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GEOLOGY OF BALDY AREA, WEST SLOPE OF MOUNT TIMPANOGOS, UTAH COUNTY, UTAH

by

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GEOLOGY OF BALDY AREA, WEST SLOPE OF MOUNT TIMPANOGOS, UTAH COUNTY, UTAH

A thesis

submitted to

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In partial fulfillment

of the requirements for the degree

Master of Science

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by

Ben L. Olsen

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This thesis by Ben L. Olsen is accepted in its present form by the Department of Geology as satisfying the thesis requirements for the degree of Master of Science.

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Chairman

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Committee

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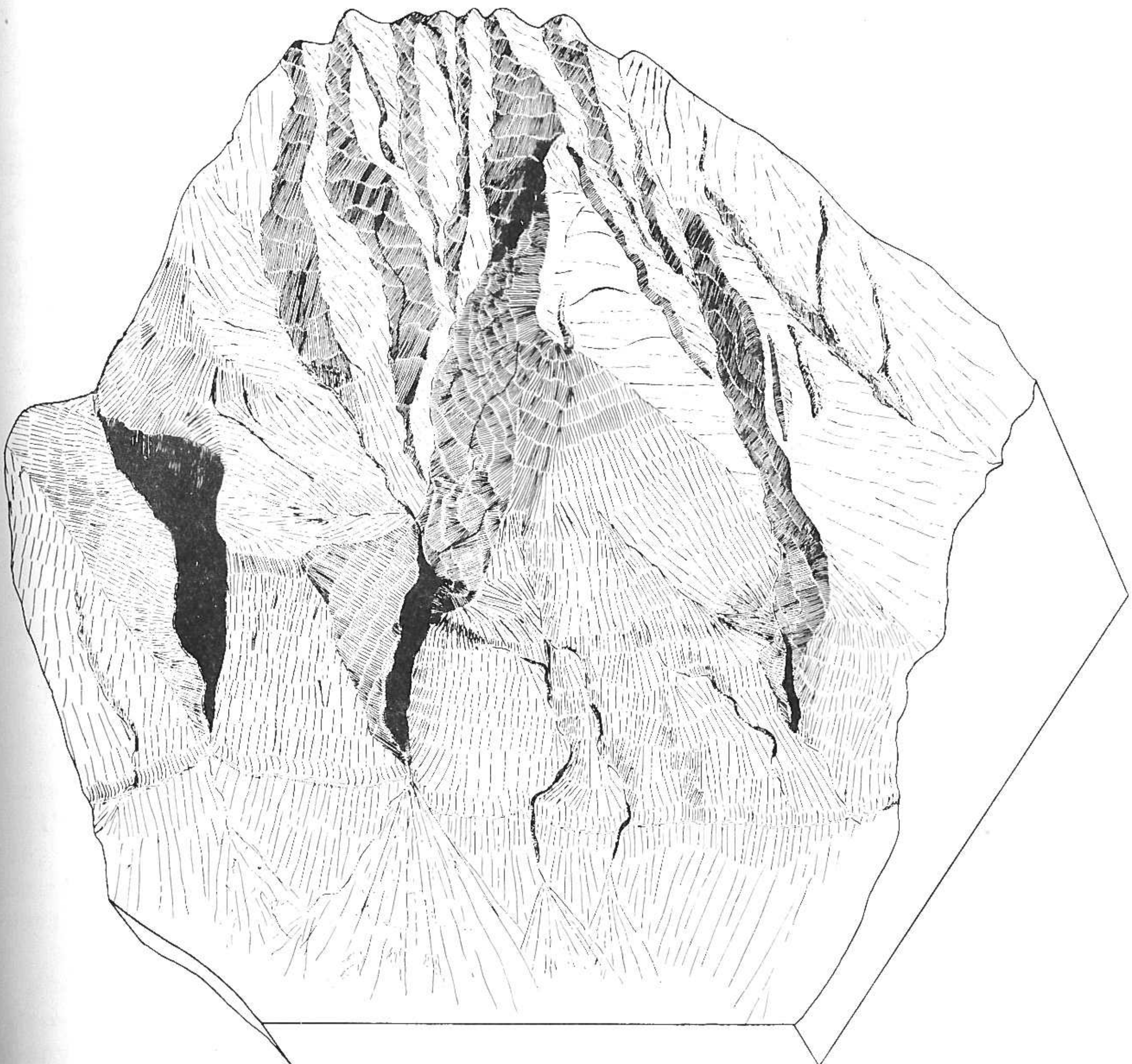
ABSTRACT

The Baldy area is situated on the west slope of Mount Timpanogos and includes approximately twelve square miles. On the north it joins the Lower American Fork-Mahogany Mountain area, mapped by R. F. Perkins; Utah Valley lies to the west, and Provo Canyon is two miles to the south.

The stratigraphic sequence in this area totals approximately 8,435 feet, and consists of parts of three marine Paleozoic formations. The Great Blue limestone and lower Manning Canyon shale are Mississippian, the upper Manning Canyon shale and Oquirrh formation being Pennsylvanian. Tertiary (?) and Quaternary fanglomerates and landslide debris, Pleistocene lacustrine deposits, and Recent alluvium lie upon or overlap older rocks.

Structurally the Baldy area is situated on an allochthon of the Deer Creek thrust plate, which moved eastward during the Early Laramide Orogeny. The folds and thrust faults in the mapped area are minor structures that formed on the eastward-moving plate. Post-thrusting normal faults along the western margin of the area have displaced strata thousands of feet. The lower escarpment along the Wasatch front has resulted from continued movements along these normal faults since Eocene time.

The area contains few materials of economic value. Water constitutes the most valuable resource in the area. Springs not only provide water for irrigation and culinary purposes in cities adjacent to the area, but also supply water power for a powerhouse. No mining is being carried on, nor is there promise of future development.



Physiographic Stereogram of Baldy Area,
West Slope of Mount Timpanogos,
Viewed from West
PLATE 2

INTRODUCTION

PURPOSE OF REPORT

Very little geologic work has been published concerning the western slope of Mount Timpanogos. Only three small-scale reconnaissance geologic maps of this area appear in published form. However, much interest has centered about Big and Little Baldy because of their physiographically and structurally anomalous positions. The idea of a landslide from the west face of Mount Timpanogos proper was held by some as a possibility to account for Big and Little Baldy, while the theory of thrusting from the west was held by others to account for this phenomenon. The present study was undertaken mainly in an effort to help solve the structural problems of the area.

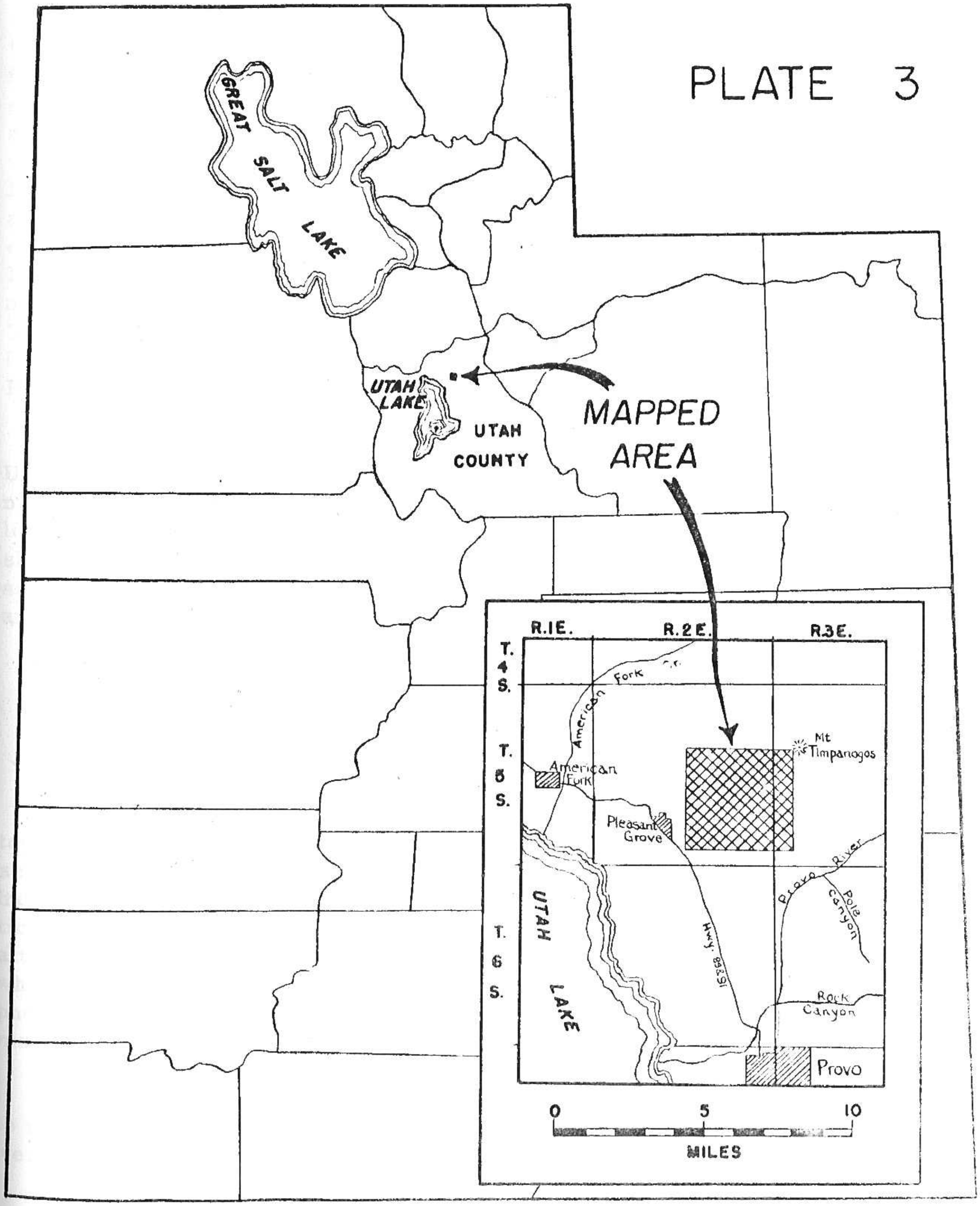
LOCATION AND ACCESSIBILITY

The Baldy area is located in north-central Utah County, Utah, upon and adjacent to the west slope of Mount Timpanogos (see Plates 2, 3, and Figure 1). Timpanogos is one of the prominent mountains in the south-central Wasatch Range and is situated at the boundary of the eastern limit of the Basin and Range Province and the western limit of the Middle Rocky Mountain Province at this locality.

The mapped area includes approximately 12 square miles and lies between parallels 40° 20' 50" and 40° 23' 50" North Latitude, and meridians 111° 38' 45" and 111° 46' 40" West Longitude. Sections 22, 23, 24, 25, 26, 27 and parts of sections 13, 14, 15, 34, 35, 36 of T. 5 S., R. 2 E., Salt Lake Base and Meridian, are included in the mapped area. A major part of the area lies within the Uinta National Forest.

Baldy area is bounded on the west by Utah Valley; on the north by Grove Creek; on the east by Mount Timpanogos; and on the south by Dry Canyon and Little Baldy.

Paved and graded roads east of Pleasant Grove and Lindon lead to the west base of the escarpment where a U. S. Forest Service road parallels the front, affording accessibility to the western margin of the area. The road to the Utah Power and Light Company Powerhouse at the mouth of Battle Creek offers the best means of access to the area.



Index Map showing the Baldy Area

PHYSICAL FEATURES

The terrane is mountainous, relief amounting to 6,320 feet with the western frontal escarpment one of the most pronounced topographic features of the area. This west escarpment is dissected by steeply V-shaped canyons and gullies, drainage being to the west. In some places the canyon walls are vertical. A northwest-southeast trending subsequent valley east of the frontal escarpment is a southern continuation of Sagebrush Flat. However, because of the massive protrusion of Big and Little Baldy above it, the valley is practically concealed in this area. A narrow ridge extends eastward from the summit of Big Baldy and abuts the west face of Mount Timpanogos. The north and south slopes of Big and Little Baldy are steep, with the topography becoming subdued near the valley level. The triangular west face of Big Baldy, along with the lower abrupt, wall-like escarpments, give bold relief to the area above Utah Valley (see Plate 2 and Figure 1).

Alluvial fans spread apron-wise from the frontal escarpment into Utah Valley. Evidence of the former existence of Lake Bonneville is recognized by its shoreline features and sediments. Vegetation is sparse on the lower part of the frontal Wasatch escarpment, but higher, scrub oak, low shrubs and numerous plants flourish. At still higher elevations aspens and pinon pines thrive. The residual soil in the subsequent valley is deep and supports a heavy growth of grass.

FIELD WORK AND LABORATORY STUDIES

Field work was begun in April 1954, and completed October 1954.

Most of the geologic mapping was done on U. S. Geological Survey topographic maps of the Orem and Timpanogos Cave quadrangles of a scale of 1:24,000 and a contour interval of 40 feet. Aerial photographs having a scale of 1:22,000 were also used for part of the area. Orientation on the topographic sheets was effected by resecting aided by an altimeter. Contacts between formations and traces of faults were walked wherever terrane and vegetation made it possible. The data on the aerial photographs and topographic sheets were transferred to a topographic map of scale 1:12,000. The final map was drafted from this base.

Vertical canyon walls and thick underbrush made it impractical to measure any sections with a tape. Thicknesses of outcropping formations were computed from scaled cross sections and the topographic sheets.

Fossils were collected where available. A study of thin sections of fusulinid limestones made possible the determination of series boundaries within the Oquirrh formation.

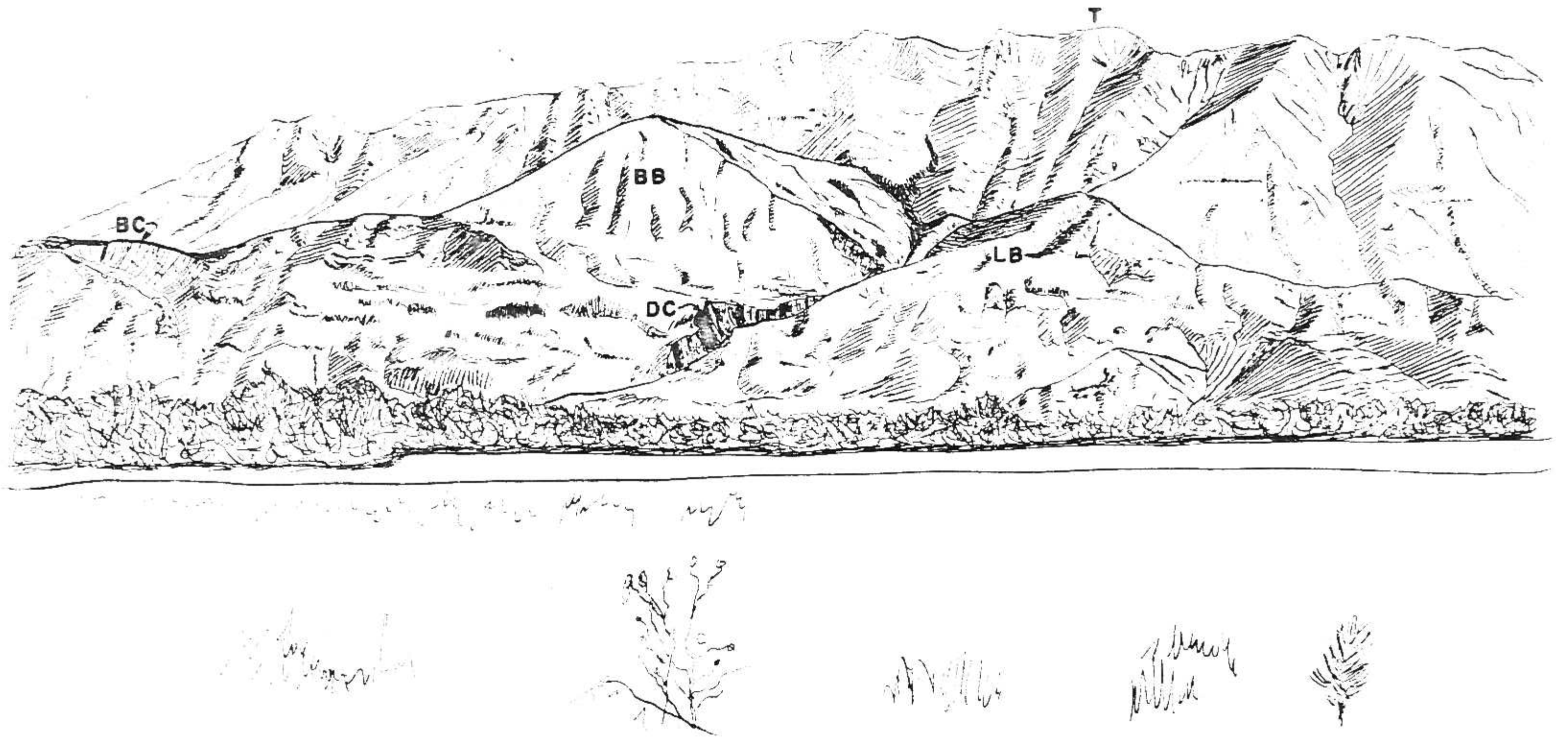


Figure 1 – Line drawing of the west slope of Mount Timpanogos showing the physiographically and structurally anomalous features

T - Mount Timpanogos, BB - Big Baldy, LB - Little Baldy, DC - Dry Canyon, BC - South rim of Battle Creek Canyon

Representative as well as unusual rock specimens were also collected in the field. Specimens from the Great Blue limestone were studied and collected in more detail than were the other formations. Insoluble residues and spectrographic analyses were made in the laboratory. Detailed analyses of a representative slab of laminated argillaceous limestone, collected from near the top of the Great Blue limestone, were made to determine the variation in grain size and mineral composition with alternating laminae (see Appendix).

PREVIOUS WORK

Little detailed geologic work has been done in the Baldy area. Included in King's Fortieth Parallel Report (1877) is a reconnaissance geologic map (Map III) of the Wasatch Mountains near Provo, Utah. Although part of the geology of that report has been found to be in error, it nonetheless comprises the first attempt at geologic mapping in the area. After a study of the ore deposits in Utah, Butler published in 1920 the first geologic map of Utah, including stratigraphic sections in the vicinity of Provo. Mr. Murray O. Hayes, head of the Brigham Young University Geology Department from 1922 to 1928, was very interested in Big and Little Baldy, and after walking over the area several times, postulated a landslide phenomenon to account for these physiographically and structurally anomalous features.* Arthur A. Baker, geologist with the United States Geological Survey, has mapped and studied portions of the area intermittently since 1937 and has concluded that the rocks comprising Big and Little Baldy are the result of overthrusting.** To date, only a preliminary stratigraphic chart of the south-central Wasatch Mountains has been published from Baker's report. In 1948, D. A. Andrews and C. B. Hunt compiled and published a geologic map of Eastern and Southern Utah. This map includes the Baldy area. The most recently published geologic map involving this area is that of Hunt (1953). However, this map, which includes only the western fringe of the area, is concerned mainly with Pleistocene geology.

*Personal Communication, August 21, 1954

**Personal Communication, August 26, 1954

GENERAL GEOLOGY

INTRODUCTION

The Baldy area on the west slope of Mount Timpanogos is composed of Carboniferous sedimentary rocks having an aggregate thickness of approximately 8, 435 feet (see Figure 2). Quaternary fluvial and lacustrine sediments slope westwardly into Utah Valley. Landslide debris is present between Big and Little Baldy.

Three Paleozoic formations are exposed, but none in full section. Mississippian rocks are 1, 600 feet thick and consist dominantly of calcilutites, shaly limestone, argillaceous limestone, and shale. Pennsylvanian rocks aggregate 6,835 feet in thickness and consist mainly of limestones, calcarenites, and orthoquartzites. The Pennsylvanian rocks of Big and Little Baldy lie discordantly above those of the Mississippian. Nomenclature applicable to the geologic formations follows that of Gilluly (1932), Baker (1947), and Baker, Huddle, and Kinney (1949).

The geologic structure of Baldy area is in many respects similar to that of adjacent areas in the south-central Wasatch Mountains. The folds and faults are superposed structures on a large overthrust plate that moved eastward during the Early Laramide Orogeny. These folds and thrust faults formed concomitantly with the overthrusting, while normal faulting, which began after the thrusting, has continued to Recent times.

SEDIMENTARY ROCKS

Mississippian System

Great Blue Limestone

Distribution. --The Great Blue limestone, which forms the frontal wall-like escarpment in the area, is exposed in cross section in the nearly vertical canyon walls of Grove Creek, Battle Creek, and Dry Canyon. It also occurs as down-faulted blocks along the front throughout the area. An abundance of talus on the slopes is characteristic of the formation.

Lithology and Depositional Environment. --The Great Blue limestone is a nearly homogeneous sequence of laminated to thin bedded, medium to light gray weathering, dark gray to black limestones. Several beds of dark brown to black shale appear to grade vertically and laterally into limestone.

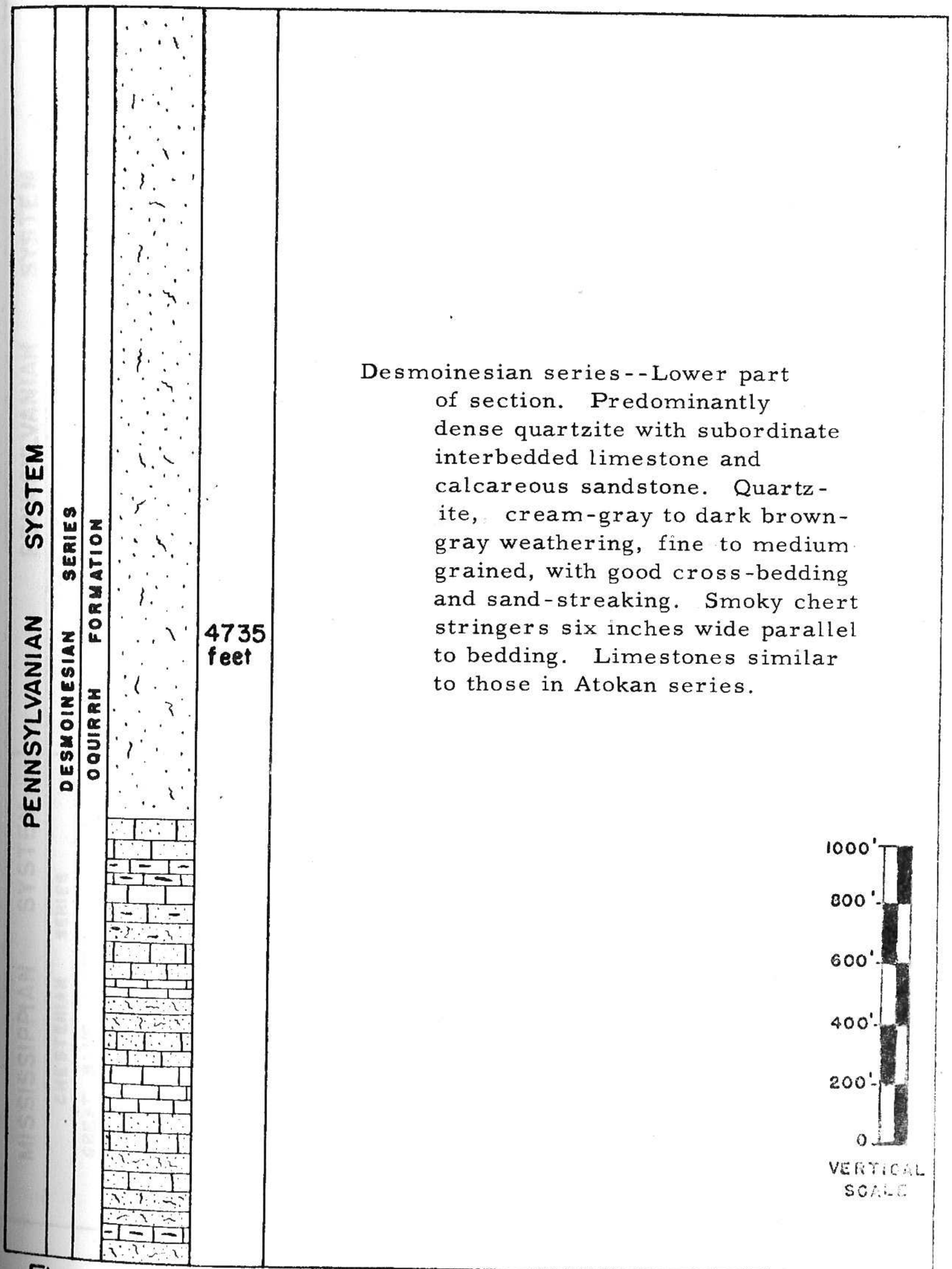


Figure 2 — Stratigraphic Column of the Exposed Rocks in the Baldy Area

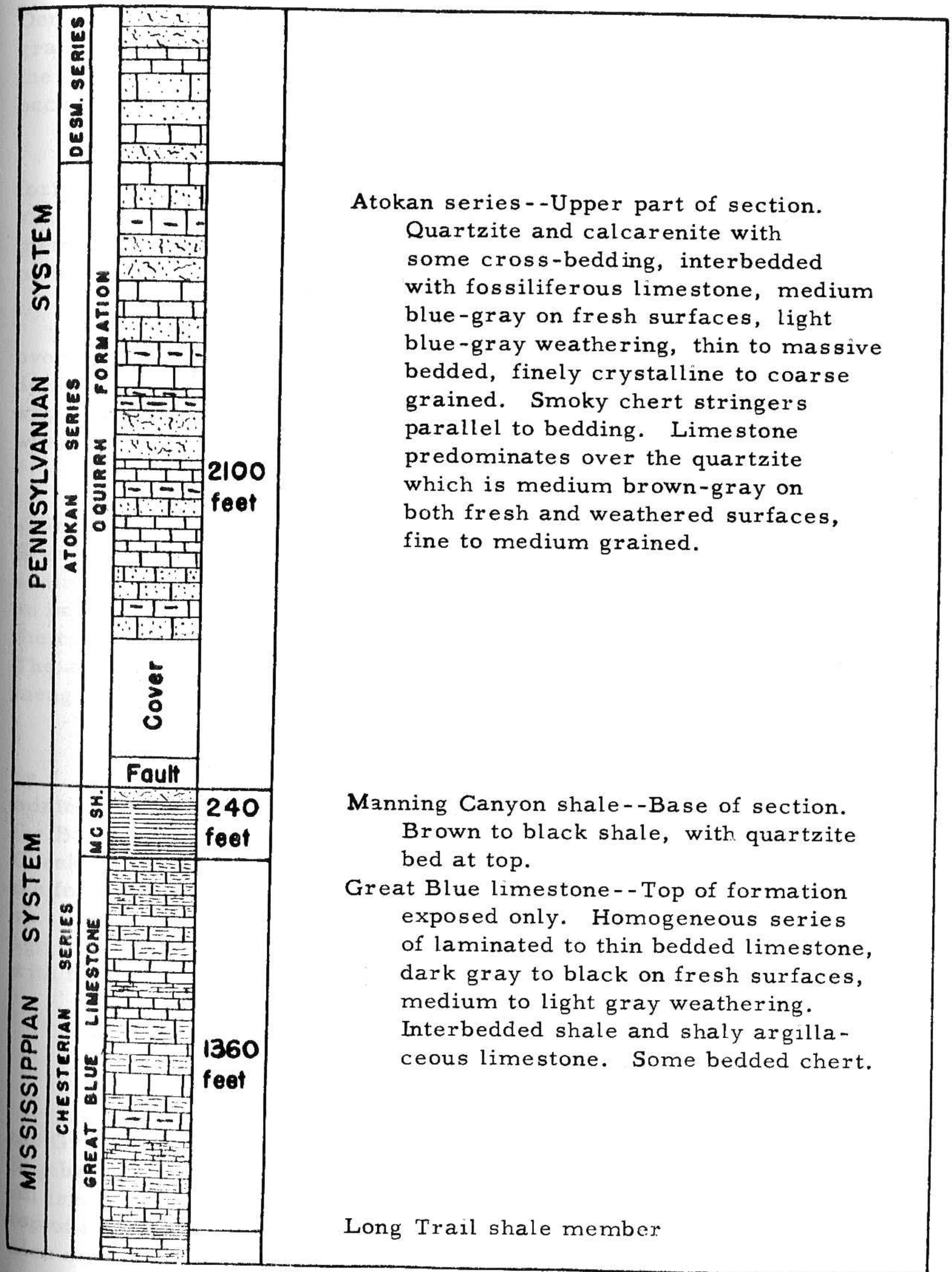


Figure 2 -- (continued)

Dense, sublithographic argillaceous limestones are common. Some dark gray to black chert parallels the bedding; however, chert is negligible in the formation. Authigenic pyrite cubes, up to an eighth of an inch square, occur near the top of the Great Blue limestone in the argillaceous beds.

Approximately 1,300 feet stratigraphically below the top of the formation is a shale unit nearly fifty feet thick. This dark carbonaceous shale, which weathers reddish-brown, is considered to be the Long Trail member of the Great Blue. Some of the strata are slaty due to dynamic metamorphism attending diastrophism.

In places the top of the Great Blue seems to be gradational with the overlying Manning Canyon shale, while in other places the contact is well defined. Laminated, black argillaceous limestones of the Great Blue give way to silicilutites and shale of the Manning Canyon. The contact was mapped where the limestones give way to predominantly shale above.

Laminated limestones and shales attest to a shallow water, near shore, possibly even littoral, environment during deposition of the Great Blue limestone. The thick sequence of calcareous and siliceous-argillaceous sediments testifies to rather stable conditions in the source area as well as on the shelf of the miogeosyncline on which they were deposited. However, the carbonaceous clastics are indicative of paralic paludal sedimentation. The alternation of marine and paludal conditions probably accounts for the meager fossil remains in the Great Blue.

Correlation and thickness. --The Great Blue limestone was named by J. E. Spurr (1895, p. 375) from exposures of the formation in the Mercur mining district. Only the upper 1,360 feet of the Great Blue is exposed in the Baldy area (measured in Battle Creek). One limestone bed in Battle Creek, approximately 160 feet above the Long Trail shale member, yielded the following fossils: Pentremites sp., Chonetes chesterensis?, Fenestrellina sp., and Cleiothyridina sublamellosa? These fossils indicate a Chesterian age for the Great Blue. The Great Blue of the Baldy area is correlated with the Great Blue formation at its type area.

Manning Canyon Shale

Distribution. --The Manning Canyon shale conformably overlies the Great Blue limestone in the Baldy area and is a slope-former. It forms Sagebrush Flat to the north and Pole Canyon to the south of the mapped area. An irregular band of the shale extends from Grove Creek to Dry Canyon on top of the escarpment formed by the Great Blue (Plate 1). The formation also occurs as float on downfaulted blocks on the west slopes of the escarpment. Referring to the Manning Canyon shale outcrops, Hunt (1953, p. 53) notes:

They are commonly covered by several feet of overburden, because they erode and weather rapidly. A line of seeps and springs occurs where the shale is overlain by pervious rocks. Where water penetrates the shale along fault or bedding planes, or permeates the weathered overburden, the material becomes very unstable and steep natural or artificial slopes are liable to landslides and mudflows.

Lithology and Depositional Environment.--Exposures of the Manning Canyon shale are rare in the area. Where exposed, the shale consists of brown to black shale with some interbedded thin bedded limestone. One-quarter inch to four inch concretions, containing pyrite cubes, are numerous. Outcrops of the shale have a characteristic residuum of dark soil. The topmost exposed part of the formation in this area consists of a rusty-weathering, medium grained, cross-bedded orthoquartzite. The shale is distorted, having acted as the lubricant over which the allochthonous Oquirrh rocks have been faulted.

The writer visualizes a mixed continental and marine environment during Manning Canyon deposition. The carbonaceous shale gives evidence of possibly littoral and/or paralic swamp conditions. However, transgressive-regressive marine action allowed the deposition of sequences of shale, limestones, and quartzites. The occurrence of pyrite near the top of the Great Blue limestone and throughout the Manning Canyon shale indicates a gradational change between Great Blue and Manning Canyon deposition.

Correlation and thickness.--The Manning Canyon shale was named by Gilluly (1932, p. 31) from outcrops of the formation in Manning and Ophir Canyons, Ophir mining district, Utah. A maximum thickness of only 240 feet of the formation is exposed in the Baldy area because an overthrust block of the Oquirrh on the Manning Canyon shale has cut out most of it (see Plate 1). This section was measured 2,000 feet south of Battle Creek in Section 23, T. 5 S., R. 2 E. In some places the shale is squeezed or practically covered so that only a small portion of it is exposed. Baker (1947) reports a thickness of 1,645 feet for the Manning Canyon four miles to the southeast in Pole Canyon, a tributary to Provo Canyon.

According to Girty (Gilluly 1932, p. 7), there are two persistent quartzite beds in the Manning Canyon shale in the type area. The upper quartzite bed marks the approximate Mississippian-Pennsylvanian systemic boundary. Above it, the shale is Pennsylvanian, and below it is Mississippian. On the basis of Gilluly's report the writer has designated, in this report, the exposed 240 feet of Manning Canyon shale as Chesterian.

Because of the contorted nature of the formation, only the following fossils were found and identified by the writer: *Dictyoclostus* sp., *Nuculana* cf. *N. montpelierensis*, and *Myalina* sp.

Pennsylvanian System

Oquirrh Formation

Distribution. --The Oquirrh formation is exposed in Mount Timpanogos as well as in Big and Little Baldy. Since this report deals especially with the area contiguous to the west face of Mount Timpanogos, the Oquirrh formation in Mount Timpanogos will not be described in this report.

The Oquirrh formation overlies the Manning Canyon shale in the mapped area as a result of overthrusting. Good bedding of the Oquirrh formation is exposed in Big and Little Baldy, but to the north and south the formation is seen only as erosional debris and slope-wash from the overthrust block. Such debris extends north to Grove Creek and south beyond the limit of the area. Along the west front, float from the Oquirrh covers much of the area.

Lithology and Depositional Environment. --Atokan and Desmoinesian Oquirrh rocks are exposed in the mapped area. The Atokan consists of fossiliferous limestones and calcarenites with interbedded quartzites. The limestones are medium blue-gray on fresh surfaces, light blue-gray on weathered surfaces, thin to massively bedded, finely to coarsely crystalline. Chert is present in many of the beds. Interbedded fine to medium grained quartzites are medium brown-gray on both fresh and weathered surfaces. Limestone predominates in this portion of the stratigraphic section.

The Desmoinesian rocks differ from those of the Atokan in that the former are composed predominantly of dense quartzites with subordinate interbedded limestones and calcarenites while the latter consist mainly of limestones with minor quartzites. The quartzites are cream-gray to dark brown on fresh surfaces and light brown-gray on weathered surfaces. Some of this fine to medium grained, fine to coarse crystalline quartzite has excellent cross-bedded sand streaking exhibited, and smoky chert stringers up to six inches wide parallel to the bedding. The limestones are similar to those in the Atokan series. The upper 2,700 feet of the exposed Desmoinesian rocks are entirely quartzitic.

Many of the quartzites and limestones in both the Atokan and Desmoinesian series were badly brecciated during tectonic activity. However, the quartzites are much more broken because of their greater brittleness.

Accelerated subsidence of the miogeosyncline and shelf areas allowed essentially uninterrupted sedimentation throughout Pennsylvanian time. Interbedded orthoquartzites and limestones form a thick assemblage in the Atokan and Desmoinesian series. These sediments suggest a nearby source area, not necessarily mountainous (maybe in process of peneplanation), rich in arenaceous material and near shore marine currents strong enough to spread them rather uniformly over the area of deposition. The abundance of limestones in the Atokan as compared to those in the Desmoinesian series suggests that the shelf area of deposition was probably more unstable during Atokan than during Desmoinesian time.

Correlation and Thickness. --The Oquirrh formation was named by Gilluly (1932, p. 34) from exposures of a thick section of alternating limestones and sandstones or quartzites in the Oquirrh Mountains. The top of the formation is not present in the Oquirrh Mountains and from studies in other areas, it is now known that the upper part of the formation where exposed in full thickness, for example, in the south-central and southern Wasatch Mountains, is Permian (Thompson, Verville, and Bissell, 1950, p. 430; Bissell, 1952). The most important guide fossils for subdividing the Oquirrh formation into series have been found to be the fusulinids (Bissell, 1939, p. 87).

Two series of the Oquirrh formation, aggregating approximately 6,835 feet, are exposed in the mapped area. The upper 2,100 feet of the Atokan series are overlain by the lower 4,735 feet of the Desmoinesian series in Big Baldy. The Atokan-Desmoinesian boundary, approximately at elevation 7,040 on the southwest spur of Big Baldy, was chosen on the basis of lithology and the first appearance of the fusuline genus *Fusulina s. s.*

Four collections of fusulinids were made from the Oquirrh formation in Big and Little Baldy. The Atokan collections were made 500 and 1,300 feet stratigraphically above the base of the exposed Oquirrh, and the Desmoinesian fusulinid collections were made 1,230 and 1,930 feet stratigraphically above the Atokan-Desmoinesian contact. Thin sections of these fusulinids reveal the genus *Fusulinella* and *Fusulina s. s.* According to Thompson (1948, p. 22), *Fusulinella* ranges from Middle Atokan to upper Desmoinesian.

Bissell (1951, p. 585) records 3,000 to 3,200 feet of Atokan rocks in the Northeast Strawberry quadrangle approximately thirty-two miles southeast of the mapped area. The writer measured 758 feet of similarly dated rocks in the Central Thorpe Hills area, twenty-eight miles southwest of the mapped area. C. R. McFarland, in the Oquirrh Mountains, twenty-eight miles west of the area, measured 1,576 feet of these rocks.*

*Personal Communication, January 1955

In the Northeast Strawberry quadrangle, Bissell (1952, p. 585) reports 3,500 to 10,500 feet of Desmoinesian rocks, while the writer measured 1,307 feet in the Central Thorpe Hills (both complete sections), and McFarland (1955) measured 1,196 feet in the Oquirrh Mountains. In the latter section McFarland did not determine the Desmoinesian-Missourian boundary.

Quaternary System

Four Quaternary rock units are differentiated on the geologic map included with this report. These include Pleistocene pre-Lake Bonneville fanglomerates, Lake Bonneville lacustrine deposits, Recent alluvium (including slope-wash), and landslide material. The fanglomerates are the oldest deposits, as the lacustrine and alluvial deposits overlie them. Other than the landslide material, the Quaternary sediments slope gently westward into Utah Valley.

Fanglomerates

The fanglomerates are exposed in the piedmont west of the escarpment. These deposits locally are deeply weathered and soil covered, especially above the level of the Bonneville formation. Hunt reports a maximum thickness of about 500 feet for the fanglomerates fringing Northern Utah Valley (1953, p. 14), and summarizes the composition of the fanglomerates as:

> ...being composed of poorly sorted materials, angular boulders, cobbles, and gravel in a sand and silt matrix; but the fans differ from one another in kinds of gravel they contain, depending on the source rocks in the immediately adjoining mountains. The fan materials are in large part poorly consolidated...

In many places the fans are well preserved, but in some instances these deposits have been faulted, and the upfaulted segments are being eroded. Hunt (1953, p. 43) has noted extensive paleosols on the top of some of the fanglomerates. Small unmapped remnants of an ancient fan occur on the north side of Big Baldy adjacent to Mount Timpanogos. All of these fanglomerates are of pre-Lake Bonneville Pleistocene age.

Lake Bonneville Group

Utah Valley was a bay along the eastern side of Lake Bonneville, the last of the Pleistocene lakes to flood the valley. The Lake Bonneville group was named by Gilbert (1890). Hunt (1953) mapped three formations within this group that approximately correspond to what Gilbert referred to as the Intermediate, Bonneville and Provo stages of Lake Bonneville. These three formations are the Alpine, Bonneville and Provo in ascending stratigraphic order. They were not mapped separately by the writer for the present report. According to Hunt, the Alpine formation has gravel, sand, and silt and clay members; the Bonneville formation has a gravel member; and the Provo formation has gravel, sand, and silt and clay members. In each formation, the gravel is the oldest member.

The Alpine formation, the oldest of the three, is overlain by the younger Bonneville formation. The Provo formation is the youngest and was deposited during the last stage of Lake Bonneville. The Bonneville group is Pleistocene in age, largely Wisconsin.

Alluvium

Alluvium in the Baldy area consists of fluvial gravel, sand, silt, and clay. These deposits are characterized by poor sorting and indistinct bedding and overlie the fanglomerates and lacustrine deposits.

Landslide Material

The writer considers the heterogeneous accumulation of coarse talus blocks between Big and Little Baldy to be landslide material which moved valleyward from the west face of Mount Timpanogos. The included debris consists of quartzites, limestones and shale. A hummocky topography characterizes the surface of the slide material.

Evidence was not obtained that dates the landslide. However, it is certain that the slide occurred later than the Baldy thrust, probably late Tertiary or Quaternary. Erosion has since dissected the material, so that its eastern limit now coincides with the eastern limit of the thrust.

STRUCTURE

GENERAL FEATURES

The major structural features of the area are folds and faults. These structures are superposed on the Deer Creek thrust plate that moved eastward during the Early Laramide Orogeny. The Provo Canyon Syncline, the east-west axis of which approximately parallels Provo Canyon, formed prior to the Laramide overthrusting. After the overthrusting, north-south folds were superposed on the former east-west folds in the Wasatch Mountains. As a result of this series of deformations, the Baldy area is located on the northern limb of the Provo Canyon Syncline. The north-south folding is expressed in the area as the broad northwest-southeast trending Grove Creek Anticline which is associated with break thrusting. However, the adjoining syncline east of this anticline is not recognizable in the area because of an overthrust Oquirrh block which covers it. Normal faulting along the western margin of the area along the Wasatch fault zone has continued from Eocene to Recent times.

Folds

Grove Creek Anticline

The Grove Creek Anticline trends northwest-southeast essentially parallel to the western front of the Wasatch Mountains and is the most pronounced fold in the area (see Plate 1). The structure plunges approximately 15° southeastward toward the axis of the Provo Canyon Syncline, and is well exposed in Grove Creek, Battle Creek and Dry Canyon. The fold is asymetrical with the eastern limb the steeper. The structural attitude of the west flank of the fold may be a pre-normal faulting feature or it may have been formed by drag associated with the normal faulting. The eastern limb of the anticline has been faulted placing Great Blue limestone over Manning Canyon shale in the northern half of the area (see Plates 1 and 4).

Thrust Faults

The mapped area is part of the large Deer Creek thrust plate. The trace of the northern margin of this major thrust extends approximately twenty miles eastward from Alpine Canyon to Charleston in Heber Valley and has been postulated to connect with the Nebo thrust southward (Eardley 1934, p. 384). Regarding this allochthon, Bissell (1951, p. 622) reports:

> Its eastern edge was thrust, similar in mechanics to an overriding frontal lobe of a glacier, ramp fashion over and against strata of the southwestern part of the Uinta Mountains. This eastward-moving plate produced folds above, below, and in front of the allochthon.

The folds and thrusts in the mapped area are interpreted as minor structures which developed on the eastward moving allochthon.

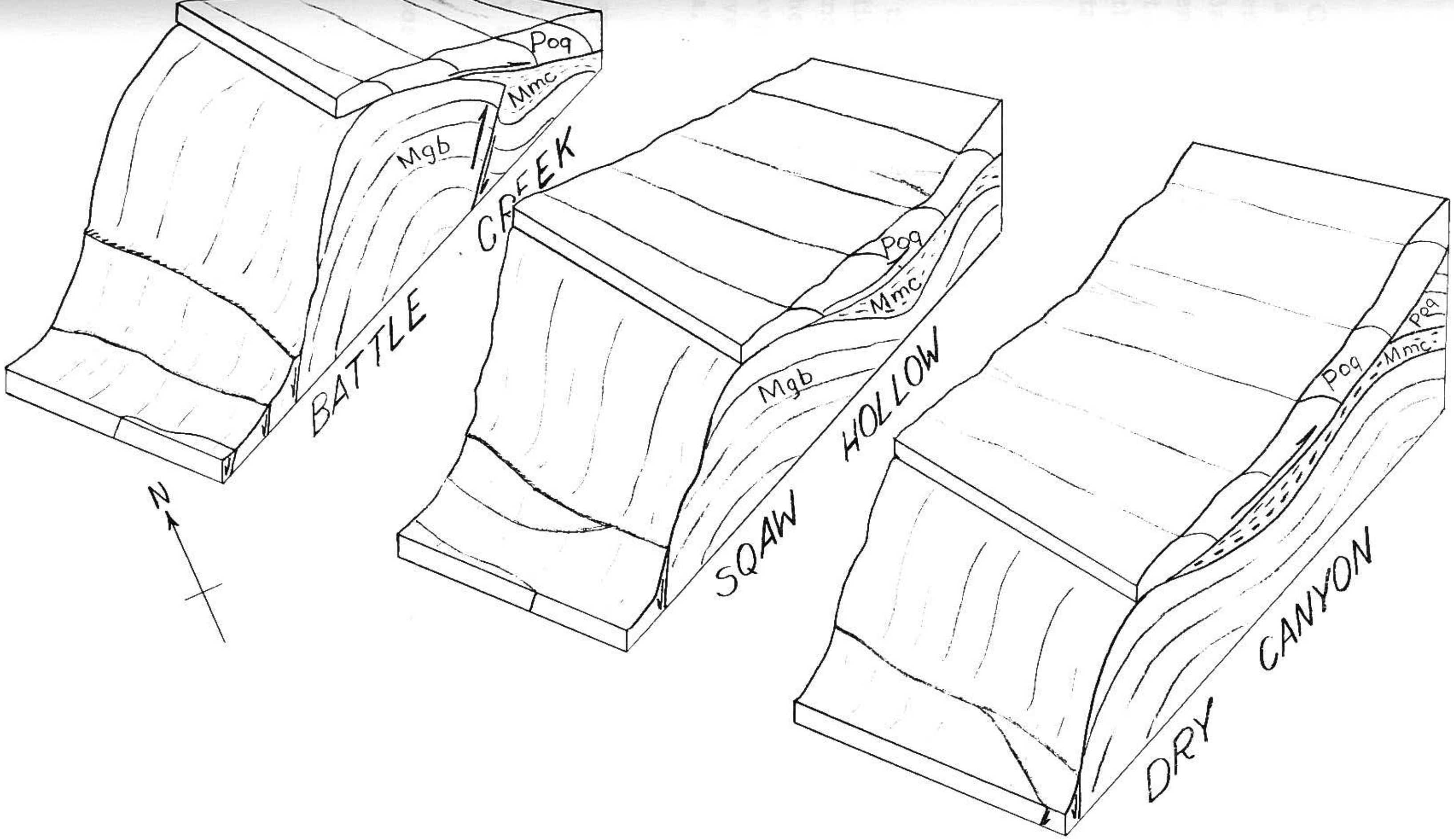


PLATE 4 STRUCTURAL BLOCK DIAGRAMS OF
BALDY AREA

Mahogany Mountain Fault

North of Grove Creek along the east flank of Mahogany Mountain the Great Blue limestone is thrust over the younger Manning Canyon shale. This thrust, which is called the Mahogany Mountain fault by Perkins (1955), extends into the area mapped by the writer and is exposed 3,000 feet north of Battle Creek in section 14. It is not known how far south this thrust extends but lack of evidence for it in Dry Canyon leads the writer to interpret it as a break thrust that dies out in the Great Blue limestone between Battle Creek and Dry Canyon. The overlying Oquirrh obscures the actual contact (see Plates 1 and 4).

Baldy Overthrust

A block of the Oquirrh formation overlies the Manning Canyon shale and the Great Blue limestone in fault contact in the mapped area. Faunal studies indicate parts of the Atokan and Desmoinesian series of this formation to be present in the allochthonous block. The general strike of the exposed Oquirrh rocks in Big and Little Baldy is N.45° W. with an average dip of 40° NE. Slope-wash from the Oquirrh extends from Grove Creek on the north beyond the southern boundary of the mapped area.

The Oquirrh formation composing Mount Timpanogos is in juxtaposition with similarly striking Oquirrh rocks of Big and Little Baldy. This has suggested to many the possibility of a gravity fault from the west face of Mount Timpanogos to account for the physiographically and structurally anomalous features of Big and Little Baldy.

Additional information that seems to support the gravity fault supposition are:

1. Approximately the upper half of Mount Timpanogos is known to be composed of the Atokan and Desmoinesian rocks of the Oquirrh formation from which the hanging wall could have moved.

2. The lithology of the Atokan and Desmoinesian rocks on Mount Timpanogos is nearly identical with that in Big and Little Baldy.

3. The surficial dips of the beds in Big and Little Baldy, in relation to those in Mount Timpanogos, are suggestive of gravitative faulting.

Although these points seem convincing for such mechanics of faulting, it is structurally incompatible that the rocks in Big and Little Baldy were once a western extension of the west face of Mount Timpanogos. Morrowan rocks of the Oquirrh formation occur in Mount Timpanogos approximately 200 feet below the high east-west ridge on the top of Big Baldy. However, these rocks do not occur in the Baldy structure. Morrowan rocks should appear in the down-dropped block if a gravity fault moved it downward.

Following are evidences that confirm an overthrust theory for Big and Little Baldy:

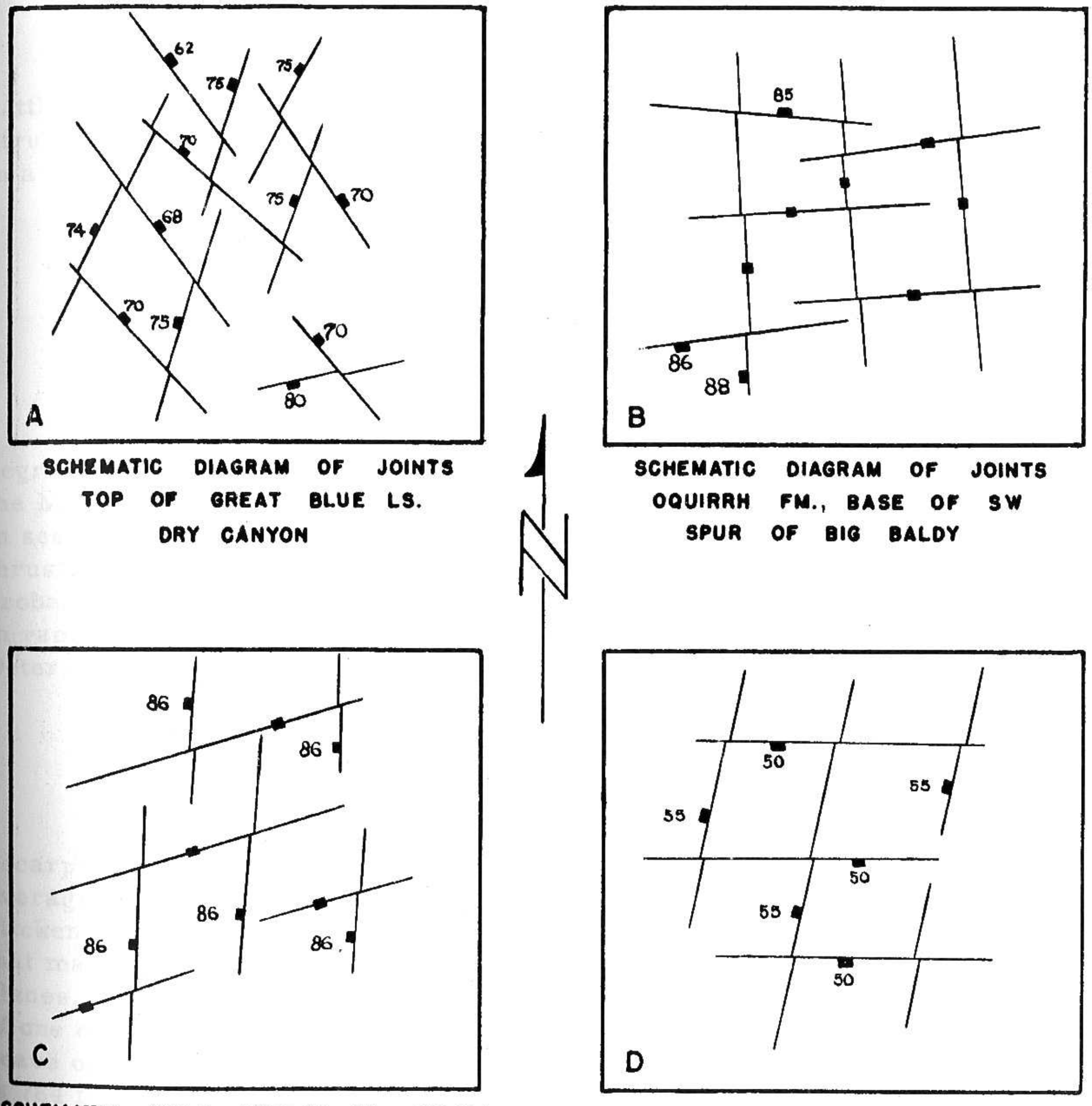
1. Oquirrh rocks are not present in Sagebrush Flat north of Grove Creek.

2. Some of the quartzite beds in the NW 1/4 of section 24, T. 5 S., R. 2 E. are overturned and dip to the west indicating compressional forces from the west (see cross-section, Plate 1).

3. Joints of the Oquirrh formation in Big Baldy form additional though inconclusive evidence as to the direction of stress. The joint systems in both the Great Blue limestone and the Oquirrh formation coincide generally and reveal a west to east stress. Figure 3 has been prepared to show the joint relationships in the Baldy area. The set of joints in A are interpreted as shear joints that developed due to compressive force acting in an east-west direction. In B, C, and D, the north-south joints are essentially parallel to the axis of the major fold of the overriding Oquirrh block composing Big and Little Baldy. These joints, formed perpendicular to the axis of compression, are release joints which formed due to tension on the convex side of the bent strata. The east-west joints are perpendicular to the axis of the fold. They are probably extension joints which resulted from slight elongation parallel to the axis of the fold.

4. A wide zone of brecciation and slickensides in the NW 1/4 of section 36, T. 5 S., R. 2 E. is evidence of thrusting and crumpling of underlying beds. Some Oquirrh calcarenite fragments are ground into the underlying shale and limestone.

5. Local thrusting is not uncommon in the south-central Wasatch Mountains. Gaines (1950, p. 55) reports a klippe of the Oquirrh formation approximately one and one-half miles south of the mouth of Provo Canyon. This klippe rests upon distorted Manning Canyon shale, and was moved



SCHEMATIC DIAGRAM OF JOINTS
TOP OF GREAT BLUE LS.
DRY CANYON

SCHEMATIC DIAGRAM OF JOINTS
OQUIRRH FM., BASE OF SW
SPUR OF BIG BALDY

SCHEMATIC FIELD SKETCH OF JOINTS
UPPER GREAT BLUE LS.
BATTLE CREEK

SCHEMATIC DIAGRAM OF JOINTS
OQUIRRH FM., TOP OF SW
SPUR OF BIG BALDY

Figure 3 — Schematic Diagrams and Field Sketch of Joints in the Baldy Area

> in from the west. Projections of the trace of the Baldy overthrust to the south would extend it to the general direction of Gaines' map.

The writer considers the Oquirrh formation composing Big and Little Baldy, as well as the slope-wash cover north and south of these structures, to be a thrust block which is now preserved as a remnant in a shallow transverse syncline. The remnant, according to Baker*

> ...extends from north of Grove Creek south a short distance beyond Provo River. It rests generally on Manning Canyon shale and in many places follows closely the Manning Canyon-Great Blue contact. The fault is generally flat as is the habit of the thrust faults in the area...

The sole of the Baldy overthrust can be determined with some degree of accuracy in Battle Creek. The overthrust block rode over the Manning Canyon shale, a reentrant of which extends up Battle Creek in sections 23 and 24 T. 5 S., R. 2 E. (see Plate 1). The sole of the thrust in this area dips approximately 10° W. However, the thrust probably approaches the immediate west base of Mount Timpanogos in ramp fashion and the dip of the fault surface increases considerably. Determination of the net slip could not be made in the mapped area.

Normal Faults

A series of normal faults along the western edge of the frontal escarpment are minor faults along the major Wasatch fault system. The average strike of these faults is N.40° W. and the dip is 40° SW. Excellent slickensides on the western exposures of the Great Blue limestone indicate that many of the surfaces along the lower escarpment are the actual fault planes. One prospect pit at the mouth of Dry Canyon exposes the footwall of one of the faults and the dip of the fault plane there is 41° SW. The heave on the easternmost normal fault in section 22, T. 5 S., R. 2 E. is 784 feet, while the throw is approximately 940 feet. The footwall on these faults has been much more active than the hanging wall. It is very possible that the term "normal upthrusts" used by Willis (1936, pp. 33, 107, 161, 171), is applicable to movement along these faults. This term suggests that the valley was left as a result of the mountain having been pushed up.

It is evident that there is no single Wasatch fault. Rather, there is a wide zone in which the greatest displacements seem to be in that part of the zone bordering the mountain front.

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*Personal communication, August 26, 1954

DATES OF TECTONICS

Many unsolved problems exist regarding the relationship of diastrophic events which occurred during the Laramide Orogeny in Central Utah. The writer was unable to date the faulting and folding in the mapped area accurately from field evidence. However, many geologists (including Bissell 1953; Eardley 1934, 1949, 1951; Marsell 1953; Spieker 1946) have discussed the orogeny in Central Utah, and the sequence of events listed below is based in large part on their works.

The Laramide orogeny followed closely on the waning stages of the mid-Cretaceous Cedar Hills Orogeny, which was responsible for north-south trending folds.

Three phases of the Laramide orogeny affected the Wasatch area of Utah. The orogenic chronology of the area is probably as follows:

1. Early Phase--Montana time

   (a) Stage 1--The Cottonwood uplift (north of American Fork Canyon) and the Northern Utah uplift (near Ogden) were epeirogenically raised, the area between the two uplifts being warped into east-west trending folds. These folds probably affected the Baldy area prior to thrusting. The east-west-trending Provo Canyon Syncline formed during this stage of compression.

   (b) Stage 2--Thrusting from the west characterized this stage of the early phase. Continued compression from the west resulted in the tightening, breaking and thrusting of the earlier north-south folds produced from the effects of the Cedar Hills Orogeny. A large overthrust, which placed a thick Paleozoic miogeosynclinal assemblage onto a thin shelf assemblage in the central and southern Wasatch Mountains, is known as the Deer Creek overthrust in the vicinity of Provo and as the Nebo overthrust farther south. The Grove Creek Anticline, the associated Mahogany Mountain break thrust and the Baldy overthrust probably occurred penecontemporaneously with the greater Deer Creek overthrust.

2. Middle Phase--Paleocene

   The Wasatch conglomerates spread eastward after the main eastward overthrusting. Angular unconformities within the Wasatch formation represent local disturbances during Paleocene time.

3. Late Phase--Eocene

In middle or late Eocene time, broad north-south folds were superposed on the older east-west folds and thrusts, resulting in cluminations and depressions. The main Uinta uplift also occurred in late Eocene time. Eardley (1951, p. 331) is of the opinion that the north-south folds of the frontal Wasatch resulted from Eocene folding, and that soon after this folding, normal faulting approximately parallel to these folds gave the present topographic expression to the area. Movement on these normal faults continued into Oligocene time and there is evidence that the movement has continued to Recent times. Concerning Recent movement on these faults, Hunt (1953, p. 38) states:

> The Lake Bonneville group is faulted too. At the mouth of American Fork Canyon the Bonneville formation is displaced about 60 feet. About one-half mile up Provo Canyon other gravel deposits of the Lake Bonneville group also are displaced a few tens of feet.

SEQUENCE OF GEOLOGIC EVENTS

The south-central Wasatch Mountains were an area of continued subsidence in an eastern miogeosyncline of the Cordilleran seaway during most of the Paleozoic era. During Upper Mississippian time the sites of the shelf and geosynclinal sedimentation were along the present sites of the Oquirrh and Wasatch Mountains (Bissell, 1952, p. 625). The lower-most Paleozoic sediments in the mapped area are represented by the upper part of the Great Blue limestone and the lower part of the Manning Canyon shale which were deposited during the Chesterian stage of the Mississippian period.

The Pennsylvanian Oquirrh basin in central and west-central Utah received clastics which were eroded from the adjacent positive areas, and were deposited in the geosyncline and associated shelf areas. The assemblage of quartzites, limestones and calcarenites during the Pennsylvanian period is known as the Oquirrh formation.

During the mid-Cretaceous Cedar Hills Orogeny, sediments of the Mississippian and Oquirrh basins were probably thrown into north-south trending folds. These folds were tightened and broken as a result of continued compression. Late in Cretaceous time, during the second phase of the Laramide Orogeny, a large thrust plate, known as the Deer Creek-Strawberry Valley overthrust, moved eastward. The folds and faults in the mapped area are minor structures superposed on this large overthrust sheet. Break thrusting in the Great Blue limestone probably occurred concomitantly with the main overthrusting, and soon thereafter the Baldy overthrust placed the Oquirrh formation over the Manning Canyon shale and upward against the west face of Mount Timpanogos. Fanglomerates and slope-wash debris formed as erosion dissected the allochthonous block. Eardley (1933, p. 243) notes that a submature to mature surface existed in the vicinity of the Wasatch Mountains prior to the normal faulting. This surface evidently had a relief of at least 3,000 feet. It is possible that the high east-west ridge on the top of Big Baldy is a remnant of this ancient topography.

During the Eocene-Oligocene epoch of normal faulting or "normal upthrusting," the Oquirrh formation, Manning Canyon shale, Great Blue limestone, and the fanglomerates were displaced thousands of feet. Movements along the Wasatch fault system continued well into Quaternary time.

The landslide debris between Big and Little Baldy has accumulated since the normal faulting. Erosion has since dissected the material so that its eastern limit now coincides with the eastern limit of the Baldy overthrust.

In Pleistocene time Lake Bonneville shored on the lower slopes of the west escarpment and sediments from this ancient lake overlap the downfaulted fanglomerates. Since the disappearance of Lake Bonneville from Utah Valley, alluvial deposits have accumulated in various places.

ECONOMIC POSSIBILITIES

Water constitutes the most valuable resource in the area. Along the western margin of the area are the Salt Lake Aqueduct, North Union Canal and the Murdock Canal, which are fed from the Deer Creek Reservoir at the head of Provo Canyon. The Salt Lake Aqueduct supplies culinary water to Salt Lake City, the North Union Canal furnishes irrigation water to Pleasant Grove and Lindon, while the Murdock Canal provides irrigation water from Lindon to Salt Lake City. Lindon obtains its culinary water from a well drilled just beyond the southwest corner of the mapped area. Pleasant Grove obtains its culinary water from springs that flow into Battle Creek. One large spring at the northern base of Big Baldy feeds into a pipe line and penstock. It is the source of water power for the Utah Power and Light Company Powerhouse at the mouth of Battle Creek. The water that leaves the powerhouse is used for irrigation purposes in Pleasant Grove.

Although economically workable deposits of clay within the Lake Bonneville group and the Manning Canyon shale have been developed north and south of the area, there has been no such development in the area under study. Alluvial deposits obscure evidence of any economically workable deposit within the lacustrine sediments if such exists. It is improbable that the Manning Canyon shale will be further exploited for its fire clay in the future. The "Old Black Dolly" tunnel is the only tunnel of consequence in the mapped area. It is located in downfaulted Manning Canyon shale east of Lindon in the SE 1/4 section 27, T. 5 S., R. 2 E. Some of the clay in the shale was used as fire clay in the Murray smelter about 1915, but because of an overabundance of silica in the clay, it was later rejected for use in the smelter. The mine was subsequently abandoned after approximately 1700 feet of tunnel had been completed.*

The quartzite in the Oquirrh formation would form sound aggregate material if crushed. However, this source probably will not be used because of more accessible supplies of clean rounded gravels in Utah Valley. The Great Blue limestone, because of its argillaceous nature, is worthless as aggregate, surfacing material, or flux.

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*Personal communication, Ed Lewis, January 1955

APPENDIX

SPECTROGRAPHIC ANALYSIS

Nine rock samples were analyzed using qualitative methods of spectrographic analysis. These samples were obtained from alternating light and dark laminae in a two foot argillaceous limestone bed near the top of the Great Blue in Dry Canyon, NW 1/4 of section 36, T. 5 S., R. 2 E. The laminae are all composed of silt size material; however, the light laminae are slightly more coarse grained than the darker laminae.

Dr. E. John Eastmond of the Physics Department of Brigham Young University made the analysis. To one part of each of the nine samples was added two parts of lithium carbonate (Li_2CO_3). This mixture was placed in a graphite electrode, which in turn was placed in a D. C. arc at 10 amps. for 30 seconds.

The results in Table I are estimates of relative content made by visual comparison of blackening on the plate. The sample with the greatest amount of iron, for example, was arbitrarily assigned the value 10. The intensity of the iron lines from the other eight samples was compared with the sample containing the greatest amount of iron, and relative numbers from 1 to 10 were assigned the other samples depending upon their iron concentration. Relative comparisons can be made vertically, but not horizontally on the table. No attempt has been made to determine the composition of elements percentage-wise.

The even numbered samples are from the dark laminae, the odd numbered samples being from the lighter ones. The results reveal no consistent variation in chemical composition with alternating light and dark laminae. Evidently the variation in color of the laminae is mainly

Sample	Si	Mg	Ca	Al	Fe	Mn	Cu	Ti
1	10	10	10	10	10	10	5	10
2	10	10	10	10	8	9	4	5
3	10	10	10	10	7	7	3	5
4	5	6	10	10	6	7	3	5
5	5	6	8	10	4	9	3	4
6	10	10	10	10	8	9	3	5
7	10	10	10	10	9	9	5	5
8	10	10	9	10	8	9	10	5
9	10	10	8	10	7	9	5	3

TABLE 1--RELATIVE ABUNDANCE OF CERTAIN ELEMENTS IN LAMINATED BED OF GREAT BLUE LIMESTONE

due to grain size variation.

INSOLUBLE RESIDUES

Standard techniques were followed for obtaining insoluble residues from seven samples of the Great Blue limestone. The samples were taken from the formation in Battle Creek, Section 23, T. 5 S., R. 2 E. One set of seven samples was dissolved in 1:5 Acetic acid while another set was dissolved in 1:8 HCl acid. The residues were thoroughly washed, dried, and carefully weighed after the action of the acids had ceased. The results of the analyses appear in Table 2. The absence of quartz crystals suggests that the quartz in the formation is detrital rather than authigenic. However, pyrite in the residues is evidence of authigenic activity. Most of the residue material is clay size.

Sample No.	Sample Description	Wt. Gms.	1:5 Acetic Acid				1:8 HCl Acid				Remarks
			Soluble		Insoluble		Soluble		Insoluble		
			Gms.	%	Gms.	%	Gms.	%	Gms.	%	
74	50 ft. below top of form. Calcisiltite, fn. to cryptoxln.	10	6.29	62.9	3.71	37.15	6.535	65.35	3.465	34.65	90% clay size material
76	200 ft. below top of form. Ls., argill., fn. grnd. to dense.	10	7.575	75.75	2.425	24.25	7.505	75.05	2.495	24.95	100% clay size material
78	490 ft. below top of form. Calcisiltite, laminated, dense.	10	4.855	48.55	5.145	51.45	5.465	54.65	4.535	45.35	100% clay size material
79	620 ft. below top of form. Ls., fn. to med. xln.	10	8.385	83.85	1.615	16.15	8.565	85.65	1.435	14.35	90% clay size material, iron-stained quartz
84	860 ft. below top of form. Ls., med.xln., chert present.	10	1.555	15.55	8.445	84.45	1.925	19.25	8.075	80.75	75% clay size material
85	1102 ft. below top of form. Ls., fn. xln.	10	6.725	67.25	3.275	32.75	7.095	70.95	2.905	29.05	authigenic pyrite cubes, 95% clay size material
90	1350 ft. below top of form. Ls., sublithographic.	10	8.485	84.85	1.515	15.15	8.495	84.95	1.505	15.05	90% clay size material, authigenic pyrite cubes

TABLE 2--CHARACTERISTIC RESIDUES FROM THE GREAT BLUE LIMESTONE, BATTLE CREEK, SECTION 23, T. 5 S., R. 2 E.

ADDENDA

Prior to the binding of this thesis, the writer was given some pertinent information from Dr. H. J. Bissell which should be included in this report. This information is conclusive evidence of an over-thrust theory for Big and Little Baldy, p. 18.

Dr. Bissell, in July, 1946, measured 1, 075 feet of Atokan rocks on Mount Timpanogos west of Aspen Grove, sections 5 and 6, T. 4S., R. 3E.* Fusulinids from this section were identified by M. L. Thompson.

Because the thickness of Atokan rocks exposed in Big Baldy (2, 100 feet, p. 12) exceeds the thickness of Atokan rocks in Mount Timpanogos (1, 075 feet), there is absolutely no possibility that the rocks in the Baldy structures could once have been part of the west face of Mount Timpanogos.

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*Personal Communication, March 10, 1954

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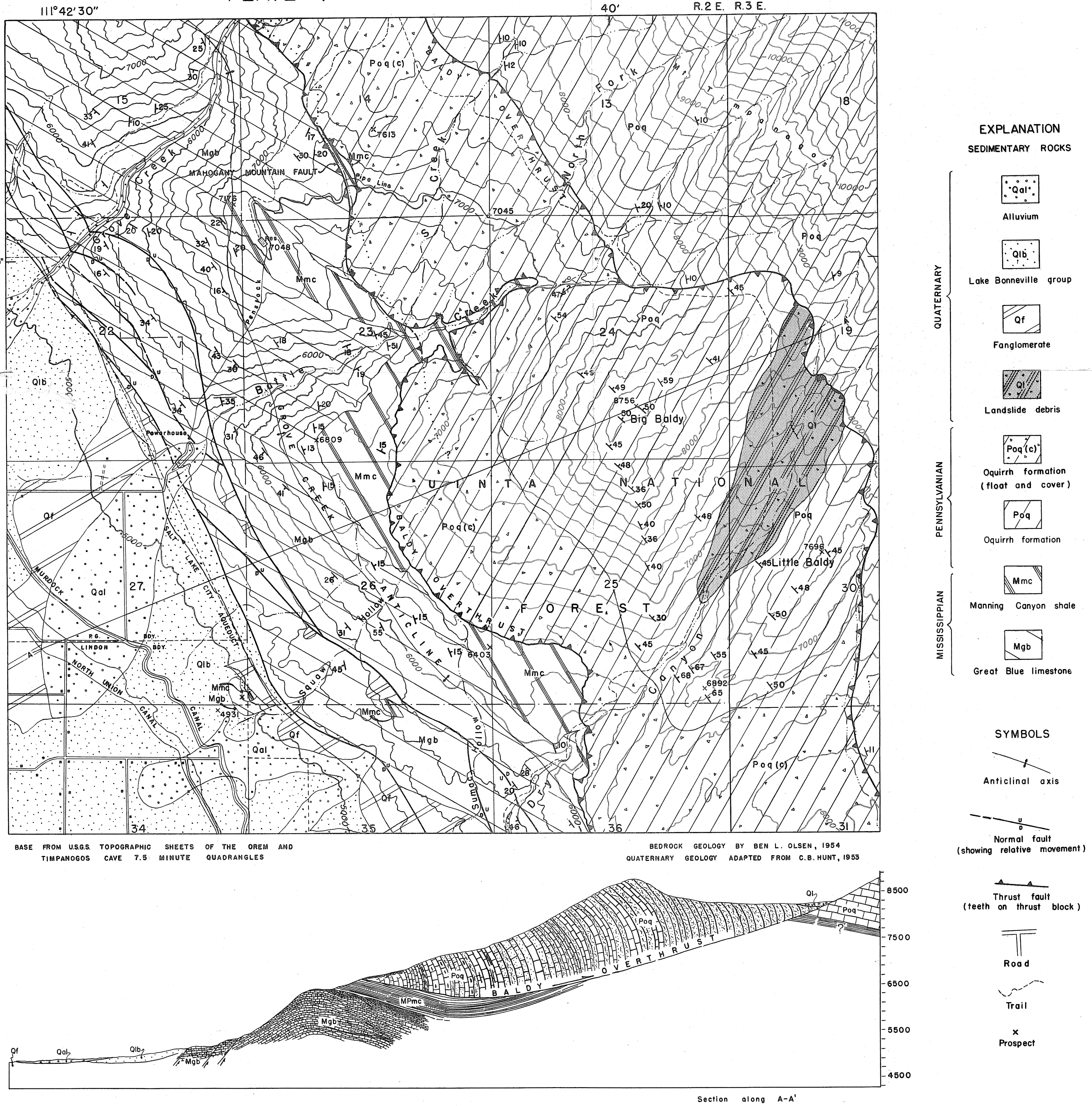
PLATE I



GEOLOGIC MAP AND CROSS SECTION OF BALDY AREA,
WEST SLOPE OF MOUNT TIMPANOGOS,
UTAH COUNTY, UTAH

Scale $\frac{1}{24,000}$

1000 0 1000 2000 3000 4000 5000 feet

CONTOUR INTERVAL 200 FEET