

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division



Timpanogos Cave National Monument

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic
Data for Timpanogos Cave National Monument

tica_geology.pdf

Version: 3/25/2013

Geologic Resources Inventory Map Document for Timpanogos Cave National Monument

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Geologic Resources Inventory Map Document



Timpanogos Cave National Monument, Utah

Document to Accompany Digital Geologic-GIS Data

[tica_geology.pdf](#)

Version: 3/25/2013

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Timpanogos Cave National Monument, Utah (TICA).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

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About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: <http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm>

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: <http://irma.nps.gov/App/Reference/Search>. To find GRI data for a specific park or parks select the appropriate park

(s), enter "GRI" as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: <http://www.nature.nps.gov/geology/inventory>, or contact:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Map and Source Map Citation

The GRI digital geologic-GIS map for Timpanogos Cave National Monument, Utah (TICA):

GRI Digital Geologic Map of Timpanogos Cave National Monument and Vicinity, Utah (GRI MapCode TICA)

The source map,

Baker, Arthur A., Crittenden, Max D., 1961, Geology of the Timpanogos Cave Quadrangle Utah, U.S. Geological Survey, Geologic Quadrangle Map, [GQ-132](#) scale 1:24,000. (*GRI Source Map ID 680*)

Additional information pertaining to each source map is also presented in the GRI Source Map Information (TICAMAP) table included with the GRI geology-GIS data.

Map Unit List

The geologic units present in source maps used for Timpanogos Cave National Monument, Utah (TICA) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qal - Alluvium). No description for water is provided. Information about each geologic unit is also presented in the Geologic Unit Information (TICAUNIT) table included with the GRI geology-GIS data. Unit names, including the lower case spelling of formation, quartzite, shale etc., appear throughout this document, as well as other GRI geologic-GIS data files, as they appear on the source map ([GQ-132](#)).

Cenozoic Era

Quaternary Period

[Qal](#) - Stream gravel
[Qt](#) - Talus and high angle alluvial cones
[Qls](#) - Landslides
[Qbg](#) - Bonneville beach gravels
[Qm](#) - Moraines

Tertiary Period

[Tt](#) - Tibble formation

Mesozoic Era

Cretaceous Period

[qm](#) - Quartz monzonite of Little Cottonwood stock

Paleozoic Era

Permian Period

[Ppc](#) - Park City formation

Pennsylvanian Period

[PNo](#) - Oquirrh formation
[PNob](#) - Bridal Veil limestone member
[PNw](#) - Weber quartzite

Pennsylvanian and Mississippian Periods

[PNMmc](#) - Manning Canyon shale

Mississippian Period

[Mdo](#) - Doughnut formation
[Mgb](#) - Great Blue limestone
[Mh](#) - Humbug formation
[Md](#) - Deseret limestone
[Mg](#) - Gardison limestone
[Mf](#) - Fitchville formation

Cambrian Period

[Cm](#) - Maxfield limestone

[Co](#) - Ophir formation

[Ct](#) - Tintic quartzite

Proterozoic Era

Precambrian

[pCm](#) - Mutual formation

[pCmf](#) - Mineral Fork tillite

[pCbc](#) - Big Cottonwood formation

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below. See the accompanying report for additional information concerning geologic units. Additional information pertaining to unit descriptions also appears in the [source map report](#) section of this document.

Qal - Stream gravel, valley-fill and low-angle alluvial cones (Quaternary)

Captured as alluvial deposits. *GRI Source Map ID 680* ([GQ-132](#)).

Qt - Talus and high-angle alluvial cones (Quaternary)

Captured as alluvial deposits. *GRI Source Map 680 ID* ([GQ-132](#)).

Qls - Landslides (Quaternary)

Captured as alluvial deposits. *GRI Source Map ID 680* ([GQ-132](#)).

Qbg - Bonneville beach gravels (Quaternary)

Captured as alluvial deposits, distinguished locally. *GRI Source Map ID 680* ([GQ-132](#)).

Qm - Moraines (Quaternary)

May include some glacial outwash. *GRI Source Map ID 680* ([GQ-132](#)).

Tt - Tibble formation (Tertiary)

Coarse red conglomerate, with some greenish reworked tuff and white algal limestone. *GRI Source Map ID 680* ([GQ-132](#)).

qm - Quartz monzonite of Little Cottonwood stock (Cretaceous?)

Captured on map. *GRI Source Map ID 680* ([GQ-132](#)).

Ppc - Park City formation (Permian)

Thin- to medium-bedded fossiliferous limestone with a medial phosphatic shale member. *GRI Source Map ID 680* ([GQ-132](#)).

PNo - Oquirrh formation (Pennsylvanian)

Fine- to medium-grained, thin- to thick-bedded sandstone inter-bedded with cherty limestone; is entirely of Pennsylvanian age in map area, although the formation is in part Permian elsewhere. *GRI Source Map ID 680* ([GQ-132](#)).

PNob - Bridal Veil limestone member (Pennsylvanian)

At the base. *GRI Source Map ID 680* ([GQ-132](#)).

PNw - Weber quartzite (Pennsylvanian)

Massive fine- to medium-grained quartzite interbedded with small amounts of cherty limestone. Weber and underlying Round Valley limestone (not exposed in map area) are equivalent to lower part of Oquirrh formation ([PNo](#)). *GRI Source Map ID 680* ([GQ-132](#)).

PNMmc - Manning Canyon shale (Pennsylvanian and Upper Mississippian)

Black shale and shaly limestone. *GRI Source Map ID 680* ([GQ-132](#)).

Mdo - Doughnut formation (Upper Mississippian)

Black shale and shaly limestone grading up into dark-gray fossiliferous limestone. Entirely converted to tactite north of the Deer Creek fault, opposite White Canyon. *GRI Source Map ID 680* ([GQ-132](#)).

Mgb - Great Blue limestone (Upper Mississippian)

Thin-bedded dark-gray limestone and shale limestone. Black shale at base. *GRI Source Map ID 680* ([GQ-132](#)).

Mh - Humbug formation (Upper Mississippian)

Thick- to thin-bedded, fine- to coarse-grained, dark- to light-gray dolomite, interbedded with tawny-weathering sandstone. *GRI Source Map ID 680* ([GQ-132](#)).

Md - Deseret limestone (Upper and Lower Mississippian)

Massive dark- to light-gray cherty dolomite. Thin-bedded platy-weathering fossiliferous limestone at base. *GRI Source Map ID 680* ([GQ-132](#)).

Mg - Gardison limestone (Lower Mississippian)

Upper part: massive gray to black coarse-grained cherty dolomite. Middle part: thin-bedded fine-grained fossiliferous limestone. Lower part: dark gray coarse-grained cross-bedded dolomite. *GRI Source Map ID 680* ([GQ-132](#)).

Mf - Fitchville formation (Lower Mississippian)

Upper part: massive dark-gray dolomite, thin white beds at top. Lower part: medium-bedded pale-gray vuggy dolomite. *GRI Source Map ID 680* ([GQ-132](#)).

Cm - Maxfield limestone (Cambrian)

Thin- to thick-bedded gray mottled magnesian limestone and dolomite. Oolitic or pisolitic, near the base. *GRI Source Map ID 680* ([GQ-132](#)).

Co - Ophit formation (Cambrian)

Upper member: blocky brown calcareous sandstone. Middle member: massive wavy-bedded gray limestone. Lower member: olive-green shale. *GRI Source Map ID 680 ([GQ-132](#))*.

Ct - Tintic quartzite (Cambrian)

Medium- to coarse-grained white or pale pinkish quartzite. Pebbly and locally purplish near the base. *GRI Source Map ID 680 ([GQ-132](#))*.

pCm - Mutual formation (Precambrian)

Rusty to red-purple quartzite, grit and conglomerate with minor red-purple or greenish shale. *GRI Source Map ID 680 ([GQ-132](#))*.

PCmf - Mineral Fork tillite (Precambrian)

Black conglomeratic quartzite or sandstone, with some thin layers of rhythmically bedded siltstone. *GRI Source Map ID 680 ([GQ-132](#))*.

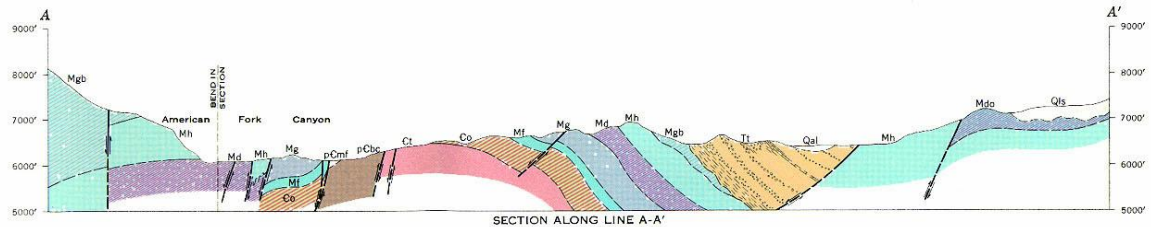
pCbc - Big Cottenwood formation (Precambrian)

Rusty-weathering quartzite and shale. *GRI Source Map ID 680 ([GQ-132](#))*.

Geologic Cross Sections

The geologic cross sections present on the source map [GQ-132](#) used for Timpanogos Cave National Monument, Utah (TICA) are presented below.

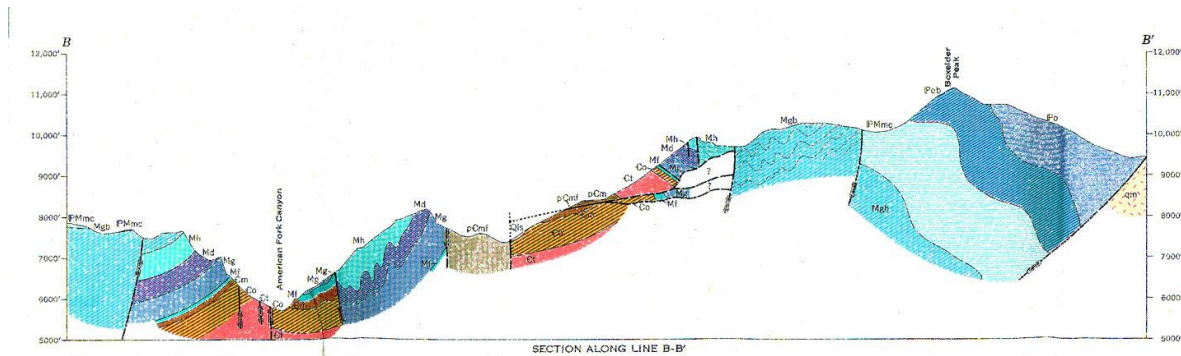
A-A'



Timpanogos Cave NM
GQ-132: Geologic Cross Section A-A'
Geology of the Timpanogos Cave Quadrangle, Utah
 by Arthur A. Baker and Max D. Crittenden, Jr.
 U.S. Geological Survey, 1961

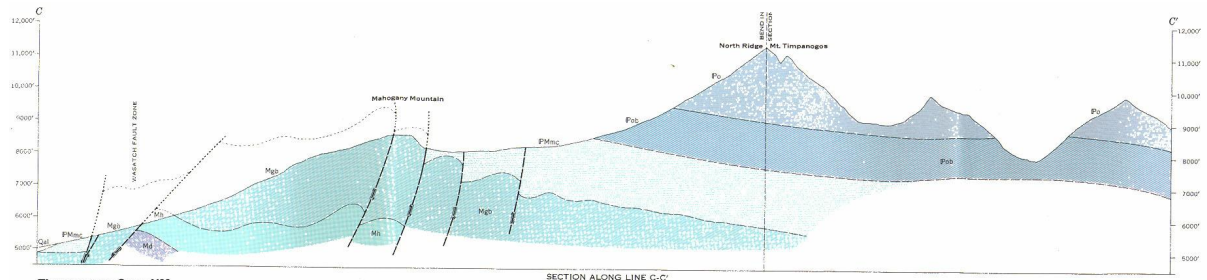
Extracted from: GRI Source Map ID 680 ([GQ-132](#)).

B-B'

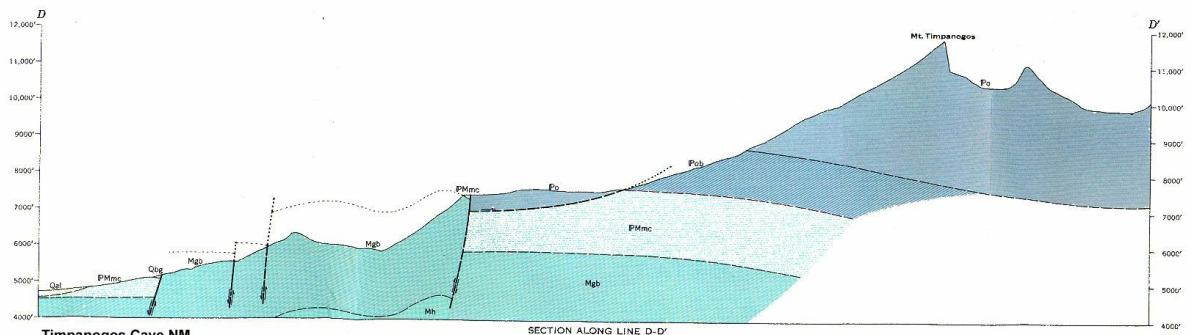


Timpanogos Cave NM
GQ-132: Geologic Cross Section B-B'
Geology of the Timpanogos Cave Quadrangle, Utah
 by Arthur A. Baker and Max D. Crittenden, Jr.
 U.S. Geological Survey, 1961

Extracted from: GRI Source Map ID 680 ([GQ-132](#)).

C-C'

Extracted from: GRI Source Map ID 680 ([GQ-132](#)).

D-D'

Extracted from: GRI Source Map ID 680 ([GQ-132](#)).

GRI Source Map Citation

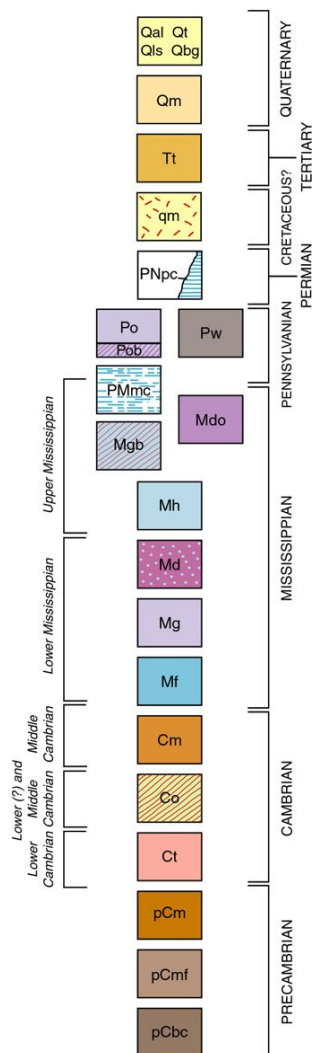
The GRI digital geologic-GIS map for Timpanogos Cave National Monument, Utah (TICA) was compiled from the following source:

Baker, Arthur A., Crittenden, Max D., 1961, Geology of the Timpanogos Cave Quadrangle Utah, U.S. Geological Survey, Geologic Quadrangle Map, GQ-132 scale 1:24,000. (*GRI Source Map ID 680*)

Additional information pertaining to each source map is also presented in the Source Map Information (MAP) table included with the GRI geology-GIS data.

GQ- 132 (Baker and Crittenden, 1961)

Correlation of Units Figure



Extracted from: GRI Source Map ID 680 ([GQ-132](#)).

Report

GEOLOGY OF THE TIMPANOGOS CAVE QUADRANGLE UTAH

by

Arthur A. Baker and Max D. Crittenden, 1961

GQ-132

Introduction

The Wasatch Mountains are a narrow upfaulted range extending nearly due north from central Utah into southern Idaho. The western face of the range forms the eastern boundary of the Basin and Range province, and for much of its extent is defined by a zone of faults and a well-marked fault scarp, which has been described in detail by G. K. Gilbert (1928). Older faults and folds within the range strike at various angles and are in places extremely complex.

An important structural feature in the southern Wasatch is the Charleston thrust fault (Baker, 1947), on which the overriding block moved so far eastward as to bring together widely dissimilar sections of sedimentary rocks; the total thickness of Upper Mississippian, Pennsylvanian, and Permian strata is ten times as great in the vicinity of Mount Timpanogos and in the Oquirrh Mountains, in the hanging wall of the fault, as it is in the part of the Wasatch Mountains carved from the footwall. The rocks above the fault, here called the thick facies, are the result of essentially continuous deposition during Late Mississippian, Pennsylvanian, and Permian time. The rocks of comparable ages now in the footwall, and called the thin facies, appear to be the result of slower, and perhaps intermittent deposition. The trace of the Charleston fault in the Timpanogos Cave quadrangle is believed to lie concealed in the hanging wall of the Deer Creek fault, a mid-Tertiary normal fault which crosses the quadrangle near its northern boundary. All but a small area in the northeast corner of the Timpanogos Cave quadrangle is therefore occupied by rocks of the upper plate of the Charleston fault, characterized by the thick facies. No marked differences are apparent, however, between the sections on the two sides of the fault in rocks older than Late Mississippian, and the description of these older rocks may be applied almost equally well throughout the quadrangle.

Precambrian Rocks

Big Cottonwood Formation

The oldest rocks in the quadrangle are rusty- to buff-weathering massive quartzite and gray to dull-purple shale, which crop out along American Fork about one-half to three-quarters of a mile upstream from the mouth of the South Fork. Although only a few hundred feet of these rocks are exposed, their lithologic character and their position immediately beneath unmistakable tillite clearly show that they belong to the Big Cottonwood formation, of late Precambrian age, which is about 76,000 feet thick in its type section in Big Cottonwood Canyon (Crittenden, Sharp, and Calkins, 1952, p. 3-41).

Mineral Fork Tillite

The Big Cottonwood formation is overlain by dark-gray to black rocks of striking appearance, which are correlated, on the basis of lithology and stratigraphic position, with the Mineral Fork tillite (Crittenden, Sharp, and Calkins, 1952, p. 4). The most distinctive and characteristic rock is tough, massive tillite, containing rounded pebbles, cobbles, and boulders in a matrix of angular sand-size grains cemented by rock flour, whose carbon content (10.5 percent C) imparts a black color to the entire formation. The large fragments consist mainly of quartzite, algal limestone or dolomite, schist, and gneiss, but include a little granite, amphibolite, and greenstone. Interbedded with the tillite are layers of coarse-grained crossbedded sandstone and rhythmically bedded siltstone.

The tillite crops out in a large area in the northwestern part of Tank Canyon, where it may be as much as 1,000 feet thick, though its base is faulted out and the structure is obscure. On American Fork, where both top and bottom are exposed, it is 250 to 300 feet thick. The upper part of the tillite is also exposed at the mouth of Preston Canyon, on the west flank of the range.

A marked unconformity at the base of the tillite is well shown in the drainage basin of Big Cottonwood Creek but not in this quadrangle.

Mutual Formation

The tillite is overlain unconformably by a unit consisting of conglomerate, quartzite, and shale. The coarser sandstones are largely gray, tan, or greenish gray; the finer sandstones and shales have the same grayish-red color as those in the Mutual formation of Big Cottonwood Canyon, with which this unit is correlated. The conglomerates contain abundant pebbles and boulders up to 5 feet in diameter, of schist, gneiss, limestone, and tillite. The formation also contains a characteristic grit, consisting of angular fragments up to a quarter of an inch in diameter of the above-named rocks and of black shale, together with grains of quartz and feldspar.

The Mutual formation is at least 1,300 feet thick in the upper part of Swinging Bridge Canyon; but it is only 100 feet thick in Tank Canyon, and it is entirely absent farther east in American Fork, where the Mineral Fork tillite is overlain directly by the Tintic quartzite. The beveling of the Mutual and older beds by the Tintic quartzite indicates that the Mutual is of Precambrian age.

Cambrian System

Tintic Quartzite

The Tintic quartzite is well exposed in American Fork Canyon near the trail to Timpanogos Cave and above the South Fork. It also crops out extensively near the divide between American Fork and Box Elder Canyons, and its full thickness—about 1,300 feet—is exposed in a cliff at the head of Swinging Bridge Creek. It consists of nearly pure quartzite, pale pink, white, or glassy on fresh fractures but more or less rusty on weathered surfaces. The quartzite is coarse to medium grained, and its lowest beds are generally crossbedded and pebbly. There is usually a 2- to 5-foot bed of pinkish basal conglomerate, in which the pebbles, regardless of the composition of the underlying rock, consist of quartz and fine-grained white to red quartzite. On the mountain front east of Alpine, this conglomerate is nearly 20 feet thick and is pale purple.

The Tintic rests unconformably on the Precambrian rocks with an angular discordance of as much as 10° in the Big Cottonwood area, and at different places in or near the quadrangle it rests on each of the Precambrian formations described above. The quartzite is interbedded with shale at its top and the Tintic

grades into the overlying Ophir formation.

Ophir Formation

The Ophir formation, which overlies the Tintic quartzite, crops out extensively in the area between Box Elder Canyon and American Fork, and in the main canyon of American Fork above the South Fork. Where measured opposite the mouth of Cattle Creek, it consists of three members: a lower shale member 250 feet thick, a medial limestone member 90 feet thick, and an upper shale and sandstone member 170 feet thick.

The lowest member consists mainly of flaky olive-green micaceous shale and siltstone, which alternate near the base with thin beds of rusty quartzite, and in most places contains a few thin glauconitic beds. It also contains abundant worm tracks, fucoid markings, and fragments of brachiopods and trilobites. The medial member is a pale-gray limestone characterized by wavy layers of silty dolomite, which on the weathered surface are tan colored and stand in relief; these become increasingly siliceous, prominent, and closely spaced toward the top. The upper member consists of brown-weathering shale intergrading with fine-grained calcareous sandstone. In some places the upper member of the Ophir, and even a part of the middle member, was removed by the erosion that preceded the deposition of the Mississippian rocks.

The Ophir formation has long been regarded as partly of Early Cambrian and partly of Middle Cambrian age. Walcott (1912, p. 189) reported Middle Cambrian trilobites from beds about 100 feet above the base in Big Cottonwood Canyon, and similar fossils have been recognized by A. R. Palmer in collections from the limestone member at several other places in the Wasatch Mountains. The bulk of the formation is thus assuredly of Middle Cambrian age. The basal beds, however, have been assigned to Lower Cambrian on the strength of *Olenellus* reported by Walcott (1891, p. 317, also 1912, p. 189, Loc. 30a) from the base of the lower member in Big Cottonwood Canyon. Recently, a few poorly preserved trilobite fragments were collected from shale beds resting directly on the Tintic quartzite at Walcott's locality west of the Maxfield mine in Big Cottonwood Canyon and also at the head of Neff Canyon nearby. These fossils were determined by A. R. Palmer to be Middle Cambrian types not known to occur with the olenellids of Walcott's collections, nor in modern collections from western Utah. This evidence casts some doubt on the existence of Lower Cambrian beds in the Ophir in Big Cottonwood Canyon, and suggests, in fact, that the whole of the formation in this area may well be Middle Cambrian.

Maxfield Limestone

The Ophir formation grades upward into dark-gray oolitic to pisolitic limestone correlated with the lower member of the Maxfield limestone, which in the Cottonwood area (Catkins and Butler, 1942, p. 14-18), consists of massive blue-gray mottled or speckled limestone and dolomite, with oolitic to pisolitic beds at the base and a conspicuous layer of laminated white-weathering dolomite at the top. In the west branch of Tank Canyon, where the Maxfield reaches a thickness of about 200 feet, all of these units can be recognized. Elsewhere in the quadrangle all or most of the formation has been removed beneath the unconformity at the base of the Mississippian beds.

The part of the Maxfield formation exposed in the Timpanogos Cave quadrangle, is of Middle Cambrian age, since it consists entirely of beds equivalent to the lower member of the formation as defined for the Cottonwood area (Catkins and Butler, 1942, p. 16) where Middle Cambrian fossils have been obtained from both the middle and upper members. A Middle Cambrian age was also assigned by A. R. Palmer to a single collection from beds about 50 feet thick at the base of the formation, on the north side of American Fork Canyon just west of the mouth of Cattle Creek.

Carboniferous Systems

Fitchville Formation

The Cambrian rocks are unconformably overlain in this quadrangle, and also in the Cottonwood area and the Oquirrh Mountains, by a well-defined lithologic unit 100 to 175 feet thick, to which Gilluly (1932, p. 20-22) and Calkins and Butler (1942, p. 20-22) applied the name Jefferson(?) dolomite. The use of this name was based on an inferred correlation with the Jefferson dolomite of Montana, which is of Devonian age. This correlation was never established, however, and fossils found in this unit in and near the Timpanogos Cave area have now been identified by Helen Duncan as of Mississippian age. We shall therefore call this unit the Fitchville formation, the name applied to it in the East Tintic Mountains by Morris and Lovering, 1960.

Although the Fitchville rests, in the Wasatch Mountains, on Cambrian rocks that range from the upper part of the Maxfield to the lower member of the Ophir, the unconformity at its base is rarely marked by noticeable angular discordance of beds, the largest thus far observed (in the Cottonwood area) being about 10°.

The basal beds of the Fitchville, 2 to 10 feet thick, generally consist of tan-weathering crossbedded flaggy dolomitic sandstone and sandy dolomite containing well-rounded frosted quartz grains up to 2 mm in diameter, and, in some places, quartz pebbles as much as an inch in diameter. The rest of the formation consists mainly of two thick layers of massive dolomite, separated in some places by a few feet of rock resembling that at the base but nowhere pebbly. The lower massive layer is light to medium gray on weathered surfaces; the upper, which is partly detrital, is dark gray. The formation contains a good many vugs, especially in the thin-bedded carbonate layers. At the top of the Fitchville, as mapped in this quadrangle, is a persistent bed of very fine grained dolomite, medium-light gray on fresh fractures but nearly white on weathered surfaces. In most of the area it is a single bed 15 inches to 3 feet thick, but in a few places it splits into two or three thinner beds.

Gardison Limestone

The Fitchville formation is conformably overlain by a thick sequence of limestone and dolomite correlated with the Gardison limestone, of Early Mississippian age, in the Tintic district (Morris and Lovering, 1960). These beds were formerly called Madison, but since the unit does not include the lowest Mississippian beds, that term is now considered to be inappropriate.

The Gardison comprises, in ascending order: (1) 10 to 30 feet of dark-gray coarse-grained crossbedded dolomite, (2) 80 to 100 feet of thin-bedded blue-gray limestone with tan-weathering silty partings, which forms a strongly banded unit in part highly fossiliferous, and (3) about 400 feet of dark-gray massive limestone and dolomite, enclosing roughly tabular masses of white chert 2 to 4 inches thick, which become increasingly abundant upward. The top of the formation is drawn at the base of a thin black carbonaceous shale. In some places, where that bed is absent or concealed, it has been drawn at the base of a zone of platy-weathering shaly limestone that is about 100 feet higher in the section. The total measured thickness of the Gardison in Box Elder Canyon and near the mouth of American Fork Canyon is about 600 feet.

Deseret Limestone

The Gardison limestone is overlain conformably by a massive cliff-forming unit correlated with the Deseret limestone of the Oquirrh Mountains. This formation, in which Timpanogos Cave is located, consists of light- to dark-gray fine- to coarse-grained dolomite with abundant lenticular chert. It was found to be 420 feet thick in Box Elder Canyon. The base of the formation is drawn at the base of one thin

phosphatic and slightly uraniferous black shale noted above, wherever that bed can be recognized. In most places the Deseret contains only a few scattered fossils-mainly brachiopods and syringoporoid corals-and, largely on the basis of collections from the type locality, is generally regarded as entirely of Late Mississippian age. In this area, however, platy-weathering silty limestones which form a marked bench 100 to 200 feet above the base of the formation opposite the mouth of Little Mill Canyon contain a large and distinctive fauna which Mackenzie Gordon and J. T. Dutro (written communication, 1959) assign to the Osage (Early Mississippian). The upper part of the Deseret, though nowhere so fossiliferous, is still assumed to be Late Mississippian.

Humbug Formation

The Deseret limestone is conformably overlain by the Humbug formation, which is characterized by an alternation of tawny-weathering fine- to medium-grained limy sandstone with thin- to thick-bedded fine- to coarse-grained limestone and dolomite. The base of the Humbug is arbitrarily placed at the lowest persistent bed of sandstone. A variable thickness of pale-gray limestone relatively free from sandstone is included at the top of the Humbug beneath the lowest dark shale, dark limestone, or thin beds of siliceous sandstone at the base of the overlying Great Blue limestone or Doughnut formation. The Humbug formation on the north side of Box Elder Canyon is about 800 feet thick.

Thick Facies

Great Blue limestone.-In the area south of the Charleston and Deer Creek faults, the Humbug formation is conformably overlain by the Great Blue limestone, which is about 2,800 feet thick and is widely exposed in the quadrangle. The Great Blue forms most of the bedrock in the west face of Mahogany Mountain, on the walls of the South Fork of American Fork, and on the south spur of Box Elder Peak. It consists chiefly of calcitic thin bedded shaly limestone that is dark-gray to black on fresh fracture but weathers into flakes or thin slabs that are commonly light-gray or pinkish tan. A bed of black shale with same thin beds of rusty weathering fine-grained dark-gray siliceous sandstone is commonly present at the base of the Great Blue and marks a sharp contact with the underlying Humbug formation. Fossils of Late Mississippian age, together with the lithology and stratigraphic position of this unit, leave no doubt of its correlation with the Great Blue of the type locality in the Oquirrh Mountains.

Manning Canyon shale.-The Manning Canyon shale forms benches and areas of low relief north and west of Mount Timpanogos. It consists of black shale interbedded with gray to black limestone, and fine-grained to gritty, commonly quartzitic sandstone. Its exposures are generally poor. Its thickness as measured in Rock Canyon east of Provo is 1,650 feet. The boundary between Upper Mississippian and Pennsylvanian at that locality appears to lie a few tens of feet below a thick limestone bed near the middle of the Manning Canyon shale (Mackenzie Gordon, Jr., oral communication, 1957).

Oquirrh formation.-The Oquirrh formation crops out on the slopes of Mount Timpanogos and on the north slope of Box Elder Peak. The dominantly quartzitic rocks that form the upper slopes of the mountain are underlain by about 1,200 feet of medium- to dark-gray limestone that is here locally designated the Bridal Veil limestone member of the Oquirrh. The name is taken from Bridal Veil Falls, on the south side of Provo Canyon in sec. 34, T. 5 S., R. 3 E., about 2½ miles southeast of the southeast corner of the Timpanogos Cave quadrangle. This limestone member appears to be the approximate equivalent of a similar limestone unit at the base of the Oquirrh at the southern end of the Oquirrh Mountains where it has been named the West Canyon limestone member (Nygren, 1958). The main body of the Oquirrh consists chiefly of fine- to medium-grained thin- to thick-bedded tan-weathering sandstone and quartzite, most of it slightly calcareous. This rock is interlayered with numerous beds of medium- to dark-gray limestone, which make prominent gray bands on the steep upper slopes of Mount Timpanogos. Only about 4,000 feet of Oquirrh, including the Bridal Veil limestone member, is exposed in Mount Timpanogos, but the formation occupies a vast area to the east, where its total thickness is about

26,000 feet.

The Bridal Veil member contains abundant fossils of Early Pennsylvanian age, and these, together with fusulinids and other fossils from the beds above, indicate that the Oquirrh as a whole represents nearly all the Pennsylvanian and some of the Permian. The part of the Oquirrh exposed in this quadrangle, however, is probably all of Des Moines age or older.

Thin Facies

Doughnut formation.-In the area north of the Charleston and Deer Creek faults, the Humbug formation is overlain conformably by dark-gray to black shale with a few beds of rusty-weathering sandstone. The shale grades upward into black to dark-gray thin-bedded limestone, rich in fossils, that weathers to form pale-gray to pinkish plates and slabs. The dark shale and limestone constitute a lithologic unit, to which Crittenden, Sharp, and Calkins (1952, p. 10) gave the provisional name "Doughnut" formation. Doughnut formation is now proposed as a formal name for the unit. The type locality is in the cliffs, east and northeast of Doughnut Falls (E. edge NEB sec. 19, T. 2 S., R. 3 E.) on Mill D South Fork, a tributary of Big Cottonwood Creek, about 8 miles north of the Timpanogos Cave quadrangle. Fossils studied by Mackenzie Gordon, Jr. (oral communication, 1957) indicate that the entire formation is Upper Mississippian.

The Doughnut has not yet been correlated with any well-defined part of the thick facies. In lithology it resembles both the Manning Canyon shale and the lower part of the Great Blue limestone; but paleontologic evidence is not yet sufficient for closer correlation, or for determining whether any part of Late Mississippian time is unrepresented in the thin facies.

The Doughnut formation may be as much as 1,200 feet thick on the east side of American Fork at the extreme northeast corner of the quadrangle. The thickness decreases to the northeast, however, and is less than 300 feet in the Cottonwood area.

Round Valley Limestone.-The Doughnut formation is overlain with apparent conformity by light-gray limestone which contains nodules of chert and many alicified fossils of a distinctive salmon-pink color. This unit, containing an abundant Pennsylvanian fauna, was formerly called Morgan(?) by Calkins and Butler (1942, p. 28-29), but has more recently been referred to informally by us and has been formally defined by Sadlick (1955, p. 5657) as the Round Valley limestone. Because of faulting, this formation does not actually crop out in the Timpanogos Cave quadrangle, but it must be present beneath the Weber quartzite in the northeast corner. It is estimated to be 400 feet thick in outcrops only half a mile to the northeast. The Round Valley limestone is believed to be equivalent, at least in part, to the Bridal Veil limestone member of the Oquirrh formation.

Weber quartzite.-A small area of Weber quartzite crops out below a thrust fault on the north side of Mill Canyon, in the northeast corner of the quadrangle. The Weber consists of gray to tan fine- to medium-grained quartzite with a few beds of medium- to dark-gray cherty limestone. Its thickness in the Cottonwood-American Fork area, where it is fully exposed, is only about 1,500 feet (Calkins and Butler, 1942, p. 29), but is somewhat greater in the canyon of Provo Deer Creek, to the east. Fossils collected from the Weber on Snake Creek northwest of Heber are of Early Pennsylvanian age. The Weber, together with the underlying Round Valley limestone thus appear to be approximately equivalent to the lower part of the Oquirrh, including the Bridal Veil limestone member.

Permian System

Park City Formation

The Park City formation, which overlies the Weber quartzite in the thin facies, includes an upper and a lower member that consist mainly of thin- to medium-bedded fossiliferous limestone with some interbedded sandstone, and a middle member consisting of phosphatic shale. The lower, middle, and upper members as measured in Sids Canyon, northwest of Heber (Baker, 1947), are respectively 450, 60, and 350 feet thick. Only the lower part of the lower member crops out within the Timpanogos Cave quadrangle, in a small area north of the Deer Creek fault on the north slope of Mill Canyon. On the basis of fossils collected in Sids Canyon and at other localities, the entire formation is regarded as Permian.

Cretaceous (?) System

Quartz Monzonite of Little Cottonwood Stock

The northwest corner of the quadrangle contains a small part of the Little Cottonwood stock. This intrusive mass consists of quartz monzonite, which generally shows phenocrysts of potash feldspar, generally about an inch and rarely as much as 3 inches in diameter, in a medium-grained ground-mass consisting chiefly of plagioclase, quartz, and orthoclase with a little biotite and hornblende.

The quartz monzonite is cut off on the south by the Deer Creek fault, along which it is in contact with unmetamorphosed sedimentary formations from the Gardison to the Oquirrh in the area of the thick facies. Just north of the quadrangle, opposite White Canyon, the intrusive contact appears in the footwall of the fault, and for hundreds of feet east from this contact the calcareous rocks are intensely metamorphosed.

The stock is tentatively regarded as Cretaceous in age because it is cut by the Charleston thrust. Radiometric ages differ widely and so far are inconclusive.

Tertiary System

Tibble Formation

The youngest consolidated rock in the quadrangle forms prominent red-stained outcrops along the southeast side of American Fork Canyon for about three-quarters of a mile above the mouth of Tibble Fork, for which the unit is here named Tibble formation. The type locality is in sec. 7 and 8, T. 4 S., R. 3 E., between Tibble Fork and Mill Canyon, adjacent to American Fork. It includes pebble to boulder conglomerate, sandy to shaly greenish-gray to reddish-brown tuffaceous sediments, and thin lenticular beds of white freshwater algal(?) limestone. The larger boulders, generally well rounded and many of them several feet in diameter, are gray to red andesite or latite; the smaller fragments, 1 inch to 6 inches in diameter and mostly angular, are mainly sedimentary rocks, including quartzite, limestone, a brown-weathered rock like some of that in the Thaynes formation (Triassic), and red sandstone probably from the Ankareh (also Triassic) (Boutwell, 1912). Although the northernmost outcrop of the Tibble is within a mile of the Little Cottonwood stock, and is topographically below its outcrops, it contains no fragments of intrusive or contact-metamorphic rock, and therefore must be younger than the quartz-monzonite, or must have been deposited far above its present position.

The formation occupies large areas in the basins of Tibble, Mill, and Deer Creeks, and dips persistently some 20° to 40° northeastward until cut off by the Deer Creek fault. Its thickness along American Fork Canyon (section A-A) appears to be about 2,500 feet, though an unknown thickness has been removed

by erosion. The basal beds rest on an old erosion surface beneath which the rocks are generally stained with iron oxide to depths of several hundred feet. In road-cuts opposite the mouth of Tibble Fork, this staining has imparted a deep red color to shaly limestones of the Great Blue; to the northwest, on the sides of Wide Hollow and in the eastern spurs of Box Elder Peak, it has affected the Bridal Veil limestone member and the main body of the Oquirrh formation as well.

The Tibble formation is believed to be a fluvatile deposit chiefly of nonvolcanic origin, formed around the margins of a basin in which volcanic rocks were accumulating. It is thus partly contemporaneous with the volcanics, intertongues with them locally, and contains a considerable though varying proportion of reworked volcanic debris. It may be contemporaneous with the volcanic rocks near Park City, or with the Norwood tuff which yielded vertebrate remains of early Oligocene age (Eardley 1944, p. 845). The only fossils that have been found in the Tibble formation are smooth ostracodes in the limestone, and these are not diagnostic as to age.

Pleistocene and Recent Deposits

No attempt has been made to distinguish all the Pleistocene and Recent deposits or to map them completely. All material clearly of glacial origin has been shown as moraine though some of it may be outwash. The areas mapped as alluvium, Qal, include some fairly large bodies of sheet wash in Willow Canyon and Preston Canyon that may have been deposited by shallow ice. Narrow irregular strips of alluvium along American Fork and South Fork are not mapped. Several areas of talus and rock glacier are shown on the northern part of the map, but larger areas of both in the great cirques on Mount Timpanogos are not shown. Landslides are visible at several places, but only one large slide in the northeast corner of the quadrangle and a smaller one in Tank Canyon are shown.

Structure

Folds

The dominant fold in the Timpanogos Cave quadrangle is an eastward-plunging anticline whose axis emerges from the mountain front about 2 miles north of the mouth of American Fork, and extends east approximately to the mouth of the South Fork. The apparent sharp bend to the northeast is largely the result of the deep trenching of the north limb of the fold by the canyon of American Fork. Although the general form of this anticline, as outlined by the northward dip along Box Elder Canyon and the southward dip along the south side of American Fork, is that of a broad open fold, its axial region contains two tightly compressed synclines broken by innumerable faults. The resulting steep dips and complex structures contribute to the rugged and picturesque scenery of the north slope of the canyon opposite Timpanogos Cave. For a mile east of the mountain front American Fork Canyon passes through another area of structural complexity. The thin-bedded limestone of the Great Blue has been thrown into a series of overturned and locally recumbent folds that are thought to be related to an eastward-moving thrust block south of Sagebrush Flat. Both the folds and the associated faults are cut off to the north by the Forest Gate fault, and apparently die out to the south.

Faults

Charleston fault zone.-The name Charleston fault was given by Baker (Baker, 1947; and Baker, Huddle, and Kinney, 1949) to a great overthrust that for many miles northeast and east of Mount Timpanogos forms the boundary between rocks of the thick and thin facies of the Carboniferous. Movement on this

thrust appears to have occurred in Late Cretaceous time, for its trace is overlapped east of the Wasatch Mountains in the Uinta Basin by rocks of earliest Tertiary age (Baker, Huddle, and Kinney, 1949, p. 1196).

The westernmost place at which the Charleston fault zone shows its characteristic habit is along Mill Canyon, about half a mile east of the eastern boundary of the Timpanogos Cave quadrangle. A plate of Tintic quartzite has there been thrust over southeast-dipping Permian and Triassic rocks (Park City to Thaynes), and is itself overridden by Mississippian rocks (Deseret and Humbug). These thrust plates appear to terminate toward the west against a normal fault that is believed to be continuous with the Deer Creek normal fault. If this is true, the Charleston thrust zone must be offset by the Deer Creek fault, and its trace must be concealed at depth within the hanging wall of the normal fault beneath Boxelder Peak.

There is no trace of the thrust in the footwall of the normal fault within the quadrangle. To the west, however, near the junction of the Traverse Range with the Wasatch Mountains there are erosional remnants of a low-dipping shear zone in which the quartz monzonite has been crushed and sheared to a dense fine-grained streaky mylonite.

In one place near Fort Canyon there are small remnants of crushed quartzite probably derived from the hanging wall. The intensity of this shearing and crushing is far too great to be attributed to any combination of normal faults, and it is therefore regarded as part of the Charleston thrust. Beneath the Traverse Range and adjoining valleys, the sole of the thrust must be at still greater depths because it is offset by both the Deer Creek and Wasatch faults. Outcrops of crushed quartzite along the flanks of the Traverse Range are suspected of marking the trace of a higher thrust within the upper plate of the Charleston fault, perhaps like the one beneath Sagebrush Flat on the west slope of Mt. Timpanogos.

Deer Creek fault.-A normal fault of large displacement trends nearly due west across the northern part of the quadrangle. This fault is named for its exposures in the upper part of Deer Creek, in secs. 1 and 2, T. 4 S., R. 2 E., where it dips 38° south and separates intensely metamorphosed rocks of Carboniferous age in the foot wall from unmetamorphosed rocks of Carboniferous age in the hanging wall. Near the head of Deer Creek and west across the divide into the drainage of Dry Creek, unmetamorphosed limestone and sandstone of the Oquirrh formation in the hanging wall are faulted against coarse-grained quartz monzonite in the footwall.

From upper Deer Creek eastward to American Fork the Deer Creek fault is largely concealed by moraines, but scattered exposures indicate that it separates the Tibble formation from Carboniferous rocks. The fault crosses the canyon of American Fork at the big spring above Mill Canyon, where the Tibble formation, dipping northeast, abuts against rocks of late Paleozoic age along the fault whose trace reveals a dip of 35° southwest. These relations continue eastward to a point at least 1,000 feet beyond the edge of the quadrangle, and for much of this distance the fault is well exposed in the steep south bank of Mill Canyon. Beyond that point, the fault can be followed, though with less certainty as to location, the remaining 2,000 feet to the intersection with the Charleston thrust.

All observations on the Deer Creek fault point to its being a normal fault with a rather low dip to the south and a displacement of some thousands of feet. It is believed to cut the Charleston thrust, which must be thrown well below the surface in the hanging wall. Yet the low dip of the normal fault suggests that it may actually have availed itself of a preexisting fracture in or near the thrust for considerable distances.

The Deer Creek fault is believed to be of mid- to late-Tertiary age, because it is younger than both the Little Cottonwood stock (Cretaceous?) and the Tibble formation (possibly latest Eocene). On the other hand, it must be distinctly older than the Wasatch fault, which forms the frontal escarpment of the range, since it crosses the mountains at right angles but has no surface expression; the summits on the southern or down-thrown side are just as high as those to the north. Mapping gives evidence, moreover,

that this fault may be cut off and displaced by the Wasatch fault near the northwest corner of the Timpanogos cave quadrangle.

Faults south of Charleston fault zone.-The rocks that overlie the Charleston fault are cut by several faults of different ages. Probably among the oldest are some small overthrusts in Tank Canyon, which are folded with the beds and cut by later taints. A larger thrust fault, perhaps related to the Charleston fault, crops out on Sagebrush Flat west of Mount Timpanogos. This fault has brought a mass of quartzite of the Oquirrh formation from somewhere west of the present range and shoved it over the Great Blue limestone and Manning Canyon shale. Its sole turns upward at the east, and is almost parallel to the face of the mountain. The fault is cut off at the west by the largest of a series of reverse faults with downthrow to the east; south of the quadrangle it is offset by a series of normal faultly in the Wasatch zone.

The Forest Gate fault, so named because it crosses American Fork at the entrance of the National Forest, is conspicuous on the map because it separates a comparatively simple pattern of thick formations-Great Blue, Manning Canyon, and Oquirrh--on the south from intricately faulted older and thinner formations on the north. In places, however, as at the mouth of American Fork Canyon, incompetent rocks just south of the fault are intensely contorted, while those north of it dip almost uniformly southward. The Forest Gate fault, for most of its length seems to be a normal fault with a moderately steep south dip; at the west end, it is believed to be a tear.

The rocks in the anticlinal area are cut by at least two sets of complexly branching normal faults that strike nearly east. The most persistent extends eastward from Willow Canyon, through the head of Swinging Bridge and Tank Canyons, and ends against the Forest Gate fault in an area of great structural complexity. Another fault zone with downthrow on the northeast extends northwestward from upper American Fork to the head of Box Elder Creek. Among the numerous other faults in the quadrangle are two small, inconspicuous overthrusts in Wadsworth Canyon.

Wasatch fault zone.-Normal faults on which the Wasatch block moved upward are exposed in many places along the west base of the range. One of the largest, which extends south-southeastward from the mouth of American Fork Canyon, has a footwall of Great Blue limestone and a hanging wall of Manning Canyon shale. The top of the Great Blue limestone is displaced by this series of faults and by associated flexures from the summit of Mahogany Mountain, at an altitude of approximately 9,000 feet, to a position below the valley floor, so that the total displacement must be more than 4,000 feet (section C-C').

Recent movement has formed fresh scarps 20 to 40 feet high in valley deposits along part of the mountain front. A series of such scarps can be traced from the south edge of the quadrangle to the mouth of Willow Canyon. From there to Box Elder Canyon there is no trace of displacement along the foot of the slope, but the aerial photos suggest that the movement may have been taken up on an older fault with a low west dip that follows the Ophir formation across the bedrock spurs on both sides of Wadsworth Canyon. In Box Elder Canyon it meets a fault dipping about 40° south on which the displacement apparently shifted back to the mountain front, and from there to Dry Creek Canyon a fresh scarp again appears in moraines and alluvium.

Geologic History

The earliest event recorded by rocks exposed in the Timpanogos Cave quadrangle was the deposition, in late Precambrian time, of the layers of sand and mud that now form the uppermost part of the Big Cottonwood formation.

This deposition was interrupted by a period of glaciation during which tongues of ice extended into the area and deposited great bodies of till (now tillite). This ancient glaciation was followed by local uplift and erosion, and by deposition on the eroded surface of red sand, mud, and gravel, which now constitute the Mutual formation. This formation is the youngest unit of the Precambrian system.

Near the beginning of Cambrian time another widespread uplift, combined with slight warping, was followed by erosion and by subsidence. The sea, advancing eastward over the land during Early and Middle Cambrian time, laid down over a thousand feet of sand (now the Tintic quartzite), then a few hundred feet mainly of silt (now the Ophir formation), and finally more than a thousand feet mainly of limy ooze (now the Maxfield limestone).

Whether deposition continued into the Ordovician, Silurian, and Devonian periods is not known, but no sedimentary rocks representing any of those periods have been found in this part of the Wasatch Mountains. If any were deposited, they were removed, together with much of the Cambrian in some places, during the long erosion interval that is recorded in the rather inconspicuous unconformity at the base of the Mississippian.

During Early Mississippian and much of Late Mississippian time, layers of carbonates, at times alternating with sandy sediments, accumulated at roughly equal rates north and south of the future site of the Charleston fault zone; these were to become the Fitchville, Gardison, Deseret, and Humbug formations. Later in the Mississippian, and throughout Pennsylvanian and Permian time, more than 30,000 feet of sediments accumulated in the basin to the south and west, while to the north and east less than 5,000 feet of beds were laid down. Much of the Oquirrh and Park City and much or all of the Great Blue and Manning Canyon formations, and the Permian Kirkman limestone and Diamond Creek sandstone may be missing to the north. During the middle part of the period of deposition of the Park City in Permian time, shallow stagnant seas that provided the conditions required for the deposition of phosphate apparently persisted over most of the region.

The crustal unrest of the Laramide culminated in the great dislocations on the Charleston thrust, which according to evidence southeast of Provo took place in Late Cretaceous time. Present evidence indicates that the Charleston thrust followed closely the intrusion of the Little Cottonwood stock.

During and after a period of erosion that probably occupied much of the Eocene and early Oligocene, the conglomerate and reworked volcanics of the Tibble formation were deposited, possibly while volcanic rocks were being erupted in the Park City area to the northeast. Normal displacements along the Deer Creek fault then dropped the Tibble down several thousand feet in American Fork Canyon and east of Mount Timpanogos.

The latest structural features of the area are the normal faults along which the Wasatch block was elevated. Such movements began in the Tertiary, perhaps in the Pliocene or earlier, and have continued into Recent time.

The principal geologic activity in this region from late Tertiary time to the present has been the carving out, by streams, frost action, and glaciers, of a rugged mountain landscape. Great cirques that flank the summits of Box Elder Peak and Mount Timpanogos are impressive evidence of glaciers that disappeared centuries ago. (The so-called "Timpanogos Glacier" is in fact only a large snowfield that often melts away entirely by late summer.) American Fork, the deepest canyon in the quadrangle, must have been occupied by ice above Tibble Fork, but its jagged "V"-shaped lower canyon—so well seen from the trail to Timpanogos Cave—is striking testimony to the erosive power of frost and running water.

During part of Quaternary time, Lake Bonneville, of which Great Salt Lake is a remnant, covered the low ground in the southwest corner of the quadrangle. Its highest shoreline, called the Bonneville shoreline, was about 5,135 feet above sea-level, and the Provo shoreline, at which it stood longest, a little over

4,800 feet. Both are expressed by the contours along the foot of the range.

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