5-1976

Quaternary Geomorphic Features of the Bear River Range, North-Central Utah

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QUATERNARY GEOMORPHIC FEATURES OF THE BEAR RIVER RANGE, NORTH-CENTRAL UTAH

by

Jerome Vernon DeGraff

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

UTAH STATE UNIVERSITY
Logan, Utah

1976

ACKNOWLEDGMENTS

The author thanks Dr. Robert Q. Oaks, Jr., for his field assistance, advice, and critical evaluation of this manuscript; and Drs. Clyde T. Hardy and Donald R. Olsen for their helpful suggestions, assistance in the field, and review of the manuscript.

The perspective and information supplied by Dr. A. R. Southard, Department of Soils and Biometeorology, Utah State University, and Dr. Kenneth L. Pierce, U. S. Geological Survey, were invaluable in interpreting the evidence seen in the field. Dr. E. Arlo Richardson, State Climatologist of Utah was generous with information on climatic factors affecting the region. Drs. Jan A. Henderson and H. Charles Romesburg Department of Forestry and Outdoor Recreation, Utah State University, supplied data on vegetative cover and statistical analysis. Suggestions and insights provided by Drs. Peter T. Kolesar and Richard R. Alexander, Department of Geology, Utah State University, were greatly appreciated.

Administrative help and programming assistance provided by Dr. Leon Huber, Utah Water Resources Laboratory, made possible the computer plotted canyons profiles. Dr. Joel E. Fletcher and Mr. Frank Haws supplied hydrologic data.

Various individuals were generous in allowing the author to cross or examine features on their property. Mr. Elmer Riggs, Mr. F. Dean McBride, Mr. Mervin Salvesan, and the Logan District Ranger Office, Wasatch National Forest, have all assisted in providing necessary access.

The author is grateful for field assistance from the following graduate and undergraduate students: K. C. Baum, Dave Bernard, Don French, Dan Grudvig, Art Mendenhall, Mike McKee, Dick Poulson, Doug Sprinkel, and Alan Sweide. Special thanks go to Don French for use of his jeep. Chad Nichols was generous with his time and piloting skills during the several aerial-reconnaissance flights.

Contractual support from the U. S. Forest Service, a Grant-In-Aid of Research for Sigma Xi, The Scientific Research Society of North America, and assistance from the Department of Geology and College of Science of Utah State University provided the financial support to conduct this investigation.

The encouragement and help supplied by my wife, Sandy, was the most important element needed to insure the successful completion of this project.

Jerome V. DeGraff

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ABSTRACT

Quaternary Geomorphic Features of the

Bear River Range, North-Central Utah

by

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Utah State University, 1976

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Department: Geology

The Bear River Range, in north-central Utah, contains a variety of geomorphic elements influenced by the geologic setting and events. Controlling factors of the geologic setting include: (1) a syncline (west) and an anticline with a crestal graben (east) within the part of the mountain range studied, and an adjacent graben valley along the west side of the range; and (2) bedrock of Precambrian and Paleozoic age in the core of the range, predominantly of shallow-marine carbonates and covered in the graben by shaly and conglomeratic rocks of early Cenozoic age, with fanglomerates and lake deposits of later Cenozoic age. Geologic events contributing to geomorphic development include: (1) (?) Bull Lake and Pinedale glaciation; (2) various levels of Lake Bonneville; and (3) Hypsithermal climatic conditions.

The eighteen canyons along the western front of the Bear River Range in Utah, in sequence from north to south, are: High Creek, Oxkiller Hollow, Cherry Creek, City Creek, Nebo Creek, Smithfield, Birch, Dry (North), Hyde Park, Green, Logan, Dry (South), Providence, Millville, Blacksmith Fork, Hyrum, Paradise Dry, and East. An attempt was made to relate gradient changes along longitudinal canyon profiles to lithologies, attitudes, or other structural controls. The only consistent gradient change is a steepening of the gradient downstream from outcrops of Swan Peak Formation. A pronounced asymmetry in cross-valley profiles probably results from micro-climatic differences that cause north-facing slopes to be steeper than south-facing slopes despite close similarities in structure and lithology across canyons. Several canyons which do not cross the syncline axis have no measurable discharge. Water from these drainages apparently moves along the strike or down the east-dipping rocks of the western limb of the Logan Peak syncline to emerge as springs added to the surface flow in cross-axial canyon streams. Leakage is probably concentrated in the Lodgepole and Great Blue Formations.

Minor geomorphic elements within the Bear River Range result from glacial, periglacial, and fluvial processes, and landslides. Periglacial action has produced both nivation and patterned diamicton.

Glacial features are present in Logan Canyon and its tributaries, Birch, Providence, and the South Fork of Smithfield canyons. In addition to these previously mapped glacial areas, High Creek Canyon was subjected to glacial modification in the upper reach of South Fork tributary, and Leatham Hollow (Blacksmith Fork Canyon), in the upper reach of its major southern tributary.

Nivation modified the heads of Smithfield, Green, Cottonwood, and Dry (South) canyons by carving cirques floored by rock debris. Evidence for glacial action downstream from these cirques is absent.

Patterned diamicton sites are widely distributed within the range. There is no consistent relationship to exposed lithologies or physical setting. The apparent relationship of slope aspect, elevation, and solar radiation suggests an origin by a temperature-dependent process, for near-identical temperatures were calculated for all patterned diamicton sites. Based, in part, on a reconstruction of Pleistocene temperatures, the patterned diamicton sites probably are a form of patterned ground resulting from frost action during glacial episodes.

Alluvial fans lie at the mouths of many tributary canyons. Based on degree of soil development and relations to features of known age, a sequence of fan development is recognized. Alluvial fans formed prior to Wisconsinan time and repeatedly thereafter during interglacial and glacial periods. Many of the fans formed after the Pleistocene under the favorable conditions that existed during the Hypsithermal interval.

Landslides in the study area are commonly old, inactive features. Only a few sites are recent in age, or currently active. Slopes with a

west-component aspect are more prone to movement than other aspects. The most frequently disturbed lithology consists of Tertiary formations which are often conglomeratic. A wide range of slope inclinations have landslides, but the dominant slope is 20 to 24 percent. The main elevation range for landslides is between 6,000 to 6,999 feet.

Quaternary stream alluvium and Lake Bonneville deposits are found along the eastern margin of Cache Valley and in the lower reaches of most canyons. This material has been deposited since the Provo phase of Lake Bonneville. In several places, lake or stream terraces are mapped.

(215 pages)

INTRODUCTION

General Statement

The Bear River Range, north-central Utah, and the eastern margin of Cache Valley, Utah, comprise the 595 square miles investigated. Previous workers restricted their geomorphic studies to selected areas or to certain processes and features.

The major geomorphic elements identified in this investigation are compiled on a map at the scale of 1:48,000 (Plate 1). This map has a topographic base derived from the 7.5-minute topographic coverage of the area. Minor geomorphic features such as landslides, alluvial fans, and glacial and periglacial features are included in this study. Geomorphic processes responsible for these elements are analyzed. A chronology through late Pleistocene and Holocene time is developed to outline the events resulting in the features found in the region.

Location and Accessibility

The thesis area is in the north-central part of Utah (Figure 1). The location falls within the Middle Rocky Mountain physiographic province near the western boundary between it and the Basin and Range province (Raisz, 1952). The main physical features within the area are the western portion of the southern part of the Bear River Range and the

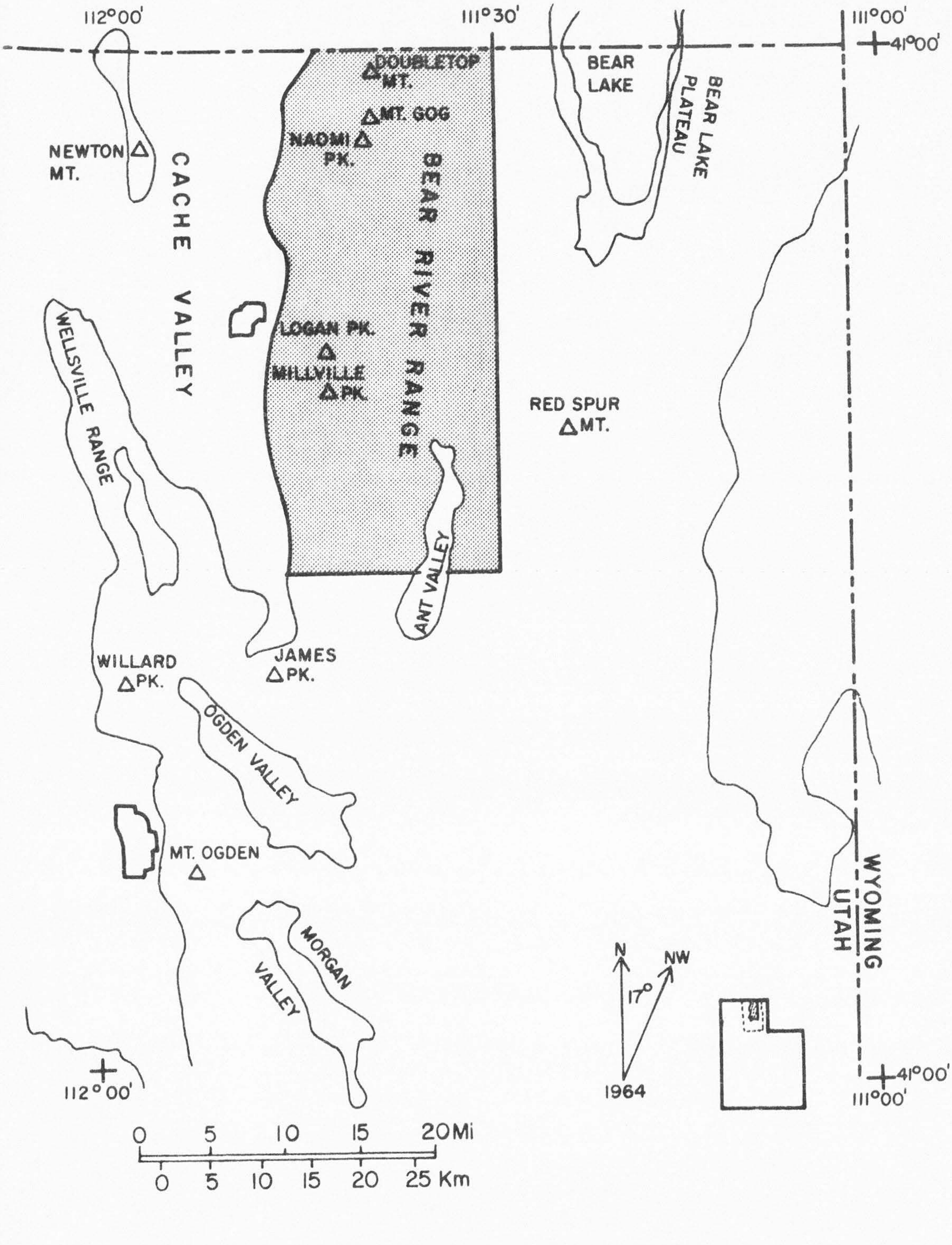

Figure 1. Index map showing location of the study area.

adjacent southern part of Cache Valley. The thesis area extends from 111° 30'00" to about 111° 52' 30" West longitude and 42° 00'00" to 41° 30'00" North latitude. The 5200-foot contour interval is the western boundary along the valley margin. It includes all of the following 7.5-minute topographic maps: Tony Grove Creek, Temple Peak, Boulder Mountain, Hardware Ranch, Naomi Peak, Mt. Elmer, Logan Peak, and Porcupine Reservoir (Figure 2). Additionally, the eastern parts of the following 7.5-minute topographic quadrangle maps are included: Richmond, Smithfield, Logan, and Paradise (Figure 2).

U. S. Highway 89 and 91, State Highways 61, 101, 163, 170, and 217, county roads, and town streets provide complete vehicular access to Cache Valley. The mountain areas in the southern part of the study area have few negotiable roads. State Highway 242 and unimproved roads in Providence, Millville, Hyrum, Paradise Dry, and East canyons provide vehicular access. Four-wheel drive vehicles can travel along a number of trails through the southern part of the study area. Except for the area between Blacksmith Fork and East canyons, the mountain land is administered by the U. S. Department of Agriculture, Forest Service. The rest of the land is controlled by the Utah Department of Fish and Wildlife or is privately owned and difficult to enter.

The northern part of the area studied is controlled by the U. S. Department of Agriculture, Forest Service. Except for unimproved roads, in High Creek, Smithfield, Green, and Logan canyons, vehicular travel is limited to U. S. Highway 89. A number of small roads extend to selected points from U. S. Highway 89, but do not connect to other

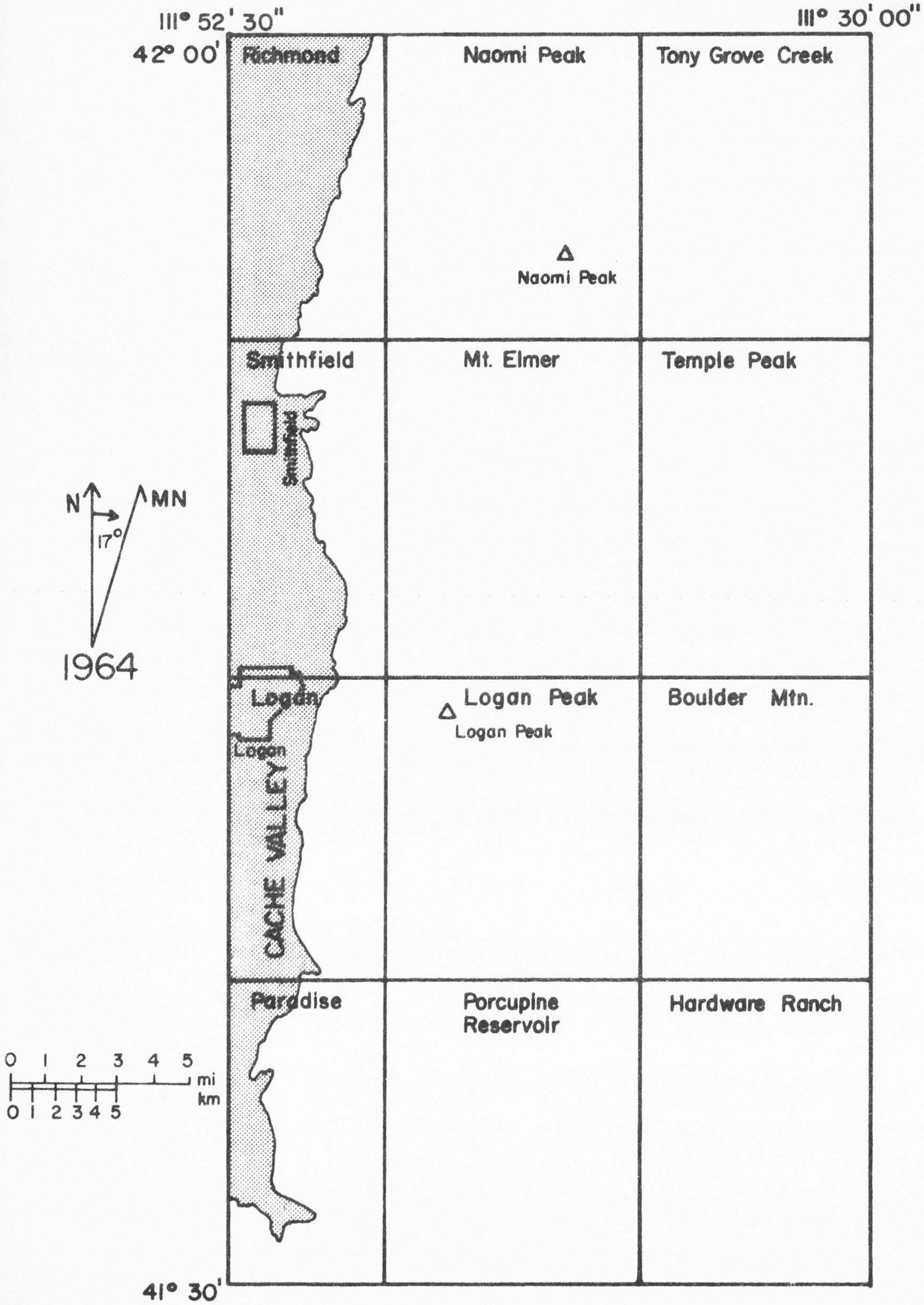

Figure 2. 7.5-minute topographic map coverage of the study area.

roads. This northern mountain area contains many trails and roads which can be negotiated by four-wheel drive vehicles. This part of the thesis area is criss-crossed with established trails maintained by the Forest Service.

Field and Laboratory Work

A variety of field techniques were used to investigate the Bear River Range. Aerial reconnaissance flights were conducted over the area in the spring of 1974, spring of 1975, and fall of 1975. Over eight hours of air time were logged in a Cessna 182 and Cessna 172. The most important features were photographed for later scrutiny. The ground survey took place from May through early November 1974. Some additional examination of specific features took place during the spring and summer of 1975. A number of areas, in the more rugged sectors of the Bear River Range, had to be reached by foot or horseback. The distances involved often required several days in travel time.

Laboratory work primarily involved the examination of collected material. Two thin sections were prepared from a rock sample collected at the mouth of Leatham Hollow. Alluvial fans in Logan and Blacksmith Fork canyons were sampled to determine the relative amounts of gravel, sand, and fines (silt-plus-clay). Factors such as the presence of boulders, stratification, and angularity were recorded for each sampling site. The samples were split, weighed, and sieved, and the sieved fractions weighed again. Longitudinal profiles of the major canyons were derived from the 7.5-minute topographic quadrangle maps. The numerical values were gained through use of a Hewlett-Packard 9801A calculator system. Using a subroutine written by Dr. Leon Huber (Appendix A), these values were used by an EAI 590 computer to generate large-scale longitudinal profiles for each major canyon in the thesis area.

Previous Investigations

The geomorphology of the Bear River Range, Utah, has been studied previously only in selected areas or for certain processes or features. No previous work has attempted to deal with the main geomorphic elements of Quaternary age in the entire range in Utah.

Some geomorphic work has been included in studies dealing with other geologic problems. J. Stewart Williams (1948) dealt with some of the geomorphology in his study of the Paleozoic rocks in the Logan quadrangle. These and some additional topics such as landslides, were discussed in his publication on the geology of Cache County (Williams, 1958a). Several landslides were identified during an investigation of the geology of the Paradise 7.5-minute topographic quadrangle (Mullins and Izett, 1964).

Only three investigations deal with geomorphology exclusively. Two unpublished M. S. theses deal with geomorphic features in the Bear River range. J. L. Young (1939) conducted a detailed survey of glaciated areas between Blacksmith Fork Canyon and the Utah-Idaho state line, He mapped erosional and depositional features resulting from glacial action. Additionally, he tried to establish a chronology of Pleistocene glacial events in this area. E. J. Williams (1964) studied the geomorphology of Logan Canyon. His area included the segment from the mouth to the junction with Tony Grove Creek. His study encompassed a variety of geomorphic elements such as alluvial fans, glaciation, and solution features. J. Stewart Williams (1962) mapped in detail deposits and features of Lake Bonneville. He outlined a chronology of events relating lake features to different levels of Lake Bonneville.

Geologic Setting

The rocks of the Bear River Range are sedimentary in origin. Rocks representing deposition during Precambrian and Paleozoic time are widely exposed (Williams, 1948, 1958a). Carbonate rocks account for about 55 percent of the thickness of the exposed stratigraphic column (Table 1). About 40 percent of the section is sandstone and quartzite. Shale and conglomerate comprises a minor amount of the rocks in the Bear River Range. Refinement of the stratigraphy by recent studies has subdivided the basic units described by Williams (1948) without changing their character (Table 2). Past workers generally have assumed that these same formations are present beneath the valley floor. This assumption seems confirmed by recent geophysical studies (Peterson and Oriel, 1970; Stanley, 1972). Except for some outliers of Paleozoic rocks, only alluvium and outcrops of Tertiary and Quaternary

Table 1. Stratigraphic section in the Bear River Range.

Unit	Principal composition	Thickness (feet)
Quaternary System		
Post-lake deposits	Alluvial deposits	
Lake Bonneville Group	Lacustrine deposits	
Provo Formation		
Bonneville Formation		
Alpine Formation		
Tertiary System		
Salt Lake Formation	Sandstone, conglomerate and limestone	800[a]
Wasatch Formation	Conglomerate, mudstone, sandstone, and limestone	530[b]
Permian-Pennsylvanian Systems		
Oquirrh Formation	Sandstone, limestone and shale	600[c]
Mississippian System		
Great Blue Formation	Limestone	725[c]
Little Flat Formation	Sandstone	800[c]
Lodgepole Formation	Limestone	750[c]
Mississippian-Devonian Systems		
Leatham Formation	Siltstone and dolostone	400[c]
Devonian System		
Beirdneau Formation	Dolostone and sandstone	1,087[d]
Hyrum Formation	Dolostone	932[d]
Water Canyon Formation	Dolostone and sandstone	495[e]
Ordovician-Silurian Systems		
Laketown Formation	Dolostone	1,422[f]
Ordovician System		
Fish Haven Formation	Dolostone	140[b]
Swan Peak Formation	Quartzite and shale	350[g]
Garden City Formation	Limestone and dolostone	1,405[h]
Cambrian System		
St. Charles Formation	Dolostone and quartzite	1,015[i]

Table 1. (Continued)

Unit	Principal Composition	Thickness (feet)
Cambrian System (Cont.)		
Nounan Formation	Dolostone	1,125[j]
Bloomington Formation	Limestone and shale	1,495[j]
Blacksmith Formation	Dolostone	485[j]
Ute Formation	Limestone and shale	745[j]
Langston Formation	Dolostone, limestone shale, and siltstone	360[k]
Brigham Formation	Quartzite and shale	2,549[k]
Precambrian System		
Mutual Formation	Quartzite, purple and white	336[k]
Precambrian quartzite	Quartzite and shale	Base not exposed

a Smithfield (Adamson, Hardy, and Williams, 1955)
b Wellsville Mtn (Williams, 1948)
c Paradise Quadrangle (Mullins and Izett, 1964)
d Blacksmith Fork Canyon (Williams, 1971)
e Water Canyon (Taylor, 1963)
f Tony Grove Lake (Budge, 1966)
g Green Canyon (VanDorston, 1969)
h Green Canyon (Ross, 1951)
i High Creek (Maxey, 1941)
j High Creek (Maxey, 1958)
k Birch Canyon (Galloway, 1970)

Table 2. Williams' 1948 stratigraphic names and their current equivalents.

Time Units	Stratigraphic names Williams (1948)	Current
Quaternary System		
	Alluvium	Lake Bonneville and post-lake deposits
Tertiary System		
	Salt Lake Formation	Salt Lake Formation
	Wasatch Formation	Wasatch Formation
Permian-Pennsylvanian		
	Wells Formation	Oquirrh Formation
Mississippian System		
	Brazer Formation	Great Blue and Little Flat Formations
	Madison Formation	Lodgepole and Leatham Formations
Devonian System		
	Jefferson Formation	Beirdneau, Hyrum, and Water Canyon Formations
Ordovician-Silurian System		
	Laketown Formation	Laketown Formation
Ordovician System		
	Fish Haven and Swan Peak Formations	Fish Haven and Swan Peak Formations
	Garden City Formation	Garden City Formation
Cambrian System		
	St. Charles Formation	St. Charles Formation
	Nounan Formation	Nounan Formation
	Bloomington Formation	Bloomington Formation
	Blacksmith Formation	Blacksmith Formation
	Ute Formation	Ute Formation
	Langston Formation	Langston Formation
	Brigham Formation	Brigham Formation
Precambrian System		
	Big Cottonwood Series	Mutual Formation and Precambrian quartzite

formations are exposed along the eastern valley margin (Williams, 1948, 1958a, 1962; Adamson, Hardy and Williams, 1955). The Quaternary Lake Bonneville Group and alluvium are exposed throughout the remainder of Cache Valley within the thesis area (Williams, 1962).

The thesis area includes parts of the Bear River Range and Cache Valley (Plates 2 and 3). Cache Valley is a north-trending, rather flat-floored valley which parallels the Bear River Range. The valley has dropped relative to the mountains to form a structural graben (Williams, 1948, 1958a; Mullins and Izett, 1964). The offset has occurred along faults along the valley margin adjacent to the western front of the Bear River Range. This fault zone continues to be active (Cook, 1971). Detailed studies have lead to the conclusion that displacement takes place on several west-dipping normal faults rather than a single fault plane (Williams, 1948, 1958a; Galloway, 1970; Mullins and Izatt, 1964; Mendenhall, 1975).

The Bear River Range incorporates two major folds within the study area (Figure 3). The Logan Peak syncline trends north-northeast near the western front of the range. The mountain front intersects the syncline just north of East Canyon (Williams, 1948). The Strawberry Valley anticline runs almost parallel to the Logan Peak syncline along the eastern part of the study area.

The tectonic evolution of the north-central Utah region can be related to the major geologic events of the western United States (Roberts, 1972). From the late Precambrian through Pennsylvanian-Permian

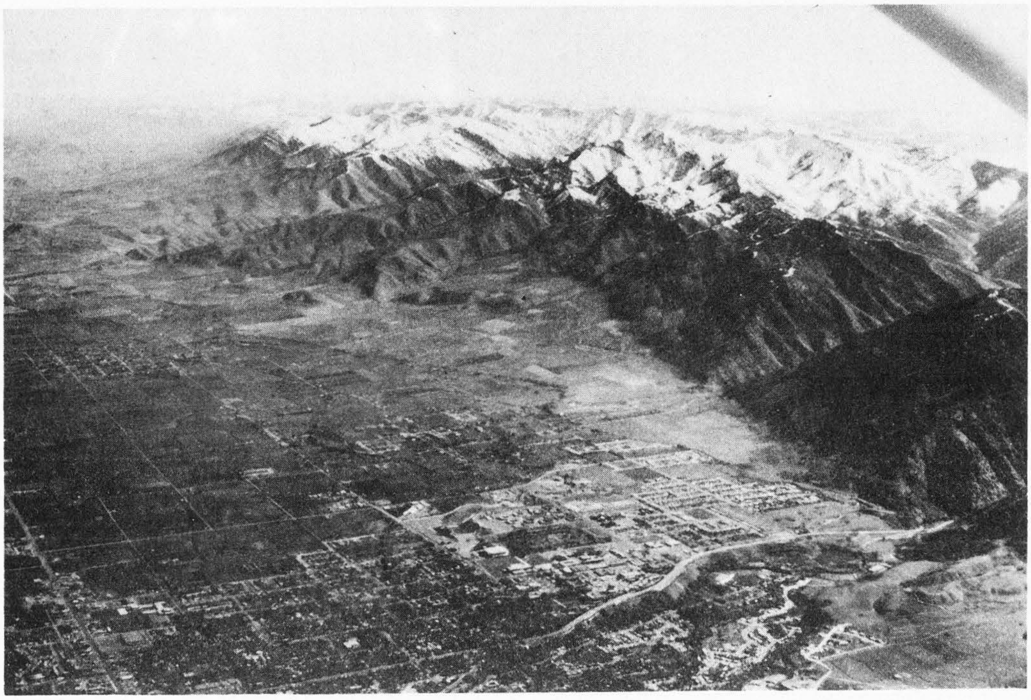

Plate 2. An oblique aerial view north along the western front of the Bear River Range.

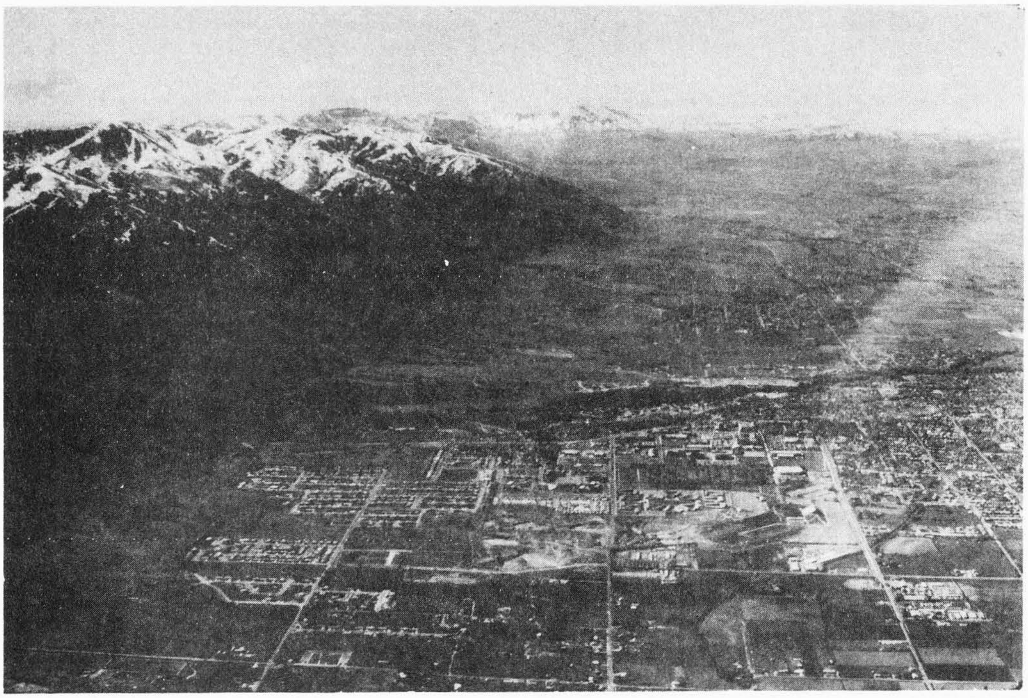

Plate 3. An oblique aerial view south along the western front of the Bear River Range.

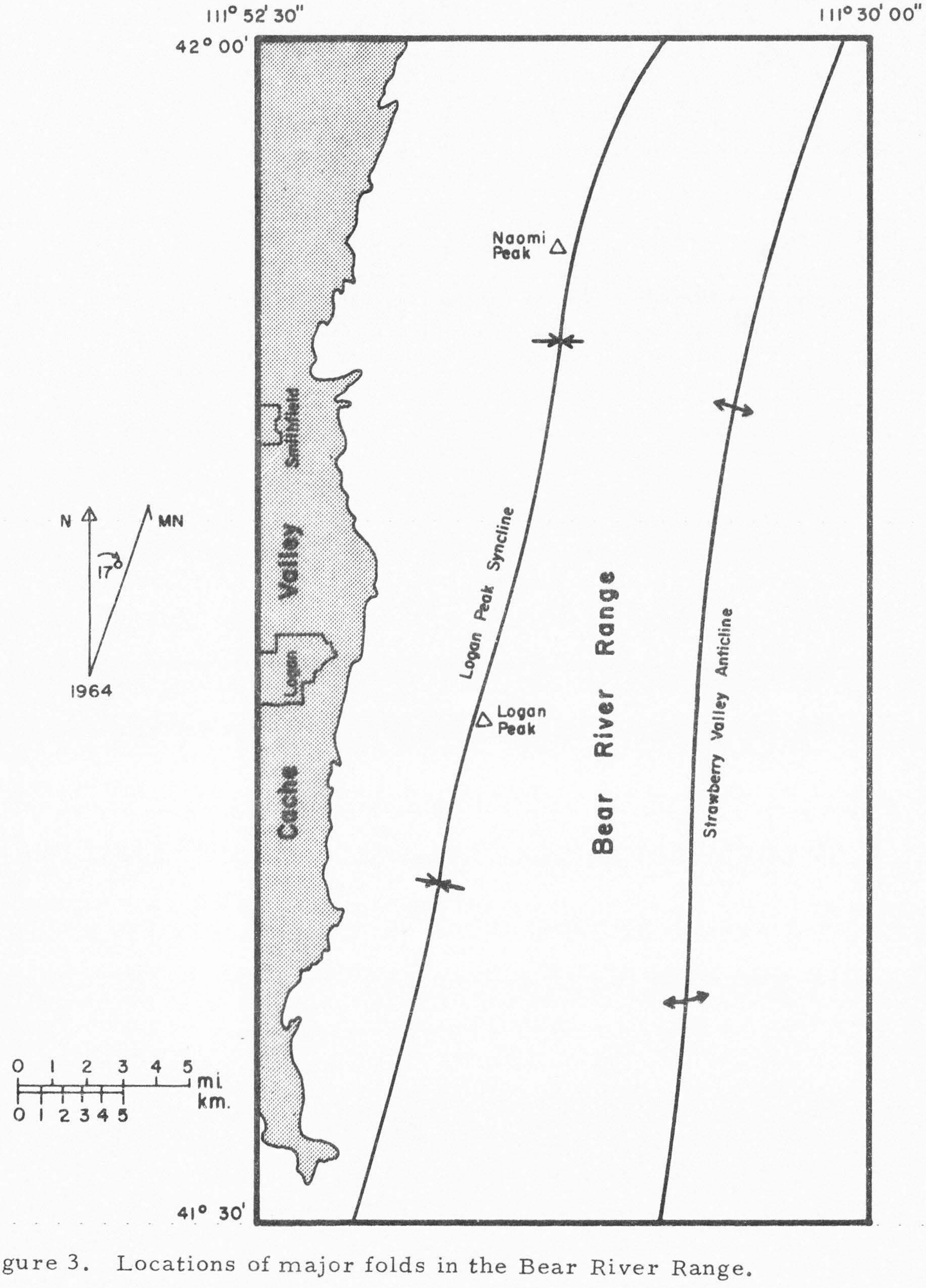

Figure 3. Locations of major folds in the Bear River Range.

time, this area was almost continuously a site of shallow-water, marine deposition. This conclusion is based on the origins and nearly continuous ages of rock formations presently exposed in the Bear River Range. Regional studies suggest that additional deposition through Triassic and Jurassic time may have taken place. Although earlier tectonic events affected this region, tectonic evolution of the present physiography took place during the Laramide orogeny. Uplift of the ancestral Bear River Range appears to have begun in the late Jurassic (Armstrong and Cressman, 1963). It is generally agreed that the folds now found in the range are Laramide in age (Williams, 1958a). In the early Tertiary, north-south normal faulting initiated the present overall Basin and Range topography including the Cache Valley graben. Restriction of the early Tertiary Wasatch Formation to accordant summits and valleys within the mountains and to downfaulted inliers along the valley margins, and the middle to late Tertiary Salt Lake Formation to valleys and valley margins support this concept. The pediments cut out on the Salt Lake Formation along the margins of Cache Valley indicate subsequent periods of quiescence. Renewed movement on the normal faults between Cache Valley and the Bear River Range began in the late Tertiary and continues through the present. Erosion has continued to shape the mountainous terrain during this period.

Lake Bonneville was an important pluvial lake during the glacial parts of the Pleistocene Epoch. The lake underwent a number of fluctuations in level. Investigators have identified features and deposits associated with stable periods. The oldest stillstand recognized is the Alpine level, deposits of which are called the Alpine Formation. Studies in the Salt Lake Valley indicate that the Alpine level may correlate with the Bull Lake glaciation (Morrison, 1961). The Bonneville level and the younger Provo level appear to correlate with the Pinedale glaciation (Morrison, 1961). Cache Valley contained an extension of Lake Bonneville in north-central Utah. Extensive mapping in Cache Valley by Williams (1962) has identified probable features of the Alpine level near 5,100 feet, those of the Bonneville level near 5,135 feet, and those of the Provo level near 4,800 feet. Some variation exists in the exact elevation of the Bonneville level at various points in Cache Valley (Crittenden, 1963). Age determinations suggest that the Alpine maximum was around 37,000 years ago. The Bonneville maximum apparently was between 25,000 to 14,000 years ago. The Provo maximum is suggested to have been about 12,000 to 11,000 years ago (Broecker and Orr, 1958).

Red Rock Pass is located in Idaho at the north end of Cache Valley. Lake Bonneville overflowed at Red Rock Pass, and flooded a considerable extent of the Snake River valley (Malde, 1968). This flood is believed related to Lake Thatcher in Gem Valley, Idaho. Prior to the flood at Red Rock Pass, Lake Thatcher had formed as a result of blocking and disruption of the Bear River by lava flows, probably along the present route of the Portneuf River to the Snake River. The impounded water formed Lake Thatcher in Gem Valley and eventually overflowed into Lake Bonneville through Oneida Narrows. The draining of Lake Thatcher took place about 27,000 years ago (Bright, 1963).

Some workers suggest that the overflow at Red Rock Pass happened about this same time as a result of the additional lake water and increased drainage via the Bear River (Malde, 1968). This concept seems substantiated by radiocarbon dates and analysis of soil development on related deposits. If the initial flood took place at this time, it pre-dates the Bonneville level. The relationship of Lake Bonneville and Lake Thatcher deposits in Gem Valley shows that the Bonneville level extended into the valley through Oneida Narrows (Bright, 1963). Sometime between 18,000 and 11,500 years ago, outflow through Red Rock Pass took place (Bright, 1963; Broecker and Orr, 1958). The outlet was subsequently cut to the Provo level. If the concept that the Bear River drainage provided the necessary water to create an overflow condition, then the overflow between 18,000 and 11,500 years ago may have been the only Bonneville flood (Bright, 1963). It is possible that the overflow at the Bonneville level was the second flood to drain through Red Rock Pass (Malde, 1968). Based on the information accumulated, at least one and possibly two overflows took place.

CANYONS

General Statement

The eighteen major canyons which open into Cache Valley along the western front of the Bear River Range constitute the main geomorphic elements in this area (Figure 4). A systematic examination of these features is based on a canyon-by-canyon description starting with the northernmost and proceeding southward.

Cross-valley and longitudinal profiles are used to describe the canyons. The cross-valley profiles are constructed perpendicular to the canyon. Profile cross-sections are two miles apart, except for the cross-sections of Logan and Blacksmith Fork canyons. Because of the low gradients in these two canyons, the cross-sections are separated by four miles.

Except for Logan and Blacksmith Fork canyons, all longitudinal profiles start at 5000 feet along the margin of Cache Valley. Logan and Blacksmith Fork longitudinal profiles begin at 4600 feet. The longitudinal profiles follow the thalweg from a point just downstream from the mouth to the upstream end of the canyon. The locations of faults and lithologic contacts noted along the longitudinal profiles are based primarily on mapping by Williams (1948). Some more recent structural

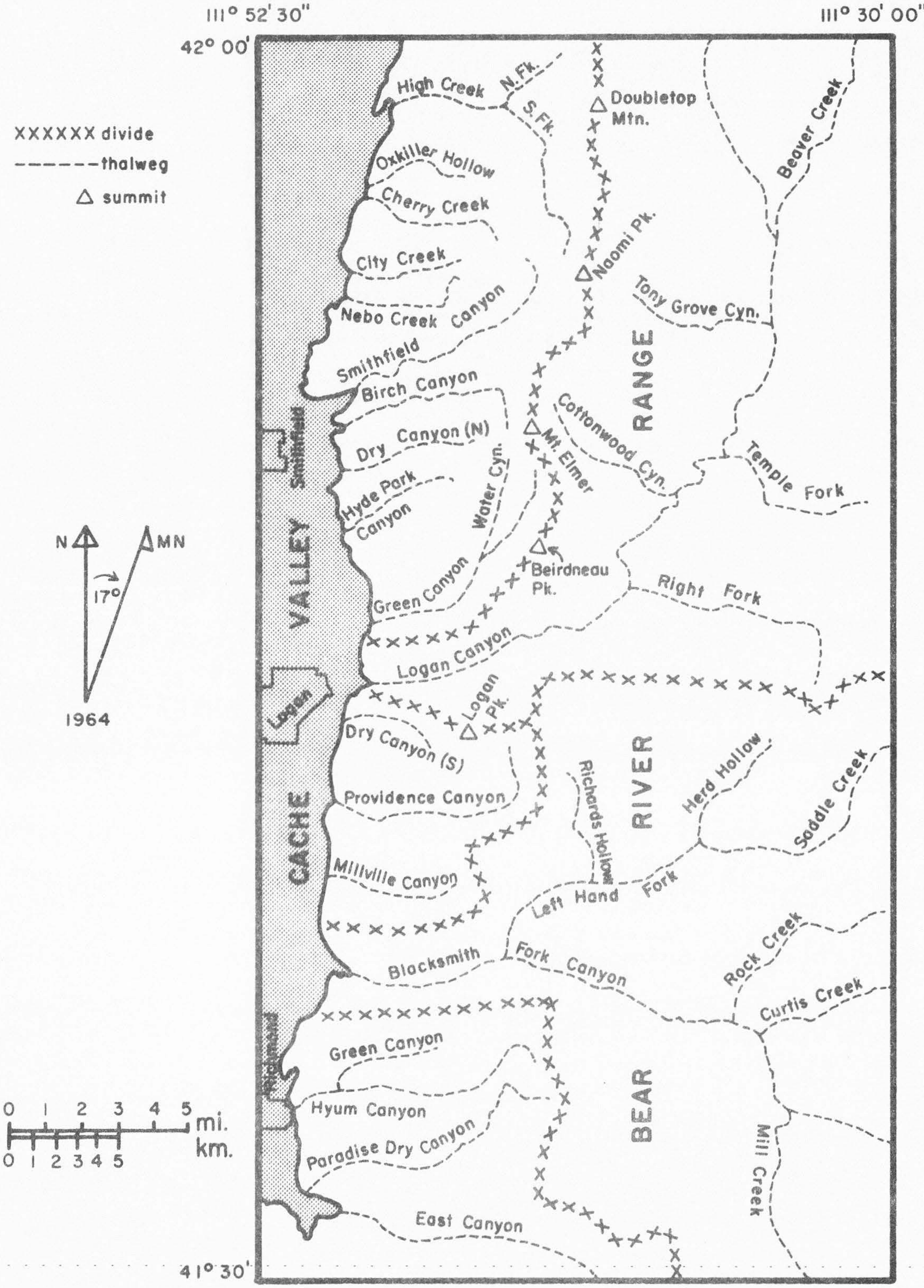

Figure 4. Locations of canyons within the Bear River Range.

mapping has supplemented this source (Mullins and Izett, 1964; Galloway, 1970; Mendenhall, 1975).

Changes in the overall concave-up longitudinal profile of a canyon are classified by gradient changes and curvature characteristics of profile segments. The overall concave-up profile of a canyon is a combination of planar, concave, and convex segments of varying length and radii. The convex-up segments usually reflect anomalous departures from the overall concave-up profile. With the aid of a French curve, the convex-up segments were delineated along each profile. A convex-up segment is defined as a profile segment consisting of three or more consecutive contour intervals that fits a convex-up curve (Figure 5).

Gradient changes are defined on the basis of angle of change and abruptness between concave or planar segments. Inflections are defined as changes in slope that include two or more contour intervals in segments immediately upstream and downstream from the point of inflection. If the upstream segment projects above the downstream segment, it is an upward inflection. If the upstream segment projects below, it is a downward inflection (Figure 5). More abrupt changes are defined as treads or risers. Risers and treads are defined as abrupt changes in slope that extend only one contour interval upstream or downstream from the point of change. A tread projects above the downstream profile. A riser projects below the downstream profile.

The locations of treads, risers, inflections and convex-up segments were determined with the aid of a French curve and straight edge.

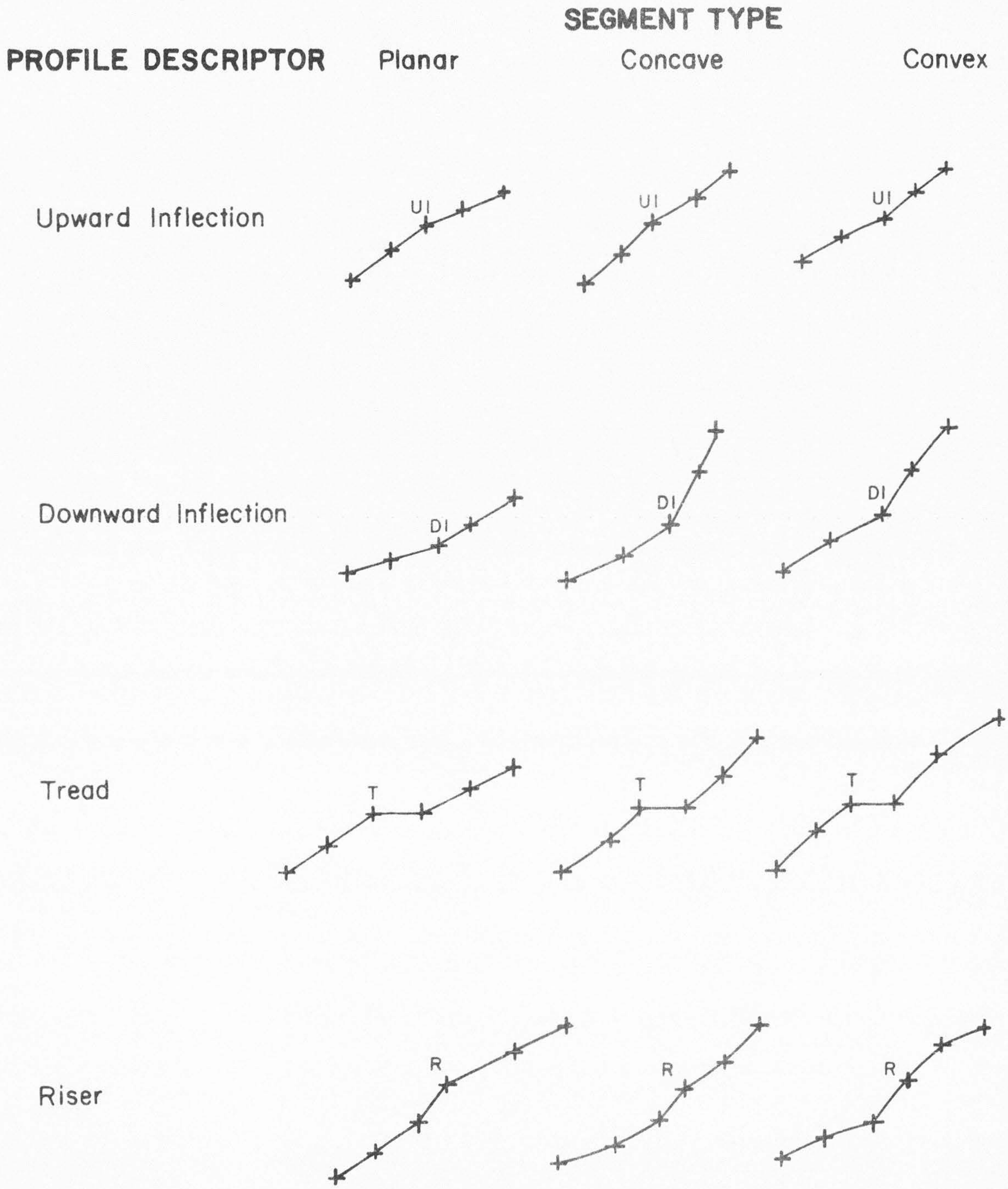

Figure 5. Classification of profile changes.

The examination starts at the highest point on the profile at the head of the canyon and proceeds toward the lowest point at the mouth. First the convex-up segments are identified along the entire profile. Beginning again at the highest point, treads, risers, and inflections between adjacent planar and concave segments are delineated.

Description

High Creek Canyon

High Creek Canyon is the northernmost canyon in the thesis area (Figure 4). The canyon follows a general east-west trend from its mouth upstream to the first major fork. The mouth is located in sec. 13, T. 14 N., R. 1 E. Within the Bear River Range, the main canyon splits into the North Fork, then Bear Canyon, and South Fork, then Little Left Hand Fork, and Bullen Hole Fork tributaries. The North Fork heads at 8,920 feet on the west flank of an unnamed peak (9,454 feet) located approximately 0.5 mile south of the Utah-Idaho state line. The Bear Canyon branch heads at 8,600 feet on the northwest flank of Doubletop Mountain (9,873 feet). South Fork heads at 8,520 feet near High Creek Lake (8,762 feet). Little Left Hand Fork heads at 9,000 feet on the west flank of a peak (9,736 feet) on the ridge separating it from Steam Mill Canyon. Bullen Hole Fork heads at 8,920 feet on the ridge separating it from White Pine Canyon.

High Creek Canyon along the main course and the North Fork can be characterized, in cross-section, as a narrow-bottomed, steep-walled canyon (Figure 6). The same description applies to the main course and the South Fork, except for the uppermost reaches of South Fork. In this section, the canyon bottom is wider as a result of minor glacial erosion (Figure 7). The overall drainage basin widens headward from the mouth.

The highest point in the longitudinal profiles is within the Nounan Formation (Plate 4). There are nine convex-up segments.

The highest point in the longitudinal profile of South Fork of High Creek Canyon is within the Garden City Formation (Plate 5). There are eleven convex-up segments along the profile.

Oxkiller Hollow

Oxkiller Hollow is a small canyon trending generally east-west (Figure 4). The canyon mouth is located in sec. 24, T. 14 N., R. 1 E. at an altitude of 5,000 feet. The head of Oxkiller Hollow is at an elevation of 8,240 feet on the west flank of a peak (9,210 feet) that lies west of the South Fork of High Creek Canyon.

Oxkiller Hollow can be characterized as a steep-walled, narrow-bottomed canyon along the entire course (Figure 8). The drainage basin is rectangular in shape.

The highest point along the longitudinal profile of Oxkiller Hollow is within the Ute Formation (Plate 6). There are three convex-up segments along this profile.

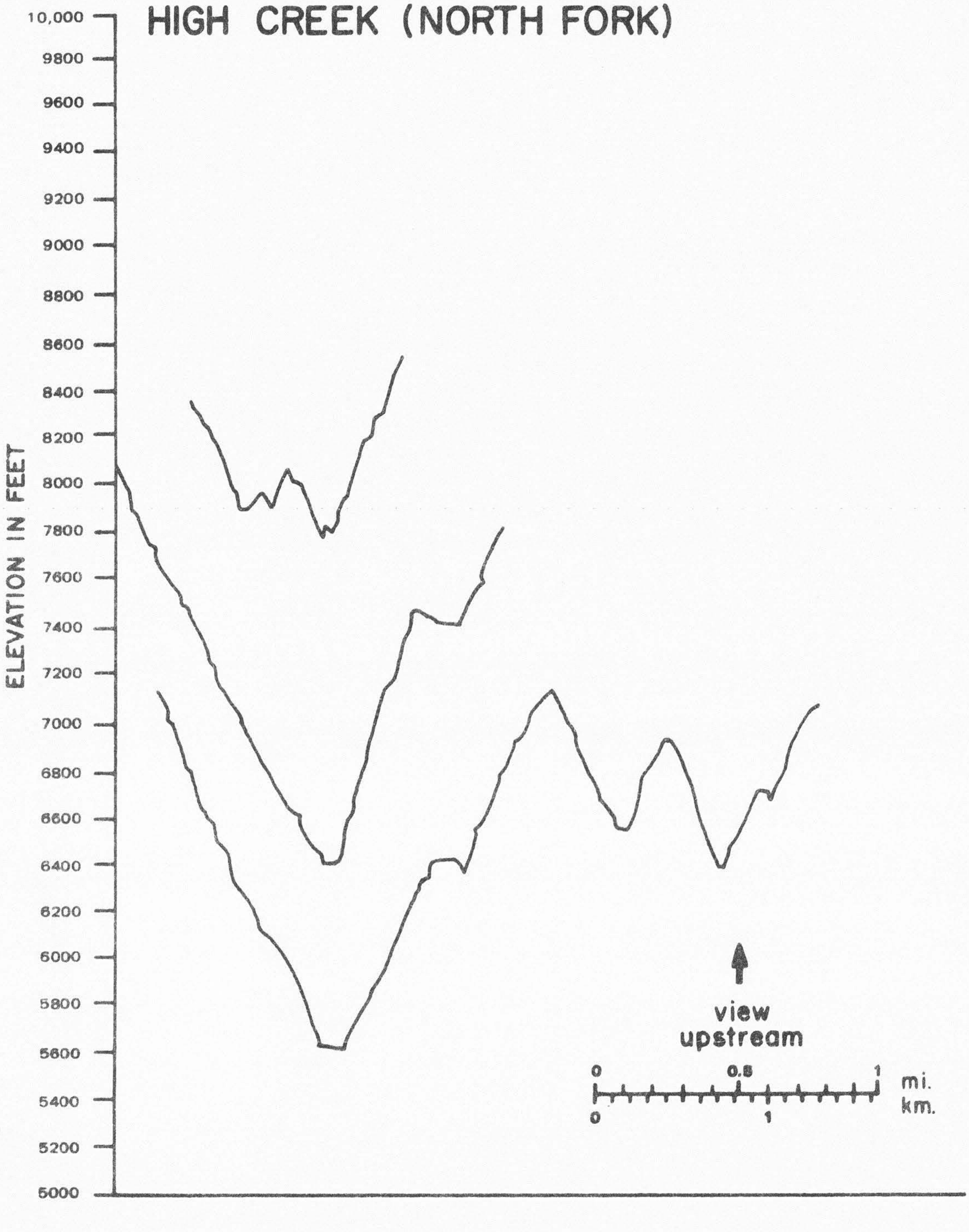

Figure 6. Cross-valley profiles of North Fork of High Creek Canyon.

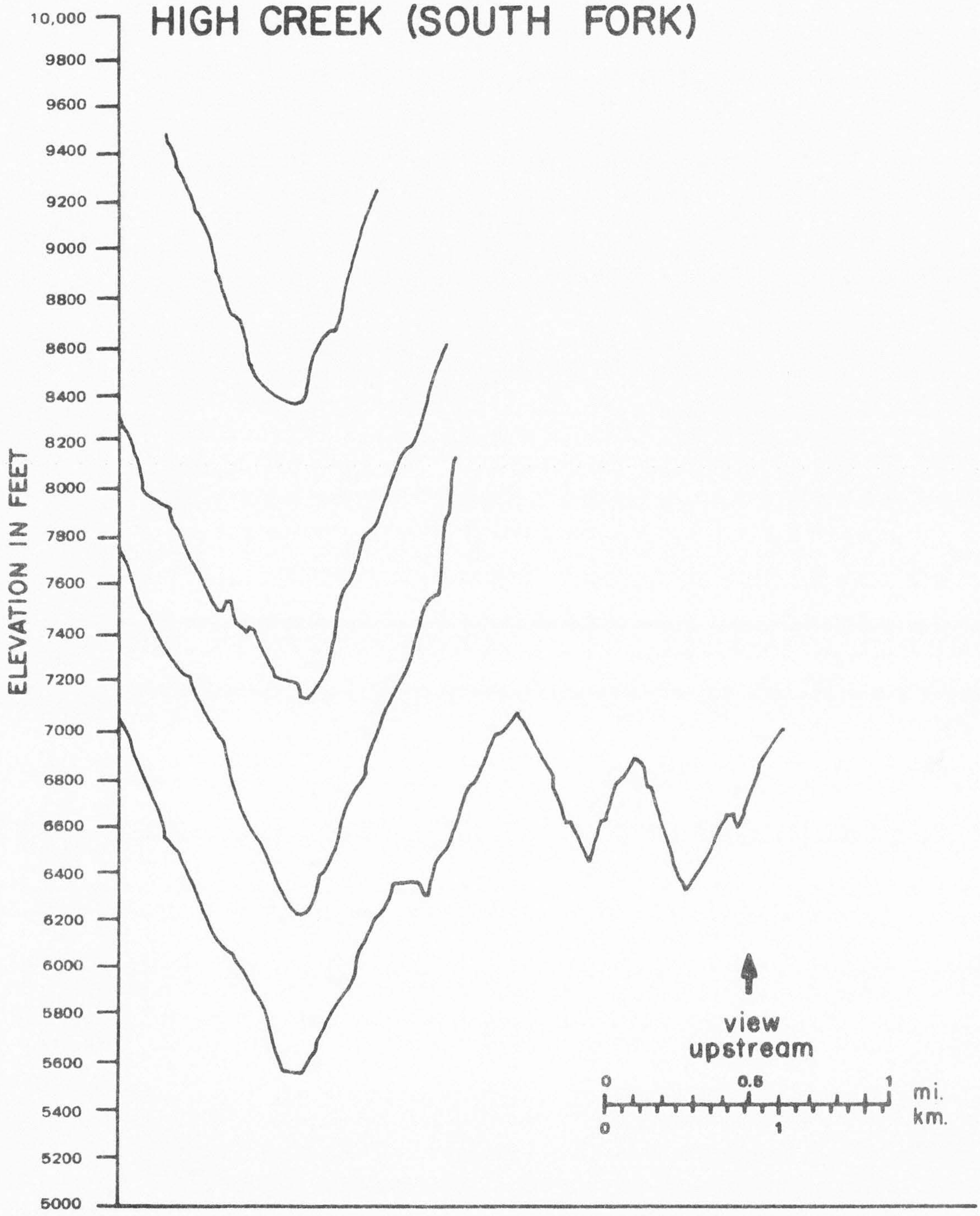

Figure 7. Cross-valley profiles of South Fork of High Creek Canyon.

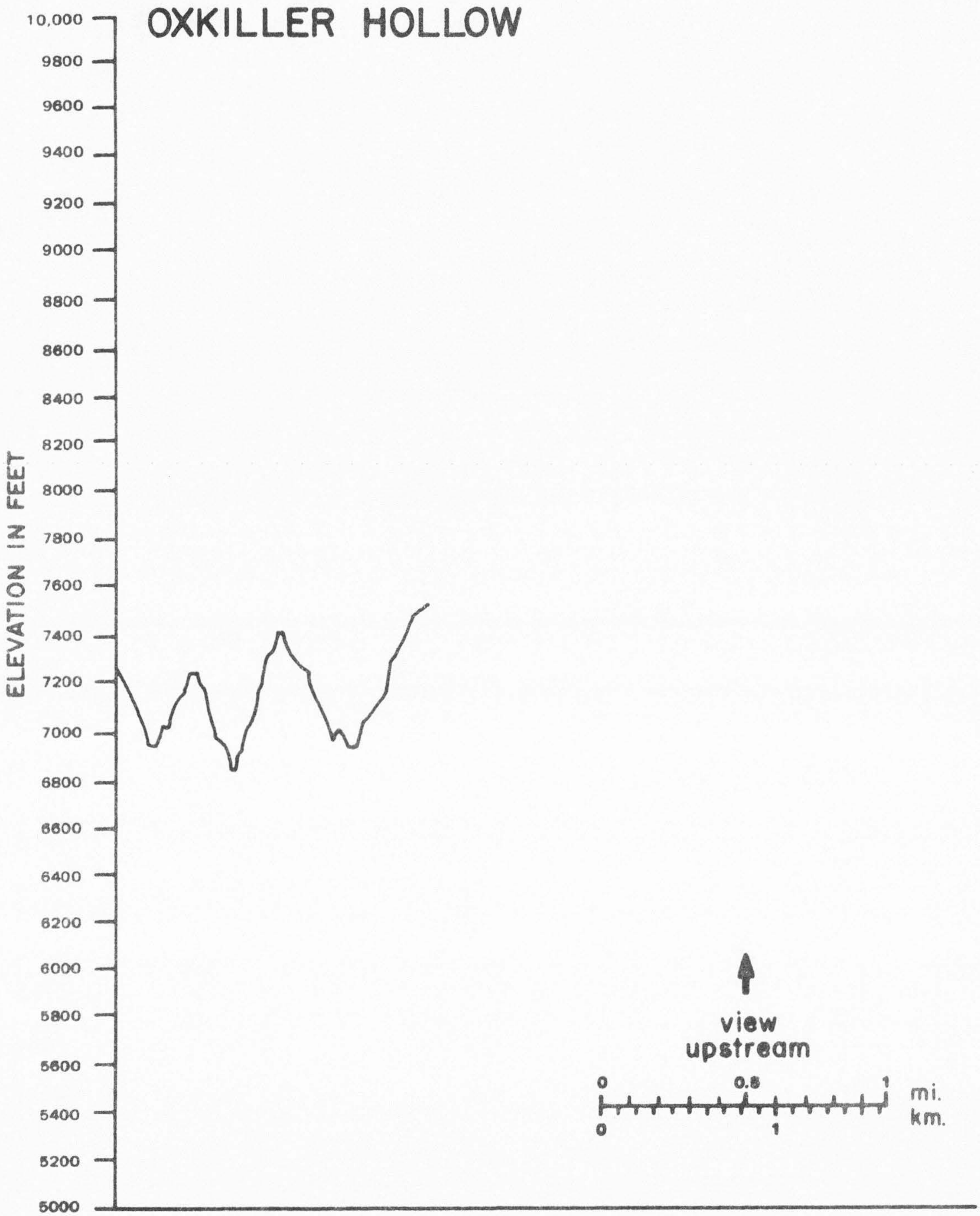

Figure 8. Cross-valley profiles of Oxkiller Hollow.

Cherry Creek Canyon

Cherry Creek Canyon is oriented in a generally east-west direction (Figure 4). The mouth of the canyon is located in sec. 24, T. 14, N., R. 1 E. The head of the canyon lies at an elevation of 8,600 feet on the southwest flank of Cherry Peak (9,765 feet).

The bottom of Cherry Creek Canyon is slightly wider near the mouth than along the main extent of the canyon. With this exception, the canyon can be described as narrow-bottomed and steep-walled (Figure 9). In plan view, the drainage basin widens headward from a point near the mouth.

The highest point on the longitudinal profile of Cherry Creek Canyon is within the Nounan Formation (Plate 7). There are eight convex-up segments along this profile.

City Creek Canyon

City Creek Canyon trends east-west (Figure 4). The canyon mouth is located in sec. 36, T. 14, N., R. 1 E. Location of the head is at 8,280 feet on the southwest flank of a peak (9,338 feet) along the northeast southwest trending divide between Smithfield and Cherry Creek canyons.

City Creek Canyon is a steep-walled, narrow-bottomed canyon (Figure 10). The drainage basin is rectangular in shape.

The highest point along the longitudinal profile of City Creek

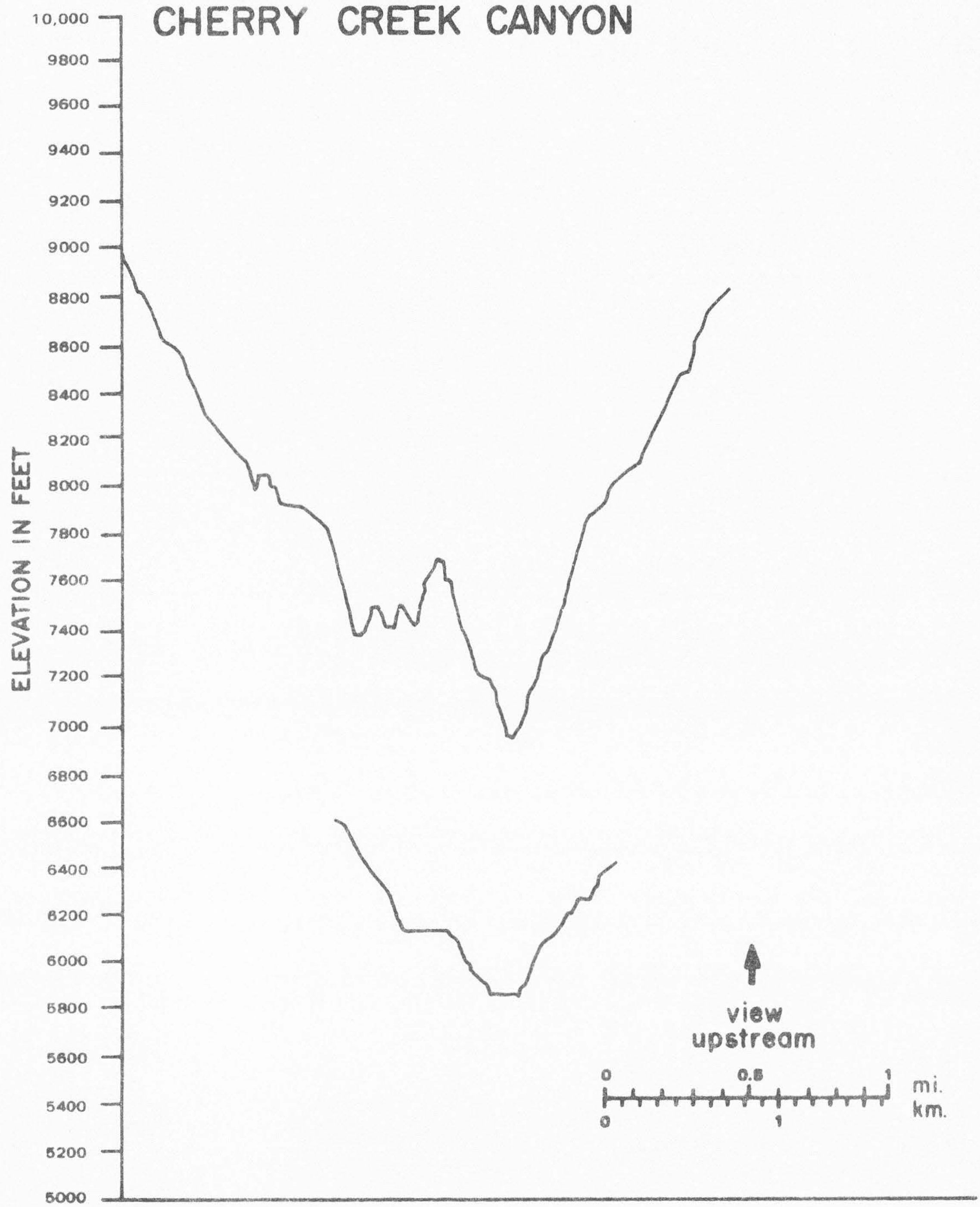

Figure 9. Cross-valley profiles of Cherry Creek Canyon.

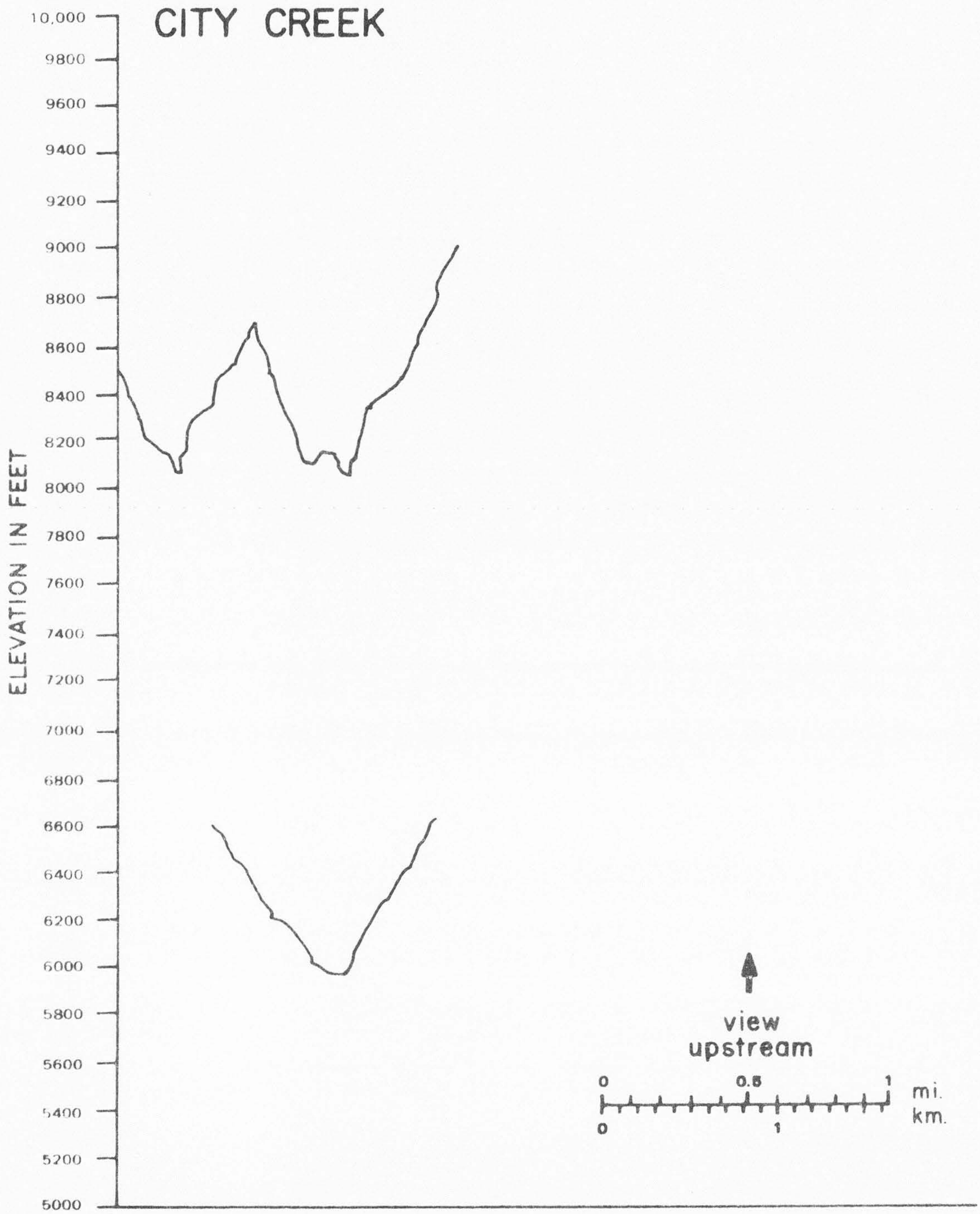

Figure 10. Cross-valley profiles of City Creek Canyon.

Canyon is within the Bloomington Formation (Plate 8). There are five convex-up segments along the profile.

Nebo Creek Canyon

Nebo Creek Canyon is oriented in a generally east-west direction (Figure 4). The mouth of the canyon is located in sec. 1, T. 13 N., R. 1 E. The canyon head is located at 8,080 feet on the southwest flank of a peak (9,041 feet) on the divide between Smithfield and Cherry Creek canyons.

Nebo Creek Canyon has low, moderately steep walls (Figure 11). The canyon bottom is wider near the mouth than near the head. In plan view, the drainage basin is rectangular in shape.

The highest point on the longitudinal profile of Nebo Creek Canyon is within the Blacksmith Formation (Plate 9). There are ten convex-up segments along the profile.

Smithfield Canyon

Smithfield Canyon trends generally northeast-southwest in its lower reach, but turns to nearly north-south in its upper reach (Figure 4). The canyon mouth lies within sec. 23, T. 13 N., R. 1 E. At an elevation of 8,960 feet, the head of the canyon is on the southeast flank of Cherry Peak, northwest of Naomi Peak (9,979 feet).

Smithfield Canyon is a narrow-bottomed, steep-walled canyon along the lower reach (Figure 12). The upper reach can be characterized in the same way except for the part near the head where the canyon

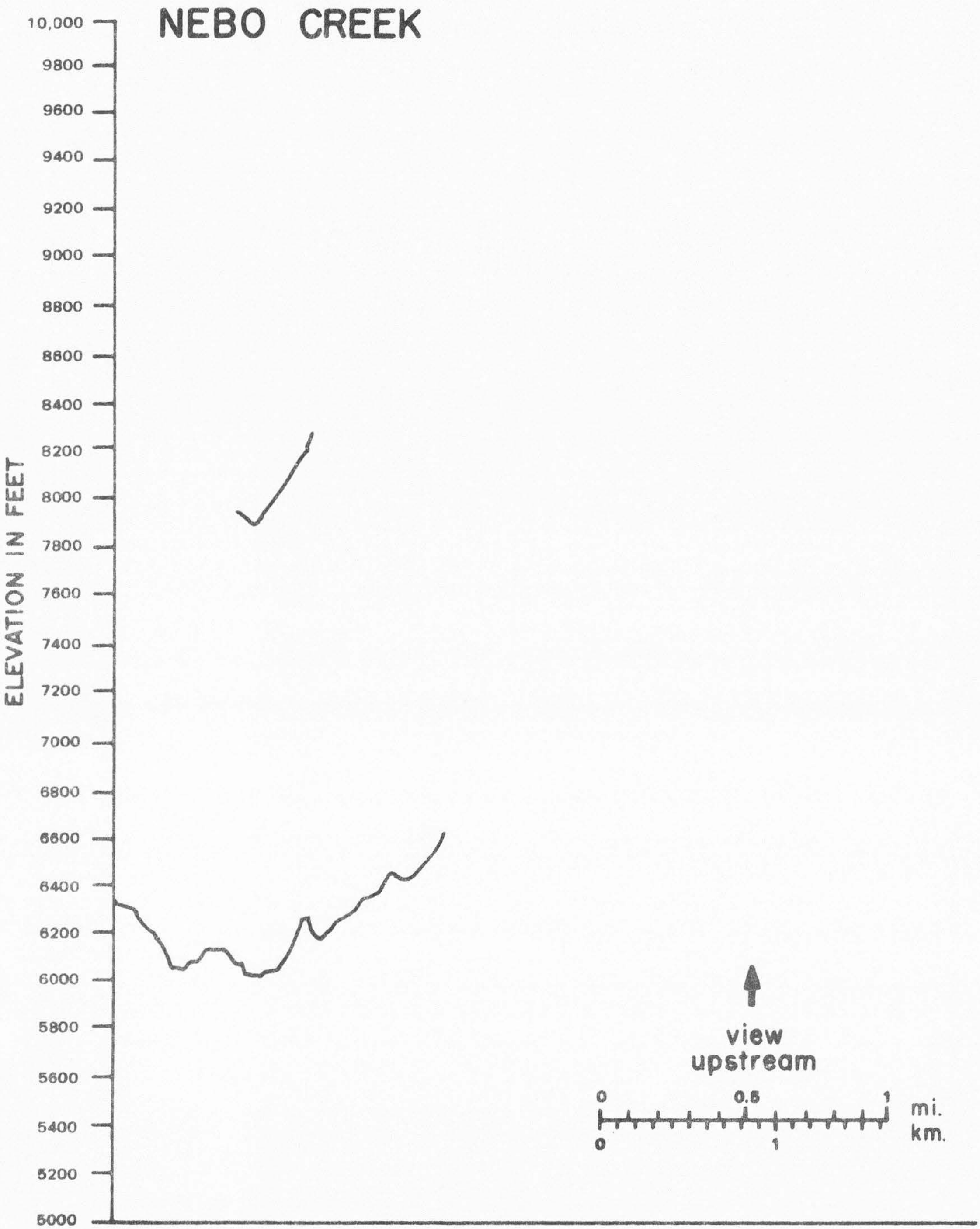

Figure 11. Cross-valley profiles of Nebo Creek Canyon.

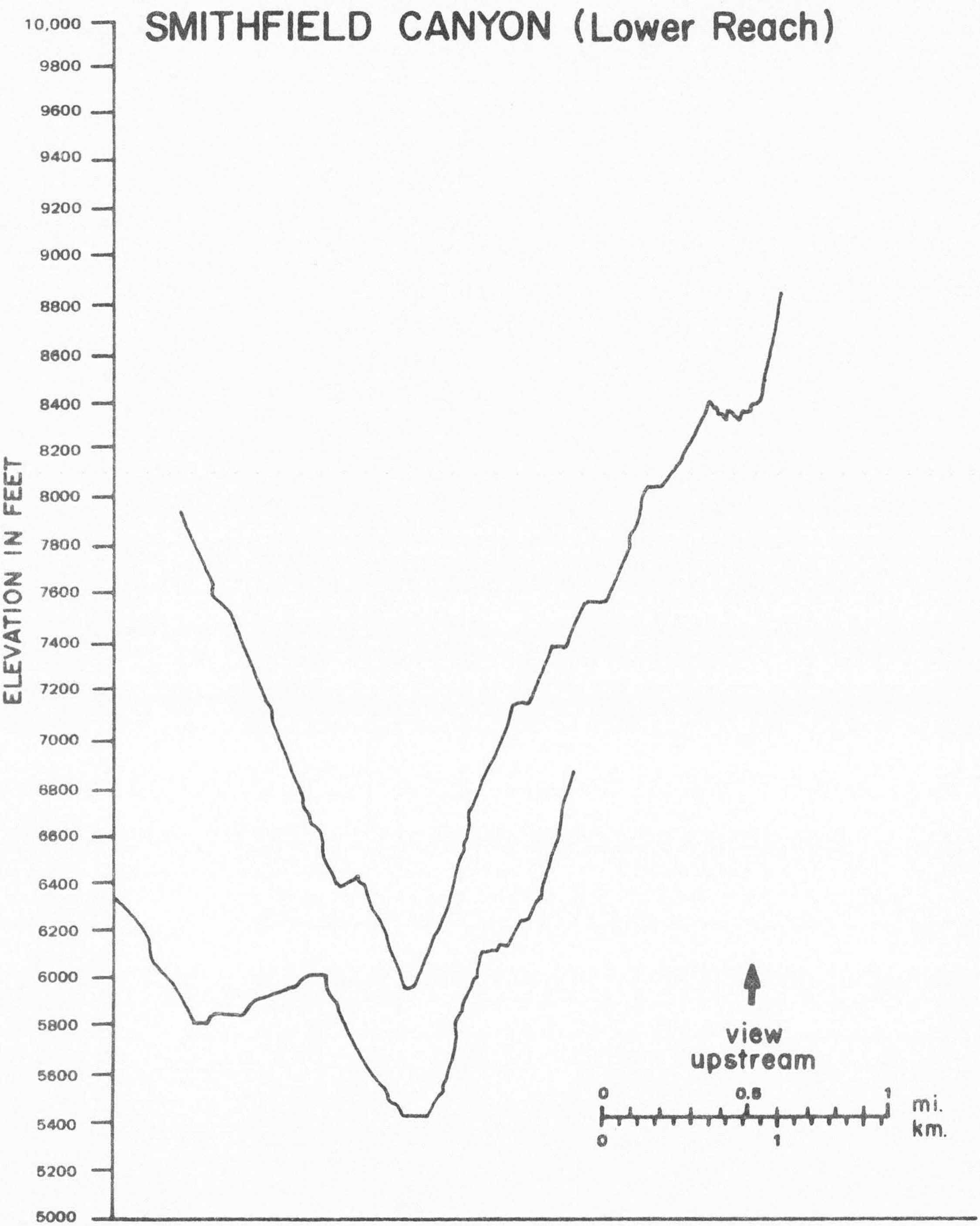

Figure 12. Cross-valley profiles of Smithfield Canyon (lower reach)

bottom widens significantly (Figure 13). The drainage basin can be described as widening headward in plan view.

The highest point along the longitudinal profile of Smithfield Canyon is within the Garden City Formation (Plate 10). There are seven convex-up segments in this profile.

Birch Canyon

Birch Canyon trends east-west in its lower reach, but nearly north-south in its upper reach (Figure 4). Location of the canyon mouth is in sec. 26, T. 13 N., R. 1 E. The head of Birch Canyon is at an elevation of 9,000 feet on the north flank of Mt. Jardine (9,566 feet).

Birch Canyon can be characterized as a narrow-bottomed, steep-walled canyon (Figure 14). In plan view, the drainage basin is rectangular.

The highest point on the longitudinal profile of Birch Canyon is within the Jefferson Formation (Plate 11). There are eight convex-up segments along the profile.

Dry Canyon (North)

Dry Canyon (North) follows an east-west trend (Figure 4). The canyon mouth is located in sec. 36, T. 13 N., R. 1 E. The head of the canyon lies at an elevation of 8,720 feet on the west flank of Mt. Jardine (9,566 feet). The canyon is characterized as a narrow-bottomed, steep-walled canyon along its entire course (Figure 15).

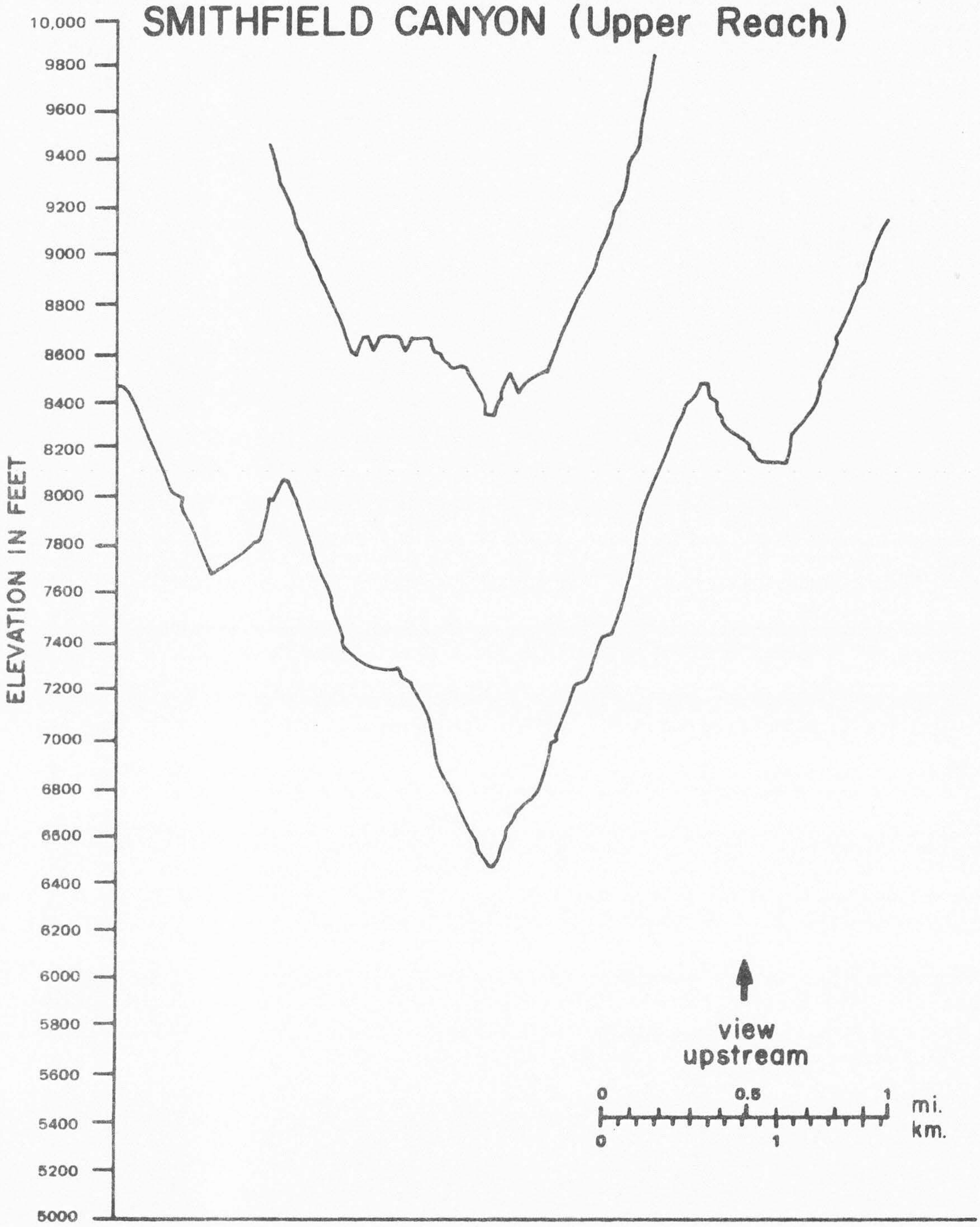

Figure 13. Cross-valley profiles of Smithfield Canyon (upper reach)

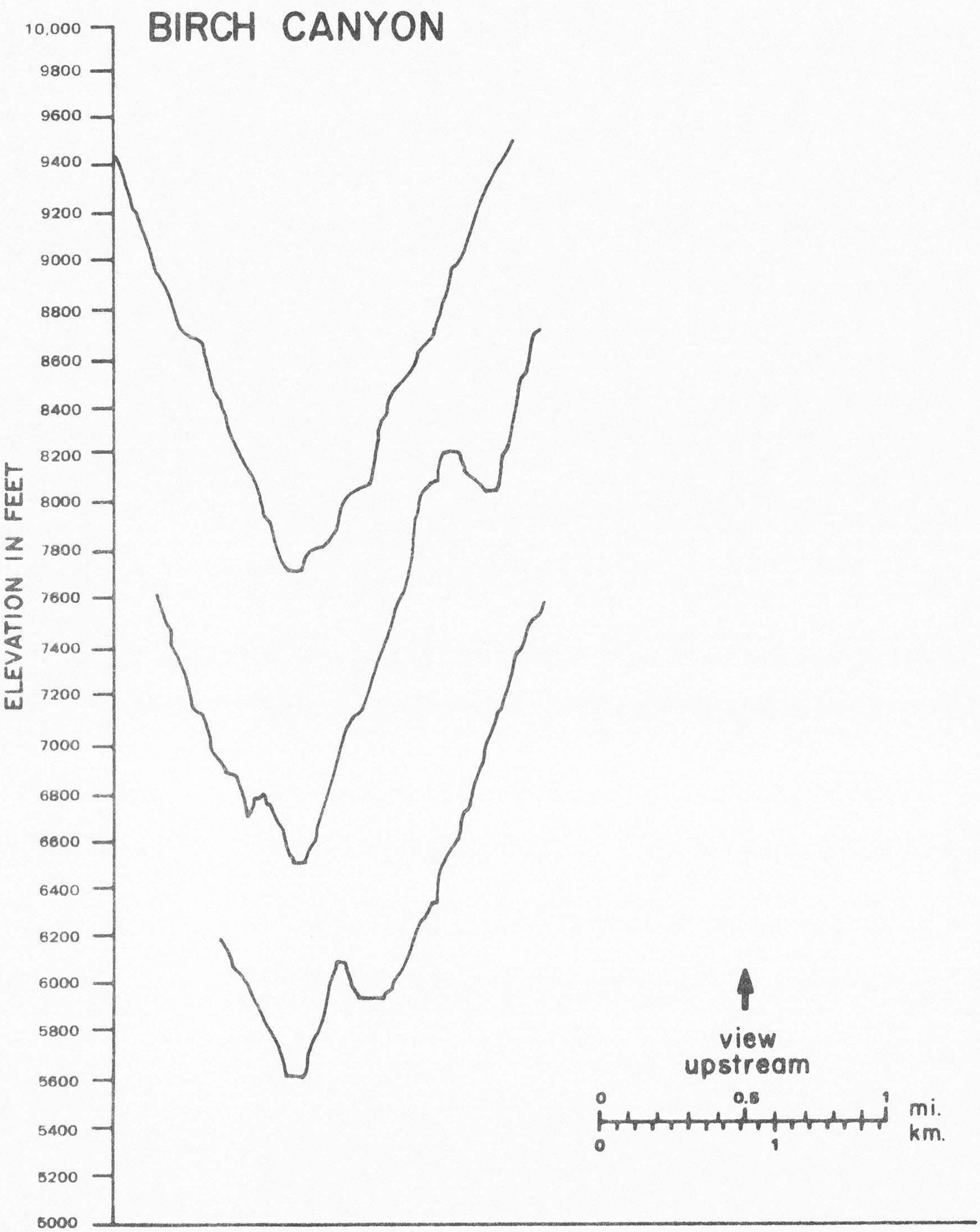

Figure 14. Cross-valley profiles of Birch Canyon.

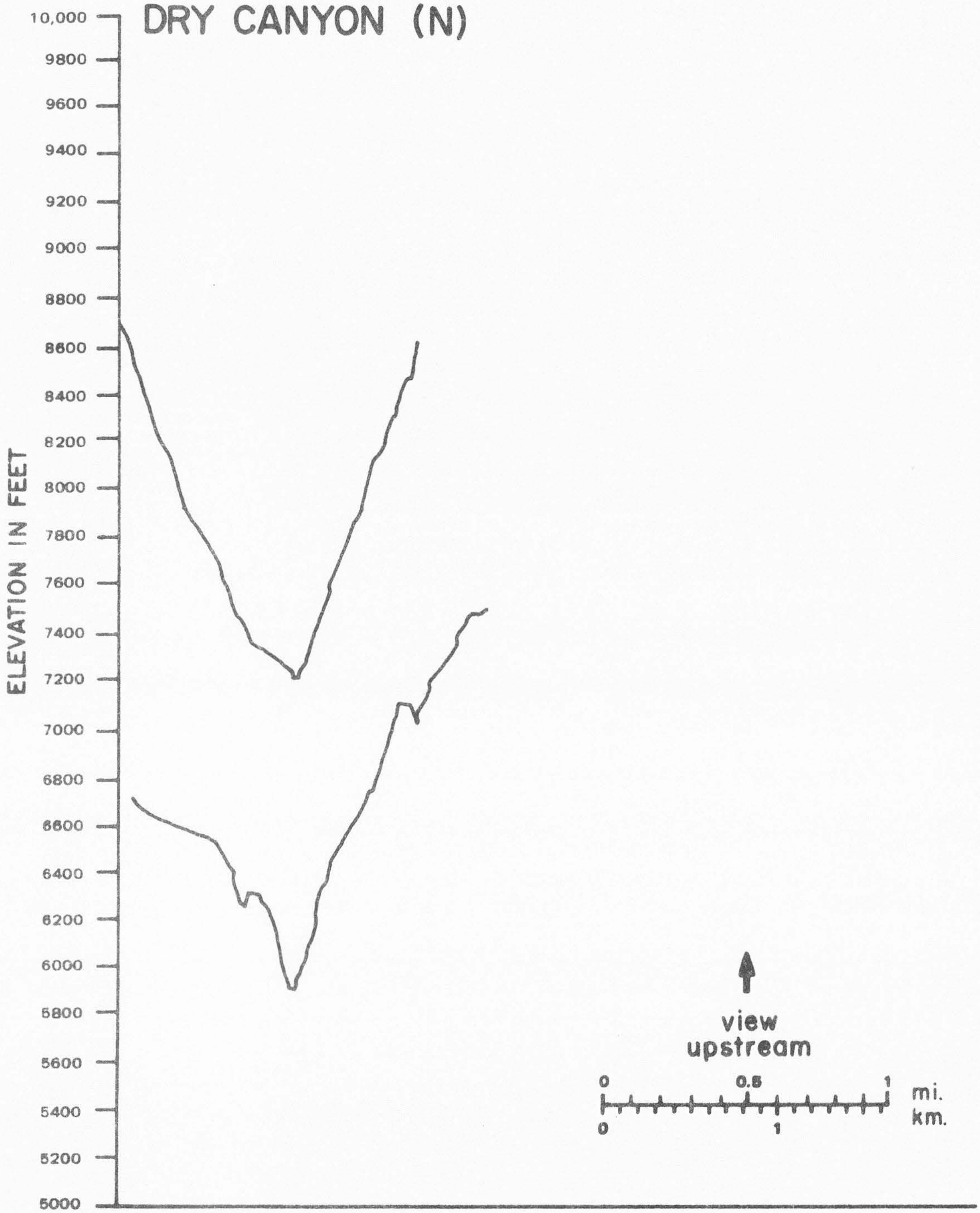

Figure 15. Cross-valley profiles of Dry Canyon (North).

The highest point on the longitudinal profile of Dry Canyon (North) is within the Jefferson Formation (Plate 12). There are six convex-up segments along the profile.

Hyde Park Canyon

Hyde Park Canyon trends generally east-west (Figure 4). The canyon mouth is in sec. 1, T. 12 N., R. 1 E. The head of Hyde Park Canyon is at an elevation of 8,800 feet on the southwest flank of a peak (9,208 feet) on the divide between Dry Canyon (North) and Water Canyon, a tributary of Smithfield Canyon. The canyon has a narrow-bottom and steep walls in the lower reach. In the upper reach, the overall canyon bottom is significantly wider (Figure 16). The drainage basin is rectangular in shape (Figure 4).

The highest point on the longitudinal profile of Hyde Park Canyon is within the Laketown Formation (Plate 13). There are seven convex-up segments along the profile.

Green Canyon

Green Canyon follows an east-west trend in its lower reach, and a northeast-southwest trend in its upper reach (Figure 4). Location of the canyon mouth is in sec. 24, T. 12 N., R. 1 E. At an elevation of 9,320 feet, the head lies on the north flank of a peak (9,378 feet) northeast of Mt. Jardine (9,566 feet). Green Canyon has one major tributary, Water Canyon. In the lower reach, Green Canyon is a steep-walled, narrow-bottomed canyon (Figure 17). The canyon bottom is significantly

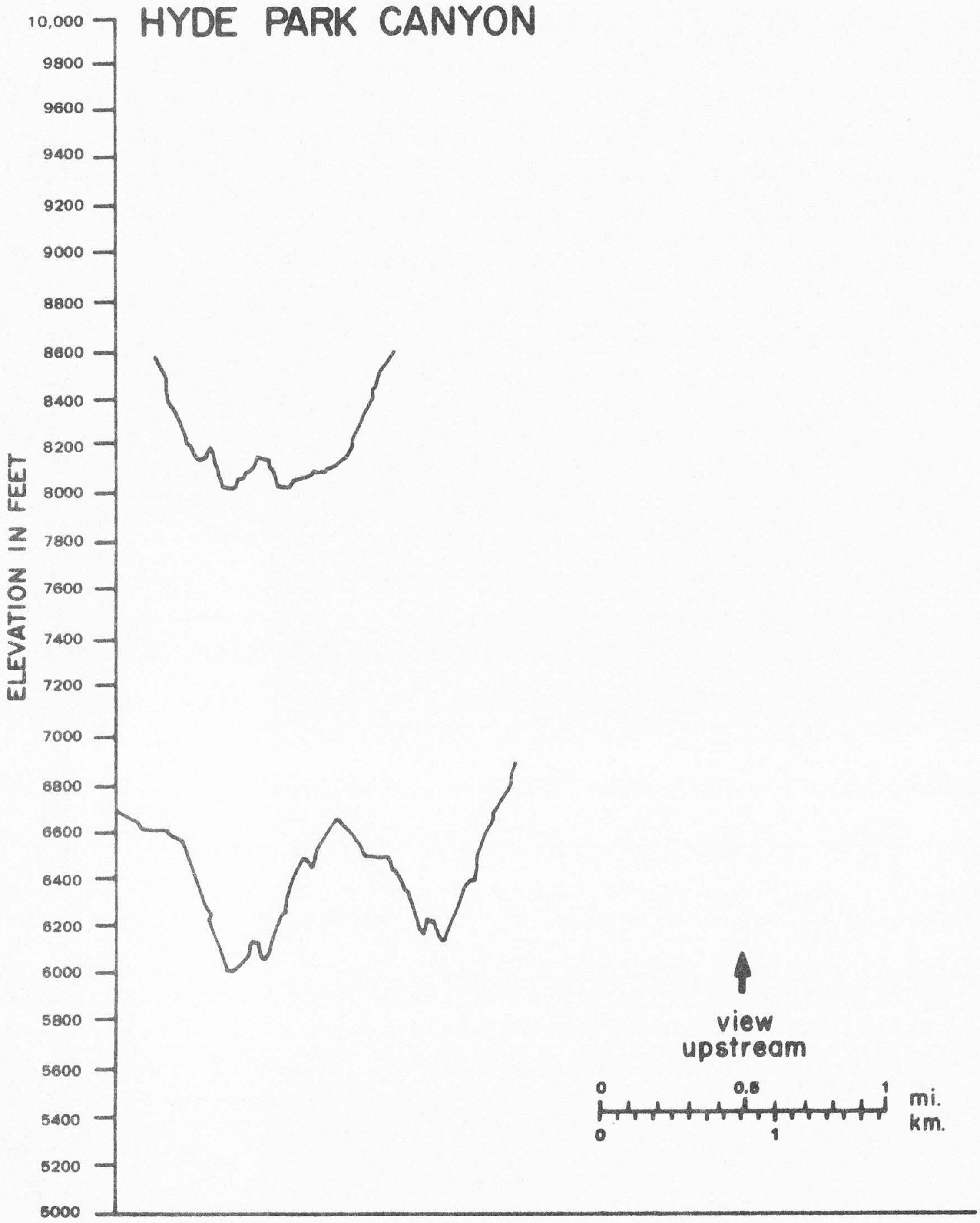

Figure 16. Cross-valley profiles of Hyde Park Canyon.

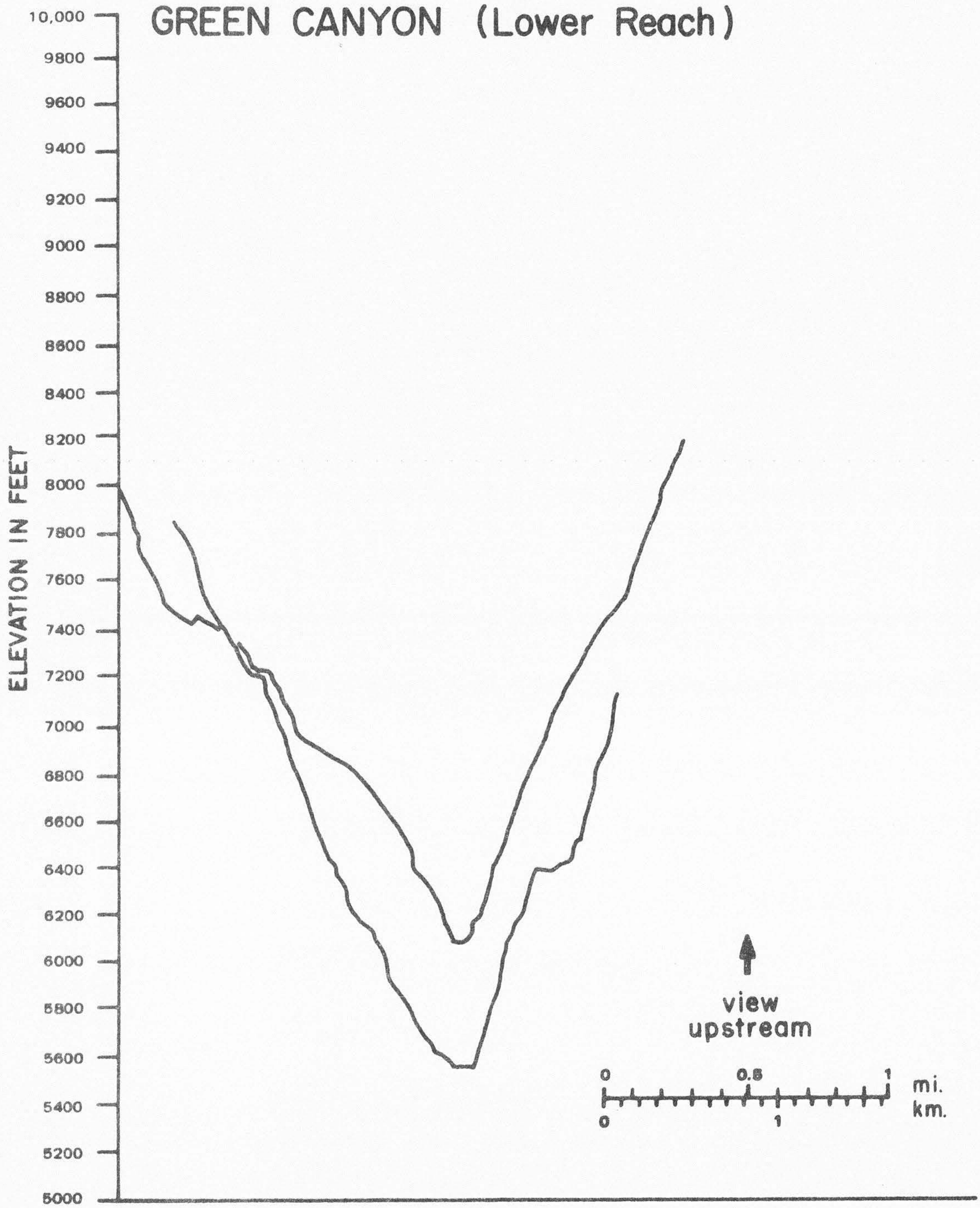

Figure 17. Cross-valley profiles of Green Canyon (lower reach)

wider in the upper reach (Figure 18). The overall drainage basin widens headward from the mouth.

The highest point on the longitudinal profile is within the Jefferson Formation (Plate 14). There are nine convex-up segments along the profile.

Logan Canyon

Logan Canyon is the largest canyon along the western part of the Bear River Range (Plate 15). The canyon mouth is located in sec. 36, T. 12 N., R. 1 E. The canyon trends east-northeast in its lower reach, generally northeast in its middle reach, and nearly north in its upper reach which extends into Idaho (Plate 16) (Figure 4). The canyon bottom is at an elevation of 7,600 feet at the Utah-Idaho state line, where it leaves the thesis area. Logan Canyon has a number of large tributary canyons. The three largest tributary canyons are Right Hand Fork, Temple Fork, and Beaver Creek. The lower reach of the canyon can be characterized as narrow-bottomed, steep-walled with high divides (Figure 19). The middle reach has steep walls, a narrow bottom, and lower divides than the lower reach (Figure 20). The upper reach has a broad valley bottom, moderately steep sides, and high divides (Figure 21). The lower part of the Beaver Creek tributary canyon is quite narrow-bottomed and steep-walled. It broadens with steep walls near the head in Beaver Basin (Figure 22).

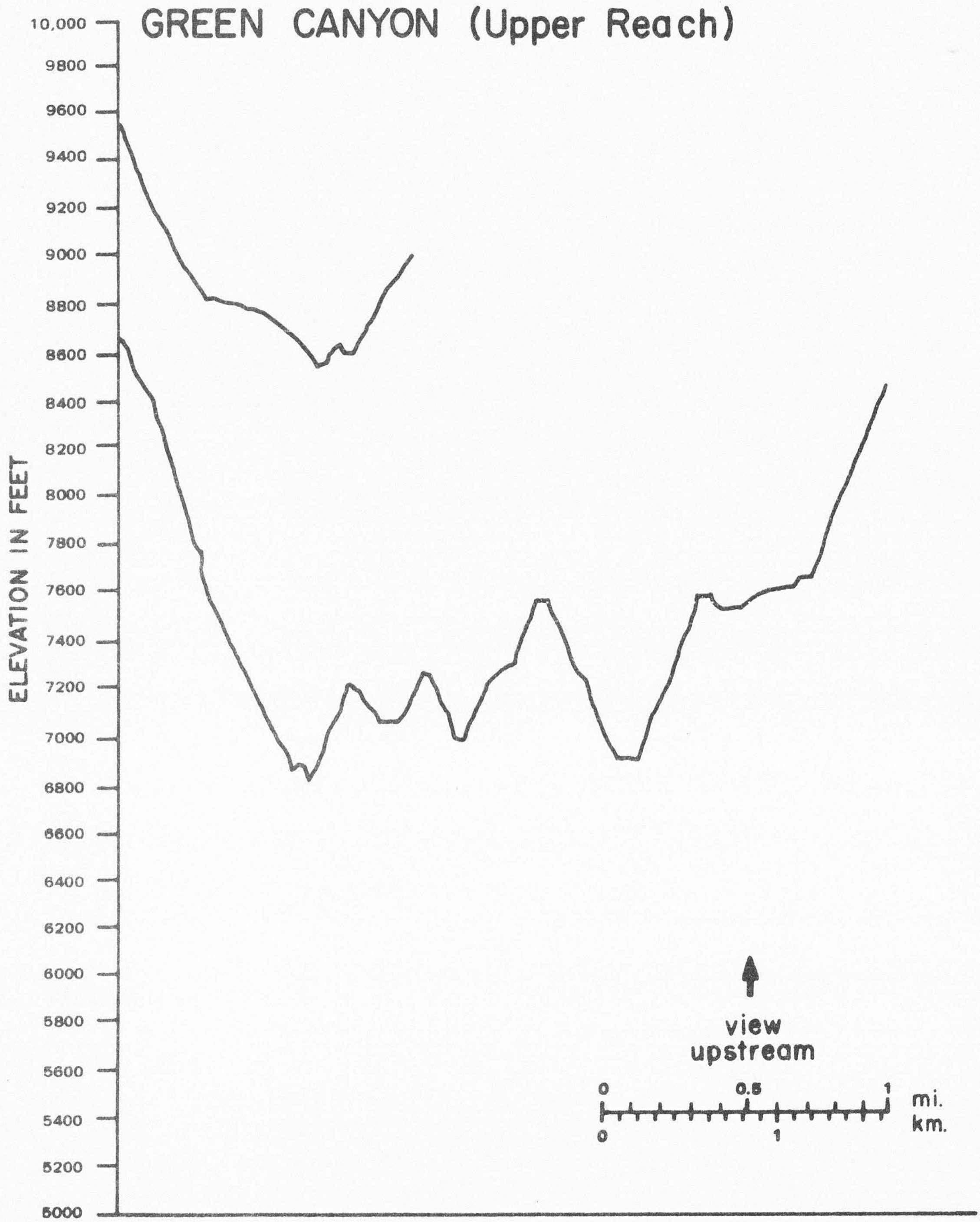

Figure 18. Cross-valley profiles of Green Canyon (upper reach)

Plate 15. An oblique aerial view east up Logan Canyon

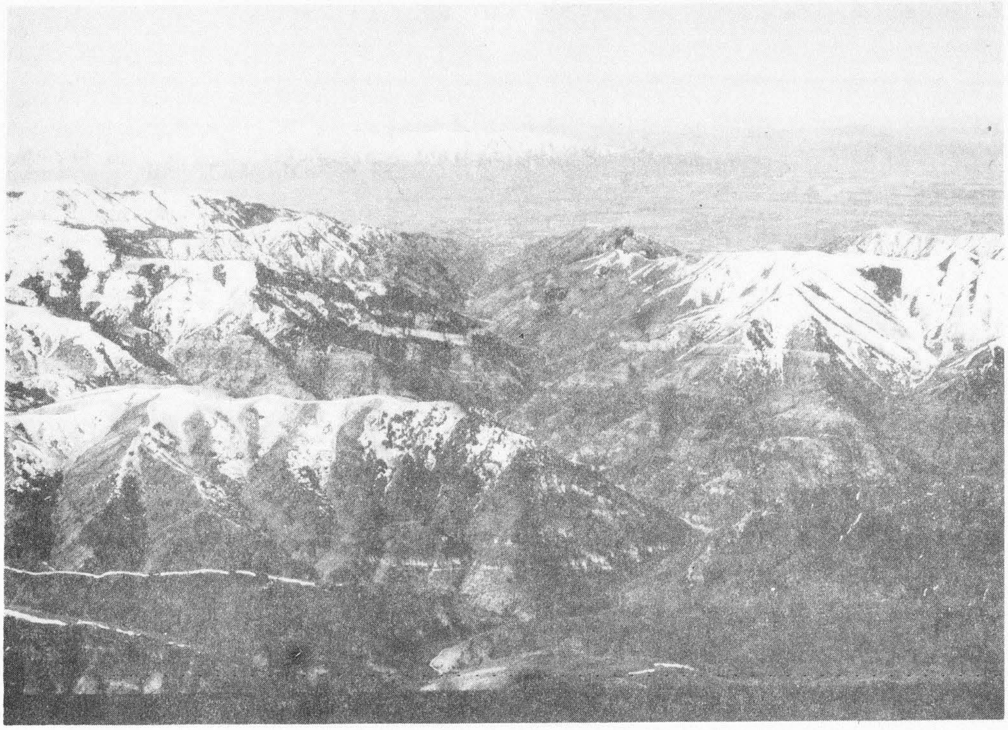

Plate 16. An oblique aerial view west down Logan Canyon

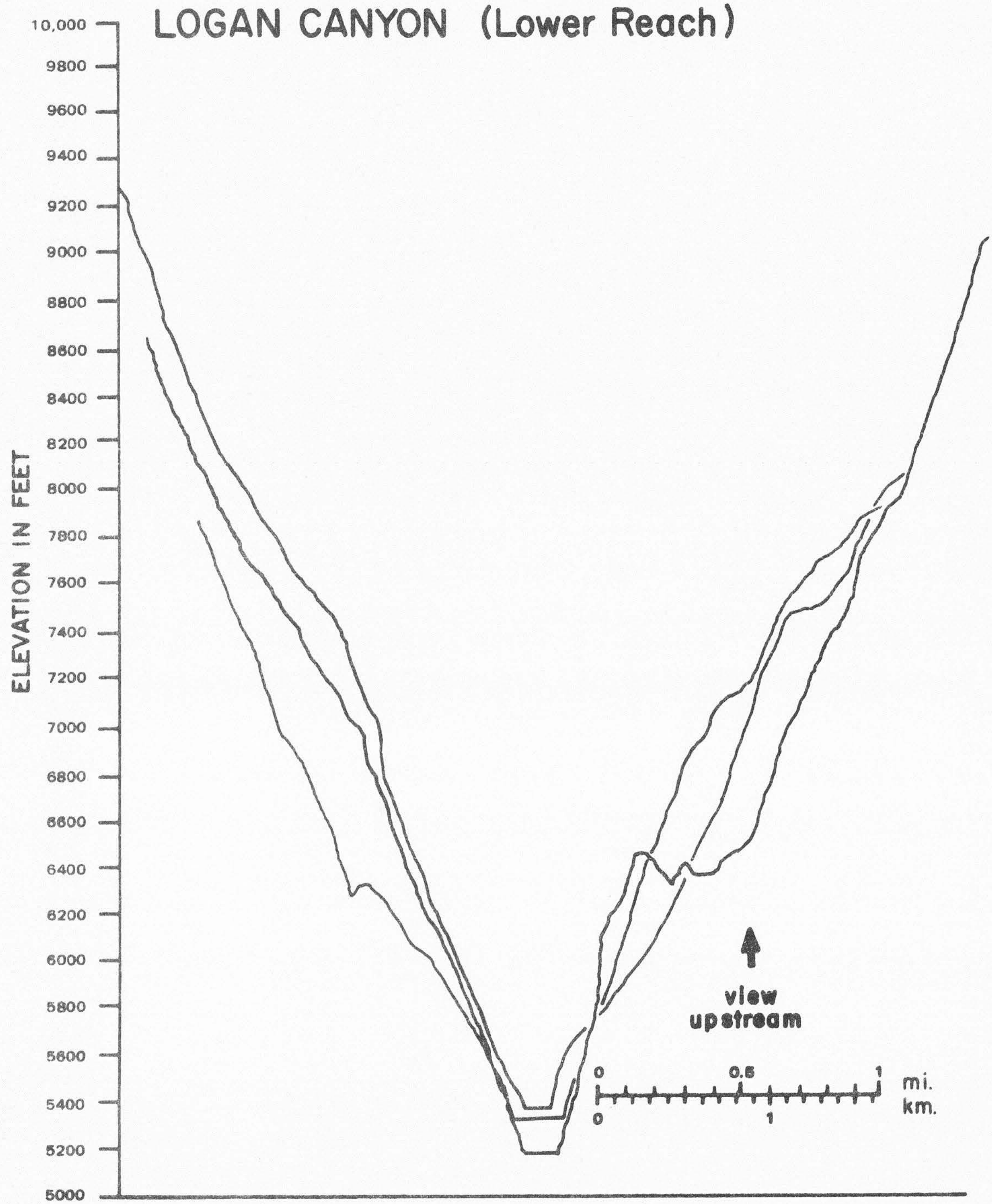

Figure 19. Cross-valley profiles of Logan Canyon (lower reach)

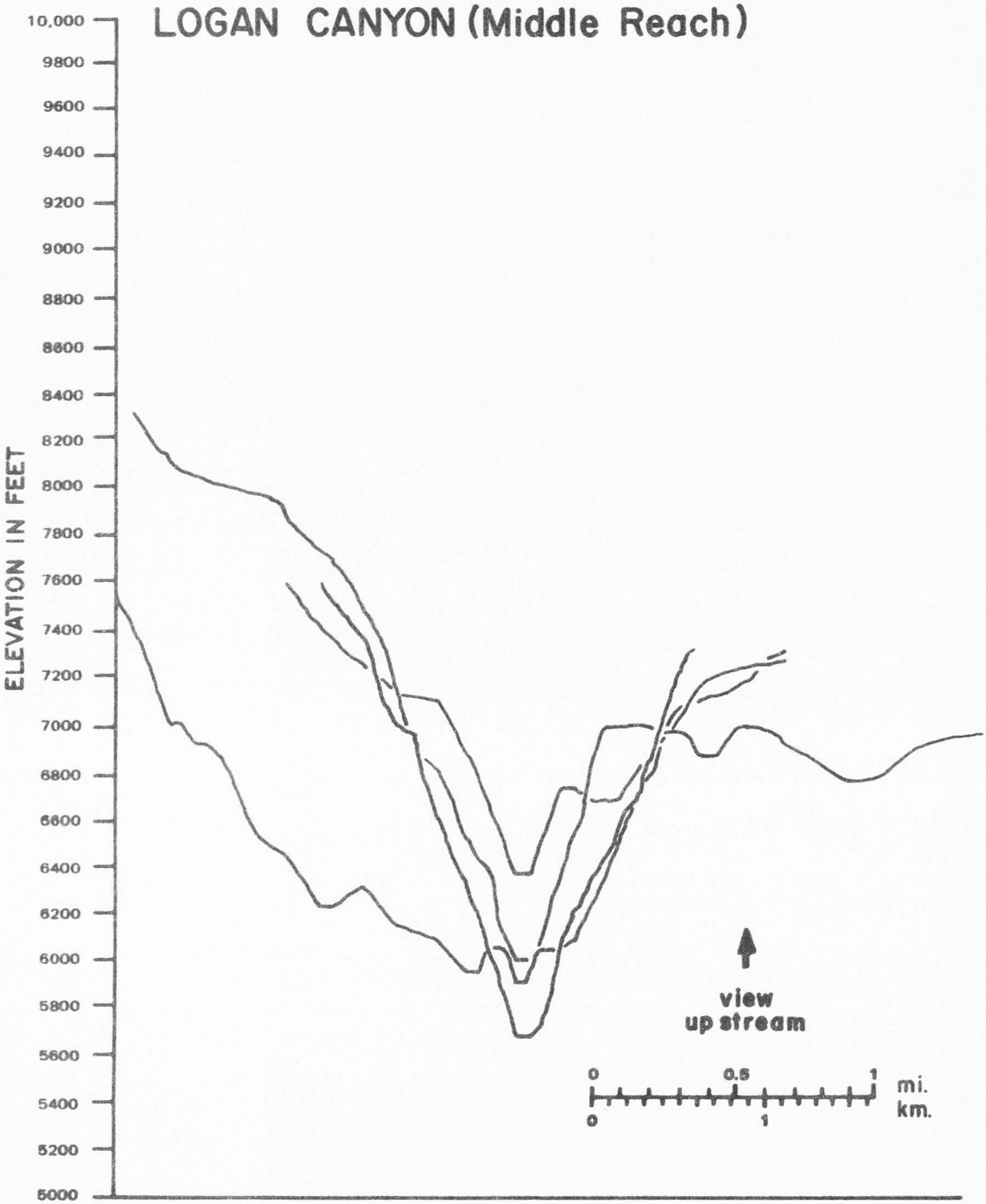

Figure 20. Cross-valley profile of Logan Canyon (middle reach).

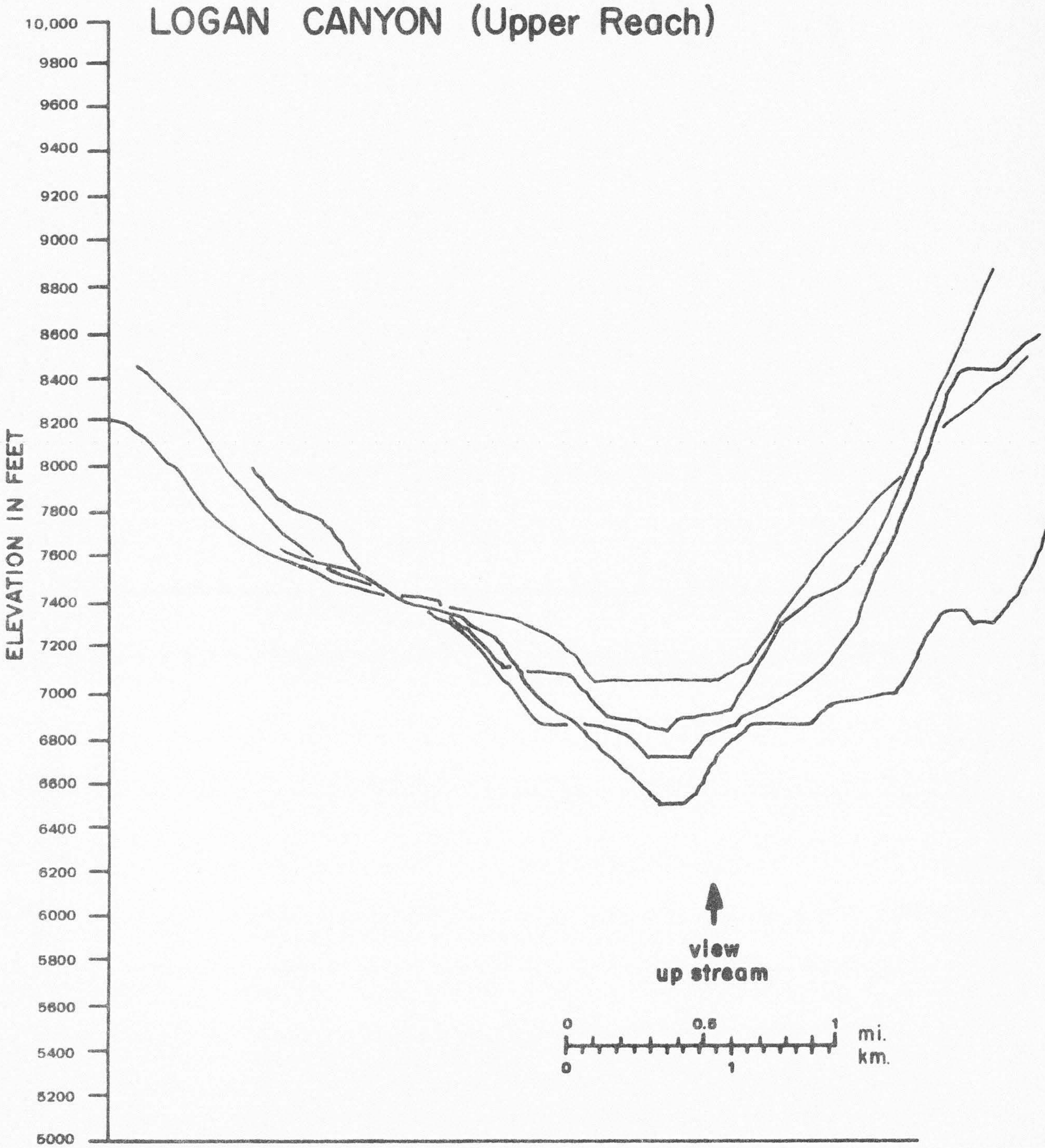

Figure 21. Cross-valley profile of Logan Canyon (upper reach).

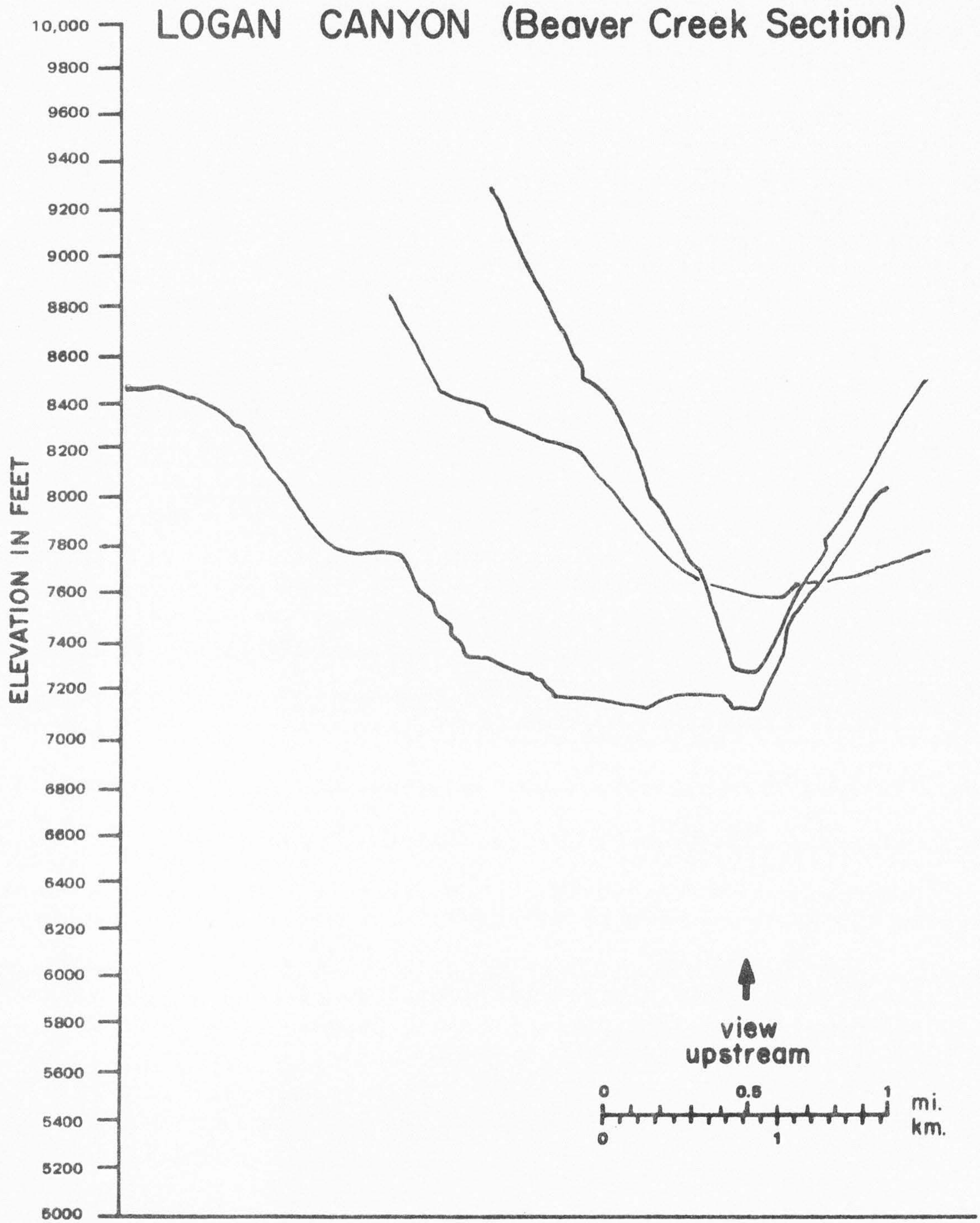

Figure 22. Cross-valley of Logan Canyon (Beaver Creek).

Two profiles have been constructed for Logan Canyon. One profile follows the canyon from the mouth, along the Logan River channel, to the Utah-Idaho state line (Plate 17). The other profile traces the same path to the junction with the Beaver Creek tributary and thence through Beaver Basin to the Utah-Idaho state line (Plate 18).

The highest point on the longitudinal profile of the main part of Logan Canyon is within the Wasatch Formation. (Plate 17). There are four convex-up segments along the profile.

The highest point on the profile along Logan Canyon and the Beaver Creek tributary of the Logan River is within the Garden City Formation (Plate 18). There are four convex-up segments along the profile.

Dry Canyon (South)

Dry Canyon (South) trends northwest-southeast (Figure 4). The canyon mouth is in sec. 36, T. 12 N., R. 1 E. The head lies at an elevation of 8,560 feet on the west flank of Logan Peak (9,710 feet). Dry Canyon (South) is a canyon with a narrow bottom and steep walls (Figure 23). The drainage basin is rectangular in shape.

The highest point on the longitudinal profile of Dry Canyon (South) is found within the Wells Formation (Plate 19). There are four convex-up segments along the profile.

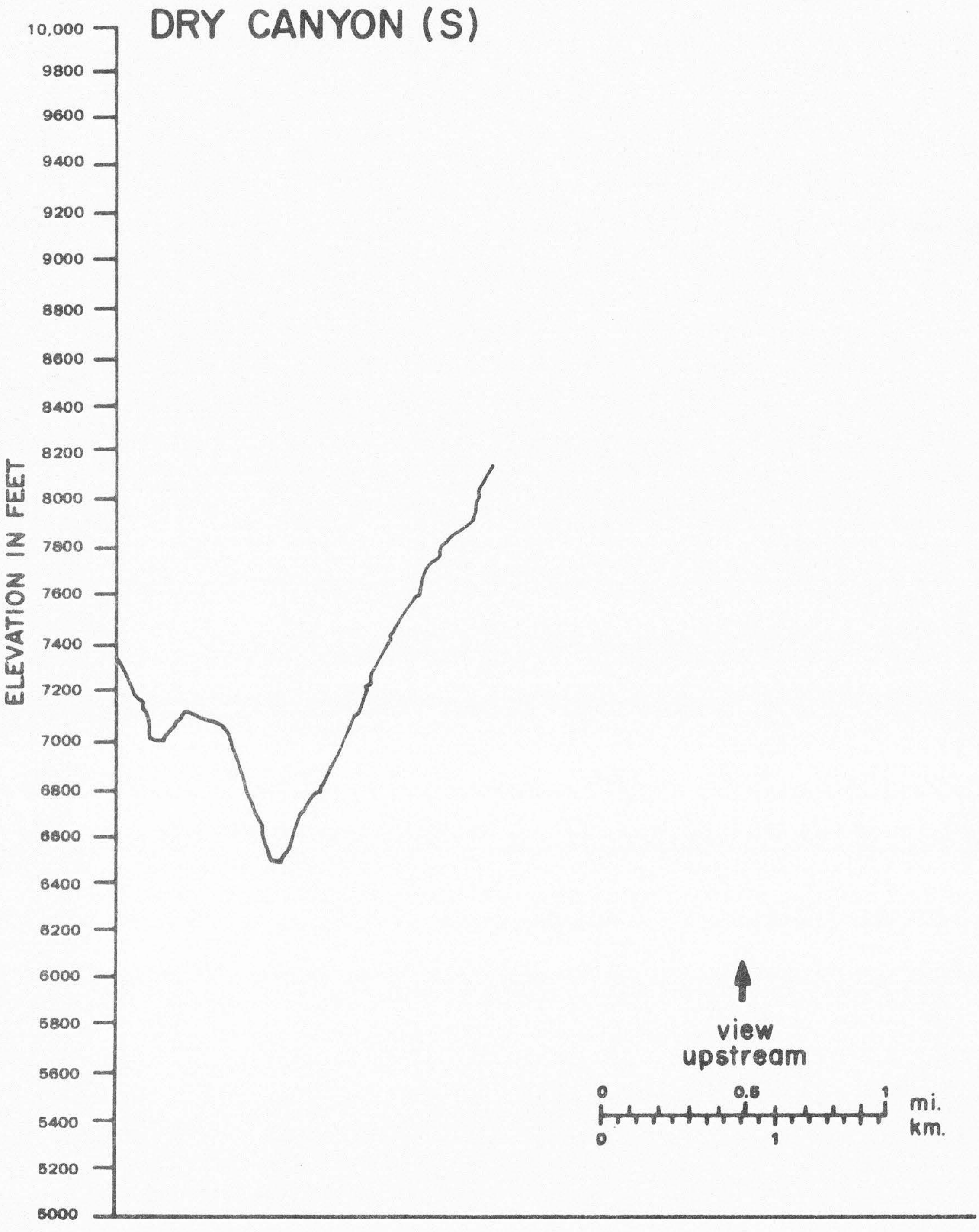

Figure 23. Cross-valley profiles of Dry Canyon (South).

Providence Canyon

Providence Canyon has an east-west trend in its lower reach, but a north-south trend in its upper reach (Figure 4). Location of the mouth is in sec. 14, T. 11 N., R. 1 E. The head of the canyon is at an elevation of 8,800 feet on the east side of Providence Lake, just west of the crest of the Bear River Range. Providence Canyon has a narrow bottom and steep walls along the lower reach. The upper reach has a wide bottom and low, gentle sides (Figure 24). The drainage basin widens headward from the mouth.

The highest point on the longitudinal profile of Providence Canyon is within the Brazer Formation (Plate 20). There are nine convex-up segments along the profile.

Millville Canyon

Millville Canyon follows an east-west trend in its lower reach, and a northeast-southwest trend in its upper reach (Figure 4). The mouth of the canyon is in sec. 26, T. 11 N., R. 1 E. The head of Millville Canyon is at an elevation of 7,240 feet just northwest of a peak (7,445 feet) along the divide between Blacksmith Fork and Providence Canyons. The canyon has a narrow bottom and steep walls (Figure 25). The drainage basin is rectangular in shape.

The highest point on the longitudinal profile along Millville Canyon is within the Brazer Formation (Plate 21). There are four convex-up segments along this profile.

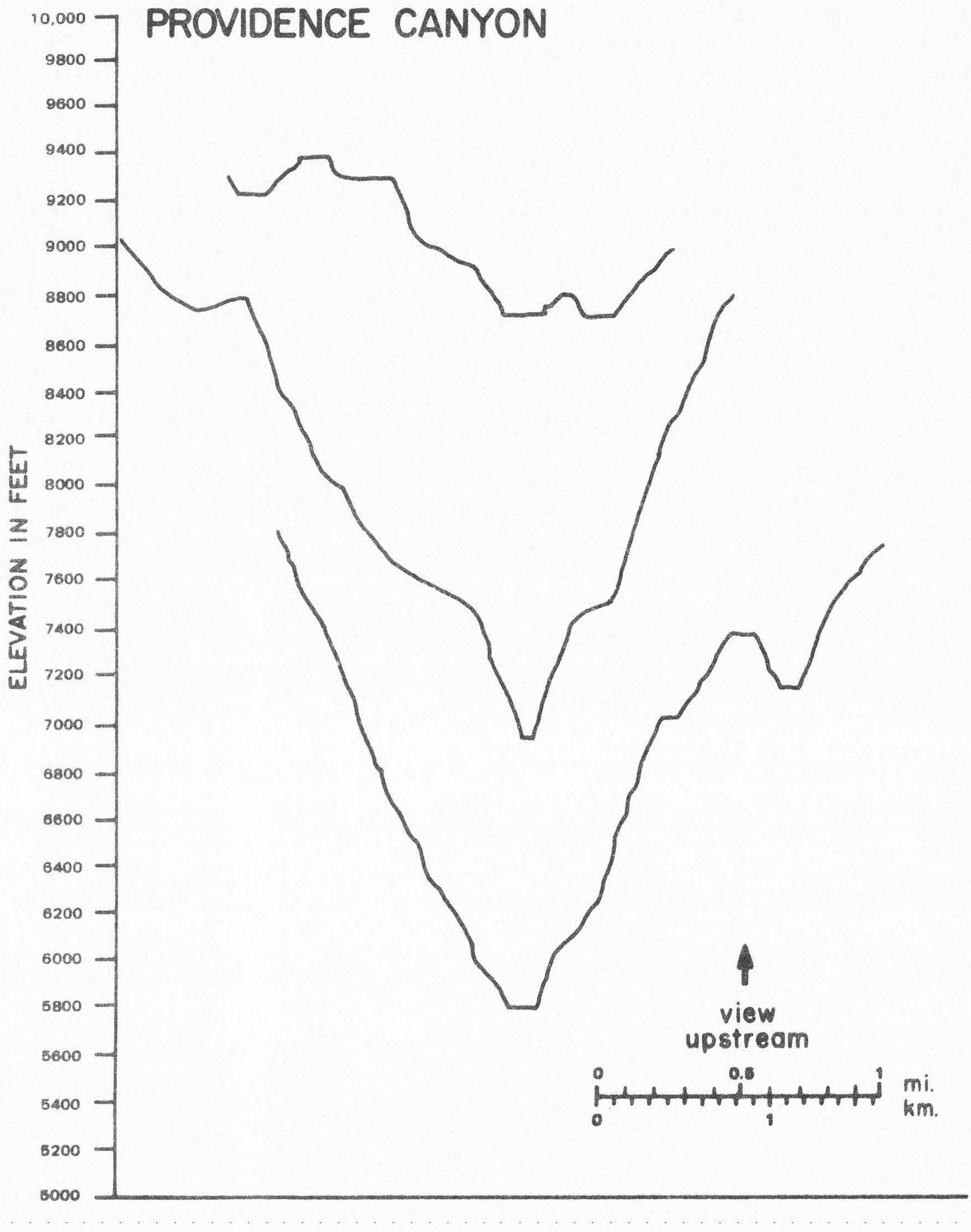

Figure 24. Cross-valley profiles of Providence Canyon.

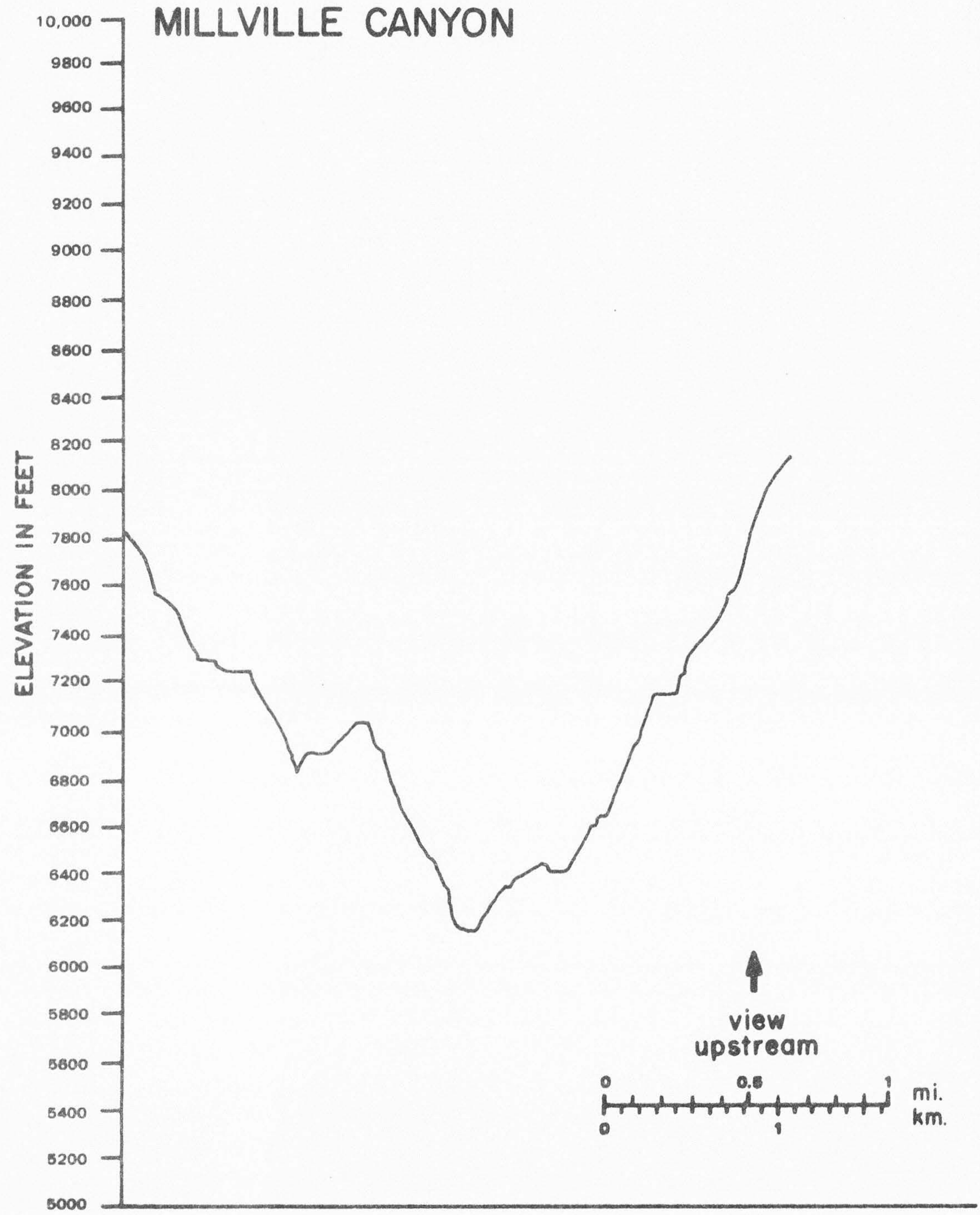

Figure 25. Cross-valley profiles of Millville Canyon.

Blacksmith Fork Canyon

Blacksmith Fork Canyon is the second largest canyon in the Bear River Range (Figure 4). The main canyon follows a general east-west trend to the area of Hardware Ranch, where it turns south and then east again (Plates 22 and 23). The Left Hand Fork tributary canyon trends generally northeast to southwest. Location of the canyon mouth is in sec. 11, T. 10 N., R. 1 E. The head of Blacksmith Fork Canyon lies beyond the eastern boundary of the thesis area. The point at which Blacksmith Fork Canyon crosses the eastern boundary is about 2.0 miles due east of the mutual corner of R. 3 E., R. 4 E., T. 10 N., and T. 9 N. The main tributaries of Blacksmith Fork Canyon are Left Hand Fork, Herd Hollow, Rock Creek, Curtis Creek, Mill Creek, and Sheep Creek (Figure 4). The drainage basin becomes wider toward the head of the canyon. The main Blacksmith Fork Canyon is steep walled with a narrow bottom along the lower reach (Figure 26). The divides are lower along the upper reach than the lower. The canyon has a narrower canyon bottom at the upstream end of the canyon along the upper reach (Figure 27). Left Hand Fork Canyon has a narrow bottom and steep walls along the lower reach (Figure 28). The canyon bottom widens and the walls are gentler in the upper reach (Figure 29).

Two longitudinal profiles were constructed for Blacksmith Fork Canyon. One profile traces along the main canyon from the mouth to the eastern boundary. The other profile follows along from the canyon mouth and along Left Hand Fork tributary.

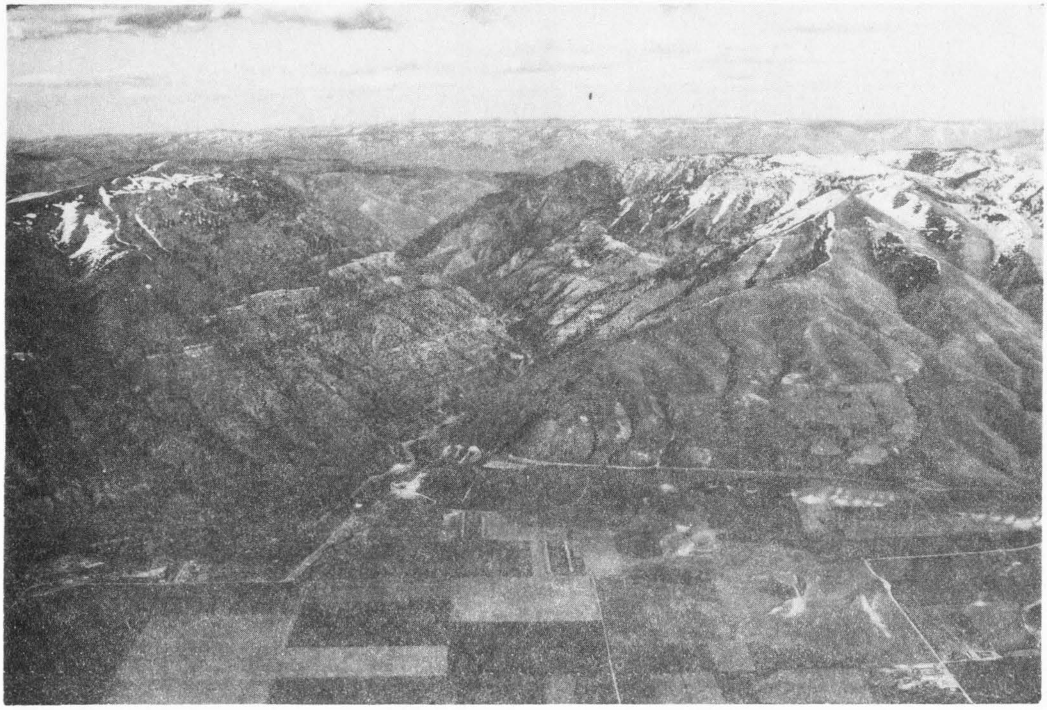

Plate 22. An oblique aerial view east up Blacksmith Fork Canyon

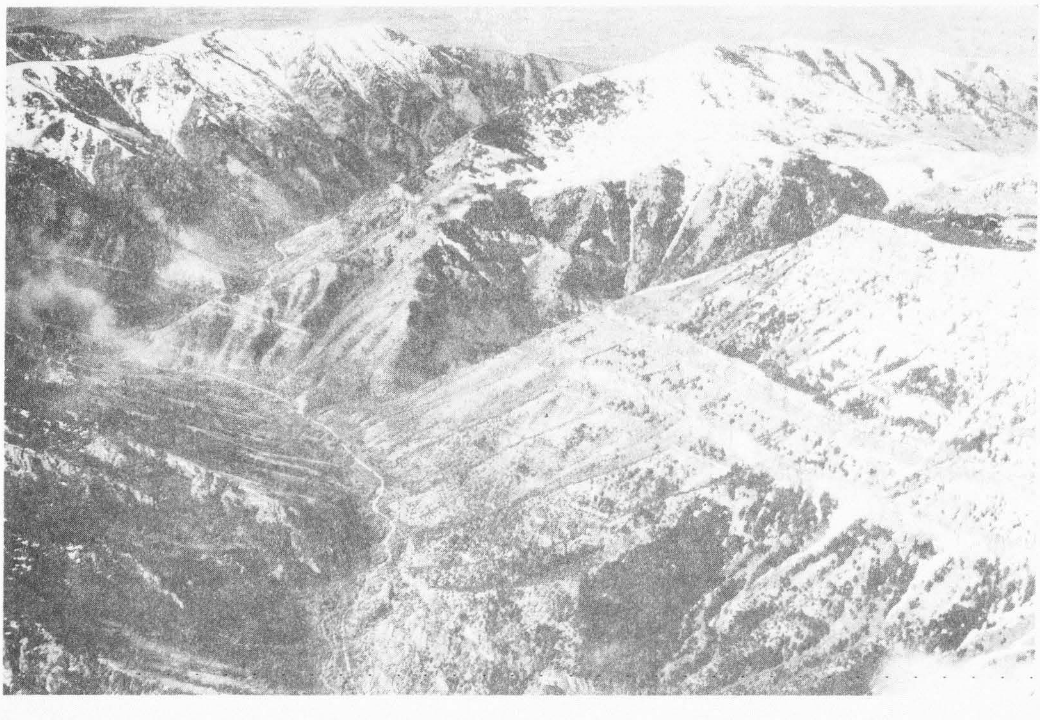

Plate 23. An oblique aerial view west down Blacksmith Fork Canyon

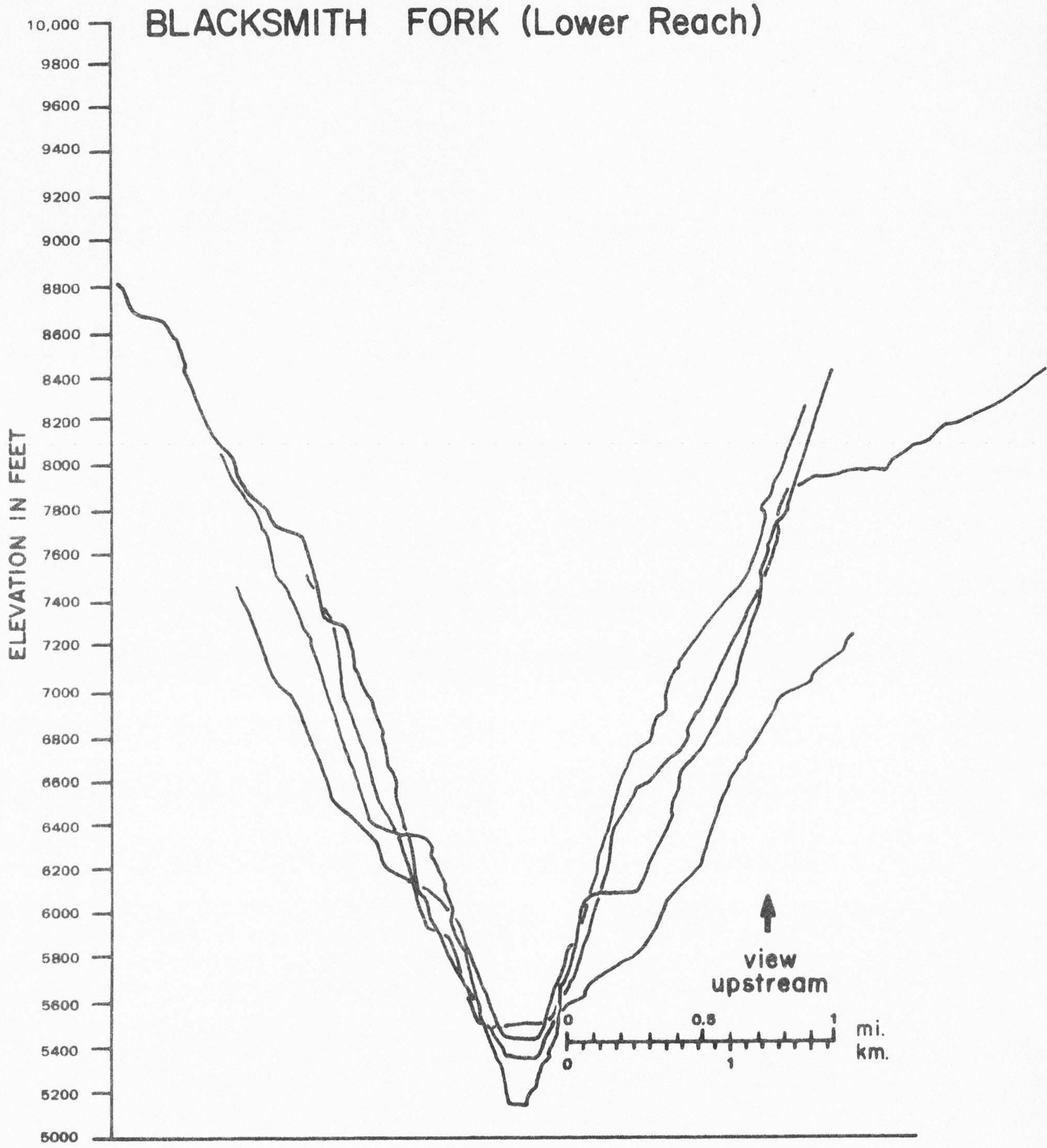

Figure 26. Cross-valley profiles of Blacksmith Fork Canyon (lower reach).

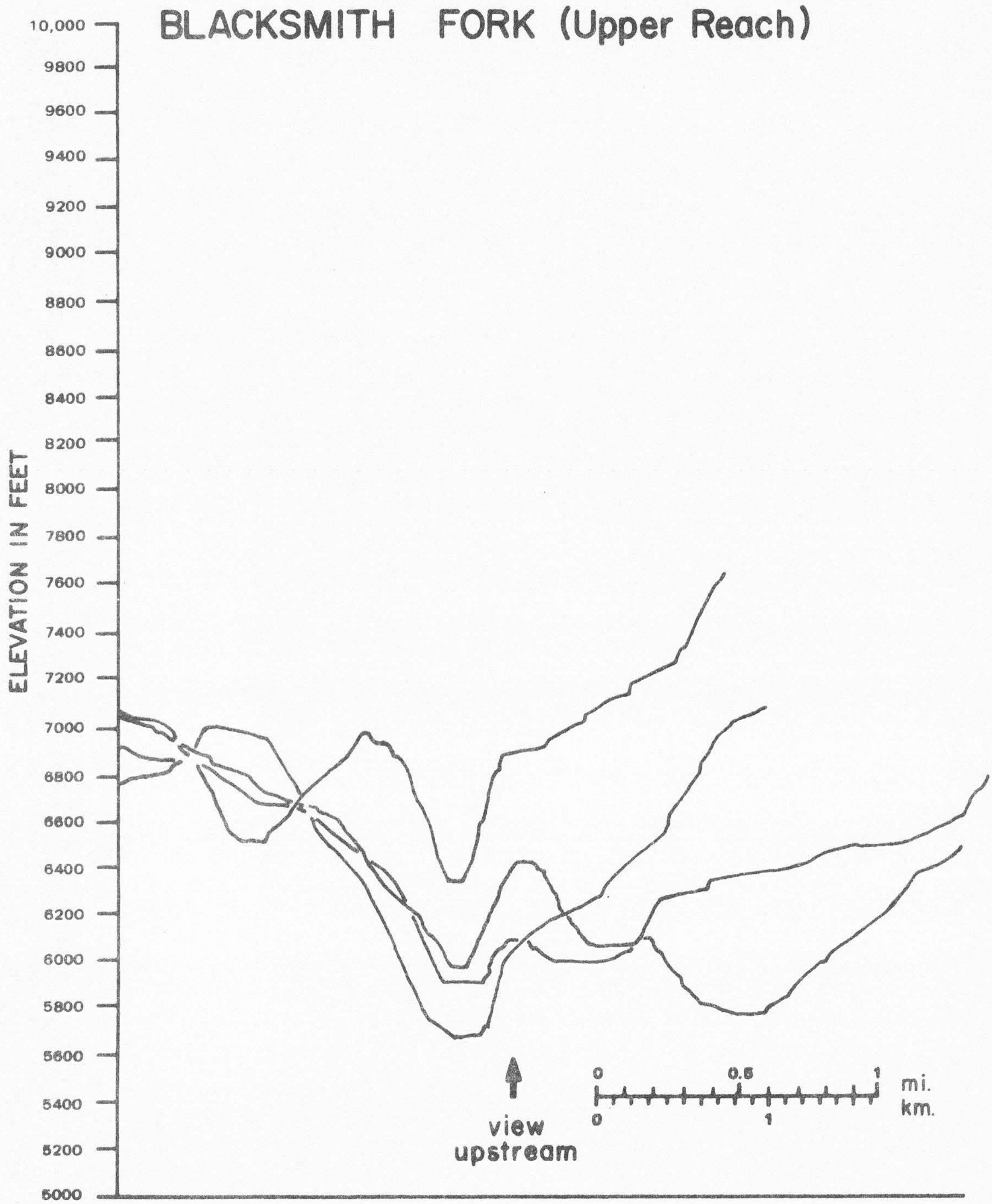

Figure 27. Cross-valley profiles of Blacksmith Fork (upper reach).

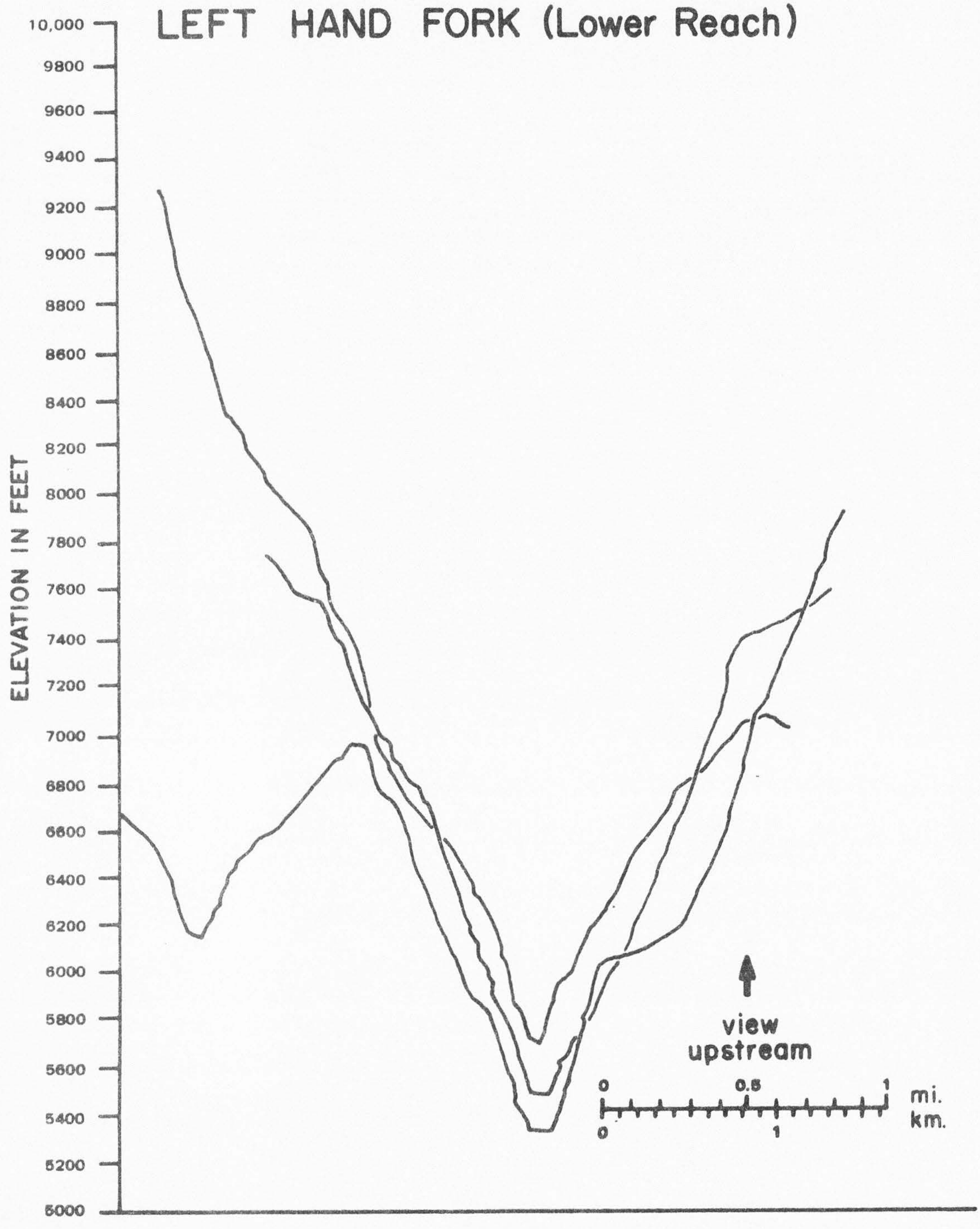

Figure 28. Cross-valley profiles of Left Hand Fork of Blacksmith Fork Canyon (lower reach).

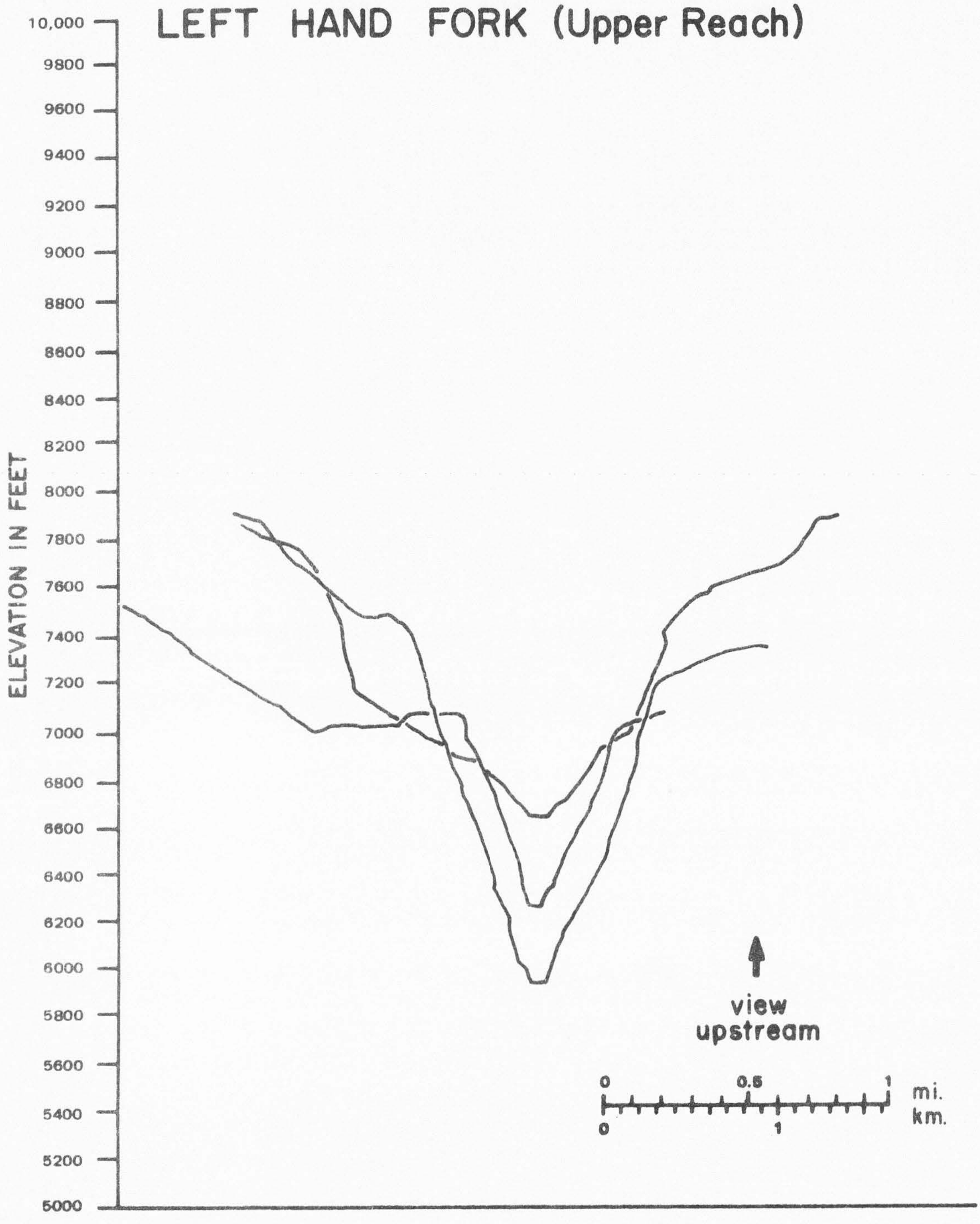

Figure 29. Cross-valley profiles of Left Hand Fork of Blacksmith Fork Canyon (upper reach).

The highest point on the longitudinal profile along the main Blacksmith Fork Canyon is within the Nounan Formation (Plate 24). There are three convex-up segments along the profile.

The highest point on the longitudinal profile along the Left Hand Fork tributary is within the Wasatch Formation (Plate 25). There are three convex-up segments along the profile.

Hyrum Canyon

Hyrum Canyon is a small canyon trending east-west in its lower reach, and northeast-southwest in its upper reach (Figure 4). The mouth of the canyon is in sec. 26, T. 10 N., R. 1 E. The canyon head lies at an elevation of 7,920 feet on the southwest flank of a peak (8,055 feet) on the divide between Blacksmith Fork and East Canyons. A major tributary of Hyrum Canyon is Green Canyon. The Green Canyon tributary has low sides and a broad bottom in the lower reach. The walls are steeper and the canyon bottom narrower in the upper reach (Figure 20). The drainage basin has a rectangular shape. Hyrum Canyon has low, steep walls and a narrow canyon bottom in the lower reach. The walls become steeper and higher in the upper reach (Figure 31).

Two profiles have been constructed for Hyrum Canyon. One profile follows the main Hyrum Canyon from its mouth to head. The other profile traces along the Green Canyon tributary from the mouth of Hyrum Canyon.

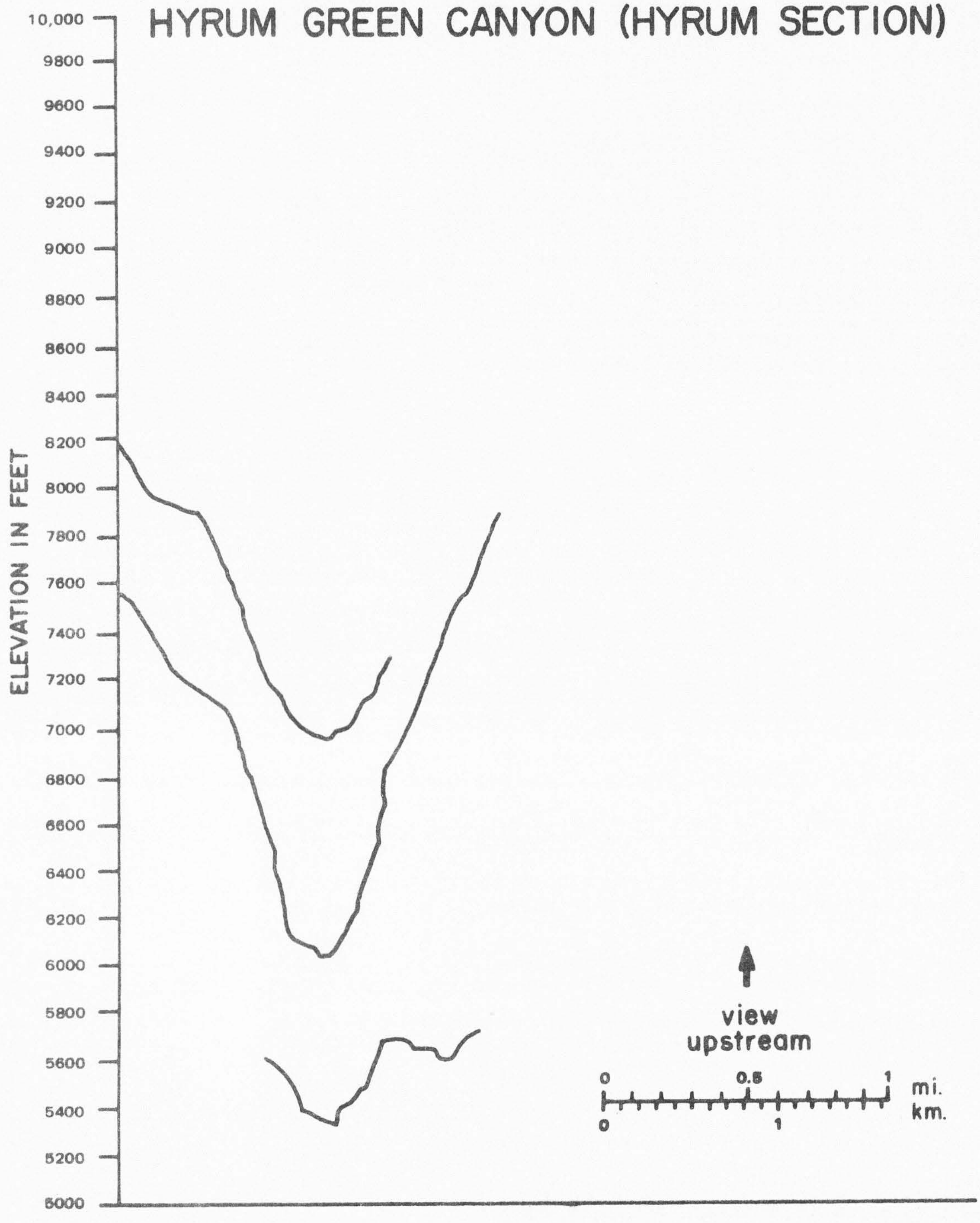

Figure 30. Cross-valley profiles of Hyrum Canyon along the Hyrum section.

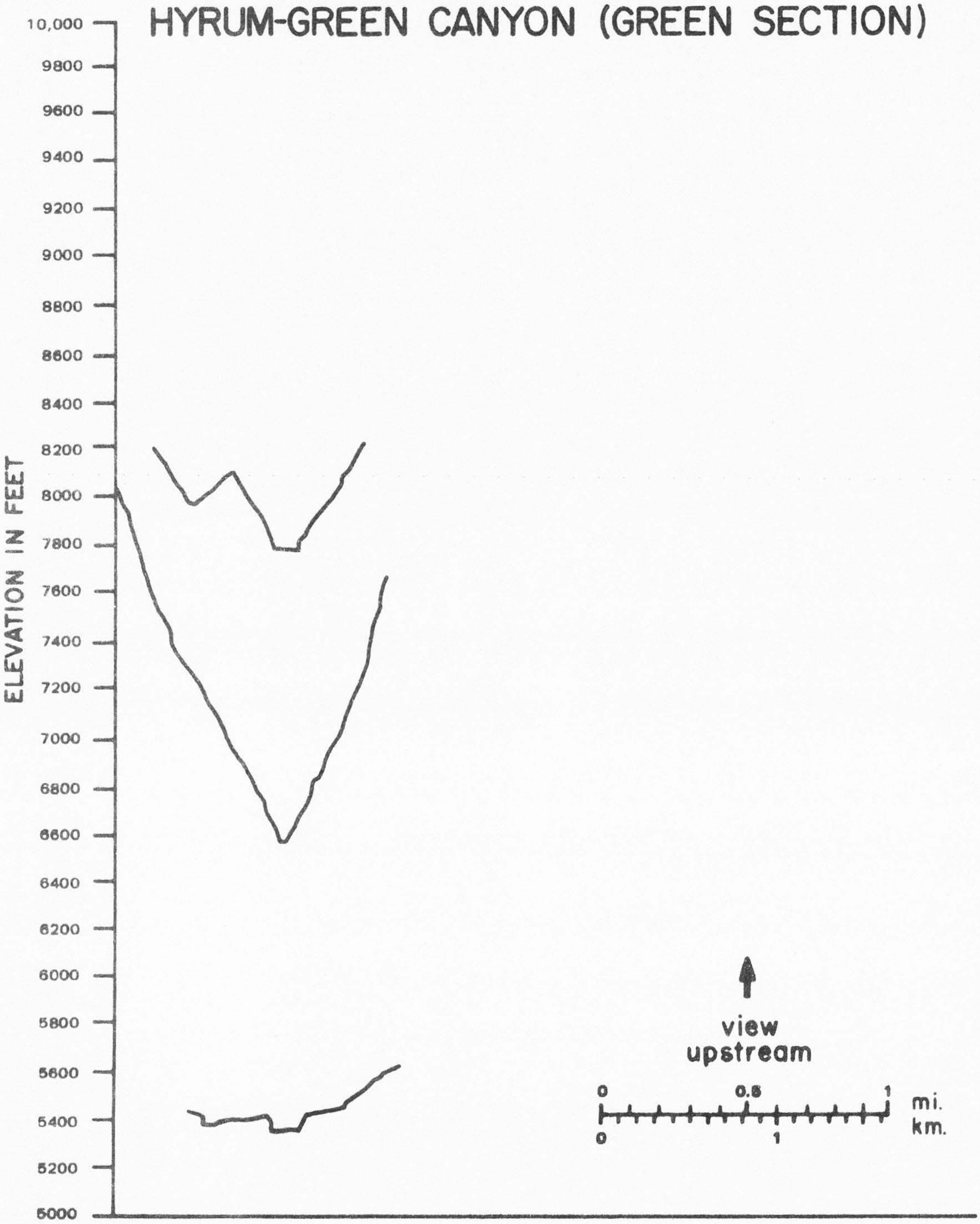

Figure 31. Cross-valley profiles of Hyrum Canyon along the Green section.

The highest point on the longitudinal profile along the Green Canyon tributary to Hyrum Canyon is within the Brazer Formation (Plate 26). There are seven convex-up segments along the profile.

The highest point on the longitudinal profile along Hyrum Canyon is within the Laketown Formation (Plate 27). There are nine convex-up segments along the profile.

Paradise Dry Canyon

Paradise Dry Canyon has a generally northeast to southwest trend (Figure 4). The canyon mouth is located in sec. 2, T. 9 N., R. 1 E. The head of Paradise Dry Canyon is at an elevation of 7,920 feet on the northwest flank of a peak (8,102 feet) on the divide between Blacksmith Fork and East Canyons. Paradise Dry Canyon can be characterized as a narrow-bottomed, steep-walled canyon along its entire reach (Figure 32). The drainage basin widens from the mouth towards the head of the canyon.

The highest point on the longitudinal profile of Paradise Dry Canyon is within the Laketown Formation (Plate 28). There are two convex-up segments along the profile.

East Canyon

East Canyon is the southernmost canyon in the thesis area. Within the area studied, East Canyon has an overall east-west trend (Figure 4). The canyon mouth is in sec. 11, T. 9 N., R. 1 E. The head of East Canyon lies outside the southern boundary of the study area.

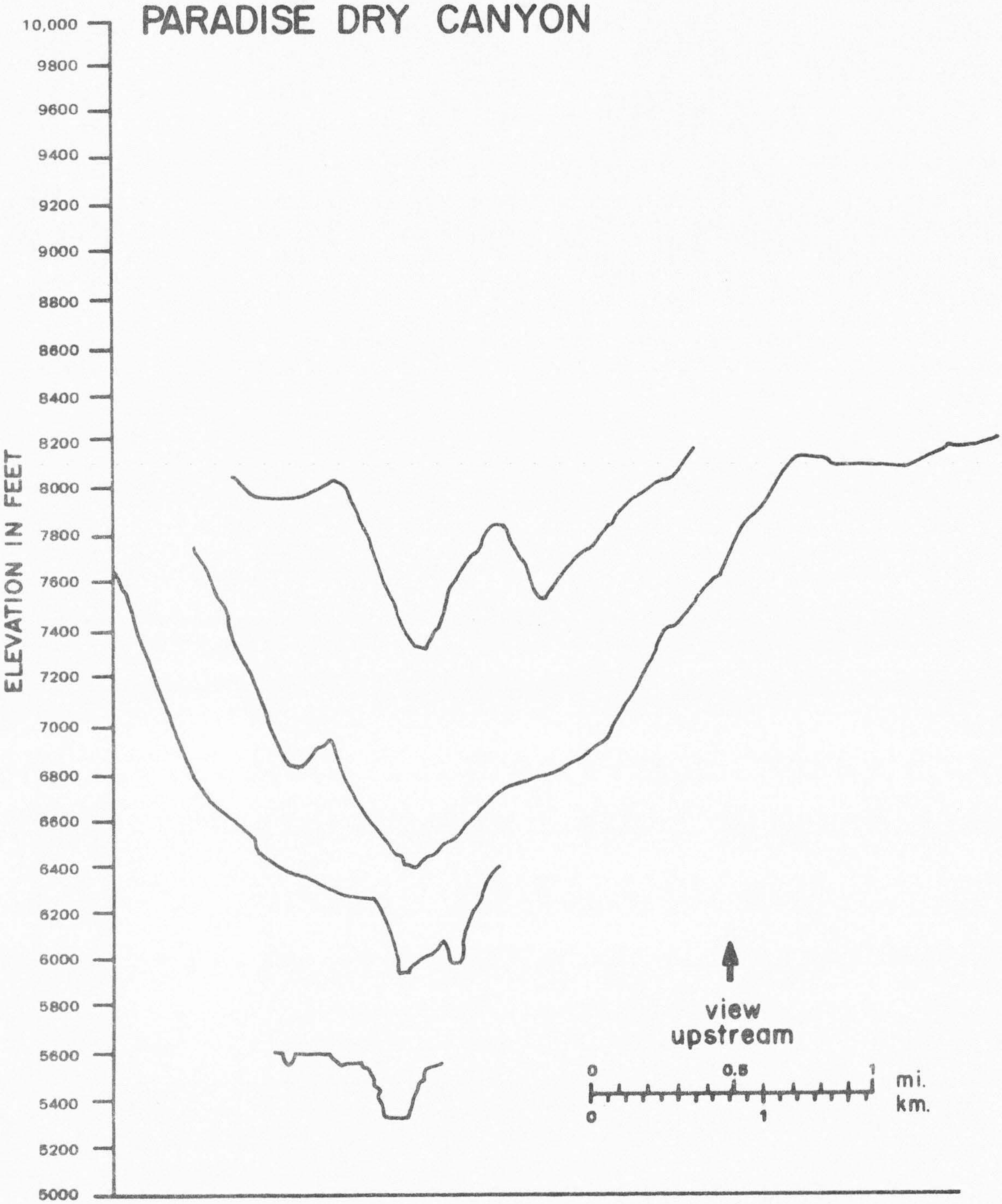

Figure 32. Cross-valley profiles of Paradise Dry Canyon.

The canyon crosses the southern boundary near the dividing line between R. 2 E. and R. 3 E. in T. 9 N., at an elevation of 5,960 feet. A significant part of the canyon within the thesis area is beneath Porcupine Reservoir. As a consequence, no longitudinal profile was constructed. Cross-valley profiles were made above and below the submerged part of the canyon. East Canyon can be characterized as a narrow-bottomed, steep-walled canyon along the reach within the study area (Figure 33). The drainage basin widens from the mouth toward the head of the canyon.

Analysis

An analysis of the longitudinal profiles shows that except for one rock formation, there is no consistent relation between lithology and gradient changes. The one consistent change is a convex-up profile segment where the thalweg crosses the Swan Peak Formation. The Swan Peak Formation is a resistant quartzite which results in a steep gradient change downstream. The gradient change results from the improved erosive power in the less resistant beds downstream from the Swan Peak Formation. It is possible that some other rock units may cause similar gradient changes. These changes could not be detected with the current resolution of mapped stratigraphic information.

The physical description of canyons within the Bear River Range leads to comparisons among the canyons of varying sizes and ages. Some facts about the drainage basin associated with each canyon reveals relationships that are not obvious from the physical description alone

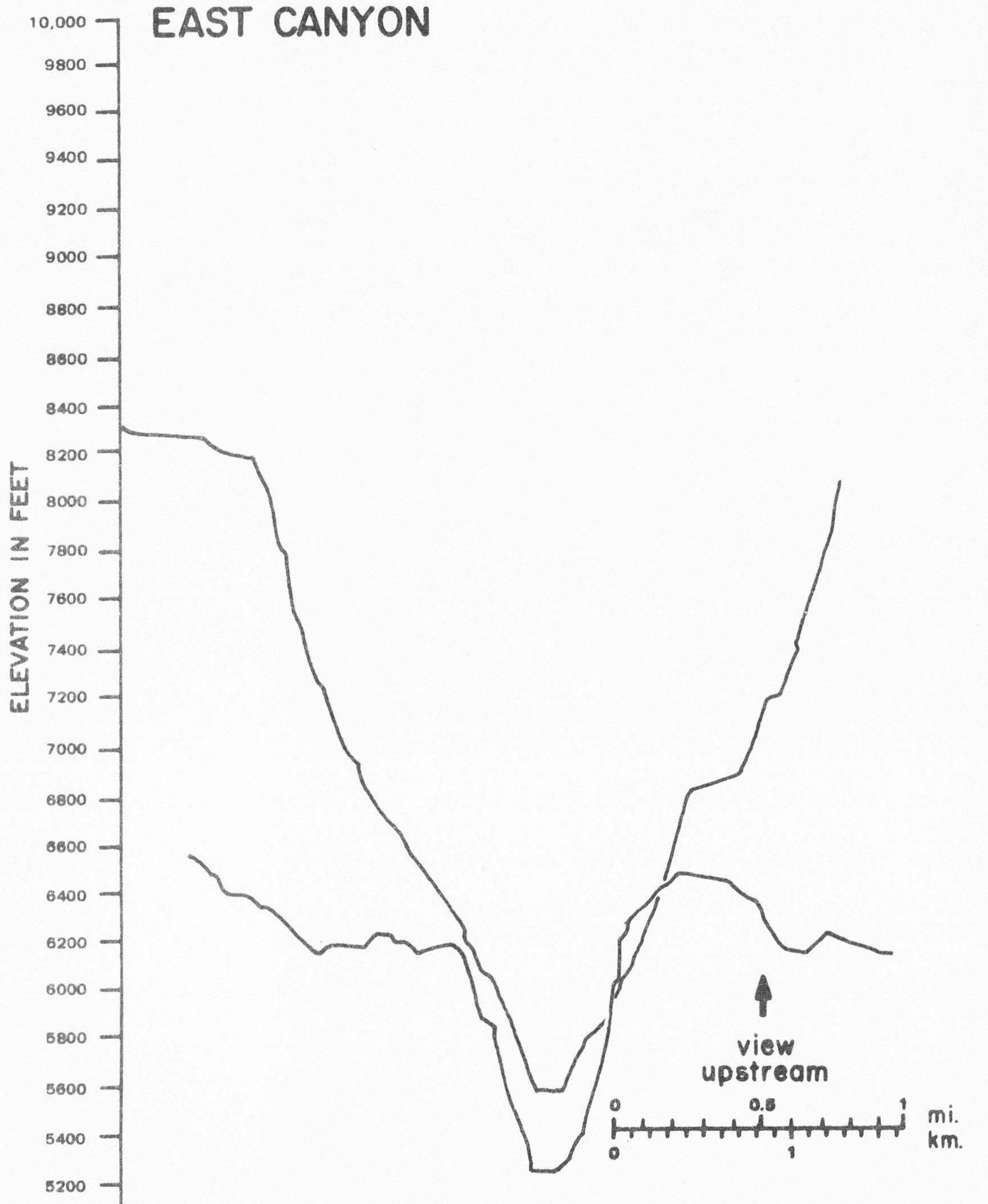

Figure 33. Cross-valley profiles of East Canyon.

(Table 3). It is clear that the longer streams have a lower average grade. This is especially obvious in the case of Logan and Blacksmith Fork canyons. Some variation in this generalization can be attributed to the structures and the rock types exposed along the canyon. Green Canyon has an average grade of 10 percent along a stream course 8.2 miles long. Paradise Dry Canyon has a 7 percent grade along a stream course 8.3 miles long. The steeper grade for the same stream distance in Green Canyon compared to Paradise Dry Canyon may be partly due to differing resistances to erosion. Green Canyon cuts into dense, hard dolostones. Paradise Dry Canyon is cut into more easily eroded limestones. Additionally the dip of the beds in the two canyons is different. Green Canyon is steeply eastward. The formations exposed in Paradise Dry Canyon are nearly horizontal downstream and dip gently westward upstream. The few exceptions to the concept that longer stream lengths correlate with lower gradients probably can be attributed to these variables.

There are some differences in the shapes of canyons developed along the western front of the Bear River Range. Logan, Blacksmith Fork, and East canyons are the only major streams that extend across the Logan Peak syncline. Cross-valley profiles show that all other canyons are narrow-bottomed with steep walls. Cross-valley profiles of the lower and middle reaches of Logan and Blacksmith Fork canyons also show narrow bottoms and steep walls. The main difference is in the upper reach of each stream. In this part, those canyons that are

Table 3. Characteristics of canyons and drainage basins within the Bear River Range

Canyon	Alt Mouth (ft.)	Alt. Head (ft.)	Ave. Grade (%)	Max. Stream Length (mi.)	Basin Shape (Plan view)
High Creek	5,000	8,920	11	6.5 North Fork	
	5,000	8,520	9	7.8 South Fork	triangular
Oxkiller Hollow	5,000	8,240	18	3.4	rectangular
Cherry Creek	5,000	8,600	13	5.2	triangular
City Creek	5,000	8,280	15	4.2	rectangular
Nebo Creek	5,000	8,080	16	3.7	rectangular
Smithfield	5,000	8,960	9	8.4	triangular
Birch	5,000	9,000	12	6.5	rectangular
Dry (North)	5,000	8,720	15	4.7	rectangular
Hyde Park	5,000	8,800	17	4.2	rectangular
Green	5,000	9,320	10	8.2	triangular
Logan	4,800	(7,600)	2	(27.7)	triangular
Dry (South)	5,000	8,560	17	3.9	rectangular
Providence	5,000	8,800	11	6.5	triangular
Millville	5,000	7.240	14	3.0	rectangular
Blacksmith Fork	4,800	6,520	2	21.3 Left Hand Fork	
	4,800	6.640	2	20.5 Main stream	triangular
Hyrum-Green	5,000	8,000	9	6.2 Green section	
	5,000	7,920	7	8.1 Hyrum section	rectangular
Paradise Dry	5,000	7,920	7	8.3	triangular
East	4,800	(5,960)	---	N.A.	triangular

not cross-axial remain steep-walled and narrow. Each cross-axial canyon exhibits wider, flatter bottoms with gentler sloping walls in the upper reach. East Canyon is not extensive enough within the study area to determine if the same circumstance is true for its cross-valley profile.

A comparison of the canyon walls on each cross-valley profile shows that marked asymmetry exists. The north-facing canyon wall is consistently steeper than the south-facing wall. Studies of valley asymmetry have attributed this phenomenon to structural, lithologic, microclimatic, and other factors at different localities (Wilson, 1968). In the canyons studied structural elements and rock formations are essentially the same on opposite sides of the canyon. This factor strongly suggests that microclimatic conditions are responsible for the cross-valley asymmetry.

Vegetational evidence indicates that microclimatic conditions are different between north-facing and south-facing canyon walls. Plant communities are distinctly different on opposite sides of the canyon. Communities on the south-facing are characterized by plants which tolerate drier conditions. Communities on north-facing walls require higher amounts of moisture. Additionally, the communities on the south-facing walls typically cover the surface more sparely (Henderson, oral comm., Nov. 1975).

The microclimatic conditions on south-facing and north-facing walls which is reflected in the vegetation patterns are largely attributable to exposure to different amounts of potential insolation. A south-facing slope would receive more solar insolation in the Northern Hemisphere. This causes a higher evaporation rate, more frequent freeze-and-thaw cycles, and shorter retention of snow cover than on north-facing walls. The vegetation reflects the resulting differences in temperatures and soil moisture. The effects of higher solar insolation on the south-facing walls include more rapid weathering, more landsliding, and more sheetwash on south-facing walls than on north-facing walls. The resulting difference in erosion rates causes the north-facing walls to be steeper in the Northern Hemisphere (Thornbury, 1954).

The hydrologic characteristics of the canyons show some marked differences (Table 4). The drainage-basin area has been measured for each canyon using 7.5-minute topographic maps and a calculator-planimeter system. The average annual discharge in thousand acre-feet was computed on the values obtained in the 1960-68 water years (Bjorklund and McGreevy, 1971). Some values for the larger drainages were taken from the U. S. Department of the Interior, Geological Survey Water Supply Paper (1974). The average annual discharge was plotted against the drainage area for canyons that do not cross the axis of the Logan Peak syncline but have measurable discharges (Figure 34). A multiple-linear-regression analysis with stepwise deletion of variables was used on the points to yield the slope, intercept, and R-squared values for the best fitting line (Table 6). This computation employed the STATPAC

Table 4. Hydrologic characteristics of drainage basins within the Bear River Range.

Canyons	Stream	Drainage area (sq. mi.)	Ave. Ann discharge (thous. acre-ft)	Cross-Axial
High Creek	High Creek	21.4	19	no
Oxkiller Hollow	---	2.8	N. S. *	no
Cherry Creek	Cherry Creek	6.5	4	no
City Creek	City Creek	6.1	N. S.	no
Nebo Creek	Nebo Creek	4.0	N. S.	no
Smithfield	Summit Creek	16.8	12	no
Birgh	---	7.0	2	no
Dry (North)	---	4.9	N. S.	no
Hyde Park	---	4.6	N. S.	no
Green	---	13.9	N. S.	no
Logan	Logan River	218.0	162	yes
Dry (South)	---	6.4	N. S.	no
Providence	Spring Creek	11.9	7	no
Millville	---	6.8	N. S.	no
Blacksmith Fork	Blacksmith Fork River	260.0	79	yes
Hyrum-Green	---	12.7	N. S.	no
Paradise Dry	---	12.8	N. S.	no
East	Little Bear River	203.0	24	yes

* Average annual discharge is not significant (NS) enough to be measured

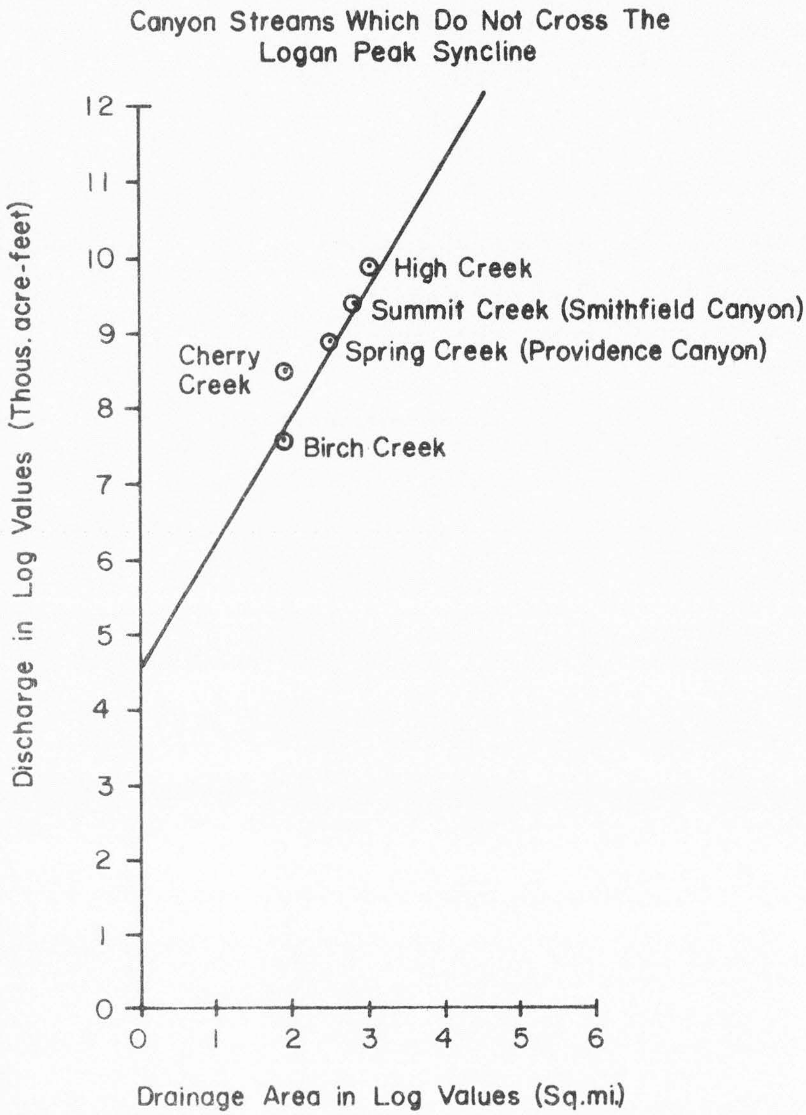

Figure 34. Comparison between discharge and drainage area for canyon streams which do not cross the Logan Peak syncline.

library in the Burroughs 6700 computer. The line for this plot has an R-square value of 92 percent. This is a very reliable fit in which most of the points fall on or very near the line (Romesburg, oral comm., Nov. 1975). The same method was applied to a comparison of average annual discharge to drainage-basin area for the three minor cross-axial streams (Figure 35). The best fit line determined for these points has a low R-square value of 17 percent, so that the line is not statistically significant. Because the rock types, structure, climate, and precipitation are essentially the same for drainages of both the cross-axial streams and those that do not cross the syncline axis, another factor is probably responsible for the difference in reliability between lines drawn for plots of the same variables.

Ten canyons have not appreciable annual discharge (Table 4). Despite the catchment size, no measurable discharges occur at the mouths of these canyons. The water must move through the sub-surface. Because the western limb of the Logan Peak syncline dips upstream in each case, except in the headward portions of Providence, Millville, Hyrum, and Paradise Dry canyons the water lost from these canyons along permeable rock formations probably would either move eastward or parallel to strike, and so ultimately would emerge as surface water in the larger cross-axial canyons. Thus the drainage areas of the cross-axial canyons probably also effectively include drainage areas of the smaller canyons that lack discharge. When the appropriate areas of canyons without discharge are added to the measured areas of

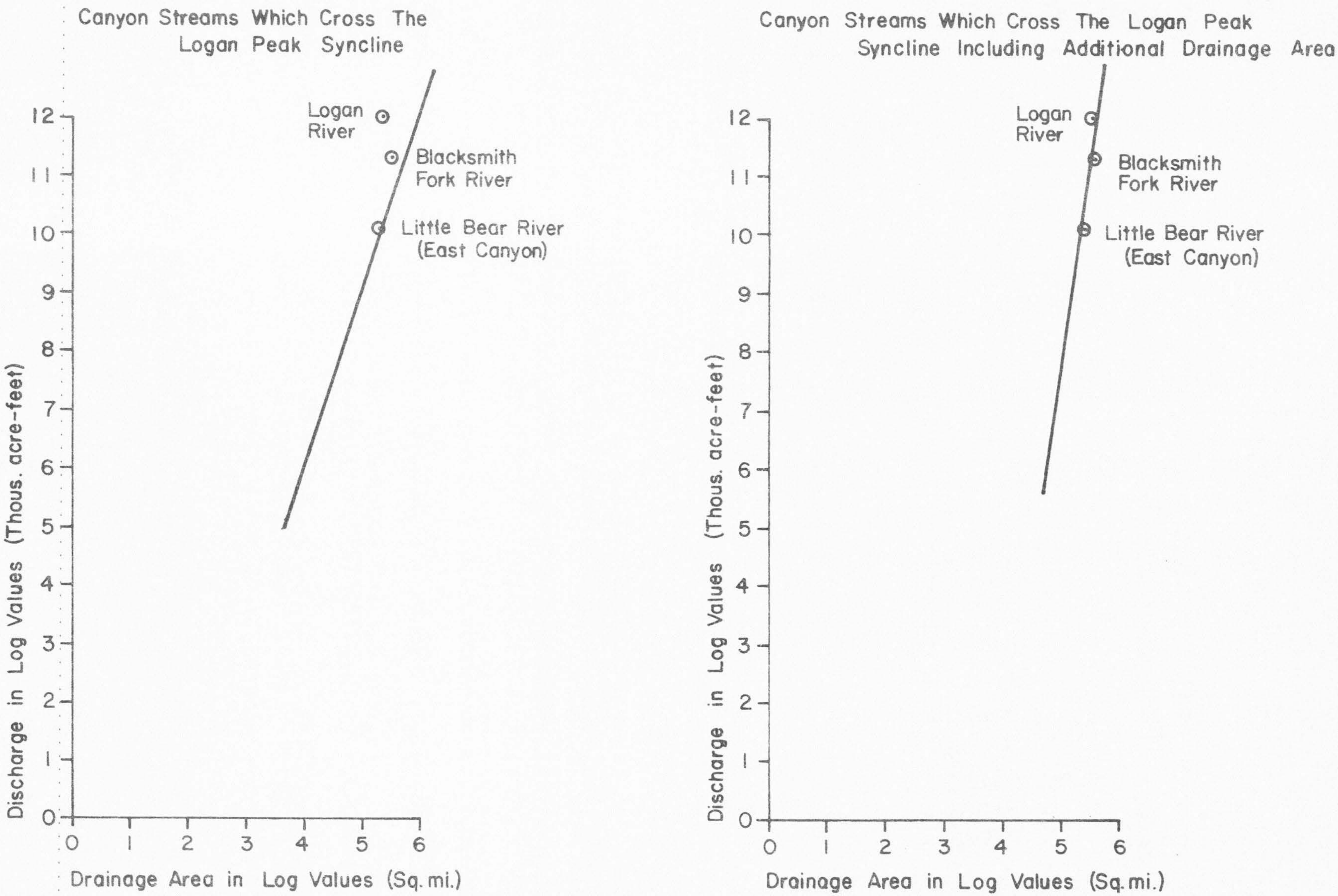

Figure 35. Comparison between discharge and normal, and adjusted drainage areas for canyon streams which cross the Logan Peak syncline.

cross-axial canyons, and the results are replotted for annual discharge and drainage, the statistical values for the best fitting line yields an R-square value of 67 percent (Figure 35, Table 5). A value of 67 percent is considered barely reliable for some predictive purposes (Romesburg, oral comm., Nov. 1975). In this case, the improvement in R-square values for the best fitting line supports the leakage concept.

Table 5. Linear regression statistical values for discharge against drainage area models

Test	Intercept	Slope (°)	R-square (%)
Canyon streams which do not cross the Logan Peak Syncline	4.64	59.5	92
Canyon streams that cross the Logan Peak Syncline	−5.83	72.3	17
Canyon streams that cross the Logan Peak Syncline including added drainage	−28.70	82.1	67
All canyon streams with discharge	6.68	39.9	81
All canyon streams with discharge including added drainage	6.74	39.1	82

To further test the statistical reliability of this idea, all of the canyons with average annual discharge values and drainage areas were compared statistically (Figure 36). A line with an R-square value of 81 percent can be plotted using values for all canyon, so this indicates

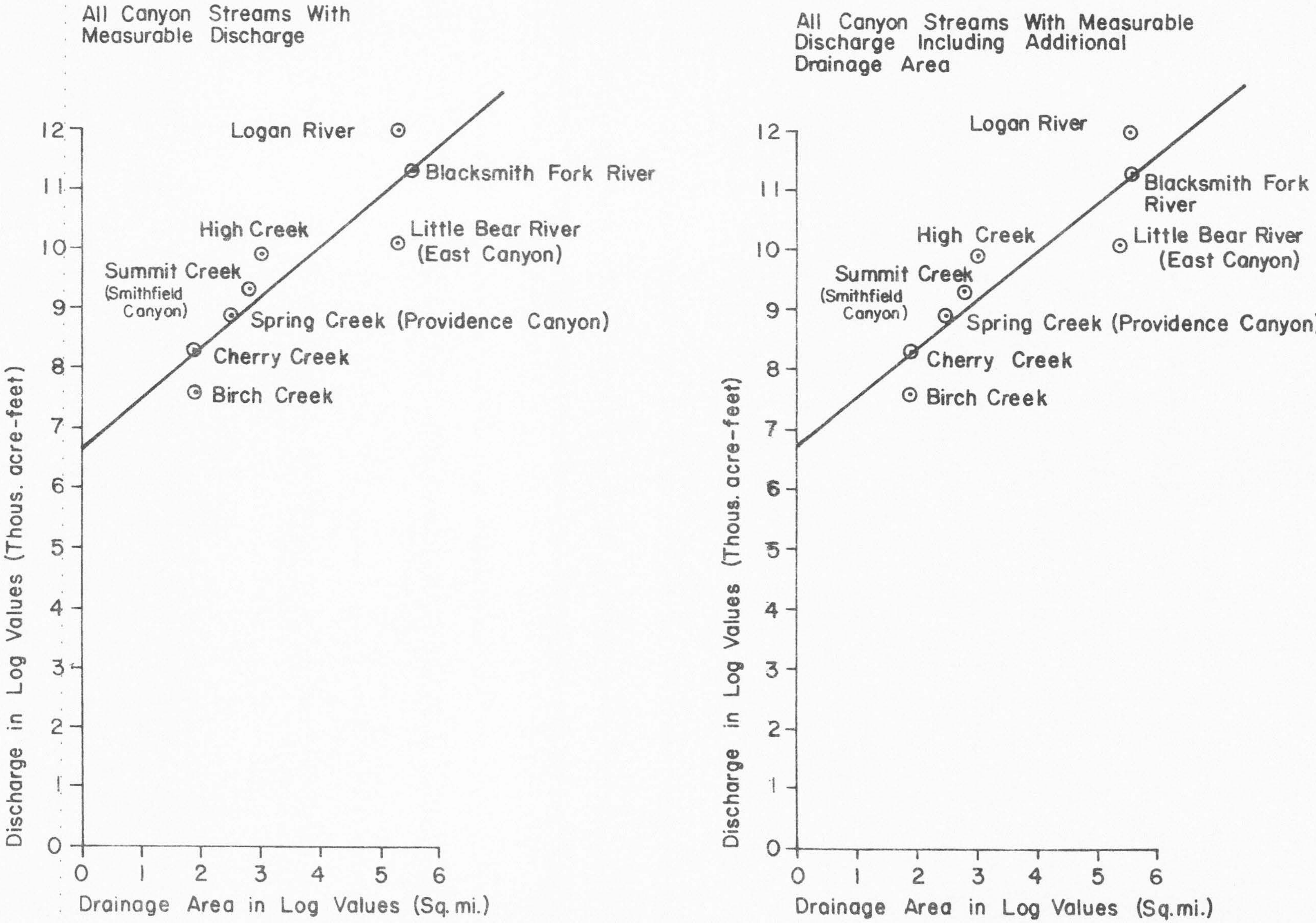

Figure 36. Comparison between discharge and normal, and asjusted drainage area for all canyon streams.

that the relationship of discharge and drainage area is consistent for all drainages in this part of the Bear River Range. If the leakage concept is valid, an improvement on this reliability should result from adding drainage areas of streams lacking discharge to the appropriate cross-axial canyons. Such improvement was found, although the improvement is small (Figure 36, Table 5). Thus, the two lines of statistical evidence support the leakage concept.

It would appear that the drainages that do not cross the syncline axis and have no appreciable discharge lose water underground through the rocks. Part of this water probably enters into the surface water discharged from the large cross-axial streams. A number of large springs add water to the surface flow in the large cross-axial streams. This water probably includes water leaked from the non-discharge drainages. Representative of these springs are Dewitt and Ricks springs in Logan Canyon. Dewitt springs has an estimated average annual discharge of 10 thousand acre-feet. Ricks spring has an estimated average annual discharge of 8 thousand acre-feet (Haws, oral comm., 1975).

The leakage between drainage basins is controlled by the stratigraphy of the Bear River Range. The water moving out of a small non-cross axial drainage would move parallel to the strike or down dip of the rock formation. Based on the mapped stratigraphic units, it is suggested that leakage is primarily through the Lodgepole and Great Blue Formations. These limestone rock units are subject to solution features and are the source of many springs. On the assumption that these two formations were the main conduits of leaked water, drainages with no appreciable discharge were added to the cross-axial drainage that would intercept water along the specified rock formations. The drainage are from Oxkiller Hollow, Birch Creek, Dry Canyon (North), Hyde Park Canyon, Green Canyon, and Dry Canyon (South) were added to the area for Logan Canyon. The drainage for Millville Canyon and Hyrum-Green Canyon was added to the area of Blacksmith Fork Canyon. Paradise Dry Canyon drainage area was added to the area of East Canyon. The statistical results suggest that this assumption does not completely satisfy the problem. It is quite likely that some part of the water from drainages with measureable discharge is leaked along the Lodgepole and Great Blue Formations. A more quantitative hydrologic investigation should be able to apportion drainage area from non-cross axial streams with and without measureable discharge to obtain an improved statistical model. Although an analysis of leakage into the large cross-axial drainages has not previously been attempted, the results are consistent with ground water and other hydrologic factors operating in this region (Fletcher, oral, comm., June, 1975).

GLACIATED CANYONS AND CIRQUES

General Statement

The extent of glaciated terrain in the Bear River Range was mapped and studied by Young (1939). He described the effects of glaciation from Blacksmith Fork Canyon as far north as the Utah-Idaho state line. Particular attention was given to the extensive glacial action in Logan Canyon and its tributaries. Young recognized and mapped the glacial features and deposits in the upper part of Providence Canyon and near Logan Peak. E. J. Williams (1964) compiled a detailed description of glacial features in the areas of Tony Grove Canyon. This tributary of Logan Canyon contains some conspicuous and well-defined glacial features. Both investigators recognized the effects of two glacial episodes, the older much more extensive. These two events were related to advances recognized in the Uinta, Wasatch, Teton, and Wind River mountains. Williams specifically related the other features in Tony Grove Canyon to the Bull Lake glacial episode, and the younger, to the Pinedale glacial episode. The work of Holmes and Moss (1955) and Blackwelder (1931) formed the basis for his correlations. Williams noted the difficulty in distinguishing moraine from weathered conglomerate of the Wasatch Formation. This difficulty is especially acute where the glacial moraine is eroded from outcrops of the Wasatch Formation.

Glacial deposits include lateral moraines, recessional moraines, ground moraines, and erratics. The shape and gradient in glaciated canyons is a conspicuous product of glacial erosion. Cirques are the main erosional feature created by glacial ice. A number of cirques are occupied by water for all or part of the year.

Description

High Creek Canyon

High Creek Canyon has been glaciated along the upper reach of South Fork tributary (Plate 29). Glacial erosion in High Creek Canyon and its tributaries has not been reported or mapped previously. The head of South Fork is a cirque (Table 6). The back wall of the cirque is an almost vertical cliff. Garden City Formation is exposed in the floor and lower walls of the cirque. Swan Peak Formation and Fish Haven Formation are exposed in the upper cirque walls. The cirque bottom is occupied by High Creek Lake (Plate 30). The lake is dammed by a rock lip of Garden City Formation. Glacial deposits are found downvalley, from the lake to the lower limit of ice. Ground moraine and erratics are the most prominent deposits. A number of small ponds and marshy areas are present near the lower extent of ice in the canyon. Probable recessional moraine and ground moraine have created poor drainage conditions near the former terminus. These deposits, erratics and

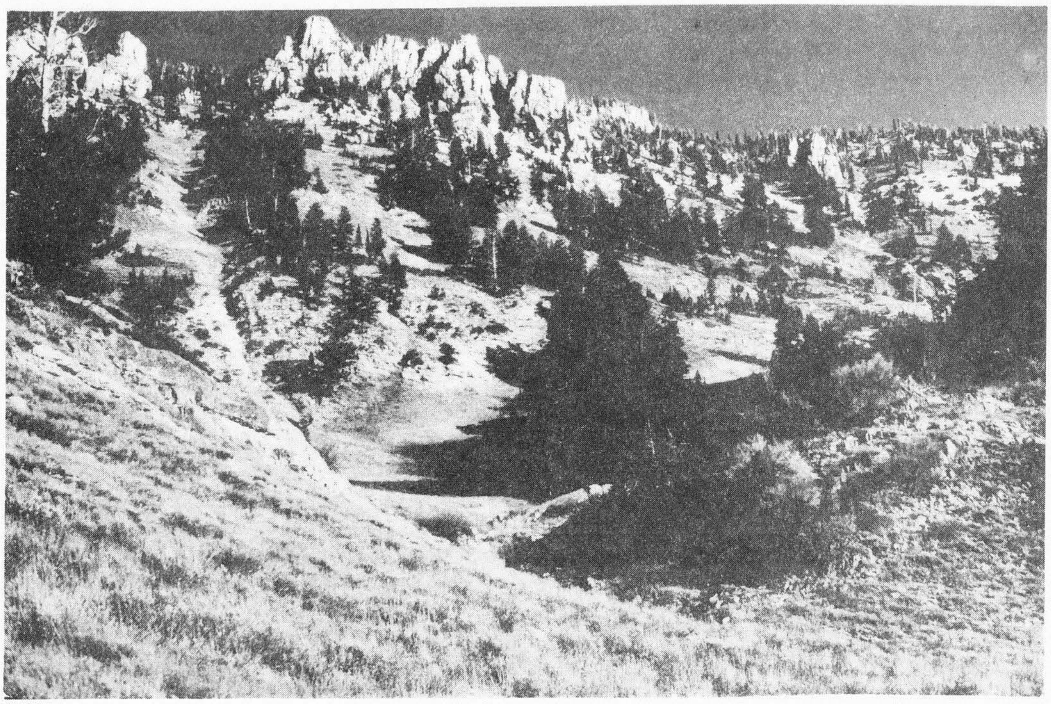

Plate 29. View upstream of South Fork of High Creek Canyon.

Plate 30. View of High Creek Lake from cliff at the head of South Fork.

Table 6. Description of glacial and nivation cirques in the Bear River Range.

Canyon	Tributary	Feature	Aspect	Cirque floor elev. (ft)	Cirque Relief min (ft)	Cirque Relief max (ft)	Downvalley Elev. (ft)	Ice limits distance (mi)
High Creek	South Fork	glacial cirque	N	8,800	240 -	1,000	7,000	1.8
Smithfield	Main[1]	nivation cirque	S	8,800	160 -	885	-----[2]	---[2]
	South Fork	glacial cirque	N	8,680	280 -	996	8,200	0.6
Birch	Main	glacial cirque	N	7,920	1,040 -	1,645	7,200	0.7
Green	Main	nivation cirque	SE	9,320	58 -	232	-----	---
	Main[3]	glacial cirque	SE	8,848	352 -	718	8,480	0.6
Logan	Main[4]	------------	---	-----	---	---	5,960	10.9
	Upper Spring Hollow	glacial cirque	NE	8,640	400 -	1,012	7,640[5]	1.1[5]
	Crescent Lake	glacial cirque	E	8,760	160 -	885	7,400	1.0[6]
	Steep Hollow	glacial cirque	E	8,640	280 -	1,233	7,280	1.4
	Hell's Kitchen	glacial cirque	SE	8,160	300 -	1,122	7,440	0.8
	Steam Mill	glacial cirque	E	8,640	360 -	1,096	6,880	3.2
	Beaver Creek[7]	------------	--	-----	---	---	6,920	2.8
	White Pine	glacial cirque	E	8,400	560 -	1,400	6,400	4.0
	Bunchgrass	glacial cirque	SE	8,400	80 -	1,350	6,280	4.0
	Tony Grove	glacial cirque	SE	8,040	440 -	1,939	6,240	4.6
	Cottonwood-South Fork	nivation cirque	SE	8,920	200 -	756	-----	---
	Cottonwood-South Fork	nivation cirque	SE	8,680	320 -	996	-----	---
	Cottonwood-Main	nivation cirque	E	8,440	160 -	902	-----	---
	Spring Hollow	glacial cirque	N	7,440	804 -	1,478	5,440	0.7
	Mill Hollow	glacial cirque	N	8,520	480 -	1,190	6,280	0.9
Dry (South)	Main	nivation cirque	N	8,480	120 -	800	-----	---
Providence	Main	glacial cirque	E	8,720	80 -	990	8,560	1.2

Table 6. Description of glacial and nivation cirques in the Bear River Range (Continued)

Canyon	Tributary	Feature	Aspect	Cirque floor elev. (ft)	Cirque Relief min (ft)	Cirque Relief max (ft)	Downvalley Elev. (ft)	Ice limits distance (mi)
Blacksmith Fork	Leatham Hollow	glacial cirque	E	7,000	200 -	1,064	6,800	0.5

[1] All tributaries designated as main indicate that the described feature is at the head of the main canyon.

[2] The lower limit downvalley is only indicated for the farthest extent of glacial ice beyond the limits of the glacial cirque. This elevation and distance is based on glacial erosion and deposits. Because no ice moves from a nivation cirque, no downvalley elevation or distance is noted.

[3] This glacial cirque is adjacent to the western head of the nivation cirque located at the head of the main Green Canyon.

[4] The source of the glacier for Logan Canyon is the Franklin Basin area in Idaho. This area is outside the boundaries of the study area. Therefore, no description of the glacial cirque is given. The lower limit of glacial ice downvalley is noted. The distance along which the ice extended is measured from the Utah-Idaho state line.

[5] Upper Spring Hollow is the tributary adjacent and north of Crescent Lake Canyon. The name is not presently used on the 7.5-minute topographic map. Upper Spring Hollow is the name used by Young (1939). The lower limit downvalley indicates the elevation and distance where this tributary canyon joins the Logan Canyon thalweg. This junction is outside the northern boundary of the study area.

[6] The lower limit downvalley of ice indicates the elevation at which the tributary canyon joins the thalweg of Logan Canyon. The distance is from the glacial cirque to the same point. This is true for all Logan Canyon tributaries except Hells' Kitchen Canyon. The ice in this canyon did not join the Logan Canyon glacier.

[7] Beaver Creek tributary contained ice from a glacial cirque in the Egan Basin area in Idaho. This source area is north of the boundaries of the study area. The glacial ice occupying this tributary did not join the main glacier in Logan Canyon. The downvalley ice limits are measured from the Utah-Idaho state line.

the downstream change to a narrow cross-valley profile help define the downvalley limit of glacial ice. Many of the glacial erratics are boulders of Swan Peak Formation found high on the side slopes of the canyon. This position and the size precludes their transport by water. The absence of outcrops of Swan Peak Formation in the cliffs above the erratics eliminates the possibility of their derivation from the upper canyons walls. The most likely transport mechanism that satisfactorily explains their location is glacial ice.

Smithfield Canyon

Smithfield Canyon contained a small glacier at the head of the South Fork tributary (Table 6). This glaciated area was described by Young (1939). The bedrock exposed in the walls and floor of the cirque is the Jefferson Formation. The ice appears to have extended only about one half of a mile down the canyon from the cirque. Only ground moraine is recognized along the glaciated part of the canyon.

Birch Canyon

Birch Canyon contained a small glacier at the head of the main canyon (Table 6). This feature was described by Young (1939). The effects of ice and snow have produced a well-developed amphitheater. The bedrock exposed in the walls and floor of the cirque appears to be the Jefferson Formation. Ground moraine extends for a distance of about one half mile down the canyon.

Green Canyon

Green Canyon has a small cirque near the head of the main canyon. This cirque has not previously been described (Table 6). The bedrock exposed in the cirque is the Madison Formation. The ice extended approximately one quarter of a mile down the canyon. The only deposits appear to be hummocky areas of ground moraine.

Logan Canyon

Logan Canyon and its tributaries were extensively glaciated (Plate 1). J. L. Young (1939) and E. J. Williams (1964) delineated almost all of the areas affected by glacial activity in this drainage. The main glacier down Logan Canyon came from a source in Franklin Basin. The Franklin Basin is in Idaho north of the boundary of the study area. The maximum extent of this ice down Logan Canyon was just downstream from the Tony Grove cattleguard near the present junction of the Logan River and Bear Creek. The terminus is approximately 16 miles up stream from the mouth of Logan Canyon. A small mass of glacial moraine is found at this point. It may be a preserved remnant of end moraine that has remained intact as a result of its location on the inside of a meander bend.

Nine tributary canyons contained glacial ice (Table 6). Young (1939) recognized and mapped glacial deposits and features in Upper Spring Hollow, Crescent Lake, Steep Hollow, Hell's Kitchen, Steam Mill, Beaver Creek, White Pine, Bunchgrass, and Tony Grove Canyons.

With the exception of Beaver Creek and Hell's Kitchen canyons, the cirques of these canyons expose Garden City Formation in the floor and lower walls and Swan Peak Formation and Fish Haven Formation in the upper walls. These same canyons extended into the main canyon and contributed ice to the Logan Canyon glacier. Hell's Kitchen Canyon has only Garden City Formation exposed in the cirque. The ice extending down this canyon did not reach the glacier in Logan Canyon. The source of ice for Beaver Creek Canyon is in Idaho north of the boundary of the study area. The ice probably was generated in Egan Basin and flowed into the Beaver Creek area, but did not contribute ice to the main glacier in Logan Canyon. The maximum extent of this ice reached a point about 24 miles from the mouth of Logan Canyon. This is near the point where a stream from Stump Hollow presently joins Beaver Creek. In addition to the glacial elements described by Young (1939), some sand deposits are present near the point where the canyon would have been blocked by ice. These deposits probably represent deposition in a small body of water impounded by the glacier.

Mill and Spring hollows are the 11th and 12th tributary canyons which contained glaciers. Both of these tributary canyons join the main Logan Canyon at a point about four miles from the mouth of Logan Canyon. Because both of these tributary canyons join the main canyon well below the maximum downcanyon extent of the Logan Canyon glacier, neither tributary contributed ice to the main glacier. In addition, neither tributary glacier extended completely down the tributary canyon to enter Logan Canyon.

Spring Hollow has a prominent cirque (Table 6). Young (1939) found some evidence to suggest that ice had flowed down Spring Hollow. A prominent lateral moraine along the eastern margin of the canyon helps to delineate the maximum extent of the glacier downstream. The ice extended approximately one half of a mile from the cirque. The bedrock exposed in the cirque is the Brazer Formation.

Mill Hollow previously has not been described as glaciated (Table 6). The cirque area of Mill Hollow is more prominent than nearby Spring Hollow. The bedrock exposed in the cirque is the Brazer Formation. Ground moraine of a few feet in thickness covers the canyon floor. A lateral moraine extends along the east margin of the canyon. The ice appears to have flowed down the canyon for a distance of about a mile from the cirque.

Providence Canyon

Providence Canyon was glaciated along its upper reach. The glacial elements in this canyon were recognized and mapped by Young (1939). The cirque is at the head of the canyon by Logan Peak (Table 6). The bedrock exposed is Brazer formation in the floor and lower walls and Wells Formation in the upper walls. Lateral moraines as well as ground moraine are found. The glacier extended down the canyon for a distance of about two miles from the cirque.

Blacksmith Fork Canyon

Blacksmith Fork Canyon had only one glacier within the boundaries of its drainage. This glacier was located in Leatham Hollow, a tributary to the Left Hand Fork of Blacksmith Fork Canyon. The cirque of this small glacier is not as well developed as some other former glaciers of comparable size. The ice modified the cross-valley configuration. The only discernable glacial deposits are ground moraine.

Analysis

The development of glaciers in the Bear River Range depended on the balance of forces controlling accumulation and ablation. The factors favoring accumulation and retention of snow were dominant at the cirques mapped. In this area, solar radiation and wind patterns seem to be the important factors favoring accumulation and retention of snow.

Glacial cirques face north, northeast, east, and southeast. No cirques open to the west or have a west-component direction. The west or west-component direction would allow direct solar radiation on the snow accumulation area when diurnal temperatures are highest. It is apparent that cirque orientations reduce the total amount of solar radiation received and restrict direct radiation to the cooler parts of the day. These orientations are favorable to retaining a maximum amount of snow.

There are two groups of cirques. One group is located on the eastern side of the main ridge of the Bear River Range. The second group is located on the western side of the main ridge. This group includes the South Forks of High Creek and Smithfield Canyons, Birch Canyon, and Mill and Spring Hollows. The location of cirques in both groups appears to be influenced by wind patterns.

The group located on the eastern side of the main ridge of the Bear River Range gave rise to the largest glaciers. The general prevailing westerly winds are assumed to have controlled storm direction during the glacial parts of the Pleistoncene. The greatest snow accumulation would occur on the iceward or eastern side of the main ridge. This seems to account for both the size and preponderance of glacial cirques with this location.

The cirques in the South Forks of High Creek and Smithfield Canyons, Birch Canyon, and Mill and Spring Hollows were not subject to favorable snow accumulation based on the general wind pattern. Snow accumulation for these cirques resulted from a localized wind pattern. An examination of the topography around each site suggests that wind was funneled into these cirques. This localized wind pattern created a favorable snow accumulation site (Richardson, oral comm., March, 1976). Once sufficient snow accumulated a second attribute unique to these cirques came into play. All five cirque open to the north. A north orientation provides the greatest protection from solar radiation. Cirques with this orientation receive the least amount of solar radiation during the year and have no direct radiation during the warmest parts of the day. At these sites, snow accumulation resulting from the localized wind pattern was protected from solar radiation by the north-facing direction of these cirques. The existance of glacial cirques at locations that would not normally be suitable appears to result from this combination of localized wind pattern and favorable orientation.

NIVATION CIRQUES

General Statement

Many localities exhibit a configuration and morphology suggesting nivation activity (Plate 1). Nivation cirques are distributed throughout the Bear River Range, where cirques and other glacial features are found (Table 6). The main differences between glacial cirques and nivation cirques appears to be aspect and elevation. These factors control the persistence of snow fields and the amount of ice generated for a glacier. All the cirques with large glaciers open with a north or east aspect. The majority of nivation cirques open toward the south or southeast. In those cases where nivation cirques have a north or east aspect, the elevation or relief of the catchment area is significantly less than the glacial cirques in the same area. These differences would affect the amounts of solar insolation received, the temperature ranges, and amounts of snow received from the prevailing winds. Such differences prevented these sites from generating sufficient ice for a glacier. The permanent snowfield and ice that did form actively eroded prominent basins. Nivation cirques are considered periglacial features (Washburn, 1973).

Description

Smithfield Canyon

J. L. Young (1939) recognized and described the nivation cirque at the head of Smithfield Canyon (Plate 31, Table 6). The bedrock exposed in the nivation cirque is Garden City Formation. The ice and snow that occupied this cirque have piled rock debris into a hummocky topography within the cirque (Plate 32).

Green Canyon

A nivation cirque at the head of Green Canyon (Table 6) is on the east side of the glacial cirque in Green Canyon. The bedrock exposed in this cirque appears to be the Madison Formation. This site is similar in aspect, and elevation to the glacial cirque in Green Canyon. The probable reason for this site not becoming a glacial cirque is the significantly lower relief between the floor and the top of the surrounding walls. This low relief reduced the amount of snow caught within the basin.

Logan Canyon

Logan Canyon has three nivation cirques about the crest of the Bear River Range at points opposite to nivation cirques or glacial cirques in Smithfield, Birch, and Green Canyons. The first nivation cirque is on the south flank of Mt. Elmer. The bedrock exposed in the basin appears to be Jefferson Formation. The second nivation cirque

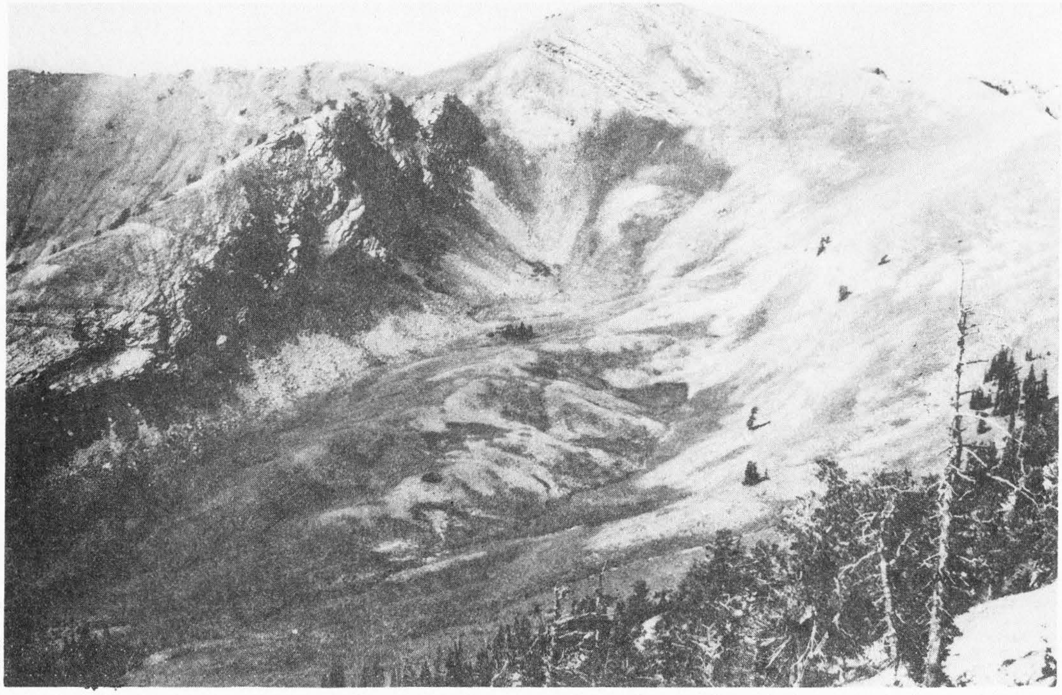

Plate 31. View northwest of nivation basin at the head of Smithfield Canyon.

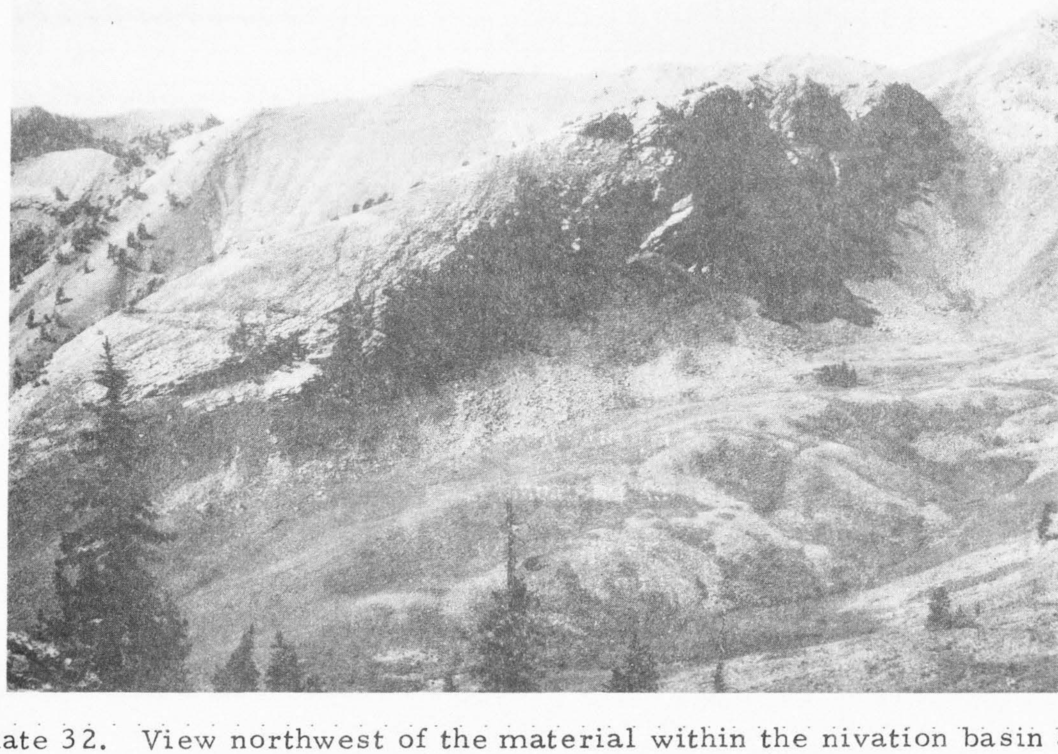

Plate 32. View northwest of the material within the nivation basin at the head of Smithfield Canyon.

is at the South Fork branch of Cottonwood Canyon. This cirque is located on the east flank of Mt. Elmer. Jefferson Formation appears to be exposed in this nivation cirque. The third nivation cirque abuts the crest of the Bear River Range just north of Mt. Elmer. The bedrock exposed in this cirque appears to be Laketown Formation. This nivation cirque was described by Young (1939).

Dry Canyon (South)

Dry Canyon (South) has a nivation cirque at its head (Table 6). This nivation cirque has Brazer Formation exposed in the floor and walls. The ice and snow accumulation in this cirque carved an amphitheater and left deposits of rock debris.

Analysis

The possibility exists that some of the nivation cirques may have been host to small active glaciers. This is particularly true of those cirques which have aspects and elevations similar to nearby glacial cirques. The nivation cirques described do not contain definite evidence of glaciation. All nivation cirques display the morphology indicating active nivation.

Nivations cirques developed where conditions were insufficient for accumulating or retaining snow necessary to an active glacier. The factors responsible were poor location, unfavorable aspect, and insufficient accumulation aeea. In many instances, a combination of these factors restricted the site to nivation rather than glacial activity. The nivation cirque at the head of Dry Canyon (South) is representative of poor location for glacial development. Neither general or localized wind patterns were adequate to produce sufficient snow accumulation. Smithfield Canyon nivation cirque has many attributes favorable to the development of a glacier. This nivation cirque has a southwest aspect. It appears that this unfavorable aspect was important enough to restrict activity to nivation. Insufficient accumulation area can be illustrated by the nivation cirque at the head of Green Canyon. The minimum relief of this cirque is small compared to most glacial cirques. This factor may have reduced the depth of snow that could accumulate. In each instance, the same factors affecting the development of glaciers in the Bear River Range controlled the development of nivation cirques. The balance of accumulation and ablation restricted the nivation cirques to ice and snow erosion at the accumulation site.

PATTERNED DIAMICTON

General Statement

Four canyons contain localities with a beaded or striped pattern. On aerial photographs, the appearance of these areas is similar to patterned ground associated with periglacial environments (Plate 33). The term, patterned ground, is defined in the American Geological Institute Glossary (1975) as:

> A group term suggested by Washburn (1950) for certain well-defined, more or less symmetrical forms, such as circles, polygons, nets, steps, and stripes, that are characteristic of, but not necessarily confined to, surficial material subject to intensive frost action.

Patterned diamicton at sites in the Bear River Range most closely resemble circles and stripes. Ground observations revealed that the patterned appearance involved only regolith at these sites. The pattern was much less apparent in ground-level observations. The mounds responsible for the pattern range from 13 to 66 feet across. The average mound diameter is 40 feet, and total relief is only 1 to 3 feet. The mounds are usually composed of sand, gravel, and cobbles. There is little difference in grain sizes between the mound and intermound areas. Only one site exhibits coarser material in the intermound area, but this circumstance may result from flushing out of fine material from low intermound areas during spring runoff (Southard and Williams, 1970).

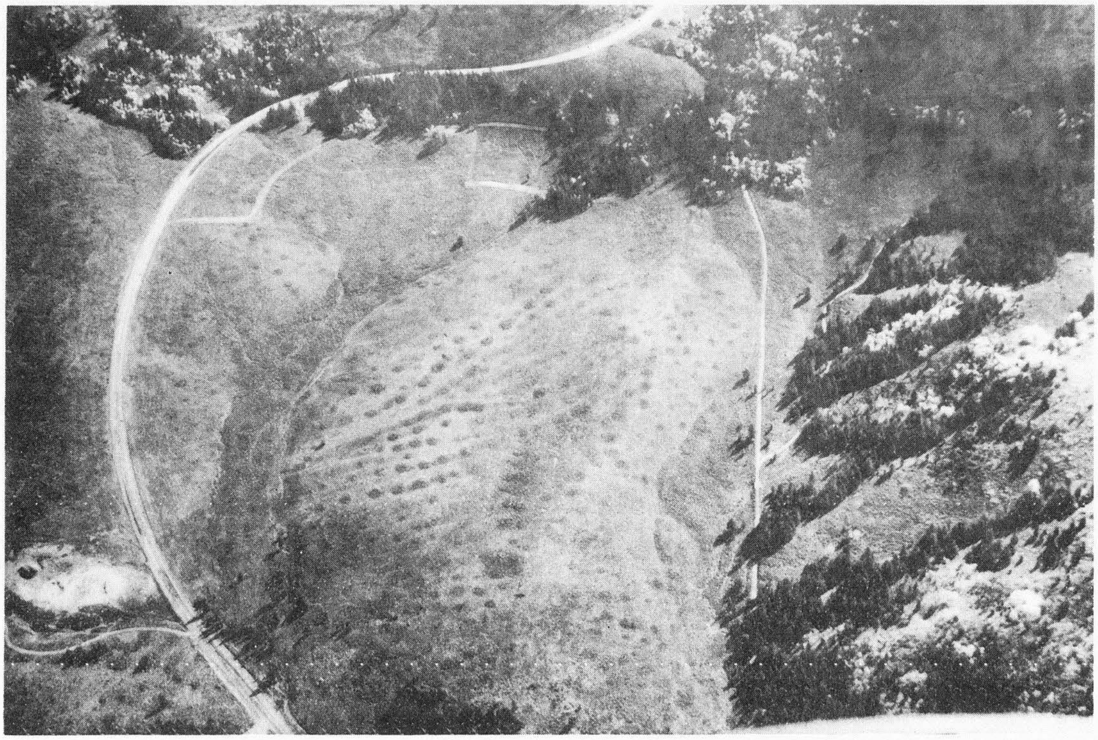

Plate 33. An oblique aerial view of patterned ground in the Southern part of Bear Basin.

The material both in and among the mounds appears to be derived from the same source at each site; but the parent material varies among different localities. These areas have benn designated on Plate 1 as patterned diamicton of Quaternary age, in keeping with previous work in this region (Southard and Williams, 1970; Williams and Southard, 1970).

Description

McKenzie Flat

One area of patterned diamicton is outside the confines of the canyons in the Bear River Range. This site is on McKenzie Flat, a pediment surface, just south of the mouth of East Canyon. This diamicton field is within secs. 13, 14, 23, and 24, T. 9 N., R. 1 E., and on the Paradise 7.5-minute topographic map. Table 7 summarizes the physical dimensions of this patterned diamicton as site 1. The mounds are aligned in beaded stripes down the slope. The regolith was derived from the underlying Salt Lake Formation.

Green Canyon

Green Canyon is the northermost drainage basin. It contains patchy areas of patterned diamicton. Most of the diamicton sites are along the upper part of the canyon in the area adjacent to Mt. Jardine. The physical dimensions of sites two through five are summarized in Table 7.

Table 7. Physical dimensions and characteristics of patterned diamicton.

Site	Upper Elev. (ft)	Lower Elev. (ft)	Slope (°)	Slope (%)	Aspect	Area Acres	Area Hectares
1	5,600	5,400	5	9	NW	204	83
2	9,200	8,400	23	42	SE	26	11
3	9.360	8,800	20	36	S	19	8
4	9,000	8,480	12	21	S	45	18
5	9,440	9,200	10	18	SE	26	11
6	9,160	8,360	22	40	S	51	21
7	8,560	8,440	4	7	SE	109	44
8	8,880	8,800	6	11	SE	6	2
9	8,080	8,000	4	7	SW	13	5
10	8,040	7,800	10	18	W	19	8
11	7,920	7,880	0	0	Horiz.	19	8
12	7,400	7,080	10	18	SW	58	23
13	8,320	7,840	14	25	SW	38	15
14	7,800	7,560	9	16	SW	58	23
15	6,200	6,160	5	9	W	19	8
16	6,600	6,480	4	7	SW	19	8
17	6,960	6,840	4	7	S	19	8
18	6,920	6,720	6	11	E	51	21
19	7,560	7,480	5	9	E	13	5
20	7,520	7,440	5	9	E	19	8
21	7,520	7,440	5	9	SW	13	5
22	7,120	7,000	4	7	W	134	54
23	7,120	7,040	5	9	NE	13	5
24	7,280	7,200	4	7	SW	32	13
25	6,800	6,720	0	0	Horiz.	45	18
26	6,880	6,760	8	14	NW	32	13
27	7,000	6,880	17	31	W	32	13
28	6,640	6,560	6	11	NW	13	5

Table 7. (Continued)

Site	Upper Elev. (ft)	Lower Elev. (ft)	Slope (°)	Slope (%)	Aspect	Area Acres	Area Hectares
28	6,640	6,560	6	11	NW	13	5
29	7,080	7,000	0	0	Horiz.	19	8
30	7,200	7,040	15	27	E	13	5
31	6,840	6,520	13	23	SW	70	28
32	7,160	7,040	0	0	Horiz.	45	18
33	7,080	6,920	0	0	Horiz.	371	150
34	8,600	8,480	9	16	SW	38	15
35	8,520	8,400	6	11	S	32	13
36	6,960	6,800	5	9	NW	19	8
37	7,080	6,840	7	12	W	32	13
38	7,200	6,840	10	18	W	38	15
39	7,688	7,400	0	0	Horiz.	346	140

The second site is on the south flank of Mt. Jardine, which forms the western slope of Green Canyon. This location is on the Mt. Elmer 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith probably was derived from the Madison Formation by nivation and weathering processes.

The third site is on the southeast flank of Mt. Jardine. This location is on the Mt. Elmer 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith probably was derived from the Madison Formation through nivation and weathering processes.

The fourth site is on the east flank of Mt. Jardine. This location is on the Mt. Elmer 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The patterned diamicton occupies a probable nivation basin. The regolith involved was probably derived from the Madison Formation.

The fifth site is at the head of Green Canyon. This area is on the ridge just north of Mt. Jardine peak. This location is on the Mt. Elmer 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith probably was derived from the Madison Formation.

Logan Canyon

Logan Canyon contains areas with the patterned morphology. Most of the areas affected are in the upper reaches of the drainage basin. The physical dimensions of sites 6 through 22 are summarized in Table 7.

The sixth site is at the head of Cottonwood Canyon, a tributary of Logan Canyon, near the main ridge leading toward Naomi Peak to the north. This location is on the Naomi Peak 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the Laketown Formation which underlies the area.

The seventh site is about 1.0 mile due north of Tony Grove Lake near the head of Bunchgrass Creek Canyon. This location is on the Naomi Peak 7.5-minute topographic map. The mounds are evenly distributed within the area. The regolith was probably derived from the underlying Garden City Formation.

The eighth site is in the basin forming the head of Steam Mill Canyon. This location is on the Naomi Peak 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the underlying Garden City Formation.

The ninth site is about 1.3 miles due north of Borden Reservoir and approximately 1.0 mile due east of Barrel Spring. This location is on the Temple Peak 7.5-minute topographic map. The mounds are evenly distributed. The regolith was derived from weathering of the conglomerate member of the Wasatch Formation.

The tenth site is 0.5 mile northwest of the fourth site, 1.5 miles due south of Temple Spring, and approximately 2.5 miles due north of Trigaro Spring. This location is on the Temple Peak 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was derived from the conglomerate member of the Wasatch Formation.

The eleventh site is 0.7 miles due north of Tin Cup Spring, 1.2 miles due south of the head of Log Cabin Hollow, and 6.3 miles due east of Logan Cave. This location is on the Temple Peak 7.5-minute topographic map. The mounds are evenly distributed over the area. The regolith was probably derived from the Bloomington Formation.

The twelfth site is near the 7,430-foot summit between Blind Hollow and Bear Hollow. It is 1.7 miles north of the Twin Bridges picnic area in Logan Canyon. This location is on the Temple Peak 7.5-minute topographic map. The mounds are evenly distributed over this area. The regolith was probably derived from the Laketown Formation which underlies the site.

The thirteenth site is 1.1 miles due south of Rex Reservoir, 3.2 miles due east of Lewis M. Turner Campground, and near the head of Little Bear Creek Canyon. This location is on the Tony Grove Creek 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the underlying Bloomington Formation.

The fourteenth site is in White Pine Canyon. It is about 2.6 miles upstream from the junction of White Pine Creek and the Logan River. This location is on the Tony Grove Creek 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from glacial ground moraine composed of rock material from several formations which outcrop in the upper part of White Pine Canyon.

The fifteenth site is just south of the Utah State University Forestry Field State in Logan Canyon. It is adjacent to the Logan River at the mouth of West Hodges Creek. This location is on the Temple Peak 7.5-minute topographic map. The mounds are evenly distributed over the area. The regolith was probably derived from glacial ground moraine and stream alluvium.

The sixteenth site is near the junction of White Pine Creek and the Logan River. It is about 2.1 miles due north of the Utah State University Forestry Field Station. This location is on the Tony Grove Creek 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from both glacial ground moraine and stream alluvium.

The seventeenth site is on the west slope of Logan Canyon about 2.7 miles due north of Lewis M. Turner Campground. This location is on the Tony Grove Creek 7.5-minute topographic map. The mounds are evenly distributed over the area. The regolith was probably derived from both glacial ground moraine and stream alluvium.

The eighteenth site is just north of the twelfth site. It is about 3.1 miles due north of Lewis M. Turner Campground. This location is on the Tony Grove Creek 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from both glacial ground moraine and stream alluvium.

The nineteenth site is just north of the junction of Crescent Lake Canyon and Logan Canyon. It is on the western slope of Logan Canyon. This location is on the Tony Grove Creek 7.5-minute topographic map. The mounds are evenly distributed over the area. The regolith was probably derived from both glacial ground moraine and stream alluvium.

The twentieth site is just north of the fourteenth site. It is approximately 1.1 miles due south of the intersection of the Logan River and the Utah-Idaho state line and on the west side of Logan Canyon. This location is on the Tony Grove Creek 7.5-minute topographic map. The mounds are evenly distributed over the area. The regolith was probably derived from glacial ground moraine and stream alluvium.

The twenty-first site is just north of site fourteen on the east slope of Logan Canyon. It is about 0.5 miles south of the intersection of the Logan River and the Utah-Idaho state line. This location is on the Tony Grove Creek 7.5-minute topographic map. The mounds are evenly distributed over the area. The regolith was probably derived from glacial ground moraine and stream alluvium.

The twenty-second site is at Beaver Basin. The western margin of this site is adjacent to State Highway 243. The site is bisected by U. S. Highway 89. This location is on the Tony Grove Creek 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from alluvial material.

Blacksmith Fork Canyon

Blacksmith Fork Canyon, like Logan Canyon, has a large number of patterned diamicton sites. Some of the largest sites are found in this drainage area. As in the other drainage basins, the patterned diamicton sites are in the upper reaches of the basin. The physical dimensions of the twenty-third through thirty-eighth sites are summarized in Table 7.

The twenty-third site is at Bear Spring. It is about 3.6 miles east on Dip Hollow Road from the road junction with the Saddle Creek-Elk Valley Road. This location is on the Boulder Mountain 7.5-minute topographic map. The mounds are evenly distributed over the area. The regolith was derived from the Wasatch Formation.

The twenty-fourth site is in sec. 21, T. 11 N., R. 4 E. at the junction of two small unimproved roads. This location is on the Boulder Mountain 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith is derived from the Wasatch Formation.

The twenty-fifth site is at Squaw Flats in secs. 29 and 30, T. 11 N., R. 4 E. This location is on the Boulder Mountain 7.5-minute topographic map. The mounds are evenly distributed over the flat area with some alignment into beaded stripes along the sloping margins. The regolith was probably derived from the Wasatch Formation.

The twenty-sixth site is just west of Squaw Flats. The area is in sec. 25, T. 11 N., R. 3 E. and sec. 30, T. 11 N., R. 4 E. This location is on the Boulder Mountain 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the Wasatch Formation.

The twenty-seventh site is just northeast of Squaw Flats along the west side of the Hardware Ranch-Danish Dugway Road. The area is in secs. 20 and 29, T. 11 N., R. 4 E. This location is on the Boulder

Mountain 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the Wasatch Formation.

The twenty-eighth site is on the north side of Blacksmith Fork Canyon. The area is on a summit between Rock Creek and North Cottonwood Canyon in sec. 9, T. 10 N., R. 3 E. This location is on the Hardware Ranch 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the underlying Brigham Formation.

The twenty-ninth site is on the 7,088-foot summit on the south side of Blacksmith Fork Canyon. It is in secs. 16 and 21, T. 10 N., R. 3 E. This location is on the Hardware Ranch 7.5-minute topographic map. The mounds are evenly distributed over the flat area. The regolith was probably derived from the underlying Brigham Formation.

The thirtieth site is 0.6 miles southwest of the seventh site. This area is in sec. 20, T. 10 N., R. 3 E. The location is on the Hardware Ranch 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith is probably derived from the underlying Brigham Formation.

The thirty-first site is 0.8 mile southeast of the seventh site. It is in sec. 21, T. 10 N., R. 3 E. This location is on the Hardware Ranch 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the underlying Brigham Formation.

The thirty-second site is at the head of Curtis Hollow, a tributary to Mill Creek. It is in secs. 29 and 32, T. 10 N., R. 3 E. This location is on the Hardware Ranch 7.5-minute topographic map. The mounds are evenly distributed over the flat area. Some mounds are aligned in beaded stripes down the sloping margins. The regolith was probably derived from the Brigham Formation.

The thirty-third site is at Bear Flat. Bear Flat is the area at the head of Fox and Bear Hollows, tributaries of Mill Creek. This location is on the Hardware Ranch and Porcupine Reservoir 7.5-minute topographic maps. The mounds are evenly distributed over the areas, except for some beaded stripes down the sloping margins. The regolith was derived from the Wasatch Formation.

The thirty-four site is 0.5 miles due west of Buck Spring. It is in secs. 17 and 20, T. 9 N., R. 4 E. This location is on the Hardware Ranch 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the underlying Wasatch Formation.

The thirty-fifth site is about 0.7 miles due north of Buck Spring and at the head of Petes Hollow. It is in sec. 17, T. 9 N., R. 4 E. This location is on the Hardware Ranch 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the Wasatch Formation underlying the area.

The thirty-sixth site is 2.1 miles up South Cottonwood Canyon from its junction with Blacksmith Fork Canyon. It is in sec. 20 and 29,

T. 10 N., R. 3 E. This location is on the Porcupine Reservoir 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the Brigham Formation.

The thirty-seventh site is 3.0 miles up South Cottonwood Canyon from its junction with Blacksmith Fork Canyon. It is in sec. 29, T. 10., R 3 E. This location is on the Porcupine Reservoir 7.5-minute topographic map. The regolith was probably derived from the underlying Brigham Formation.

The thirty-eighth site is 3.2 miles up South Cottonwood Canyon from its junction with Blacksmith Fork Canyon. It is in secs. 29 and 32, T. 10 N., R. 3 E. This location is on the Porcupine Reservoir 7.5-minute topographic map. The mounds are aligned in beaded stripes down the slope. The regolith was probably derived from the Wasatch Formation.

East Canyon

The southernmost canyon containing patterned diamicton is East Canyon. The second largest site is located in this drainage basin. The physical dimensions of the thirty-ninth site are summarized in Table 7.

The thirty-ninth site is about 2.3 miles due south of Bear Flats and 3.7 miles due east of the eastern end of Porcupine Reservoir. This location is on the Porcupine Reservoir 7.5-minute topographic map. The mounds are evenly distributed over the flat part of the area. Some mounds are aligned in beaded stripes along the sloping margins. The regolith was probably derived from the Wasatch Formation.

The thirty-nine patterned diamicton sites that have been identified and mapped (Plate 1), occupy approximately 2,359 acres. Regolith at each site was derived from carbonates, quartzites, conglomerates, or unconsolidated material. Williams and Southard (1970) and Southard and Williams (1970) noted the presence of a clay layer in the B horizon of the soil profile at depths of 2 to 4 feet at some patterned diamicton sites. This clay layer was attributed to the tuffaceous Salt Lake Formation, from which the soil had been derived at those localities.

Analysis

Locations of the sites are not restricted to specific physiographic settings. Patterned diamicton sites are found through a wide range of elevations, on a variety of slope gradients, and oriented in every direction (aspect) except north.

A graphic representation of the elevation ranges of patterned diamicton sites within the Bear River Range shows a seemingly random distribution. However, if the elevation ranges are grouped according to slope aspect, a distribution pattern becomes apparent. Different aspects encompass limited elevation ranges (Figure 37).

The elevation data for patterned diamicton sites can be evaluated relative to a number of factors (Table 8). The highest and lowest elevation values establish the limits of sites for a particular aspect. These

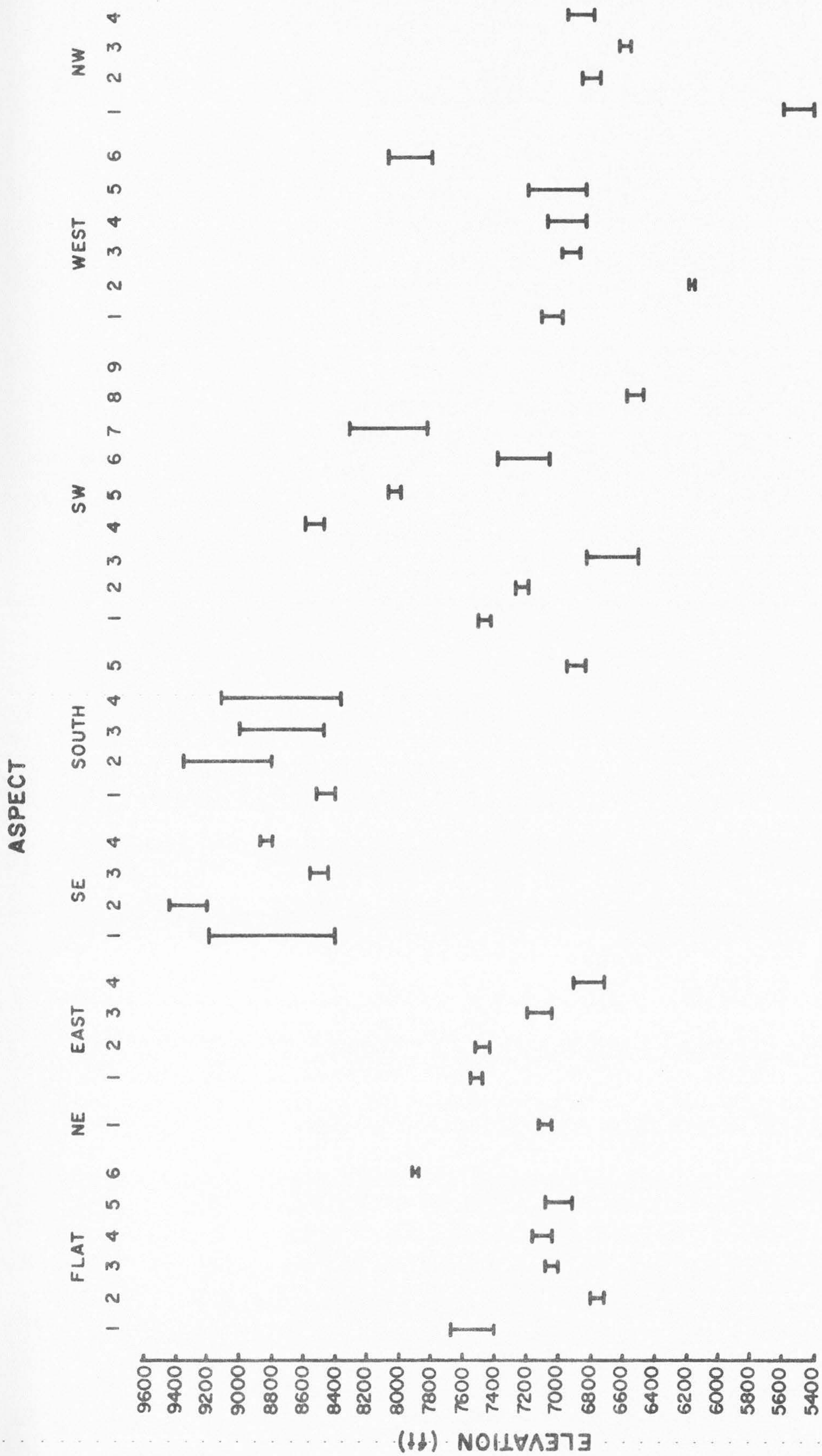

Figure 37. Elevation ranges of patterned-diamicton fields compared with aspect.

Table 8. Diamicton site elevation values compared with aspect.

Direction Slope faces	Highest elevation	Lowest elevation	Elevation limit extremes Upper	Lower	Ave. of midpoints of elev. ranges
FLAT	7920 ft.	6720 ft	7288 ft	7167 ft.	7220 ft.
NORTHEAST	7120 ft.	7040 ft.	7120 ft.	7040 ft.	7080 ft.
EAST	7560 ft.	6720 ft.	7300 ft.	7170 ft.	7232 ft.
SOUTHEAST	9440 ft.	8400 ft.	9020 ft.	8710 ft.	8865 ft.
SOUTH	9360 ft.	6840 ft.	8600 ft.	8176 ft.	8388 ft.
SOUTHEAST	8600 ft.	6480 ft.	7604 ft.	7400 ft.	7491 ft.

extreme limits do not necessarily indicate the elevation of most of the patterned diamicton with a particular aspect. A more representative range can be constructed by using the mean of the upper values and the mean of the lower values for all patterned diamicton fields having a particular slope aspect. The range between illustrates the elevation range of the majority of patterned diamicton. Another significant value is the mean of the midpoints of the elevation ranges. This value best represents the mean elevation at which patterned diamicton sites are found on a particular aspect. A representation of the mean of the midpoints of the ranges and the extreme values shows that distribution of patterned diamicton is related to aspect (Figure 38).

The relation between elevation and aspect suggests a casual relationship between the elevation and solar insolation. To obtain values for different aspects, the total annual potential insolation for each site was compiled from prepared tables (Frank and Lee, 1966). The values taken from the tables compensate for both the slope and the latitude of each site. Insolation values for each aspect were averaged, and then compared with the mean elevation for the same aspect (Figure 39). It is clear that the elevation of patterned diamicton sites is strongly correlated with the amount of annual potential insolation.

One anomalous point can be noted. The potential insolation curve almost crosses the elevation curve for southeast-facing sites. This is inconsistent with the relationship between the two curves for all other

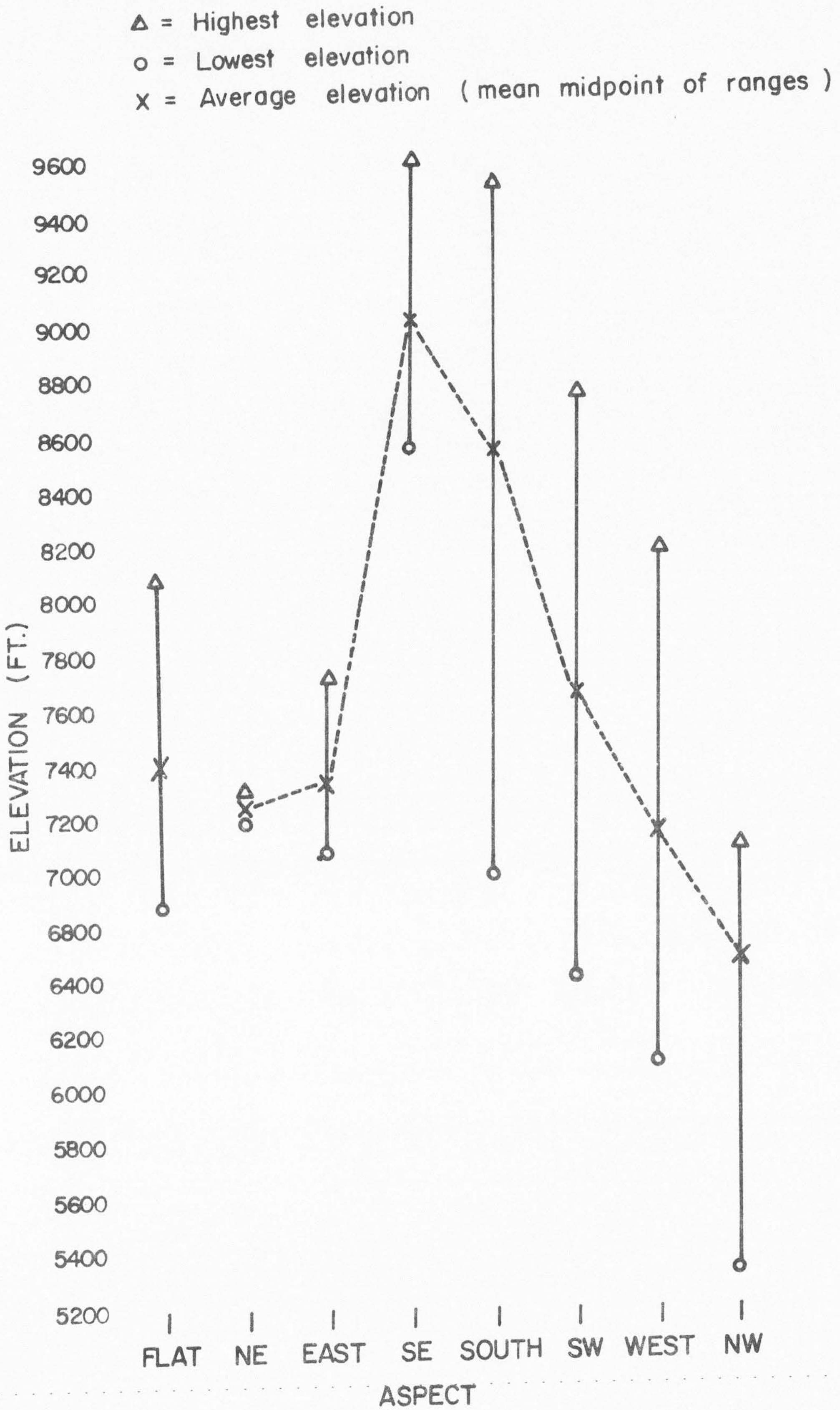

Figure 38. Mean and extreme elevation values for patterned diamicton yields compared with aspect.

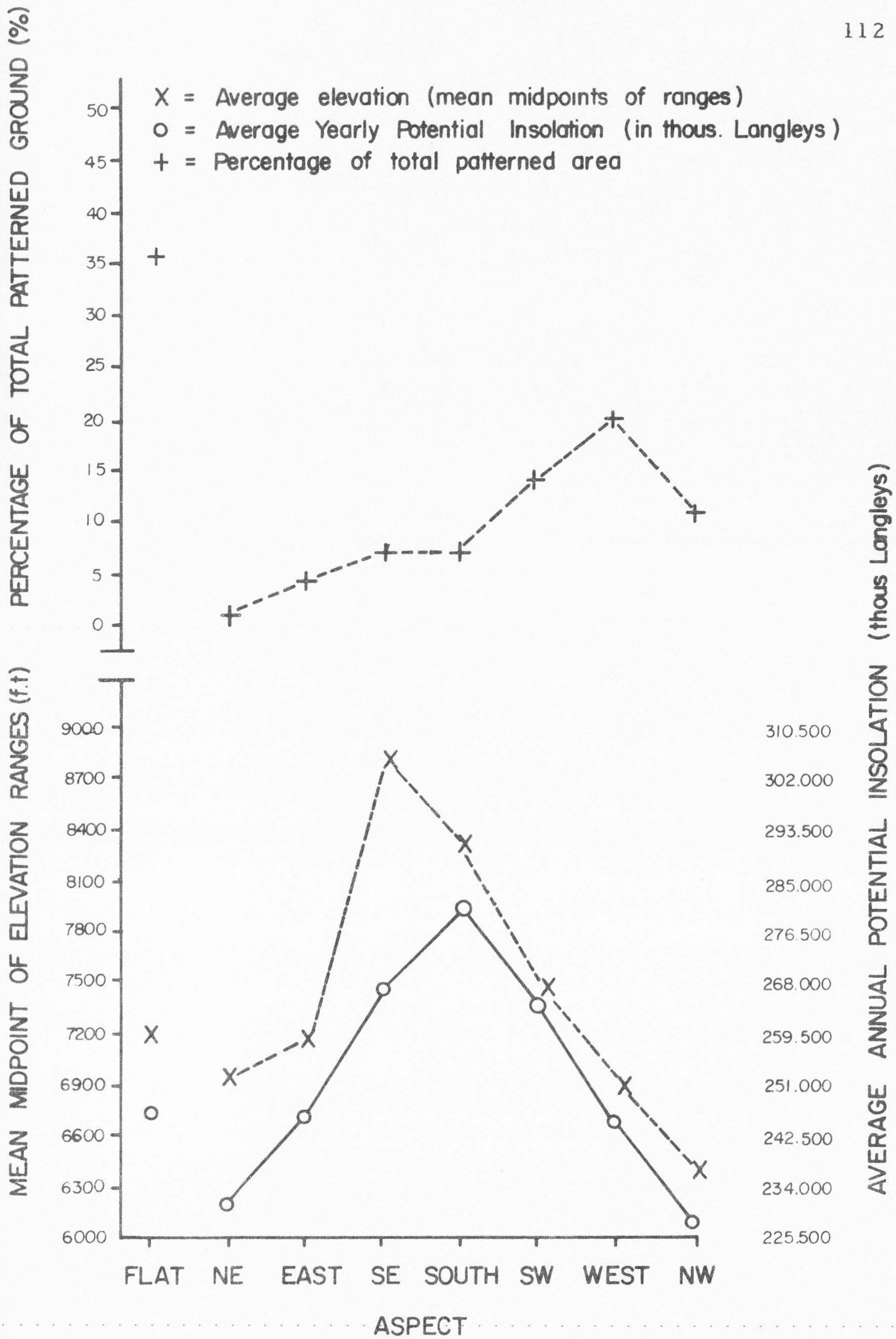

Figure 39. Mean elevation, potential insolation, and percentage of total patterned diamicton fields compared with aspect.

aspects. A re-examination of the southeast-facing sites revealed that most of these localities were located within basin-like areas. This is unlike the sites for other aspects. It is suggested that the location of these patterned diamicton fields in a basin changes some of the effects of insolation and temperature affecting the formation of patterned diamicton. The basins would tend to accumulate a greater amount of snow than slopes or ridge tops. This snow cover would tend to persist later into the spring. This persistence would result from the shading effect of the walls of the basin. The snow cover would become shaded in the late afternoon when air temperatures are highest. This would retard the melting of the snow. When the snow is removed to allow frost action to form patterned diamicton fields, the diurnal air temperatures would be too high for effective freeze-and-thaw cycles. If the site is at a higher elevation than predicted based on the elevation and insolation curves for other aspects, the temperatures would be colder in the late spring when effective frost action would begin to form patterned diamicton. Therefore, the higher than expected elevations of southeast-facing sites in basins would produce lower diurnal temperatures in the late spring when the snow cover is reduced sufficiently to allow patterned diamicton formation to take place. In this manner, elevation compensates for the higher temperatures experienced in the late spring. This assumption seems supported by the single nonbasinal site which faces southeast. The mean elevation is 8,500 feet at this location. If this value were used as the mean elevation for all southeast-facing slopes, the elevation curve would be more consistent in comparison to the solar-insolation curve.

Among the 2,359 acres of patterned diamicton fields, there is a variation in the percentage found on different aspects (Figure 39). The percentage-of-area curve is similar to the curves for solar insolation and mean site elevation. The higher values coincide with flat, southwest- and west-facing directions. These higher values probably are related to daily variations in temperature. Higher daily temperatures occur on southwest- and west-facing slopes in the Northern Hemisphere. If the temperature is near freezing, this attribute of aspect increases the number of freeze-and-thaw cycles for these aspects. Additionally, the insulating effect of snow would be less on these slopes. Snow cover would be more readily removed or reduced at the beginning of Winter or end of Spring. Unlike east- or southeast-facing slopes, west- and southwest-facing slopes would receive direct sunlight in the afternoon when diurnal temperatures are highest. This results in a greater number of freeze-and-thaw cycles on these slopes. The greater number of freeze-and-thaw cycles probably is responsible for the larger total area of patterned diamicton sites on these slopes and on flat slopes.

In examining the interrelationship of aspect, elevation, and solar insolation, the controlling variable appears to be temperature. Average temperatures can be determined for Summer, Winter, and annual periods. These average temperatures were calculated for each aspect. Dr. E. Arlo Richardson, Utah State Climatologist, (oral comm., March 1975) provided the data and formulae necessary to compute these temperatures. The formulae (Appendix C) compensate for differences in the general temperature and pressure of the atmosphere, aspect, and elevation. The values, for the temperature periods, were calculated for each aspect. All of these temperatures are an average of the temperatures at sites facing a particular direction (Table 9). It is clear that this temperature variation is not directly related to the average annual potential insolation received on a particular aspect. A graphic representation of the annual, Summer, and Winter temperatures plotted against aspects shows a basically linear relationship for patterned diamicton sites (Figure 40). The line generated for a particular time period duplicates variations found in other lines. The greatest range in temperature is 7.1^{o}F for average Summer temperatures. The smallest range in values is 4.3^{o}F for average Winter temperatures. Average annual temperatures have a range of 5.4^{o}F. The temperature data illustrate a balance between aspect, elevation, and solar insolation. This balance provides very nearly the same temperature range at each patterned diamicton site. Thus, temperature probably is the primary factor controlling the locations of these sites.

The genesis of many patterned diamicton fields is believed to be frost heaving due to freeze-and-thaw cycles(Washburn, 1973). The temperatures presently associated with patterned diamicton fields are too high for active frost heaving.

Table 9. Winter, summer and annual temperatures compared to aspect.

Direction slope faces	Ave. winter temperature	Ave. summer temperature	Ave. annual temperature	Ave. annual potential insolation (thous. Langleys)
FLAT	17.6°F.	67.1°F.	42.4°F.	247.228
NORTHEAST	16.1°F.	66.3°F.	41.0°F.	233.449
EAST	17.6°F.	67.1°F.	42.4°F.	246.637
SOUTHEAST	14.4°F.	61.0°F.	37.9°F.	269.026
SOUTH	15.9°F.	63.2°F.	39.8°F.	282.320
SOUTHWEST	18.7°F.	67.3°F.	43.3°F.	266.740
WEST	18.3°F.	68.1°F.	43.3°F.	246.573
NORTHWEST	17.0°F.	67.7°F.	42.2°F.	228.664

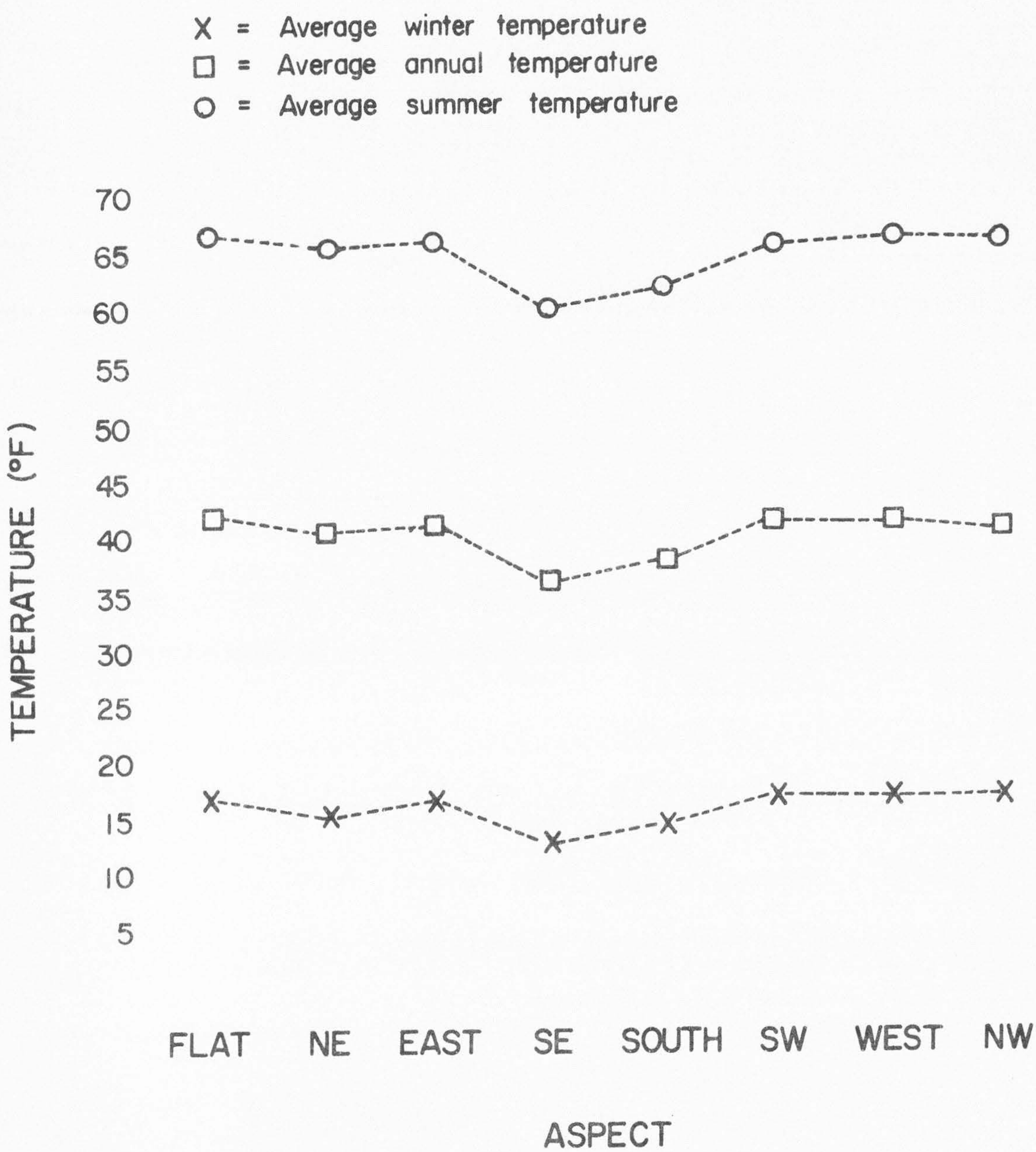

Figure 40. Temperature values for winter, summer, and annual periods compared with aspect.

Patterned diamicton fields studied in the Bear River Range appear to be inactive. Erosion is currently modifying these fields. This conclusion is supported by present field observations and by a previous investigation (Southard and Williams, 1970). If frost heaving were responsible for the creation of the patterned diamicton fields, it must have operated during a cooler period than the present.

Climatic conditions during the Pleistoncene would be compatible with active frost heaving. Richmond (1965) suggested that the average summer temperature in the Northern Rocky Mountains would have been colder by about 17.5°F at this time, whereas the average winter temperature is assumed to have been about the same as current values. Combining these values with the present temperature data provides an approximation of the thermal regime during the Pleistocene. The average winter temperature at patterned diamicton fields is about 16.5°F. If the 17.5°F value is subtracted from the currently calculated average summer temperatures for patterned diamicton sites, the summer temperature during the Pleistocene would be about 47.1°F. The Pleistocene average annual temperature, at patterned diamicton fields, would be approximately 31.9°F. This value would be very favorable for producing freeze-and-thaw cycles during diurnal temperatures variations (Washburn, 1973).

It is clear that patterned diamicton sites in the Bear River Range are inactive forms currently subjected to erosional modification. Their location is closely correlated with the same temperature range. The temperature is a balance among elevation, aspect, and solar insolation. Current temperatures are insufficient to create patterned diamicton. This suggests that frost heaving during colder climatic periods is responsible for genesis of patterned diamicton in this area. Temperature values calculated for the Pleistoncene would satisfy the temperature requirement for frost heaving. Some additional activity may have occurred, later, during the Neoglacial (Williams, 1958b).

The evidence suggests that relict periglacial features are found in the Bear River Range. These features are farther south than the limits usually assigned to periglacial activity associated with the Pleisocene (Washburn, 1973). Similar features have been described on the western Snake River Plain in Idaho (Malde, 1961, 1964). Although patterned diamicton fields in the Bear River Range are at a lower latitude, they are at higher elevations than the features described on the western Snake River Plain. The temperature increases associated with lower latitudinal localities may be compensated by the temperature decreases associated with higher elevation. The limits of periglacial activity may need to be revised to include north-central Utah.

ALLUVIAL FANS

General Statement

Alluvial fans of varying sizes and ages have been mapped and examined in the six drainages of the Bear River Range: Green, Logan, Providence, Blacksmith Fork, Paradise Dry, and East canyons. The features have been identified based on the definition in the Glossary of Geology (1974):

> A low outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream (esp. in a semiarid region) at the place where it issues from a narrow mountain valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or whenever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases; it is steepest near the mouth of the valley where its apex points upstream, and gradually decreasing gradient.

Tabulated for each fan are the area of the fan, area of its drainage, stream length, streamflow direction, highest elevation of the drainage, lowest elevation of the drainage, relief of the drainage, and drainage gradient (Appendix B). By means of a computer-processed statistical program, these data were analyzed for means, standard deviations, and stepwise deletion of independent and dependent variables. Investigations of alluvial fans in other parts of the country have related the fan size to the size of the drainage basin (Bull, 1964; Denny, 1965). An evaluation of this relationship and other influencing variables was attempted

(Table 10). The same procedure was applied to only the fans that appear to have formed during the Hypsithermal (Table 11). In all cases, the correlation is tenuous at best. Low values for the coefficient of determination indicate that the linear regression best fitting the data points has no statistical significance.

Description

The alluvial fans issue into the main canyon bottoms from smaller tributary canyons. All fans exhibit a typical radiating fan shape in plan view with the apex at the mouth of the tributary canyon. Most of the fans have little or no apparent stratification, contain some large boulders or cobbles, but consist chiefly of gravel, sand and fines. These factors suggest that the fans were deposited by mudflows or intermittent streams. During deposition of post-glacial fans, climatic conditions were probably arid to semiarid and with sparse vegetative cover on surfaces subject to periods of intense rainfall. Williams (1964) described a mudflow deposit in the lower part of Grassy Flat Canyon. Grassy Flat is a tributary to Logan Canyon. An alluvial fan probably formed from this mudflow. Subsequent erosion by the Logan River has removed the fan. However, this site provides good evidence for a mudflow origin of some small alluvial fans.

Based on the variety of fan sizes, degrees of soil development on undissected surfaces, and relations to other features, it appears that alluvial fan deposition took place during several episodes. The most

Table 10. Statistical evaluation of fan area as a dependent variable using all alluvial fan values. *

Independent variable	Corr. Coef.	Intercept	Slope	Coef. Deter.
Drainage area	.47298	−5.0324	.4267	22.3%
Drainage area x gradient	.54013	0.2208	.5369	29.2%
Gradient	.02440	−0.9923	.0127	00.5%
Stream length	.48312	9.8753	.2527	23.3%
Relief	.47110	8,8831	.2654	22.2%

* Both the dependent and independent variables are converted to natural log values before statistical model is applied.

Table 11. Statistical evaluation of fan area as a dependent variable using hypsithermal age fan values. *

Independent variable	Corr. Coef.	Intercept	Slope	Coef. Deter.
Drainage area	.57542	−4.5248	.5200	33.1%
Drainage area x gradient	.55954	0.5264	.5416	31.3%
Gradient	−.37300	−1.2304	−.9472	13.9%
Stream length	.53979	9.9387	.2674	29.1%
Relief	.46053	8.7083	.1726	21.2%

* Both the dependent and independent variables are converted to natural log values before statistical model is applied.

recent episode probably was during the Hypsithermal. Some fans may be as old as pre-Wisconsinan in age. To illustrate the chronology of alluvial-fan deposition, it is convenient to begin with the youngest group of fans and proceed to the oldest group.

Interprepetation of relative age from soil development on undissected fan surfaces has contributed to the sequence of fan-building episodes. Soil pits were dug on many of the alluvial fans. Dr. A. R. Southard, Department of Soils and Biometerology, provided interpretations of soil development and relative age. Five criteria were used to establish relative age. These criteria were employed on the assumption that climatic condition were similar at all sites, and on the observable condition that the source bedrock was composed predominantly of carbonate rocks. The five criteria were the thickness of the mollic epipedon within the same pedogenic setting, translocation of clay within the profile, leaching of calcium carbonate from the upper horizon, thickness of calcium carbonate accumulations in the lower horizon, and soil color. Soil colors with greater red component generally are indicative of longer soil development time.

The majority of alluvial fans formed during post-Pleistocene time. Many lie below the Provo level of Lake Bonneville, but contain no interbedded or covering lake sediments. In a few places, such as near the mouth of Logan Canyon, dissection shows such fans to overlie lake sediments at the Provo level, and hence to be younger than 11,000 years old.

Several lines of evidence suggest that much of the deposition occurred during the Hypsithermal (Flint, 1971). Many fans, in Logan and Blacksmith Fork canyons, have been truncated along the toe by stream action. In several places, the projected gradient of fans on opposite sides of the main canyon appear to cross, and would block the present stream course (Williams, 1956). The present stream would need to downcut between 6 and 40 feet to excavate the current channel through these fans. This suggests that, at some time, the Logan and Blacksmith Fork rivers were intermittent or, even, ephemeral streams. A significant period of semi-arid or arid climatic conditions would be required to substantially reduce runoff to the extent that the streams would be diminished to intermittent or ephemeral flow. Such conditions also would favor formation of alluvial fans.

Several fans of probable Hypsithermal age were sampled to determine the percentage composition of the material (Table 12 and 13). The gravel and larger particles tend to be angular in all of the fans. Where stratification was present it was poor and localized within the exposed section. Based on the composition and character of the fan material, the youngest fans probably formed through deposition of debris flows or mudflows.

In Blacksmith Fork Canyon, several fans of probable Hypsithermal age have two distinct levels. One level is graded to a point 6 to 12 feet above the other segment at a particular site. In two cases, both fan segments were sampled (Table 13). The segment at a higher level

Table 12. Composition and character of alluvial fans of Hypsithermal-age in Logan Canyon.

Fan	Mileage*	Gravel %	Sand %	Fines+ %	Strat.	Angularity	Cobbles=
1	3.6	68.3	25.5	6.2	poor	sub-angular	present
2	3.9	69.1	23.8	7.1	none	sub-angular	present
3	4.2	79.4	14.0	6.6	none	sub-angular	present
4	6.4	73.1	21.9	5.0	none	sub-angular	present
5	7.4	63.9	30.1	6.1	none	sub-angular	present
6	9.1	65.1	31.3	3.6	none	sub-angular	present
7	10.1	62.4	31.9	5.7	none	sub-angular	present
8	10.4	67.5	29.1	3.4	none	sub-angular	present
9	10.7	58.1	35.3	6.6	none	sub-angular	present
Mean values		67.4	27.0	5.6			

* Mileage values are east on U. S. Highway 89 from the corner of Main street and 400 North in Logan, Utah

= Also includes all sizes larger than cobbles

\+ Includes silt and clay sizes

Table 13. Composition and character of alluvial fans of Hypsithermal-age in Blacksmith Fork Canyon.

Fan	Mileage*	Gravel %	Sand %	Fines[+]	Strat.	Angularity	Cobbles[=]
1	2.4	69.5	22.2	8.3	none	sub-angular	present
2	3.2	71.3	24.4	4.3	none	sub-angular	present
3	4.3	62.0	33.1	4.9	none	sub-angular	present
4	4.8	75.5	21.1	3.3	none	sub-angular	present
5	5.1	67.2	22.1	10.7	poor	sub-angular	present
6	5.7	63.6	28.2	8.2	poor	sub-angular	present
7	6.7	71.8	21.2	6.9	none	sub-angular	present
8	8.7	74.2	21.1	4.8	none	sub-angular	present
9	8.7	71.6	19.3	4.2	none	sub-angular	present
10	8.9	72.2	21.9	5.9	none	sub-angular	present
11	9.2	76.5	19.3	4.2	none	sub-angular	present
12	9.2	79.0	18.8	2.2	none	sub-angular	present
13	9.7	72.3	24.8	2.9	none	sub-angular	present
14	10.1	72.9	22.7	3.4	poor	sub-angular	present
Mean values		71.5	23.2	5.3			

* Mileage values are east on Utah Highway 242 from the intersection of Utah Highways 101 and 242.

= Also includes all sizes larger than cobbles

These samples were collected from fan segments graded to a higher level than the segment of Hypsithermal Age located at the same site. It is inferred that the higher level is older than the lower segment at each particular site.

Includes silt and clay sizes.

appears to be slightly older than the lower segment at each location. The higher segment is less extensive compared to the lower segment. The higher segment has a slightly greater percentage of gravel and a smaller percentage of sand and fines than the inferred younger segment. This would be expected, if subsequent erosion of the older, higher segment resulted in washing out of finer material that was deposited as part of the lower segment.

Tab Hollow and Wood Camp Hollow are two tributary canyons of Logan Canyon. An alluvial fan formed at the mouth of each canyon. These fans are rather large and well above the farthest encroachment of Lake Bonneville. In order to establish the relative age of each fan, the soil development was examined. Both alluvial fans have a soil development consistent with an age of formation during the Hypsithermal. Each soil profile has a thick mollic epipedon. The soil structure was subangular and blocky in each case. The upper 38 cm of the soil profile of Wood Camp Hollow was non-calcareous. The upper 20 cm of the Tab Hollow soil profile was non-calcareous. The higher point of unleached calcium carbonate there is attributed to a higher percentage of gravel in the Tab Hollow fan material. The soil was slightly browner at 38 cm in the Wood Camp Hollow soil profile (A. R. Southard, oral comm., 1975).

All fans of presumed Hypsitermal age are graded to levels above the present stream, and are composed of subangular, essentially unstratified material. This composition and percentages of gravel, sand, and fines suggest that deposition took place chiefly through mudflows.

Some alluvial fans may have formed during the Provo phase of Lake Bonneville. Mill Hollow is a tributary of Logan Canyon (Plate 34) There are three distinct fan surfaces at different levels at the mouth of this canyon (Plate 35). These fan segments form a fan complex representing three episodes of fan formation. E. J. Williams (1964) studied this locality and concluded that the features were terraces built at the Bonneville level by stream deposition. The configuration of these features more closely resembles alluvial fans than alluvial terraces (Amer. Geol. Institute, 1974). The lowest fan segment at Mill Hollow is least dissected. This segment is graded to a point about 20 to 25 feet above the present river level. Soil development on this segment has formed a thick mollic epipedon. The color difference at depth is indistinct. The calcium carbonate has been leached from the upper 40 cm of the soil profile. Soil structure is strong and blocky. The soil development on this fan segment is consistent with fan formation during the Provo phase of Lake Bonneville. It has been suggested that insufficient water was available to transport the material from Mill Hollow to Logan Canyon in sufficient quantities to form this feature (Williams, 1964). However, a small glacier existed in the upper part of Mill Hollow. Late Pinedale glaciation probably coincided with the Provo phase of Lake Bonneville. The meltwater from the Mill Hollow glacier or a permanent snowfield probably would have been sufficient to supply material for

Plate 34. View upstream south of the head of Mill Hollow.

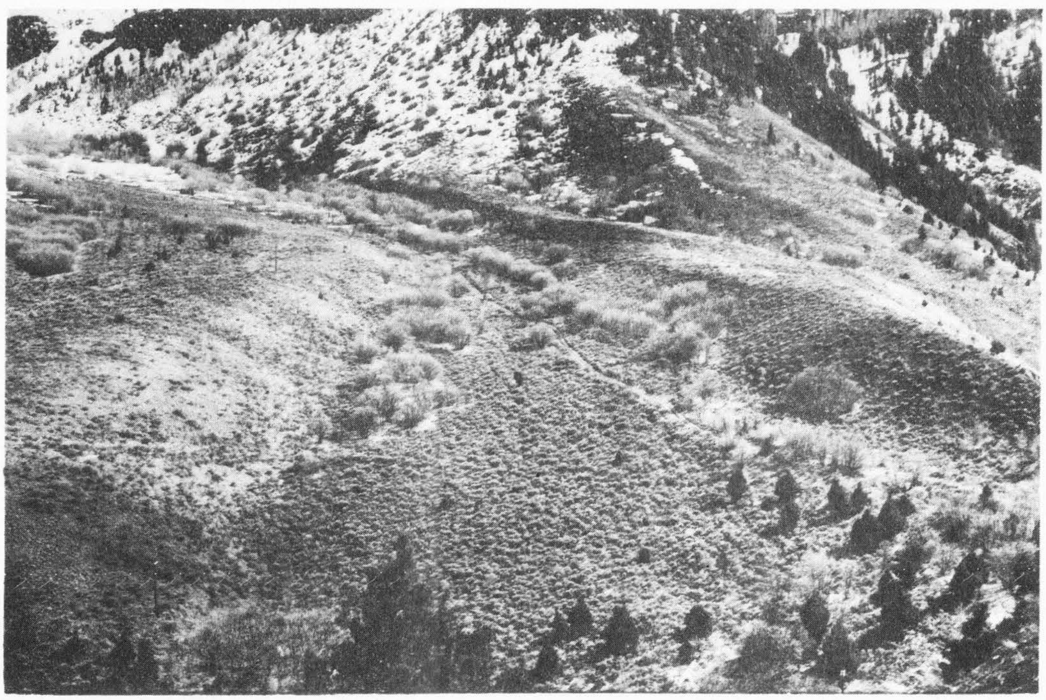

Plate 35. View of the alluvial fan segments at the mouth of Mill Hollow.

alluvial fan formation (Plate 24). In addition, erosive action of the snow and ice would have supplied material for the fan deposit.

Spring Hollow is the upstream tributary canyon of Logan Canyon adjacent to Mill Hollow. A fan complex resembling that in Mill Hollow is present at the mouth of this canyon. The lowest fan segment at this site corresponds to the lowest alluvial fan segment at Mill Hollow. It is suggested that this also formed during the Provo phase of Lake Bonneville. A small glacier existed in the upper reach of Spring Hollow. The glacier or perennial snowfields would have supplied sufficient water and material for formation of the lowest alluvial-fan segment at Spring Hollow.

The fan segments representing alluvial-fan deposition during the Provo stillstand of Lake Bonneville appear to have developed due to special circumstances. These fans had sufficient water and material supplied by glaciers or permanent snowfields. Some other large tributaries may also have formed alluvial fans. However, only the magnitude of material that makes up the fans at Spring and Mill Hollow prevented their removal during subsequent erosion.

A flat-topped terrace at the Bonneville level formed in the mouth of East Canyon. An alluvial fan from a tributary canyon was deposited on this terrace. This position implies that the fan is younger than the Bonneville Formation. Soil development on the fan suggests that the fan may have formed prior to the Provo phase and after the Bonneville level (A. R. Southard, oral comm., 1975). This is partly based on the differences in soil development between the fan and the terrace. Some other alluvial fans may have formed during this interglacial interval, but subsequent erosion and deposition have obliterated these fans.

A number of fans associated with some large tributary canyons to Logan and Blacksmith Fork canyons appear to be contemporaneous with the Bonneville level of Lake Bonneville.

The middle level or next highest level at Mill Hollow may be contemporaneous with the Bonneville level. The soil development is inadequate to provide a relative age for this level. The high proportion of cobbles and gravel in the upper two meters of this fan segment prevents a reliable soil development assessment. This level is graded to a point some forty to sixty feet above the present river level. There are two segments at this level at Mill Hollow. The segments clearly were continuous and have since been dissected. This dissection took place prior to the deposition of the Provo level fan.

At Spring Hollow, two fan segments on either side of the canyon mouth appear to be contemporaneous with the Mill Hollow middle level. An erosional notch in the end of the upper segment was noted by Williams (1964). This notch is not bedrock controlled and is at the same elevations as the Bonneville level shoreline. This suggests that the Spring Hollow fan formed at or just prior to the Bonneville level.

Matched segments of a large alluvial fan lie at the same level on opposite sides of Leatham Hollow in Left Hand Fork, a tributary to Blacksmith Fork Canyon. The two segments are separated by a lower surface which grades to the present stream level. The overall appearance and size is very similar to fan segments of Mill and Spring Hollows. The soil development at this alluvial fan suggests that formation was contemporaneous with the Bonneville level of Lake Bonneville. A thick mollic epipedon is found. The soil profile is non-calcareous in the upper 100 cm. The soil structure is prismatic. There is a well developed argillic horizon. The lower soil profile has a brown color. The degree of soil development supports a formation age of Bonneville level-time (A. R. Southard, oral comm., 1975). Leatham Hollow like Spring and Mill Hollows, has the special circumstances of a glacier located within the upper reaches of the tributary canyon. In each case, the material that was deposited to form the fan was extensive enough to survive subsequent erosion and re-deposition.

The highest fan segments at the mouth of Mill Hollow appears comparable to the Alpinephase of Lake Bonneville. These segments show the greatest dissection. Only small remnants remain. They are graded to a point approximately some 60 to 70 feet above the present river level. Analysis of soil development on this fan segment yields results consistent with fan formation during the Alpine lake phase. A thick mollic epipedon is found within the profile. Soil structure is prismatic. A well developed argillic horizon is found in the lower soil profile. The color is brown. The sool is non-calareous between 35 cm and 70 cm. It is suggested that the profile from 35 cm and deeper represents a buried paleosoil. Material washed from the nearby slope would tend to change the character of the upper profile including recharge by water rich in calcium carbonate.

A similar high fan remnant is found at the downstream side of Spring Hollow. The location of this remnant relative to the other Spring Hollow fans and to the Mill Hollow remnant suggests that it was formed during the Alpine phase of Lake Bonneville.

An old alluvial fan is found on the east side of Beaver Basin in Logan Canyon (Plate 36). The head of this inactive fan is covered by a thick stand of conifers, and the fan surface is slightly dissected. The western toe of this large fan was truncated by glacial ice during the maximum ice advance, probably Bull Lake or early Pinedale in age. The distinct fan appearance is enhanced by the ice-trimmed toe and stream courses along the sides. Additionally, the discharge of the stream at the head is intermittent and small. These factors have preserved the fan morphology. Possible relict periglacial patterned ground is found on the fan surface and adjacent parts of Beaver Basin (Williams and Southard, 1970). The soil is comparable to that developed on some pediments believed to be pre-Wisconsinan in age in Cache Valley (Southard and Williams, 1970). Numerous soil pits were excavated by a backhoe on this fan. The pits were usually dug to a depth of 8 ft; but often reached a depth of 18 ft. No bedrock was encountered in these pits. The mollic epipedon reaches a thickness of 30 cm. A strong prismatic soil structure is found in the profile. The soil colors are strong

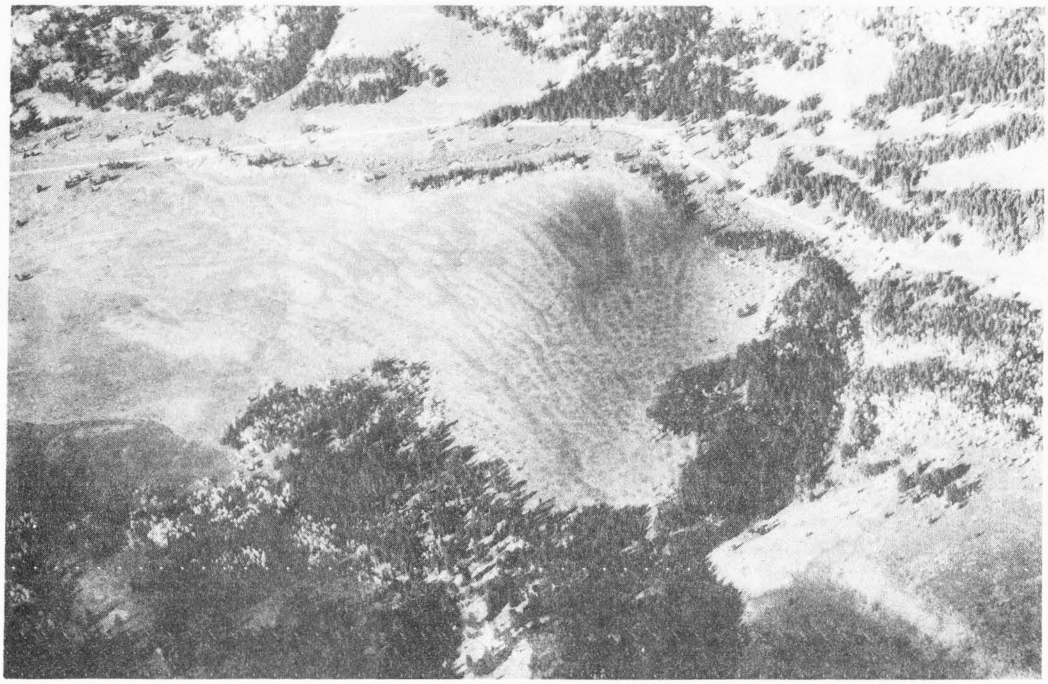

Plate 36. An oblique aerial view of the alluvial fan in the Beaver Basin.

brown shades. The profile contains a strongly developed argillic horizon. Effective leaching of calcium carbonate extends to a depth of 200 cm.

Analysis

Alluvial fans have formed at different times during the Pleistocene and Holocene. Representative of these fan-building episodes still exist. It is probable that many of the tributary canyons with recent fans previously had fans formed during earlier episodes. These fans have been eroded away in the intervals between fan-building episodes. A number of reasons account for the few representatives of early fan-building episodes that still are found in the Bear River Range. One factor is the proximity to active streams. The Beaver Basin fan is formed in a basin where only the small Beaver Creek flows. Neither this small stream or the smaller stream at the fan source area are capable of removing the amount of material deposited in the fan. This would not be as likely if the Beaver Basin fan had been deposited in the main Logan Canyon. Another factor is the amount of stream discharge during periods between fan-forming episodes. The small fans of probable Hypsithermal age are at the mouths of small tributaries with insufficient discharge to effectively dissect them. The largest tributaries have no alluvial fans. It is reasonable to assume that fans which formed at these tributary mouths have since been removed by the combined action of both the main canyon stream and the tributary stream. In the Bear River Range, it appears that the drainage basin must be at least five square miles in area to acquire sufficient flow to actively erode any alluvial fan previously formed (Table 14). This tabulation excludes tributaries where active glaciation may modify the situation. The third factor accounting for the existence of fans formed during earlier episodes deals with the circumstances under which such fans were deposited. The alluvial fans at Spring, Mill, and Leatham Hollows formed under special circumstances. In each case, a glacier or permanent snowfield supplied water and sediment in large quantities. The material forming the fan was significantly greater than that deposited at the mouths of tributary canyons of comparable size. This special circumstance created features that were large enough to be preserved during periods of fan degradation.

There appear to be seven episodes of alluvial fan formation in the Bear River Range. The oldest episode was pre-Alpine in age. The Beaver Basin fan represents the fans formed during this episode. The second episode coincided with the Alpine stillstand of Lake Bonneville and the Bull Lake glacial advance. This fan-forming episode is represented by the highest fan remnant at Mill Hollow. Due to the similarity of circumstances, fans were probably formed at Spring and Leatham Hollows at this time. The third episode occurred after the Alpine stillstand of Lake Bonneville and prior to the Bonneville stillstand. There are no representatives clearly identified with this episode. The fourth episode coincided with the Bonneville stillstand of Lake Bonneville. The large remnants at the mouths of Mill, Spring, and Leatham Hollows

Table 14. Tributary canyons with and without alluvial fans.

Canyon	Drainage area (sq mi)	Fan area (sq mi)
Right Fork - Logan Canyon	24.57	-----
Rock Creek	14.10	-----
Richards Hollow	9.87	-----
South Cottonwood-Blacksmith Fork	9.40	-----
Herd Hollow	7.39	-----
Leatham Hollow	4.95	.0242
Wood Camp Hollow	3.98	.0037
Mill Hollow	3.11	.0464
Tab Hollow	2.49	.0024
North Cottonwood-Blacksmith Fork	2.41	.0033
Chicken Creek	2.30	.0017
Spring Hollow	2.27	.0292
Left Hand Fork No. 6	1.66	.0040
Beirdneau Hollow	1.57	.0133
East Canyon No. 11	1.26	.0123

represent fans formed during this time. The fifth fan-forming episode took place after the Bonneville stillstand and prior to the Provo stillstand. The East Canyon fan is representative of this group. The sixth episode coincided with the Provo stillstand of Lake Bonneville. The lowest remnants at Spring and Mill Hollows represent fans formed during this period. The seventh episode occurred during the Hypsithermal. The numerous small fans in Logan and Blacksmith Fork Canyons are presentative of these fans. The four fan-forming episodes prior to and between stillstands of Lake Bonneville and during the Hypsithermal produced alluvial fans through deposition of mudflows and related agents. The three episodes that coincided with Lake Bonneville stillstands produced fans under special circumstances. These fans were formed by glacial meltwater and debris. Deposition probably occurred by mudflows and intermittent stream flow.

LANDSLIDES

General Statement

Landslides are present in many parts of the Bear River Range. Features too small to map at a scale of 1:48,000 are not included. Also, the map does not include areas of slow mass movement such as soil creep or solifluction. All the mapped features are one acre or larger in size. Over 1,818 acres (2.84 square miles) of terrain have been disturbed by landslides. Individual slides or flows range in size from six acres to as much as 456 acres.

The classification of these features follows the system used in the compilation of Utah landslides (Schroder, 1971). The classification system is an adaptiation of the classes defined by Varnes (1958). The classification system defines mass movements based on the speed of the movement and the type of material involved. The speed of movement is unknown for most of the features mapped. Depending on the material involved, the mapped features are defined as a rock-slip, debris-slip, or earth-slip. One of the mapped features, a debris-flow, was observed to move rapidly. Another feature which is still active involves a number of units moving at a slow rate. On the basis of the type of material involved, this feature would ordinarily be classified as a debris-slide if no longer active. Instead, it is classified as a blockslide based on the observed rotational movement of units within the feature.

In describing each feature, the planar shape is given by the ratio of length (downslope) to width (parallel to contours). This number has been adjusted so that features which are equal in length and width have a value of 0. Features which are longer than wide have positive values greater than 0. Those which are wider than long have negative values less than 0.

Description

Four parts of the Bear River Range contain mass movements which were identified and mapped. Landslides are present in Logan, Blacksmith Fork, and East canyons, and along the western front of the Bear River Range.

Logan Canyon

The northernmost canyon containing mass movements is Logan Canyon. Six features have been mapped in this area (Table 15).

The first feature is on the north side of Logan Canyon across from the Second Dam in Logan River, about 4.9 miles up Logan Canyon from the intersection of Main Street and 400 North in Logan. This location is represented on the Logan Peak 7.5-minute topographic map. This feature is classified as a rockslip. The length-to-width ratio is +4.7. The material involved was derived from the Jefferson Formation. There is

Table 15. Characteristics of landslides in the Bear River Range.

Feature	Scarp Elev. (ft)	Toe Elev. (ft)	Relief (ft)	Aspect	Slope (°)	Slope (%)	Area Acres	Area Hect.
1	5,280	5.040	240	SE	15	27	7	3
2	6,240	6,000	240	SW	12	21	26	11
3	6,600	6.080	520	W	20	36	19	8
4	6,480	6,240	240	NW	13	23	12	5
5	6,720	6,240	480	W	20	36	45	18
6	6,480	6.280	200	W	14	25	6	2
7	5,640	5,280	360	NW	28	53	6	2
8	6,600	5.800	800	NW	11	19	122	49
9	6,640	6,200	440	SW	12	21	45	18
10	7,000	6,720	280	N	16	27	6	2
11	6,800	6,680	120	N	9	16	6	2
12	7,000	6,680	320	SW	18	32	13	5
13	6,720	6,600	120	SW	17	31	6	2
14	6,680	6,400	280	W	19	34	13	5
15	6,800	6,480	320	NW	13	23	186	75
16	5,880	5,360	520	N	30	58	6	2
17	5,760	5,560	200	W	12	21	6	2
18	5,880	5.600	280	W	19	34	13	5
19	6,600	6,000	600	NW	11	19	122	49
20	6,400	6,000	400	W	18	32	19	8
21	6,760	6,040	720	W	15	27	96	39
22	6,080	5.360	720	SW	20	36	45	18
23	6,160	5,920	240	SE	16	27	13	5
24	5,520	5,400	120	SE	6	11	19	8
25	5,440	5,240	200	W	20	36	6	2
26	5,400	5,200	200	N	19	34	9	4
27	5,680	5,000	680	W	18	33	95	38

Table 15 (Continued)

Feature	Scarp Elev. (ft)	Toe Elev. (ft)	Relief (ft)	Aspect	Slope (°)	Slope (%)	Area Acres	Area Hect.
28	5,600	5,040	560	NW	24	44	41	16
29	5,320	5,160	160	NW	24	44	6	2
30	5,600	5,160	440	W	12	21	29	12
31	6,040	5,560	480	SW	13	23	456	182
32	5,760	5,240	520	W	16	28	62	25
33	7,640	6,040	1,600	W	19	35	45	18
34	5,800	5,120	680	SW	27	51	19	8
35	5,400	5,040	360	NW	9	16	95	38
36	5,440	5,120	280	NW	10	17	65	26

no evidence of current movement. The movement appears to have followed the dip slope. Undercutting of the canyon wall may have been responsible for the movement. This feature was originally described by E. J. Williams (1964).

The second feature is on the east side of Temple Fork Canyon, a tributary to Logan Canyon. It is just east of the junction of Temple Fork Creek and Spawn Creek, about 1.3 miles upstream from Logan Canyon. This feature is a debris-slip. This location is represented on the Temple Fork 7.5-minute topographic map. The length-to-width ratio is +0.2. The material involved was derived by weathering from the Wasatch Formation. There is no indication of current movement. Movement may have resulted from undercutting of the slope by lateral erosion of Temple Creek.

The third feature is on the east side of Logan Canyon, 0.7 mile south of the junction of West Hodges Creek and the Logan River. This location is represented on the Temple Fork 7.5-minute topographic map. This feature is a debris-slip. The length-to-width ratio is +1.3. The material involved was derived by weathering from the Wasatch Formation. There is no evidence of current movement. Movement may have been initiated by undercutting of the bank by the Logan River, by glacial erosion, or by both.

The fourth feature is on the east side of Logan Canyon just south of the junction between Little Bear Creek and the Logan River. The site is adjacent to the Utah State University Forestry Field Station. This location is represented on the Tony Grove Creek 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is +1.0. The material involved was derived by weathering from the Wasatch Formation. There is no indication of current activity. Undercutting of the slope through erosion by the Logan River, Little Bear Creek, or glacial ice created the unstable condition responsible for this movement.

The fifth feature is on the east side of Logan Canyon about 0.3 miles north of the Utah State University Forestry Field Station. The northern edge of the feature is directly east of the intersection of U. S. Highway 89 and the U. S. Forest Service road to Tony Grove Lake. This location is represented on the Tony Grove Creek 7.5-minute topographic map. This feature is a debris-slip. The length-to-width ratio is −0.3. The material involved was derived by weathering from the Wasatch Formation. There is no evidence of current movement. Movement may have been caused by undercutting of the slope by the Logan River or by glacial ice.

The sixth feature is on the east side of Logan Canyon about 0.4 mile north of the Utah State University Forestry Field Station. It occupies the same general site as feature five near the northern (upstream) end. The feature is debris-slip. The length-to-width ration is +0.4. The material involved was derived by weathering from the Wasatch Formation. There is no indication of current movement. The cause of this movement is probably the same as for feature five.

Blacksmith Fork Canyon

The large number of mass movements mapped in Blacksmith Fork Canyon include many located along the Left Hand Fork tributary. The upper reaches of Left Hand Fork along Saddle Creek are the most prone to slippage. Fifteen features have been mapped in the drainage of Blacksmith Fork Canyon (Table 15).

The seventh feature is in Blacksmith Fork Canyon east of the Hyrum City power plant. It is on the south side of the canyon 0.1 miles east of the Hyrum City Park. The location is represented on the Logan Peak 7.5-minute topographic map. This feature is a rock-slip. The length-to-width ratio is +4.7. The material involved is derived from the St. Charles Formation. There is no evidence of current movement.

The eighth feature is in the canyon of the Left Hand Fork tributary to Blacksmith Fork Canyon. It is on the south side of the canyon directly across from Gray Cliffs Spring. This location is represented on the Boulder Mountain 7.5-minute topographic map. This feature is a debris-slip. The length-to-width ratio is +1.1. The material involved probably was derived from the Bloomington Formation. There is no indication of current movement. Movement may be related to unstable slopes resulting from faulting. A normal fault is mapped (Williams, 1948) adjacent to the southwestern margin of the feature. The debris-slip is on the downdropped side of the fault.

The ninth feature is on the north side of Rock Creek valley, just east of the Hardware Ranch-Danish Dugway road. It is in sec. 32, T. 11 N., R. 4 E. This location is represented on the Boulder Mountain 7.5-minute topographic map. This feature is a debris-slip. It has a length-to-width ratio of +0.7. The material involved was derived from the Brigham Formation. There is no evidence of current movement. The debris-slip is bordered by two normal faults (Williams, 1948). The feature is situated on a downdropped block. Unstable slopes created by past movement on the faults may have resulted in mass movement.

The tenth feature is along the Hardware Ranch-Danish Dugway road at a point where it crosses an intermittent stream. This site is 0.2 mile east of the connecting road to Saddle Creek and Elk Valley. The feature is in sec. 20, T. 11 N., R. 4 E. The location is represented on the Boulder Mountain 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is +1.8. The material involved was probably derived from the Brigham Formation. There is no indication of current movement.

The eleventh feature is along the road connecting the Hardware Ranch-Danish Dugway road to the Saddle Creek-Elk Valley road. The site is 0.2 mile north along the road in sec. 20, T. 11 N., R. 4 E. The location is represented on the Boulder Mountain 7.5-minute topographic map. The feature is a debris-flow. Rapid movement is shown by the torn bark of aspen trunks in the stable areas along the margin of the flow. The length-to-width ratio is +0.5. The material involved was probably derived by weathering from the Wasatch Formation. The most recent movement occurred in the spring of 1974. A number of aspen trees were swept along with the flow material. Trees adjacent to the flow were battered and scraped by trees carried by the movement. Debris blocked the road necessitating excavation and repair by U. S. Forest Service road crews.

The twelfth feature is along the road connecting the Hardware Ranch-Danish Dugway road to the Saddle Creek-Elk Valley road. The site is 0.4 miles north along the road in sec. 20, T. 11 N., R 4 E. This location is represented on the Boulder Mountain 7.5-minute topographic map. This feature is a debris-slip. The length-to-width ratio is +0.2. The material involved was probably derived from the Brigham Formation. There is no indication of current movement.

The thirteenth feature is along the road connecting the Hardware Ranch-Danish Dugway road to the Saddle Creek-Elk Valley road. The site extends 0.6 miles along the road in secs. 17 and 20, T. 11 N., R. 4 E. This location is represented on the Boulder Mountain 7.5-minute topographic map. This feature is a debris-slip. The length-to-width ratio is +0.7. The material involved was probably derived from the Brigham Formation. There is no indication of current movement.

The fifteenth feature is the Saddle Creek landslip zone. This zone is on the southeast side of Saddle Creek Valley. It extends for a distance of approximately 1.5 miles northward from near the junction between Dip Hollow road and the Saddle Creek-Elk Valley road. The site is in secs. 8 and 9, T. 11 N., R. 4 E. This location is represented on the Boulder Mountain 7.5-minute topographic map. The mappable landslips in this zone are earth-slips. Approximately 40 percent of the terrain included within the zone is undisturbed. The length-to-width ratio of the zone is −0.8. The material involved was derived by weathering from the Wasatch Formation. Recent movement along the zone is evidenced by sag ponds, recent ground cracks near the scarps, and trees bent in response to slower ground movement. A fault parallels the upper boundary of the landslip zone (Cluff and Others, 1975). The landslip zone is on the downdropped side. Displacement on this fault has contributed to the instability of this side of Saddle Creek Valley. This contributing factor and the nature of the material involved has lead to the creation of the Saddle Creek landslip zone.

The sixteenth feature is along State Highway 101 about 3.0 miles west of Hardware Ranch. The site is on the south side of Blacksmith

Fork Canyon in sec. 17, T. 10 N. R. 3 E. This location is represented on the Hardware Ranch 7.5-minute topographic map. This feature is a rock-slip. The length-to-width ratio is +1.5. The material involved was derived from the Brigham Formation. There is no evidence of current movement.

The seventeenth feature is about 0.2 miles south of Hardware Ranch along the road leading south to Anderson Ranch. This site is on the east side of Blacksmith Fork Canyon in sec. 14, T. 10 N., R. 3 E. This location is represented on the Hardware Ranch 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is 0. The material involved was derived by weathering from the Wasatch Formation. There is no indication of current movement.

The eighteenth feature is about 0.6 miles south of Hardware Ranch along the road leading south to Anderson Ranch. This site is on the east side of Blacksmith Fork Canyon in sec. 14, T. 10 N., R. 3 E. This location is represented on the Hardware Ranch 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is −0.4. The material involved was derived by weathering from the Wasatch Formation. The toe of the slide is at road level. This fact combined with the relatively fresh appearance suggests that the slide may have been triggered by original road construction along the slope. There is no evidence of current movement.

The nineteenth feature is on the east side of Sheep Creek Valley just south of the junction of Sheep Creek Valley and Petes Hollow. The site is in sec. 36, T. 10 N., R. 3 E. This location is represented on the Hardware Ranch 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is +0.7. The material involved was derived by weathering from the Wasatch Formation. There is no indication of current movement.

The twentieth feature is on the east side of Sheep Creek Valley about 1.0 miles south of the junction of Sheep Creek Valley and Petes Hollow. This site is adjacent to the south margin of feature fourteen. This location is represented on the Hardware Ranch 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is +0.6. The material involved was derived by weathering from the Wasatch Formation. There is no evidence of current movement.

The twenty-first feature is on the east side of Sheep Creek Valley about 1.4 miles south of the junction of Sheep Creek Valley and Petes Hollow. This site is adjacent to the south margin of feature twenty. This location is represented on the Hardware Ranch 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is +0.6. The material involved was derived by weathering from the Wasatch Formation. There is no evidence of current movement.

East Canyon

The southernmost canyon containing identified and mapped mass movements is East Canyon. Two mass movements were mapped by Mullins and Izett (1964). These features are described in Table 15.

The twenty-second feature is about 2.1 miles east along the LaPlata road near the mouth of East Canyon. This site is in secs. 7 and 18, T. 9 N., R. 2 E. This location is represented on the Paradise 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is +1.4. The material was derived from the Great Blue Formation. Movement probably resulted from failure of the shale in the underlying Little Flat Formation. There is no evidence of current movement. The debris-slip has undergone a significant amount of erosional modification resulting in a subdued morphology. This debris-slip was mapped by Mullins and Izett (1964).

The twenty-third feature is about 2.6 miles east along LaPlata road near the mouth of East Canyon. This site is in secs. 7 and 18, T. 9 N., R. 2 E. This location is represented on the Paradise 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is −0.3. The material involved was derived from the Great Blue Formation. Movement probably resulted from failure of the shale in the underlying Little Flat Formation. There is no indication of current activity. In terms of relative age, this feature resembles feature 22. This debris-slip was mapped by Mullins and Izett (1964).

The twenty-fourth feature is at the edge of Porcupine Reservoir near the right abutment of the dam. This location is represented on the Paradise 7.5-minute topographic map. This feature is classified as a blockslide (Plate 37). Movement is slow. A number of units exhibit rotation. The length-to-width ratio is −0.2. The material was derived

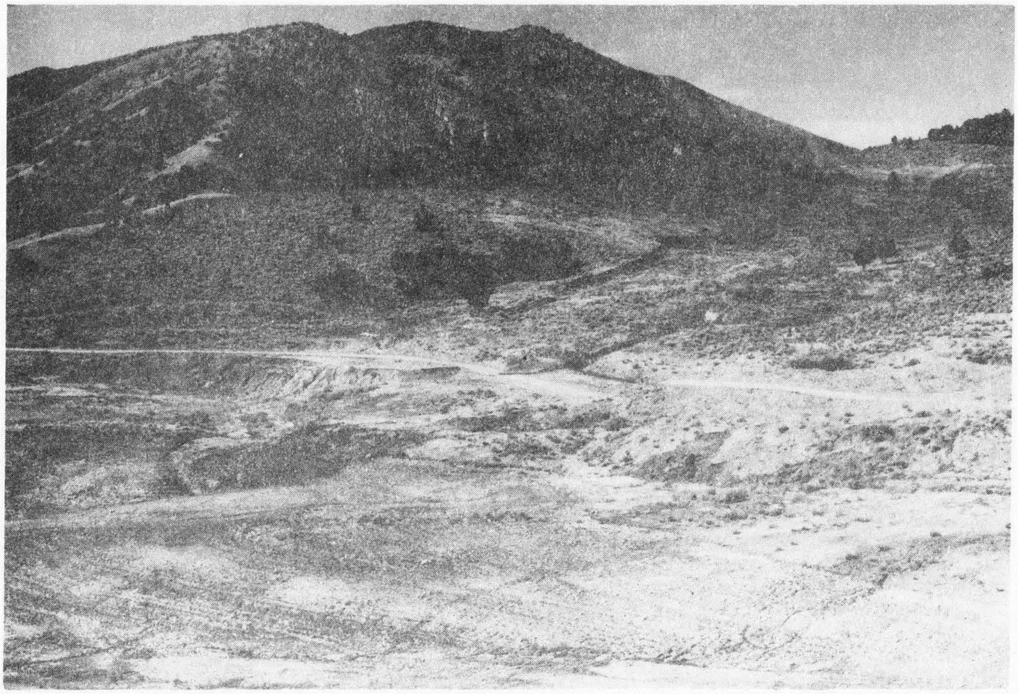

Plate 37. View west of the landslide on the edge of Porcupine Reservoir

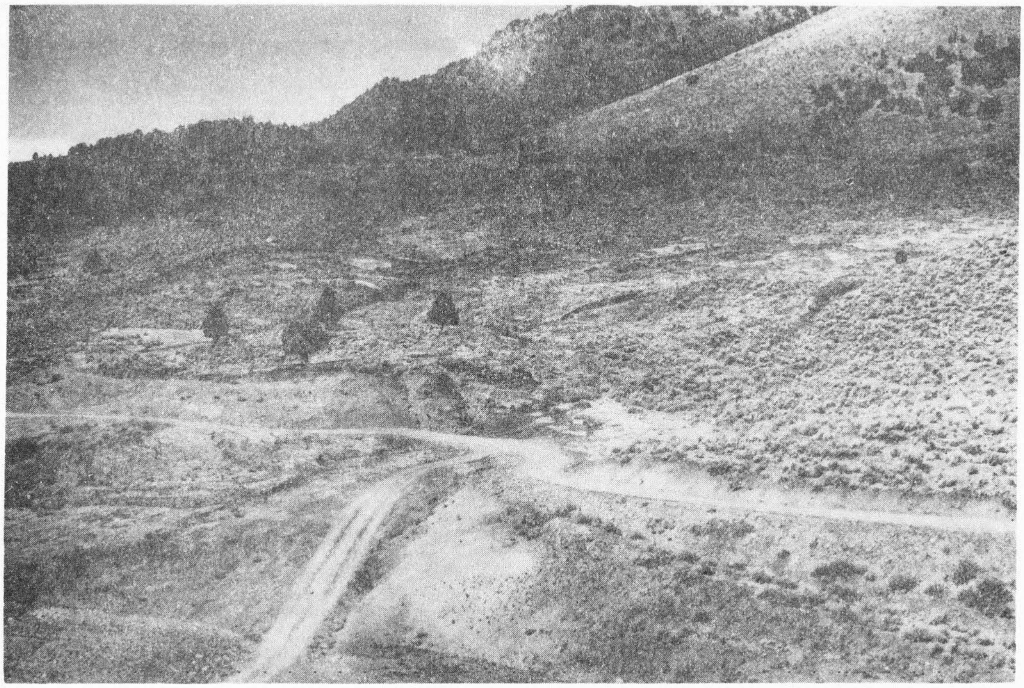

Plate 38. Closer view of landslide mass on the edge of Porcupine Reservoir.

by weathering from the Wasatch Formation. The blockslide is currently active (Plate 38). Fresh cracks are visible near the scarp and at several points on the slide mass. The upper mass of the slide consists of rotated blocks. There is some flowage within the mass near the toe. It appears that the area along the bottom of the slope may have been excavated during the construction of Porcupine Reservoir dam. This work may have undercut the slope in this area. A high water table, which occurs in the spring when the reservoir is filled, probably contributed greatly to movement.

Along the mountain front

Twelve landslides are found along the western front of the Bear River Range. These features are described from north to south (Table 15).

The twenty-fifth feature is north of the mouth of High Creek Canyon. The site is in secs. 5 and 6, T. 14 E., R. 2 E. This location is represented on the Richmond 7.5-minute topographic map. The feature is a debris-slip. The boundaries of this landslide were mapped during a previous investigation (Cluff and others, 1975). The length-to-width ratio is −0.1. The material involved was derived from the Salt Lake Formation. The Salt Lake Formation in this area is mapped as a fanglomerate (Williams, 1948). There is no indication of current movement.

The twenty-sixth feature is at the north side of the mouth of High Creek Canyon. The site is in sec. 6, T. 14 N., R. 2 E. and sec. 31,

T. 15 N., R. 2 E. This location is represented on the Richmond 7.5-minute topographic map. This feature is a debris-slip. The boundaries of this landslide were mapped during a previous investigation (Cluff and others, 1975). The length-to-width ratio is —0.4. The material involved is derived from the Salt Lake Formation. The Salt Lake Formation in this area is mapped as a fanglomerate (Williams, 1948). There is no evidence of current movement.

The twenty-seventh feature is north of the mouth of High Creek Canyon. The site is just south of the second feature in sec. 6, T. 14 N., R. 2 E. This location is represented on the Richmond 7.5-minute topographic map. The feature is a debris-slip. The boundaries of this landslide were mapped during a previous investigation (Cluff and others, 1975). The length-to-width ratio is —0.4. The material was derived from the Salt Lake Formation. The Salt Lake Formation in this area is mapped as a fanglomerate (Williams, 1948). There is no evidence of current movement.

The twenty-eighth feature is notrh of the mouth of High Creek Canyon. The site is just south of the third feature in sec. 6, T. 14 N., R. 2 E. This location is represented on the Richmond 7.5-minute topographic map. The feature is a debris-slip. The boundaries of this landslide were mapped during a previous investigation (Cluff and others, 1975). The length-to-width ratio is —0.3. The material was derived from the Salt Lake Formation. The Salt Lake Formation in this area is mapped as a fanglomerate (Williams, 1948). There is no indication of current movement.

The twenty-ninth feature is just north of the mouth of Oxkiller Hollow. The site is in secs. 18 and 19, T. 14 N., R. 2 E. and secs. 13 and 24, T. 14 N., R. 2 E. This location is represented on the Richmong 7.5-minute topographic map. The feature is a debris-slip. The boundaries of this landslide were mapped during a previous investigation (Cluff and others, 1975). The length-to-width ratio is ~0.7. The material was derived from the Salt Lake Formation. The Salt Lake Formation in this area is mapped as a fanglomerate (Williams, 1948). There is no evidence of current movement.

The thirtieth feature is just north of the mouth of Cherry Creek Canyon. The site is in sec. 19, T. 14 N., R. 2 E. and sec. 24, T. 14 N., R. 2 E. This location is represented on the Richmond 7.5-minute topographic map. The feature is a rock-slip. The boundaries of this landslide were mapped during a previous investigation (Cluff and others, 1975). The length-to-width ratio is ~0.7. The rock material involved in this movement was derived from the conglomerate member of the Salt Lake Formation (Mendenhall, 1975). There is no indication of current movement.

The thirty-first feature is on the north slope of Cherry Creek Canyon. The site is in secs. 19 and 30, T. 14 N., R. 2 E. The location is represented on the Richmond 7.5-minute topographic map. The feature is a rock-slip. This landslide was mapped by Mendenhall (1975).

The length-to-width ratio is +0.9. The rock material involved in the movement was derived from the conglomerate member of the Salt Lake Formation (Mendenhall, 1975). There is no evidence of current movement.

The thirty-second feature is directly east of Richmond in sec. 24, T. 14 N., R. 1 E. The location is represented on the Richmond 7.5-minute topographic map. The feature is a debris-slip. The boundaries of this landslide were mapped during a previous investigation (Cluff and others, 1975). The length-to-width ratio is 0. The material involved in the movement was derived from the Salt Lake Formation. The Salt Lake Formation in this area is mapped as a fanglomerate (Williams, 1948). There is no evidence of current movement.

The thirty-third feature is in secs. 25 and 36, T. 14 N., R 1 E. and secs. 30 and 31, T. 14 N., R. 2 E. This location is represented on the Richmond 7.5-minute topographic map. The feature is a debris-slip. The boundaries of this landslide were mapped during a previous investigation (Cluff and others, 1975). The length-to-width ratio is +2.0. The material involved in the movement was derived from the Salt Lake Formation. The Salt Lake Formation in this area is mapped as a fanglomerate (Williams, 1948). There is no indication of current movement.

The thirty-fourth feature is just south of the mouth of Birch Canyon. The site is in sec. 25, T. 13 N., R. 1 E. This location is represented on the Smithfield 7.5-minute topographic map. The feature is a debris-slip. The boundaries of this landslide were mapped during a previous investigation (Cluff and others, 1975). The length-to-width ratio is +1.4. The material involved in the movement was derived from the Salt Lake Formation. The Salt Lake Formation in this area is mapped as a fanglomerate facies (Williams, 1948). There is no indication of current movement.

The thirty-fifth feature is just north of the McKenzie Flat area near the mouth of East Canyon. The site is in secs. 11 and 14, T. 9 N., R. 1 E. The location is represented on the Paradise 7.5-minute topographic map. The feature is a debris-slip. The length-to-width ratio is − 0.1. The material involved was derived from the Salt Lake Formation. This area is mapped as Salt Lake Formation (Williams, 1948). There is no indication of current movement.

The thirty-sixth feature is on the east side of South Fork Canyon. The site is in secs. 14 and 23, T. 9 N., R. 1 E. The location is represented on the Paradise 7.5-minute topographic map. The feature is a debris slip. The length-to-width ratio is +0.1. The material involved in the movement was derived from the Salt Lake Formation. This area is mapped as Salt Lake Formation (Williams, 1948). There is no indication of current movement.

Analysis

The following summarizes the factors controlling the contributing to landslides in the Bear River Range of Utah. Landslide potential hinges on four variable: stratigraphic unit, elevation range, aspect, and slope.

Stratigraphic units involved in landslides include formations of Tertiary, Mississippian, Devonian, and Cambrian age. These formations are composed of a variety of rock types (Figure 41).

The Tertiary stratigraphic units involved in landslides are the Salt Lake Formation and Wasatch Formation. The Salt Lake Formation of late and middle Tertiary age is usually restricted to the margins of Cache Valley and some valleys within the Bear River Range. The Salt Lake Formation is composed of tuffaceous and conglomeratic members. Twelve landslides involve this stratigraphic unit. This represents 33 percent of all mapped landslides in the study area. A total of 961 acres or 53 percent of the disturbed area mapped involves the Salt Lake Formation. The mean landslide involving this stratigraphic unit is 80 acres. The Wasatch Formation of early Tertiary age is found as downfaulted inliers along the margins of Cache Valley, and in mountain valleys and on accordant summits. The Wasatch Formation is composed of limestone, mudstone, and conglomerate beds. Thirteen landslides involve this stratigraphic unit. This represents 36 percent of all mapped landslides in the study area. A total of 575 acres or 31 percent of the disturbed area mapped involves the Wasatch Formation. The mean landslide involving this stratigraphic unit is 44 acres.

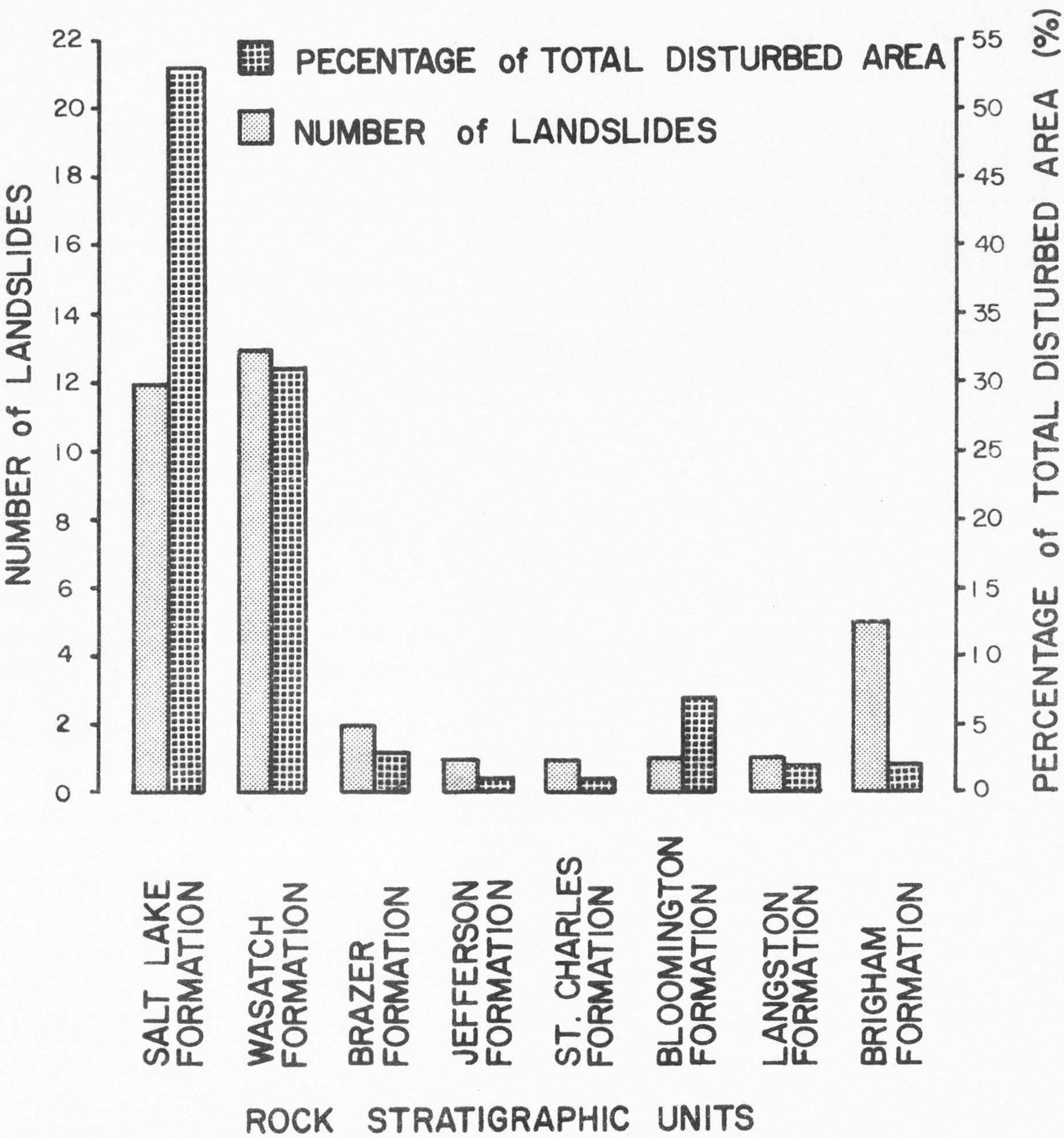

Figure 41. Landslides and stratigraphic units in the Bear River Range.

The Mississippian stratigraphic unit involved in landslides is the Brazer Formation (Great Blue and Little Flat). The Brazer Formation consists primarily of limestone and sandstone beds. Two landslides involve this stratigraphic unit. This represents five percent of all mapped landslides in the study area. A total of 58 acres of 3 percent of the disturbed area mapped involves the Brazer Formation. The mean landslide involving this stratigraphic unit is 29 acres.

The Devonian stratigraphic unit involved in landslides is the Jefferson Formation. The Jefferson Formation consists of dolostones and sandstones. One landslide involves this stratigraphic unit. This represents 3 percent of the mapped landslides in the study area. A total of 7 acres or 1 percent of the disturbed area mapped involved the Jefferson Formation. The mean landslide involving this stratigraphic unit is 7 acres.

The Cambrian stratigraphic units involved in landslides are the St. Charles, Bloomington, Langston, and Brigham Formations. The St. Charles Formation is composed of dolostone and quartzite. One landslide involves this stratigraphic unit. This represents 3 percent of all mapped landslides in the study area. A total of 6 acres or 1 percent of the disturbed area mapped involves the St. Charles Formation. The mean landslide involving this stratigraphic unit is 6 acres. The Bloomington Formation is composed of limestone and shale. One landslide involves this stratigraphic unit. This represents 3 percent of all mapped landslides in the study area. A total of 122 acres or 7 percent of the disturbed area involves the Bloomington Formation. The mean landslide involving this stratigraphic unit is 122 acres. The Langston Formation is composed of dolostone, limestone, shale, and siltstone. One landslide involves this stratigraphic unit. This represents 3 percent of all landslides in the study area. A total of 45 acres or 2 percent of the disturbed area mapped involves the Langston Formation. The mean landslide involving this stratigraphic unit is 45 acres. The Brigham Formation is composed of quartzite and shale. Five landslides involve this stratigraphic unit. This represents 14 percent of all mapped landslides in the study area. A total of 44 acres or 2 percent of the disturbed area mapped involves the Brigham Formation. The mean landslide involving this stratigraphic unit is 9 acres.

Based on the landslides mapped in the study area, Tertiary stratigraphic units are the most prone to landsliding. It is often the conglomerate member with a high percentage of clay in the matrix that is incorporated into the landslide. The conglomerate member moves due to a loss of support. Failure of the tuffaceous member of the Salt Lake Formation causes large scale slumping by the conglomerate member. Failure of the mudstone member of the Wasatch Formation results in sliding by the conglomerate member. In both cases, landslides involve movement of the coarse-grained member as a result of failure in the underlying fine-grained member. In addition to being the most frequently disturbed stratigraphic units, the Salt Lake and Wasatch

Formations account for 84 percent of the total area disturbed by landslide and have some of the largest landslides.

Aspect is another variable that influences the location of landslides in the Bear River Range (Figure 42). Slopes with a west aspect or with an aspect with a west-component are most prone to landsliding. Ninety-two percent of the area disturbed by landslides is located on slopes with these aspects. In addition, landslides on slopes with a west or west-component aspect are more numerous and of larger size than on other slope aspects. This potential for landslides probably results from the effect of solar radiation received during higher diurnal temperature periods. During the winter, these slope aspects would receive less snow accumulation and be blown free of snow more frequently than slopes with other aspects. The effect of solar radiation during the higher diurnal temperature periods would increase water in the soil by melting snow and ice which is the predominate precipitation of the area. During the summer, these slopes are much dryer. This restricts the amount of vegetation on slopes with these aspects. Consequently, the same factor creates saturated material on slopes with sparse vegetative cover.

The elevation of landslides can be a controlling factor (Figure 43). The study area can be divided into 5 elevation zones of 1000 feet per interval. Of these five zones, only three contain landslides. The first elevation zone is between 5,000 to 5,999 feet. Four hundred eighty-four acres or 27 percent of the area disturbed by landslides is located

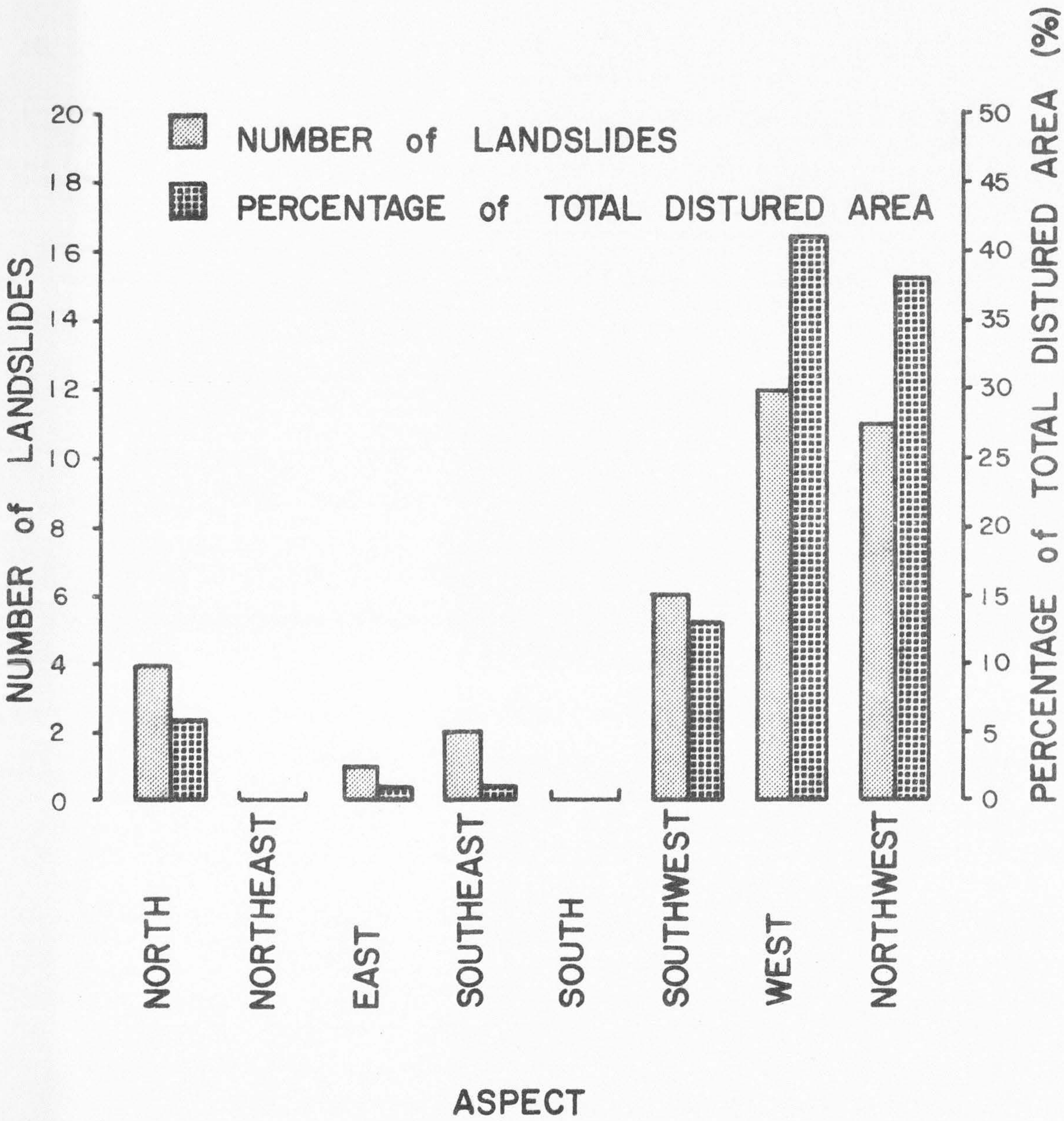

Figure 42. Landslides and aspect in the Bear River Range.

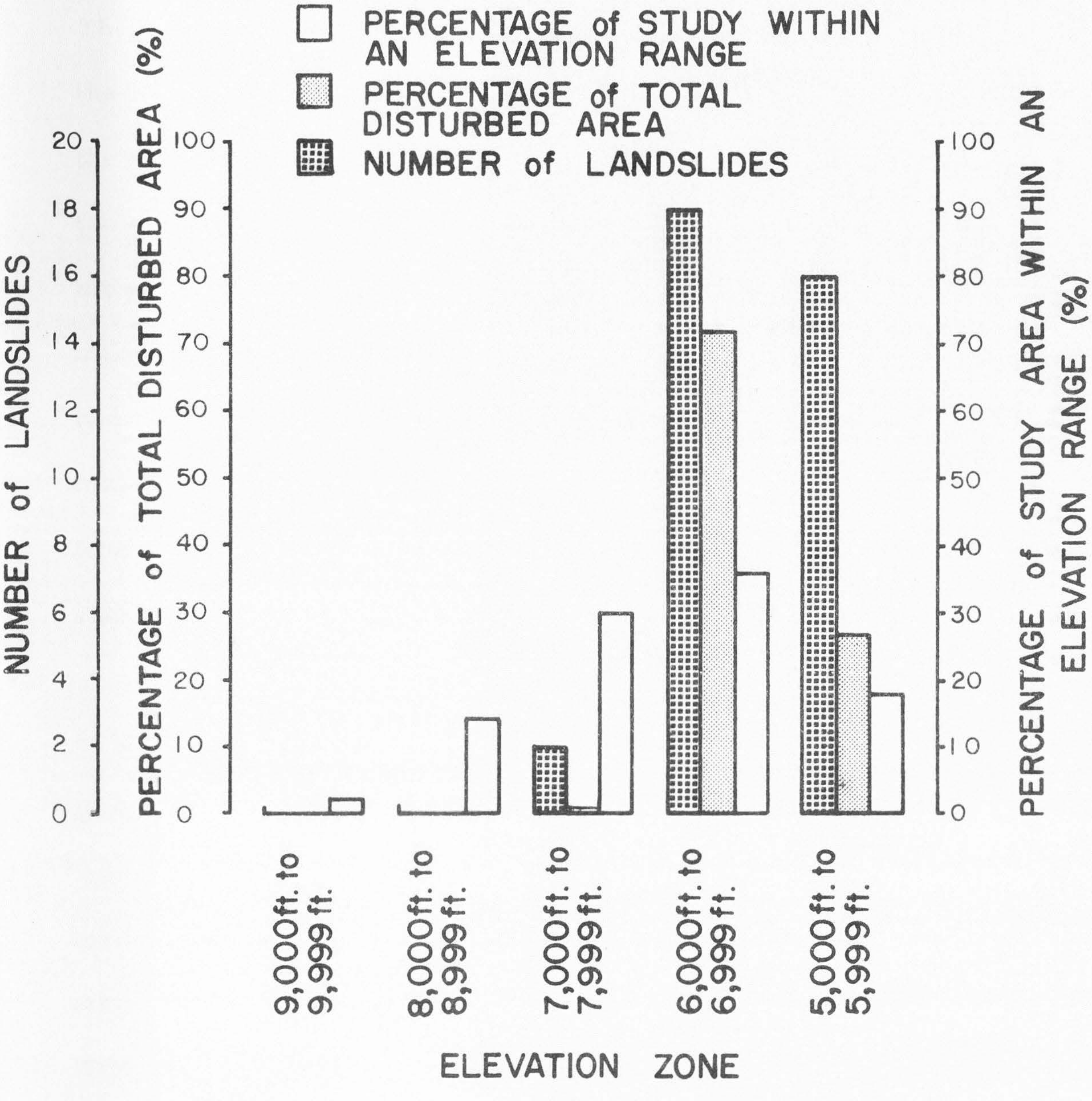

Figure 43. Landslides and elevation ranges in the Bear River Range.

within this zone. In the zone between 6,000 to 6,999 feet, 1,315 acres or 72 percent of the area disturbed by landslides is found in this zone. The zone between 7,000 to 7,999 feet contains 19 acres or 1 percent of the area disturbed by landslides. The preponderance of landslides in the elevation zone from 6,000 to 6,999 feet may reflect the amount of the study area with landslide prone slopes. The 6,000 to 6,999 feet elevation zone includes the landslide-prone steeper slopes but excludes many of the steepest slopes where other factors reduce landslide potential. The distribution of the study area between elevation zones is normal (Figure 43). As a result, the preponderance of landslides in the 6,000 to 6,999 feet elevation zone reflect actual landslide susceptibility rather than the amount of study area in that zone.

Slope is frequently an important controlling factor in the location of landslides. The mean slope value for landslides in the Bear River Range is 27 percent. A graphic representation showing the number of landslides for each slope interval and the percentage of the total area involved shows that the highest number of landslides and the greatest amount of area disturbed are on slopes of 20-24 percent (Figure 44). Within a plus or minus value of about 11 percent about the mean value, approximately 83 percent of all landslides are included. In other words, slopes ranging from 39 to 15 percent include roughly 95 percent of the total area disturbed by landslides. This range probably covers the dominant slopes in the study area. However, the preponderance of landslides

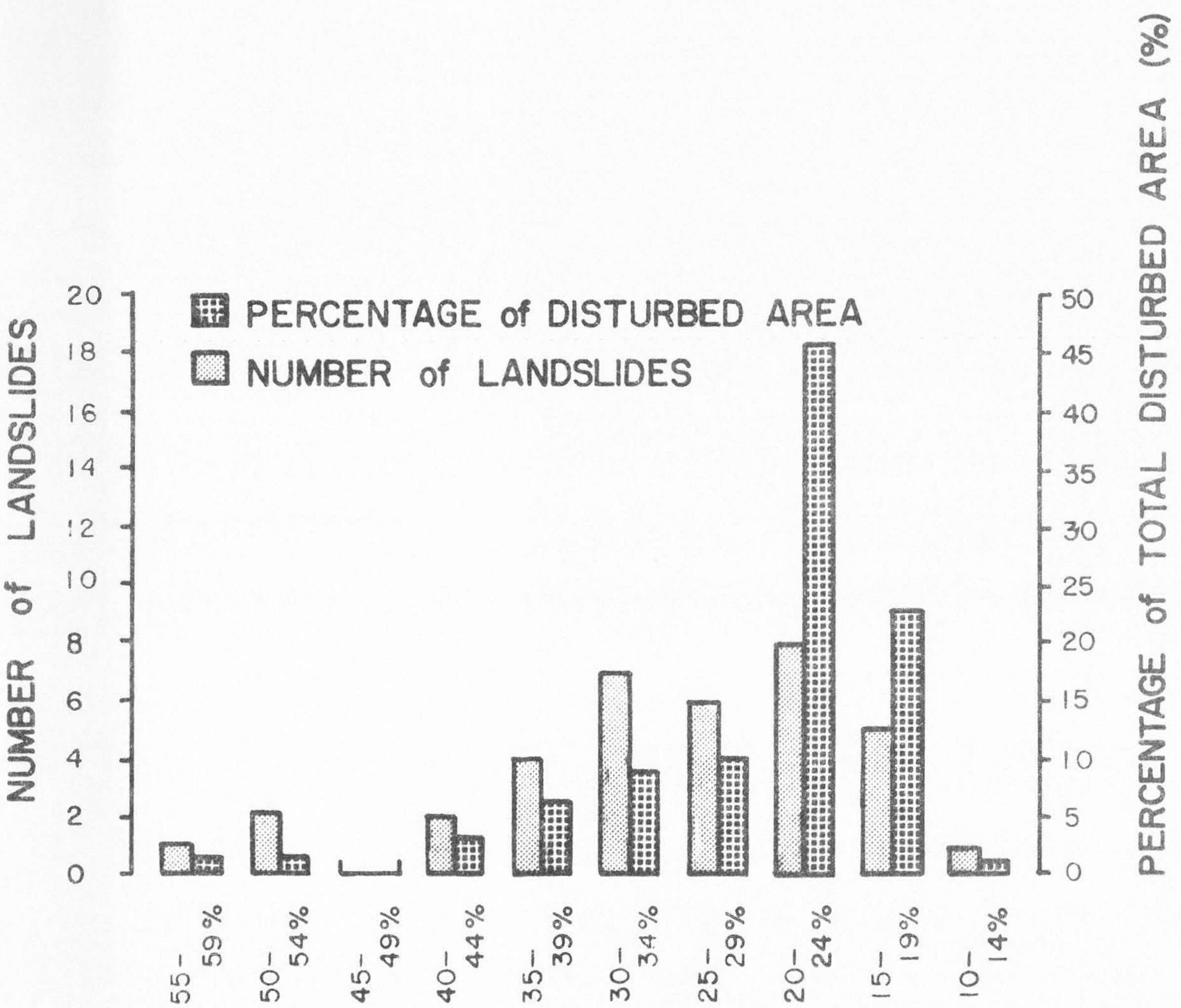

Figure 44. Landslides and slope in the Bear River Range.

in the 20 to 24 percent slope zone indicates a significant and real landslide potential.

Only two landslides mapped were active. One active landslide is feature eleven in Blacksmith Fork Canyon. This landslide may be active due to the existence of a road across the lower part of the feature. The other active landslide is feature twenty-four in East Canyon. This landslide is near the right abutment of Porcupine Reservoir dam and adjacent to the reservoir rim. Movement by this landslide results from the unstable slope created during dam construction and the higher water table established by the reservoir. Both of the active landslides are small compared to other in the Bear River Range. It appears that both features exist, at least in part, as a result of disturbances created by man.

The majority of landslides in the Bear River Range appear to be older than historic time. It is suggested that most of the landslides developed during the late Pleistocene. The bulk of the mapped landslides probably developed during glacial intervals with a few being formed during interglacial intervals. This conclusion is based on the climatic controls likely to contribute to landsliding. The two most critical factors would be precipitation and temperature. Current climatic conditions seem unfavorable for landsliding on the scale that has taken place in the past. Conditions during interglacial intervals were similar to present. This indicates that interglacial landslides were probably controlled by localized factors. An example of an interglacial landslide may be feature five near the Utah State University Forestry Field Station in Logan Canyon. This landslide may have developed during an interglacial interval as a result of oversteepening of the slope by ice during the previous glacial interval. During glacial intervals, precipitation would be higher. This enhances the potential for saturation of material prone to landsliding. The temperatures during a glacial interval would promote freezing and thawing. These and related factors of a glacial interval climate would be conducive to landsliding. For these reasons, most of the inactive landslides in the Bear River Range are considered to be the result of failure during a glacial interval.

QUATERNARY STREAM ALLUVIUM AND LAKE DEPOSITS

General Statement

Along the eastern margin of Cache Valley and in the lower part of some canyons, stream alluvium and Lake Bonneville deposits are mapped (Williams, 1962). Terraces produced by either Lake Bonneville or stream action are found in Blacksmith Fork and East canyons.

Description

Near the mouths of some canyons, stream action has excavated the Lake Bonneville deposits. This action is subsequent to the last maximum of Lake Bonneville in Cache Valley. The stream flow from High Creek, Cherry Creek, Smithfield, Logan, Providence, Blacksmith Fork, and East canyons has been sufficient to excavate Lake Bonneville features and deposit stream alluvium (Williams, 1962). Because Lake Bonneville extends into the lower reaches of the canyons during lake maxima, all canyons, contain remnants of Lake Bonneville deposits (Table 16).

Terraces are found in Blacksmith Fork and East Canyons. Blacksmith Fork Canyon has two terrace levels near the canyon mouth. Both terraces were produced by stream action. The older terrace is smaller and about 10 feet higher than the younger terrace. The younger and

Table 16. The extent of the Bonneville shoreline up canyons.

	Extent of Bonneville Shoreline	
	Elevation (ft)	Miles from Mouth (mi)
High Creek	5,133	0.6[+]
Oxkiller Hollow	5,134	0.3
Cherry Creek	5,134	0.4
City Creek	5,135	0.3
Nebo	5,136	0.3
Smithfield	5,137	0.8
Birch	5,138	0.5
Dry (North)	5,139	0.4
Hyde Park	5,140	0.4
Green	5,141	0.6
Logan	5,142*	7.3
Dry (South)	5,142	0.3
Providence	5,148	0.9
Millville	5,150	0.4
Blacksmith Fork	5,160*	5.9
Hyrum	5,183	2.4
Paradise Dry	5,185	2.4
East	5,185	2.6

[+]All distance up canyon are measured between the 5000-feet contour and the upstream elevation value. Two exceptions are Logan and Blacksmith Fork canyon where the distance is measured from the 4600-feet contour.

*The elevation values for Logan and Blacksmith Fork canyons are based on the values published by Crittenden (1963). The other values are estimations based on the change in elevation of the Bonneville shoreline between Franklin, Idaho, Logan Canyon, and Blacksmith Fork Canyon.

more extensive terrace is adjacent to the Blacksmith Fork river. In the vicinity of Hardware Ranch, in the upper Blacksmith Fork Canyon, two terrace levels are found. The largest and older terrace forms a large meadow. It is approximately 6 feet higher than the level of the younger terrace. The younger and smaller terraces is incised along the southern edge of the older terrace. The younger terrace is adjacent to the Blacksmith Fork river. Both terraces appear to be the products of stream action. A terrace near the mouth of East Canyon was built by Lake Bonneville. This terrace corresponds to the shoreline of the Bonneville stillstand of Lake Bonneville (Williams, 1962). An examination of the soil development on this terrace found development to be consistent with the age of the Bonneville stillstand (Southard, oral comm., 1975).

Lake Bonneville deposits are found along the eastern margin of Cache Valley and in the lower part of some canyons. These deposits were mapped in detail by Williams (1962). Drawing from this source, the lake deposits are generalized into units representing the Alpine, Bonneville, and Provo phases of Lake Bonneville. These units illustrate the relative extent of existing Lake Bonneville features.

GEOMORPHIC DEVELOPMENT DURING THE PLEISTOCENE AND HOLOCENE

A chronology of geomorphic development must place the origin of specific features in a relative-time framework. A few features may be restricted to limited time periods by interrelationships to events or features with known dates. Many features can not be correlated to specific times within the overall sequence.

The Bear River Range and Cache Valley initially assumed their overall present configuration prior to the Quaternary. Tectonic events responsible for these features began in the early Tertiary and continue through the present. Thus, the physiographic setting, at the beginning of the Pleistocene, probably was similar to the present, and the climate may also have been similar (Flint, 1971). The volumes of rock removed to form the many large canyons on the western front of the Bear River Range is not apparent at the mouths of the canyons. The material must underlie the Lake Bonneville sediments. Erosion apparently was predominate within the valley prior to the Pleistocene and, perhaps, during the early part of the Pleistocene. This is based on the presence of two pediments cut on the Salt Lake Formation of Tertiary age along the margins of Cache Valley. These pediments subsequently were offset by faults and dissected. Thus, origin and major excavation of the canyons certainly pre-dates Wisconsinan time. By the onset of Bull Lake glaciation, the canyons essentially had their present configuration. The thalweg were probably at a slightly higher level than the present. Tributary canyons were in existence in nearly their present configuration. From the Wisconsian through the Holocene,the main development evidenced in the Bear River Range involved repeated glaciation and changes in the level of Lake Bonneville. By the time of the earliest apparent glaciation, the Beaver Basin alluvial fan was well developed. Soil development on the feature may even predate Wisconsian glaciation (Southard, oral comm., 1975). The toe of the fan was truncated by glacial ice during its maximum advance. Alluvial fans probably formed at other large tributaries. Specifically, the higher levels of fan segments at Mill and Spring Hollows may have formed during the major glacial advance. The degree of soil development is consistent with this interpretation. Glaciers occupied the higher tributary canyons of Logan Canyon. Tongues of ice from Tony Grove, White Pine, Steep Hollow, Stream Mill, Crescent Lake, Upper Spring Hollow, and Bunchgrass Creek canyons joined the main glacier from Franklin Basin in Logan Canyon. The upper part of Providence Canyon was filled by a glacier extending southward from a cirque near Logan Peak. Another glacier extended northward from the cirque at High Creek Lake down the South Fork of High Creek Canyon. Small glaciers occupies the South Fork of Smithfield, and the heads of Spring Hollow, Mill Hollow, Leatham Hollow, Green, and Birch canyons. Glacial erosion began to produce the cirques at White Pine, High Creek, and Tony Grove lakes and elsewhere. Ridges and peaks were shaped into mountain glacial topography by adjacent valley glaciers. A broad valley was carved in the soft Wasatch Formation by the thin ice in the upper part of Logan Canyon and along its tributaries. Nivation modified the heads of Smithfield, Green, Cottonwood and Dry Canyon (South). Patterned morphology began to form at many diamicton sites due to frost heaving. Lake Bonneville at the Alpine maximum extended into the lower reaches of the main canyons. Lacustrine deposits accumulated along the mountain front. Some landslides may have formed.

The interglacial allowed erosion of glacial deposits. Streams incised the material in tributary canyons and along Logan Canyon. Some alluvial-fan deposition probably took place.

During early Pinedale glaciation, glaciers reoccupied the earlier Bull Lake cirques and glaciated valleys. This glaciation was less extensive. Probably only the upper reaches of the canyons were further modified by glacial erosion. Bull Lake till was reworked and redeposited (Williams, 1964). Additional nivation and formation of patterned diamicton took place. Lake Bonneville at the highest Bonneville level flooded the lower part of canyons opening into Cache Valley. Active fan formation took place at Spring, Mill, and Leatham Hollows. Lacustrine deposits accumulated in the lower canyon reaches and along the mountain front. Some landslides may have formed. The dissected and eroded landslides at Sheep Creek and the mouth of East Canyon probably formed about this time.

Landslides probably occurred during the interglacial between early and late Pinedale glacial episodes. Some alluvial-fan deposition probably took place during this interglacial. The fan formed on deposits at the Bonneville level in East Canyon is probably an example.

The late Pinedale glacial episode allowed reoccupation of early Pinedale glacial cirques and valleys. Nivation and diamicton sites were reactiviated. Lake Bonneville at the Provo level extended to the mouths of most of the canyons opening into Cache Valley. Lacustrine deposits accumulated along the mountain front. Some landsliding probably took place during this glacial episode. The large landslide just upstream from the Forestry Field Station in Logan Canyon is a probable example. This landslide was apparently undercut by the early maximum glacial advance. The dissection and erosional modification of the feature suggests that it formed fairly long ago. Some alluvial-fan deposition at Mill and Spring Hollows probably took place during the glacial maximum during this late Pinedale glaciation.

Erosion of glacial, lacustrine, and nivation deposits took place in the early Holocene. Diamicton fields were erosionally modified. Lacustrine deposits along the mountain front were excavated, especially by the large streams such as Logan and Blacksmith Fork rivers. Several landslides probably occurred due to rapidly over-steepened slopes created by the erosion.

During the Hypsithermal, many alluvial fans formed at mouths of tributary canyons to the main canyons such as Logan and Blacksmith Fork. Stream flow was reduced to intermittent or ephermeral flow. Large streamlike Logan River could not remove the material deposited from tributary canyons. Alluvial-fan development locally succeeded in nearly blocking the drainage in some canyons.

During the Neoglacial, nivation activity occurred in glacial and nivation cirques. Formation of patterned diamicton was re-activated on some favorable sites. Some landsliding took place as a result of increased precipitation and active physical weathering.

Since the Neoglacial streams have re-established perrenniel flow in the main canyons and some tributary canyons. The toes of alluvial fans have been truncated. Erosion of the patterned-diamicton fields gradually is reducing the distinctive patterned morphology. Dissection of sandy lacustrine shoreline deposits and re-deposition as floodplains farther out in the valley are actively carried on by runoff and channel flow. Glacial and nivation deposits are being eroded and transported down the canyons toward Cache Valley. Landslides have formed, and several are still active. * This includes the landslide at the edge of Porcupine Reservoir, and that along the Hardware Ranch-Danish Dugway road.

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APPENDIXES

Appendix A

Computer Program for Generating Longitudinal Profiles Along Canyon Thalwegs on an EAI 590 Computer System

Main Program

```
C       ARRAY A AND B ARE EQUIVALENT TO SUBROUTINE ARRAYS X AND Y
        COMMON A(500),B(500),M(50)
        MK=0
        READ (6,100)MAX,YIN,YST
  100   FORMAT (I6,2F10.0)
C       CALCULATE THE Y VALUE ARRAY TO MAXIMUM ELEVATION (MAX)
        B(1)=YIN
        DO 10 I=2,MAX
        B(I)=B(I-1)+YST
   10   CONTINUE
        READ (6,101)KY,MLINE,MAXIS,MGRID,MLABX,MLABY,MTITLE,MGX,MGY,MDX,
       1MDY,AT,BT,G2T,BAGT,JSZ,DHT,AINC,BINC,AL,BL,AS,BS,ASCALE,BSCALE,
       2AVAL,BVAL,AREF,BREF,AP,BP,AN,BN,MSMBL,MVX,MVY,MVT
  101   FORMAT(6I4,I2,2I4,2I2/2F8.0,F9.2,F8.0,I2,F9.2/6F8.2,4F6.2/
       *6F8.0,I4,3I3)
        READ (6,102)J
  102   FORMAT(I3)
        AS=AL+3.0
        BS=0.0
        A(1)=0.0
   15   DO 20 K=1,J
        READ (6,103)M(K)
  103   FORMAT(I3)
        MK=M(K)
        READ (6,104) (A(I).I=2,MK)
  104   FORMAT(15F4.2)
        CALL GRAPH(A,B,MK,KY,MLINE,MSMBL,MAXIS,MGRID,MLABX,MLABY,
       1MTITLE,AT,BT,G2T,BAGT,MGX,MGY,MDX,MDY,JSZ,DHT,AINC,BINC,AL,BL,AS,
       2BS,MVX,MVY,MVT,ASCALE,BSCALE,AREF,BREF,AVAL,BVAL,AP,BP,AN,BN)
   20   CONTINUE
        END
```

Subroutine Program

```
C     GRAPH OF Y VS X ON ARITHMETIC PAPER
      SUBROUTINE GRAPH(X,Y,N,JY,NLINE,NSMBL,NAXIS,NGRID,NLABX,NLABY,
     1NTITLE,XT,YT,H2T,ANGT,NGX,NGY,NDX,NDY,ISZ,CHT,XINC,YINC,XL,YL,XS,
     2YS,NVX,NVY,NVT,XSCALE,YSCALE,XREF,YREF,XVAL,YVAL,XP,YP,XN,YN)
      DIMENSION X(1),Y(1),FMTX(25),FMTY(25),FMTT(25)
C     X AND Y ARE THE DATA TO BE PLOTTED.  N IS THE NUMBER OF DATA PTS
C     JY IS THE NO OF THE Y VAR BEING PLOTTED WHEN MORE THAN 1 PLOTTED
C     IF NLINE = 0 POINT PLOT NSYMBL = SYMBOL CODE (0 TO 10)
C              = 1 LINE PLOT
C     NAXIS = 0 DO NOT DRAW AXIS
C           = 1 DRAW AXIS WITH TICK MARKS PUT EVERY XINC AND YINC
C     NGRID = 0 DO NOT DRAW GRID
C           = 1 DRAW GRID - USE SAME INCREMENTS ON X AND Y AXIS AS TICKS
C     NLABX = -1 JUST PLOT VALUES WITH TICK MARKS IF NAXIS = 1
C           =  0 DO NOT LABEL ABSCISSA
C           =  1 LABEL ABSCISSA AND IF TICKED PLOT VALUES
C     NLABY = -1 JUST PLOT VALUES WITH TICK MARKS IF CALLED FOR
C           =  0 DO NOT LABEL Y AXIS
C           =  1 LABEL Y AXIS AND IF TICKED PLOT VALUES
C     NTITLE = 0 DO NOT PLOT GRAPH TITLE
C            = 1 PLOT GRAPH TITLE
C     (XT,YT) STARTING POSITION FOR PLOTTING TITLE IN INCHES
C     H2T AND ANGT ARE CHARACTER HT AND ANGLE FOR PLOTTING TITLE
C     NGX IS NO OF TICKS TO SKIP BEFORE WRITING VALUES ON ABSCISSA
C     NGY IS NO OF TICKS TO SKIP BEFORE WRITING VALUES ON Y AXIS
C     NDX = NO OF PLACES TO RIGHT OF DECIMAL PT FOR PLOTTING X VALUES
C     NDY = NO OF PLACES TO RIGHT OF DECIMAL PT FOR PLOTTING Y VALUES
C     ISZ = SIZE ARGUMENT FOR PLOTTING VALUES AND SYMBOL IN UNITS OF .05
C     CHT = 1/2 HT OF CHARACTERS TO BE PLOTTED WITH PLTEXT
C     XINC = INCREMENT ON X AXIS FOR TICKS AND GRID IN INCHES
C     YINC = INCREMENT ON Y AXIS FOR TICKS AND GRID IN INCHES
C     XL AND YL ARE LENGTH OF X AND Y AXIS IN INCHES
C     (XS,YS) IS LOCATION OF NEXT STANDBY FROM CURRENT REF IN INCHES
C      FMTX IS FORMAT OF X LABEL AND MUST BE LESS THAN 99 CHARACTERS
C      FMTY IS FORMAT OF Y LABEL AND MUST BE LESS THAN 99 CHARACTERS
C      FMTT IS FORMAT OF TITLE AND MUST BE LESS THAN 99 CHARACTERS
C     NVX IS NO OF VARIABLES IN FORMAT FOR XLABEL LE 25
C     NVY IS NO OF VARIABLES IN FORMAT FOR YLABEL LE 25
C     NVT IS NO OF VARIABLES IN FORMAT FOR TITLE LE 25
C     XSCALE = SCALE FACTOR IN X - PROBLEM UNITS/INCH
C     YSCALE = SCALE FACTOR IN Y - PROBLEM UNITS/INCH
C     (XREF,YREF) IS REFERENCE POSITION IN INCHES FROM STANDBY
C     (XVAL,YVAL) PROBLEM UNITS AT (XREF,YREF)
C     XP = PLOT SIZE (POSITIVE INCHES IN X DIRECTION FROM REFERENCE)
C     YP = PLOT SIZE (POSITIVE INCHES IN Y DIRECTION FROM REFERENCE)
C     XN = PLOT SIZE (NEGATIVE INCHES IN X DIRECTION FROM REFERENCE)
C     YN = PLOT SIZE (NEGATIVE INCHES IN Y DIRECTION FROM REFERENCE)
C     IF SSW B ON SKIP WRITING READY PLOTTER, ETC
    1 OCT 23500
      J   .2
      J   .3
```

```
      2 TYPE 500
    500 FORMAT(39HREADY PLOTTER AT STANDBY POSITION - RSR/)
        OCT 25000
      3 CALL SBYSET
        CALL PLTSET(XSCALE,YSCALE,XREF,YREF,XVAL,YVAL,XP,YP,XN,YN)
C         CHECK TO SEE IF NEED TO READ TITLES
    200 FORMAT(20A4)
        IF(NTITLE.EQ.1.AND.JY.EQ.1) READ(6,200)(FMTT(I),I=1,NVT
        IF(NLABX.EQ.1.AND.JY.EQ.1) READ(6,200)(FMTX(I),I=1,NVX)
        IF(NLABY.EQ.1)READ(6,200)(FMTY(I),I=1,NVY)
C       DRAW AXIS IF NAXIS GT 0
        CALL PENUP
        IF (NAXIS)100,100,5
      5 CALL INPLOT(0.,0.)
        NX=XL/XINC+.5
        NY=YL/YINC+.5
        IF(NX.EQ.0)NX=1
        IF(NY.EQ.0)NY=1
        IXM=ISZ*2
        RISZ=ISZ
        CALL QSIZE(ISZ)
        CALL CHSIZE(CHT,0.)
C       DRAW X AXIS
        CALL PENDN
        IF(NLABX)15,10,15
     10 CALL INPLOT(XL,0.)
        GO TO 40
     15 Y1=0.-RISZ*.05-2.*CHT
     16 CALL QSIZE(IXM)
        CALL XMARK
        CALL QSIZE(ISZ)
        CALL PENUP
        VAL=XVAL
        XX=0.
        CALL CHECK(XSCALE,XVAL,XX,VAL,RNCOL,NDX)
        X1=XX-CHT*(RNCOL-1.)*.8
     17 CALL INPLOT(X1,Y1)
        CALL PLTVAL(VAL,NDX)
        CALL INPLOT(0.,0.)
        CALL PENDN
        DO 30 I=1,NX
        RI=I
        XX=XINC*RI
        CALL INPLOT(XX,0.)
        CALL XMARK
        IF(NLABX)20,30,20
C       CHECK TO SEE IF NEED TO PLOT VAL
     20 IF(MOD(I,NGX).NE.0) GO TO 30
        CALL QSIZE(IXM)
        CALL XMARK
        CALL QSIZE(ISZ)
        CALL CHECK(XSCALE,XVAL,XX,VAL,RNCOL,NDX)
        X1=XX-CHT*(RNCOL-1.)*.8
        CALL PENUP
        CALL INPLOT(X1,Y1)
```

```
      CALL PLTVAL(VAL,NDX)
      CALL INPLOT(XX,0.)
      CALL PENDN
   30 CONTINUE
   40 CALL PENUP
      CALL INPLOT(0.,0.)
C     DO Y AXIS
      CALL PENDN
      IF(NLABY)50,45,50
   45 CALL INPLOT(0.,YL)
      GO TO 75
   50 CALL QSIZE(IXM)
      CALL YMARK
      CALL QSIZE(ISZ)
      CALL PENUP
      VAL=YVAL
      YY=0.
      CALL CHECK(YSCALE,YVAL,YY,VAL,RNCOL,NDY)
      X1=0.-1.6*RNCOL*CHT-CHT-RISZ*.05
      X1MAX=X1
      CALL INPLOT(X1,0.)
      CALL PLTVAL(VAL,NDY)
      CALL INPLOT(0.,0.)
      CALL PENDN
      DO 65 I=1,NY
      RI=I
      YY=YINC*RI
      CALL INPLOT(0.,YY)
      CALL YMARK
      IF(NLABY)55,65,55
C     CHECK TO SEE IF NEED TO PLOT VAL
   55 IF(MOD(I,NGY).NE.0) GOTO 65
      CALL QSIZE(IXM)
      CALL YMARK
      CALL QSIZE(ISZ)
      CALL CHECK(YSCALE,YVAL,YY,VAL,RNCOL,NDY)
      X1=0.-1.6*RNCOL*CHT-CHT-RISZ*.05
      IF(ABS(X1).GT.ABS(X1MAX)) X1MAX=X1
      CALL PENUP
      CALL INPLOT(X1,YY)
      CALL PLTVAL(VAL,NDY)
      CALL INPLOT(0.,YY)
      CALL PENDN
   65 CONTINUE
   75 CALL PENUP
C     SEE IF GRID CALLED FOR
      IF(NGRID)100,100,80
   80 NX=NX/NGX
      IF(NX.LE.0) NX=1
      NY=NY/NGY
      IF(NY.LE.0) NY=1
      DO 85 I=1,NX,2
      RI=I*NGX
      X1=XINC*RI
      CALL INPLOT(X1,0.)
```

```
      CALL PENDN
      CALL INPLOT(X1,YL)
      CALL PENUP
   82 L=I+1
      IF(L.GT.NX) GO TO 86
      RL=L*NGX
      X1=XINC*RL
      CALL INPLOT(X1,YL)
      CALL PENDN
      CALL INPLOT(X1,0.)
      CALL PENUP
   85 CONTINUE
   86 DO 90 I=1,NY,2
      RI=I*NGY
      Y1=YINC*RI
      CALL INPLOT(0.,Y1)
      CALL PENDN
      CALL INPLOT(XL,Y1)
      CALL PENUP
   92 L=I+1
      IF(L.GT.NY) GO TO 100
      RL=L*NGY
      Y1=YINC*RL
      CALL INPLOT(XL,Y1)
      CALL PENDN
      CALL INPLOT(0.,Y1)
      CALL PENUP
   90 CONTINUE
C     PLOT X AND Y DATA
  100 XX=X(1)
      YY=Y(1)
  101 CALL PLOT(XX,YY)
      CALL QSIZE(ISZ)
      CALL SYMBOL(NSMBL)
      DO 120 I=2,N
      IF(NLINE.EQ.0) CALL PENUP
      XX=X(I)
      YY=Y(I)
  102 CALL PLOT(XX,YY)
      CALL SYMBOL(NSMBL)
  120 CONTINUE
      CALL PENUP
      IF(NAXIS)140,140,122
C     LABEL ABSCISSA
  122 IF(NLABX)130,130,125
  125 RL=4*NVX-5
      CHL=1.6*RL*CHT
      IF(CHL.GT.(XL-XN))PAUSE 1
      X1=(XL-CHL)*.5
      Y1=0.-.05*RISZ-5.*CHT
      CALL INPLOT(X1,Y1)
      CALL PLTEXT
      ADR FMTX
C     LABEL Y AXIS
  130 IF(NLABY)140,140,135
```

```
  135 CALL CHSIZE(CHT,90.)
      RL=4*NVY-5
      CHL=1.6*RL*CHT
      IF(CHL.GT.(YL-YN)) PAUSE 2
      Y1=(YL-CHL)*.5
      X1=X1MAX-3.*CHT
      CALL INPLOT(X1,Y1)
      CALL PLTEXT
      ADR FMTY
C     TEST TO SEE IF NEED GRAPH TITLE
  140 IF(NTITLE)150,150,145
C     PLOT TITLE
  145 CALL INPLOT(XT,YT)
      CALL CHSIZE(H2T,ANGT)
      CALL PLTEXT
      ADR FMTT
  150 CALL INPLOT(XS,YS)
      RETURN
      END
```

Appendix B

Tabulation of Alluvial-Fan Measurements

Fan	Upper Elev. (ft)	Lower Elev. (ft)	Relief (ft)	Length (mi)	Area Fan (sq mi)	Area source (sq mi)	Flow dir.
I. Green Canyon							
1	6,640	5,200	1,440	.53	.0014	.07	S
2	7,475	5,200	2,275	.77	.0059	.17	N
3	7,169	5.240	1,929	.79	.0036	.11	S
4	7,120	5,400	2,480	.69	.0036	.12	N
5	7,960	5,480	2,480	1.17	.0029	.38	S
II. Logan Canyon							
1	7,323	4,800	2,523	1.08	.0058	.38	N
2	7,00	4,840	2,160	.87	.0068	.13	S
3	7,360	4.880	2,480	.94	.0064	.18	S
4	8,720	4,880	3,840	1.65	.0035	.86	N
5	7.475	4,960	2,515	1.20	.0060	.29	S
6	7,320	5,000	2,320	.76	.0136	.74	S
7	7,000	5,000	2,000	.60	.0037	.06	N
8	7,680	5,000	2,680	.80	.0064	.10	N
9	8,000	5,000	3,000	.94	.0071	.08	N
10	8,253	5,000	3,253	1.05	.0129	.21	N
11	6,400	5,040	1,360	.44	.0017	.04	S
12	6,960	5,040	1,920	.57	.0013	.07	S
13	7,800	5.080	2,720	1.20	.0121	.51	S
14	7,600	5,040	2,560	1.14	.0043	.16	N
15	8,914	5,120	3,794	2.32	.0133	1.57	S
16	8,573	5,120	3,453	1.38	.0038	.42	S
17	8,000	5,120	2,880	1.26	.0045	.35	N
18	8,320	5,120	3,200	1.37	.0060	.46	N

Appendix B. (Continued)

Fan	Upper Elev. (ft)	Lower Elev. (ft)	Relief (ft)	Length (mi)	Fan (sq mi)	Area source (sq mi)	Flow dir.
II. Logan Canyon (Cont.)							
19	7,200	5,120	2,080	.65	.0010	.09	S
20	6,120	5,120	1,000	.29	.0003	.02	S
21	8,040	5,160	2,880	1.15	.0023	.22	S
22	7,200	5,160	2,040	.83	.0041	.17	N
23	6,583	5,160	1,423	.54	.0019	.09	S
24	8,400	5,160	3,240	1.36	.0073	.33	S
25	7,600	5,200	2,400	1.02	.0026	.15	S
26	6,760	5,200	1,560	.68	.0106	.12	N
27	8,400	5,200	3,200	1.58	.0041	.48	S
28	8,914	5,280	3,634	2.77	.0028	2.49	S
29	7,522	5,200	2,322	.95	.0024	.21	N
30	9,065	5,320	3,745	2.89	.0037	3.98	S
31	6,920	5,560	1,360	3.20	.0017	2.30	N
32	8,560	6,760	1,800	.91	.0009	.15	S
33	8,560	6,800	1,760	.75	.0004	.07	S
34	8,800	6,840	1,960	1.02	.0004	.24	S
35	8,800	6,840	1,960	.95	.0004	.19	S
36	9,161	7,040	2,121	2.10	.2596	.56	W
III. Providence Canyon							
1	6,760	5,560	1,200	.39	.0057	.04	N
2	7,760	5,640	2,120	.96	.0071	.20	S
3	8,800	5,920	2,880	1.06	.0056	.24	N
4	7,280	6,160	1,120	.29	.0046	.01	N

Appendix B. (Continued)

Fan	Upper Elev. (ft)	Lower Elev. (ft)	Relief (ft)	Length (mi)	Area Fan (sq mi)	Area source (sq mi)	Flow dir.
IV. Blacksmith Fork - Main Canyon							
1	8,184	4,880	3,304	1.37	.0033	.46	S
2	7,640	4,920	2,720	.90	.0026	.19	S
3	7,838	4,880	2,958	1.22	.0028	.34	N
4	7,200	4,880	2,320	.82	.0037	.11	N
5	8,800	4,920	3,880	1.34	.0009	.48	S
6	7,840	5,000	2,840	1.06	.0063	.24	N
7	8,106	5,000	3,106	1.50	.0140	.75	N
8	8,455	5,000	3,455	1.15	.0025	.22	S
9	8,116	5,000	3,116	1.06	.0044	.15	N
10	8,080	5,000	3,080	1.13	.0090	.21	S
11	8,000	5,040	2,960	.96	.0111	.18	S
12	8,200	5,040	3,160	1.50	.0145	.61	N
13	7,600	5,040	2,560	.81	.0055	.09	S
14	6,400	5,040	1,360	.39	.0024	.04	S
15	7,560	5,080	2,480	.79	.0050	.11	S
16	8,258	5,080	3,178	1.89	.0042	.65	N
17	7,040	5,160	1,880	.62	.0023	.10	S
18	7,133	5,080	2,053	.77	.0103	.15	S
19	7,040	5,080	1,960	.66	.0039	.10	S
20	6,360	5,080	1,280	.52	.0036	.07	S
21	7,480	5,120	2,360	1.02	.0015	.19	N
22	6,000	5,120	880	.28	.0009	.01	S
23	7,576	5,120	2,456	1.19	.0134	.33	S
24	6,400	5,160	1,240	.54	.0019	.05	S
25	7,680	5,160	2,520	1.04	.0060	.37	N
26	7,040	5,200	1,840	.77	.0025	.10	S

Appendix B. (Continued)

Fan	Upper Elev. (ft)	Lower Elev. (ft)	Relief (ft)	Length (mi)	Fan (sq mi)	Area source (sq mi)	Flow dir.
IV. Blacksmith Fork - Main Canyon (Cont.)							
27	7,680	5,200	2,480	.94	.0064	.28	N
28	7,576	5,200	2,376	1.00	.0049	.20	S
29	7,586	5,240	2,346	1.20	.0160	.52	S
30	7,136	5,240	1,896	.81	.0181	.15	S
31	6,040	5,240	800	.24	.0011	.01	S
32	7,480	5,280	2,200	1.69	.0033	.45	S
33	7.920	5,280	2,640	2.07	.0151	.61	N
34	7,000	5,240	1,760	1.67	.0223	.55	S
35	7,800	5,280	2,520	2.31	.0270	.99	N
36	6,760	5,280	1,480	.63	.0017	.09	S
37	6,720	5,280	1,440	.62	.0077	.10	S
38	6,600	5,280	1,320	.50	.0020	.04	S
39	6,840	5,320	1,5	.65	.0033	.12	S
40	6,200	5,320	880	.36	.0018	.03	S
41	6,840	5,320	1,520	2.78	.0033	2.41	S
42	6,480	5,400	1,080	.48	.0052	.05	S
43	6,600	5,400	1,120	.68	.0136	.20	S
44	7,000	5,400	1,600	1.11	.0012	.47	N
45	6,240	5,440	800	.30	.0003	.02	S
46	6,720	5,480	1,240	.65	.0018	.11	S
47	6,600	5,480	1,120	.58	.0076	.08	N
48	6,600	5,520	1,080	.95	.0086	.21	N
49	6,080	5,520	560	1.56	.0073	.64	S
50	5,680	5,520	160	.69	.0049	.19	S
51	6,360	5,600	760	1.05	.0336	.28	N
52	7,088	5,560	1,528	2.25	.0033	.95	E

Appendix B. (Continued)

Fan	Upper Elev. (ft)	Lower Elev. (ft)	Relief (ft)	Length (mi)	Fan	Area source (sq mi)	Flow dir.
IV. Blacksmith Fork - Main Canyon (Cont.)							
53	6,320	5,600	720	.50	.0007	.04	W
54	6,320	5,600	720	.58	.005	.06	W
55	6,440	5,640	800	1.24	.0017	.33	W
56	6,440	5,640	800	1.22	.0019	.28	W
57	6,440	5,640	800	.81	.0010	.12	W
58	6,640	5,800	840	1.53	.0011	.57	S
59	6,680	6,120	560	.52	.0015	.07	S
60	8,135	6,240	1,892	.88	.0032	.19	N
61	6,800	5,960	840	.76	.0008	.12	S
62	7,760	6,000	1,760	.84	.0038	.17	S
63	7,760	6,040	1,720	.76	.0060	.07	S
64	7,000	5.960	1,040	.97	.0036	.16	W
65	7,000	6,040	960	.97	.0022	.38	W
66	7,400	6,080	1,320	1.47	.0044	.55	W
67	6,468	6,080	388	.42	.0020	.07	E
68	7,338	6,120	1,218	1.03	.0041	.16	W
69	6,642	6,160	482	.48	.0010	.05	E
70	7,338	6,200	1,138	.99	.0027	.29	W
71	8,000	6,560	1,440	1.46	.0014	.47	S
72	6,253	5,800	453	.41	.0014	.04	W
73	6,240	5,800	440	.40	.0008	.04	W
74	6,280	5,840	440	.40	.0005	.04	W
75	7,080	5,840	1,240	2.64	.0032	1.16	E
76	7,000	5,840	1,160	2.53	.0012	1.21	E
77	6,240	5,960	280	.47	.0009	.07	W
78	6,800	6,000	800	.90	.0009	.14	E

Appendix B. (Continued)

Fan	Upper Elev. (ft)	Lower Elev. (ft)	Relief (ft)	Length (mi)	Area Fan (sq mi)	Area source (sq mi)	Flow dir.
IV. Blacksmith Fork - Main Canyon (Cont.)							
79	6,480	6,040	440	.41	.0014	.08	W
80	6,640	6,280	360	.57	.0016	.14	W
81	6,640	6,320	320	.54	.0004	.10	W
82	6,720	6,320	400	.82	.0014	.22	W
V. Blacksmith Fork - Left Hand Fork							
1	8,520	5,200	3,320	1.10	0.089	.15	S
2	8,600	5,240	3,360	1.14	.0073	.32	S
3	8,720	5,280	3,440	1.34	.0042	.30	S
4	7,544	5,320	2,224	1.08	.0077	.45	N
5	6,840	5,320	1,520	.67	.0010	.08	S
6	8,800	5,400	3,400	1.83	.0040	1.66	S
7	7,280	5,400	1,880	.76	.0034	.10	S
8	7,544	5,440	2,104	.75	.0027	.14	N
9	7,360	5,440	1,920	.82	.0069	.14	S
10	6,320	5,480	840	.26	.0009	.02	S
11	7,160	5,480	1,680	.49	.0023	.07	N
12	6,920	5,480	1,440	.43	.0008	.03	S
13	7,000	5,480	1,520	.45	.0009	.04	S
14	7,120	5,480	1,640	.44	.0032	.04	N
15	7,200	5,520	1.680	.58	.0026	.08	N
16	7,200	5,560	1,640	.49	.0026	.04	N
17	6,760	5,560	1,200	.39	.0031	.04	N
18	7,000	5,560	1,440	1.03	.0045	.20	N
19	6,600	5,560	1,040	.33	.0010	.02	N
20	7,040	5,760	1,280	.45	.0005	.05	N

Appendix B. (Continued)

Fan	Upper Elev. (ft)	Lower Elev. (ft)	Relief (ft)	Length (mi)	Area Fan (sq mi)	Area Source (sq mi)	Flow dir.
V. Blacksmith Fork - Left Hand Fork (Cont.)							
21	7,040	5,800	1,240	.50	.0005	.08	S
22	7,480	5,800	1,680	.88	.0014	.14	S
23	7,040	5,800	1,240	1.23	.0014	.64	N
24	7,200	5,800	1,400	.57	.0004	.10	S
25	7,480	5,840	1,640	1.78	.0011	.59	S
26	7,120	5,880	1,240	.37	.0006	.04	S
27	7,440	5,880	1,560	1.49	.0017	.55	S
28	7,400	5,960	1,440	1.76	.0037	.63	S
29	7,440	6,400	1,040	2.22	.0034	1.87	S
30	7,525	6,440	1,085	.96	.0074	.20	S
VI. Paradise Dry Canyon							
1	5,800	5,280	520	.58	.0021	.05	S
2	5,960	5,280	680	.64	.0015	.05	S
3	5,840	5,320	520	.43	.0008	.03	S
4	7,480	5,320	2,160	1.32	.0034	.36	S
5	6.920	5,360	1,560	.68	.0009	.05	S
6	7,113	5,520	1,593	.64	.0050	.10	S
7	7,680	5,600	2,080	1.00	.0030	.16	S
VII. East Canyon							
1	7,147	5,080	2.067	2.05	.0071	.70	S
2	6,600	5,120	1,480	.81	.0063	.13	N
3	6,840	5,200	1,640	1.51	.0071	.51	S
4	6,240	5,400	840	.41	.0017	.04	S
5	6,400	5,400	1,000	.49	.0036	.03	S
6	7,000	5,400	1,600	.72	.0046	.09	S

Appendix B. (Continued)

Fan	Upper Elev. (ft)	Lower Elev. (ft)	Relief (ft)	Length (mi)	Area Fan (sq mi)	Area Source (sq mi)	Flow dir.
VII. East Canyon (Cont.)							
7	5,880	5,400	480	.21	.0004	.01	S
8	7,240	5,440	1,800	.72	.0016	.14	S
9	7,600	5,440	2,160	.84	.0030	.14	N
10	6,440	5,440	1,000	.34	.0007	.03	S
11	8,480	5,480	3,000	1.97	.0123	1.26	S
12	6,640	5,480	1,160	.52	.0028	.06	S
13	6,160	5,480	680	.35	.0016	.02	S
14	8,211	5,520	2,691	1.09	.0049	.21	S
15	6,680	5,560	1,120	.50	.0007	.05	S
16	8,240	5,640	2,600	1.88	.0256	.74	S
17	7,600	5,600	2,000	1.11	.0022	.35	N
18	8.040	5,640	2,400	1.49	.0050	.61	S

Appendix C

Climatic Equations

The following formulae calculate the ground level temperature for specific sites. These values take into account the general atmospheric parameters and site characteristics such as drainage and location.

T_e local temperature effect

T_f free-air temperature

T_7 700 millibar temperature

γ lapse rate between the 750 mb and 550 mb levels

H_7 height of the 700 millibar level above sea level

H_s height of the site above sea level

T_a site temperature

1st formula: $T_f = T_7 + \gamma (H_7 - H_s)$

2nd formula: $T_a = T_f + T_e$

PLATE I

Base from U.S. Dept. Int. Geol. Survey

CONTOUR INTERVAL 40 FEET

N MN

SCALE 1:48000

2 1 0.5 0 1 2 MILES

2000 0 2000 4000 6000 8000 10000 12000 14000 FEET

2 1 0 1 2 KILOMETERS

EXPLANATION

QUATERNARY ALLUVIUM	Qal	LANDSLIDE SCARP (ACTIVE)	
LAKE BONNEVILLE DEPOSIT	Qb	SCARP (INACTIVE)	
TERRACE		DEPOSIT	
PATTERNED DIAMICTON		GLACIAL CIRQUE	
NIVATION CIRQUE		ICE LIMITS (PROBABLE)	
ALLUVIAL FAN			

Geomorphology by Jerome V. DeGraff, 1974-1975

MAP SHOWING THE QUATERNARY GEOMORPHIC FEATURES OF THE BEAR RIVER RANGE, NORTH-CENTRAL UTAH

PLATE 4

LONGITUDINAL PROFILE OF THE NORTH FORK OF HIGH CREEK CANYON

PLATE 5

LONGITUDINAL PROFILE OF THE SOUTH FORK OF HIGH CREEK CANYON

LONGITUDINAL PROFILE OF OXKILLER HOLLOW

PLATE 7

LONGITUDINAL PROFILE OF
CHERRY CREEK CANYON
ELEVATION IN FEET
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
DISTANCE IN MILES
0
1
2
3
4
5
6
7
8
9
10
CONVEX
LAKE BONNEVILLE GRP
T
R
SALT LAKE FORMATION
T
CONVEX
R
UI
R
T
BRIGHAM FORMATION
CONVEX
T
CONVEX
R
LANGSTON FM
UTE FM
BLACKSMITH FM
UI
R
BLOOMINGTON FM
(Stream Flows Oblique to Strike)
UI
CONVEX
R
NOUNAN FM
CONVEX
CONVEX
CONVEX
T

PLATE 8

LONGITUDINAL PROFILE OF
CITY CREEK CANYON
ELEVATION IN FEET
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
DISTANCE IN MILES
0
1
2
3
4
5
6
7
8
9
10
UI
UI
UI
CONVEX
R
CONVEX
CONVEX
R
UI
T
UI
UI
UI
CONVEX
CONVEX
R
R
DI
SALT LAKE FORMATION
BRIGHAM FM
LANGSTON FM
UTE FORMATION
BLACKSMITH FORMATION
BLOOMINGTON FM

PLATE 9

LONGITUDINAL PROFILE OF NEBO CREEK CANYON

PLATE 10

LONGITUDINAL PROFILE OF SMITHFIELD CANYON

PLATE II

LONGITUDINAL PROFILE OF BIRCH CANYON

PLATE 12


LONGITUDINAL PROFILE OF DRY CANYON (NORTH)
ELEVATION IN FEET
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
DISTANCE IN MILES
0
1
2
3
4
5
6
7
8
9
10
SALT LAKE FM
BRIGHAM FM
LANGSTON FM
UTE FM
BLACKSMITH FM
BLOOMINGTON FM
NOUNAN FM
ST. CHARLES FM
GARDEN CITY FM
SWAN PEAK FM
LAKETOWN FM
JEFFERSON FM
R
DI
T
UI
CONVEX

PLATE 13

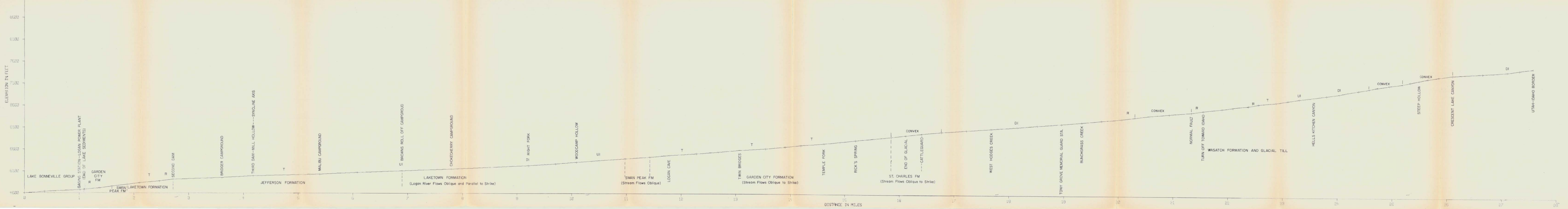

LONGITUDINAL PROFILE OF
HYDE PARK CANYON
ELEVATION IN FEET
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
DISTANCE IN MILES
0
1
2
3
4
5
6
7
8
9
10
SALT LAKE FORMATION
BLACKSMITH FM
BLOOMINGTON FM
NOUNAN FM
ST. CHARLES FM
GARDEN CITY FM
SWAN PEAK FM
LAKETOWN FM
UI
CONVEX
R
T
DI

PLATE 14

LONGITUDINAL PROFILE OF GREEN CANYON

PLATE 17

LONGITUDINAL PROFILE OF THE MAIN SECTION OF LOGAN CANYON



LONGITUDINAL PROFILE OF THE
BEAVER CREEK SECTION OF LOGAN CANYON

PLATE 18

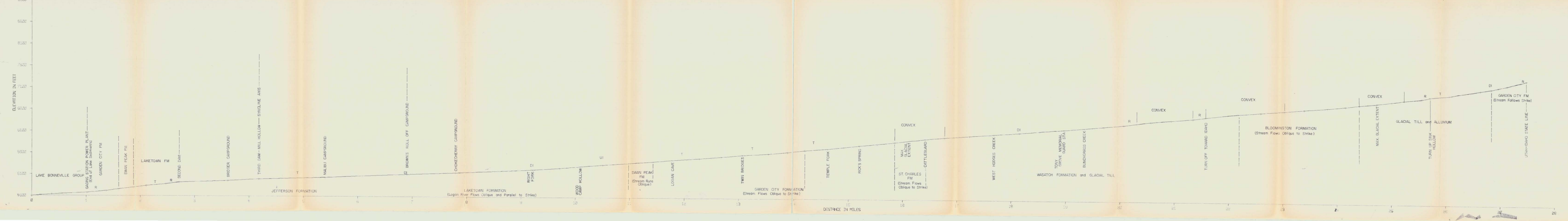


PLATE 19

LONGITUDINAL PROFILE OF
DRY CANYON (SOUTH)
ELEVATION IN FEET
DISTANCE IN MILES
LAKE BONNEVILLE GROUP
GARDEN CITY FM
SWAN PEAK FM
LAKETOWN FM
JEFFERSON FORMATION
MADISON FM
BRAZER FM
SYNCLINE AXIS
WELLS FM
8400
CONVEX
UI
R
T


LONGITUDINAL PROFILE OF
PROVIDENCE CANYON
PLATE 20
ELEVATION IN FEET
DISTANCE IN MILES
LAKE BONNEVILLE GROUP
LAKETOWN FM
JEFFERSON FM
MADISON FM
BRAZER FM
SYNCLINE AXIS
CONVEX
UI
T
R
DI
(Stream Follows Strike)

LONGITUDINAL PROFILE OF MILLVILLE CANYON

PLATE 21

PLATE 24

LONGITUDINAL PROFILE OF THE
MAIN SECTION OF BLACKSMITH FORK CANYON

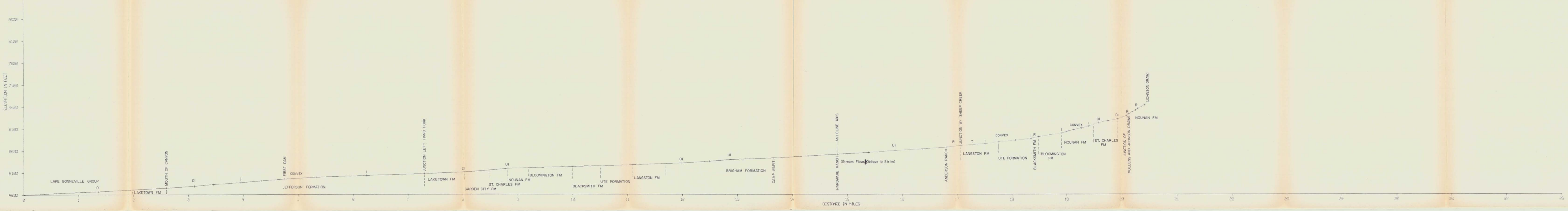


PLATE 26


LONGITUDINAL PROFILE OF THE
GREEN CANYON SECTION OF HYRUM CANYON
ELEVATION IN FEET
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
DISTANCE IN MILES
0
1
2
3
4
5
6
7
8
9
10
LAKE BONNEVILLE GROUP
SALT LAKE FORMATION
JEFFERSON FM
MADISON FM
BRAZER FORMATION
SYNCLINE AXIS
CONVEX
R
T
DI
UI

PLATE 27


LONGITUDINAL PROFILE OF
THE MAIN SECTION OF HYRUM CANYON
ELEVATION IN FEET
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
LAKE BONNEVILLE GROUP
R
T
R
SALT LAKE FORMATION
UI
R
MADISON FORMATION
CONVEX
CONVEX
CONVEX
R
CONVEX
SYNCLINE AXIS
BRAZER FORMATION
CONVEX
CONVEX
R
T
MADISON FM
CONVEX
JEFFERSON FORMATION
(Stream Flows Oblique To Strike)
UI
UI
DI
LAKETOWN FORMATION
CONVEX
R
T
CONVEX
0
1
2
3
4
5
6
7
8
9
10
DISTANCE IN MILES

PLATE 28

LONGITUDINAL PROFILE OF PARADISE DRY CANYON