden Gate into the Mammoth "hole" area, leaving high lateral moraines east of Sheepeater Canyon, and smaller moraines northeast of Golden Gate Canyon and west of Golden Gate. This boundary may be represented by kame gravels draped around the drumloidal hill north of Mammoth. Capitol Hill and other conical hills of kame gravel (pkg) near Mammoth probably represent places where sediment from melt waters filled holes in the stagnant ice perhaps formed by the melting effect of hot springs.

In the Obsidian Creek-Mammoth area the Deckard Flats flow regimen, as compared to the previous full-glacial flow regimen, apparently reflects lowering of ice levels, together with topographic effects and the stagnation of the icecap to the south. With melting of the icecap to the south, glaciers from valleys in the Gallatin Range were free to flow eastward down the drainages, and had to flow around the topographic obstacles of Bunsen Peak, Terrace Mountain, and the bedrock ridge west of Swan Lake.

Deposits of a younger phase of Deckard Flats time, the Sheepeater Canyon Bridge phase, form fresh bouldery moraines southeast of Mammoth. The main glacier that deposited these moraines flowed down Sheepeater Canyon of the Gardner River, where it picked up abundant basalt erratics; the inner set of these moraines arcs up Lava Creek—an indication that Gallatin ice was the last in that area. Moraines and outwash correlative with those near Sheepeater Canyon Bridge occur a mile west of Blacktail Pond.

South of the Washburn Range, inwash fan deposits (pkf) indicate an ice-front position roughly correlated, by mapping, with the Deckard Flats position of both northern Absaroka Range and Gallatin Range glaciers; the nature of the inwash (pkf) is controlled by the bedrock upslope.

Evidence for Pinedale age of glaciation—A Pinedale age for the last glaciation of the entire mapped area (excluding Palmer Mountain) is favored over assigning some higher elements to the Bull Lake Glaciation or to the pre-Bull Lake glaciations, for the following reasons:

1. All the striations on andesites and basalts from the crest of the Washburn Range to levels covered by Deckard Flats advance are equally fresh, with weathering rinds less than one-fourth mm thick.
2. Most striations on the Washburn Range are on 1- to 3-foot boulders which have been loosened but not removed from their soft volcanic matrix.
3. In places, striations from the highest glacial phase are crossed on the same boulder by those of a lower glacial phase. Since the last glaciations these boulders have weathered completely or partly out of the bedrock. If the glacial scourings forming these striations had been separated by a nonglacial time (perhaps 40,000-100,000 years long), interim weathering and frost action would have so loosened the boulders that the later glaciation would have removed them.
4. The variability of soils does not correlate well with the different levels of glaciation. Soil profiles T and M are weakly developed, yet related to the highest levels. Soil profiles D and E are similar, yet separated by the Deckard Flats boundary. Soil profile L is deep and shows clay films but is within the Deckard Flats limit. Soil profile A is well developed; this apparently reflects the parent material, which includes clay that, when locally concentrated in lenses at the top of profile A and also in post-Deckard Flats alluvial fans, displays extraordinarily well developed color, texture, and structure.
5. Aside from perhaps the Deckard Flats limit, no boundary of age significance is apparent, from the valley floors to to the highest glacial features, and no break could be traced laterally for any distance.
6. Above the Deckard Flats limit, in places such as Bunsen Peak, the Obsidian Creek-Lava Creek area, and Mount Everts, all glacial features are related to the full-glacial flow pattern.
7. Pinedale glaciers extended 30 miles downvalley from the Deckard Flats limit; upvalley from the end moraines the highest topographic evidence of fresh glacial erosion and deposition traces to and terminates at the Pinedale end moraines. For glaciations of different age and extent, ice-surface profiles always tend to converge upvalley towards the glacial source area; assignment of the higher-level glacial features in the mapped area to a pre-Pinedale glaciation would require just the opposite—that the profiles cross and then diverge upvalley towards the source.

Pinedale hydrothermal explosion—During deglaciation of the Roaring Mountain area, hydrothermal explosions ejected altered rock debris for a radius of 0.5-1 mile. They left two nearby areas of multiple craters that are now more than 80 feet deep (not to be confused with shallower pits due to acid leaching). These explosions probably occurred during the final stages in the melting of the icecap whose axis was in the same area. This places the explosion in the later part of middle Pinedale time and not, as I had tentatively concluded, in late Bull Lake time (in Muffler and others, 1971, p. 732). According to the mechanism postulated, as the icecap was thinning during deglaciation geothermal heat melted through the ice in the Roaring Mountain area and formed an ice-surrounded lake. Hydrothermal ground water beneath the lake would reach a boiling-point temperature equilibrated to the hydrostatic pressure, including the depth of the lake. Then, by the mechanism postulated for the Yellowstone Park area by Muffler, White, and Truesdell (1971, p. 734-736), failure of some part of the ice dam would suddenly drain the lake, thereby lowering the hydrostatic pressure and causing the thermal waters below the surface of Roaring Mountain to flash to steam and eject the enveloping rocks.

Pinedale floods—Upon the sudden release of glacially dammed lakes, floodwaters about 150 feet deep rushed down the Yellowstone River valley. At least one flood came into the Yellowstone River from Lamar River (east of the mapped area) probably in late Pinedale time, and a later flood came down the Yellowstone River through The Narrows area (east of the mapped area) perhaps in latest Pinedale time. Along the Black Canyon of the Yellowstone, floodwaters picked up talus blocks and, probably during waning stages, left longitudinal and midchannel bars in the wider areas. Near the confluence of Bear Creek and the Yellowstone, floodwaters eroded the bedrock to form so-called scablands. About 0.5 mile east of Gardiner, floodwaters rushed around a bedrock knob and reached about 150 feet above the present Yellowstone River.

Boulder-studded longitudinal bars as much as 1 mile long are found below Gardiner, and a midchannel bar with a bouldery crest and 40 feet of relief occurs just downstream from the Gardiner High School.

Pinedale alluviation and colluviation—Pinedale outwash was noted in only a few places, probably because most Pinedale end moraines lie outside the mapped area. More widespread, especially in the southwestern half of the mapped area, is locally derived alluvium (ps, pg, pfs, pfg) along intermittent stream courses; this alluvium is thought to have been emplaced mainly during deglaciation and in late Pinedale time.

During deglaciation and in late Pinedale time frost action and solifluction were favored by freshly undercut slopes and probably by more moist as well as more severe climates. Glaciated slopes of rhyolite tuff in the Lava Creek area, of basalt in Sheepeater Canyon, and gneiss, schist, and basalt in the Black Canyon were frost riven to produce Pinedale talus or scree (pta, pst). Frost attacked the well-jointed intrusive rocks of Bunsen Peak and Palmer Mountain to produce slopes of block rubble (prb).

Solifluction activity occurs in fine-matrixed deposits when the ground thaws from the surface down, forming a soupy slurry of rocks and mud that flows on even gentle slopes. Such activity was probably common throughout the mapped area during deglaciation and in late Pinedale time.

HOLOCENE COLLUVIATION AND ALLUVIATION

Frost activity and solifluction continued with diminished intensity into Holocene time. In places such as the block rubble (rb) on Bunsen Peak and on Palmer Mountain and the talus (ta) in Black and Sheepeater Canyons, modern activity is clearly evident. In most areas of Pinedale activity (pta, pst, prb) as well as in till and glacial rubble areas, Holocene movement has locally occurred.

Stream gravels were transported and deposited along the larger streams, and fans of gravel and mudflow deposits accumulated on flats below eroding slopes, especially in the northern part of the mapped area.

Peaty deposits are accumulating in marshy areas. On Swan Lake Flat (stratigraphic section 7) about 4.5 meters of peaty marl has accumulated since glaciation. The base of these sediments has a C^{14} date of 13,530±130 years B. P. (M. Bender, Univ. Wisconsin, sample WIS-432). A volcanic ash similar in properties to the 6,700-year-old Mazama ash (R. E. Wilcox, written commun, 1970) from Crater Lake, Oregon, occurs at a depth of 2.3 meters.

LANDSLIDING

Most of the area between Bunsen Peak and the Yellowstone River is susceptible to landsliding because of shaly bedrock that commonly contains swelling clays. As described by Waldrop and Hyden (1963), failure in underlying shaly rocks causes overlying rocks to break away along fissures and move by block gliding. With increasing movement the material becomes more homogenized and eventually forms mudflows.

In this area of probable general landsliding throughout late Quaternary time, post-Pinedale movement ranges from earthflows several miles long to only partly disrupted till. The entire area of mapped landslides (ls) north of Gardiner either is now actually moving or is susceptible to movement if disturbed.

The bench southwest of Gardiner displays many small scarps cutting the basalt bedrock (Fraser and others, 1969, p. 69-73); more scarps are present than can be shown at map scale. Like Fraser, Waldrop, and Hyden (1969, p. 74) I consider most if not all of these scarps to represent gravity slumping, forming small-scale graben-and-horst patterns because of failure of the underlying shaly rocks. The fault blocks moved downward and outward toward the Yellowstone River valley 500-1,000 feet below.

Most of the landslides in the area probably started in late middle Pinedale time; during deglaciation, conditions were most favorable for landsliding because of oversteepened slopes and abundant ground moisture.

HYDROTHERMAL ACTIVITY

Travertine is accumulating at Mammoth Hot Springs and locally along the Yellowstone River near Bear Creek. The character of springs varies, with some springs having a life cycle of less than 50 years. Above Mammoth Hot Springs, Pinyon Terrace is inactive and forested, yet is of postglacial age.

In the southwest corner of the mapped area acidic hydrothermal solutions continue to alter bedrock and surficial deposits. Sinter deposits accumulate around hot springs and diatomaceous sediment accumulates in siliceous waters in cooler marshy areas.

QUATERNARY FAULTING

North-trending normal faults, mostly downdropped to the east, are common in the southern part of the mapped area. Most were not observed to offset any surficial deposits; they do offset tuff of the Quaternary Yellowstone Group and are topographically expressed. In a few places in the southeastern corner of the mapped area, offset of surficial units was noted. Two miles west of Grebe Lake, Pinedale gravel is offset 10 feet. North and northeast of Grebe Lake, sag ponds and small abrupt escarpments apparently indicate postglacial movement.

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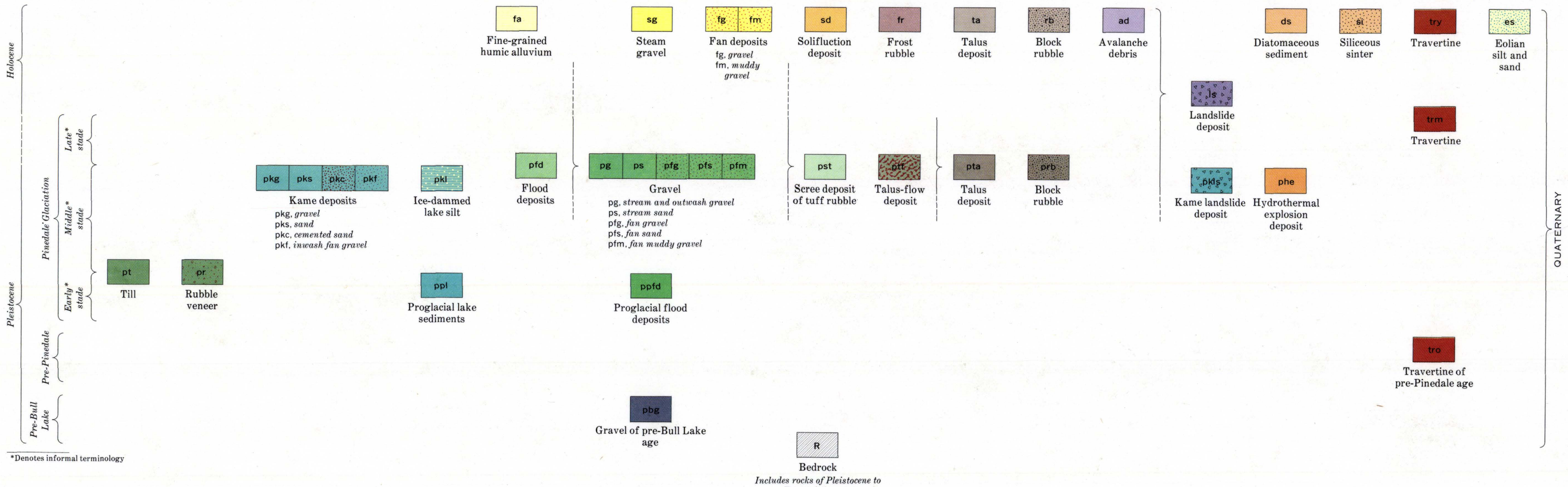
EXPLANATION



*Denotes informal terminology

Contact
Dashed where inferred

Fault having Quaternary movement
Solid where map unit is offset; dashed where map unit is probably offset but mantled by unmapped local colluvium; short dashed where topographically expressed but mantled by map unit; dotted where inferred and concealed. Bar and ball on downthrown side

PL
Limit of early Pinedale ice
Dashed where inferred

PD
Limit of late middle Pinedale Deckard Flats ice
Dashed where inferred

Direction of Pinedale ice movement
Shown by glacial molding, streaming, or scouring feature

Pinedale glacial striation

② ①
Pinedale glacial striations of differing orientation
Striations labeled 2 show relations indicating they were formed subsequent to those labeled 1

Pinedale melt-water channel
Showing direction of flow

Crest of morainal ridge
Underlain by till or kame deposits

Kame terrace scarp

Stream terrace scarp or scarp in flood deposits

Slump scarp

3
Location and number of stratigraphic section

F
Location and letter of soil profile

20 ≤5
Estimated thickness of surficial deposits, in feet
≤5 indicates less than 5 feet thick

* C,Hi,O
Location and kind of erratic
- A, *volcanic rock from Absaroka Volcanic Supergroup*
- B, *basalt, mostly from Quaternary lava flows*
- Bi, *intrusive rock from Bunsen Peak*
- C, *Precambrian crystalline rock, mostly coarse-grained gneiss*
- Gi, *Gallatin intrusive*
- Hi, *intrusive rock from Mount Holmes area*
- K *quartz and chert pebble conglomerate from Cretaceous and other Mesozoic rocks*
- L, *limestone*
- O, *obsidian, mostly from Obsidian Cliff flow*
- Q, *quartzite, both from Quadrant and Flathead Sandstones*
- R, *stony rhyolite, probably from lava flow*
- T, *travertine*
- X, *crystalline rock less than 4 inches in diameter, may be reworked from conglomerate such as that along Lava Creek*
- Y, *tuff of Yellowstone Group, includes erratics of basal vitrophyre resting on other tuff units*

HYDROTHERMAL FEATURES

▲
Sinter-depositing hot spring

■
Travertine-depositing hot spring

●
Warm spring

○
Gas vent

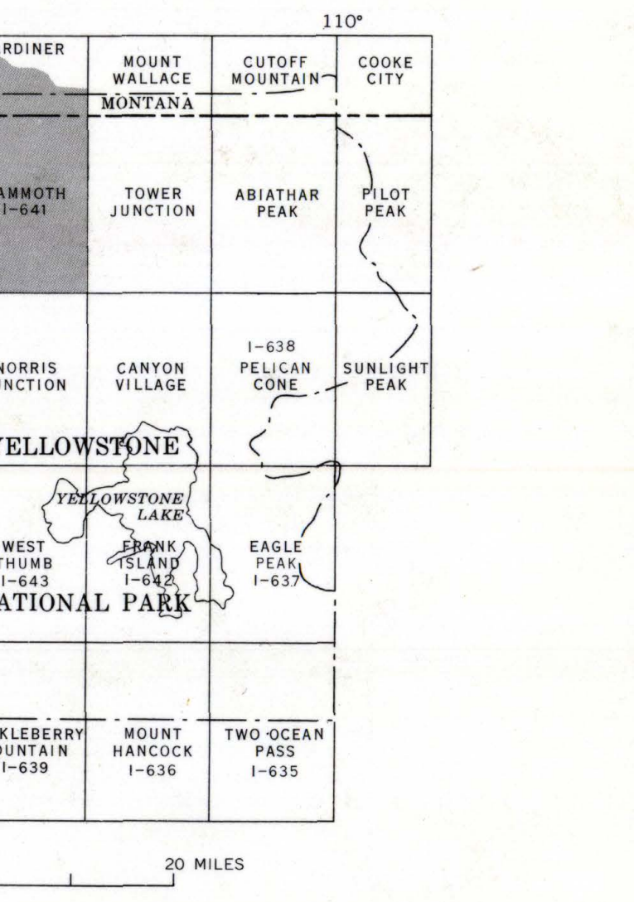
HA
Area of hydrothermal alteration and hot-spring deposition

SURFICIAL GEOLOGIC MAP OF THE MAMMOTH QUADRANGLE AND PART OF THE GARDINER QUADRANGLE, YELLOWSTONE NATIONAL PARK, WYOMING AND MONTANA

By

Kenneth L. Pierce

1973



INDEX MAP OF YELLOWSTONE NATIONAL PARK SHOWING LOCATION OF MAMMOTH AND GARDINER QUADRANGLES AND PUBLISHED MISCELLANEOUS GEOLOGIC INVESTIGATIONS MAPS

For sale by U.S. Geological Survey, price $1.00

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~~Wyoming (Mammoth quad.). Surficial. 1:62,500. 1974.~~
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