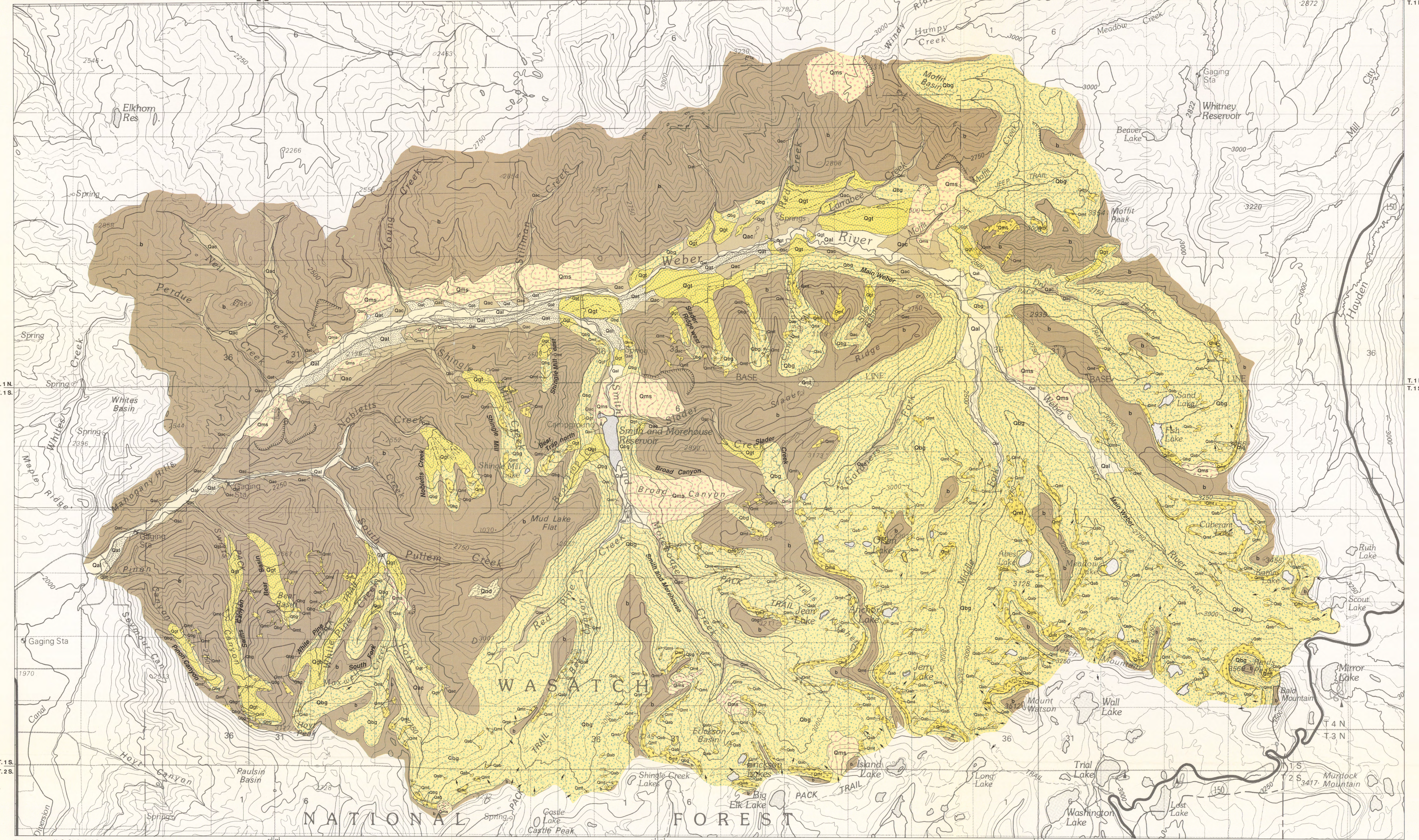
COGEOMAP — *Cooperative Project between*
UTAH GEOLOGICAL SURVEY
Utah Department of Natural Resources, *and*
THE UNITED STATES GEOLOGICAL SURVEY



Base map from U. S. Geological Survey
Salt Lake City and Kings Peak 30 x 60
minute series, 1980, 1982

Lori J. Douglas, Cartographer

QUATERNARY GEOLOGIC MAP OF THE UPPER WEBER RIVER DRAINAGE BASIN, SUMMIT COUNTY, UTAH

by

Charles G. Oviatt

1994

CONTOUR INTERVAL 50 METERS
SCALE 1:50,000

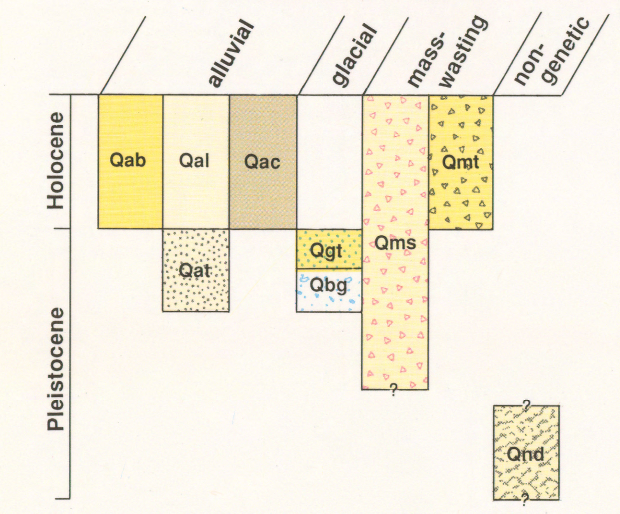
1 0 1 2 3 4 5
MILES

5,000 0 5,000 10,000 15,000 20,000 25,000 30,000
FEET

1 0 1 2 3 4 5
KILOMETERS

Map Area

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Qal — Alluvium (Holocene) - *Coarse to fine-grained alluvium along floodplains and channels of major streams. Maximum thickness probably less than 60 feet (20 m).*

Qac — Alluvium and colluvium (Holocene) - *Coarse to fine-grained alluvium and colluvium of lower order streams and hillslopes. Maximum thickness probably less than 60 feet (20 m).*

Qab — Bog deposits (Holocene) - *Fine-grained alluvium and peat in bogs filling shallow depressions at higher elevations in glaciated valleys. Maximum thickness probably less than 60 feet (20 m).*

Qmt — Talus deposits (Holocene) - *Deposits of angular boulders on steep slopes below cliffs, especially in glaciated valleys; includes thickened talus in protalus ramparts and avalanch boulder tongues. Maximum thickness unknown.*

Qat — Terrace alluvium (late Pleistocene) - *Coarse-grained outwash alluvium forming terraces along the Weber River Valley downstream from terminal moraines. Maximum thickness probably less than 160 feet (50 m).*

Qgt — Glacial till (late Pleistocene) - *Poorly sorted bouldery till that forms lateral, terminal, and recessional moraines; most likely of Pinedale (late Wisconsin) age. Maximum thickness probably less than 240 feet (75 m).*

Qbg — Glacial till (late Pleistocene) - *Thin, discontinuous glacial till overlying bedrock ; poorly sorted bouldery till; includes areas of erratics and striated bedrock. Maximum thickness unknown.*

Qms — Landslide deposits (Holocene and Pleistocene) - *Deposits of large landslides, slumps, debris slides, and rock slides; many are post-glacial, but some large slides existed prior to glaciation. Maximum thickness unknown.*

Qnd — Diamicton (Pleistocene ?) - *Deposits of rounded boulders in a fine-grained matrix; depositional environment unknown (probably glacial or fluvial). Maximum thickness probably less than 100 feet (30 m).*

b — Precambrian, Paleozoic, Mesozoic, and Tertiary Rocks - *Bedrock (see Bryant, 1990).*

SYMBOLS

Contact

Landslide head scarp

Direction of ice flow as indicated by crescentic fractures or lunate gouges in bedrock.

Ridge crest of moraine (in glacial till) or protalus rampart (in talus)

Bear Trap north — Informal names of glaciers dissussed in text

QUATERNARY GEOLOGIC MAP OF THE UPPER WEBER RIVER DRAINAGE BASIN, SUMMIT COUNTY, UTAH

by
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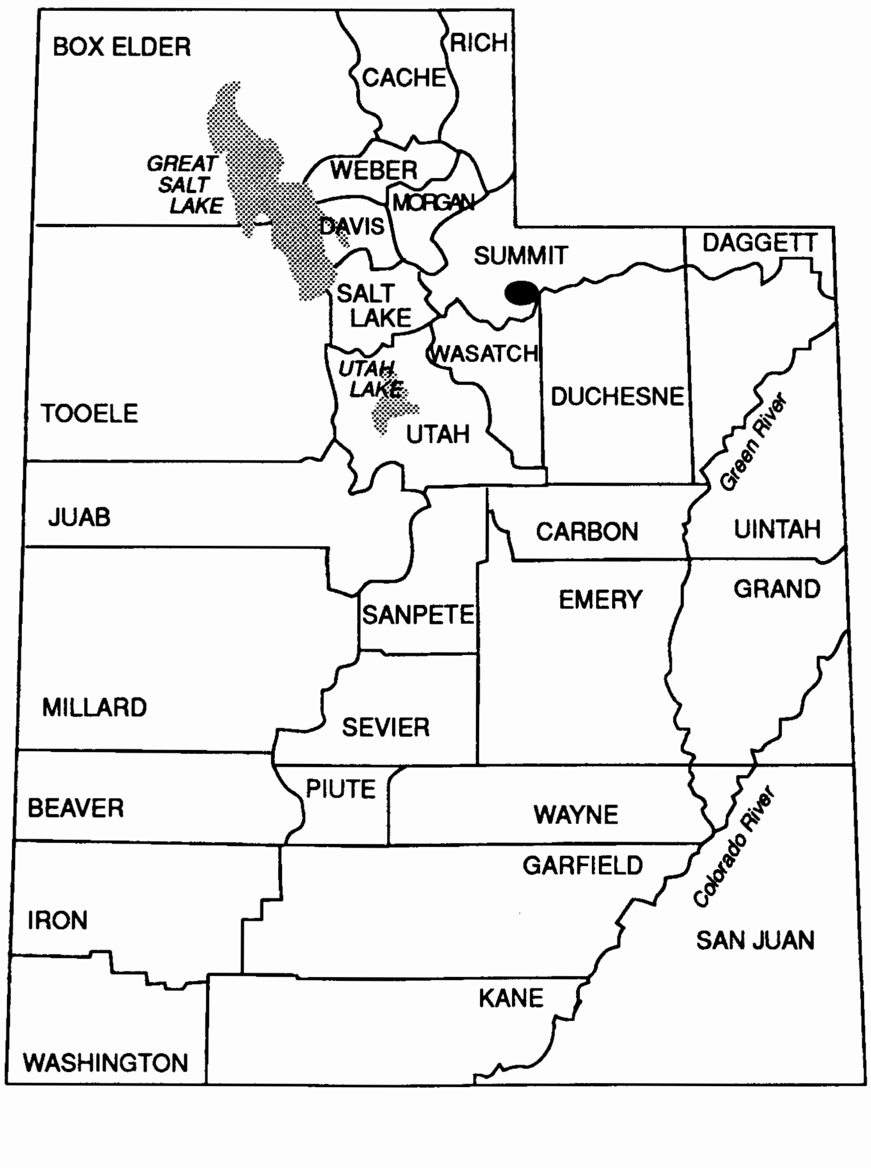
Department of Geology
Kansas State University



MAP 156

1994

UTAH GEOLOGICAL SURVEY
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UNITED STATES GEOLOGICAL SURVEY

Oviatt QUATERNARY GEOLOGIC MAP OF THE UPPER WEBER RIVER DRAINAGE BASIN, SUMMIT COUNTY, UTAH Utah Geological Survey Map 156

QUATERNARY GEOLOGIC MAP OF THE UPPER WEBER RIVER DRAINAGE BASIN, SUMMIT COUNTY, UTAH

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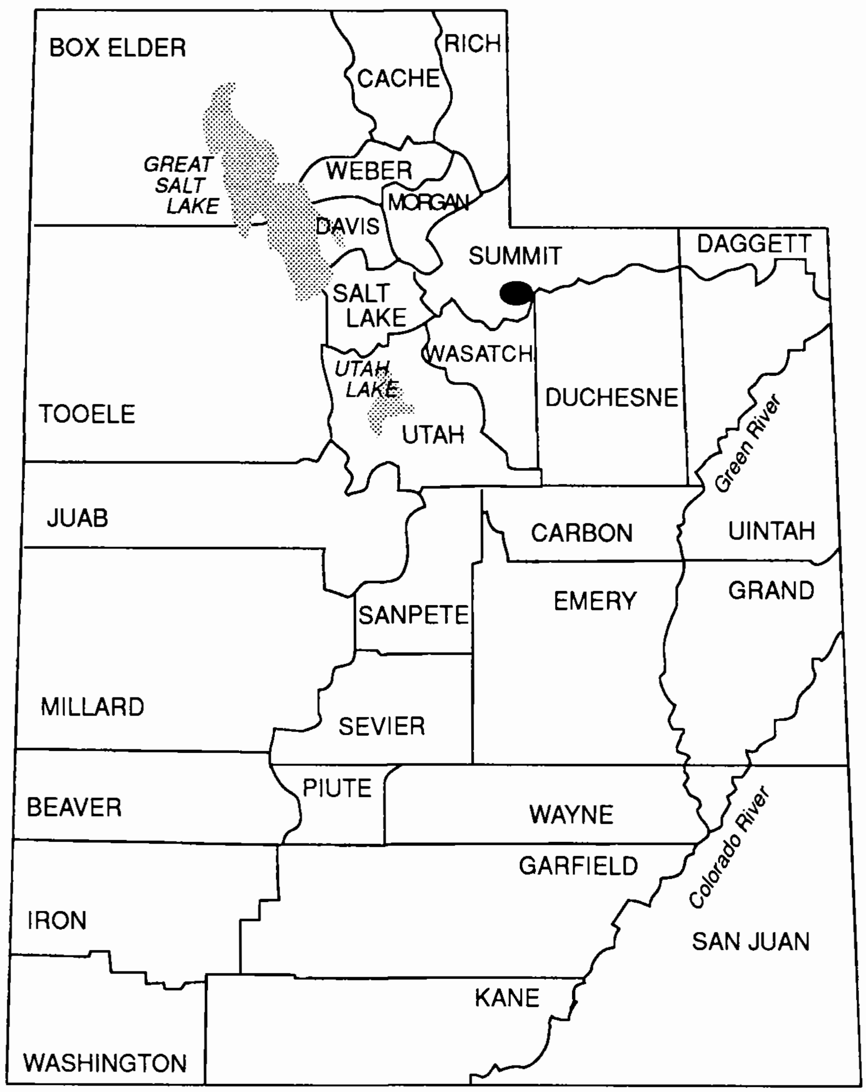

MAP 156 **1994**
UTAH GEOLOGICAL SURVEY
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UTAH GEOLOGICAL SURVEY
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QUATERNARY GEOLOGIC MAP OF THE UPPER WEBER RIVER DRAINAGE BASIN, SUMMIT COUNTY, UTAH

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ABSTRACT

Quaternary deposits in part of the western Uinta Mountains of northeastern Utah have been mapped at a scale of 1:50,000. The map area includes parts of eight 7.5-minute quadrangles. Numerous Quaternary landslides, and glacial deposits of one major Pleistocene glaciation (Pinedale) are widespread in the area. Significant potential geologic hazards from mass-wasting processes include large landslides, slumps, rockslides, debris slides, avalanches, and rock fall, as well as high runoff and sediment production caused by increasing land use on steep slopes.

Pinedale (late Wisconsin) glaciers formed an ice field in the highest parts of the map area that was drained by valley glaciers in the main Weber River Valley, Smith and Morehouse Canyon, and South Fork. Numerous small cirque glaciers and small valley glaciers occupied steep canyons on north-facing slopes. Equilibrium-line altitudes of Pinedale glaciers were lowest in the western part of the map area (about 8,270 ft; 2,520 m), and became progressively higher with distance to the east (about 9,180 ft; 2,800 m at the east end of map area). This gradient (about 1,000 ft per 12 mi; 300 m per 20 km) was probably caused by a west-to-east moisture gradient during the Pinedale glaciation.

INTRODUCTION

This map and report were prepared as part of the Cooperative Geologic Mapping Project (COGEOMAP) of the U.S. Geological Survey (USGS) and to document the Quaternary geology and extent of late Pleistocene glaciation in the upper part of the Weber River drainage basin in the Uinta Mountains, Utah (figure 1). The map area includes parts of the following USGS 7.5-minute quadrangles: Crandall Canyon, Hidden Lake, Slader Basin, Whitney Reservoir, Kamas, Hoyt Peak, Erickson Basin, and Mirror Lake. Surficial deposits were mapped in the field on aerial photographs at a scale of 1:24,000, and the data were transferred to 1:24,000-scale orthophotoquads, which were then reduced and compiled at a scale of 1:50,000.

The map area has high topographic relief, with altitudes ranging from about 6,500 feet (1,980 m) along the Weber River east of Oakley, Utah, to over 11,500 feet (3,500 m) along the Weber River drainage divide in the high mountains. Bedrock in the map area ranges in age from Precambrian to Tertiary and most of it has been previously mapped (Weeks, 1907; Forrester, 1937; Hooper, 1951; Root, 1952; Morris, 1953; Williams, 1953; Larsen, 1954; Meecham and Bitter, 1959; Hansen, 1969, 1986; Lindsay, 1969; Wallace, 1972; Crittenden and Peterman, 1975; Spreng, 1979; Bryant, 1985, 1990).

Although no climatic data are available for the map area, Barnhardt (1973) estimated climate parameters for three elevations on Bald Mountain, 10,700, 11,290, and 11,900 feet (3,261, 3,441, and 3,627 m), using weather data from Brighton, Utah, and inferences from lapse rate and radiosonde data. At 11,290 feet (3,441 m), the estimated mean annual air temperature is 29°F (-2°C), mean July temperature is 48°F (9°C), and mean January temperature is 13°F (-11°C). At Trial Lake, a few kilometers south of the map area (figure 1) at an elevation near 9,800 feet (3,000 m), mean annual precipitation is about 38 inches (96 cm), with the greatest monthly average in January and the lowest in July. Precipitation values are lower, and temperature values higher, at lower elevations in the map area.

Vegetation in the map area ranges from thick shrubs or grasslands on south-facing slopes at lower elevations, to coniferous forest dominated by spruce and fir, to alpine tundra on the summits of the highest peaks. Subalpine meadows and bogs are common high in glaciated valleys.

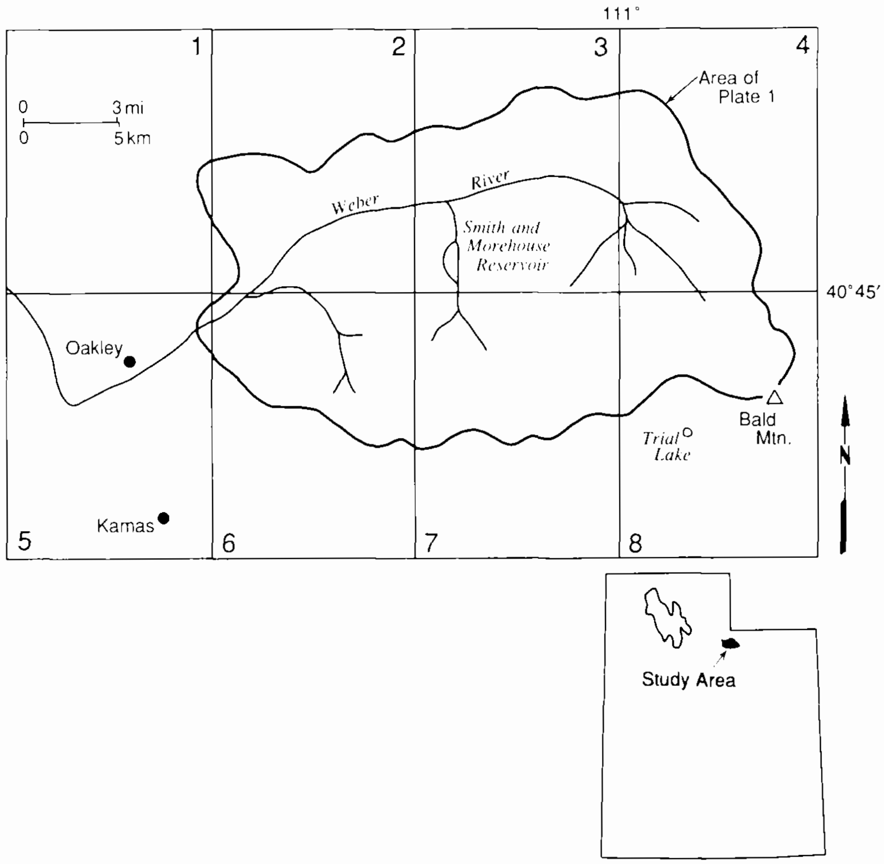


Figure 1. Map showing the location of the map area in the western Uinta Mountains. USGS 7.5-minute topographic quadrangles are numbered: 1) Crandall Canyon, 2) Hidden Lake, 3) Slader Basin, 4) Whitney Reservoir, 5) Kamas, 6) Hoyt Peak, 7) Erickson Basin, 8) Mirror Lake.

Quaternary deposits in the upper Weber River drainage basin can be classified as glacial, mass-wasting, alluvial, and colluvial. All of these deposits are thin over most of the area, and only in a few places do they attain thicknesses greater than a few tens of meters. The principal landforms in the area were produced by fluvial erosion and deposition, mountain glaciation, and mass wasting.

During the late Pleistocene the eastern part of the map area was covered by an ice field from which distributary glaciers flowed down the major valleys (figures 2 and 3). Glaciers in the western part of the area were smaller and tended to be confined to the upper parts of individual valleys rather than emanating from an ice field (figure 4). Glacial features were mapped throughout the Uinta Mountains by Atwood (1907, 1909), and smaller areas in the range have been mapped or studied more recently by Bradley (1936), Barnhardt (1973), Grogger (1974, 1975, 1978), Currey (1980), Carrara and others (1985), and Shroba (1988). Mapping for this project shows that many more small valleys were glaciated in the study area than were previously recognized, and it refines our knowledge of late Pleistocene glacier limits in this part of the Uinta Mountains.

The area has been, and continues to be, developed for private residences and commercial interests, and for public recreation and water resources. This map and report supply information on the distribution of landslides, which constitute a significant geologic hazard within the study area. Large landslides are present throughout the area, but the greatest number are along the Weber River Valley where development is proceeding rapidly. Because the Weber River drainage basin is an important watershed for thousands of people, including local residents, land use should be managed carefully to protect water resources.

DESCRIPTION OF MAP UNITS

A system of descriptive and genetic map units, similar to those used on previous COGEOMAP projects, is used on this map. Quaternary deposits were deposited in alluvial (a), glacial (g), and mass-wasting (m) environments, as indicated by the first lower case letter in the map-unit symbol. The second lower case letter in the map-unit symbol indicates other distinguishing characteristics of the deposit, such as Qat for alluvium underlying terraces, or Qgt for glacial till. Two small areas of coarse-grained deposits, for which the depositional environment is not known, are mapped as "non-genetic" diamicton (Qnd).

Pre-Quaternary Rocks

Precambrian, Paleozoic, Mesozoic, and Tertiary Rocks (b)

Bedrock in the map area ranges in age from Precambrian to Tertiary. Most of the area mapped as bedrock (b) on the map is covered by thin colluvium (generally less than 16 ft; 5 m), and no attempt was made to distinguish colluvium as a map unit at the scale of 1:50,000. The higher parts of the map area are underlain by the Proterozoic Uinta Mountain Group, which consists of quartzite, sandstone, and shale. These rocks are overlain by Paleozoic and Mesozoic sedimentary rocks that dip to the north and northwest on the north flank of the Uinta arch. Tertiary sandstone, conglomerate, and shale, primarily of the Wasatch Formation, overlie the older rocks unconformably, mostly north of the Weber River.

Figure 2. *View west from the summit of Bald Mountain showing the broad glaciated surface with numerous lakes and peaks that once stood as nunataks above the ice field. Mount Watson, which is on the drainage divide between the Weber and Provo River drainage basins, is in the center of the photograph.*

Figure 3. *View to the northwest from the summit of Bald Mountain showing Reids Peak and the glaciated valley of the Weber River. Boulder field in the foreground is part of a periglacial felsenmeer that blankets the summit of Bald Mountain and other nunataks in the area. The felsenmeer probably formed during periods of Pleistocene glaciation. Other periglacial features at high altitudes in the area include sorted nets and polygons, sorted stripes, and debris islands.*

Figure 4. *View west toward Hoyt Peak and the cirques on its north flank and at the head of South Fork. Light-colored cliffs in the middle ground are the Cambrian Tintic Quartzite.*

The most important aspect of the bedrock geology from the point of view of Quaternary geology is its influence on the geomorphology of the area. For instance, the Weber River Valley has formed along the contact between gently dipping Tertiary rocks and more steeply dipping Paleozoic and Mesozoic rocks (Bryant, 1990). This contact also coincides with a major structural boundary – the north flank fault zone and the approximately located Absaroka thrust fault. Major tributary canyons of the Weber River are eroded into the Precambrian and Phanerozoic rocks by fluvial, mass-wasting, and glacial processes.

The reader may refer to the following studies for further information on bedrock geology (Weeks, 1907; Forrester, 1937; Hooper, 1951; Root, 1952; Morris, 1953; Williams, 1953; Larsen, 1954; Meecham and Bitter, 1959; Hansen, 1969, 1986; Lindsay, 1969; Wallace, 1972; Crittenden and Peterman, 1975; Spreng, 1979; Bryant, 1985, 1990).

Quaternary Deposits

Glacial Deposits

Glacial deposits cover a large area in the Weber River drainage basin, although they are generally thin except where glacial till (Qgt) forms end or lateral moraines. The map unit Qbg is used over a large part of the area and represents thin and discontinuous glacial till overlying bedrock. The boundaries of Qbg represent the approximate limit of glacial ice at its late Pleistocene maximum. The line is drawn partly on the basis of the distribution of till and erratics, but clues from erosional glacial landforms, such as striations on bedrock and the inferred upper limit of ice on cirque headwalls, were also used. Within the area mapped as Qbg, glacial deposits are generally thin, but hummocky moraines are locally well de- veloped, such as north of Bald Mountain and Reids Peak (Barnhardt, 1973).

Thick glacial deposits in end and lateral moraines are mapped in the lower parts of valleys. They consist of bouldery, hummocky to smooth-sided mounds of debris generally less than 50 feet (15 m) thick. Well-defined moraine ridge crests are indicated on the map by dashed lines. The best developed moraines are along the main Weber River Valley, at the mouth of Smith and Morehouse Creek, and along Nobletts Creek and South Fork. The longitudinal gradients of many smaller canyons are so steep that well-defined lateral and end moraines are not present, but masses of glacial till have been mapped in the lower parts of the valleys.

Although Atwood (1909) mapped moraines of two different ages in the Uinta Mountains, no evidence was found to distinguish moraines of more than one major glaciation. Atwood (1909) used position in the valley as a primary indicator of the relative age of moraines, but mapping for this project showed no significant difference in morphology or weathering between Atwood's two groups. All the preserved moraines in the Weber River drainage basin are most likely related to the Wisconsin-age Pinedale glaciation which is correlative with marine oxygen-isotope stages 3 and 2 (Pierce and others, 1976; Madsen and Currey, 1979). No numerical ages are available for Uinta Mountain glacial deposits. If correlation with the Pinedale glaciation is correct, the glaciers were probably at their maximum down-valley extent approximately 20 thousand years ago (Porter and others, 1983).

Mass-Wasting Deposits

Mass-wasting deposits in the area are mapped as landslides (Qms) and talus (Qmt). The landslides are primarily large complex landforms that probably resulted in multiple episodes of movement and a number of different mass-wasting processes, including rotational slumping, earth flow, and debris slide. Although some landslides are derived from Proterozoic rocks, especially the Red Pine Shale, most are derived from Paleozoic, Mesozoic, and Tertiary rocks. Landslide headscarps are marked by hachured lines on the map.

In the higher parts of the map area, some landslides formed in post-glacial time in quartzite and sandstone of the Uinta Mountain Group. They consist of large rock slumps and rock slides on cirque headwalls that were oversteepened by glacial erosion and left unsupported when the glaciers melted. Examples of these are west of Island Lake at the head of Smith and Morehouse Creek, and at the head of Dry Fork.

One of the largest landslide complexes in the map area is in Broad Canyon, a tributary of Smith and Morehouse Canyon, where the Proterozoic Red Pine Shale and associated units have failed. At least the lower half of Broad Canyon was glaciated by the main Smith and Morehouse glacier, adding to the geomorphic complexity of this area. Some movement of the landslide is probably post-glacial, but the landslide probably existed prior to glaciation.

A rock slide in South Fork canyon just south of the confluence with White Pine Creek and Pullem Creek was mistaken by Atwood (1909) for the terminal moraine of the South Fork glacier deposited during the later of his two glacial epochs. However, the feature is clearly a rock slide derived from Madison Limestone cliffs directly above it on the east side of the canyon. The rock slide contains almost no fine material and only a few shrubs and coniferous trees have taken root on its surface. Most of the limestone blocks are disintegrating into angular blocks of cobble to pebble size. The South Fork rock slide is post-glacial in age as shown by its position across the glaciated valley, which it has dammed. South Fork may have formed a lake after the rock slide dammed the valley, but the creek now drains through a karst swallow hole in the Madison Limestone on the upstream side of the rock slide (figure 5). The water re-emerges on the downstream side of the rock slide at the lower limit of Madison Limestone outcrops. Organic debris and clastic sediment accumulate on the upstream side of the rock slide when the swallow hole is episodically blocked during flood events. Layers of debris and sediment exposed by recent stream incision (figure 5) indicate multiple episodes of downcutting and channel filling. There is potential for determining the approximate age of the rock slide from these deposits, which contain abundant material for radiocarbon dating.

Landslides are a significant geologic hazard along Weber Canyon downstream from Smith and Morehouse Creek. In this area landslides line both sides of the valley, including many areas where residences and subdivisions have been built. Most land-

Figure 5. Photograph of the swallow hole (arrow) in the Madison Limestone on the upstream side of the rock slide in South Fork. The vertical exposure of fluvial gravel and organic debris in the foreground is about 6 feet (2 m) high.

slides on the north side of the valley are derived from the Wasatch Formation, whereas those on the south side are derived from Mesozoic rocks, primarily the Ankareh Formation. Although there is no evidence that these landslides have moved significantly in recent time, landslide stability is difficult to predict, and these featrues should be regarded as potentially hazardous.

A landslide in section 6, T. 1 S., R. 7 E., on the south side of the Weber River Valley across from Perdue Creek at and near Hidden Lake, consists of rock debris derived from the Ankareh Formation and Nugget Sandstone. The landslide is perched in a vulnerable position 120 to 440 feet (35-130 m) above the valley, and is being undercut by the Weber River. A number of houses in a subdivision are built on the landslide, and other houses and a highway are built in the narrow river valley below the landslide. It is difficult to know when or if this landslide will move again, but if people are aware of the hazard they can prepare for any hazardous situation that may develop. Other landslides in developed areas (refer to the map) pose similar potential hazards.

Another mass-wasting problem that is a lesser hazard, but is still a concern for water and soil quality, is a large area of steep slopes on the Wasatch Formation on the north side of the Weber River east of Smith and Morehouse Creek. In this area numerous small debris slides in the headward parts of the drainage networks are feeding abundant sediment into steep stream channels tributary to the Weber River. Channel bottoms of high-gradient streams in this area are choked with sediment. Some of the larger debris slide head scarps are indicated on the map by short, curved hachured lines. It is clear that the ratio of surface runoff to infiltration is higher in this area than in surrounding areas, probably because of overgrazing by sheep. This is a major concern because it indicates that this part of the Weber River watershed is in disequilibrium – less water recharges groundwater systems and surface water is probably of lower quality than in surrounding areas.

Talus deposits (Qmt) are most abundant and thickest in the high glaciated part of the map area. Talus deposits are common along cirque headwalls and below cliffs around peaks that stood as nunataks during periods of maximum glaciation. The talus consists of loose angular boulders of locally derived bedrock, in most cases quartzite or sandstone, on steep slopes with little vegetation. On the map, dashed lines within areas mapped as talus indicate ridge crests of protalus ramparts, which form when late-season snow or ice on the slopes allows blocks to slide or roll farther from the cliff and accumulate in a ridge or rampart (figure 6). Lichen cover on many of the boulders in the protalus ramparts is extensive (≥50%), suggesting that they formed in late Pleistocene time.

Talus cones are active today, but no protalus ramparts are presently forming. Boulders accumulate in talus cones through processes of snow avalanching and rock fall directly from cliffs. Avalanche boulder tongues (accumulations of rock debris deposited dominantly by avalanching [Barnhardt, 1973]) are mapped with the talus (Qmt).

Alluvial Deposits

Alluvium in the map area is divided into four map units, Qal, Qac, Qat, and Qab. The distinction between Qal and Qac is arbitrary in some places, but in general the alluvium mapped as Qal is found along major perennial streams and underlies floodplains and the lowest young terraces directly above floodplains. Qac consists of the deposits of smaller order streams, many of which are ephemeral and tributary to the larger perennial streams. The designation Qac refers to the presence of a large component of slope-wash colluvium in these deposits. Alluvium mapped as Qal and Qac is post-glacial (Holocene) in age.

Along the Weber River Valley, gravel terraces that grade downstream from late Pleistocene end moraines of the Weber River glacier and Smith and Morehouse glacier are mapped as

Figure 6. Photograph of a protalus rampart at the base of a talus slope on the north flank of the first unnamed peak west of Mount Watson, at the head of the Middle Fork of the Weber River.

Qat. The terrace surfaces are 30 to 50 feet (10 to 15 m) above the modern Weber River, and represent outwash deposition during glaciation.

In higher parts of glaciated valleys near drainage divides, the glacially scoured bedrock surfaces are uneven, allowing lakes and bogs to form (figure 7). Bog deposits are mapped as Qab because many contain an alluvial detrital component, however, much of the total volume of the bog deposits consists of sedge and moss peat. Barnhardt (1973) and Currey (1980) reported radiocarbon ages of 8,235 ± 345 yr B.P., and 2,970 ± 150 yr B.P., for peat and wood from bogs near Bald Mountain. The 8,200 year age was for peat near the base of a bog, and indicates that deglaciation was complete on the north slope of Bald Mountain by at least this time in the early Holocene. Like other mountain ranges in the Rocky Mountain region, the Uinta Mountains were probably deglaciated long before 8,000 yr B.P. (Porter and others, 1983).

Non-genetic Diamicton (Qnd)

Two small areas of coarse gravel of uncertain origin were mapped in the central part of the area. Both deposits consist of boulders of Uinta Mountain quartzite and fine-grained material in low, vegetated mounds (relief <32 ft, 10 m) on remnants of a high-level erosion surface--Mud Lake Flat and Slader Ridge. The erosion surface is probably part of the Gilbert Peak surface of probable Oligocene age (Bradley, 1936; Hansen, 1986). The boulder deposits may be much younger than the erosion surface, and are mapped as Quaternary deposits (Qnd), even though no definite evidence of their ages has been found.

The designation "nd" is used for the boulder deposits to indicate their undetermined origin. They could have been deposited by glaciers or by streams, but in the absence of exposures of fresh material and surficial geomorphic expression, their origin cannot be determined.

Quaternary Glaciation

During the Pleistocene, glaciers repeatedly accumulated in the Uinta Mountains and carved the majestic alpine landscape found there. Although the preserved stratigraphic record documents only a few major advances of ice in the Uinta Mountains (Atwood, 1909; Bradley, 1936), the global record of glaciation shows many cycles of ice accumulation and melting (Imbrie and others, 1984), each with a magnitude similar to the last major glaciation. Therefore, large-scale landforms in the study area, such as cirques, glacial troughs, and horns, are probably the result of many episodes of glacial erosion. The preserved record of the last major glaciation in the Weber River drainage basin provides a general template for the character of previous, poorly documented glaciations.

The maximum extent of glaciers in the Weber River drainage basin during the Pinedale glaciation is generally indicated by the extent of the Qgt and Qbg units. This map can be used to describe the glaciers and to compare the climates of Pinedale time and of today. At their maximum extent, large valley glaciers flowed down the Weber, Smith and Morehouse, and South Fork valleys from an extensive ice field, only part of which was in the Weber River basin. Other valley glaciers outside the map area drained the ice field down the Bear River, Provo River, and smaller valleys on the south flank of the range (Atwood, 1909).

The distribution of erosional features that indicate ice-flow directions in the vicinity of modern drainage divides along the crest of the range show the ice mass was an ice field and not an ice cap. In saddles or cols between horns or nunataks, striations and other erosional features are common. Crescentic fractures, lunate gouges, and possible cavitation pits (figures 8 and 9) on quartzite bedrock indicate ice flow in both directions away from the cols, and therefore demonstrate that the ice divides were essentially the same as the modern drainage divides. Flow in an

Figure 7. *Bog near the drainage divide north of Kamas Lake (north of Bald Mountain). The bog has almost completely filled the depression with moss and sedge peat.*

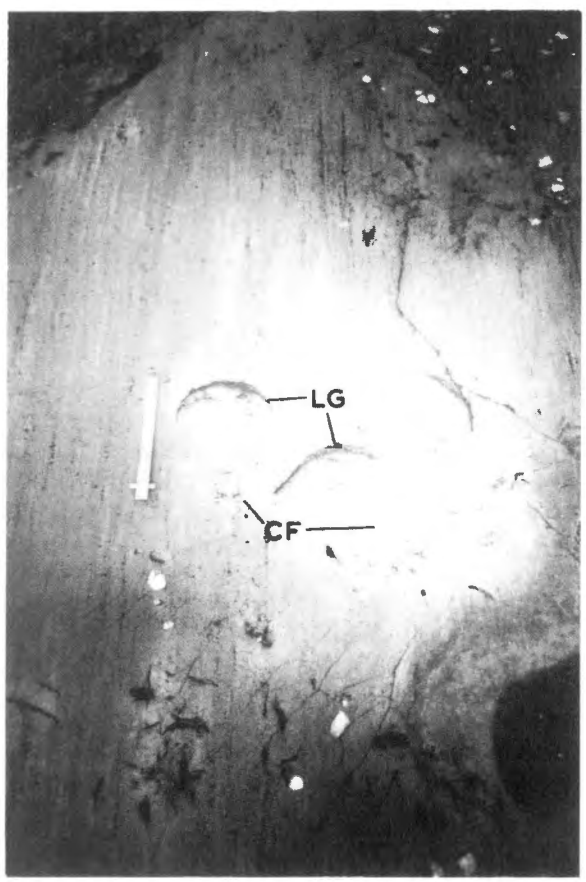
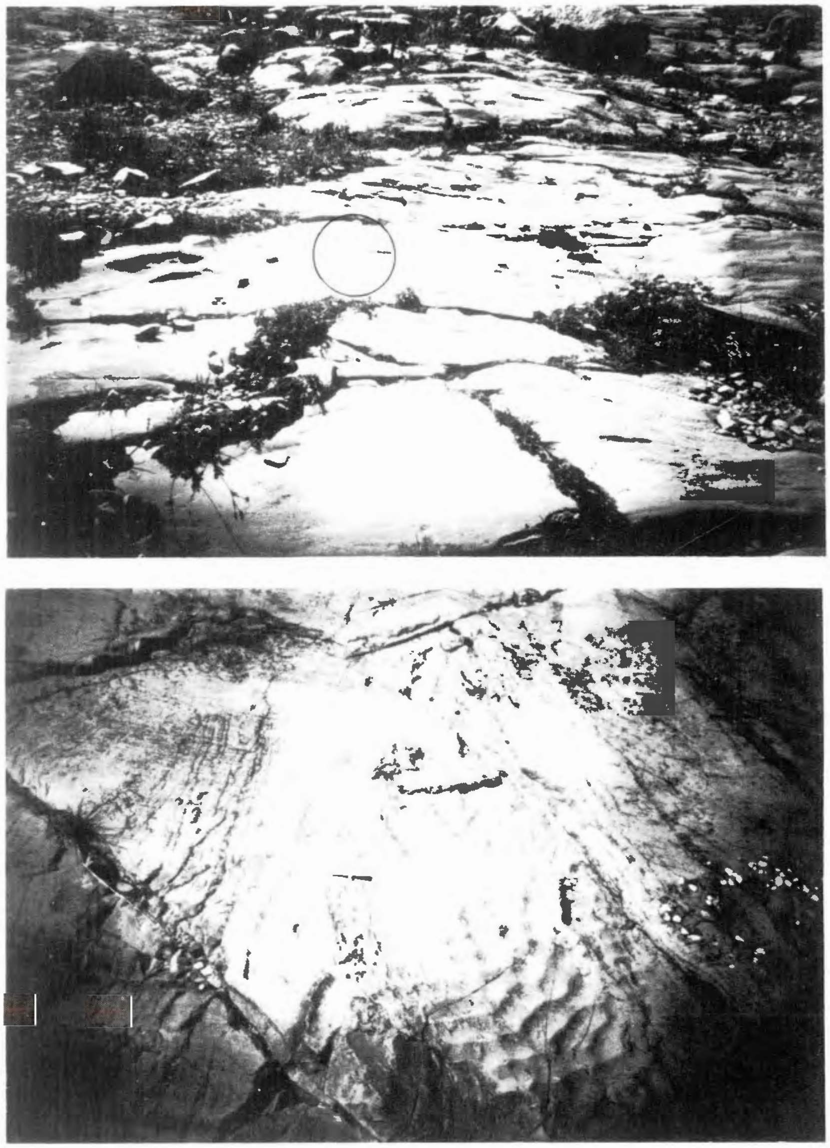


Figure 8. *Striations, crescentic fractures (CF), and lunate gouges (LG) on quartzite. The ice flowed away from the viewer (toward the top of the photograph). Note that the lunate gouges are concave in an up-ice direction, and the crescentic fractures are concave in a down-ice direction. The scale is 6 inches (15 cm) long.*

A



B

Figure 9A and 9B. *Striated and polished quartzite surfaces showing possible cavitation pits on the down-ice sides (right) of low rises in the quartzite. The scale is 6 inches (15 cm) long in each photograph. Cavitation pits form where melt water flowing at high velocity in a confined space at the base of the glacier suddenly enters an enlarged cavity at the base of the ice (Drewry, 1986) (such as the areas on the right sides of the photographs). At high velocity, pressure is decreased, and tiny airless bubbles form in the water. Within the cavity, the velocity decreases and the pressure increases causing the bubbles to collapse. When bubbles collapse next to the rock they exert a very high, but localized stress on the rock, and over a long period of flow the rock is pitted. Figure 9A shows a large area of small pits, and figure 9B shows larger pits that have formed a pattern that looks like ripple marks.*

ice field is strongly influenced by underlying topography, in contrast to flow in an ice cap, which is determined by the morphology of the ice dome. If the directional features in the Uinta Mountains showed there had been significant flow through the divides, then the ice mass would be more likely classified as an ice cap (Sugden and John, 1976).

In addition to the large ice-field-valley-glacier system, a number of smaller valley glaciers or enlarged cirque glaciers formed in the steep, north-facing valleys tributary to the Weber River. These glaciers were fed in most cases by single cirques and ended at intermediate elevations in the valleys or terminated at the lateral moraines of larger valley glaciers (for example, the small glaciers on the north slope of Slader Ridge). Atwood (1909) recognized that Swifts Canyon and Bear Basin had been glaciated, but did not recognize glacial features in numerous other small canyons in the map area.

The extent of glacial ice can be used to estimate the equilibrium-line altitude (ELA) of the Pinedale glaciers. The equilibrium line on a glacier is the boundary between the glacier's accumulation zone, where more snow falls during the winter than melts the following summer, and the ablation zone, where during a melting season the previous winter's snowfall, and that part of the glacier that flowed down valley to the ablation zone, melts. In the accumulation zone, there is a net increase in mass each year, and there is a net decrease in mass in the ablation zone. The glacier is in mass balance when input equals output. When input exceeds output for a sufficiently long period, the glacier advances down valley, and the altitude of the equilibrium line is lowered.

On a modern glacier the equilibrium line can be identified readily by field observations – it often appears at the end of the ablation season as the distinct lower boundary of fresh snow and firn that fell the previous winter in contrast to the debris-laden ice exposed at the glacier surface in the ablation zone. For paleoglaciers, however, other means must be used to determine the ELA. A number of methods, some more subjective than others, have been employed by researchers in mountain ranges throughout the world. Meierding (1982) applied five different techniques to a large number of glaciated valleys in the Colorado Front Range and found that two methods, accumulation-area ratio (AAR) and toe-to-headwall altitude ratio (THAR), gave the most consistent results. These two methods also yielded approximately the same estimates of ELA when applied to the glacial models.

For this project, the toe-to-headwall altitude ratio (THAR) method was used to estimate paleo-ELAs of Pinedale glaciers in the Weber River drainage basin. The THAR method was used because it was easier and faster than the AAR method. In the THAR method, the lower and upper altitudinal limit of ice in each valley are estimated from the map and the ELA is calculated using the following formula:

$$\mathbf{ELA = Z_t + [0.4(Z_h - Z_t)]}$$

where Z_t is the lower limit of ice at the end moraine, and Z_h is the upper limit of ice at the cirque headwall. All values are in meters above sea level. A THAR of 0.4 was used for glaciers in the Weber River basin because Meierding (1982) found that for the Rocky Mountains this ratio gave results that were most consistent with other methods, especially the AAR method.

The THAR analysis results are listed in table 1 and shown in figure 10. The data show that the ELA for glaciers in the Weber River drainage basin increased with distance to the east from the western end of the mountain range (figure 10). The regional ELA gradient is about 1,000 feet (300 m) per 12 miles (20 km) and probably reflects a primary moisture source for the glaciers in the west.

Mulvey (1985) calculated an ELA value of 9,246 feet (2,819 m) for the western Uinta Mountains in his regional study of Pinedale ELAs in the eastern Great Basin. He used the THAR method with a THAR of 0.5. Mulvey did not report which glaciers he used in determining this ELA, but by comparison, the Z_t and Z_h data for Smith and Morehouse glacier in table 1 would yield an ELA of 9,266 feet (2,825 m) if a THAR of 0.5 were used. Porter and others (1983, figure 4-2) show an altitude of 9,840 feet (3,000 m) in the central part of the Uinta Mountains on their map of cirque floor altitudes for late Wisconsin glaciers in the western United States. A cirque-floor altitude of 9,840 feet (3,000 m) is reasonable for the eastern part of the Weber River basin. Zielinski and McCoy (1987) compared the data of Porter and others (1983, figure 4-2) to modern snowpack data in altitudinal gradients, and suggested that the changes in temperature or snow accumulation patterns from the late Pleistocene to the present were not uniform across the Great Basin.

No attempt was made to estimate the amount of ELA depression in the Weber River basin during Pinedale time as compared to modern ELAs in the area. Currey and James (1982) suggested that late Pleistocene ELAs in north-central Utah may have been on the order of 2,600 feet (800 m) lower than modern ELAs. Madsen and Currey (1979) estimate that the late Pleistocene mean annual temperature in the Little Cottonwood Canyon area of the Wasatch Range was at least 9°F (5°C) colder than today.

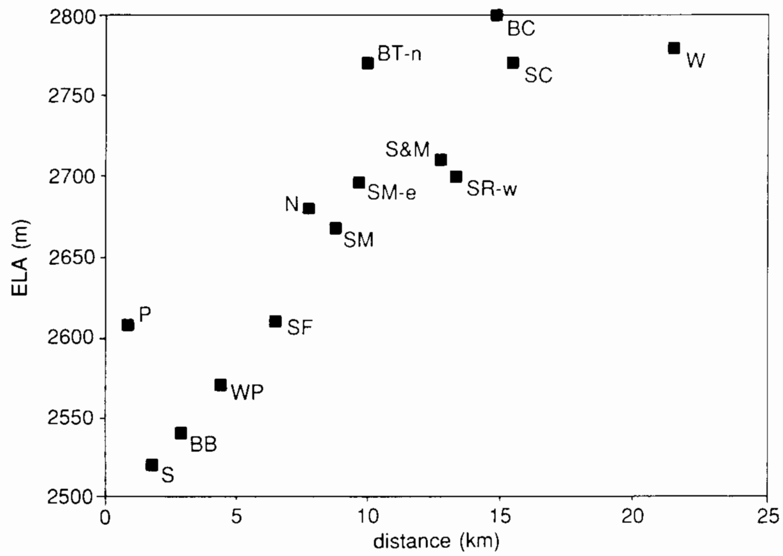


Figure 10. *Diagram showing a plot of the equilibruim-line altitudes (ELA) of Pinedale glaciers in the Weber River drainage basin versus distance east of an arbitrary north-south line west of Pinon Canyon (data from table 1). Refer to the map for locations of glaciers. P=Pinon Canyon; S=Swifts Canyon; BB=Bear Basin; WP=White Pine; SF=South Fork; N=Nobletts Creek; SM=Shingle Mill; SM-e=Shingle Mill east; BT-n=Bear Trap north; S&M=Smith and Morehouse; SR-w=Slader Ridge west; BC=Broad Canyon; SC=Slader Creek; W=main Weber Valley glacier.*

Table 1.
ELA estimates for Pinedale glaciers in the Weber River drainage basin.

glacier[1]	Z_t[2] (m)	Z_h[3] (m)	ELA[4] (m)	dist.[5] (km)
Pinon Canyon	2440	2860	2610	0.9
Swifts Canyon	2200	3000	2520	1.8
Bear Basin	2300	2900	2524	2.9
White Pine	2250	3050	2570	4.4
South Fork	2250	3150	2610	6.5
Nobletts Creek	2500	2950	2680	7.7
Shingle Mill	2480	2950	2670	8.7
Shingle Mill east	2500	2990	2700	9.6
Bear Trap north	2650	2950	2770	9.9
Smith & Morehouse	2250	3400	2710	12.7
Slader Ridge west	2500	3000	2700	13.3
Broad Canyon	2600	3100	2800	14.8
Slader Creek	2550	3100	2770	15.4
Main Weber	2300	3500	2780	21.5

[1]see map for locations of valleys
[2]altitude of lower limit of glacier
[3]altitude of upper limit of glacier
[4]calculated by the THAR method, see text
[5]distance east of an arbitrary north-south line west of Pinon Canyon

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