UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

AFFILIATED WITH

THE COLLEGE OF MINES AND MINERAL INDUSTRIES
UNIVERSITY OF UTAH
SALT LAKE CITY, UTAH

GEOLOGY OF THE SOUTHERN LAKESIDE MOUNTAINS, UTAH

By JOHN C. YOUNG

Bulletin 56

October, 1955

Price $1.50

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

The Utah Geological and Mineralogical Survey was authorized by act (the Utah State Legislature in 1931; however, no funds were made availab for its establishment until 1941 when the State Government was reorganiz(and the Utah Geological and Mineralogical Survey was placed within the ne State Department of Publicity and Industrial Development where the Surv(functioned until July 1, 1949. Effective as of that date, the Survey was tran ferred by law to the College of Mines and Mineral Industries, University (Utah.

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3. "The investigation of the kind, amount, and availability of the variou mineral substances contained in State lands, with a view of the most effecti and profitable administration of such lands for the State.

4. "The consideration of such other scientific and economic problems a in the judgment of the Board of Regents, should come within the field of tl Survey.

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The Utah Geological and Mineralogical Survey has published maps, ci culars, and bulletins as well as articles in popular and scientific magazine For a partial list of these, see the closing pages of this publication. For oth(information concerning the geological and mineralogical resources of Uta address:

ARTHUR L. CRAWFORD, *Director*

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

College of Mines and Mineral Industries

University of Utah

Salt Lake City, Utah

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FOREWORD

The Northern Utah Highland (Eardley, 1939, p. 1,285) has become generally recognized as a positive element from Precambrian to Laramide time. Wide exposures of Archean metaquartzites, schists, and gneisses in the Raft River Range and the Grouse Creek Mountains of northwestern Utah and of Middle (?) Precambrian siliceous and carbonate sediments still farther to the northwest in the Harrison Peak area of Idaho, suggest the possible connection of the northern Utah positive element with a larger pre-Laramide "Northwestern Utah Highland," which in turn may have had connections with a still larger "basement complex" to the northeast, underlying the quartzites of the Uinta Mountain group of late Precambrian age, and the intermediate series of Middle (?) Precambrian marbles, metadolomites, metaquartzites, phyllites, schists and gneisses variously exposed at Red Creek, north of the Uintas; at Encampment, in the Sierra Madre Mountains; at Atlantic City, south of the Wind River Range; and elsewhere in Wyoming.

In the Ruby Mountains southwest of Wells, Nevada, archean schists and gneisses suggest a southwestern extension of the paleogeography of the land exposed in the Northern Utah Highland in Precambrian time; and, as pointed out by Eardley, the crystalline mass composing the Uncompahgre Highland, which has been a positive element most of the time since the middle of the Paleozoic era lies in southwestern Colorado with its elongated axis pointing northwestward in line with the Northern Utah Highland.

South of the Northern Utah Highland, Eardley and Christiansen have described quartzites and other Proterozoic sediments in the Sheeprock (Eardley) and Canyon (Christiansen) Ranges of central Utah. A thick mass of what appears to be a similar sequence is exposed at Trout Creek, Utah, approximately 75 miles farther west. The source of these sediments and their relation to the Northern Utah Highland is still an intriguing problem.

Our knowledge of these interrelationships will be enhanced greatly by further detailed studies of the "windows" through the roof formed by later sediments which thatch all older structures, and wall in the "basement."

In the following pages is detailed the evidence portrayed in a "side wall" of the Northern Utah Highland. The Lakeside Mountains protrude as an island completely wrapped in a sea of Quaternary fill. Although the "basement complex" is not here revealed, the Cambrian quartzites and later Paleozoic sequence which accumulated upon this "basement" are clearly shown, and the position of the Lakeside Mountains along the western flank of the Northern Utah Highland gives the exposures in this range unusual significance.

The Utah Geological and Mineralogical Survey is fortunate in being able to reprint as one of its bulletins this thesis by John C. Young, a scholar in his own right, and a grandson of Utah's eminent judge, statesman, and most illustrious soldier, General Richard W. Young, who commanded the first Utah and 145th Field Artillery in World War I.

Arthur L. Crawford, Director
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

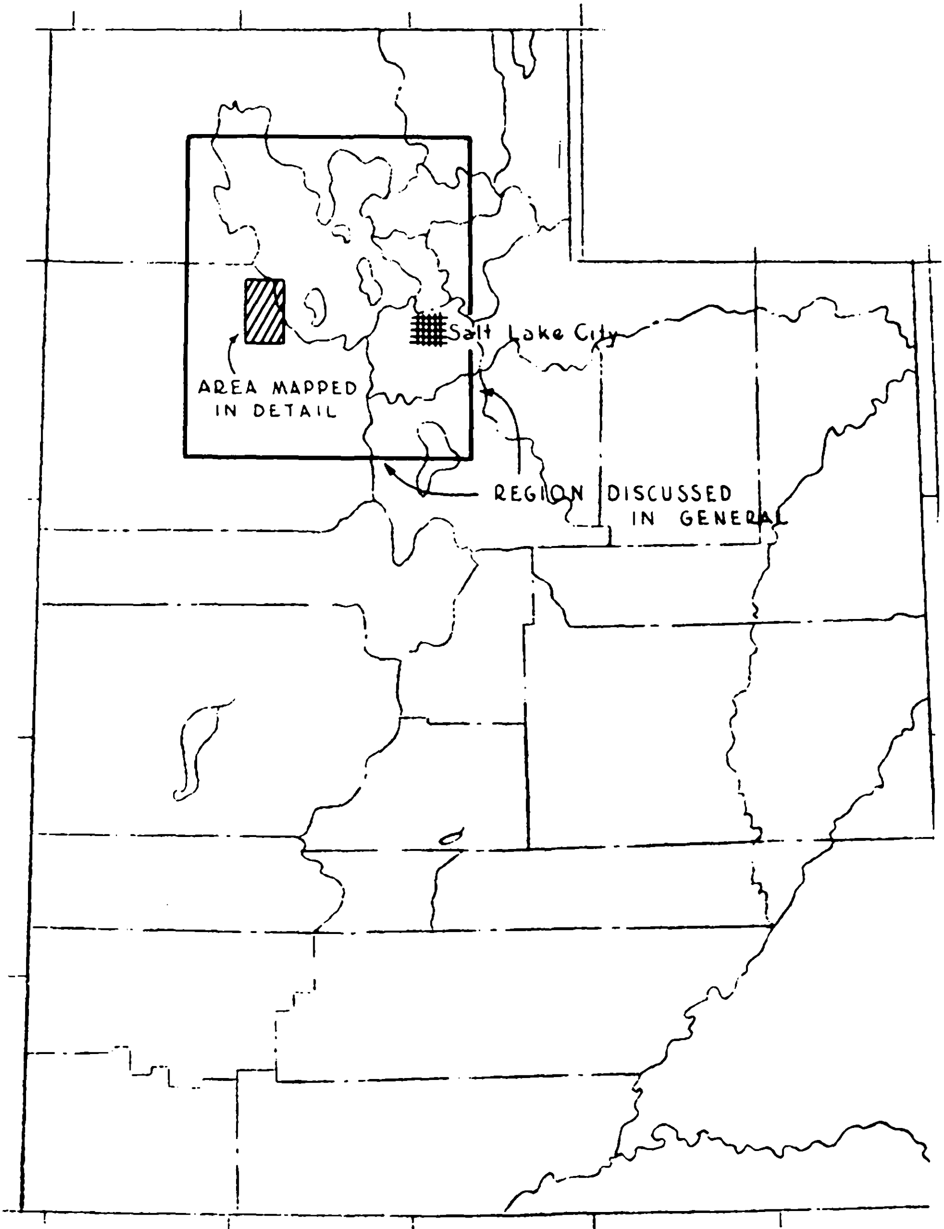

Fig. 1. OUTLINE MAP OF UTAH, showing region discussed general and area mapped in detail.

GEOLOGY OF THE SOUTHERN LAKESIDE MOUNTAINS, UTAH[1]

by John C. Young[2]

ABSTRACT

The Lakeside Mountains are a north-by-northwest-trending range of Paleozoic rocks located on the southwestern side of Great Salt Lake. Marine strata representing every geologic period from Cambrian to Permian (?) are well exposed in the range. These consist of 5,495+ feet of Cambrian, 1,666 feet of Ordovician, 546 feet of Silurian, 1,711 feet of Devonian, 3,458+ feet of Mississippian, and an estimated 5,000+ feet of Pennsylvanian-Permian (?).

Bordering the range on its southwestern side is the large, high-angle Lakeside fault which has a maximum known stratigraphic displacement of over 9,000 feet. Several other longitudinal and transverse faults of much smaller displacement exist in the range. Folding is predominantly gentle in the immediate area.

Consideration of regional structural, stratigraphic and physiographic relationships suggests:

1. The Lakeside fault may be related to a proposed major basement-controlled fracture zone extending in an east-west direction from the vicinity of the north end of the Oquirrh Mountains, through the area between the Stansbury Mountains and Stansbury Peninsula, to the vicinity of the south end of the Lakeside Mountains.

2. This proposed east-west zone developed during a time of regional compression to accomodate differential shortening between the relatively rigid Northern Utah Highland to the north and the relatively pliable Oquirrh Basin to the south.

3. The main displacement on the Lakeside fault occurred either in early Cretaceous time or during the late Cretaceous-early Tertiary Laramide orogeny.

4. Prolonged mid-Tertiary erosion was followed by renewed movement of up to 1,500-2,000 feet along the Lakeside fault, together with gentle regional uparching centering about the area immediately west of the Lakeside Mountains.

5. Fairly recent movement on the fault (although pre-Lake Bonneville) has offset pedimented surfaces along the west side of the range.

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[1]Thesis presented for the M.S. degree, Department of Geology, University of Utah.

[2]Formerly a geologist with the Standard Oil Company of California, now temporarily with the United States Army, Corps of Engineers, Beach Erosion Board, Washington, D. C.

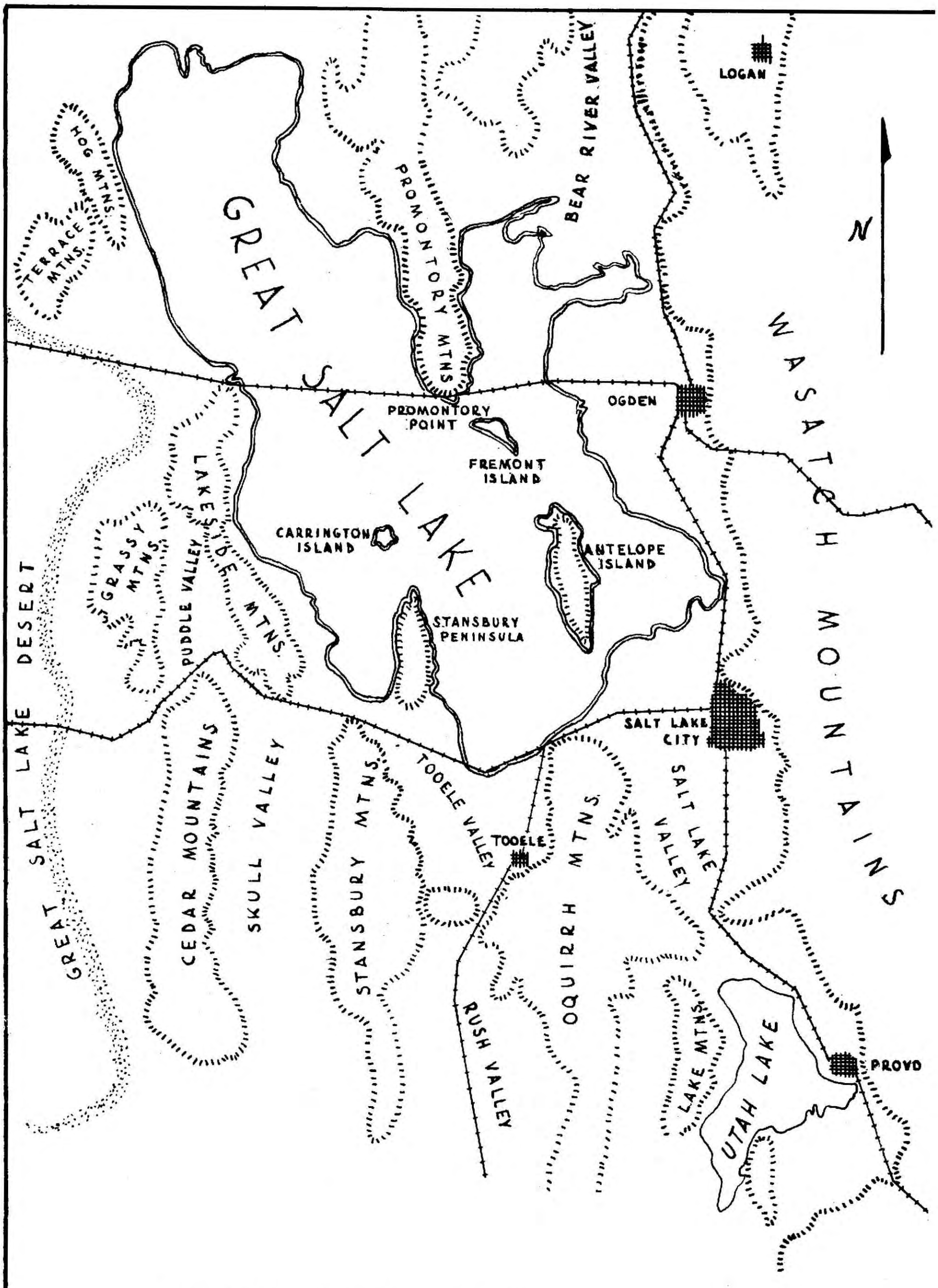


FIGURE 1a. SKETCH MAP OF REGION DISCUSSED IN GENERAL

INTRODUCTION

The vast region encompassing western Utah and most of Nevada is relatively untouched geologically. Only a few important contributions to the geology of this area have been made at widely separated intervals in the past. Many little known basins and ranges still await investigation by the earth scientist.

Though the geology of the Wasatch front is fairly well known through the works of numerous geologists, not much of general importance has been published concerning the geology of western Utah excepting the following works: King's classical Fortieth Parallel Survey; and U.S.G.S. Professional Papers no. 111, "Ore Deposits of Utah"; no. 80, "Geology and Ore Deposits of the San Francisco and Adjacent Districts, Utah"; by B. S. Butler; no. 173, "Geology and Ore Deposits of the Stockton and Fairfield Quadrangles, Utah," by James Gilluly; and no. 177, "The Gold Hill Mining District, Utah," by T. B. Nolan.

The writer undertook a study of the southern part of the Lakeside Mountains, Tooele County, Utah, as a subject for a master's thesis upon the suggestion of J. Stewart Williams, Professor of Geology at the Utah State Agricultural College. The purpose of the study was to describe the local geologic features of the area and to determine their relationship to broader structural and stratigraphic features of the Great Salt Lake Basin and adjacent areas.

The Lakeside Mountains are a north by northwest trending range of Paleozoic rocks located on the southwest side of Great Salt Lake. With a length of approximately 18 miles and a maximum width of about 5 miles, they form one of the smaller units of the so-called Basin and Range system of mountain ranges. They are reached from Salt Lake City by travelling west on highway 40-50 for 60 miles. This highway and the Western Pacific Railroad skirt the south end of the range. The small railroad settlement of Delle is located at the southern tip of the range and is the point from which unimproved dirt roads lead into the area. These roads, very poor to impassible in wet weather, skirt the eastern and western margins of the range and are used almost exclusively by stockmen who winter sheep and cattle in the area. Another dirt road leads northward from Delle to the Cal-Utah mine, a distance of about 5 miles (Plate I).

FIELD WORK AND ACKNOWLEDGEMENTS

Field work was carried on during the fall of 1950 and the winter and spring of 1951. The geology was plotted on aerial photographs having a scale of about three inches to the mile. An approximate land grid system was constructed on the photographs by interpolation between known section corners accurately located on the photographs. The geology on the photographs was then transferred to a map by means of a Radial Planimetric Plotter.

Sincere appreciation is extended to Professor William Lee Stokes, Armand J. Eardley, and F. W. Christiansen for valuable suggestions and criticisms pertaining to both the field work and preparation of the report. Professor Stokes' identification of fossils is gratefully acknowledged. The writer is also indebted to the Department of Geology of the University of Utah for financial assistance, and to the Standard Oil Company of California for the use of their aerial photographs and measured section. Thanks is given to Melvin C. Johnson, Rod M. Nielson, Henry J. Moore, Harold J. Clifford, and Ralph Goodell for untiring assistance in the measurement of sections.

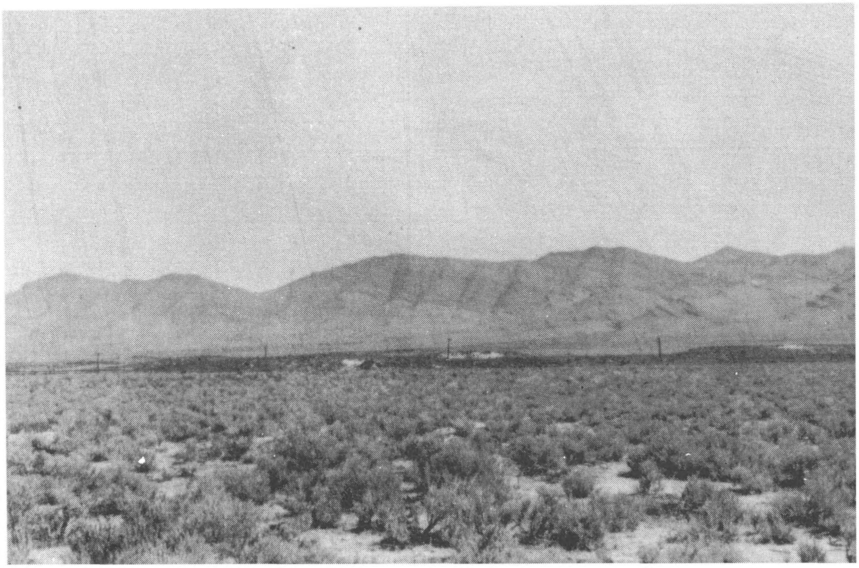


Figure 1b. The Lakeside Range from slightly south of west showing the bold west-facing scarp formed by the Basin and Range Lakeside fault. Quaternary lake sediments and aeolian dunes form the foreground.

STRATIGRAPHY

Introduction

Marine strata representing every geologic period from Cambrian to Pennsylvanian are well exposed in the Lakeside Mountains. Rocks are predominantly dolomites and limestones, with lesser amounts of sandstone, siltstone, shale, and quartzite. Precambrian and Mesozoic rocks are not exposed in the area. The nearest sections with which correlation is attempted are in the Oquirrh Mountains (Gilluly, 1932), the Logan Quadrangle (Williams, 1948), and the Randolph Quadrangle (Kindle, 1908, Richardson, 1913).

Detailed measurement of sections was made by means of a Brunton-tape traverse. The Lower and Middle Cambrian section, and part of the Upper Cambrian Lynch dolomite, were measured in section 1, T. 2 N., R. 9 W., and sections 17, 20, and 29 of T. 2 N., R. 8 W. The remaining Cambrian section was measured in section 10, T. 2 N., R. 9 W. Measurement of the Lower Ordovician to upper Mississippian sequence began in sections 35 and 36 of T. 2 N., R. 9 W., and proceeded in a southeasterly direction through section 1 of T. 1 N., R. 9 W., and sections 6, 7, 8, and 17 of T. 1 N., R. 8 W. The upper Mississippian - lower Pennsylvanian (?) Manning Canyon formation which occurs in very limited exposures west of the Lakeside fault, and the several thousand feet of Pennsylvanian - Permian sandstone and limestone of the Oquirrh formation occurring in the southern part of the area were not measured. Late Tertiary (?), Pleistocene, and Recent alluvium of unknown thickness flanks the range.

Cambrian System

Rocks of Cambrian age are widely exposed in the northern part of the area mapped. None of the few fossils collected were diagnostic of the Cambrian, consequently correlation was based on lithologic features and stratigraphic position below known early Ordovician rocks. Five lithologically distinct divisions are recognized: a lower quartzite of unknown thickness; a thin shale; a thick series of limestone and shaly limestone; a thin calcareous shale; and a thick dolomitic sequence. These divisions are tentatively correlated with the Oquirrh Mountains section of Gilluly (1932) and are named accordingly. It is recognized that more thorough study would undoubtedly render further division of the three upper formations, as well as probable higher placement of the Cambrian - Ordovician boundary, advisable. The writer leaves these revisions to those more familiar with the Cambrian system in western Utah.

Tintic Quartzite

Approximately 740 feet of Tintic quartzite crops out in the extreme northeastern part of the area and forms low "bald" hills on the otherwise featureless lake flat. White to rusty to purple cross-bedded quartzites predominate, with much of the lower half of the section containing abundant pebbles up to 1 inch in diameter. Neither the top nor bottom portions were actually seen but the upper part becomes finer grained and slightly micaceous and probably grades into the overlying Ophir shale.

It is fairly certain that at least the upper part of the Tintic quartzite is of early Cambrian age for it lies conformably beneath a shale formation containing Lower and Middle Cambrian fossils. (Gilluly, 1932, p. 8).

Ophir Shale

The position of the non-resistant Ophir shale is indicated by a "covered" interval with small fragments of micaceous, green to olive-drab to gray shale occurring as float. The thickness of this interval was estimated to be 150-200 feet. The Ophir is reported to lie conformably upon the Tintic quartzite at other places and is thought to do so here. A Lower and Middle Cambrian age is assigned to the formation by Gilluly (1932, p. 11-12).

Hartmann (?) Limestone

The first bedrock outcrop above the Ophir shale interval is a silty, blue-gray limestone. Its contact with the underlying shale was not observed. Subordinate Ophir-like shales which are interbedded with the limestone probably indicate a transition zone between the shale and limestone. Several prominent beds of micaceous limestone and shale, one 35 feet thick, occur at higher horizons in the limestone indicating the recurrence of conditions favorable to the deposition of shale. In addition, thin, brown to tan silty partings are prominent throughout the lower two-thirds of the formation and give crudely banded appearance to the outcrops. Three thin beds of dolomite occur in the upper one-fourth of the formation. The total thickness of the Hartmann (?) in the Lakeside Mountains is 1062 feet. The presence of several cliff-forming members produces alternating steep and gentle slopes. The only fossil remains found in the interval are unidentifiable trilobite fragments. Closer examination would probably yield diagnostic fossils. Correlation with the Middle Cambrian Hartmann limestone is proposed solely on the basis of lithology and stratigraphic position. The boundary between the Hartmann (?) limestone and the overlying Bowman (?) limestone appears to be gradational and was arbitratily placed at the bottom of the first prominent non-resistant bed in the gradational interval between the two.

Measurement of this formation was broken at one point so that the thickness presented here may be inaccurate. The writer regards it to be fairly close to the true thickness, however.

Bowman (?) Limestone

The Bowman (?) limestone of Middle Cambrian age (Gilluly, 1932, p. 15) rests conformably upon the Hartmann (?) limestone. In the Lakeside Mountains the Bowman consists of 167 feet of poorly exposed, thin-bedded and non-resistant, silty limestones and shales, and subordinate intraformational conglomerate. A conspicuous 18 foot layer of slightly silty limestone containing abundant small, black, carbonaceous (?) nodules occurs 31 feet above the base. Above this member is a 60 foot interval of dense, non-resistant, blue-gray to blue-green nodular limestone interbedded with fissile, gray-green to olive drab shale and occasional intraformational conglomerate. The upper 50-60 feet of the formation and the upper contact were concealed by debris derived from the overlying cliffs of massive Lynch (?) dolomite, and their character was not ascertained.

Lynch (?) Dolomite

3327 feet of massive light - to dark - gray dolomites rests with apparent conformity upon the Bowman (?) limestone. These beds are correlated with the Upper Cambrian Lynch dolomite in the Oquirrh Mountains on the basis of lithologic similarity and stratigraphic position above probable Middle Cambrian limestone and below Lower Ordovician limestone. Fossils are exceedingly scarce in the formation and no diagnostic ones were collected. The lower boundary was concealed but can be located approximately at the base of the massive dolomite cliffs which rise above the non-resistant Bowman (?) limestone. Rapid lateral changes in the lowermost beds of the Lynch dolomite such as have been described in the Oquirrh Mountains (Gilluly, 1932, p. 16) were not apparent in the Lakeside Mountains. The lowermost beds in the Lakesides, however, were traced for only a short distance.

The lower 224 feet of the Lynch (?) dolomite forms a prominent cliff and consists of densely crystalline medium-to dark-gray dolomite in the lower half and a very light gray dolomite in the upper half. A conspicuous 14 foot zone of alternating light and dark bands of dolomite separates these two zones. Above the bottom member lie alternating thick and thin layers of light, medium and dark-gray dolomite with several thin limestone members. Fairly rapid lateral variation in the color of some of these layers is common. Cliff-forming members predominate but alternate with softer members. The topography created is generally rugged and abrupt in character. Slightly above the middle of the formation is a conspicuous sandy zone having several thin beds of impure to almost pure and partly crossbedded sandstone. This zone thins and varies considerably in character from where it was measured on the western side of the range to the eastern side of the range and may have only a localized extent. The upper part of the formation can be divided into two parts on the basis of color. The lower half is mostly dense, dark gray, cliff-forming dolomite having a few light layers. The upper half is mostly medium to light gray dolomite -- somewhat less resistant than that below but still forming steep and rugged slopes. These two upper intervals show lateral changes in both color and thickness of their constituent units.

Numerous small, rod-like or "twiggy" bodies of white crystalline dolomite are characteristic of many of the darker layers of the Lynch (?) dolomite. They become more numerous progressively upwards and create a "spangled" effect upon close examination. No beds which could confidently be used over much distance as "marker" beds were found in the formation.

The upper boundary of the Lynch (?) dolomite is difficult to place. No boundary that would be generally satisfactory could be established in the field. The uppermost beds vary along strike between dolomite and limestone. At some places the contact appears to be marked by a sudden change from dolomite to "typical" Garden City limestone. At other places there may be several alternating beds of limestone and dolomite. Although such variation in some cases is due to dolomitization near faults and fissures, these variations also occur away from altered areas and must be primary in nature. A more thorough study should be made of this boundary zone in order to ascertain its character and significance. According to Grant Steele (personal communication, 1951), who is studying the Cambrian of the eastern Great Basin, the upper part of the type Lynch dolomite in the Oquirrh Mountains is early Ordovician in age. From this, it would seem that the upper part of the Lynch (?) in the Lakesides may also be Ordovician.

Ordovician System

Formations in the Ordovician system of the Lakeside Mountains are correlated with those recognized by Richardson (1913) in the Randolph Quadrangle of northeastern Utah. Three lithologically distinct formations are present: Lower Ordovician Garden City limestone; Middle Ordovician Swan Peak formation; Upper Ordovician Fish Haven dolomite. They are very well exposed on both sides of the range. Lack of recognized Ordovician in the Oquirrh Mountains, and dissimilarity with the Ordovician in the Gold Hill district precludes correlating specific Lakeside Mountains Ordovician formations with either of these sections.

F. F. Hintze (1949, p. 42) recognized the above divisions in the Lakeside Mountains. He collected fossils and estimated thicknesses at about the same locality measured by the writer. He concluded that "the fossils found indicate little doubt as to correlation with the northeastern Utah section in which the same fossils are present and the lithology strikingly similar."

Garden City Limestone

Hintze estimated a thickness of 840 - feet of Garden City limestone in the Lakeside Mountains. The writer measured slightly over a thousand feet but was not certain of the lower contact. The limestone is mostly dark to medium gray on fresh fracture and weathers generally blue-gray. It is densely crystalline to fragmental with many cherty and silty layers and fairly common intraformational conglomerate. The upper half is slightly more silty than the lower half and has a decided brownish tinge when seen from a distance. The formation, as a whole, produces steep and rugged topography. Silt increases in the upper 100 feet and the formation finally grades into the Swan Peak formation -- the boundary being arbitrarily chosen where silt and sand become and remain prominent. A fossil collection from the lower part (?) of the Swan Peak indicates the arbitrary nature of the boundary and is listed in the following section under the Swan Peak formation.

Swan Peak Formation

Edwin Kirk (1933, p. 38) did not recognize the presence of the Swan Peak formation (partly, if not wholly equivalent to the Eureka quartzite in his article) in the Lakeside Mountains. F. F. Hintze (1949, p. 42) recognized it but reported a thickness of only 2 feet. Later, Lehi F. Hintze (1951, p. 91-92) measured the formation in the Lakeside Mountains and subdivided it into two units having an aggregate thickness of 141 feet. He recognized a lower unit, 140 feet thick, consisting of interbedded shales, siltstones and limestones, and an upper quartzitic unit 1 foot thick. The author, unaware of these previous measurements, measured 124 feet of mostly silty, fucoidal limestones and siltstones, topped by 15 feet of sandstone and quartzite. This total thickness of 139 feet agrees very well with Lehi Hintze's measurement of 141 feet. The upper sandy and quartzitic layer shows considerable variation in thickness and may possibly even lense out at some places.

The Swan Peak formation is a distinct non-resistant unit which is easily traced since it lies between two resistant and massive formations. Its upper contact is extremely abrupt, consisting of a sharp change from light gray to white sandstone or quartzite to dark gray, very resistant dolomite.

Fossils collected in the Swan Peak formation at its point of measurement have been reported upon by Dr. Stokes as follows:

> Orthis swanensis
> Phosphatic brachiopods
> Ostracods
> Goniotelus petersoni
> Cyrtocone cephalopods
>
> There can be no doubt that this is the widespread fauna found in many places just below or in the basal part of the Swan Peak quartzite. The orthid brachiopods and Goniotelus are positive guides. The age of the fossils is late in the early Ordovician.

Fish Haven Dolomite

The Fish Haven dolomite crops out as a series of medium to dark gray cliffs rising above the gently sloping bench formed by the

Swan Peak formation and has an aggregate thickness of 514 feet. The lower 100 feet consists of distinctively banded layers of light and dark gray, coarsely crystalline dolomite. The bands vary in thickness from less than an inch to 15-20 feet and the thicker ones are easily observed from a distance. The remaining part is made up of generally dense, massive, somewhat cherty, light to dark gray dolomite. Large chain corals (Halysites sp.) were found by the author. Hintze reported these and also Streptelasma and Favosites (1949, p. 42).

Silurian System

Laketown Dolomite

Only one Silurian formation occurs in the Lakeside section, namely, the Laketown dolomite, originally recognized by Richardson in the Randolph Quadrangle (1913, p. 407). The Laketown is a cliff-former and difficult to separate from the underlying Fish Haven dolomite. An examination of the section in company with Wm. Lee Stokes revealed an inconspicuous horizon which is believed to mark the contact. The beds above this horizon are generally more massive and uniformly colored. They contain numerous vugs -- some lined with clear quartz crystal; and the presence of pentameroid brachiopods and large crinoid stems is a good indication, according to Dr. Stokes, of a Silurian rather than Ordovician age.

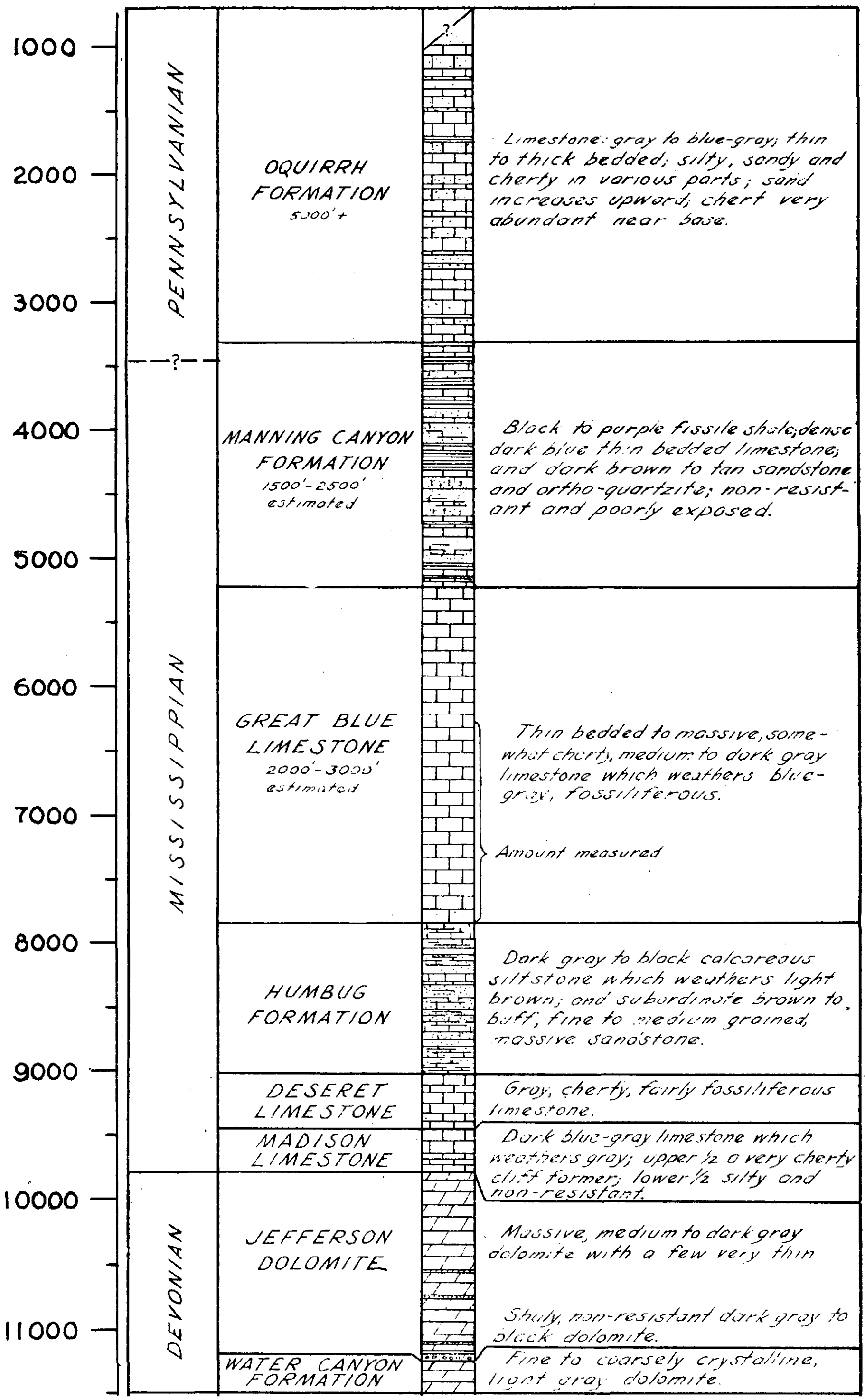


Plate III. Generalized Stratigraphic Section, Southern Lakeside Mountains, Utah

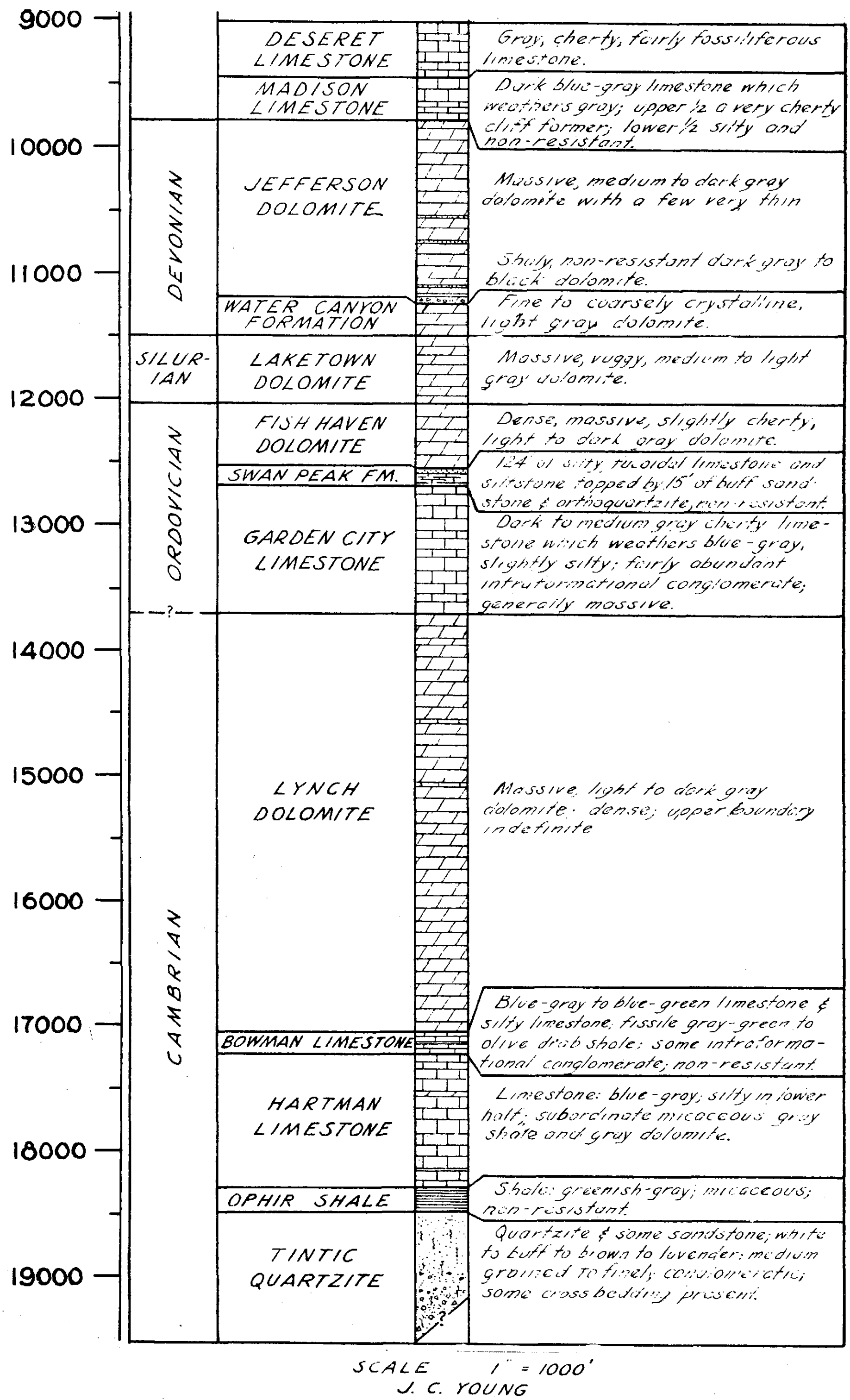


Plate III. Generalized Stratigraphic Section, Southern Lakeside Mountains, Utah

F. F. Hintze (1949, p. 42) recognized the presence of the Laketown dolomite in the Lakeside Mountains. Although he was unable to find a suitable plain of separation between the Ordovician and Silurian dolomites, he estimated the thickness of each. His thickness of 500 feet for the Fish Haven corresponds surprisingly well with the 514 feet measured by the author. The author's measured thickness of 546 feet of Laketown dolomite is considerably greater than Hintze's estimate of 300 feet.

A scanty fossil collection made along the line of measurement of the Laketown dolomite was examined by Dr. Stokes who reported:

> Favosites sp.
> Crinoid stems
> Cup corals, unidentifiable
> Pentameroid brachiopods, several types
>
> Preservation of these fossils as is common in all Laketown collections is very poor but the types represented and the method of preservation leaves no doubt as to the formation represented. The age is Middle Silurian (Niagaran).

Devonian System

Devonian rocks rest disconformably upon the Laketown dolomite and are contained in two formations: the Lower Devonian Water Canyon formation and the Upper Devonian Jefferson dolomite. These correlate to J. Stewart Williams' Water Canyon formation of the Logan Quadrangle (1948, p. 1138), and the Jefferson formation first recognized by Kindle in northeastern Utah (1908, p. 17).

Water Canyon Formation

The Water Canyon formation forms a distinctive 242 foot light gray to almost white unit as contrasted with the medium to dark gray beds above and below it. The basal bed is distinguished by a thin, irregular layer of slightly silty dolomite which is much lighter in color than the layer below and which contains fairly abundant fish fragments. Above this, the formation, as a whole, consists of fine to coarsely crystalline light gray dolomite becoming mostly medium gray toward the top. It generally weathers to a smooth, sugary surface.

Dr. Stokes' report on the fossils collected follows:

Glossoidaspis cf. G. giganteus
Other fish fragments
This collection contains the same type of broken fish fragments as the type Water Canyon which is considered to be early Devonian (Ulsterian).

Jefferson Dolomite

The base of a 5-15 foot bed of medium to coarse dolomitic conglomerate with lenses of siltstone and sandstone marks the lower contact of the Jefferson dolomite. The conglomerate consists mostly of angular pieces of dolomite derived from the underlying Water Canyon dolomite. Lenses of sandstone up to 8 feet thick are present and a relief on the surface of contact of up to 15 feet was noted. Commonly a 1-4 foot bed of very dark gray dolomite filled with white bryozoan fragments and some corals occurs above the breccia. Together, these two beds usually form a cliff. Above the basal zone the Jefferson can be divided into two lithologically distinct but unnamed units. The lower of these consists of 137 feet of shaly, non-resistant, dark gray to black dolomite, while the upper unit consists of 1333 feet of mostly resistant, massive, medium to dark gray dolomite which forms an imposing cliff. The uppermost part of this upper unit, however, is less resistant and is usually covered with float from the overlying formation. The total thickness of the Jefferson dolomite in the Lakeside Mountains is 1469 feet.

Several specimens of Cladopora collected from the formation along the line of measurement were examined by Dr. Stokes who commented:

> The single species represented in your collections from the higher Devonian rocks is almost universally present in the Jefferson formation and its equivalents in Utah and vicinity and the age is Late Devonian (Senecan and perhaps Chatauquan).

Mississippian System

The formations of Mississippian age in the Lakeside Mountains are correlated with those in the Stockton-Fairfield Quadrangle: i. e., Lower Mississippian Madison limestone; and Upper Mississippian Deseret limestone, Humbug formation, and Great Blue limestone. These beds occur over a wide area in the east-central part of the thesis area.

Madison Limestone

The Madison limestone consists of 329 feet of dark blue-gray limestone which weathers generally gray and whose upper half forms a bold cliff containing numerous lenses and layers of chert. The lower half is thin-bedded with the basal 20-30 feet slightly silty and very soft. The Madison is separated from the Devonian beds by a 1-3 foot bed of impure sandstone. Since the actual contact zone is generally covered, the change from dolomite to limestone is usually the best indication that the contact has been crossed. The upper contact is arbitrarily placed at the top of the cherty, cliff-forming member.

The only fossils collected from the Madison limestone were corals and crinoid plates. Dr. Stokes reports:

> The specimens collected from this interval are not sufficient to positively identify it; however, the lithology and position leave no doubt that the Madison is present.

Deseret Limestone

The Deseret limestone overlies the Madison without any notable change of lithology except that it is somewhat less resistant and less cherty than the beds below. Gilluly noted a 9 foot layer of black phosphatic shale separating the two formations in the Oquirrh Mountains but this was not found in the Lakeside section. The Deseret is predominantly a gray, cherty, fairly fossiliferous limestone which forms ledge and slope topography above the massive cliff of Madison.

The fossils collected from the formation have been studied by Dr. Stokes, whose determinations are as follows:

Euomphalus sp.
Schizophora sp.
Camarotoechia sp.
Spirifer cf. S. centronatus
Spirifer sp.
Crinoid plates
Schuchertella, sp.

Dr. Stokes further reports:

> There is nothing in this collection to distinguish the Deseret from the Madison as far as I can tell. It has been the experience of all who have dealt with these formations that they cannot be separated paleontologically with complete certainty. All that can be said is that this collection is pre-Humbug and probably related very closely with the Madison. Your breakdown of the Madison-Deseret on lithologic or topographic features is safe because it has been used by most previous workers.

Humbug Formation

The Humbug formation rests conformably upon the Deseret limestone. Gilluly (1932, p. 27) arbitrarily places the contact below the first layer of sandstone 2 feet thick or over, but states that this sandstone comes and goes in section and may appear considerably higher in one place than in another. In the Lakeside Mountains a definite lithologic break, with a 2-3 foot bed of coarsely crystalline and fragmental limestone regarded as marking the basal bed of the Humbug, was discovered. Above this, siltstones and sandstones predominate with the siltstone more abundant and generally calcareous. Limestones and chert are also occasionally seen. The siltstone is dark gray to black on fresh fracture but usually weathers a light tan to brown. The sandstone is brownish-gray to buff, generally massive, fine to medium grained, and, in part, slightly porous. The Humbug formation in the Lakeside Mountains is characterized by fairly rugged topography with several conspicuous ledges of sandstone and cherty limestone.

No diagnostic fossils were obtained from the Humbug formation.

Great Blue Limestone

The Humbug-Great Blue contact is arbitrarily chosen at the horizon where limestone becomes predominant over siltstone and sandstone. The first 55-65 feet of sediment above this contact is fairly non-resistant, medium crystalline, gray limestone with a few large cup corals and black cherty lenses. Above this is a 75 foot interval of sandy limestone which weathers brown to tan. The remaining exposed Great Blue limestone consists of thin bedded to massive, somewhat cherty (mostly black), medium to dark gray limestone which weathers generally blue-gray and ranges in texture from finely crystalline to coarsely fragmental. Large cup corals are prominent in several layers and fairly abundant throughout most of the formation. Several beds rich in bryozoans pelecypods, and brachiopods are found in the upper part of the exposed portion. An unknown amount of the upper part of the Great Blue is not represented in this section since it is cut-out by the Lakeside fault.

The results of Dr. Stokes' study of the fossils collected from the Great Blue limestone are as follows:

Lithostrotionella sp.

Cup coral like Zaphrentis stansburyi

Fenestella sp.

Polypora sp.

Productella sp.

Orthotetes sp.

Although there is some difficulty in understanding the present classification of the type of coral formerly designated as Zaphrentis stansburyi it is nevertheless a reliable guide to the upper Brazer or its equivalent the Great Blue limestone. The other fossils reinforce this opinion. There is little doubt that the Great Blue limestone is late Mississippian in age and that it is represented in your fossil collections.

Mississippian-Pennsylvanian (?) Beds

Manning Canyon Formation

Limited exposures of the non-resistant Manning Canyon formation occur southwest of the Lakeside fault and exhibit confused strike and dip readings indicative of tight folding and incompetence. Lithologically, the formation consists of black fissile shales which weather black to purple to brown to orange, thin bedded blue-gray to dark-gray limestones, fragmental limestones which contain fairly abundant fossils and usually weather brown to orange and lensing light tan to dark brown sandstones and orthoquartzites which show variable characteristics of crossbedding, grain size, cementation and porosity.

The writer and Carl Helms Jr. collected fossils from the Manning Canyon formation in the southern part of the Cedar Mountains (25 miles south of the south end of Lakeside Mountains) and noted a similar lithology.

At the Cedar Mountains location, the formation has an estimated thickness of 1500-2500 feet. The thickness in the Lakeside Mountains could not be estimated but may be of a roughly comparable figure.

Although exposures of the Manning Canyon formation are generally poor in the southern Cedar Mountains, the lower contact appears to be fairly abrupt, while the upper contact is gradational through an interval of 100-200 feet into the Oquirrh formation, and was arbitrarily placed above the uppermost bed of dark to black shales.

On the basis of fossils (see below) from a locality thought to be fairly close to the upper boundary of the Manning Canyon formation, at least 7/8 of the formation is assigned an Upper Mississippian (Meramec and/or Chester) age, with the uppermost part possibly Lower Pennsylvanian. According to W. L. Sadlick, however, there is a very good possibility that the entire formation in the Cedar-Lakeside Mountains region is of Mississippian age (personal communication, 1952).

The following fossils were collected from the upper 1/3 of the Manning Canyon formation in the southern Cedar Mountains (S. E. 1/4, T. 4 S., R. 10 W.) and identified by Dr. Stokes.

Eumorphoceras plummeri
Discitoceras texanum
Cravenoceras merriami
Cravenoceras Nevadense
Orthoceras sp.
Leiorhynchus carboniferum
Moorefieldella sp.
Ariculopecten catacus
Gastropod

Although this collection contains several species identical with those reported by Youngquist (1949) as being found in the White Pine shale of Nevada, to which he assigns a Meramecian (Upper Mississippian) age, W. L. Sadlick favors a later age (Chester) for these fossils. He states:

> These fossils must all be Chester because _Cravenoceras nevadense_ and _Eumorphoceras plummeri_ together, without _Goniotites_, indicate a Chesterian age.

Pennsylvanian and Permian (?) Systems

Oquirrh Formation

The Pennsylvanian-Permian (?) Oquirrh formation appears to lie conformably upon the Manning Canyon formation and consists of a thick series of cherty limestones, silty limestones, siltstones, and calcareous sandstones. No attempt was made to measure the formation but it is believed that over 5000 feet are exposed southwest of the Lakeside fault. Very cherty limestones make up the lower 300-400 feet. Chert decreases, but remains prominent, above this, and sandy limestone and calcareous siltstone increase upward. Alternating resistant and fairly soft beds characterize the area of outcrop. Generally speaking, the Oquirrh formation is much less resistant to erosion, however, than the older Paleozoic rocks in the range.

Fossils collected from the lower part of the Oquirrh formation in the southern Cedar Mountains prove its Pennsylvanian age and are listed below. Beds rich in fusulines were found higher in the formation in the Lakeside Mountains but no identifications were made. It was not established whether Oquirrh of Permian age occurs in the Lakeside Mountains, but fusulines of lower Permian age (Wolfcampian -- identified by R. W. Hollingsworth for the Standard Oil Company of California) occur approximately 5000 feet above the base of the formation in the southern Cedar Mountains.

The following fossils from the southern Cedar Mountains were identified by Dr. Stokes. They were collected at various localities in the SE 1/4, T. 4 S., R. 10 W., and the NE 1/4, T. 5 S., R. 10 W., and all occur in the lower 1000 feet of the formation.

Composita, several species
Dictyoclastus sp.
Linoproductus sp.
Echinochonchus sp.
Marginifera sp.
Spirifer sp.
Eumetria sp.
Cleiothyrodina sp.
Ambococoelea sp.
Punctospirifer kentuckensis
Pustula sp.
Coral
Crinoid stems
Triphophyllum

The presence of Punctospirifer kentuckensis and the abundance of productid brachiopods seems to indicate quite positively that this is Pennsylvanian, probably early in the period.

A scanty collection from the lower 2000-3000 feet of the Oquirrh formation in sec. 20, 20, T. 1 N., R. 8 W. in the Lakeside Mountains was identified by Dr. Stokes as follows:

Marginifera sp.
Spirifer octiplicata
Chonetes sp.
Productid brachiopods
Crinoid plates
Fusulinids, small primitive types

Dr. Stokes further reports:

I am unable to determine some of these fossils specifically but the presence of small fusulinids and of the Spirifer octiplicata type of brachiopod definitely prove an early Pennsylvanian age for the collection.

Tertiary and Quaternary Deposits

No outcrops of known Tertiary rocks occur within or surrounding the southern Lakeside Mountains. Tertiary strata undoubtedly occur subsurface in the broad valleys east and south of the range. Tertiary strata may be thin to non-existent in the narrower and shallower valley immediately to the west.

The Quaternary is represented by both consolidated and unconsolidated alluvial terraces, fans, and valley fill. Ancient Lake Bonneville completely surrounded the range and left unmistakable evidence of its presence in the form of lake terraces and marly deposits. The deposits in some of the small valleys of the range have been partially removed by erosion and are now very well displayed in longitudinal cross-section. They consist mainly of conglomerate and fine grained, friable white marls.

Many small but well formed alluvial fans occur along the western side of the range. A thin veneer (0 to 30-50 feet thick) of coarse alluvium spreads outward from these fans, and conceals -- except for scattered outcrops -- the pedimented surface of the Manning Canyon formation occurring west of the Lakeside fault.

Unknown thicknesses of Quaternary valley fill occur in the valleys to the east and south of the range and also west of the pediment flanking the west side of the range.

STRUCTURE

Faults

Several high-angle, transverse and longitudinal intra-range faults of small to moderate displacement cut the southern part of the Lakeside Mountains and give the range the aspect of a very simple fault mosaic (Plate I). Bordering the main mass of the range on the southwestern side is a large, high-angle fault with a maximum known stratigraphic displacement of about 9500 feet. This is here named the Lakeside fault and is the major structural feature in the area of the Lakeside Mountains.

The southeastern segment of the Lakeside fault trends about N. 45-55° W. It strikes obliquely through the south end of the range to section 35, T. 2 N., R. 9 W., where the trend changes to about N. 25° W. and the fault becomes coincident with the southwestern border of the range. The stratigraphic throw increases from approximately 7500 feet at the southeasternmost exposure, where it disappears beneath the alluvium of northern Skull Valley, to approximately 9500 feet at its northwesternmost exposure. The trace of the fault could not be followed farther northwestward than sections 9 and 10, T. 2 N., R. 9 W., where the mountain front loses its abrupt, straight-line character and becomes low and irregular. Very brief reconnaissance in the region northwest of the mapped area indicated two possibilities: 1) the fault dies out rapidly (perhaps splitting into several faults which die out), or, 2) it may be terminated by, or join with, a possible east-by-northeast trending zone of transverse faulting several miles north of the area under consideration. The trace of the fault to the southeast beneath the alluvium is unknown but the map relations suggest that it coalesces with a possible zone of approximately east-west, predominantly strike-slip faulting. (See "Regional Setting and Structural Chronology" below.) This postulated strike-slip fault zone would be in the form of a transverse shift or tear zone existing between the Stansbury Mountains and Stansbury Peninsula and continuing eastward past the north end of the Oquirrh Mountains. Eardley (1939, Plate I) has mapped east by southeast trending faults in the Stansbury Peninsula which could possibly join this transverse zone.

Evidence for the high-angle nature of the Lakeside fault consists of 1) a fairly straightline trace, and 2), actual exposures of the fault scarp, which are, in all places high-angle to vertical. Steep (70^{o}-90^{o}), valleyward dipping walls of cemented fault breccia are found at several places along the fault trace and are thought to represent the actual badly eroded fault surface. At one locality, such a face of breccia dips steeply into the mountain block. A few slickensided surfaces occurring in these breccia remnants show horizontal and oblique, as well as vertical slippage. Such variations in the direction of slickensides might be the result of differential adjustments between the various small blocks adjacent to the fault plane, and, since no one direction seems to be predominant, are not considered as indicative of the over-all direction of movement of the fault. The absence of much folding or shearing along the fault, at least in the upthrown block, is worthy of note. This can probably be attributed in part to the relatively high competency of the formations composing the upthrown block.

The lesser faults of the Lakeside Mountains fall roughly into two specific trends: a north-by-northeast trend, and a north-by-northwest-trend. The most prominent of those having a north-by-northeast trend are the high-angle to vertical Iron Hollow and Craner Canyon faults (Plate I). Both of these intersect with, and apparently terminate at the Lakeside fault. Each has a stratigraphic displacement ranging up to several hundred feet but this decreases and finally dies out away from the Lakeside fault. In both, the southeastern side has moved up in relation to the northwestern side.

The only major north-by-northwest-trending fault, other than the Lakeside fault, is the Hidden Mine fault. This fault trends nearly parallel to the Lakeside fault, and, as in the Lakeside fault, the northeastern side is upthrown. It begins slightly south of Craner Canyon (Plate I) and increases rapidly in displacement northwestward. Its trace northwestward, beyond that shown on the geologic map, is unknown. It is, as nearly as can be determined, essentially vertical. The maximum displacement of the Hidden Mine fault in the area mapped is estimated to be nearly 3000 feet (See cross-section C-C', Plate I).

Folds

The structure of that part of the Lakeside Mountains lying northeast of the Lakeside fault and included in the mapped area is that of a very broad, northwest-trending syncline which plunges gently southward. As the syncline is traced northwestward, the axis becomes approximately coincident with the Hidden Mine fault (Plate I). A poorly defined east-by-northeast-trending anticlinal warp lies at right angles to this syncline north of the area under consideration. The oldest rocks of the range (early Cambrian Tintic quartzite) are exposed east of the intersection of the synclinal and anticlinal trends.

Folding is more pronounced in the Upper Mississippian and Lower Pennsylvanian beds which form the pediment and low mountains southwest of the Lakeside fault (Plate I). Scattered exposures of shale of the

Manning Canyon formation occur for a distance of over 3 miles immediately west of the fault, and since considerable variation in attitudes was noted, the Manning Canyon may be considerably folded in the area. Extensive outcrops of the Oquirrh formation making up the hills southeast of the area of outcrop of Manning Canyon formation display several small, south-plunging anticlines and synclines which tend to die out away from the Lakeside fault. These may be related to movement along the fault, and if so, seemingly indicate a horizontal as well as vertical component of movement along this part of the fault. The folding in this area is not as pronounced as in the area of Manning Canyon to the northwest; the dips here average about 25-35^{o} and have not been observed to exceed 59^{o}.

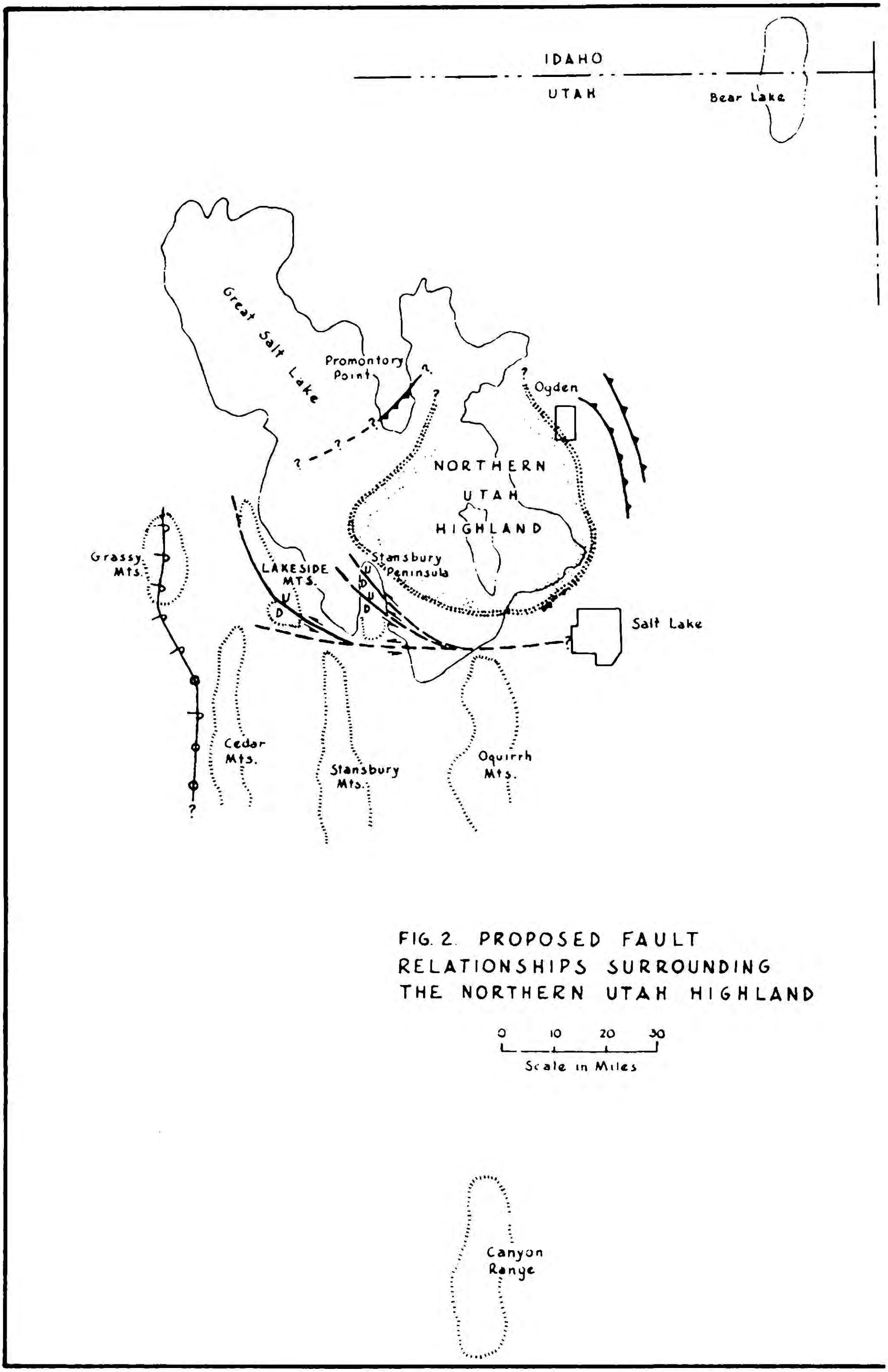


FIG. 2 PROPOSED FAULT RELATIONSHIPS SURROUNDING THE NORTHERN UTAH HIGHLAND

REGIONAL SETTING AND STRUCTURAL CHRONOLOGY

Regional Structural Relationships

Northwest of Salt Lake City, in an area centering roughly about Antelope Island, extensive exposures of Precambrian rocks indicate the presence of a present day stratigraphic, though not topographic, highland. Evidence that this area might have been topographically positive in Proterozoic time has been presented by Eardley and Hatch (1940). They further proposed that the area continued to be intermittently elevated following Proterozoic time (p. 830), and that it acted as a buttress during the Laramide Revolution which resisted intense deformation while the thicker lense of sedimentary rocks to the east folded and were thrust against it. They applied the name "Northern Utah Highland" to this positive area.

If this hypothesis is essentially valid, then it may be assumed that some, perhaps most, of the Paleozoic deposits thinned over the Highland, that some may have never been deposited, and that others may have been partially or completely removed by erosion during certain epochs of Paleozoic time. Further, there may have been periods when the Highland lost its positive tendencies so that some Paleozoic formations underwent no thinning over it.

The foregoing assumptions are partly supported by direct evidence, but much must be left to speculation based on the existing regional structural and stratigraphic picture. Westward thickening from the Highland can be demonstrated by a comparison of the sections in the Lakeside Mountains and the Stansbury Peninsula. Although the section in the Stansbury Peninsula has not been measured, the writer has traversed it and has a tentative idea of the exposed formations and their relative thicknesses. There is a virtual, perhaps, complete absence of Silurian rocks in the Peninsula (Stokes, personal communication), whereas 13 miles to the west in the Lakeside Mountains the Silurian rocks are over 500 feet thick. This, together with noticeable thickening of Ordovician and Devonian formations between the Peninsula and the Lakeside Mountains, probable thickening in the Cambrian and Mississippian formations, and postulated thickening in the Oquirrh formation and Proterozoic rocks, indicates that the positive tendencies of the Highland area were being felt to some extent in the vicinity of the Stansbury Peninsula, and that the area of the Lakeside Mountains was one of appreciable subsidence although it lay somewhat east of the deepest part of the Paleozoic (and Proterozoic ?) trough.

Admittedly, some of this westward thickening can be attributed to the regional stratigraphic trend of thickening between the foreland and the geosynclinal trough. However, the fact that such abnormally rapid westward thickening occurs in the Ordovician, Silurian and Devonian systems between the Stansbury Peninsula and Lakeside Mountains would seem to indicate a local acceleration of the regional trend.

Thickening to the northwest and south of the Highland cannot be demonstrated, but is proposed on the basis of regional structural and stratigraphic trends. The great thickness of up to 30 thousand feet of Upper Mississippian, Pennsylvanian and Permian rocks deposited south of the Highland area in the Oquirrh Basin probably rapidly decreased to 1/2 or 1/3 of that over the Highland. Such rapid thinning may have been of considerable significance in localizing the postulated zone of structural adjustment (shift zone) along the south side of the Highland.

Thinning of Triassic and Jurassic rocks over the area is also impossible to demonstrate. The Lower Triassic seaway probably covered much or all of western Utah. The complete absence of outcrops renders it unprofitable to speculate about the deposition of post-Lower Triassic rocks in the area.

Thus, even though Mesozoic thinning is impossible to demonstrate, it is probable that by late Jurassic time the aggregate thickness of sedimentary rocks, including Proterozoic, occurring over the Northern Utah Highland area was somewhat less than the aggregate thicknesses of sediments occurring about the Highland. The author suggests that the thinness of sedimentary cover over the Highland area probably accentuated its tendency to act more or less as a structural unit, and under regional compression, resulted in its acting as a semi-rigid knot while the thicker sediments about the Highland yielded by folding and thrusting. The Highland acted, relatively, as a plunger on its eastern side and a buttress on its western side. The plunger effect resulted in the relative westward thrusting (onto the Highland) of the thick lense of Paleozoic, Jurassic and Triassic rocks lying immediately east of the Highland (Eardley, 1944). The buttressing effect resulted in the tight folding and large-scale overturning of the thick geosynclinal sediments in, and south of the Grassy Mountains area immediately west of the Lakeside Mountains (fig. 2). Transverse shift zones would, of necessity, have formed north and south of the Highland to accomodate the differential shortening between the relatively rigid Highland and the fairly pliable sediments to the north and south. There is some evidence of such a zone on the southern side extending in an east-west direction from the vicinity of the north end of the Oquirrh Mountains, where the strata trend roughly east-west in tight folds, through the area between the Stansbury Mountains and Stansbury Peninsula, to the vicinity of the south end of the Lakeside Mountains, where it is proposed that the Lakeside fault may help terminate the shift zone (Fig. 2). The previously mentioned faults cutting southeastward through the Stansbury Peninsula might also join this shift zone.

Evidence of such a zone north of the Highland is lacking. In fact, the northern boundaries of the Highland are so indefinite that the position of such a zone, if it does exist, is impossible to place due to lack of knowledge of the area. It might be noted, however, that Eardley (1940, Plate I) has mapped a northeast trending thrust crossing the southern end of the Promontory Peninsula which may possibly be a reflection of such a zone (Fig. 2).

Age of Folds and Faults

Time of Folding

No direct evidence was found to date the folding in the Lakeside Mountains. One period of major folding seems to be evident. Lesser periods of rather minor folding followed the major folding, with the latest one probably accompanying, or resulting from, the late Tertiary and Pleistocene Basin and Range faulting.

The writer suggests that the major folding may have commenced in very late Jurassic time and culminated in early Cretaceous time. Regional evidence for deformation at this time includes: 1) uplift, and, possibly, folding and thrusting in southeastern Idaho during very late Jurassic -- early Cretaceous time is strongly suggested by the presence there of the upper Jurassic -- Lower Cretaceous (?) Ephraim conglomerate (Stokes, 1944, p. 969); and, 2) in central Utah upper Jurassic (?) and/or Lower Cretaceous conglomerates of the Morrison (?) formation in the Gunnison area are indicative of nearby orogeny to the west. Since the Lakeside Mountains lie between, and somewhat west of these areas, it is not unreasonable to suppose that they, too, were deformed at this same time. 3) Indirect evidence for uplift, and at least some deformation in this intervening area is offered by the thick, conglomeratic Lower Cretaceous Kelvin formation occurring in and east of the northern part of the Central Wasatch Mountains (Stokes, 1944, p. 970).

The Upper Cretaceous-early Tertiary folding and faulting, so well demonstrated in the Wasatch Mountains, was probably of less importance in the Lakeside Mountains area than the proposed late Jurassic early Cretaceous deformation. This was due to the fact that much of the sedimentary cover of relatively large areas of western Utah (including the Lakeside area) was shed during and following the earlier deformation, so that, when compressional forces again swept the area in late Cretaceous and early Tertiary time, the forces were, this time, transmitted primarily through the competent "basement" rocks.

The earlier formed folds in the sedimentary cover of the region were, generally speaking, only moderately intensified in Laramide time. The full brunt of the Laramide forces were felt in the thick lense of sediments east of the Northern Utah Highland.

A later, rather minor period of gentle folding resulted in the already described (p. 40) east-by-northeast-trending anticlinal warp forming at right angles to the earlier trend of folding. There is a possibility, however, that this east by northeast folding may have been slightly prior to the Laramide Revolution and related to the east-west folding of Montana age described by Eardley in the north-central Wasatch Mountains (1944, p. 865).

The latest folding in the Lakeside Mountains appears to have accompanied the latest, or "Basin and Range" fault movement along the Lakeside fault. This is demonstrated by the drag along the northern part of the fault. It is conceivable that such drag may be of an earlier period of faulting, but since folding of this type is found fairly commonly along so-called Basin and Range faults, it's age is probably late Tertiary and/or younger.

Time of Faulting

There is evidence of at least two distinct periods of major faulting, separated by a long time interval, along the Lakeside fault. This evidence consists of the following: 1) The Lakeside fault has a maximum stratigraphic displacement of over 9000 feet compared with a maximum present-day topographic relief of only 2600 feet. Since there is some evidence (see "Geomorphology" below) that most of this later displacement of approximately 2,600 feet took place after the development of a sub-mature topographic surface in middle Tertiary time, i.e., in the Basin and Range time of faulting, then the remaining 6500-7500 feet of displacement must have occurred before -- most likely during very late Jurassic and early Cretaceous time, or late Cretaceous and early Tertiary time. 2) If the 9,500 feet of vertical movement had occurred in Basin and Range time, it is improbable that most of this could have eroded since, especially in view of the fact that the maximum amount of Basin and Range faulting along the Wasatch fault was probably somewhat less than 7000 feet, but the Wasatch Mountains, even though they received several times the precipitation of the Lakeside Mountains during Pleistocene time, still rise as much as 7000 feet above the adjoining valley floors. 3) If all the faulting had occurred before Basin and Range time, then the present abrupt, linear front -- with fault breccia still clinging in places -- would have to be attributed entirely to fairly recent differential erosion along the fault; the older, harder rocks making up the resistant or mountain block and the younger and softer rocks comprising the valley block. Interestingly enough, along much of the southwestern side of the Lakeside Mountains, the hard and dense early and middle Paleozoic formations do comprise the mountain block and the softer, more easily eroded Manning Canyon formation makes up much of the valley immediately adjacent to the fault. The best argument against a purely "differential erosion" theory for the present relief of the Lakesides, however, is that as the mountain block is traced northward from slightly northwest of the point where the Lakeside fault makes its abrupt change in direction (Plate I), the throw of the fault increases, and the age (and, presumably, hardness) of the rocks increases, but the height of the mountain block, instead of increasing too, decreases and finally nearly dies out entirely. And just before the northwestward trace of the fault begins to become obscure, hard, dense and massive Cambrian limestones and dolomites are in fault contact with soft Manning Canyon formation; yet, the mountain front is rapidly decreasing in height, abruptness and linearity.

The foregoing evidence, then, indicates at least two distinct, and long-separated intervals of faulting in the Lakeside Mountains.

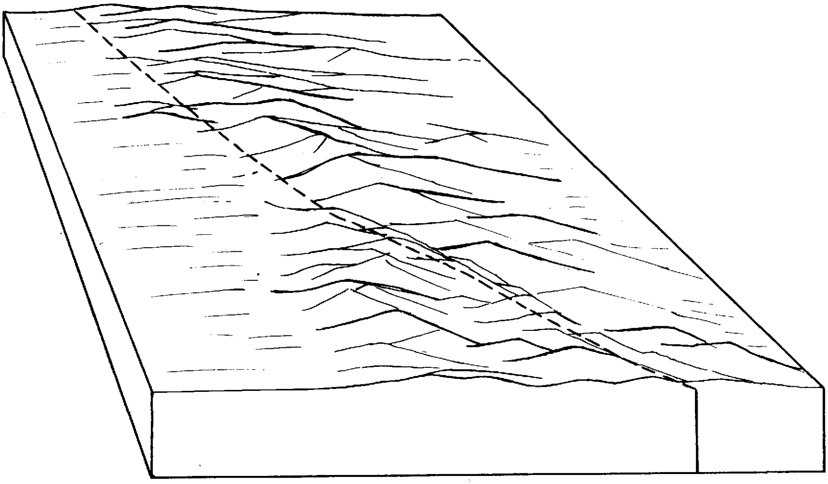
From a consideration of morphologic evidence, there is little question that the latest faulting occurred during the so-called Basin and Range period of deformation which began in late Tertiary time and has continued intermittently to the present.

The earlier period of faulting, however, is not so easily placed. In the discussion of folds it was suggested that the initial period of folding in the Lakeside Mountains was also the most intense. Now the proposal is made that the major faulting of the region accompanied this initial, most intense folding, and resulted in a maximum stratigraphic displacement of possibly 6500 to 7500 feet. Since the date of this folding is conjectural, the time of the first faulting must remain in question too, and await the time when additional information on the region may help clarify the problem.

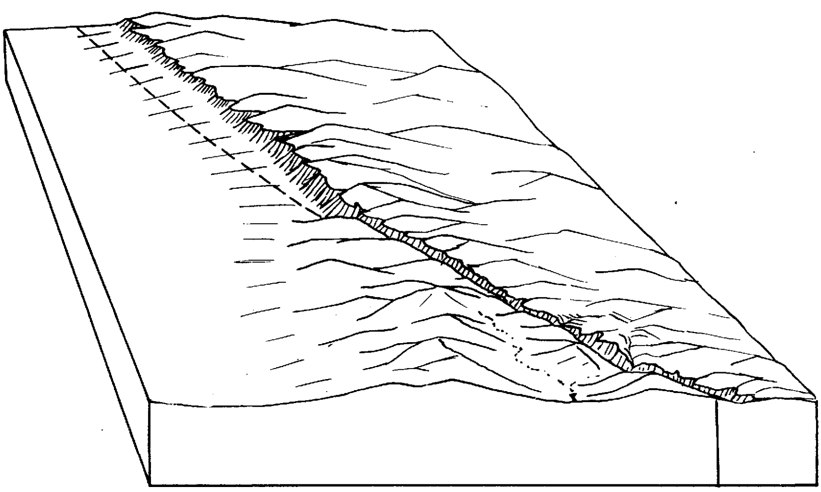
GEOMORPHOLOGY

Morphologically, the southern part of the Lakeside Mountains may be classed as a tilted fault block. The range is bounded on the west side by a large high-angle fault which is responsible for the fairly straight and topographically abrupt western face. The highest elevations occur close to the western border of the range and decrease gradually toward the east side which is irregular in form and consists of numerous alluvial embayments and intervening spurs.

As previously mentioned (p. 49-52), most of the present relief of the range is believed to be due to late Tertiary and Pleistocene faulting along an older fault which had its inception either in very late Jurassic and early Cretaceous time or late Cretaceous and early Tertiary time. A period of relative quiescence preceded the late Tertiary and Pleistocene faulting and allowed the development of a mature to submature topography over a wide area in northern Utah which has already been described by Gilluly (1928, p. 1118-1122) and Eardley (1933). Remnants of this ancient topography may possibly exist along the crest of the Lakeside Mountains as evidenced by the fairly flat and even crestline which may be best observed from state highway 36, slightly south of Tooele, or from the crest itself. This evidence is only suggestive of such a surface, however, and there may have been instead, prior to the

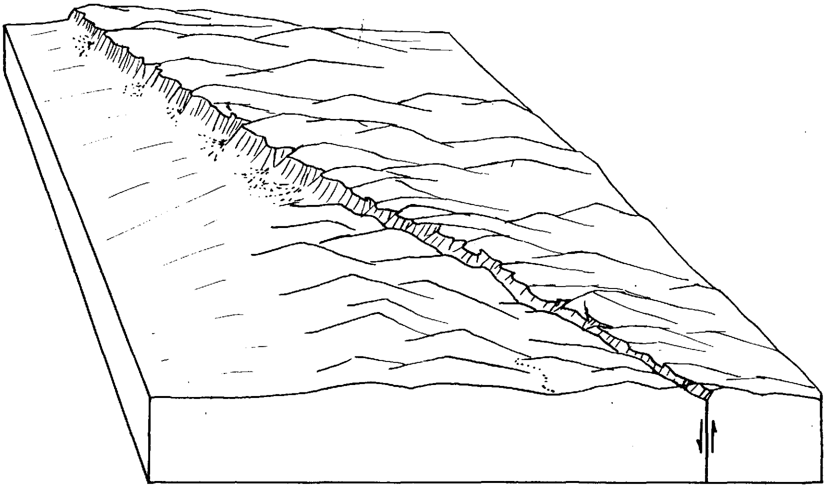


1. Low hills are all that are left of ancestral Lakeside Mountains following prolonged mid-Tertiary erosion. Trace of Lakeside fault shown as a dotted line.

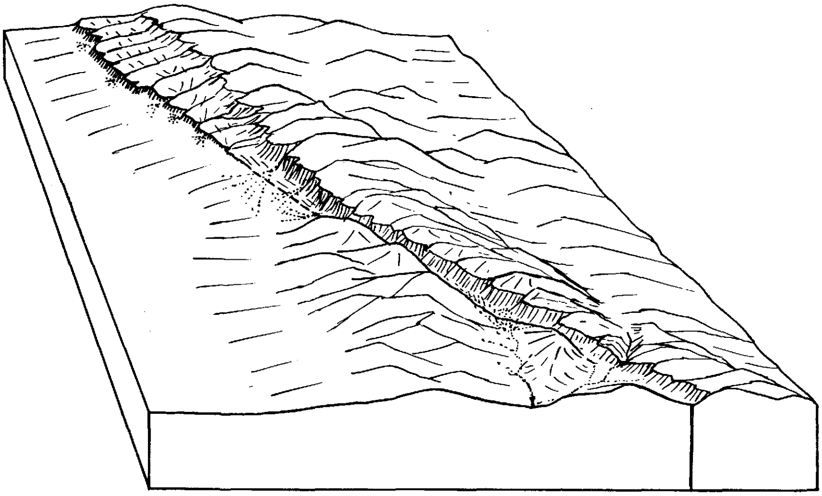


3. Unprotected part of fault front eroded back and pediment forms. Debris from erosion of scarp carried to lower-lying valleys.

Plate II. Postulated Geomorphic Development of the Lakeside Mountains from Late Tertiary Time to the Present



2. Late Tertiary inception of Basin and Range faulting. Lakeside fault rejuvinated.



4. Renewed movement along northern part of fault offsets pediment, and erosion cuts deep gullies in new scarp.

Plate II. Postulated Geomorphic Development of the Lakeside Mountains from Late Tertiary Time to the Present

Plate IIa. The Lakeside Mountains, looking north along the boundary between Rs. 8 and 9 W., from U. S. Highway 40, showing the mature topography of the southern end of the range. This topography was inherited from the period before the Basin and Range faulting, inaugurating Tertiary uplift. The saddle left of center marks the trace of the Lakeside fault which bounds the west side of the range north of this saddle and then crosses the range diagonally to become lost in the mature foothills to the right of the picture. Foreground is lake marl of Quaternary age.

Basin and Range faulting, an area of low hills occupying the site of the present topographically high areas in the Lakeside Mountains, reflecting the inequalities in hardness of rocks in juxtaposition from the older movements along the fault. Such a topography could still be considered in the sub-mature stage of development.

Plate II expresses diagramatically the postulated geomorphic history of the Lakeside Mountains since their rejuvenation in late Tertiary or early Pleistocene time.

1). Low hills are all that are left of the ancestral Lakeside Mountains following prolonged mid-Tertiary erosion. Trace of the Lakeside fault is shown as dotted line.

2). Late Tertiary (many writers have suggested middle or late Miocene) inception of Basin and Range faulting. Earlier-formed, high angle Lakeside fault, coinciding with the Basin and Range trend of faulting, is rejuvinated, and, intermittently, its eastern side moves relatively upward as much as 2000 feet. The maximum movement probably centers in sections 1 and 2, T. 1 N., R. 9 W., and section 35, T. 2 N., R. 9 W. (Plate I), with offset decreasing in both directions. The movement on the fault is accompanied by gentle regional upwarping of the area

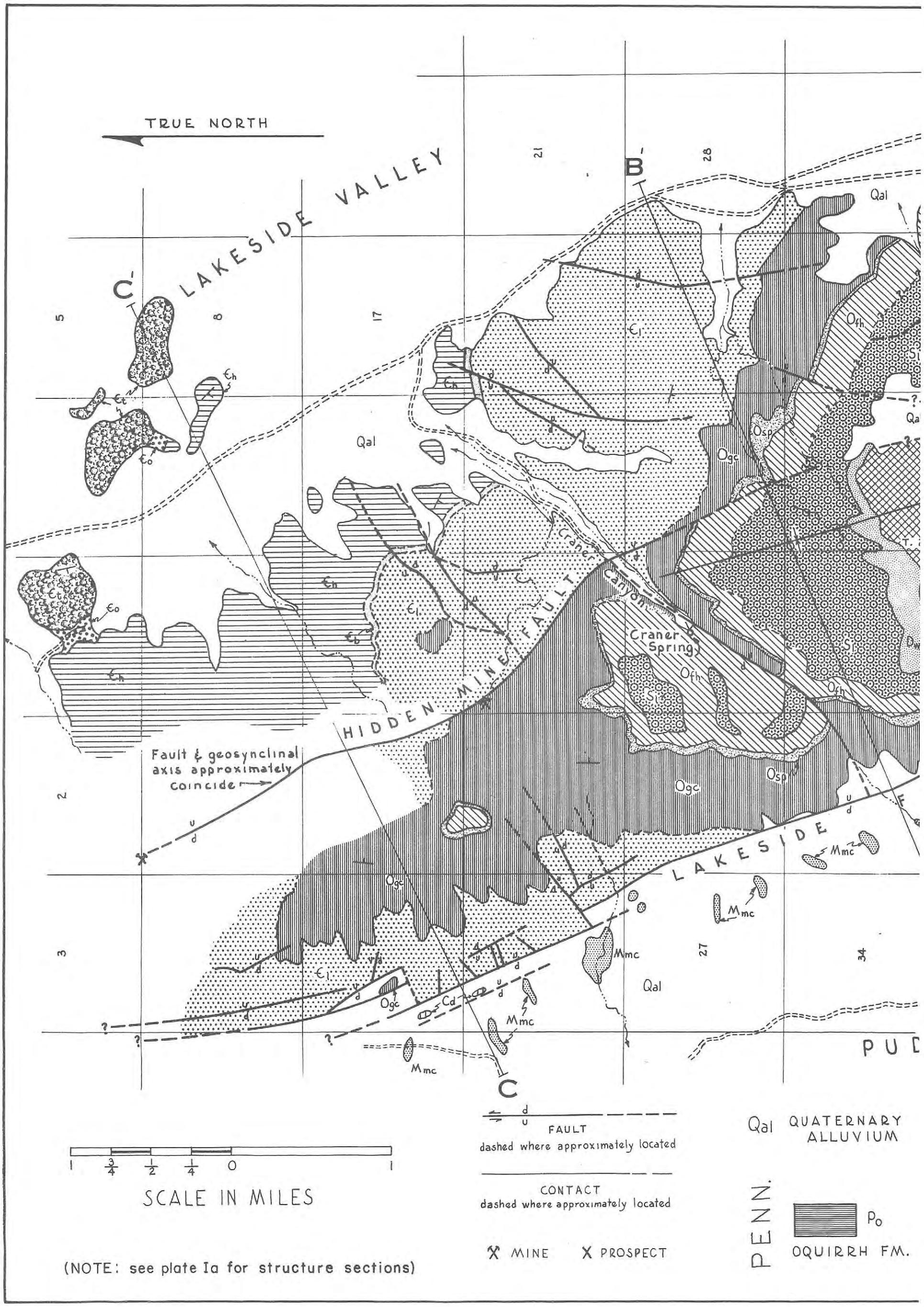
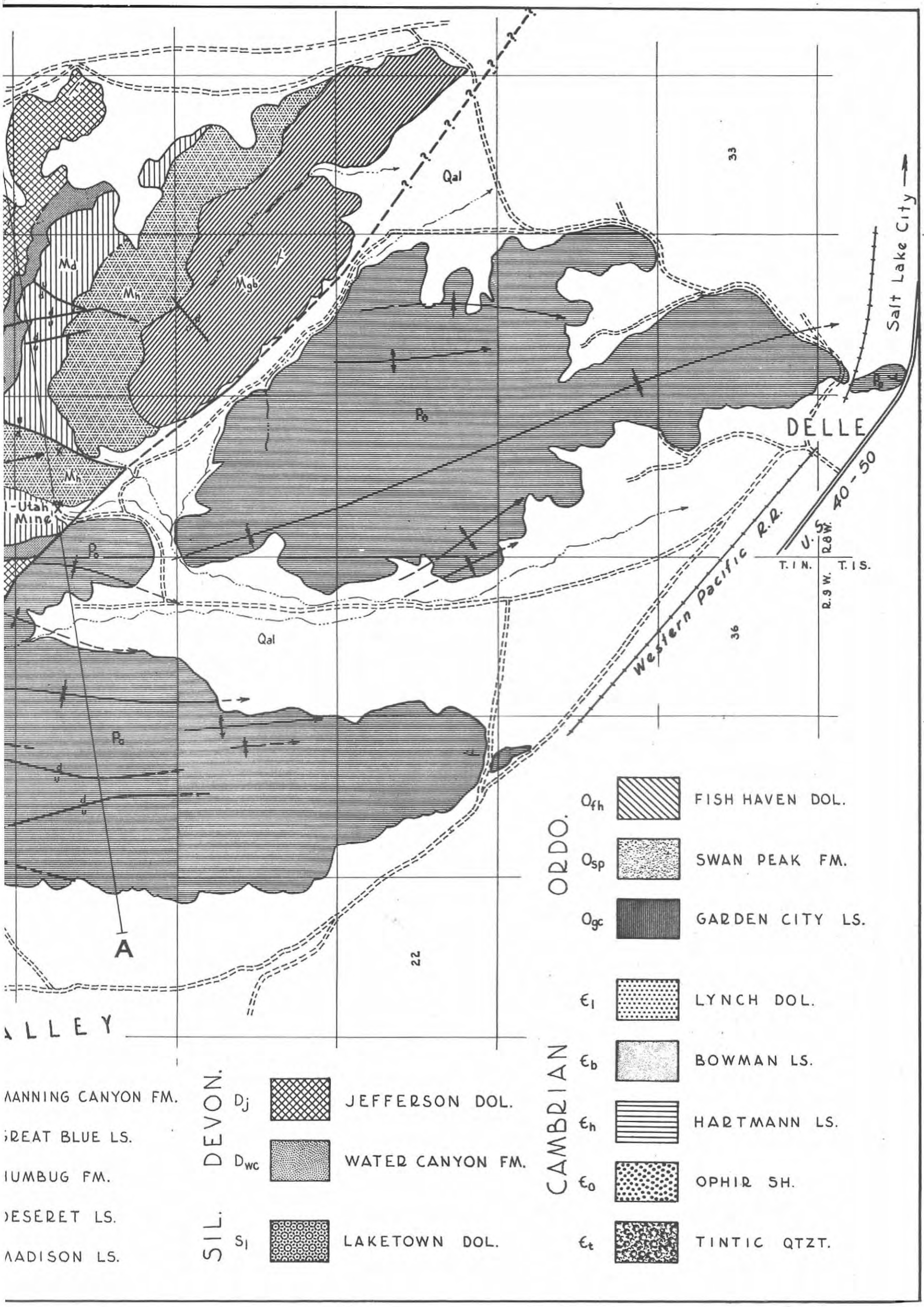
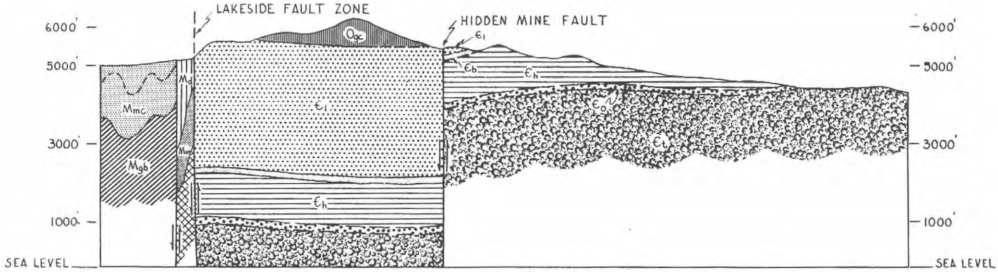


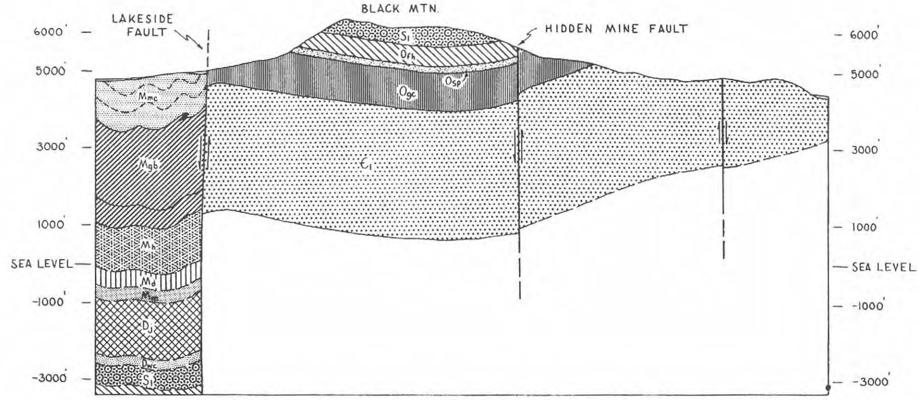
PLATE I. GEOLOGIC MAP OF SOUTHERN



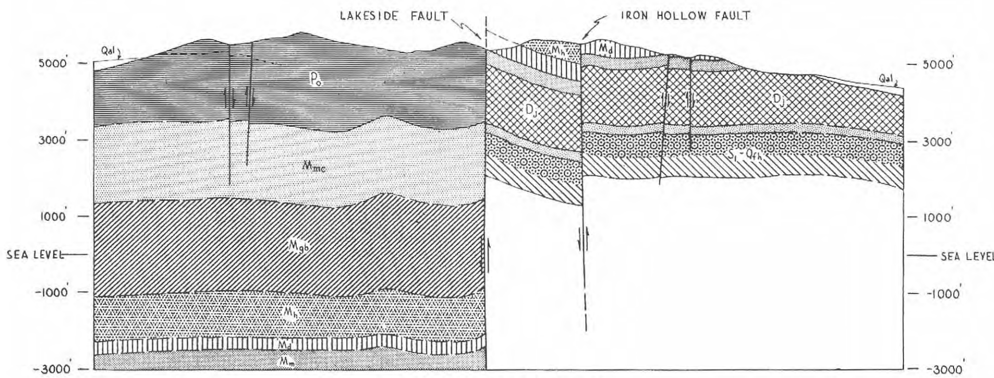
E MOUNTAINS, TOOELE COUNTY, UTAH



STRUCTURE SECTION C-C'



STRUCTURE SECTION B-B'



STRUCTURE SECTION A-A'

PLATE Ia. STRUCTURE SECTIONS IN THE LAKESIDE MOUNTAINS, TOOELE COUNTY, UTAH

(SEE PLATE I FOR LINES OF SECTIONS)

HORIZONTAL SCALE: 0 — ½ — 1 one mile

centering about Puddle Valley and extending eastward into the Lakeside Mountains, southward into the Cedar Mountains and westward into the Grassy Range.

3). Because of the regional upwarp, most of the sediments which are shedding onto the downdropped block are, in turn, carried into the adjacent, lower-lying Great Salt Lake Basin and Skull Valley on the east and Great Salt Lake Desert on the west. Those areas in the downdropped block which are composed of the soft Manning Canyon formation are easily eroded and gradually form into a pediment. The fault scarp adjacent to these easily eroded beds is left open to full-scale attack by erosion and the mountain front is gradually worn back from the fault trace and finally coalesces with the pediment forming west of it. The trace of the fault through this segment is obscured. The scarp southeast of this area of Manning Canyon, however, is protected by the fairly resistant Oquirrh formation adjacent to it in the downdropped block and is not worn back appreciably. The trace of the fault beneath the pediment is shown as a dashed line.

4). Latest stage of faulting (post-Tertiary -- pre-Lake Bonneville) results in uplift of up to 500 - feet in sections 10, 15, 22, 26, 27, T. 2 N., R. 9 W. (Plate I). The pediment is offset vertically and has been trenched by deep and narrow washes. The scarp remains abrupt, and in places, has remnants of the original fault breccia plastered to it. This most recent faulting dies out southeastward, and in sections 1, T. 1 N., R. 9 W., and 35, T. 2 N., R. 9 W., the pediment has not been appreciably elevated and forms a minor reentrant in mountain front. The trace of the fault through this segment is dashed. The upthrown side lying adjacent to the resistant Oquirrh formation remains steep and abrupt, although large washes have cut headward through the Oquirrh and are now beginning to vigorously erode the scarp.

GEOLOGIC HISTORY

Reconstruction of the geologic events occurring in the Lakeside Mountains area during much of Paleozoic time and in late Pleistocene and recent times can be accomplished by studying the present-day exposure of the corresponding deposits. Since Mesozoic and Cenozoic rocks are missing or not exposed, geologic events during Mesozoic and Cenozoic times must be postulated on the basis of events in adjoining regions where stratigraphic evidence is at hand. Precambrian rocks, consisting of tillites, and argillaceous and arenaceous beds are found in some of the islands of Great Salt Lake and constitute the nearest known exposures of these rocks (Eardley and Hatch, 1940, p. 796-97).

The known geologic history of the Lakeside area began with the deposition of great quantities of sand and fine-grained conglomerate in early Cambrian time. These beds were deposited in a slowly transgressing early Cambrian sea. The fine-grained conglomerate may have been derived from exposures of lower Precambrian (Archeozoic ?) rocks in the Northern Utah Highland area east of the Lakeside area. Seas continued to occupy the area sporadically during Middle and Late Cambrian times but surrounding land areas were now much lower. Great series of limestones and dolomites, with lesser amounts of shale, were deposited. The dolomites probably represent shallow-water conditions.

Ordovician, Silurian and Devonian periods witnessed frequent oscillation of the seas over the area. That the seas continued to be mostly shallow might be indicated by the predominance of dolomite over limestone. There were long periods of emergence, especially early in the Ordovician period and throughout much of the Silurian period. The sedimentary record indicates that the area was emergent for longer periods than it was submerged. Absence of beds representing much of this time may be attributed either to non-deposition or deposition and removal by subsequent erosion. That such removal took place is undoubted, but the lack of channeling or of abrupt variation in thicknesses of formations shows that the emergence was gentle and the lands were never far above sea level.

Thick Late Devonian conglomerates (Stokes, personal communication) in the northern Stansbury Mountains and several hundred feet of coarse sandstone and quartzite immediately below the Madison limestone in the Stansbury Peninsula indicate nearby unrest in Late Devonian time. Little evidence of this unrest could be found in the Lakeside Mountains. There, Mississippian limestones are separated from Devonian dolomites by a 1 to 3 foot bed of impure sandstone. The conglomerate and sandstone to the east may represent movement of the Northern Utah Highland in Late Devonian time.

Calcareous deposition became predominant in the Lakeside area following the Devonian. Limestones, with smaller amounts of calcareous siltstones and sandstones, comprise the Mississippian rocks. Deposits from the middle of the period are unrepresented. Notable change in the sedimentary environment following the deposition of a thick series of Upper Mississippian limestones, resulted in the black shales, impure orthoquartzites, and dark-gray limestones of the Upper Mississippian and Lower Pennsylvanian (?) Manning Canyon formation. Perhaps a large area of shallow, stagnant, sometimes toxic water with low-lying borderlands might approximate the conditions. Occasional floods of sand and silt could indicate minor unrest in adjoining areas or temporary changes in climatic conditions.

A gradual return of more normal marine conditions ensued in early Pennsylvanian time. Fairly rapid subsidence now began in the Oquirrh basin, and the Lakeside area, though somewhat removed from the center of the basin, was covered with several thousand feet of limestone and sandstone. Similar deposition probably continued into Permian time.

It is not known whether Upper Permian, Triassic, or Jurassic rocks were ever deposited in the area. Limestones containing the

Meekoceras fauna have been found near Salt Lake City and near Gold Hill, Utah (Nolan, 1935, p. 42). This suggests the presence of a lower Triassic sea in the intervening area. The nearest known occurrences of Middle and Upper Triassic, and of Jurassic rocks are in the Wasatch Mountains east of Salt Lake City. They have not been reported from western Utah. Paleotectonic maps published to date do not show Middle Triassic to Upper Jurassic sediments in the Lakeside area.

Regional compression from the west, postulated as beginning in very late Jurassic (?) time, resulted in the first major folding and faulting in the Lakeside area. The Lakeside fault probably came into being at this time, possibly having a fairly large strike-slip as well as dip-slip component. This orogenic phase corresponded to the Nevadan orogeny of western Nevada and eastern California, although it probably reached its climax in the Lakeside area in early Cretaceous time, somewhat later than to the west. The Northern Utah Highland, covered with a comparatively thin veneer of sedimentary rocks, acted as a semi-rigid structural unit which resisted intense deformation while the comparatively thick trough of sedimentary rocks to the west folded and overturned and those to the east buckled and thrust onto the eastern side of the Highland. Transverse shift zones formed along the southern border of the Highland, and possibly also along the northern border. Resultant uplift and erosion spread the

Lower Cretaceous Kelvin conglomerate eastward over northeastern Utah. Minor unrest continued in western Utah until late Cretaceous time when the strong compressional forces of the Laramide orogeny swept the region, again from the west. This time, however, some of the sedimentary cover of western Utah had already been stripped off as a result of the Nevadan orogeny and the main forces tended to be transferred eastward to the Wasatch area by the more competent "basement" rocks. Thus, the earlier-formed folds and faults in western Utah were now merely accentuated and, very likely, some new high-angle basement controlled faults were formed.

Laramide forces gradually subsided, and by middle Tertiary time the region was fairly quiet. As a consequence, a sub-mature to mature topography was developed over a wide area of northern and western Utah. In late Tertiary and Pleistocene times, compressional (?) forces were again felt over a wide area of western North America. The Great Basin region yielded this time by block-faulting on a large scale. Many of these faults followed older lines of faulting. Others broke along previously unfaulted lines. The faulting during this time, whether following older faults or breaking along new lines, was predominantly basement-controlled and tended to form wedges and tilted fault blocks, some of which likely passed into high-angle reverse faults at depth. This type of faulting offered vertical relief to the compressional (?) forces and folding was minimized due to this plus the fact that the sedimentary cover was fairly shallow in many places. The Lakeside Mountains were rejuvinated at this time and their bold western escarpment and rather even crest-line resulted. Evidence that this type of faulting has continued to the present time is offered by the presence of basal scarplets along many ranges of the Great Basin and by earthquakes such as the Pleasant Valley earthquake of Nevada in 1915 which was merely the rejuvination of a typical Basin and Range fault.

DETAILED MEASURED SECTIONS

Mississippian System

Great Blue limestone	Thickness in feet
Fault (Great Blue limestone incomplete)	
1. Limestone: medium to dark gray; weathers light blue-gray; dense; massive; very fossiliferous (bryozoa; brachiopods, few corals); abundant medium to large black chert nodules which weather predominantly orange to light tan	11
2. Limestone: same as #1 except less fossiliferous and less cherty.	11
3. Limestone: same as #1	17
4. Limestone: same as #2	17
5. Limestone: lithographic; very dark gray; weathered medium gray; few fossils	19
6. Limestone: medium gray on fresh and weathered surface; medium crystalline to fragmental; very few fossils; lower 69 feet contains a few widely spaced black chert layers and lenses	86
7. Limestone: same as #6 except contains less chert and weathers blue-gray with a rough surface; occasional silicified cup corals. .	71
8. Covered: float indicates same as #7	70
9. Limestone: Same as #6 except fossils and chert increase in lower half until the lower 100 feet contains abundant layers, lenses and nodules of black chert which average 2-5 inches thick; lower 100 feet more resistant than above	311
10. Limestone: dark gray; weathers medium blue-gray; medium crystalline; dense; slightly cherty; fairly abundant fossil fragments and few silicified corals; resistant	15

Great Blue limestone continued	Thickness In feet
11. Limestone: silty; very dark gray, weathers light gray to light tan; very fossiliferous (bryozoa, corals, few brachiopods); upper 23 feet contains a few black chert lenses with a thin bed of calcareous sandstone near the top	30
12. Limestone: dark gray to medium blue-gray; weathers medium to light gray; texture ranges from coarsely crystalline to finely crystalline; mostly dense; contains abundant silicified cup corals; chert in thin irregular layers and occasional nodules	20
13. Limestone: same as #11 except that corals are very abundant and bottom 3 feet contains a thin sandy and silty layer which weathers buff.	38
14. Limestone: same as #11, except cup corals less abundant. . . .	144
15. Limestone: dark gray to medium blue-gray; weathers blue-gray; coarsely fragmental with sandy partings	34
16. Limestone: medium gray on fresh and weathered surfaces; medium grained crystalline: 15% of interval consists of black to dark gray chert lenses and nodules which weather brown to black; some fossil debris	22
17. Limestone: same as #15	43
18. Limestone: same as #16 except chert weathers rust to brown	21
19. Limestone: dark gray to medium blue-gray; weathers blue-gray; densely crystalline to coarsely fragmental; sandy partings; some small scale cross-bedding; sand medium to coarse grained and weathers out on surface; sandy partings decrease upwards and finally disappear near top	60
20. Limestone: same as #19 except for abundant lenses and nodules of black to dark gray chert which weather rust to brown and make up 15-25% of the unit	70
21. Limestone: same as #19 except sandstone partings occur throughout interval; top few feet becomes very coarse grained fragmental limestone	76

Great Blue limestone continued	Thickness in feet
22. Limestone: silty; tan to yellow on fresh and weathered surface; less resistant than above	4
23. Limestone: dark blue-gray to dark gray; weathers gray; dense; abundant fossil debris in part of interval; contains a few black chert lenses	64
24. Limestone: slightly sandy; fossiliferous; coarse grained to fragmental except for a fine grained and dense 12 foot layer near the middle of unit; upper 59 feet contains a few black chert lenses	103
25. Limestone: sandy; medium to dark blue-gray; weathers gray to tan; dense; thin bedded; few fossil fragments	20
26. Limestone: medium blue-gray on fresh and weathered surface; thick bedded; moderately resistant; occasional black chert stringers; very fossiliferous: contains abundant cup corals, organ-pipe coral colonies, crinoid columnals and a few brachiopods	24
27. Alternating limestone, sandy limestone; and calcareous sandstone; generally medium to dark gray and weathers tan to brown to blue-gray; limestone is fairly fossiliferous; poorly exposed	53
28. Sandstone: calcareous; dark tan-gray; weathers brown to light tan; fine grained and unfossiliferous.	24
29. Limestone: medium gray on fresh and weathered surface; medium to coarsely crystalline with fairly abundant fossil debris; few black cherty lenses which weather brown; occasional large cup corals; fairly non-resistant	59
Total exposed Great Blue limestone.	1537

Humbug formation		Thickness in feet
1.	Limestone: sandy and silty; very dark gray; weathers light tan to brown to occasionally gray; occasional sandy mottling on weathered surface; densely crystalline; mostly thin bedded; not very resistant	172
2.	Calcareous siltstone and silty limestone: very dark gray; gray to light tan on weathered surface; dense and unfossiliferous; siltstone mostly medium grained, upper few feet are sandy limestone	37
3.	Same as #2 except lower 17 feet is very thin bedded	51
4.	Siltstone: calcareous; very dark gray; weathers light gray; dense; resistant; concordant nodules and bands of black chert which are 2 to 8 inches thick and weathered mostly brown make up about 15% of bottom half of unit and 20% of top half; middle 16 feet of unit is sandy limestone which weathers brown to gray; unfossiliferous	40
5.	Limestone: sandy and silty, very dark gray, weathers gray to dark brown-gray to rust; dense; few nodules and lenses of black chert which weather brown, bedding units 1 to 4 inches thick, less resistant than unit above	27
6.	Siltstone: calcareous and carbonaceous; black; weathers grayish-tan; dense; thin bedded; non-resistant	27
7.	Interbedded sandstone, calcareous sandstone and siltstone, and silty limestone: sandstone and siltstone mostly dark gray to almost black and weathers dark brown to buff; limestone is dark gray and weathers medium gray with fairly abundant fossil debris	58
8.	Sandstone: brownish-gray to light buff, weathers dark to medium brown to tan; mostly medium grained but finer grained toward the top; cemented by calcite; both thin and massive bedding, occasional slight cross-bedding; fairly resistant and forms prominent outcrops; more massive beds are friable on weathered surface, grains consist mostly of quartz with a few grains of dark gray chert	150

Humbug formation continued	Thickness in feet
9. Siltstone: dark gray to almost black; weathers gray-brown to tan; calcareous; thin bedded; dense fine to coarse grained upper part very carbonaceous; lower part is porous on weathered surface	19
10. Sandstone: dark gray-brown to light tan-gray; weathers mostly brown to tan; fine to medium grained; well sorted; made up mostly of frosted, subangular quartz grains; cemented by calcite; lower 50 feet is non-resistant and thin-bedded; upper 34 feet is massive and resistant	84
11. Sandstone: same as #10 except more massive, and non-calcareous	90
12. Siltstone: dark gray to almost black; weathers light tan; medium to coarse grained; carbonaceous; thin bedded and fairly non-resistant except for a 7 foot bed of massive sandstone in upper 1/3 of unit	27
13. Sandstone: dark gray, weathers light brown; massive; fine grained; carbonaceous	27
14. Siltstone: mostly very dark gray; very dark to medium gray to tan on weathered surface; slightly to moderately calcareous; tight; well sorted; some beds very carbonaceous; generally thin bedded and non-resistant but several beds -- especially in the upper part -- are massive and resistant . .	165
15. Limestone: lithographic; very dark gray to almost black, weathers medium gray and smooth; unfossiliferous, medium bedded; resistant cliff former; lenses of black chert are fairly common in the lower 19 feet of unit and become very prominent (30 - 40%) and more continuous in upper 15 feet of unit; chert weathers light brown in lower part and dark gray to brown in upper part; upper 15 feet very resistant	34
16. Mostly covered: float indicates black, thin-bedded, slightly calcareous siltstone which weathers brown to light tan to occasionally lavender, unfossiliferous	88

Humbug formation continued	Thickness in feet
17. Limestone: very dark blue-gray; weathers medium to light blue-gray; densely crystalline; unfossiliferous; resistant; lower 3 feet has partings which are very slightly silty; upper 4 feet is massive	7
18. Mostly covered: probably the same as #16	41
19. Chert: black on both fresh and weathered surface; bedded in layers a fraction of an inch to 6 inches thick; a few thin silty layers lie between the chert layers	10
20. Covered: float indicates lithologies similar to #16	17
21. Limestone: coarsely fragmental; gray; weathers gray with a lavender tinge; consists mostly of fossil debris and fairly abundant small angular fragments of dark gray and black chert; lower and upper contacts covered but believed to mark the lowermost bed of the Humbug formation	2
Total Thickness of Humbug Formation . . .	1,173

Deseret limestone	Thickness in feet
1. Limestone: medium gray on fresh and weathered surface; thick bedded but non-resistant; fairly abundant layers and irregular lenses and nodules of black chert which weather brown; fairly fossiliferous (mostly hash)	53
2. Interbedded chert, dolomite, and limestone: chert is black and in two layers each 1 foot thick and separated by a 1 foot bed of gray dolomite; 3 foot bed of blue-gray resistant limestone forms upper half of interval; chert weathers brown, entire unit is resistant	6
3. Mineralized layer (upward boundary believed to be controlled by massive chert layers described in #2): consists of medium gray dolomite (dolomitized limestone ?) interspersed with white calcite veins up to 2 feet thick and occasional fragments of black chert, some iron staining on weathered surface . . .	10
4. Limestone: medium gray on fresh and weathered surface; non-resistant; fossiliferous; occasional lenses of black chert; very rough on weathered surface	15
5. Limestone: medium gray on fresh and weathered surface; very fossiliferous (corals, gastropods, crinoid columnals); resistant -- forms a ledgy cliff; ledges formed by thin silty layers (up to 1/2 inch) separating units of limestone 4-8 inches thick; contains a few layers and lenses (1 - 2 inches thick) of black chert; upper 20 feet is more resistant than that below and forms a cliff	75
6. Limestone: medium to dark gray, weathers medium gray to blue-gray; mostly fragmental (much fossil debris), cemented by calcite; less resistant than units above and below and forms a talus slope of angular, blocky, to almost shaly talus; contains a few silicified corals, upper 29 feet is very fossiliferous with some layers consisting entirely of fossils and fragments, fossils include Euomphalus sp., Camarotoechia sp., Spirifer sp.	89

Deseret limestone continued	Thickness in feet
7. Limestone: same as #8 except resistant cliff former	20
8. Limestone: medium to dark gray; weathers medium gray to blue-gray; medium crystalline to fragmental; fragmental layers tend to be slightly cross-bedded; fossiliferous; mostly thin bedded and not very resistant; occasional iron stained shaly partings; weathered surfaces generally fairly smooth; upper 1/3 of unit contains a few lenses of black chert; silicified corals are very abundant in certain layers	151
Total Deseret limestone	419

Madison Limestone	Thickness in feet
1. Limestone: dark gray; weathers gray to blue-gray with a rough pitted surface; finely crystalline in upper half but medium crystalline to fragmental in lower half, lowermost part of upper half contains numerous stringers and blebs of black chert up to 6 inches thick; chert weathers brown to orange-brown; lower half contains abundant brachiopods and fragments; generally massive throughout unit	71
2. Limestone: cherty; limestone is dark gray and weathers gray; finely crystalline to finely fragmental; chert makes up about 30% of unit and is in thin discontinuous to continuous layers and lenses which parallel bedding; chert is black, calcareous, and weathers brown to tan to brown-orange; this unit forms a distinctive and easily recognized cliff at most exposures	39
3. Limestone: dark blue-gray; weathers blue-gray with a rough surface; fairly fossiliferous; lenses and irregular nodules of black chert (1-3 inches thick) occur at intervals of 2 to 3 feet; chert weathers black to dark brown; resistant cliff former	30
4. Limestone: dark blue-gray; weathers gray to blue-gray; medium crystalline to finely fragmental; thin bedded with bedding very irregular and lensy; fossiliferous (including Tetracoralla, Syringoporidae, and crinoid columnals not as resistant as cliff forming units above but still fairly resistant	164
5. Limestone: mostly covered but probably about the same as #4 except less resistant and very slightly silty	20
6. Limestone: sandy and impure; light gray to tan-orange on fresh surface; weathers mostly light tan-gray; thin bedded and non-resistant; sand grains similar to those found in thin sandstone layer which separates the Devonian from the Mississippian (see #7); apparently gradational into overlying unit; contact with underlying sandstone layer was not observed	4

Madison limestone continued	Thickness in feet
7. Sandstone: coarse to very coarse grained, grains are clear to very light amber quartz, angular to sub-angular and mostly frosted, there are a very few small particles of magnetite (?) included, sandstone is cemented by silica, iron, and calcite (specimens examined under the binocular microscope show each separately and all three together), not very well sorted, weathers a light tan to buff with occasional lenses and layers of deeply tinted orange, red, and brown iron staining, upper contact not observed, lower contact appears abrupt, conformable, and fairly regular, unit averages about 1 foot in thickness but was observed to be up to 3 feet thick	1
Total Madison limestone	329
Total exposed Mississippian	3,458

Devonian System

Jefferson dolomite		Thickness in feet
1.	Dolomite: silty; light brown-gray to dull orange-gray, very light tan; dense; non-resistant, most of interval below bed here described is covered but float indicated similar lithologies that gradually grade into #2	47
2.	Dolomite: mostly gray; weathers light gray; fine grained crystalline; float indicates some dense thin bedded brown dolomite which is not seen in outcrops; interval is thin bedded and weathers to smooth surface; upper 55 feet is slightly calcareous and exhibits occasional undulatory bedding	112
3.	Dolomite: gray to gray brown; weathers light gray; slightly calcareous; fine to coarse grained crystalline; very thin bedded where bedding apparent	58
4.	Dolomite: medium to light gray; light gray on weathered surface; slightly calcareous; few small vugs; thin bedded. .	54
5.	Dolomite: medium gray; light gray on weathered surface; fine grained crystalline; thin to medium bedded except bedding not apparent throughout much of upper 150 feet of interval; some layers in upper 80 feet weather with indistinct blebs	224
6.	Dolomite: gray to dark gray; weathers light to medium gray; medium to fine grained; mostly dense; middle 1/3 is very slightly silty and weathers light gray to occasionally buff	121
7.	Dolomite: medium gray; weathers light gray; coarsely crystalline; thin bedded where bedding apparent; 10 foot layer of slightly silty dolomite in upper 1/3 of unit	124
8.	Dolomite: sandy; medium to light gray; thin bedded; bedding undulates, sand grains medium to very coarse . .	4
9.	Dolomite: medium gray; weathers light gray; few vugs; coarsely crystalline to fragmental (?) near top; more resistant than above units	22

Jefferson dolomite continued	Thickness in feet
10. Dolomite: dark gray; coarsely crystalline; thin bedded; contact with unit below is undulating with relief of up to 4 inches; 1 foot above contact is a 10 inch layer of chert concretions up to 6 inches in diameter; many fossil fragments	11
11. Dolomite: dark to medium gray on both fresh and weathered surface; medium to coarse grained crystalline; mostly thin bedded; top 4 feet has numerous small (1/4 - 1/2 inch) vugs	37
12. Sandstone: consists of coarse, angular to subrounded white quartz grains; weathers brown to dark brown; contact with dolomite above and below is sharp and regular	3
13. Dolomite: dark to medium gray; medium to coarsely crystalline; vuggy (calcite filled) in part; occasional irregular or undulating bedding contains fossils (Cladopora) near top	38
14. Dolomite; slightly sandy; gray; weathers light gray; fine to medium crystalline	6
15. Sandstone: consists of fine to medium grains of white quartz which weathers buff to reddish-brown; persistant	2
16. Dolomite: similar to #13	5
17. Dolomite: dark gray; finely crystalline; dense; medium bedded (1 - 3 inches); vuggy and mottled in part; two very vuggy intervals with vugs filled with calcite	68
18. Dolomite: medium gray on fresh and weathered surface; very coarsely crystalline; thin bedded; near top of unit is a 1 foot bed of gray chert which weathers brown and appears to be fairly continuous although it varies somewhat in thickness	21

Jefferson dolomite continued	Thickness in feet
19. Sandstone: consists of coarse, subrounded grains of white quartz; weathers brown to light tan; small scale torrential cross-bedding in part	6
20. Dolomite: sandy; dark gray, weathers medium gray with brown sand forming thin laminations on weathered surface; coarsely crystalline	7
21. Dolomite: dark gray; weathers medium gray; thick bedded (apparently 1/2 - 1 1/2 feet), slightly mottled in middle of unit becoming vuggy (1/2 - 1 inch in diameter and filled with calcite) in middle and top of unit; few irregular blebs of chert near top	45
22. Dolomite: dark gray; medium bedded (1 - 2 inches), few vuggs filled with calcite	14
23. Dolomite: medium to light gray on fresh and weathered surface; massively bedded; medium to fine grained crystalline; becomes mottled (medium and light gray) at top	13
24. Dolomite: medium to dark gray on both fresh and weathered surface; dark gray predominates; thin bedded in part (less than 1/10 inch) but forms massive units; mostly medium crystalline; vuggy in part; upper 40 feet weathers to smooth surfaces, is slightly mottled, and the bedding is not apparent; 41 feet above the base of the unit is a 2 foot zone containing small dolomite concretions and calcite filled vugs (1 inch in diameter).	86
25. Dolomite conglomerate: consists of angular fragments of light and dark gray dolomite up to 1 1/2 feet in length and in haphazard arrangement, layer varies from three to five feet in thickness, contact above conglomerate is irregular with relief of up to 3 feet; 6 foot bed of dark gray, somewhat deformed dolomite immediately above conglomerate which contains small white blebs and stringers arranged parallel to bedding	10

Jefferson dolomite continued	Thickness in feet
26. Dolomite: dark gray on fresh and weathered surface; medium to coarse crystalline; very thin bedded but resistant; bedding irregular in part; vuggy in part	27
27. Dolomitic conglomerate: jumbled and disoriented layer of angular fragments of dolomite and silty dolomite; layer varies in thickness from 2 - 4 feet with up to three feet of relief on the upper contact	3
28. Dolomite: dark to medium to light gray; weathers predominantly medium gray; medium to coarsely crystalline. . .	25
29. Dolomite: alternating layers of dark to medium gray; weathers medium to very light gray in layers ranging from several inches to 3 - 4 feet thick; lighter layers generally very finely crystalline; darker layers generally medium to coarse crystalline; thin (1/16 inch) and undulating bedding seen in larger units; upper half of interval consists of beds which are slightly to very vuggy; smaller vugs generally filled with calcite and dolomite; some of large vugs are up to 3 inches in diameter; top 10 feet contains small irregular blebs of chert	92
30. Dolomite: dark gray to brown in lower part becoming dark gray in upper part; lower part weathers dark to light gray; upper part dark gray; some thin and irregular bedding; may show small scale channeling	4
31. Dolomite: medium gray; weathers light gray; dense; very slightly calcareous	17
32. Dolomite: dark gray; weathers medium to light gray; finely crystalline and dense; massive; top 2 feet is finely laminated and separated from beds below by an irregular surface with 4 - 5 inches relief; small scale channeling and crumpling in top part	14
33. Dolomite: dark gray; weathers dark to medium gray; some undulating bedding; irregular blebs seen on weathered surface which cut across bedding planes	12

Jefferson dolomite continued	Thickness in feet
Note: units 8 through 33 of the Jefferson dolomite are more resistant than those immediately above and those below and form an imposing step -- like cliff which has a dark gray color when viewed from a distance.	
34. Dolomite: shaly; non-resistant; mostly thin bedded; color varies from buff to very dark gray with dark gray predominant; several thin layers are phosphatic (?) appearing; dolomite is coarse to finely crystalline; shaly partings	45
35. Sandstone: light brown to buff on both fresh and weathered surface; consists of coarse to very coarse grains of subangular white quartz cemented by iron stained calcite; resistant; slightly cross-bedded; about in middle of unit is an 8 - 12 inch layer of fine conglomerate which is composed of very coarse grains of quartz and larger angular to subrounded pebbles of dolomite	7
36. Dolomite; shaly partings; dark gray on fresh and weathered surface; fine to coarsely crystalline; smooth to saccharoidal on weathered surface; dense; thin bedded; non-resistant . . .	16
37. Shale and dolomite: 8 inch layer of dark gray to black, coarsely crystalline, thin bedded, resistant dolomite topped by about 5 feet of non-resistant (partly covered) dense black shale which weathers brown to lavender	6
38. Dolomite: medium to dark gray on fresh and weathered surface; finely crystalline and dense; thin bedded -- laminated in part; non-resistant	19
39. Covered: probably the same as #38	15
40. Dolomite and dolomitic conglomerate: lying upon very prominent contact showing relief of up to 15 feet; beds above contact zone consist of 5-15 feet of dolomitic conglomerate with angular pieces of light to dark dolomite up to 1 1/2 feet in diameter; conglomerate becomes finer upward and grades into massive, dark gray dolomite which is sugary, somewhat iron stained, and mottled on weathered surface	29
Total Jefferson dolomite.	1,469

Water Canyon dolomite	Thickness in feet
1. Dolomite: light gray; weathers medium gray; medium to fine crystalline and weathered to a finely sugary surface texture; very thin bedded -- bedding gently contorted; there is a distinctive two foot bed of brown dolomite which weathers brown and is non-resistant 12 feet below the top of this unit; above this brown layer the dolomite becomes coarsely crystalline and weathers coarsely sugary, this top 12 foot unit is medium gray, somewhat vuggy, and forms a cliff	36
2. Dolomite: light gray; densely crystalline.	33
3. Dolomite: medium gray on fresh and weathered surfaces; some thin laminations near bottom; densely crystalline	7
4. Dolomite: light gray-brown; weathered surface is rough and pitted; very slightly calcareous; top ten feet is more resistant than rest of unit	130
5. Dolomite: light brown-gray; weathers very light gray to almost white; slightly calcareous; dense -- micro crystalline; fossiliferous near base and at intervals; slightly irregular bedding at intervals; 2 inch layer of sandstone 2 feet above base; abundant and easily recognized fish scales (definitely Devonian according to Stokes) are found in a six inch layer about 8 - 12 inches above base; base is slightly irregular and shows relief of up to 4 inches, unit more resistant than uppermost unit of Laketown dolomite. . .	35
6. Dolomite, light brown-gray; slightly silty; in part iron stained; irregular bedding; thickness of unit varies from about 8 inches to 15 inches, averages about a foot; both upper and lower contacts are irregular; apparently a zone of gradation from Laketown to Water Canyon, unfossiliferous	1
Total Water Canyon formation	242
Total Devonian	1,711

Silurian System

Laketown dolomite	Thickness in feet
1. Dolomite: dark to medium gray; weathers medium to light gray; dense crystalline; some slightly irregular bedding seen but most bedding unapparent; becomes dark gray toward bottom; resistant	114
2. Dolomite: mostly medium to light gray; much contortion of bedding and abundant intraformational conglomerate, with angular particles from 1/2 to 8 - 12 inches in length; conglomerate consists of dolomite and a very few chert fragments; 8 feet above base of unit is a 5 foot bed of very thin-bedded, shaly, calcareous dolomite which weathers like shale; intraformational conglomerate becomes less abundant in top ten feet and is replaced by several thin shaly dolomite layers; unfossiliferous; entire unit is non-resistant	70
3. Dolomite: light gray, coarsely crystalline; weathers sugary; occasional very fine fragments of irregular light blue-gray dolomite; fairly non-resistant; upper 17 feet is slightly vuggy with vugs lined with small quartz crystals	38
4. Dolomite: light, medium, and dark gray; mostly coarsely crystalline; weathers to sugary texture; irregular bedding with occasional intraformational conglomerate; fairly non-resistant	15
5. Dolomite: light gray; bedding contorted; some coarse intraformational conglomerate; some chert containing silicified <u>Syringopora</u>	24
6. Dolomite: light gray; weathers very light gray to almost white with a sugary surface texture; coarsely crystalline; fairly porous; slightly vuggy	20
7. Dolomite: medium to light gray on fresh and weathered surface; slightly cherty; alternating finely and coarsely crystalline texture; coarsely crystalline predominates and weathers to sugary surface; slightly blotchy on weathered surface	12

Laketown dolomite continued	Thickness in feet
8. Dolomite: very light gray on fresh and weathered surface; medium to coarse grained; sugary; porous (very finely vuggy); grains cemented by calcite; generally non-resistant; contact between this and the underlying medium gray unit is gradational through a five foot zone	41
9. Dolomite: medium gray; fine to medium crystalline, becoming coarser upwards; dense; resistant cliff former; few fossils (corals and medium sized crinoid columnals); top 36 feet is slightly vuggy and has a sugary weathered surface	66
10. Dolomite: medium to light gray; coarse grained crystalline; sugary on weathered surface; thin and irregularly bedded where bedding apparent; more resistant than below but less resistant than above; no chert; few vugs in middle part of unit -- some filled with calcite	45
11. Dolomite: medium gray on fresh and weathered surface; coarsely crystalline; sugary weathered surface; some layers slightly vuggy; thin bedded in part with some irregular bedding; upper 29 feet is slightly cherty (thin brown layers) and contains a few thin layers of small (1/8 - 1/2 inch) dolomite concretions	57
12. Dolomite: mostly dark gray on fresh and weathered surface, contains abundant light gray to white chert in irregular but closely spaced layers 1/8 - 1/16 inch thick; these are interspersed with less cherty layers; numerous very small vugs. .	34
13. Dolomite: same as #12 except that chert makes up larger percentage of unit and weathers brown	4
14. Dolomite: medium gray on fresh and weathered surface; medium crystalline; fossiliferous; contains large crinoid columnals and numerous Pentameroid brachiopods; vuggy; vugs and some brachiopods are lined with small clear quartz crystals; more resistant than bed immediately below .	6
Total Laketown dolomite	546
Total Silurian	546

Ordovician System

Fish Haven dolomite		Thickness in feet
1.	Dolomite: medium gray; medium to coarse crystalline; dense; chert in thin bands, lenses and layers 6 inches to 3 feet apart; chert not very noticeable except on close inspection; top 2 feet shows some evidence of a silicified surface and forms a small bench	60
2.	Dolomite: medium gray; weathers blue-gray; very rough and pitted surface, fairly continuous chert layers 1 - 4 inches thick and occasional nodules of chert	8
3.	Dolomite: medium to dark gray; medium crystalline; dense; few corals (?); very rough on weathered surface	35
4.	Dolomite; medium gray; medium to coarse grained crystalline to fragmental; blotchy in part; some irregular bedding; more resistant than above or below; weathered surface very rough and pitted; toward top becomes entirely crystalline with several indistinct alternating 2 - 5 foot layers of medium and light gray; also, bedding becomes more irregular and blotchy in upper 1/4	53
5.	Dolomite: same as #4 except less resistant and contains some very thin bedded, laminated layers	33
6.	Dolomite: light gray becoming medium gray toward top; vuggy (small); resistant; becomes slightly cherty and somewhat blotchy near top	15
7.	Dolomite: medium gray; weathers light gray; non-resistant; densely crystalline	11
8.	Dolomite: dark gray; weathers dark to medium gray; cherty (in fine blotches and fragments); small vugs (some filled with clear quartz crystals); densely crystalline; resistant	12
9.	Dolomite: medium to light gray on fresh and weathered surfaces; slightly vuggy in part; slightly porous in upper part . .	21

Fish Haven dolomite continued	Thickness in feet
10. Dolomite: alternating bands of dark, medium, and light gray on both fresh and weathered surfaces; bands 1 - 3 feet thick; 3 - 4 foot layers of cherty dolomite near top; unfossiliferous .	25
11. Dolomite: gray; weathers light gray; densely crystalline; thin bedded in part	10
12. Dolomite: dark gray; weathers dark gray; densely crystalline; numerous small blobs of gray chert which weather brown-orange	6
13. Dolomite: medium gray; light blue-gray on weathered surface; crystalline (finely sugary); very thin cherty layers in upper two feet	16
14. Dolomite: dark to medium gray; gray to light gray on weathered surface; weathers slightly blotchy in part; few layers of fossil debris; increasingly cherty near top; chert irregular and discontinuous and weathers black to brown to orange	43
15. Dolomite: dark gray; common irregular, discontinuous layers of gray chert which weathers brown to black; both chert and dolomite are very fossiliferous; <u>Halysites</u> sp. . . .	10
16. Dolomite: dark gray; dense; crystalline; resistant	13
17. Dolomite: slightly calcareous; dark gray; weathers light blue-gray; dense; less resistant than beds above	8
18. Dolomite: medium to dark gray on both fresh and weathered surfaces; dense; less resistant than beds below	35
19. Dolomite: light gray, finely fragmental to medium crystalline; weathers light gray with a rough and pitted surface; slight banding of units noted; very thin-bedded in part (1/32 inch); resistant; becomes dense (except for few small vugs) and medium gray toward top; few corals	51

Fish Haven dolomite continued	Thickness in feet
20. Dolomite: alternating layers of very light gray and very dark gray with generally sharp contacts having up to 4 inches of relief; individual layers 1 - 3 feet thick, becoming thicker toward top of unit; dense; this unit and that below form a distinctive banded unit when seen from a distance . . .	14
21. Dolomite: dark gray; weathers dark gray; fossiliferous; coarsely clastic and resistant; chert lenses begin 4 feet above base of formation; lenses are thin and discontinuous and consist of dark gray chert which weathers brown to black and makes up only a small percent of the rock	35
Total Fish Haven dolomite	514

Swan Peak formation		Thickness in feet
1.	Sandstone: quartzitic, in part; fine grained; grains consist of angular, well-sorted, clear quartz; weathers white to light tan to dull rust; unevenly iron stained; sandstone is mostly friable except for upper 4 feet which is mostly quartzite, exhibits torrential cross-bedding, and is more resistant than beds below; abrupt upper contact with dark gray dolomite of overlying Fish Haven dolomite	15
2.	Covered: float indicates mostly light tan to rusty colored siltstone and sandy siltstone, also some arenaceous limestone with abundant fossils found in float; fossils include cephalopods, brachiopods and ostracods; this interval is non-resistant and forms gentle, talus mantled slopes	78
3.	Siltstone: calcareous; dull brown-gray; light tan on weathered surface; thin bedded; non-resistant slope maker .	26
4.	Limestone: silty and sandy; dark gray but weathers brown-gray to rust brown; iron staining prominent; thin bedded; fossiliferous in part; in its less silty and sandy parts the limestone consists of well rounded small grains of limestone cemented by crystalline limestone. Contact with underlying Garden City limestone is gradational and arbitrarily chosen where silt and sand become and remain prominent . .	20
	Total Swan Peak formation	139

Garden City limestone		Thickness in feet
1.	Limestone: dark gray; weathers light blue-gray with rusty mottles; very finely crystalline; thin bedded; dense; slightly silty	20
2.	Limestone: slightly silty; light gray; silt weathers out on surface so that surface is mostly rust-brown in color	37
3.	Limestone: same as #2	7
4.	Limestone: light gray; weathers light gray with light brown iron staining fairly evenly distributed over the surface; very slightly silty; thin bedded; few horn corals; some fossil debris .	68
5.	Limestone: slightly silty and slightly dolomitic; dark gray; weathers buff in mottled pattern, fine to medium crystalline; dense; thin bedded	5
6.	Limestone: dark gray; weathers medium gray with a few iron stains which give it a blotchy appearance; finely crystalline; contains some very thin silty layers	27
7.	Limestone: dark gray; weathers blue-gray; slightly silty toward bottom but silt decreases upward until practically pure limestone in top 20 feet	60
8.	Limestone: slightly silty and slightly dolomitic; dark to medium gray; weathers light blue-gray; silt coats surface irregularly with buff to yellow mottles; limestone varies from dense medium crystalline to fragmental (in part fossil debris); abundant small brachiopods in the top foot.	83
9.	Limestone: slightly cherty; dark gray; medium gray on weathered surface with mottled iron staining throughout interval	19
10.	Limestone: dolomitic; medium gray; weathers blue-gray; chert makes up 30 - 60 percent of the interval	7

Garden City limestone continued	Thickness in feet
11. Limestone: medium gray; weathers medium gray; slightly iron stained; small amount of black chert; medium crystalline	7
12. Dolomite: slightly sandy and silty with abundant black chert; medium gray; weathers light gray to tan; chert makes up 15 - 50 per cent of rock and weathers brown to tan to yellow; upper 5 feet consists of calcareous dolomite with chert making up 50 - 75 per cent of unit	43
13. Limestone: gray, weathers blue gray	1
14. Limestone: dark gray; weathers light blue-gray; fairly abundant thin layers of black mottled chert; chert weathers brown to buff; fine fossil hash and intraformational conglomerate abundant in limestone. Abundant fucoidal(?) markings; top 9 feet very cherty and slightly dolomitic	100
15. Limestone: dark gray; gray to blue-gray on weathered surface; medium crystalline to fragmental; slightly silty; silt weathers out on surface creating a mottled effect of brown to buff on blue-gray; upper 32 feet contains numerous thin silty partings and much fossil hash; fossils include gastropods and occasional brachiopods (?)	53
16. Limestone: dark gray; weathers blue-gray to light blue-gray; some fossil hash and abundant fine intraformational conglomerate; dense; contains slight amount of silt which weathers out on surface producing mottled tan-blue-gray appearance; becomes siltier near top	29
17. Mostly covered; float indicates silty limestone; probably the same as #19	36
18. Limestone: dark gray; weathers gray; common fine intraformational conglomerate; mostly clastic	37
19. Limestone: dark gray; weathers dull light blue-gray; thin bedded; silty partings; mostly finely crystalline; few layers (1" - 1') of intraformational conglomerate and fine fossil debris.	7
20. Limestone: gray; weathers light blue-gray; thin bedded and finely laminated; dense	50

Garden City limestone continued	Thickness in feet
21. Limestone: gray; weathers dull gray to blue-gray; slightly iron stained; coarsely crystalline; upper 2 feet silty; intraformational conglomerate fairly abundant	19
22. Limestone: gray-blue; weathers light blue; bottom 3 feet slightly silty; dense; thin to medium bedded; resistant	8
23. Limestone: medium gray; light gray to tan and very rough on weathered surface; very slightly silty; dense; fine to medium crystalline; thin bedded; some interbedded intraformational conglomerate; resistant	11
24. Mostly covered: float indicates slightly silty limestone with abundant intraformational conglomerate	75
25. Limestone: dark gray; blue-gray on weathered surface; very finely crystalline; dense; thin bedded; some small-sized intraformational conglomerate about 1/3 of the way from the top of the unit containing a few gastropods (?) rough (crenulated) on weathered surface	68
26. Limestone: medium to light gray; weathers light blue-gray; very slightly silty; medium crystalline but with conglomerate pebbles (limestone) up to 1 1/2 inch in diameter in bottom 2 feet; intraformational conglomerate becomes finer in size upward; thin to medium bedded; porous on weathered surface; upper 28 feet less resistant than below and poorly exposed	68
27. Limestone: dark gray; weathers light blue-gray; very finely crystalline; thin bedded in lower 32 feet; intraformational conglomerate occurs in upper 48 feet	68
Total thickness of Garden City limestone	1,013
Total Ordovician	1,666

Cambrian System

Lynch (?) dolomite		Thickness in feet
1.	Dolomite: light gray; weathers to various shades of gray and tan; irregular bedding; silty partings; mostly medium crystalline but some thin lenses of fragmental; lower 44 feet is slightly calcareous; upper part contains a few chert nodules; contact between this unit and the basal beds of the overlying Garden City limestone is not exposed -- where measured	68
2.	Dolomite: medium gray; gray to tan on weathered surface; fine to medium crystalline; dense; lower part slightly calcareous; upper 52 feet contains some irregular bedding with silty partings and also occasional thin layers of pinkish-brown crystalline dolomite which weathers tan	104
3.	Dolomite: light gray to pinkish-gray; weathers tan to buff; medium crystalline; dense; very slightly silty on some partings; upper 54 feet is slightly calcareous and contains some irregular bedding and fairly coarse intraformational conglomerate	97
4.	Dolomite: dark to medium gray; weathers light brown-gray; dense; finely crystalline; contains a small amount of dense, pinkish-gray chert	24
5.	Dolomite; gray to blue gray on fresh and weathered surfaces; medium crystalline; irregular mottling on weathered surface; slightly cherty with chert having peculiar structures as if it had replaced some type of protozoa (?)	16
6.	Dolomite: medium gray on fresh and weathered surfaces; medium to coarsely crystalline; few lenses of chert; contains occasional small white "twiggy" bodies	37
7.	Dolomite: light gray; coarsely crystalline; partings are slightly shaly; poorly exposed; float shows some blue-gray silty limestone	48
8.	Covered interval: float indicates lithologies similar to #7. .	21

		Thickness in feet
9.	Dolomite: medium gray; weathers medium to light gray; intraformational conglomerate is abundant and fairly coarse (fragments up to 2 inches in diameter); less resistant than beds below	24
10.	Dolomite: mostly medium gray to light blue-gray on fresh and weathered surfaces except for a 7 foot bed of very dark gray dolomite in the upper third of unit; coarsely crystalline; occasional intraformational conglomerate becoming more abundant toward the top; irregular bedding fairly common; contains occasional "twiggy" bodies; basal 38 feet contains a few lenses of small dolomite concretions; most of upper 2/3 of unit contains thin lenses and stringers of gray chert which weather brown -- possible casts of some type of protozoa (?) in upper 1/2	232
11.	Dolomite: medium to light gray on fresh and weathered surfaces; medium to coarsely crystalline; slightly laminated; a few "twiggy" bodies; interval partly covered	45
12.	Dolomite: very dark gray; lower 84 feet weathers very dark gray and upper 186 feet weathers mostly medium to dark gray; medium to coarsely crystalline; dense; contains a small amount of dolomitic breccia near middle of unit; more resistant than above; upper 42 feet contains a few lenses and blebs of gray chert which weather brown; "twiggy" bodies throughout unit but more abundant in beds which weather darkest; lower 10 feet is slightly laminated and contains a few small (up to 3/4 inches in diameter) dolomite concretions which consist of coarser grained, lighter colored dolomite in very distinctive layers	226
13.	Dolomite; very light brown-gray on fresh and weathered surfaces; coarsely crystalline to fragmental; slightly to very vuggy	112
14.	Dolomite: dark gray on fresh and weathered surfaces; irregular bedding; abundant and fairly large "twiggy" bodies; fairly resistant and massive, very rough and pitted on weathered surface	10
15.	Same as #14 except that dolomite is light gray and contains no "twiggy" bodies	8

		Thickness in feet
16.	Same as # 14	9
17.	Dolomite; dark gray on fresh and weathered surfaces; bed very distinctive due to inclusions of abundant small concretions as described in #12; may be a useful "marker" bed	2
18.	Same as #14 except "twiggy" bodies are smaller	16
19.	Dolomite: dark gray; weathers medium to light gray; medium to coarsely crystalline to fragmental; lower 30 feet contains abundant very fine intraformational conglomerate which is cemented by dolomite; contains very small "twiggy" bodies and occasional small lenses of black chert; unit is massive cliff former with individual bedding difficult to distinguish	85
20.	Dolomite: dark gray; weathers medium gray; lower 24 feet thin bedded; middle 43 feet massive; upper 30 feet thin bedded; entire unit is a resistant cliff former; slightly mottled with small "twiggy" bodies; contains a few small lenses of black chert	97
21.	Dolomite: slightly calcareous; slightly silty; medium gray on fresh and weathered surfaces; thin bedded; contact with underlying limestone is regular but highly silty	14
22.	Interbedded limestone and silt: limestone is dark gray and weathers blue-gray; dense; crystalline; parted by 1/4 to 1/8 inch silt layers; silt is tan and weathers buff to brown, contains very even bedding 1/2 to 3/4 inches thick; unit resistant .	25
23.	Covered	49
24.	Dolomite: very light gray to pink-white on fresh surface; weathers tan to pinkish tan; slightly silty in part; medium crystalline; contains a few small vugs and has occasional irregular partings; layers of fragmental and fine intraformational conglomerate; weathered surface is sugary in part; bottom 3 feet is sandy	16

	Thickness in feet
25. Sandstone: light gray-brown; weathers buff to brown; consists of fine quartz grains; dense; upper contact gradational into overlying sandy dolomite; lower contact abrupt and regular . .	5
26. Dolomite: slightly calcareous; dark blue-gray on fresh and weathered surfaces; thin bedded with bedding 1/2 to 1 inch thick; lower contact abrupt	3
27. Dolomite: sandy; otherwise same as #24	2
28. Sandstone: light tan to pinkish; weathers brown to tan to pink; medium to coarse grained, contains torrential cross-bedding	6
29. Dolomite: same as #24	5
30. Sandstone: same as #28	6
31. Dolomite: same as no. 24 except top 3 feet becomes slightly sandy and finally grades into overlying sandstone through a 6 inch interval	55
32. Dolomite: light pinkish-tan; weathers very light tan and with a smooth surface; finely crystalline; dense; thin bedded but forms massive resistant unit	67
33. Dolomite: medium to light blue-gray; weathers mottled light gray to light brown-gray; mostly thin bedded with silty and sandy partings; coarsely crystalline; few small vugs; upper half mostly covered	34
34. Dolomite: very dark blue-gray; weathers alternating medium to dark gray; medium to finely crystalline becoming medium to coarsely crystalline to fragmental in upper 2/3 of unit; contains numerous small "twiggy" bodies; bedding in upper 2/3 of unit is very irregular and has considerable small scale lensing and channeling with occasional small lenses of oolitic dolomite fossil fragments (protozoa ?)	190
35. Dolomite: gray to dark gray to blue-gray on fresh and weathered surfaces; thin bedded with sandy and silty partings; densely crystalline to fragmental; slightly calcareous in lower 20 feet; silt decreases upwards but tabular vugs which are parallel to the bedding and contain white dolomite become prominent in upper 90 feet; contains a few small irregular chert nodules	110

Lynch (?) dolomite continued	Thickness in feet
36. Covered	24
37. Limestone: gray; weathers blue-gray; silty partings; mostly fragmental with occasional intraformational conglomerate; more resistant than above or below.	13
38. Covered: float indicates silty dolomite.	32
39. Dolomite: medium to light gray to brownish-gray; densely crystalline; fairly non-resistant	43
40. Limestone: silty; gray to light gray with silty concentrated on weathered surfaces; thin bedded; poorly exposed	17
41. Dolomite: medium to dark gray	37
42. Dolomite: light gray to almost white; densely crystalline; sugary in part; resembles the Devonian Water Canyon formation	55
43. Dolomite: dark gray on fresh and weathered surfaces . . .	32
44. Dolomite: light gray on fresh and weathered surfaces; contains a few black rod-like structures	30
45. Dolomite: mostly oolitic; medium gray on fresh and weathered surfaces; slightly vuggy; upper 25 feet partly fragmental; upper 48 feet is a resistant cliff forming unit .	66
46. Limestone: gray; weathers blue-gray; silty partings; densely crystalline; silty weathers tan to brown and increases towards the top; resistant cliff-former	26
47. Limestone: dark gray; weathers blue-gray; silty partings; very thin bedded and non-resistant; contains some intraformational conglomerate; upper 7 feet is oolitic limestone which is more resistant than below	22
48. Dolomite: medium to light gray weathered surfaces are irregularly mottled in shades of gray	57
49. Dolomite: very light gray on fresh and weathered surfaces; densely crystalline	20

Lynch (?) dolomite continued

	Thickness in feet
50. Dolomite: medium to dark gray on fresh surface; mostly splotchy medium gray on weathered surface; densely crystalline; thin irregular bedding with occasional intraformational conglomerate; "twiggy" bodies present but not abundant	116
51. Dolomite: alternating layers of medium and light gray on fresh and weathered surfaces; densely crystalline; occasional small vugs; contains a very few thin and discontinuous lenses of dark gray to black dolomite which contain white "twiggy" bodies; less resistant than beds above or below	21
52. Dolomite: same as #51 except mostly very light gray; contains fairly abundant small vugs partly or completely filled with white dolomite; cliff former	233
53. Dolomite: same as #51 except almost entirely very light gray on fresh and weathered surfaces	124
54. Dolomite: medium to dark gray; weathers medium to light gray; coarsely crystalline to fragmental; oolitic in part; fairly resistant; weathers with rough surfaces; generally dense with upper 60 feet entirely densely crystalline	90
55. Dolomite: slightly calcareous; irregular silty partings; dolomite is dark gray and weathers blue-gray; silt weathers tan to brown; calcareous beds weather dull gray-brown; dolomite is dense and finely crystalline; lower 25 feet is a cliff former; upper 5 feet is sandy	35
56. Limestone: dark gray; weathers blue-gray; irregular silty partings similar to those in #55; resistant	11
57. Dolomite: similar to #55 except partings are less silty. . .	31
58. Dolomite; light gray; weathers light to very light gray; densely crystalline to sugary; massive; fairly vuggy; pitted on weathered surface; resistant	81
59. Dolomite: same as #58 except less sugary and vuggy and consists of broad alternating bands of light and medium to dark gray dolomite with twiggy bodies in the dark gray . .	19

Lynch (?) dolomite continued	Thickness in feet
60. Dolomite: same as #58 except very light gray to almost white on fresh surface; cliff former	112
61. Dolomite: medium to dark gray; mostly gray and slightly banded on weathered surface; densely crystalline except for a few fragmental layers; slight cross-bedding; beds are 1 - 3 inches thick in lower half but become up to 2 feet thick in upper half; forms together with #60; a prominent massive cliff; upper 14 feet consists of alternating light and dark bands and is transitional between the beds above and below	112
Total Lynch (?) dolomite	3,327

Bowman (?) limestone	Thickness in feet
1. Covered: float from massive cliff or Lynch dolomite above obscures the bedding. May be a shaly limestone . .	58
2. Interbedded limestone and shale: limestone is blue-gray to blue-green, lithographic, unfossiliferous, non-resistant, often in thin nodules, and sometimes does not appear like limestone except on a fresh surface because it weathers like shale; shale is gray-green to olive drab, occurs in irregular thin beds, and is fissile; unit also contains a few thin beds of intraformational conglomerate; poorly exposed but float indicated that the entire unit is probably similar to that described . . .	60
3. Limestone: slightly silty; thin bedded but in massive, resistant unit; weathers to a very rough and pitted surface; filled with abundant small black carbonaceous (?) nodules 1/8 - 1/4 inch in diameter	18
4. Mostly covered but float indicates thin bedded shaly and silty limestone with occasional intraformational conglomerate; light tan shale is probably predominent in upper 10 feet	31
Total Bowman (?) limestone	167

Hartmann (?) limestone		Thicknes in feet
1.	Limestone: dark blue-gray; weathers blue-gray with irregular blotches of tan silt on surface; thin bedded and non-resistant	15
2.	Limestone: dark gray; weathers medium to dark blue-gray with a rough pitted and blotchy surface; finely crystalline; slightly dolomitic in upper part	33
3.	Dolomite: calcareous; dark gray; weathers light gray; dense; occasional slightly silty partings	16
4.	Limestone: same as #2 except weathers mostly light blue-gray and is very dense	35
5.	Limestone: same as #2 except it contains a very few irregular chert nodules	26
6.	Limestone: same as #2 except bedding is more apparent and it is more resistant; contains a few protozoa (?)	24
7.	Covered: non-resistant	20
8.	Limestone: same as #2	13
9.	Dolomite: gray on fresh and weathered surfaces; rough on weathered surface; abundant small white "twiggy" bodies (coarsely crystalline dolomite) tending to be parallel to the bedding; upper 4 feet banded gray and blue-gray	9
10.	Limestone: same as #2 except that it contains occasional small and irregular silt nodules which weather brown	26
11.	Dolomite: gray; weathers light gray; medium crystalline; slightly calcareous in part; dense; contains irregular but persistant layers of white crystalline dolomite every 1 - 3 inches which frequently join with those above and below across the bedding plane -- these layers are thinner and more regular in the upper 5 feet	15

Hartmann (?) limestone continued	Thickness in feet
12. Limestone: mostly dolomitic; gray; splotchy medium blue-gray to medium dark gray on weathered surface; medium to coarsely crystalline; slightly vuggy; fairly resistant	63
13. Limestone: gray; weathers blue-gray with, locally, a pitted surface; dense; finely crystalline; forms massive units up to 10 feet thick but is thin bedded (1/8 - 1/16 inch) on close examination; resistant cliff former; unfossiliferous	41
14. Limestone: light blue gray; contains light gray to greenish gray micaceous shales which become prominent in upper 40 feet; silty partings in limestone; limestone is densely crystalline and evenly bedded; silt is tan to brown; resistant unit; occasional intraformational conglomerate	62
15. Limestone: same as #14 except that it doesn't contain shale and is slightly less resistant	20
16. Covered	21
17. Limestone; same as #14 except does not contain shale; silty layers are regularly about 1 - 1 1/2 inches apart and 1/2 to 1 inch thick; limestone occasionally fragmental; fairly non-resistant	27
18. Limestone: same as #17; upper 45 feet is massive cliff former	78
19. Limestone: blue-gray on fresh and weathery surfaces; very slightly silty; mostly crystalline; thinly and irregularly bedded; both resistant and non-resistant	22
20. Limestone: silty; blue-gray; crystalline and fragmental; thin bedded and non-resistant	14
21. Limestone: dark gray; weathers blue-gray; crystalline and fragmental; thin bedded with silty partings every 1 - 3 inches; massive cliff former	51

Hartmann (?) limestone continued	Thickne in feet
22. Limestone: dark blue-gray on fresh and weathered surface; densely crystalline; very slightly silty with irregular yellow-buff silty layers and lenses on weathered surface; contains numerous small (1/4 - 1 inch) beds of reddish-brown siltstone in bottom 10 feet; lower 53 feet is resistant cliff former; upper 49 feet is mostly non-resistant and contains a few trilobite fragments	116
23. Covered: non-resistant	5
24. Limestone: dark blue-gray; weathers blue-gray; densely crystalline; silty partings; resistant	35
25. Covered	10
26. Limestone: blue-gray to light gray on fresh and weathered surface; rough weathered surface; predominantly medium to coarsely fragmental with subordinant crystalline; thin to medium bedded; fairly non-resistant	37
27. Limestone: blue-gray; weathers blue; densely crystalline; contains silty partings rather evenly spaced every 1 - 2 inches which weather yellow-buff; resistant cliff former	48
28. Limestone: silty; becomes calcareous siltstone near top; weathers interbedded brown and blue-gray	21
29. Shale: micaceous; gray; weathers light gray to greenish-gray to olive gray; non-resistant; contains a few thin layers of siltstone; prominent flow cleavage developed	35
30. Limestone: slightly silty; dark blue-gray; weathers buff to blue; thin bedded and non-resistant; becomes siltier towards top and weathers into small shaly fragments	20
31. Limestone: dark blue-gray; weathers blue-gray; dense; oolitic in part; unfossiliferous; non-resistant	21

Hartmann (?) limestone continued	Thickness in feet
32. Siltstone: dull light gray to greenish-gray; non-calcareous; dense; contains slaty cleavage and may be slightly metamorphosed to a low-grade phyllite in part; fairly resistant	13
33. Limestone and siltstone interbedded: limestone is densely crystalline, blue-gray, and weathers blue; siltstone is buff to yellow and occurs in irregular lenses and layers up to 1 inch thick and spaced about 1/2 to 1 inch apart; siltstone comprises 1/3 to 1/2 of unit .	35
34. Limestone: same as #33 except silt makes up only about 5 per cent of unit although it shows up prominently on weathered surface	35
Total Hartmann (?) limestone.	1,062

Ophir shale	Thickness in feet
A covered interval of 200 feet lying beneath the limestones and above the Brigham quartzite is thought to represent the thickness of the Ophir shale. Float consisting of greenish-gray micaceous shale was found in the interval and is believed to represent the general character of the Ophir in this region	200
Total Ophir shale	200

Tintic quartzite		Thickness in feet
1.	Quartzite and sandstone: shaly; mostly brown; weathers dull green to brown; ferruginous; medium to fine grained; irregular worm-like structures on weathered surface; shale is micaceous and increases upwards indicating that unit is gradational into overlying Ophir shale	19
2.	Quartzite and sandstone: same as #1 except only slightly shaly and contains occasional cross-bedding; glistens on weathered surface	19
3.	Quartzite and sandstone: same as #1 except for absence of worm-like structures; mainly light brown to buff in color; mostly medium to very coarse grained; breaks in very large angular blocks	106
4.	Quartzite and sandstone: brown to light brown; weathers mostly light brown to brown to dark brown to dark green; occasional slight cross-bedding with lighter beds tending to be more cross-bedded than darker; medium to coarse grained; ferruginous; glistens on weathered surface	119
5.	Quartzite: light lavender to white; weathers buff to brown to purple with a fairly smooth surface; exhibits considerable exfoliation; coarse grained to finely conglomeratic; consists of lavender to pink quartz grains which are subrounded to subangular and are cemented by silica; cross-bedded	76
6.	Estimated additional Tintic quartzite exposed but not measured: generally same as #5 except with more abundant pebble conglomerate	400
	Total exposed Tintic quartzite	739
	Total exposed Cambrian	5,495
	Total Section measured	12,876

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