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FOURTH ANNUAL WEST SLOPE INTERCOLLEGIATE
GEOLOGY FIELD CONFERENCE

TO

CRATERS OF THE MOON
NATIONAL MONUMENT
IDAHO

FIELD TRIP GUIDEBOOK

By

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September 28, 1974



Landform outline map of the
UNITED STATES

with adjacent parts of Canada and Mexico

by Erwin Raisz

Scale 0  300 Miles

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GEOLOGY OF THE NORTH WASATCH COUNTRY

by

Robert Q. Oaks, Jr.

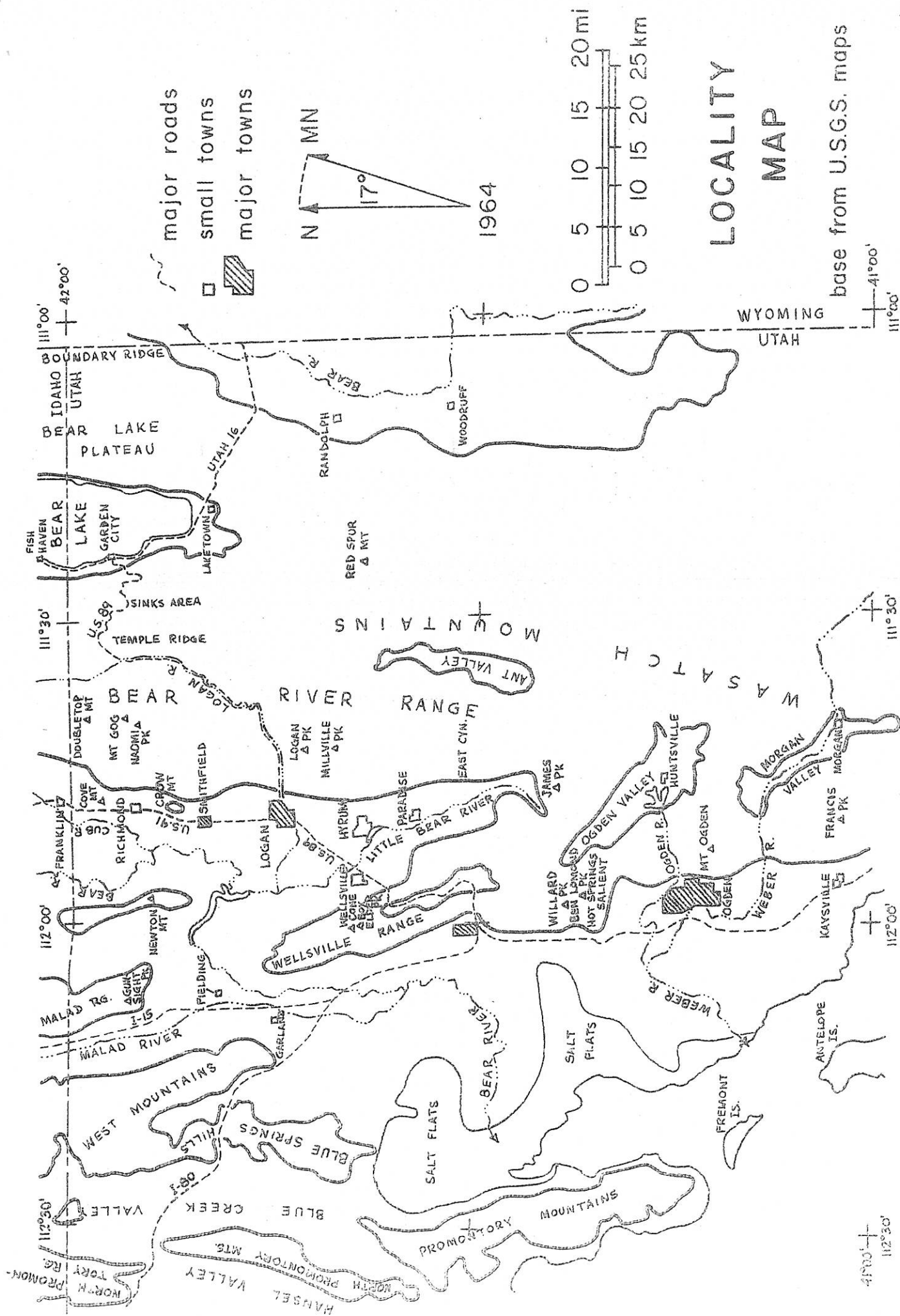
AREA

The area covered is broadly defined here as the region north of Beck's Spur (Salt Lake City), east of the famous Wasatch Fault, west of the Bear River along the Utah - Wyoming - Idaho border, and south of Soda Springs, Idaho. It includes the Wasatch Mountains (Bear River and Wellsville Ranges) in northern Utah, the Wasatch, Fish Creek, Portneuf, southern Bannock, and Malad Ranges in southern Idaho, and the enclosed valleys, primarily Morgan, Ogden, Ant, and Cache in northern Utah, and Cache, Gentile, Gem, and Portneuf in southern Idaho. This region lies on the boundary of the Middle Rocky Mountains and the Basin-and-Range physiographic provinces.

ROCKS

Rocks of the area represent an unusually complete record of the geologic ages. The oldest belong to the Precambrian Farmington Canyon Complex, rocks metamorphosed by heat and pressure and injected by granitic igneous rocks possibly more than one billion years (B.Y.) ago. These are overlain by various sedimentary rocks, including glacial tillites, quartzites, and carbonates of latest Precambrian age deposited about 0.6-0.7 B.Y. ago, then Paleozoic sedimentary rocks (6.0-2.3 million years (M.Y.) ago), Mesozoic sedimentary rocks (2.3-0.63 M.Y. ago), and Cenozoic sedimentary rocks (0.63 M.Y. ago to present).

The Farmington Canyon Complex forms the west face of the Wasatch Mountains from Beck's Spur north to Ogden; younger Precambrian sedimentary rocks overlie these older rocks in the same area, and also are present north of Ogden Valley, along the west face of the Bear River Range from Smithfield, Utah, for some distance into Idaho, and in the Malad and southern Bannock Ranges in Idaho. Paleozoic rocks are the most widespread, and form the core of each range. From about the latitude of Logan, Utah, southward, these are progressively more covered by a blanket of early Cenozoic gravel-bearing sediments of the Wasatch and Knight Formations. Mesozoic rocks are present and exposed locally in the Wasatch Mountains only from the area of Brigham City south. Late Cenozoic lake deposits, the Salt Lake Formation and Lake Bonneville Group, are present along the valley margins and valley centers, respectively.



Paleozoic rocks dominate this North Wasatch Country. These rocks are about 25,000 feet thick, are nearly entirely of marine origin, and are composed largely of carbonates (limestones and dolostones: 55%) and sandstones and quartzites (40%), with only minor amounts of shale (5%). The quartzites are ridge-formers. Those of the Tintic (Brigham) and the Swan Peak Formations of early Paleozoic age stand out in bold relief above and north of Brigham City and along the flanks of the Bear River Range. Dolostones, restricted primarily to the lower two-thirds of the Paleozoic rocks (pre-Mississippian), also tend to stand out in marked contrast to weaker shales and limestones with which they are associated. One limestone, the Lodgepole Fm. (Mississippian age) forms a remarkable, persistent cliff known locally as the "Chinese Wall;" this unit is partly correlative with the Redwall Limestone of the Grand Canyon, another well-known cliff former.

GEOLOGIC HISTORY

From study of the rocks the following overview has been derived. In the late Precambrian, sediments eroded from still-older rocks accumulated in this region. Subsidence of the earth's crust accommodated accumulation of a great thickness of sediments, and their weight led to their compaction and cementation (lithification) into sedimentary rocks. Then, mountain building accompanied by great heat changed the rocks into slates, phyllites, amphibolites, and other metamorphic rocks. The uplifted rocks were worn down by erosion. Their stubs are the Farmington Canyon Complex. This entire cycle probably took at least 1 B.Y.

About 700 M.Y. ago, during the late Precambrian, the region again began to subside, and shallow-water marine sediments (including glacial-marine sediments in the latest Precambrian) again accumulated in great thickness through a protracted period, to become lithified into sedimentary rocks of Precambrian, Paleozoic, and Mesozoic ages. Between about 100 to 55 M.Y. ago, the area again was affected by mountain building (Laramide orogeny). This time, because erosion has not cut so deeply, the evidence is much more complete.

The rocks, compressed by E-W forces, bent into elongate folds (downfold = syncline; upfold = anticline). Locally they ruptured, and plates as much as 20,000 to 30,000 feet thick were pushed horizontally across the surface of the earth through distances of miles or tens of miles. Three such layers (thrust sheets) are present at Ogden, where brownish quartzite of the Tintic (Brigham) Fm. can be seen repeated three times in the mountain face. Erosion has truncated these bent and broken rocks, removing entirely the Mesozoic rocks north of Brigham City, where once they may have been as much as 10,000 feet thick. Erosional stripping was followed by deposition of the Wasatch and Knight Formations as a blanket across the area.

About 25 to 35 M.Y. ago block faulting began to break the area into a series of valleys and ranges elongated N-S and bounded by normal faults. This disrupted the drainage and formed "closed" (i.e., unconnected) valleys in which lakes formed. Streams dissected the uplifted blocks and deposited the derived sediments in the lakes and along

the lake margins. It was at this time that the major E-W streams that cross the Wasatch Range became established across the N-S geologic structures, probably by superposition from the overlying Wasatch and Knight Formations. Explosive volcanic eruptions, probably in the Yellowstone area, contributed large amounts of ash, a major component of the Fowkes Fm., Norwood Tuff, and the Salt Lake Fm. in the North Wasatch Country. Block faulting, which continues to the present, has tilted these tuffaceous lake sediments, and, during drier periods, widespread pediments formed across these sediments.

Glaciation in the highlands and lacustrine deposition in the valleys during colder, wetter periods, and deposition of alluvial fans along the mountain fronts and at mouths of tributaries to major canyons during warmer, drier periods of the late Cenozoic ice ages have completed the geologic history of the area to the present.

GEOLOGIC FEATURES

Along the mountain margins spectacular views into the valleys afford unparalleled perspectives of many geologic features. The mountain fronts in most cases are steep escarpments along gravity (or "normal") faults on which the mountains have moved up relative to the valleys. Such faults form the west margin of the Wasatch Range, the east side of Cache Valley, the west side of Temple Ridge in Logan Canyon, both sides of Bear Lake Valley, and margins of the Malad and southern Bannock Ranges in Idaho. Vertical offset on several of these faults is known to exceed 1 mile, and may be as much as 2 miles locally. Several features associated with faulting, found along margins of the ranges, include springs, faceted spurs, deltas and alluvial fans, landslides, and offset topographic surfaces. For example, faults less than 27,000 years old offset glacial end moraines at the mouth of Little Cottonwood Canyon southeast of Salt Lake City, faults less than 11,000 years old offset alluvial fans near Willard and the delta at the mouth of Logan Canyon, and older faults offset erosional (pediment) surfaces in many places along the margins of Cache Valley.

Along the mountain margins the two prominent wave-cut shorelines of Lake Bonneville are interrupted only at canyon mouths where flattopped deltas were deposited by streams entering the lake. Diversion of the Bear River near Soda Springs (at Lava Hot Springs) by basalt flows, about 30,000 years ago, caused Gem Valley to fill with water, overtop at the present location of Oneida Narrows, and thus to cause Lake Bonneville to overflow through Red Rock Pass at the north end of Cache Valley. Evidence of this catastrophic flood is visible for many miles down the Snake River.

Of the many notable geologic features seen along the ridge crests, probably the most spectacular and readily recognized are those caused by glacial erosion. These are primarily cirques and nivation basins, present chiefly on the cooler east- and northeast-facing slopes above 8000 feet, including the areas near Mt. Ogden, Ben Lomond and Willard Peaks, Wellsville Cone and Box Elder Peak, Logan Peak, Naomi Peak (Tony Grove, White Pine, and High Creek lakes), Camp Wilderness (Gibson lakes), and Bloomington Lake. Boulder-filled glacial ground moraines and end moraines were deposited downvalley (chiefly eastward) from some, but not all, of these features. Other glacial-related features such as solifluction

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43°00'

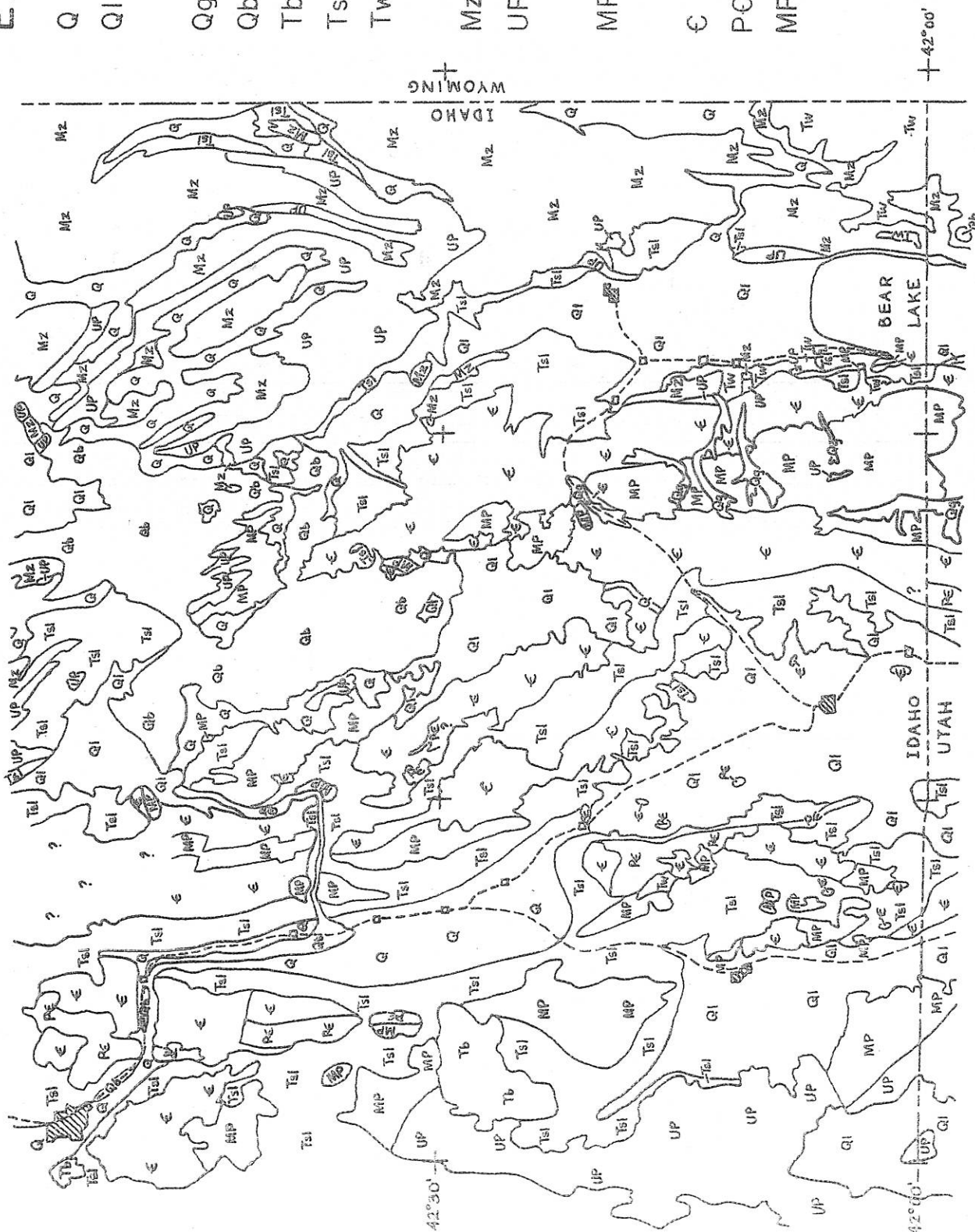
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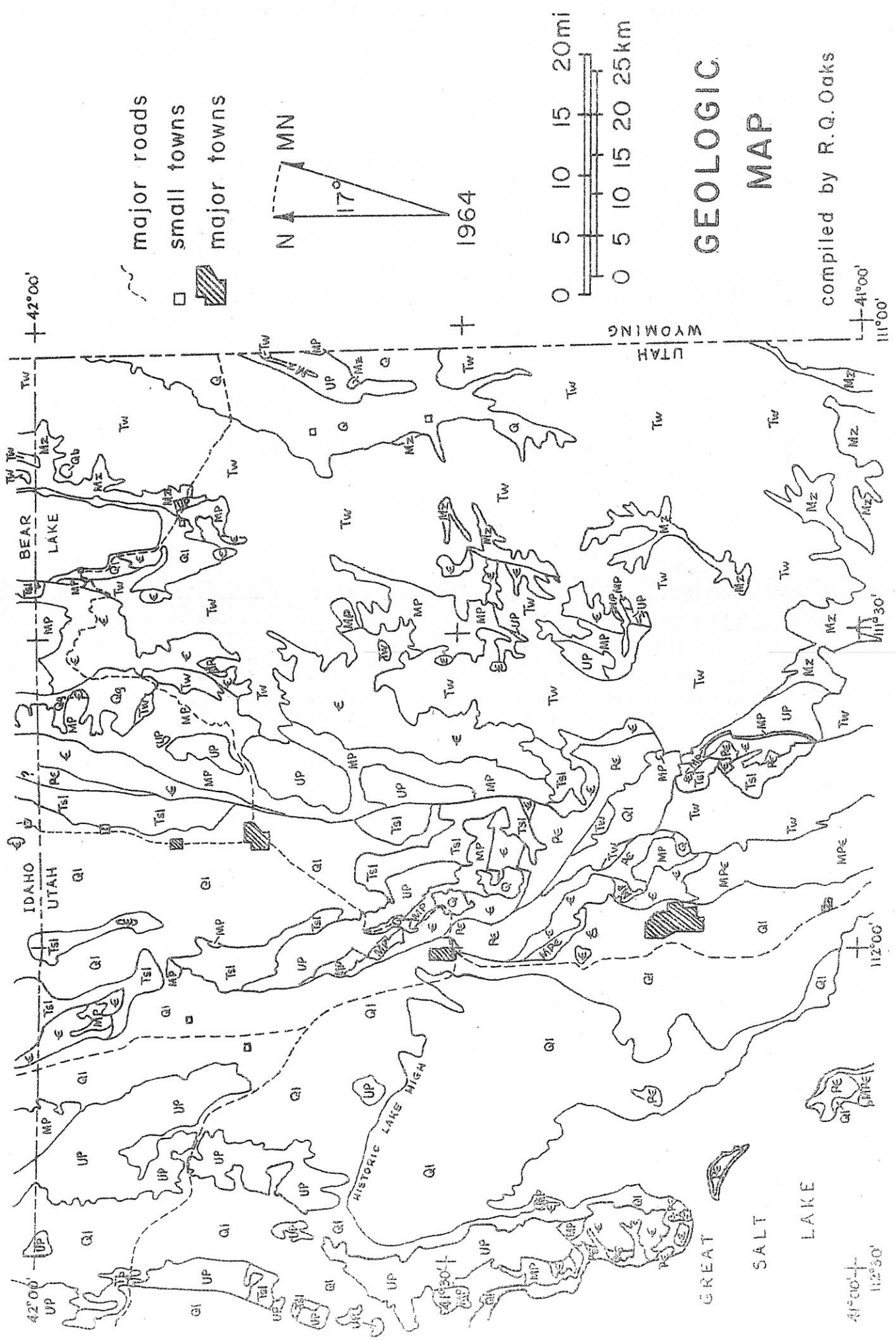
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113°30' +
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EXPLANATION

- Q alluvium, colluvium
- Ql lake and delta deposits (chiefly)
- Qg glacial deposits
- Qb basalt
- Tb basalt
- Tsl Salt Lake Fm.
- Tw Wasatch, Knight, Fowkes Fms.
- Mz Mesozoic
- UP Permo-Carboniferous
- MP Ordovician - Silurian - Devonian
- E Cambrian
- PC Upper Precambrian
- MPC "Older" Precambrian





(a form of gradual downhill movement of soil) and stone polygons occur nearby.

A synclinal fold (Logan Peak Syncline) follows the western ridge line of the Bear River Range from East Canyon northward through Logan Peak past Emigration Canyon in Idaho, where E-W faults disrupt the structure. Temple Ridge lies along the east flank of the Strawberry Valley Anticline and the west flank of the Swan Peak Syncline. By contrast, the Wellsville Range and the Wasatch Range farther south resemble a tilted block in which all the rock layers slope eastward or northeastward (homocline).

In lower areas within individual ranges solution valleys, sinkholes, caves, and springs (karst topography) are common in several limestone units, especially the Bloomington Fm., as in the Sinks area just east of Temple Ridge and west of Bear Lake Summit. Logan Cave and many other small solution caves are present in the Garden City Fm.

CONCLUSION

Without question the geology of the North Wasatch Country is varied, spectacular, and interesting for all who behold it, whether casual visitor or accustomed friend. The most important geologic messages to be found here are those of the enormous span of time, the imperceptible but gradual changes that occurred, the effectiveness of present processes in carrying out those changes given such lengths of time, the record of past environments like those of seas today, and the record of gradual, accumulated changes (evolution) shown by the fossils in the rocks.

LAKE BONNEVILLE AND THE BONNEVILLE FLOOD

(compilation from the literature)

The Bonneville shoreline is near 5080' at Red Rock Pass, 5100' at Preston, 5142' at Logan, and 5300' at the Promontory Range, where the lake was deepest. The Provo shoreline shows a similar decline northward in Cache Valley. Gilbert (1890) first recognized this anomaly, and suggested that the weight of the water depressed the Earth's surface. Where the water was deeper, the surface was depressed most. When the weight of the water was removed, the Earth's surface rebounded almost to its original position (isostasy). Those parts depressed most rebounded most, and this resulted in warped shorelines. Locally the shorelines also are offset by faults. Crittenden (1963), in a detailed study of the rebound, reported that continuing uplift for 1911-1958 was about 1 mm/year.

Many details of the Bonneville Flood and of fluctuations of Lake Bonneville have been determined during the past decade. Much remains to be learned. The Alpine, Bonneville, and Provo (Draper) formations, recognized by earlier workers beginning with Gilbert, were subdivided by Morrison (1965, 1966) on the basis of numerous minor lake fluctuations determined from studies near Delta, eastern Jordan Valley, Little Valley (Promontory Point), and elsewhere. These formations, interbedded with glacial moraines at Little Cottonwood Canyon (Richmond, 1964, Morrison, 1965) were correlated with Wisconsin glaciations, specifically Bull Lake (Alpine) and Pinedale (Bonneville and Provo). C^{14} ages of mollusc shells suggested the Alpine maximum was >37,000 years B.P., the Bonneville maximum about 20,000 to 18,000 years B.P., and the Provo maximum about 13,000 to 11,000 years B.P. (Broecker and Orr, 1958; Broecker and Kaufman, 1965; Morrison and Frye, 1965; Rubin and Alexander, 1960; Rubin and Berthold, 1961).

Gilbert (1890) believed that the Bonneville Flood occurred when the lake overtopped Red Rock Pass, and persisted until the pass was cut from the Bonneville level to the Provo level. Bright (1967) showed that lava flows diverted the Bear River from the Portneuf River Canyon near Bancroft, Idaho, southward into Gem and Gentile valleys, where Lake Thatcher (Main Canyon Fm.) formed to a level near 5445'. Mollusc shells from lake beds near the community of Thatcher yielded C^{14} ages of 27,000 to 33,000 years and organic material from soils beneath flood-corroded basalt, and a shell from lake beds impounded by basalt, both in Marsh Creek Valley, yielded C^{14} ages of 25,000 to 35,000 years and 32,500 years B.P. respectively (Malde, 1968). The level of Lake Thatcher, higher than any level of Lake Bonneville, suggests that no connection existed prior to 34,000 years B.P. through Oneida Narrows. Subsequently Lake Thatcher overtopped Oneida Narrows, which was cut prior to the Bonneville high stand, for lake shorelines of both the Bonneville and Provo levels are nested inside the Thatcher shoreline at the south end of Gentile Valley. The water overtopping at Oneida Narrows probably initially encountered easily eroded Salt Lake Fm. and downcut rapidly toward the (lower) level of Lake Bonneville. This rapid influx of water then raised the level of Lake Bonneville to the original lip of Red Rock Pass, where initial spillover probably occurred about 30,000 years B.P., based on a C^{14} age for molluscs from an alluvial terrace near American Falls believed younger than the maximum flood (Trimble and Carr, 1961).

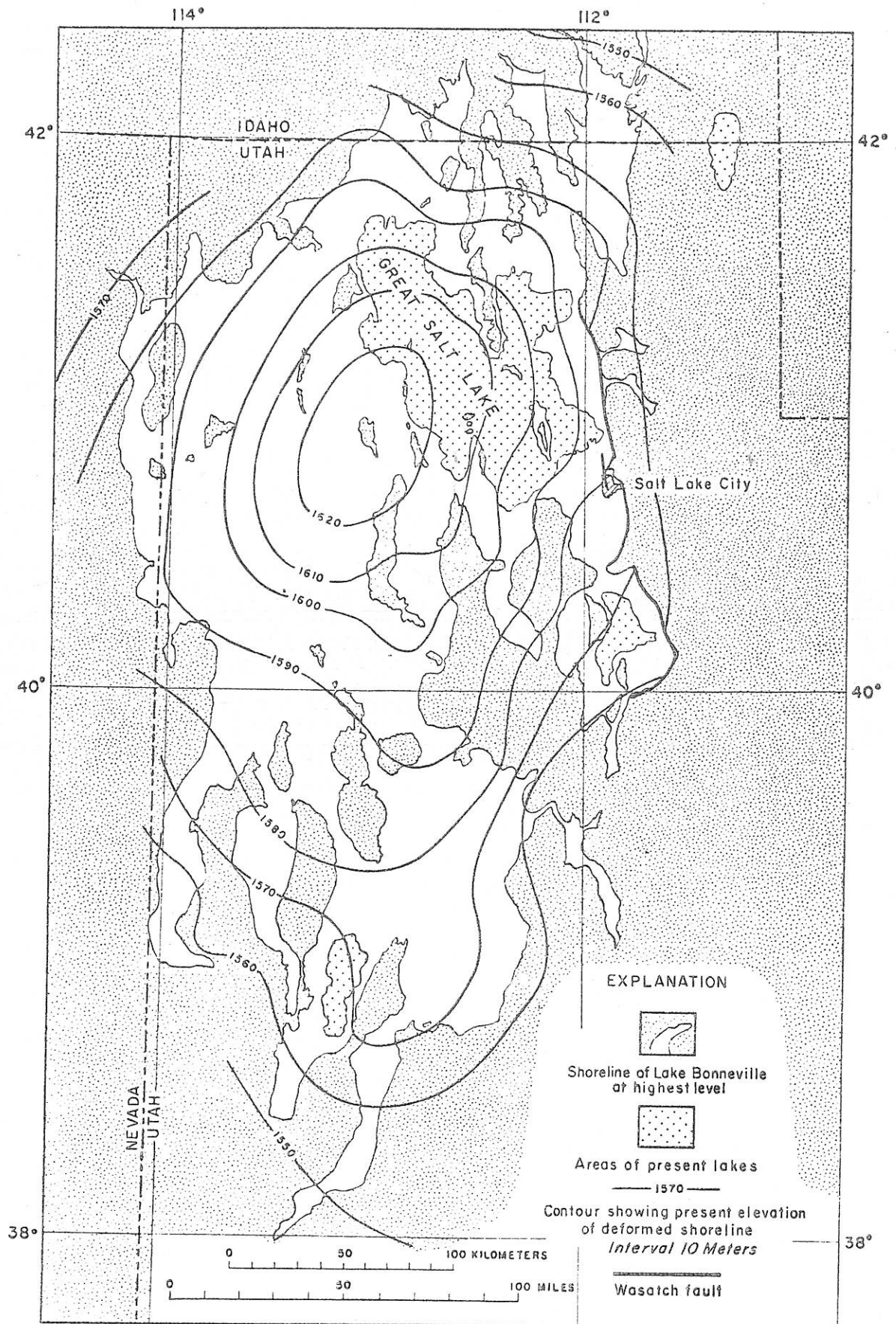


Figure 14. Map of northwestern Utah showing maximum area of Lake Bonneville and deformation of its highest shoreline. After Crittenden (1963). From King (1965), reprinted by permission of Princeton University Press.

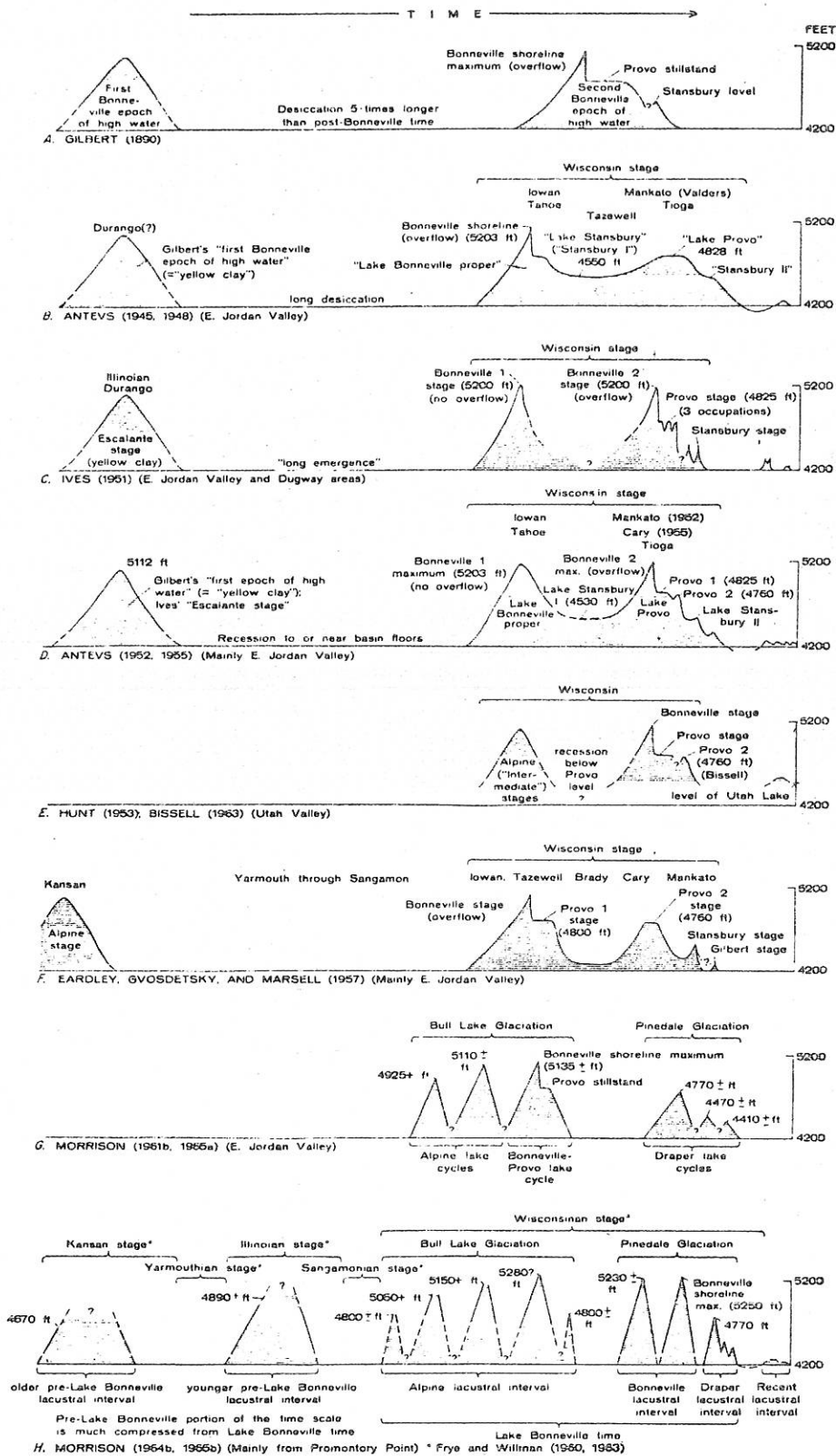
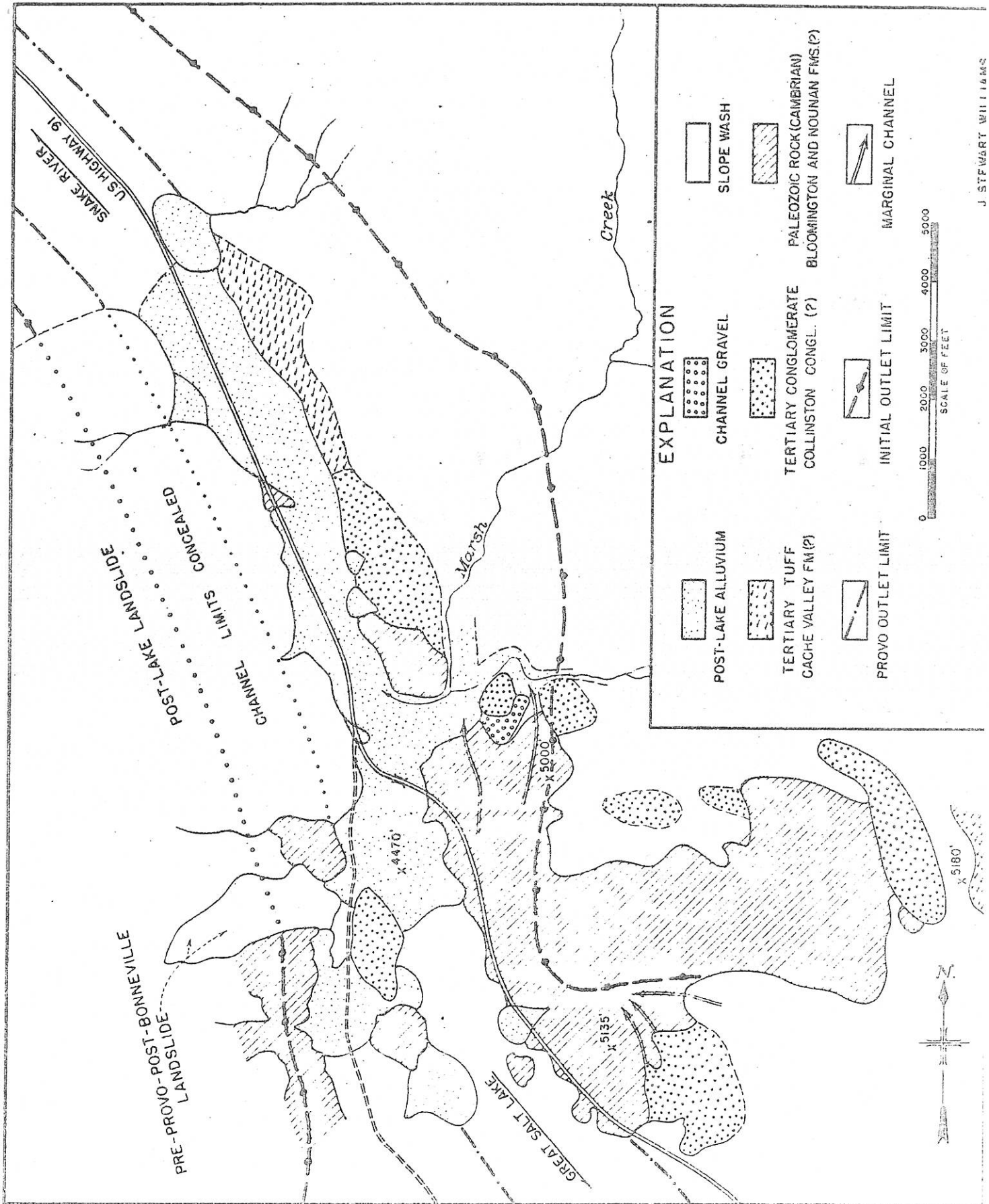


Figure 2. Interpretations of Lake Bonneville history by various geologists. Lake levels shown in graphs for E. Jordan Valley are average elevations west of the main Wasatch fault zone. From Morrison (1965), reprinted by permission of Princeton University Press.

Malde (1968) suggested the initial Bonneville Flood correlates with late Alpine time, a possibility considered earlier by Morrison (1965), who believed a second flood, during Bonneville time, also was possible but not proved. In any case, most of the excavation of resistant Cambrian bedrock in Oneida Narrows (800-1000 feet deep, 7 to 8 miles long) probably was accomplished when the level of Lake Bonneville fell between Alpine and Bonneville time, and no large, rapid influx of water to Lake Bonneville from Gem and Gentile valleys was possible thereafter.

Once Lake Bonneville overtopped Red Rock Pass, rapid downcutting probably removed surficial deposits and the Salt Lake Formation (perhaps as much as 100 feet) down to resistant bedrock near the Bonneville level. For lowering of Lake Bonneville by 100 feet at that time, Malde (1968) calculated a flood volume of 380 cubic miles. A calculated probable maximum discharge of $1/3$ cubic mile per hour near Swan Falls, S of Boise, permitted the flood duration to be computed as 6 weeks (all flow at maximum discharge) to more than 1 year if the maximum discharge was brief (Malde, 1968). The later prolonged stand at the Bonneville level probably reflects control of outflow by resistant bedrock, or a lake level slightly below the outlet. The lake level fell below the later Provo level, and a pre-Provo landslide (Maw, 1968) tore out the Bonneville shoreline just NW of Cutler Dam (Bear River Narrows). The lake then rose to the level of the pass (near, at, or possibly below the Bonneville level), and gradual downcutting of bedrock continued to the Provo level. Perhaps more resistant and/or unweathered bedrock was reached at the Provo level, for a protracted stand there produced the best-developed shoreline features of Lake Bonneville throughout most of the lake's extent.



ROAD LOG

by

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Mileage

- 0 Depart 8:00 a.m. from parking lot at NE corner of 1200 E 700 N, Logan, Utah. Proceed N on 1200 E. This is the surface of a delta built into Lake Bonneville at the mouth of Logan Canyon at the Provo level (4800') about 11,000 years ago. To the NE two scarps visible along the mountain front bound a W-sloping triangular-shaped surface. The surface is a pediment cut across lacustrine and fanglomerate beds of the Tertiary (Miocene-Pliocene) Salt Lake Formation. Both the pediment and its bounding scarps are dissected by coarse-textured drainage. The eastern edge of the pediment surface lies near 5800', its western edge, near 5500'. The base of the western scarp coincides approximately with the Bonneville shoreline (about 18,000 years ago), near 5142'. Both probably are fault-line scarps. That on the east marks the East Cache Fault, a gravity ("normal") fault of large displacement (5000 to 10,000 feet) which intersects the west limb of the Logan Peak Syncline at a low angle in such a way that older rocks appear successively along the mountain front northward (Mississippian at East Canyon, Devonian at Blacksmith Fork, Ordovician at Logan Canyon, Cambrian at Smithfield Canyon, Precambrian at High Creek).
- 1 The escarpment just N of the USU apartments marks the edge of the delta, and reflects the angle of repose of gravels in foreset beds modified but slightly by subsequent slow mass movements. Note the scarcity of gravel and the well-developed soil in thin loess at the top. This loess thickens to 5 feet in the borrow pit just N of 1400 N. Note the presence of deltas and alluvial fans at mouths of most canyons in this area.
- Turn left (W) at 1400 N, and proceed to U.S. 91. View WSW to Wellsville Mt. (Pennsylvanian - Permian Oquirrh strata dip NE). View W across Cache Butte Divide (Salt Lake Fm. and deposits of Pleistocene Lake Bonneville surround outliers of Middle Paleozoic strata that dip W). View WNW to Clarkston Mt. (Gunsight Peak) at S end of Malad Range (Cambrian, Ordovician, Silurian strata dip NE). The Bear River apparently was superimposed on bedrock of the Cache Butte Divide at the Bear River Narrows (Cutler Dam) from an unconformable overlying cover of Salt Lake Fm., remnants of which today reach 2/3 of the way up Wellsville Mt. and Clarkston Mt. View WNW to Oxford Peak, N end of southern segment of Bannock Range, E of and in front of Malad Range, and just SW of Red Rock Pass. Cross-axial streams that cross the Logan Peak Syncline (Logan River, Blacksmith Fork, East Fork of Little Bear River) appear to have been superposed from the Wasatch Fm. and are much older in origin than the Bear River at Cutler Dam.
- 2.5 Turn N on U.S. 91. View E to Bear River Range (Precambrian through Pennsylvanian strata dip E into Logan Peak Syncline). View SE to USU campus atop flat-topped delta. View NE to pediment surface noted earlier. We will see many similar pediment surfaces cut across the Salt Lake Fm. farther north.

Mileage

They also are widespread at the south end of Cache Valley and in intermontane valleys in central Idaho. Presumably they formed as once-extensive erosional surfaces graded to local base levels without drainage to the sea, possibly under more arid conditions than exist today. All these surfaces pre-date Lake Bonneville. They have been affected by erosion and by continued Basin-Range tectonics.

7-9

U.S. 91 rises northward onto the alluvial fan upon which most of Smithfield is situated. This fan was built by the stream of Smithfield Canyon (Summit Creek) after the fall of Lake Bonneville below about 4450', approximately the lower limit of the fan. Possibly the fan forms a veneer on an older fan or even a delta built into Lake Bonneville. The fan is nested in the breach through a delta built at the Provo level (visible eastward near 100 N in Smithfield). Coarse-grained nearshore lake sediments are encountered at approximately 200 N. Gravel pits both E and NE of town are in deltaic foreset beds west of and lower than the upper surface of the delta but higher than the upper surface of the fan, evidence of simultaneous entrenchment of the Provo-level delta and deltaic redeposition of the sediments as the lake level fell. A similar mini-delta is present in Logan as remnants flanking the Logan River as far W as the LDS Temple. One well west of Smithfield near the center of Cache Valley encountered Paleozoic bedrock near 3200' beneath the present valley floor of about 4450' (Williams, 1962). The crest of Mt. Logan, near 9720', suggests at least 6500' of offset along the East Cache Fault.

9.5

A linear spit of sand and gravel lies along the W face of an escarpment of the Salt Lake Fm. Cross-stratification in the borrow pit here indicates a southward direction of wave-driven currents, an observation consistent with evidence from many other wave-built features within Lake Bonneville.

10

Northward the road crosses the Salt Lake Fm., which forms Crow Mt. and surrounds and largely covers outliers of Cambrian bedrock, chiefly Brigham (Tintic) Fm. Galloway (1968) and Mendenhall (in prep.) have established that many of these outliers are parts of gigantic glide blocks that have slid into the valley along surfaces of earlier Laramide high-angle thrust fault when support for these rocks was removed by downfaulting of the valley. Wave-cut shorelines in the readily eroded Salt Lake Formation are prominent northward where that unit occurs widely below 4800'.

14-15

The road rises again at Richmond, yet this community lies on the interfluvial (divide) between two streams, City Creek and Cherry Creek, on a bedrock spur of the highly tuffaceous Salt Lake Fm. As a result of the impermeable nature of the Salt Lake Fm., residents of Richmond have encountered difficulty in obtaining adequate culinary water and in construction of leak-free basements and of sanitary facilities. The 1962 earthquake (5.7 Richter scale), centered about 7 miles east of Richmond near Tony Grove Lake and Mt. Naomi, caused considerable damage in Richmond and nearby, Utah's most destructive earthquake so far (Cook, 1972).

16-17

Just NE of Richmond a southward-pointing gravel spit lies just below the Provo level, and a distinct combolo spit near the Provo level connects Cove Mt. (just N of High Creek) to higher areas in the NE. Westward the view is across a W-facing escarpment 40 feet high cut by the Cub River. Also in this area are several well-developed recessional (wave-cut) shorelines below the Provo level.

Mileage

- 19 Elongate, lobate shape of Franklin Ramp in NE. Stone stripes mark steeper slopes up to 100 feet high along the sides of this feature, and also are present but less distinct on the upper surface. This nearly planar upper surface slopes westward from near 5800 feet at the mountain front to near 4500 feet near the toe. Southard and Williams (1970) have established that this feature is a diamicton (mixed sizes, unsorted) consisting largely of Precambrian quartzite boulders from the hills above, reworked to form the Mink Creek Conglomerate Member of the Salt Lake Fm., seen in the foothills on either side of the Franklin Ramp. This mass appears to have flowed laterally westward, unlike its pediment-capped neighbors in the foothills both N and S. The exact mechanics of the movement is uncertain. Possibly this feature represents a previously unrecognized type of mass movement. The Bonneville shoreline is broken by this feature, and the Provo shoreline, if present at all, is only weakly developed. The surface materials apparently are still creeping downhill on a montmorillonite-rich clay B-horizon of an old, well-developed soil, and this continued movement presumably has destroyed or effaced all Bonneville shorelines cut across this presumably old (but post-pediment) surface. Interestingly, the stripes are lower, drier, less vegetated areas that Southard and Williams believed formed by flushing of fines along drainage lines by springtime runoff beneath winter snowpack (a process that continues today), rather than by periglacial freeze-thaw phenomena during the Pleistocene.
- 20 Idaho State line.
- 21 Franklin. Note separation of toe of Franklin Ramp into two lobes.
- 22-23 Road descends river-cut scarp of Cub River, crosses the floodplain, and climbs the opposite scarp. Both scarps are about 25 feet high, the distance the Bonneville lake bottom lies above the modern floodplain. Smart Mt., just W of the road, is an outlier of Cambrian and Ordovician carbonates.
- 23-26 Northwestward the road rises gradually but steadily as it pulls away from the valley margin, then flattens out about 4800' near Preston. To the SW a low ridge is visible near the valley center along the course of the Bear River. This levee-like ridge consists of sediments stripped from the axis of the Preston delta as Lake Bonneville fell from the Provo level, i.e., erosion occurred upstream as base level fell, deposition occurred immediately downstream where the river encountered the new lake level.
- 26-28 Preston, Idaho, sits atop a huge delta built by the Bear River at the Provo level. The Bear River brings about one-third of the total annual runoff of 1.5×10^6 acre feet received by Great Salt Lake (Peck and Richardson, 1966). The Bear River built a correspondingly large delta into Lake Bonneville, perhaps exceeded in size and volume only by the delta at Ogden built by the combined Ogden and Weber rivers. Most of the sediment is fine grained (sand, silt, and clay, derived from the Wasatch Fm. in part), in contrast with smaller, gravel-rich deltas built at canyon mouths farther south in Cache Valley. Eastward and northward remnants of a much smaller, higher delta built at the Bonneville level are visible, flanking foothills of the Salt Lake Fm.

Mileage

- 28 Turn W on U.S. 91 at N end of Preston.
- 30-31 Preston International Airport on S (left). Road drops about 75' where it crosses a river-cut scarp and terrace below the Provo level, then turns N and descends another 200' along a steep scarp within slump topography (E-sloping surfaces, undrained sag ponds: closed depressions), to the modern floodplain of the Bear River. Eastward along the crest of the river-cut scarp of the Bear River are numerous steep, curving slump scars. Chaotic, lobate terrain of earthflows characterizes the base of the scarp. Hot springs occur along the Bear River 1 mile W of the river bridge. Small terraces within the floodplain are visible eastward.
- 32-33 Road rises nearly 300 feet to a planar surface at the same level (Provo) as Preston. Eastward, remnants of the delta built at the Bonneville level, with a planar upper surface near 5100', are separated from the Provo surface by an irregular, subdued scarp. Oneida Narrows of the Bear River is only 8 miles upstream.
- 33 Stop 1. Pull off on shoulder of road just beyond crest of hill. Brief stop to view and photograph slumps and earthflows. Fresh scarps on N side of river began forming in 1969 when 5 feet of offset were measured. Note that the Bear River is actively involved in undercutting along the S side of its valley, thereby triggering slumps and earthflows that in turn divert the Bear River away from the valley walls. Also, contrast the relative instability of fine-grained sediments along steep scarps here with the relative stability of much coarser grained gravels along steep scarps of the Logan River.
- 33-36 Northward the road traverses the partly dissected surface of the Provo delta. This delta built northward as sediment backed up east of Clifton Hill (Little Mt.) and apparently spilled northward around that impediment. This mass of sediment essentially blocked drainage upstream along the present course of Deep Creek, and the area to the north has remained marshy from the time of withdrawal of Lake Bonneville until the present (Bright, 1966). Elsewhere, evidence of a warmer, drier period about 4000 to 8000 years ago (Hypsithermal) is abundant; one example is the series of now-inactive post-lake alluvial fans in the side canyons tributary to Logan Canyon.
- 36 Banida. View NW to Oxford Peak which consists of Precambrian and Cambrian strata dipping northeastward (Raymond, 197, Shearer, in prep.). The rocks occur within two separate thrust sheets (or "plates") that traveled horizontally eastward during Laramide deformation. These thrust plates have since been broken and offset varying amounts along gravity (normal) faults that trend approximately N-S and E-W. In most cases the N-S faults are older and parallel to the Basin-Range normal faults that bound these local ranges. As Cache Valley narrows and rises northward, planar pediment surfaces on the Salt Lake Fm. are visible flanking the mountains and sloping into the valley. These surfaces are transversely dissected by streams from the mountains and terminated valleyward by abrupt fault-line scarps modified by later wave action. If these surfaces are projected into the valley they intersect above the present valley bottom which is near 4750'.

Mileage

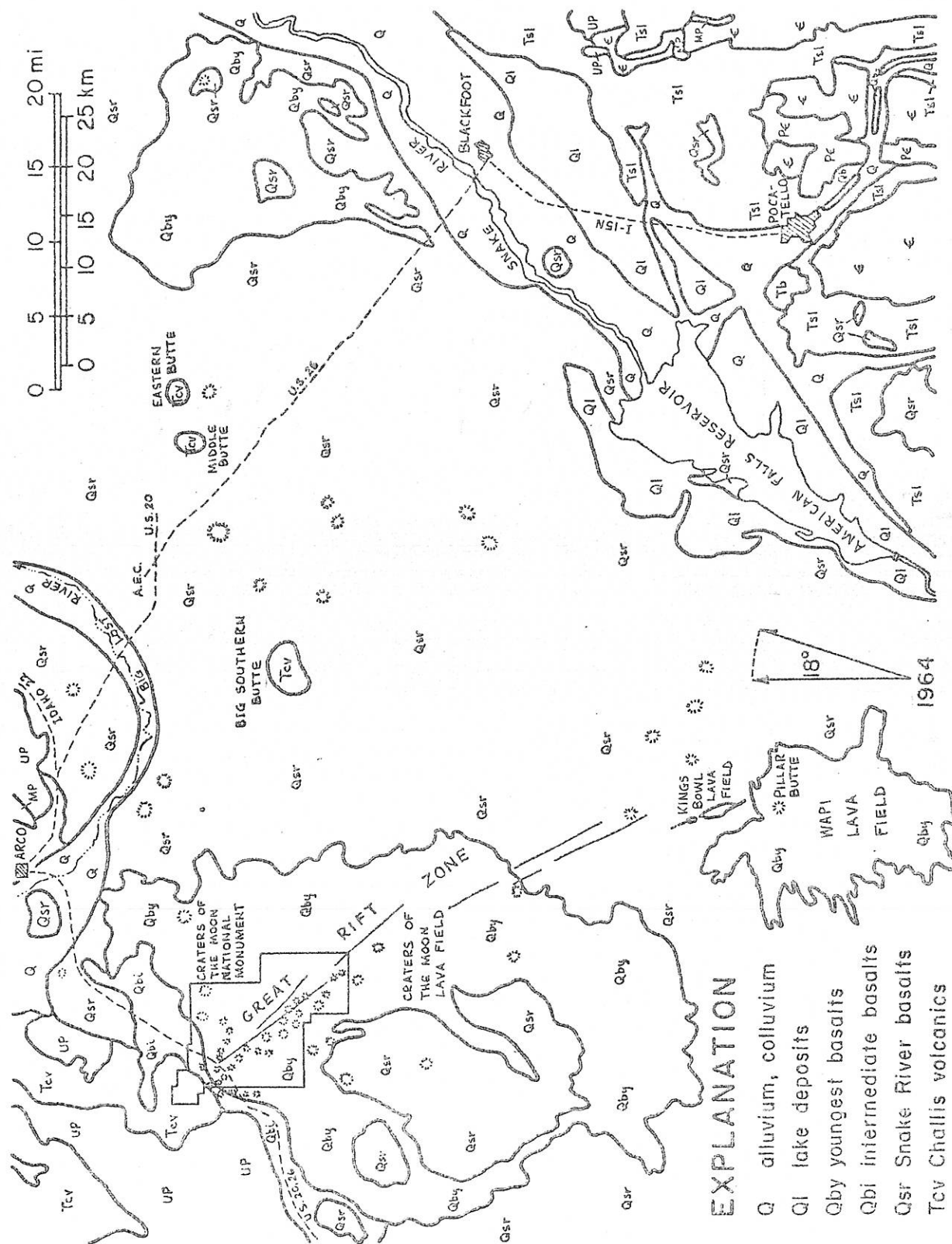
- 40 Swan Lake, altitude 4770'. Bright (1966) reported that pollen in a core 9.55 m long from Swan Lake showed no apparent break in deposition since at least 12,100 years B.P. (before 1950: C¹⁴ dates), although vegetation has risen about one zone during this time. No evidence for dessication during the Hypsithermal was noted.
- 49 Stop 2. Red Rock Pass, north end of Cache Valley. Pull off on side road to N just before highway bridge. Drivers unload vehicles at second curve, then proceed about 100 yards to turn around. Climb to top of small hill. This pass was recognized by Gilbert (1890) as an outlet for Lake Bonneville. It was long considered the only outlet for the lake (e.g., Malde, 1968, p. 9), but recently Mabey (1971) has proposed that northward outflow may once have occurred via Oneida Narrows and the Portneuf River. In any case, Lake Bonneville overtopped Red Rock Pass at least twice and at least one enormous flood poured down the valley of Marsh Creek to the Snake River (Malde, 1968). The Bonneville shoreline here is now near 5080'; the Provo shoreline, near 4750' (Gilbert, 1890). The present low point in bedrock beneath the pass is about 4755' (Williams and Milligan, 1968). Bedrock in the E-W ridge that forms the constriction at the S end of the pass has a high point at its east end near 5560' with a second low near 5180' about one mile farther east, through which overflow apparently did not occur. The pass is about 4300' wide at the Bonneville level, and about half that wide across the floor of the pass. A rather flat bedrock surface with nearly the width of the floor of the pass is present beneath the pass through a distance of nearly 2 miles from N to S, parallel to the strike of the rocks, which dip between 30° and 60° eastward. Middle Cambrian Bloomington Fm. (limestone, shale) underlies most of the pass, with the overlying Upper Cambrian Nounan Fm. (dolostone, limestone, minor sandstone) beneath the eastern part of the pass. Along the east margin of the pass is a prominent erosional scarp cut into the Salt Lake Fm. Above this scarp is a planar erosional surface and yet another erosional scarp (better seen farther N). Large, hummocky, chaotic landslide masses as much as ¼ mile across are present along the west side of the pass through 1½ miles. Return to main road and proceed north.
- 50 Red Rock Pass Monument, just N of RR overpass. Northward the extensive pediment surface on the Salt Lake Fm. is visible to the NE above the two erosional scarps. Presumably the higher scarp and the terrace below it are related to initial overtopping and outflow of the Bonneville Flood, the lower scarp to subsequent lower discharges.
- 53 Downata Hot Springs at base of foothills to W.
- 55 View W across entrenched valley of Marsh Creek. The valley itself exhibits broad meanders. Within the flat valley bottom flows a tiny stream with sinuous, closely spaced meanders, clearly incapable of cutting the existing valley. The drainage system from Red Rock Pass to this point is so small that sufficient runoff from increased rainfall would not be adequate to erode this wide, meandering valley. Runoff from the overflow of Lake Bonneville at Red Rock Pass during downcutting to the Provo level is the suggested cause.
- 57 Downey (altitude 4950').

Mileage

- 59 Intersection with I-15 N, the major road from Salt Lake City to Idaho Falls and Yellowstone. View NNW to Mt. Tom in S part of northern portion of Bannock Range. Upper Precambrian strata form the core of this range from Scout Mt. farther N to the area of Garden Creek Gap, south of Mt. Tom, where beds are vertical to overturned.
- 62 Headwaters of entrenched tributary to Marsh Creek occurs just W of road, opposite large grain storage bins. View NNE to Haystack Pk (front) and Bonneville Pk (behind), in Portneuf Range, opposite Bannock Range. Portneuf Range is a faulted homocline in which Cambrian through Silurian strata dip eastward.
- 66 Road dips down into entrenched valley of Marsh Creek just before Arimo exit.
- 68 Marsh Creek pulls away to W as the road comes onto the first lava flows (basalts). These basalts exhibit irregular vertical cooling joint surfaces commonly coated white by calcite, a product of weathering. Large vesicular holes are readily visible where gases were entrapped during cooling of the lava. Locally loess has accumulated in the vertical joint openings, more rarely, on the surface. The lava flowed down the Portneuf River Canyon from the area of Lava Hot Springs and Portneuf Valley, spilled into Marsh Valley and flowed downstream almost to Pocatello. Part of the lava backed up Marsh Valley to this point.
- 70 Lava Hot Springs exit (U.S. 30 N). Pull off on exit ramps to view well-developed pediment remnants that flank both sides of the valley. Proceed on I-15 N. After the lava filled the old stream course, the Portneuf River became established to the E, and Marsh Creek became established to the W. These two streams remain separated by the lava flows for 10 miles downstream, nearly to Inkorn, before they join.
- 76 Recreation area with shelters and sign about lavas. This is a fenced area unsuited for easy access and study of lava flows. Note that lava flows clearly follow the valley here: fluids seek the lowest topography.
- 82 Inkorn area. Road drops into entrenched valley of Portneuf River just before it turns W to join Marsh Creek. In bluffs along the right side of the road note lava flows interbedded with river gravels. Remnants of lava flows are present on both sides of the valley here, and probably originally filled the entire valley bottom. Some flows are very thick (25 to 40 feet) and exhibit columnar jointing and large vesicles. Huge quarries are cut in Cambrian carbonates (Portland Cement) along the S (left) side of road where the road and river valley turn west at the north end of the Bannock Range. Pocatello Range forms the north wall of the canyon here. Malde (1968) pointed out that the narrow canyon here formed a constriction to flow of the Bonneville Flood, so that flow in the broad valley upstream probably was tranquil, and left less evidence than seen farther downstream, below this canyon.
- 84-90 Long, steep slopes along south are ideal for rock slides; some rather recent ones are clearly visible. Locally, horizontal creep terraces ("cow-touring") are also present. The strata dip steeply eastward and locally are overturned. Precambrian quartzites underlie Cambrian quartzites westward along both sides of the road. The road rises through two remnants of the lava flow, one near the truck weighing station, the second near the W end of the canyon.

Mileage

- 91 West of the Pocatello and Bannock Ranges, the road turns north and rises out of the canyon.
- 95-98 Pocatello (altitude 4477').
- 96 Idaho State University exit. Excellent view into broad plain N of Pocatello, where three large volcanic cones are visible. Two of these cones consist of Tertiary (Pliocene?) rhyolitic flows and ejecta, the other of basalt, each formed prior to widespread eruption of basalts during the Quaternary. The latter basalts formed the Snake River Basalt Plateau, chiefly by eruptions of widely spreading, flat-lying flows from elongate fissures. View NW to Big Southern Butte, 36 miles away. Cedar Butte, much lower, occurs just NE of BSB. Middle Butte and Eastern Butte are visible 17 miles NE, close together. Several low volcanic domes, formed by intrusion of basalt from beneath, occur throughout the basalt plateau.
- 102 Flats of Quaternary alluvium and loess are flanked to the east by low hills of Salt Lake Fm. (Payette Fm.)
- 107 Just S of Ross Fork and Fort Hall (headquarters of ^{Bannock-Shoshone} Blackfoot Indian Reservation road passes onto fine-grained, flat-lying Quaternary lake beds deposited along both sides of the Snake River downstream to American Falls, a knick point formed by basalt lava flows that formed a natural dam.
- 114 Road passes from lake deposits to Quaternary alluvium deposited along the Snake River.
- 119 Take second exit in Blackfoot (altitude 4488'), at sign for Arco, Idaho. Exit on right, proceed to stop sign, then turn W (left) on U.S. 26.
- 120 Snake River.
- 121 Danskin Canal.
- 123 Just before the community of Moreland, the road leaves Quaternary alluvium of Snake River and enters vegetated basalt flows. Relative ages of flows can be determined readily from the degree to which original topography is subdued, degree of soil formation (and loess cover), and degree of vegetative cover.
- 124 Aberdeen Canal.
- 125 N-S ridge of rather recent ropy (pahoehoe) basalt flows. Contrast this fresh-appearing area, with its pressure ridges, large cracks, squeeze-ups, and collapse features, to the subdued topography of the surrounding area. Middle and East Buttes appear ahead to the right of the road, with Big Southern Butte and (lower) Cedar Butte to the left of the road. Cedar Butte is a good example of a tuff cone. It has been partly excavated for road-bed materials. Due to bedding surfaces, fractures, cooling joints, lava tunnels, etc., the basalts of the Snake River Plain are very permeable. Cultivation requires a soil 4 to 8 feet thick (derived by residual weathering and/or accumulation



EXPLANATION

Q alluvium, colluvium

Ql lake deposits

Qby youngest basalts

Qbi intermediate basalts

Qsr Snake River basalts

Tcv Challis volcanics

Tsl Salt Lake Fm.

Tb basalt

After Parsons (1968),
Stearns and others (1938)

GEOLOGIC MAP

Mileage

of loess) to slow infiltration, plus copious irrigation, generally available from deep wells that reach the water table. Note pumps here and there near cultivated fields.

- 131 Small basalt ridges and hummocks. Roadcuts expose thin loess cover on flows, caliche coatings of fractures, numerous vesicles.
- 135 Ground surface rises as road enters low, rolling topography.
- 139 Crest of rise. Small, low basaltic cinder cone in SW (left).
- 142 Low area: closed depression. Road bends to left as it begins to rise again. East and Middle Buttes to the NE (right) are also known as the Twin Buttes, although Middle Butte is composed of basalt whereas trachyte, pumice, and minor obsidian comprise East Butte. Both are approximately 2 miles in diameter, rise about 1000 feet above the surrounding plains, and consist of bedded volcanics that dip steeply southward. Although East Butte probably is a remnant of a volcanic vent or dome, the origin of Middle Butte is enigmatic (Parsons, 1968).
- 145 Small basaltic cone in SW (left).
- 148 Cedar Butte in SW (left).
- 152 Intersection, join U.S. 20. Turn W (left).
- 156 NRTS (AEC), opposite Big Southern Butte. Big Southern Butte, 3 to 5 miles in diameter, rises almost 2500 feet above the surrounding plains, and is centered 17 miles WSW of Middle Butte, 23 miles SE of Arco, due E of Craters of the Moon National Monument. It consists primarily of glassy, pumice-rich rhyolitic flows, although basaltic flows are present in lesser amounts (Stearns, Crandall, and Steward, 1938). No central crater is present, presumably due to subsequent erosion.
- 160 Cross Quaternary alluvium and Big Lost River. Note small discharge in this downstream segment, which disappears entirely 15 to 20 miles NE. Headwaters of this stream rise more than 80 river miles away in the Pioneer Mountains near Trail Creek Pass, and considerable runoff from the well-watered Pioneer and Lost River Ranges is added along its course. Then the river enters basalt terrain and loses its water downward through its bed. Stearns, Crandall, and Steward (1938) suggested the water reappears farther south as numerous springs along the canyon of the Snake River, especially at Thousand Springs west of Twin Falls.
- 166 Carboniferous strata exposed in Arco Hills are complexly folded and faulted. In Deadman Canyon, to N, dip is NE.
- 168 Intersection, Idaho 22 joins up. Sharply folded syncline in Carboniferous strata to N near major fault just to W.

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- 172 Butte City. Ridge to NE contains 150' (estimated) of (?) Cambrian quartzite, 23' of Lower Ordovician dolostone, and 326' of Middle Ordovician (Kinnikinic) quartzite, overlain by Fish Haven (U. Ord.) and Laketown (U. Ord.-Sil.) (James, 1973). The Kinnikinic is much thicker northward (2285' at Meadow Lake in the Lemhi Range), and southward the correlative Eureka Member of the Swan Peak Fm. is more than 1200' thick (Bob Smith Canyon in the Portneuf Range). This evidence and the thinness of (?) Cambrian and Lower Ordovician strata above the Precambrian Swauger Fm. led James (1973) to propose the existence of an E-W or NE-SW-trending Arco Arch active in this area during Cambrian and early Ordovician time. Continued work by Wakeley (in prep.) and by Bircher (in prep.) indicates a northern source of feldspar and quartz for the Upper Cambrian Worm Creek Member of the St. Charles Fm. in the Bear River Range.
- 175 Stop 3. Arco (altitude 5326'). Gas-and-rest stop. Those desiring evening reservations check in now at the Arco Motel, Idaho Motel, Riverside Motel, Lazy Motel, D-K Motel, Dee Hotel, or Arco Hotel and Bar. Those without lunches may want to obtain sandwiches. Turn S (left) on U.S. 20, 26, 93A, and Idaho 22.
- 177 Big Lost River again, this time about 20 river miles upstream. Note that flow is much greater here than downstream. Recent (dark) lava flows visible to W (right).
- 182 Road bends left; it is situated on older flows and follows west edge of intermediate-age lava flows. Timbered Dome Peak, to the W, rises to 8355', and consists of Tertiary (?Miocene) Challis volcanics, chiefly andesites and other intermediate igneous rocks that flank the east side of the Cretaceous Idaho Batholith 50 miles W.
- 185 Road follows contact between older flows and intermediate-age flows.
- 188 Road crosses onto intermediate-age basalt lava flows. Note pressure ridges and depressions.
- 192 Boundary of Craters of the Moon National Monument.
- 195 Bypass entrance to Monument headquarters. Note large blocky (aa) flow to W (right), scarp along road to E (left).
- 196 Stop 4. Pull off on E (left) in first parking area. Carefully cross road and climb NE flank of Grassy Knoll to first plateau. View NE into Sunset Cone. Lobe of recent aa flow ("Highway Flow") from North Crater in foreground, offset by a fault just E of road. Note that this lobe appears to have flowed uphill. The steep margin is 25' to 50' high. It is flanked in W by two small spatter cones. View ESE to huge gap in W side of North Crater, where crater walls collapsed and were carried away as enormous chunks called monoliths. View S to Silent Cone. Between this and North Crater are recent lava flows (from Big Craters) contained within lava levees. Big Craters are aligned along the Great Rift Zone, a NW-SE fracture zone that controlled much of the volcanic activity in this area (Stearns, 1963; Stearns, Grandall, and Steward, 1938; Murtaugh, 1961).

Mileage

Grassy Cone, like Sunset Cone, is a cinder cone. The activity exhibited by North Crater is typical, with a cinder cone built first, followed by eruption of lava. At Grassy Cone and Sunset Cone, both of which are older than North Crater (Murtaugh, 1961), later eruptions have concealed their related flows except locally N and NW of Grassy Cone and N of Sunset Cone. Note striking contrast of younger flows against older flows in the distance to the E. Return to cars and proceed to Monument headquarters.

- 197 Stop 5. Monument headquarters and exhibit. Lunch. Topographic maps of the monument, literature, and photos may be purchased here. Reservations for campsites must be placed at this time if you plan to camp here tonight. Proceed past campground to first parking area on right.

- 197.5 Stop 6. Devils Sewer area. Trail goes past ropy (pahoehoe) lava (North Crater Flow) with pressure ridges, lobate squeeze-ups, collapsed lava tubes, and the tripla-twist tree (limber pine postdates most recent pahoehoe flow, yielded age of about 1350 years to dendrologists at Univ. Arizona - Murtaugh, 1961). Monoliths (crater-wall remnants) are present in an older block flow (Unnamed Flow 1 of Murtaugh, 1961), in which the remnants floated away from North Crater. The monoliths here are also kipukas, older features that stand above younger flows that completely surround them, in this case the younger pahoehoe flow of North Crater.

Proceed along base of North Crater and Paisley Cone, both composed chiefly of cinders and among the youngest features in the Monument (and Snake River Plain). Note numerous large kipuka monoliths to E in Unnamed Flow 2 and Devils Orchard Flow.

- 199 Right-hand fork (one-way) follows the depression between Paisley Cone and Inferno Cone, another large cinder cone.

- 200 Stop 7. Snow Cone. Large spatter cones here, along Great Rift Zone, can be viewed (and photographed) best from top of trail up flank of Big Craters just to N. Individual spatter cones incorporate various types of bombs, including breadcrust, spindle, and pancake (cow-dung bombs of Murtaugh, 1961), in order of increasing water-vapor content and softness when they hit. Evidence of backflow along the inside of vents is clear.

Road traverses base of Inferno Cone.

- 201 Right fork crosses Crystal Fissure Flow and then Lava Cascades Flow. The latter contains a large collapsed lava dome at its SW end, just W (right) of the road, with a nearly continuous fracture along its rim. Individual pahoehoe lobes flowed E and NE from the collapsed dome. On the N flank of Broken Top, where the road turns E, not all the darker (moist) units are convincing as paleosols, the interpretation given in the sign.

- 201.5 Stop 8. Parking area, Broken Top. Trail to SW to tree molds successively crosses cinders of Broken Top, aa lava of Crystal Fissure Flow, cinders flanking Big Cinder Butte (one of world's largest cinder cones), and pahoehoe lava of Blue Dragon Flow. The latter issued from a vent near Great Owl Cavern (lava tube at the trail fork near the spatter cone, or hornito), and enveloped a forest in the area to the S. Casts of both vertical and horizontal tree trunks several feet long are common.

- Mileage Murtaugh (1961, p. 52) pointed out that only the horizontal molds have a surface pattern that resembles impressions of tree bark, whereas such patterns are absent from the smooth vertical molds. The Blue Dragon Flow has a distinctive, glassy iridescent-blue crust, first recognized by Russell (1902). Return to cars and to one-way loop road.
- 202 One-way road continues to follow cinders along base of Inferno Cone.
- 202.5 Stop 8. Turn right to parking loop. Bring flashlights and lanterns. For the first 100 yards the trail crosses the Crystal Fissure Flow, then enters the Lava Dome Complex Flows, primarily pahoehoe. Here we can see numerous details of pahoehoe flows including: (1) sharkskin (minute vertical spines about 1 mm high caused by escaping gas bubbles); (2) festoons (curving ridges and troughs buckled up during cooling as the lava beneath moved forward, and convex in the direction of movement); (3) blisters and small tubes; (4) rafted slabs; (5) pressure ridges (elongate) and tumuli (round); (6) squeeze-ups, some with grooved surfaces; (7) collapsed lava domes; (8) iridescent crusts; and (9) lava tubes or tunnels. Within lava tunnels (Indian Tunnel, Boy Scout Cave, Beauty Cave) and collapsed lava domes (Natural Bridge, Needles Cave, Last Chance Cave) are lava stalactites, terraces left by subsiding lava, waterholes and/or ice, and dangerous, loose roof blocks. We will first visit Indian Tunnel, which is reasonably open and safe. At that point the field trip will officially terminate, and those who wish to continue to more hazardous caves may proceed further. Last Chance Cave is not too bad, but Surprise Cave and some of the others should be entered only with great caution.
- 203 Main Monument road, turn right.
- 204 U.S. 20, 26, 93A, Idaho 22. Turn right to Arco or turn left to Richfield, Shoshone, Idaho Falls, and Burley. Although farther to Logan or Salt Lake City, the Idaho Falls - Burley route follows part of the path of the Bonneville Flood. In Arco there is a restaurant 1 block south of the stop light and another 1 block east of the first.
- 399 Logan, Utah.

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The generalized geologic map covering Idaho south of Pocatello was derived from Utah State University M.S. theses by Prammani (1957), Murdock (1961), Axtell (1967), Wach (1967), Davis (1969), Raymond (1971), and Shearer (in preparation); Idaho State University M.S. theses by Holmes (1958), Storey (1959), Schwarze (1959), Nalwalk (1959), and Merk (1967); Ph.D. dissertations by Ludlum (1942, 1943; Cornell), Coulter (1952?, 1956; Yale), and Beus (1963; U.C.L.A.); U.S. Geological Survey maps by Oriel (1968 open-file report), Oriel and Platt (1968 open-file report), and Armstrong (1969, map I-557); and the geologic map of Idaho by Ross and Forrester (1947).

The generalized geologic map covering Utah north of Ogden and Kaysville was derived from the geologic map of Utah by Stokes (1961, NW Quarter), and Stokes and Madsen (1961, NE Quarter), modified by maps by Mullens (1969, map GQ-790) and Crittenden (1972, map GQ-968) and Utah State University M.S. theses by Galloway (1970) and Mendenhall (in preparation).