AN ABSTRACT OF THE THESIS OF

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Title STRATIGRAPHY AND STRUCTURE OF PART OF THE FISH LAKE PLATEAU, SEVIER COUNTY, UTAH

Abstract approved Keith F. Oles (Major Professor)

Over 3,000 feet of nonmarine Late Cretaceous sedimentary rocks are exposed within the northern Fish Lake Plateau. The Cretaceous strata are overlain by over 2,000 feet of Early Tertiary nonmarine sedimentary rocks and volcanics. Landslide deposits cover over one-half of the area.

The Late Cretaceous Blackhawk Formation, the oldest formation exposed, was deposited in fluvial, swamp, coastal lagoon, and possibly shallow marine environments during the eastward retreat of the Mancos sea. This formation is overlain disconformably by the Late Cretaceous Price River Formation which is composed largely of quartz arenites derived from Paleozoic and Mesozoic sedimentary rocks exposed to the west. The sediments were carried into the area by streams and were deposited under piedmont and flood plain conditions.

The Late Cretaceous and Early Tertiary North Horn formation conformably overlies the Price River Formation. The lower part is composed largely of fluvial sandstones but, in the upper part, lacustrine mudstones and siltstones predominate. The latter were

deposited in the Uinta Lake which persisted until late middle Eocene. In this lake the Early Tertiary Flagstaff, Colton and Green River Formations were deposited in succession. After an interval of erosion, the Eocene Gray Gulch Formation was deposited and, later, lavas of Oligocene age.

Two periods of folding are reflected by structures within the area. The Early Laramide orogeny caused the disconformity between the Blackhawk and Price River Formations, and a later period of folding, between the late Eocene and Miocene, formed the Wasatch and Gates Creek monoclines. Late Tertiary normal faulting has been superimposed on the earlier structures.

There do not appear to be favorable structures for the accumulation of oil and gas. However, stratigraphic conditions exist for both the formation and accumulation of oil and gas. The Mancos Shale, a known source rock for oil and gas farther to the east, is present in the sub-surface. Sand pinchouts in Late Cretaceous strata are believed to exist in the subsurface. Potential production in this area will depend on the presence of these updip sand pinchouts.

STRATIGRAPHY AND STRUCTURE OF PART OF THE FISH LAKE PLATEAU, SEVIER COUNTY, UTAH

by

John Byron Alexander

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TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF PLATES

LIST OF TABLES

STRATIGRAPHY AND STRUCTURE OF PART OF THE FISH LAKE PLATEAU, SEVIER COUNTY, UTAH

INTRODUCTION

Location and Accessibility

The area investigated is located in the central part of Sevier County, Utah, approximately 150 miles south of Salt Lake City (Plate 1). It is rectangular in shape and is bounded by the meridians $111^{\circ}31'$ and $111^{\circ}45'$ West Longitude and by the parallels $38^{\circ}44'$ and $38^{\circ}55'$ North Latitude. It includes parts of Townships 22, 23 and 24 North and Ranges 1, 2 and 3 South, Salt Lake Meridian.

This area lies in the northern part of the Fish Lake Plateau and is within the Fish Lake National Forest. The Fish Lake Plateau lies near the center of the High Plateaus province (Plate 2) and is bounded on the north by the Wasatch Plateau, on the south by the Awapa Plateau, on the west by the Sevier Valley, and on the east by the Colorado Plateau province.

The northern edge of the area is crossed by Utah State Highway 10, and a secondary road, maintained by the U. S. Forest Service, passes in a north-south direction through the western part of the area. From these roads a number of Forest Service and private access roads make most of the region readily accessible by 4-wheel drive vehicles. Using a vehicle of this type hiking distances to any outcrop would rarely be over one-half mile. The roads at the higher elevations are only open to traffic from July 1st to about October 1st because of heavy snow.

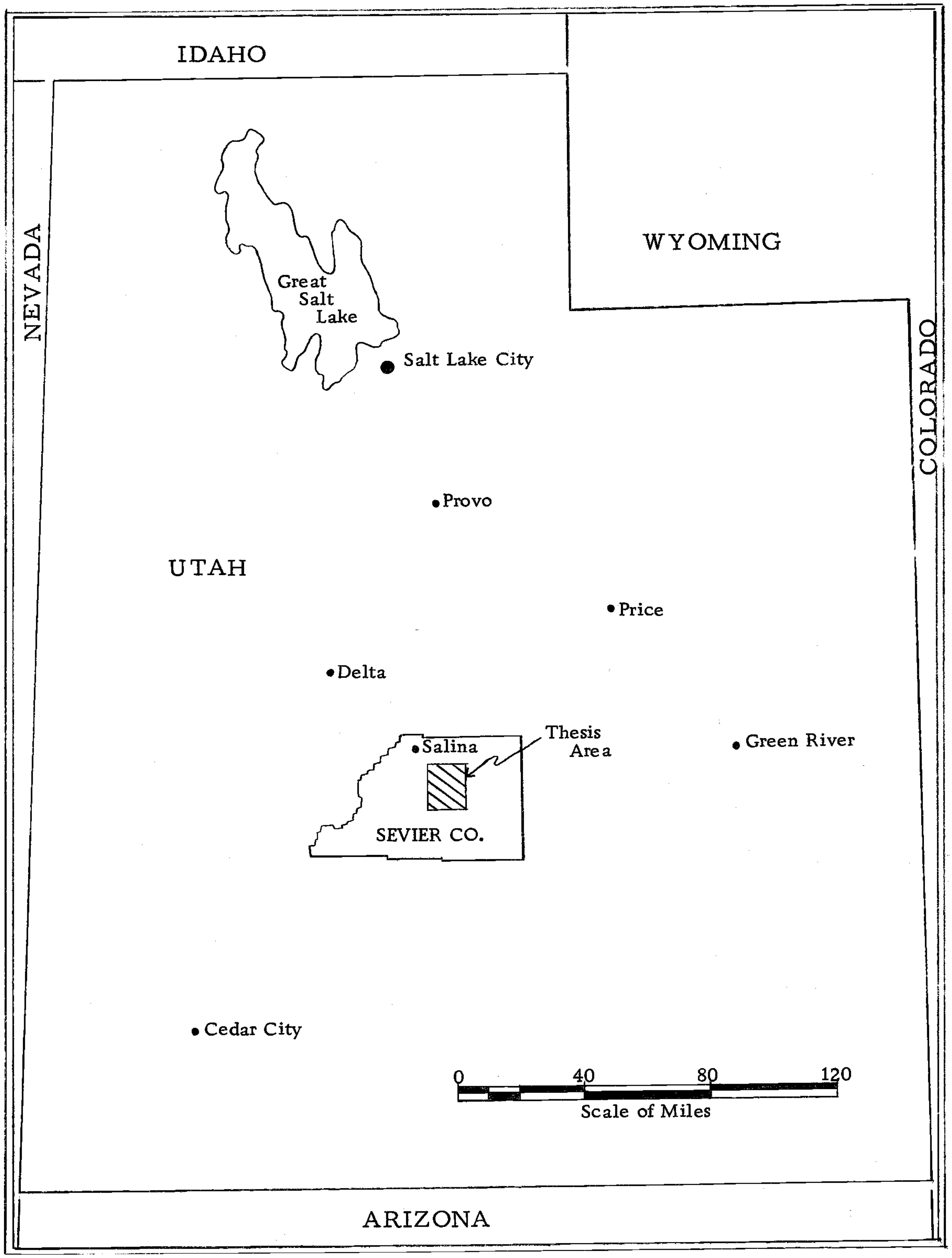


PLATE 1. Map of Utah showing location of thesis area.

Purposes and Methods of Investigation

The primary purposes of the thesis problem were: (1) to map the surface geology of the area; (2) to delineate the major structures of the area; (3) to study those sedimentary facies changes which might be of potential petroleum significance.

Field work began on June 28, 1964 and was completed September 15, 1964. The surface geology was plotted on high altitude (1:60,000) aerial photographs obtained from the U. S. Geological Survey and was transferred to U. S. Forest Service planimetric maps. Modern, large scale topographic maps are not as yet available for this area.

Formation thicknesses were computed from outcrop widths and from electric logs. No stratigraphic sections were measured as data was available from well logs and from published information collected in adjacent areas. Attitudes of foreset cross-laminations were measured and rosette diagrams (Figure 5) were prepared in an attempt to determine the direction of source areas. Twenty-five thin sections and fifteen grain mounts were prepared from selected samples and studied microscopically.

Most lithologic descriptions were done in the field with the aid of a 10X hand lens. The classification of sandstones followed in this thesis is that described by Gilbert (30, p. 289-297). In describing argillaceous sedimentary rocks, the classification of Ingram (11, p. 869-878) was used. The calcareous sedimentary rocks were classified according to the system proposed by Folk (6, p. 1-38).

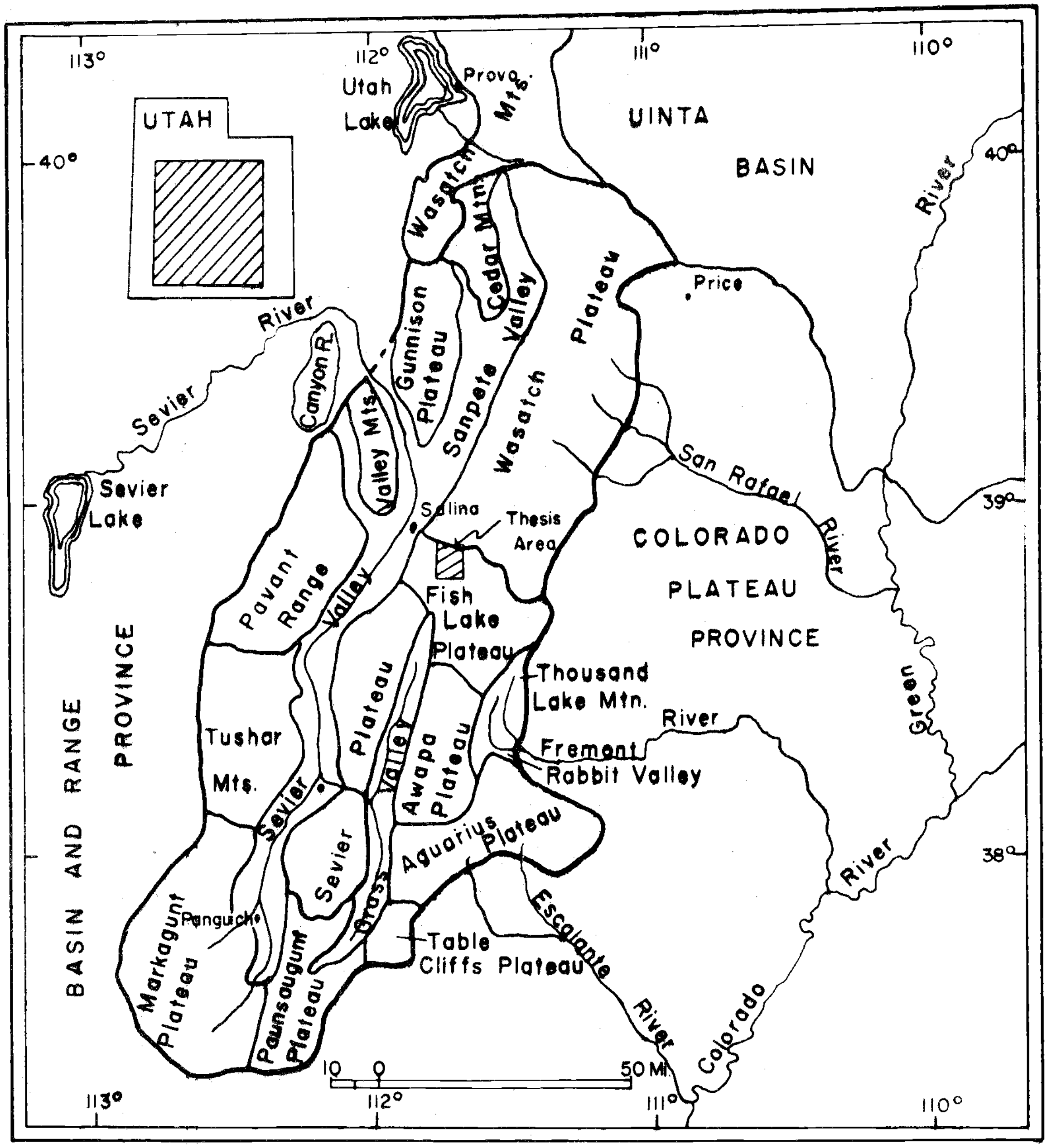


Plate 2. Index map of central Utah physiographic subdivisions (modified after Woolley, 1947, Pl.4). Heavy line indicates the High Plateau province.

Previous Work

The northern part of the Fish Lake Plateau was studied by C. E. Dutton (5). This study was of a reconnaissance nature since Dutton was primarily interested in the thick succession of igneous rocks and pyroclastics of the southern High Plateaus. In his report Dutton included a stratigraphic discussion and stratigraphic sections by E. E. Howell based on traverses of the area during 1873 and 1874. The thesis area was not treated in detail.

A reconnaissance ground-water report by Richardson (19) and a surface-water resources report by Woolley (31) included the area but did not give information concerning the bedrock.

The Wasatch Plateau and adjacent areas have been the subject of an extended study by E. M. Spieker (21, 22, 23, 24, 25, 26). The only work done by Spieker (25) south of the Wasatch Plateau concerned the coal reserves of the Salina Canyon district. The geology of the Wasatch Plateau was summarized by Spieker (23) in his discussion of the region as a transition zone between the Colorado Plateau and the Great Basin.

The northern part of the Fish Lake Plateau was mapped by Donald P. McGookey as partial fulfillment of the requirement for a Ph. D. degree at Ohio State University. An article by McGookey (16) concerning the Early Tertiary strata of areas west of the Gates Creek Monocline, was published in the Bulletin of the American Association of Petroleum Geologists.

Relief

Elevations in the area range from a minimum of 5, 800 feet in Gooseberry Valley (Figure 1) to a maximum of 10, 600 feet in the extreme southern part of the area on the lava-covered Fish Lake Plateau (Plate 3). The maximum relief is approximately 4, 800 feet.

Generally the region slopes to the north and northwest from the lava-covered highlands of the Fish Lake Plateau. In the northwest part of the area the distinguishing features are prominent dip slopes, dipping westward into Gooseberry Valley (Figure 2). In the southern part of the area, north of the lava-covered plateau, rounded hills and slopes, formed by extensive landsliding, are common features. The northeastern sector is characterized by nearly flat upland areas interrupted by steep walled canyons. The canyons, with a maximum relief of 1, 000 feet, have been produced by Salina Creek and its tributaries.

Drainage

The mapped area is drained principally by north-flowing perennial and intermittent streams which are tributary to Salina Creek. The latter, which flows to the west, is located in the extreme northern part of the area (Plate 3). Salina Creek is tributary to the Sevier River which terminates in Sevier Lake, south of Delta, Utah. Localities adjacent to the mapped area on the east and south are drained by south-flowing tributaries of the Fremont River. This stream flows to the east and is a tributary of the Colorado River.

The north-flowing streams which drain the region are generally subsequent to the north-south structures but some streams,

FIGURE 1. View south up Gooseberry Valley. The valley is formed on strata of the North Horn, Flagstaff and Colton Formations. Distant dip slopes are formed on strata of the North Horn Formation.

FIGURE 2. Dip slopes formed on strata of the North Horn Formation dip westward into Gooseberry Valley. Sandstones of the Price River Formation form the cliffs in the foreground. West of Gooseberry Valley are cuestas formed on limestones of the Green River Formation.

such as Niotche Creek and Salina Creek (Plate 3), flow across north-south trending faults with-out any change in direction and appear to be antecedent to the structures.

Climate

The nearest U. S. Weather Bureau station is at Richfield, Utah, 20 miles to the southwest. A U. S. Forest Service weather station is located within the mapped area in sec. 16, T. 23 S., R. 2 E.

The mean annual temperature within the area is about 40° F. January is the coldest month with temperatures often falling below -15° F. July is normally the warmest month, with temperatures reaching 80° F. at the higher elevations, and occasionally exceeding 100° F. at the lower elevations.

The area receives approximately 10 to 15 inches of precipitation per year. The maximum amount of rain falls during the summer months when thunderstorms occur almost daily. The thundershowers, which occur on the average of 50 days a year, cause flash-floods which are an important agent of erosion. The Forest Service is presently conducting experiments within the area in an attempt to minimize such erosion.

Most of the winter precipitation is in the form of snow which accumulates to depths in excess of 40 inches. The higher elevations are usually covered by snow from November through May.

Vegetation

Most of the area is heavily vegetated and in some places the vegetative cover is a hindrance to geological field work. There are well developed floral zones controlled by elevation. The lower areas and highland meadows are covered by grasses and low shrubs. On the steeper and drier slopes scrub oak (Quercus gambelii) predominates. Aspen (Populus tremuloides) grow in profusion along the creek bottoms and in landslide areas. Pines (Pinus edulus), junipers (Juniperus utahensis), and firs (Pseudotsuga menziesii) are found at the higher elevations in the southern part of the area.

Some farming is practiced in Gooseberry Valley, where hay is the major crop. Most of the area is used for summer range. Large bands of sheep graze at the higher elevations and cattle graze in the lower meadows and canyons. The central part of the thesis area is within a U. S. Forest Service Experimental Area in which observations are made on plant populations, rates of growth and stream run-off.

Outside of the landslide areas (Plate 3) the outcrops are generally good, except where they are obscured by thick stands of aspen and scrub oak.

STRATIGRAPHY

The mapped area is located in the High Plateaus of Utah (Plate 2) which are a transition zone, both in land forms and geology, from the Great Basin on the west to the Colorado Plateau on the east. The rocks of the High Plateaus and adjacent regions range in age from Precambrian to Quaternary.

Regional Stratigraphy

The discussion of regional stratigraphy will be restricted to an area bounded on the north by the southern end of the Wasatch Mountains, on the south by the Markagut and Paunsaugunt Plateaus, on the west by the Pavant and Canyon Ranges, and on the east by the San Rafael Swell.

A thick section of Precambrian argillites and quartzites crops out east of Salt Lake City in the southern Wasatch Mountains. Other Precambrian rocks are exposed in the Canyon Range, about 35 miles northwest of the Fish Lake Plateau, where 8,000 feet of quartzites and limestones are thrust over younger strata.

Thick sections of Paleozoic rocks, ranging in age from Cambrian to Devonian, are found in the Pavant and Canyon Ranges to the west and northwest of the thesis area. Quartzite, shale, limestone and dolomite are the dominant rock types, and the sections range in thickness from over 5,000 feet in the Pavant Range to over 10,000 feet in the Canyon Range.

The oldest Mesozoic rocks found west of the High Plateaus are cross-bedded sandstones of the Jurassic Navajo Formation (Table 1). These crop out in the Pavant Range and at the base of the southern Wasatch Mountains near Thistle, Utah. Overlying the Navajo Formation in the Sevier and San Pete Valleys is the Jurassic Arapien Shale which consists of about 10,000 feet of shale, siltstone, sandstone, limestone, and local commercial deposits of rock salt and gypsum. Overlying the Arapien Shale at many localities is a 300 to 400 foot section of varicolored sandstones and conglomerates that Spieker (23, p. 18) has tentatively correlated with the Morrison Formation of the San Rafael Swell.

The oldest Cretaceous rocks exposed on the western border of the High Plateaus are units of the Indianola Group of Colorado age. West of the Wasatch Plateau, Spieker (23, p. 21) reports that the Indianola Group ranges in thickness from 8,000 to 15,000 feet and is composed of conglomerate and sandstone, with minor shale and limestone. The Indianola Group cannot be traced on outcrop any farther east than the west flank of the Wasatch Plateau, where the unit is about 6,300 feet thick, but it is probable that the Indianola becomes finer grained to the east and grades into the middle and lower Mancos Shale (12).

East of the High Plateaus spectacular exposures of Triassic, Jurassic and Cretaceous rocks crop out on the San Rafael Swell (27, p. 23-35). The Triassic section attains thicknesses of about 1,800 feet and is composed of a variety of continental sediments. About 4,000 feet of Jurassic rocks are exposed on the San Rafael Swell and they are composed of a number of rock types which are of

TABLE 1. Correlation Chart.

System	Series	Stage	Sevier-Sanpete Valleys-Wasatch Plateau (West)	Thesis Area	San Rafael Swell Wasatch Plateau (East)	Green River Desert-San Rafael Swell
TERTIARY	OLIGOCENE			Tertiary Lavas		
TERTIARY	EOCENE			Gray Gulch Fm. ?		
TERTIARY	EOCENE		Crazy Hollow Fm.			
TERTIARY	EOCENE		Green River Fm.	Green River Fm.		
TERTIARY	EOCENE		Colton Fm.	Colton Fm.		
TERTIARY	PALEOCENE		Flagstaff Fm.	Flagstaff Fm.	Flagstaff Fm.	
CRETACEOUS	UPPER		North Horn Fm.	North Horn Fm.	North Horn Fm.	
CRETACEOUS	UPPER	MONTANAN	Price River Fm.	Price River Fm.	Mesaverde Gp.: Price River Fm.	
CRETACEOUS	UPPER	MONTANAN		Blackhawk Fm.	Mesaverde Gp.: Blackhawk Fm.	
CRETACEOUS	UPPER	MONTANAN		Star Point Ss.	Mesaverde Gp.: Star Point Ss.	
CRETACEOUS	UPPER	MONTANAN		Emery Ss.	Mancos Shale: Masuk Sh.	
CRETACEOUS	UPPER	MONTANAN			Mancos Shale: Emery Ss.	
CRETACEOUS	UPPER	COLORADOAN	Indianola Group: Six Mile Canyon Fm.	Blue Gate Sh.	Mancos Shale: Blue Gate Sh.	Mancos Sh.
CRETACEOUS	UPPER	COLORADOAN	Indianola Group: Funk Valley Fm.	Ferron Ss.	Mancos Shale: Ferron Ss.	Mancos Sh.: Ferron Ss.
CRETACEOUS	UPPER	COLORADOAN	Indianola Group: Allen Valley Fm.	Tununk Sh.	Mancos Shale: Tununk Sh.	Mancos Sh.
CRETACEOUS	LOWER		Indianola Group	Sanpete Fm.	Dakota Ss.	Dakota Ss.
CRETACEOUS	LOWER		?	Sanpete Fm.	Cedar Mt. Fm.	Cedar Mt. Fm.
CRETACEOUS / JURASSIC	LOWER / UPPER		Lower Cretaceous and Morrison (undivided)	? Morrison	Morrison Fm.	Morrison Fm.
JURASSIC	UPPER		Arapien Sh.: Twist Gulch Mbr.	?	Summerville Fm.	Summerville Fm.
JURASSIC	UPPER				Curtis Fm.	Curtis Fm.
JURASSIC	UPPER / MIDDLE		Arapien Sh.: Twelve Mile Canyon Mbr.		Entrada Ss.	Entrada Ss.
JURASSIC	MIDDLE				Carmel Fm.	Carmel Fm.
JURASSIC	LOWER		Navajo Ss. ?		Navajo Ss.	Navajo Ss.
JURASSIC	LOWER				Kayenta Fm.	Kayenta Fm.

Compiled by J. Alexander from various sources.

both marine and nonmarine origin. Only three Jurassic Formations can be correlated with units west of the Wasatch Plateau: the Navajo Sandstone, the Carmel Formation, which is correlative to the Arapien Shale, and the Morrison Formation. The Early Cretaceous rocks, represented by the Cedar Mountain Formation and the Dakota Sandstone, are chiefly nonmarine and surround the San Rafael Swell in a nearly continuous band. The Late Cretaceous Emery and Ferron Sandstones and the Mancos Shale crop out in Castle Valley and on the long slopes at the base of the east front of the Wasatch Plateau. The Mesaverde Group overlies and intertongues extensively with the Mancos Shale and these mixed marine and nonmarine beds form the Book Cliffs, the imposing series of cliffs rising above the lowlands around the San Rafael Swell.

Outcrops of Late Cretaceous sedimentary rocks, including the Blackhawk, Price River and North Horn formations, are widespread in the northern part of the Fish Lake Plateau and throughout the Wasatch Plateau. These units attain an aggregate thickness of over 5,000 feet in some areas and are composed of piedmont, flood plain, lagoonal and marine sedimentary rocks.

A thick sequence of Early and Middle Tertiary sedimentary and volcanic rocks, including the Flagstaff, Colton, Green River, Crazy Hollow and Gray Gulch Formations, overlies the older rocks of the region. The Tertiary sedimentary rocks are widespread in the Wasatch and Fish Lake Plateaus and on the east flanks of the Pavant and Canyon Ranges. They are composed predominantly of varicolored and calcareous lacustrine deposits which attain thicknesses of over 5,000 feet. A thick series of andesitic lava flows covers over 3,000 square miles of the High Plateaus south of the Wasatch Plateau. These flows are of Oligocene age and unconformably overlie older eroded sedimentary rocks. Other lavas and associated volcanic rocks are found on the western side of the Gunnison Plateau and in the eastern part of the Cedar Hills near Thistle, Utah.

Quaternary glacial moraine, landslide, and alluvial deposits are found within the region. The glacial deposits and landslides are generally restricted to the highlands of the High Plateaus. Alluvial deposits blanket the floors of the Sevier and San Pete Valleys, but within the High Plateaus alluvium is absent except in a few of the larger valleys.

Thesis Area Stratigraphy

Rocks ranging in age from Late Cretaceous to Oligocene are exposed in the northern part of the Fish Lake Plateau. Some knowledge of subsurface stratigraphy is known from two oil and gas test holes that have been drilled within the mapped area. In the following sections a summary of the known subsurface stratigraphy will be presented, followed by detailed descriptions of the exposed units.

Subsurface Stratigraphy

Over 5,000 feet of Late Jurassic and Early Cretaceous sedimentary rocks not exposed in the thesis area, have been penetrated by two oil and gas test holes, the El Paso Natural Gas Company Unit No. 1 drilled in sec. 15, T. 22 S., R. 2 E., and the Pan

American Petroleum Corporation Porcupine Ridge Unit No. 1 drilled in sec. 30, T. 22 S., R. 3 E. (Plate 3).

The oldest formation penetrated was the Morrison Formation (Table 1) of Late Jurassic and Early Cretaceous Age which was tested by the El Paso Natural Gas Company. Interpretation of the well log of this hole indicates that the top of the Morrison Formation is composed predominantly of sandstone. This is to be expected as six miles west of the test site nearly vertical beds of the Morrison Formation crop out and are composed of sandstones and conglomerates.

It is noteworthy that other Early Cretaceous strata are missing in the thesis area but are represented 20 miles to the east on the west flank of the San Rafael Swell.

The Pan American well penetrated the Tununk Shale Member of the lower Mancos Shale of Late Cretaceous age, but the El Paso Natural Gas Company test hole, located two and one half miles to the northwest, did not. Where the Tununk Member would be expected the test hole penetrated the Sanpete Formation of the Late Cretaceous Indianola Group. This fact is strong evidence that the Indianola Group becomes progressively finer-grained to the east and merges with the lower part of the Mancos Shale.

Both test holes penetrated the Late Cretaceous Ferron Sandstone and the overlying Blue Gate Member of the Mancos Shale. The Ferron is composed of fine- to medium-grained sandstone interbedded with thin siltstone and shale units. A few coal beds are present and in the Pan American hole positive oil staining was reported from the upper 100 feet of the formation. The formation appears to have a constant thickness of about 700 feet between the two wells. The Blue Gate Member represents the middle part of the Mancos Shale and is composed of calcareous shales and siltstones with a few interbedded sandstones. The unit thins from 1,590 to 690 feet, from east to west, between the two test holes. This thinning represents the regression, to the east, of the Mancos sea during the Late Cretaceous.

The Emery Sandstone of Late Cretaceous age was recorded in the El Paso Natural Gas hole but not in the Pan American hole. From a study of the well logs it appears that in the Pan American well the Emery and Ferron formations have not been differentiated. The two formations were probably grouped together because the Masuk Member of the Mancos Shale, which separates them in eastern Utah, is not present in the thesis area. In the El Paso Natural Gas Company hole the Emery Sandstone is the first stratigraphic unit recorded and has a thickness of 480 feet. In the Pan American test hole the two formations are represented by over 2,000 feet of fine- to medium-grained calcareous sandstone interbedded with a few thin siltstone and shale units.

The Star Point Sandstone is considered to be the basal unit of the Mesaverde Group and the strata represent deposition in a transition zone between the marine Mancos Shale and the predominantly continental strata of the Mesaverde Group. The upper surface of the Star Point Sandstone represents the passage from littoral marine and brackish water sandstone to the continental beds of the Blackhawk Formation. Cretaceous formations younger than the lower part of the Blackhawk formation are exposed within the mapped area and will be discussed in the following section.

Surface Stratigraphy

Blackhawk Formation

The Blackhawk Formation of Late Cretaceous age, named by Spieker and Reeside (26) for prominent exposures of coal-bearing sandstones and shales near the Blackhawk Mine on the east front of the Wasatch Plateau, is the oldest formation exposed in the mapped area. The formation consists of coal-bearing continental strata lying between the Star Point Sandstone, which is the basal unit of the Mesaverde Group, and the overlying Price River Formation. The base of the formation is not exposed within the thesis area but eight miles to the east the Blackhawk Formation conformably overlies the Star Point Sandstone (26). The upper contact is drawn at the base of the cliff-forming Castlegate Member of the Price River Formation. In most of the area this contact is obscured by rock debris but where the contact can be observed it represents a disconformity. The Price River Formation was deposited on an erosional surface of very low relief cut into the uppermost Blackhawk rocks. This disconformity when traced to the west changes to an angular unconformity in a folded belt three miles east of Salina, Utah. The angular unconformity represents the main Laramide orogeny in central Utah, which occurred between Middle and Upper Montana time (23, p. 79).

Distribution and Topographic Expression. The Blackhawk Formation is widely exposed in the Wasatch Plateau and in the Book Cliffs of eastern Utah where it thins and intertongues with the upper

TABLE 2. Stratigraphic units exposed in the northern Fish Lake Plateau.

Age	Map Unit	Thickness (feet)	Lithology
Recent	Alluvium and terrace deposits	?	Unconsolidated and poorly sorted silt, sand, gravel and boulders.
Recent	Landslide deposits		Unconsolidated clay, sand, and gravel, depending on bedrock.
Pliocene (?)	Pediment gravels	0-30	Boulders of lava and sedimentary rock in a matrix of pebbles and sand.
Oligocene	Tertiary lavas	200-1000	Gray to chocolate colored lava flows of andesitic composition.
	(Unconformity)		
Oligocene	Bullion Canyon volcanics, clastics	2,500	Gray igneous rock conglomerate, coarse tuffaceous sandstone and mud mudflows.
	(Disconformity)		
Eocene	Gray Gulch Formation	1,250	Gray tuffaceous sandstone containing glass and light gray to white shale, limestone and tuffaceous sandstone.
Eocene	Crazy Hollow Formation	1,000	Red shale and siltstone, gray salt-and-pepper sandstone.
	(Disconformity)		
Eocene	Green River Formation	300-1,150	Upper part: light gray massive and thin-bedded limestone. Lower part: green mudstone and siltstone.
Eocene	Colton Formation	550	Red and orange mudstone and siltstone, mottled with gray.

TABLE 2. Continued.

Age	Map Unit	Thickness (feet)	Lithology
Paleocene	Flagstaff Formation	90-300+	Red siltstone and limestone in northwestern part; gray and white limestone and shale in central and southern part of area.
Paleocene / Late Cretaceous	North Horn Formation	1,200	Red, orange, and gray shale, gray fluviatile sandstones.
Late Cretaceous	Price River Formation	1,100	Upper member: gray medium to coarse sandstone; Castlegate Member: gray to white cliff-forming sandstone.
	(Disconformity)		
Late Cretaceous	Blackhawk Formation	450+	Gray to brown fluviatile sandstones; gray shale and thin coal seams.
	(Base not exposed)		

part of the Mancos Shale (32). Within the mapped area the most extensive exposures of the formation are in Salina Canyon and in the tributary canyons to the south (Plate 3). The topographic expression of the formation is of a bench and bluff nature with step-like slopes of mudstones and shales between 10 to 20 foot cliffs of sandstone (Figure 3).

Lithology and Thickness. The Blackhawk Formation consists of a monotonous sequence of sandstones, mudstones, shales and thin coal beds. The sandstones are 2 to 20 feet in thickness and are light gray in color when fresh and darker gray to red brown in color when weathered. They are generally cross-bedded and show cut and fill structures which indicate a fluviatile origin. Thirty-four measurements of foreset cross-laminations suggest a source direction from the west (Figure 5). The sandstone units are composed dominantly of sub-rounded to rounded, fine- to medium-grained quartz and chert. Some units are composed of clean quartz sand cemented with calcium carbonate; others contain abundant lithic fragments and ferruginous material which, upon weathering, stains the beds a dark brown to red color. Petrographic analysis of one representative sample indicates a composition comparable to that of a quartz arenite. Hand specimen analysis of the sandstones containing abundant lithic fragments and iron oxide cement indicates that they are quartz wackes.

Dark gray fissile shales and gray even-bedded mudstones are interbedded with the sandstones. The mudstones and shales are usually sharply defined from one another and from the sandstones, indicating rapid changes in the characteristics of the materials supplied and in the environments of deposition. The shale units are generally less than five feet thick while the mudstones range in thickness from a few inches to 20 feet. The coal beds are generally less than two feet thick and grade downward into carbonaceous shale and are overlain by shale or sandstone (Figure 4). The contacts between the coal and the overlying shales are both gradational and sharp, but where sandstone overlies the coal beds the contacts are generally sharply defined. Some load structures were observed where the coal has been forced up into the overlying sandstones. The sharp contacts between the coals and sandstones indicate rapid changes in the environment of deposition, and the load structures indicate that the coal beds were covered by the coarser material prior to their consolidation.

In the Wasatch Plateau the Blackhawk Formation ranges in thickness from 700 to 1,500 feet and thins to the east (26, p. 444). Within the mapped area the thickness of the formation, as interpreted from well logs, is about 500 feet.

Age. The coal beds within the Blackhawk Formation consist of bundles of coniferous filaments with a few conifer pollen grains and some fern spores (26). Plants collected by Spieker (21, p. 136) indicate a Montana age for the formation. In the mapped area many plant fossils occur within the formation but they are poorly preserved and not identifiable.

Source Rocks and Depositional Environments. The predominance of quartz grains, their high degree of rounding and fine to medium size, indicate that the sand grains have either had a long

FIGURE 3. A vertical cliff formed by the Castlegate Member of the Price River Formation overlies steep ledge-broken slopes formed on sandstones and mudstones of the Blackhawk Formation. Salina Canyon.

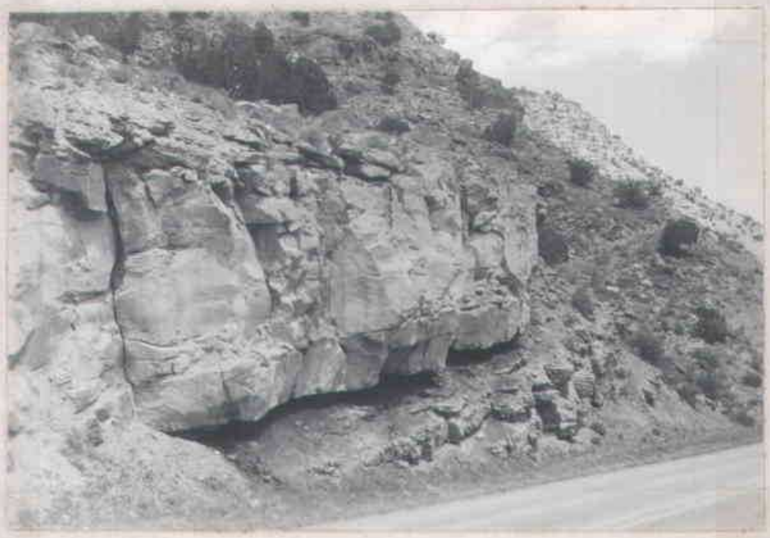
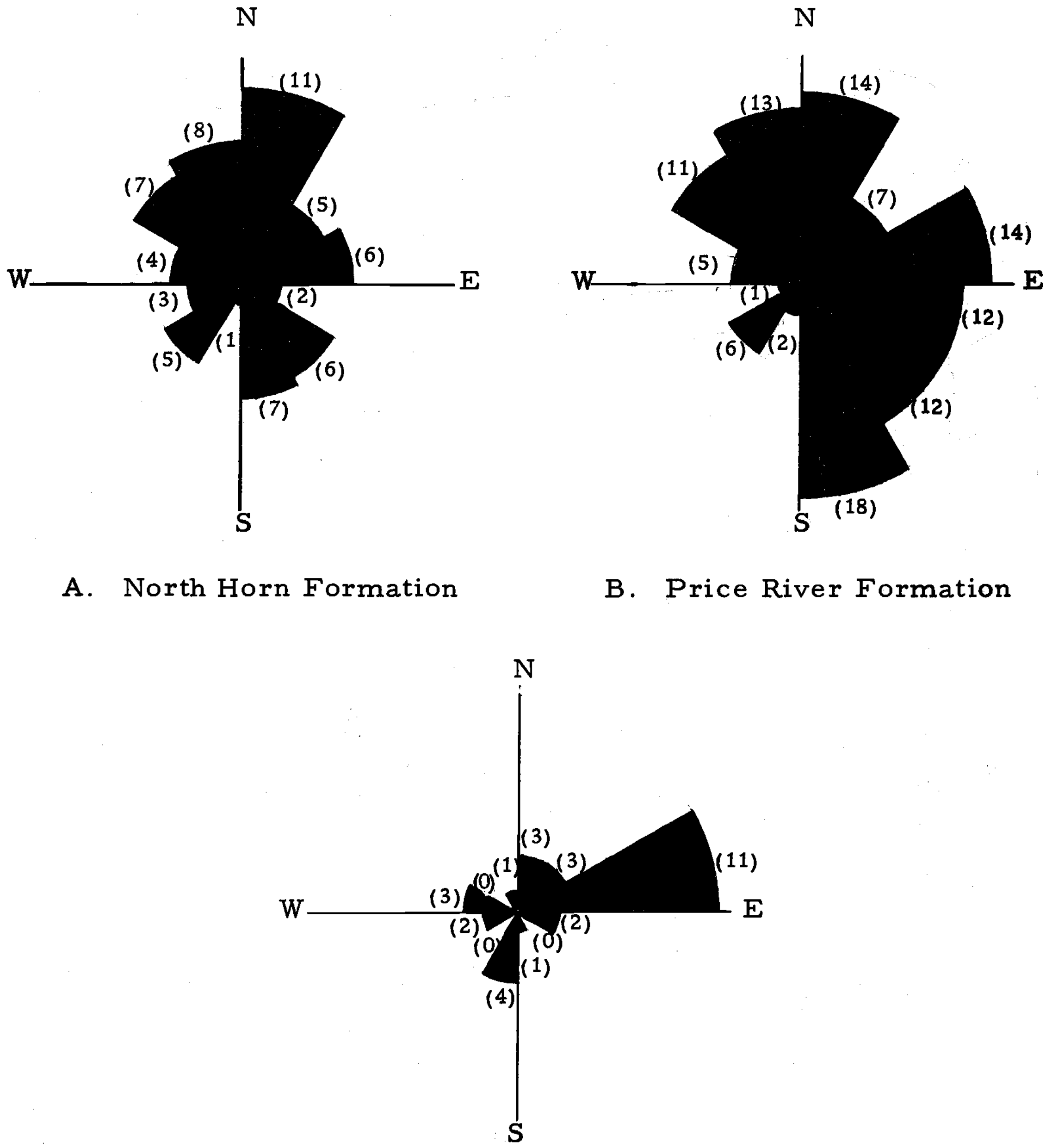


FIGURE 4. A two foot coal seam interbedded with sandstones of the Blackhawk Formation. Salina Canyon.

history of transportation and reworking or have been recycled. Thirty measurements of foreset cross-laminations in fluviatile sandstone units from four localities suggest that the sandstones were derived from source areas to the west (Figure 5). The clastic fraction of the formation was probably derived from pre-existing Triassic and Jurassic sandstones which were uplifted and subjected to erosion during the formation of the Sevier Arch. The Sevier Arch, as described by Harris (9), was located in southern Nevada and Central Utah and was uplifted in the Late Jurassic or Early Cretaceous, providing clastic material to central and eastern Utah until the Early Tertiary. In the early stages of erosion the Sevier Arch furnished coarse material which formed the sandstones and conglomerates of the Indianola Group of Colorado age. This group attains a thickness of nearly 15, 000 feet west of the southern Wasatch Mountains (23, p. 21). However, by Middle Montana time the highlands of the Sevier Arch had been worn down considerably and were supplying only fine- to medium-grained material to the sedimentary environments in which the Blackhawk Formation was being deposited.

To the east, in the Book Cliffs area, the Blackhawk Formation, as described by Young (32), intertongues extensively with the marine Mancos Shale and is characterized by littoral marine sandstone tongues which, projecting eastward into the Mancos, lose their identity by grading into shale. Above each littoral sandstone tongue, Young described lagoonal deposits of sandstone, shale and coal that were developed behind barrier bars. Young interpreted the intertonguing sandstones and the lagoonal deposits as the result of



A. North Horn Formation

B. Price River Formation

C. Black Hawk Formation

FIGURE 5. Rose diagrams recording the results of measurements of foreset cross-laminations in the Blackhawk, Price River, and North Horn Formations.

deposition in a shallow basin in which there were long periods of stability separated by sharp pulses of basin subsidence.

West of the Book Cliffs, within the mapped area, none of the strata were definitely proved to be of marine origin but it is possible that some of the shales and mudstones represent marine deposition. However, the sandstones, which are the dominant single lithologic type in the mapped area, indicate a fluviatile environment of deposition. Cross-bedding and cut and fill structures support this conclusion. The intercalated coal beds and carbonaceous shales containing leaf fossils suggest a swamp or coastal lagoon environment. These similarities and dissimilarities to the Blackhawk Formation of the Book Cliffs, as described by Young, indicate that the various units of the formation were deposited, from west to east, in piedmont fluviatile, swamp, coastal lagoon, and possibly shallow marine environments and that during Blackhawk time the Mancos sea retreated eastward as sediments spread into the marine basin. Periods of accelerated basin subsidence caused successive reinvasions of the sea resulting in the intertonguing of marine, transitional and continental sediments.

Price River Formation

The Price River Formation was named by Spieker and Reeside (26) for a series of noncoal-bearing sandstone, grit and conglomerate beds lying above the Blackhawk Formation. It includes the upper part of the Mesaverde Group and derives its name from exposures in Price Canyon, west of Castlegate, Utah. In typical development the formation consists of a basal sandstone, the Castlegate Member, which forms extensive cliffs, and an unnamed upper member, composed of sandstones and mudstones, which forms a bench and bluff topography rather than an unbroken cliff.

The Price River Formation disconformably overlies the Blackhawk Formation (Figure 2). The beds of the respective formations are parallel and the precise location of the contact is difficult to locate. In practice the contact is drawn where there is an abrupt change from a section of alternating sandstones and shales with coal beds, to one composed predominantly of sandstone.

The sandstones of the upper member of the Price River Formation grade into and intertongue with the overlying varicolored mudstones and sandstones of the Late Cretaceous and Early Tertiary North Horn Formation. The boundary between the formations is purely lithologic in nature and is placed at the base of the varicolored beds of the North Horn.

Distribution and Topographic Expression. The Price River Formation crops out extensively in Central Utah: in the Gunnison, Wasatch and Fish Lake Plateaus, westward in the Pavant Mountains, and eastward in the Book Cliffs. Within the mapped area the formation is exposed in Salina Canyon and in tributary canyons to the south where it forms steep cliffs above the underlying Blackhawk Formation. The upper member of the formation rises out of the subsurface in sec. 7, T. 22 S., R. 2 E., and the underlying Castlegate Member is first exposed in sec. 8, T. 22 S., R. 2 E. (Figure 7). The Castlegate Member at the base of the formation forms an unbroken vertical cliff 150 to 200 feet high (Figure 6). The upper unnamed member is a cliff-former in part, but generally forms steep slopes interrupted by ledges of resistant sandstone.

Lithology and Thickness. Within Salina Canyon the Castlegate Member consists of 200 feet of fine- to coarse-grained sandstone, a few thin conglomerates, and thin mudstone units. The sandstones, which are locally conglomeratic, are light gray to white in color when fresh and weather to yellow gray and buff. They are cross-bedded and display cut and fill structures indicating their fluviatile origin. The sandstones are composed predominantly of sub-angular to sub-rounded, fine- to coarse-grained quartz and chert grains weakly cemented by carbonate. In two samples which were sectioned iron oxide forms a large percentage of the cementing material. These sandstones are classified as quartz arenites.

Conglomerate units within the Castlegate Member are limited in occurrence whereas in areas to the northwest, near Manti, Utah, they are the dominant rock type (23, p. 23-24). The conglomerates in the mapped area are light gray to buff in color when fresh and dark gray to yellow brown when weathered. They occur in units ranging from 1 to 15 feet in thickness. The clasts are predominantly less than two centimeters in diameter and are composed of well-rounded white and black quartzite and chert pebbles (Figure 8) and, locally, angular- to sub-angular white limestone pebbles. The limestone clasts probably indicate that the units were derived from more than one source. The matrix is composed of sub-angular to sub-rounded, medium- to coarse-grained quartz and chert grains which

FIGURE 6. A near vertical cliff formed by resistant sandstones of the Castlegate Member of the Price River Formation. The outcrop is located in Salina Canyon within the Water Hollow graben. The steep slopes in the left foreground are formed on strata of the Blackhawk Formation.

FIGURE 7. The Castlegate Member rising from the subsurface in Salina Canyon. The steep slopes above the Castlegate cliff are formed by the upper member of the Price River Formation.

are weakly cemented by carbonate and iron oxide.

A few gray mudstone beds, generally less than one foot thick, are interbedded with the sandstones. The sandstones grade into the overlying mudstones but the contacts between the sandstones and the underlying mudstones are usually sharp.

The upper unnamed member, which is about 800 feet thick, is lithologically different from the Castlegate Member, the major differences being that the Castlegate Member tends to be more conglomeratic, and the upper member has thin, well-bedded, gray, red and brown shale and mudstone units interbedded with the sandstones. The upper member is characterized by a persistent white, fine- to medium-grained, cross-bedded, cliff-forming sandstone unit (Figure 9). This unit is 20 feet thick and is located about 150 feet above the top of the Castlegate cliff. This is a good marker unit and is recognizable throughout the area. Ferruginous concretions, generally less than one centimeter in diameter, are found within both members of the formation but are more common in the upper member.

Within the mapped area the Price River Formation has a uniform thickness of about 1,000 feet. The unit apparently thickens to the northwest as Spieker (23, p. 24) reports thicknesses in excess of 2,000 feet on the west front of the Wasatch Plateau.

<u>Age</u>. The age of the Price River Formation has been determined from mollusks, collected by Spieker (26) from the Wasatch Plateau, which are characteristic of the Late Montana stage of the Late Cretaceous. In eastern Utah the Castlegate Sandstone,

FIGURE 8. Outcrops of the Price River Formation. The light-colored cliff-forming sandstone in the center of the photograph is a persistent marker unit near the base of the upper member. Salina Canyon.

FIGURE 9. An outcrop of the Castlegate Member of the Price River Formation composed of alternating pebble conglomerates and coarse-grained sandstones. Salina Canyon.

occurring as a littoral tongue in the Mancos Shale, has also been dated as Late Montana by marine fossils within the enclosing Mancos shales. Other than some wood fragments and a few thin coal stringers with plant fragments, no fossils were found within the mapped area.

Source Rocks and Depositional Environment. The fact that the sandstones of the Price River Formation are generally clean and composed predominantly of quartz grains suggests that the sand grains have had a long history of transportation and reworking or that they have been recycled. The conglomerate units, composed of clasts of quartzite and chert are also indicative of a mature sediment. The lack of rounding of the sand grains indicates that the grains have not undergone extensive transportation. They were probably derived from pre-existing sandstone units. North of the mapped area, in the vicinity of Manti, Utah, the Price River Formation is predominantly conglomeratic and is lithologically indistinguishable from the underlying Indianola conglomerates of Colorado age. There appears to be little doubt that the Price River conglomerates and sandstone were derived from these older units during the early erosion of highlands to the west. These highlands, west of the present Sevier and Sanpete Valleys, were produced by thrust faulting which marked the beginning of the Laramide orogeny (9). The lack of thick conglomerate beds and the predominance of fine- to medium-grained sandstones within the mapped area indicate a marked facies change from the piedmont environment which existed to the northwest to an environment of flood plain and channel deposition.

To the east in the Book Cliffs, the Price River Formation, as described by Young (32), thins eastward and intertongues with the Mancos Shale. Young states that from west to east the formation displays characteristics of flood plain, lagoonal, and littoral marine deposition, and that west of Grand Junction, Colorado the formation is represented by littoral marine sandstone tongues which pass transitionally into the Mancos Shale. The facies changes from west to east indicate that within the mapped area the units of the Price River Formation were deposited as flood plain and channel deposits, and that the area represents a transition zone between the piedmont environment to the west and the lagoonal and littoral marine environments to the east.

One hundred and ten measurements of foreset cross-laminations from 14 localities do not indicate a specific source direction for the sandstones but suggest a source from the west (Figure 5). The lack of consistency in the foreset directions is believed to be a result of the fluviatile and channel conditions under which the formation was deposited.

North Horn Formation

The North Horn Formation was first defined by Spieker and Reeside (26), as the lower member of the Wasatch Formation. Later, the discovery of vertebrate fossils indicated that the lower part of the formation was Late Cretaceous rather than Early Tertiary in age. Spieker (21, p. 120) redefined the unit as the North Horn Formation and named as the type locality a section exposed at North Horn Mountain on the east side of the Wasatch Plateau. The formation typically consists of a series of fluviatile sandstones interbedded with lacustrine mudstones, siltstones and shales which are underlain by the Price River Formation and overlain by the Flagstaff Formation. The North Horn is in transitional contact with the underlying Price River Formation and the boundary between the two is difficult to set due to extensive intertonguing. The transitional contact indicates an unbroken progression from coarse-grained post-orogenic sandstones to multi-colored mudstones, siltstones and shales as the highland source areas were worn down.

The upper contact is conformable and generally is marked by a change from the soft varicolored mudstones and shales of the North Horn to the resistant red calcareous siltstones or green and gray mudstones and shales of the Flagstaff Formation. However, in Gooseberry Valley the argillaceous sediments of the North Horn Formation grade upward into the more resistant calcareous sediments with no change in color. In the southern part of the area the contact is gradational but the color changes abruptly from the red and brown mudstones and shales of the North Horn to the green and gray shales of the Flagstaff Formation.

Distribution and Topographic Expression. The North Horn Formation crops out widely in the Wasatch Plateau, Valley Mountain, Gunnison Plateau, Pavant Range and in the Fish Lake Plateau. The formation crops out extensively in the northern and central parts of the mapped area and in isolated outcrops in the southern part. The formation typically forms long slopes which are interrupted by resistant sandstones that form 10 to 30 foot cliffs. These resistant sandstones cap prominent dip slopes and form cuestas which are distinctive features in Gooseberry Valley (Figure 10). In the north-central and northeastern parts of the area the formation appears as a thin veneer overlying the Price River Formation.

Lithology and Thickness. Lithologically the North Horn Formation may be divided into two units: a lower unit, about 850 feet thick, of alternating fluviatile and lacustrine deposits, and an upper unit, about 350 feet thick, of even-bedded lacustrine deposits.

The lower unit is characterized by alternating fluviatile, cross-bedded sandstones and lacustrine mudstones, siltstones and shales. The sandstones are generally less than 25 feet thick but locally attain thicknesses of 50 feet. The sandstones are lenticular and display cut and fill structures (Figure 11). They are generally light gray to tan in color, weathering to brown, yellow brown and locally to white. The sandstones are dominantly fine- to medium-grained in texture but locally are conglomeratic. They are generally composed of sub-angular to sub-rounded, poorly sorted quartz grains with minor amounts of black chert, and they are cemented by calcium carbonate. Fresh samples from many of the beds are hard, but on outcrop they are usually soft and friable due to solution of the carbonate cement. Though most of the sandstones are classified as quartz arenites, thin-section analysis of two representative samples indicates a composition comparable to feldspathic arenites.

Conglomerate units within the formation are of minor importance. They are interbedded and gradational with coarse-grained sandstones. One distinctive unit of pebble conglomerate, about ten

FIGURE 10. Cuesta in the North Horn Formation at the northern end of Gooseberry Valley. The section is formed of alternating beds of varicolored sandstones and mudstones. Green River beds on the skyline.

FIGURE 11. A channel formed in a fine-grained sandstone unit near the base of the North Horn Formation. The channel trends in an west to east direction. Salina Canyon.

feet thick, crops out in the west-central part of the area, about one half mile south of Gates Creek. The unit forms a dip slope about one half mile long and one quarter mile wide. It is composed of rounded pebbles of red, pink and white quartzite with subordinate clasts of dark chert. The clasts are generally one to five centimeters in diameter and are in a matrix of coarse-grained quartz and quartzite grains. The conglomerate rests with slight erosional unconformity on an underlying red siltstone unit and grades upward through fine pebble conglomerate and conglomeratic sandstone to a red mudstone unit. The conglomerate probably records an orogenic pulse in the source area which caused the coarser material to be supplied to the site of deposition.

The fluviatile sandstones alternate with even-bedded varicolored mudstones, siltstones and shales. These fine-grained units are generally less than 25 feet thick where exposed, but covered slopes, which appear to be formed on mudstone beds, indicate thicknesses of over 100 feet. These units are distinctively varicolored and are red, brown, purple, or gray in color and are often mottled. Their even-bedded nature and wide lateral extent suggest that these fine-grained sediments are of lacustrine origin.

The upper unit, about 350 feet thick, is predominantly lacustrine and is similar to the North Horn Formation at its type locality as described by Spieker (21, p. 132-135). The unit is best exposed in Gooseberry Valley where it is composed of evenly-bedded red, purple, brown, gray and mottled mudstones, siltstones, and shales with a few interbedded yellow-gray to buff, fine- to medium-grained sandstones. The sandstones are in part even-bedded and in part cross-bedded, with some of the units showing channeling into underlying mudstone beds. They are 1 to 50 feet thick and are resistant, forming prominent cuestas in Gooseberry Valley. Most of the sandstones appear to be of fluviatile origin but some may be lacustrine.

Spieker states that the North Horn Formation thickens to the north and east and generally thins southwestward from 2,500 feet in the vicinity of Soldier Summit, on the north end of the Wasatch Plateau, to about 500 feet in Salina Canyon (23, p. 26). In the mapped area the North Horn Formation has a thickness of 1,200 feet. However, three miles west of the mapped area, in Salina Canyon, the formation thins and the upper part of the formation is observed to lap out onto folded Early Cretaceous rocks which appear to have formed an island within the lake in which the North Horn Formation was deposited (23, p. 66).

Age. The section of varicolored fluviatile and lacustrine sandstones, mudstones and shales which comprise the North Horn Formation was originally defined by Spieker and Reeside (26) as the lowest of three members of the Wasatch Formation of Eocene age. Originally the middle and upper members of the Wasatch Formation were represented by what are now the Flagstaff Formation and the Colton Formation respectively. Spieker (21, p. 120) states that the assignment of these three members to the Wasatch Formation was based on fresh-water mollusks collected from the Wasatch Plateau, and on structural relations, the Wasatch strata being deposited with angular unconformity on older rocks folded during the Laramide orogeny.

This episode of orogeny was believed to mark the end of the Cretaceous Period.

In 1934 dinosaurian remains were collected from the basal member of the Wasatch Formation in the vicinity of North Horn Mountain, on the east flank of the Wasatch Plateau (21, p. 120). These dinosaurian fossils indicated that the lowest member of the Wasatch Formation was of Late Cretaceous rather than Early Tertiary age. Spieker, in 1940, (21, p. 121) abandoned the name Wasatch Formation in this area and proposed the following revisions: 1) that the original lower member of the Wasatch Formation be named the North Horn Formation, 2) that the Flagstaff limestone member of the Wasatch Formation be given formational rank, and 3) that the name Colton Formation be adopted for the upper member of the Wasatch Formation. For a complete account of the revisions, refer to Spieker (21, p. 120-121).

As now interpreted, the lower two thirds of the North Horn Formation, is considered to be of Late Cretaceous age and contains a Lance-type ceratopsian fauna (16). The upper one third of the formation, as dated by mammalian fauna, is believed to be of Fort Union age, which is early Paleocene. Within the mapped area the only fossils found were abundant wood fragments which occur in many of the fine-grained, cross-bedded sandstones.

Source Rocks and Depositional Environment. The clastic materials of the North Horn Formation appear to have been derived from Early Cretaceous and older Mesozoic formations exposed to erosion during the Late Cretaceous and Early Tertiary. Spieker (22, p. 78) states that the red beds of the North Horn Formation were derived from the erosion of pre-existing red beds. This relationship is demonstrated in parts of central Utah where beds of the North Horn Formation are deep red close to Jurassic and Triassic sources, gradually fading in color eastward away from the source. These relationships are not seen in the thesis area, but the clean nature of the quartz sandstones and the good degree of rounding of the detrital grains suggest a source from pre-existing sedimentary units. Sixty-five measurements of foreset cross-laminations from fluviatile sandstones at six localities do not indicate a specific source direction but suggest a source from the west (Figure 5). Channel deposits observed within the formation suggest a predominant west to east direction of transport.

The cross-bedded sandstones with cut and fill structures which alternate with varicolored siltstones, mudstones and shales of wide lateral extent suggest alternating conditions of fluviatile and lacustrine deposition. The varicolored facies are a function of environmental conditions and indicate the deposition of heterogeneous clastic sediments including much red and other brightly colored material under oxidizing conditions on a terrain of low relief. The sharp changes from the even-bedded siltstones and mudstones to fluviatile sandstones and conglomerates attest to recurring positive movements in the source areas. These recurring positive movements periodically caused the streams to supply coarse material which temporarily invaded the basins in which the varicolored lacustrine sediments were being deposited.

Flagstaff Formation

The Flagstaff Formation was first described in the Wasatch Plateau by Spieker and Reeside (26). The unit was originally given member status and consisted of that fresh-water limestone section that is consistently present between the upper and lower varicolored members of the former Wasatch Formation. The terminology was later revised and the unit was given formational status (21, p. 120).

The only complete exposure of the Flagstaff Formation within the area mapped is west of Gooseberry Creek (Figure 12) in the extreme northwestern part of the region (Plate 3). At this locality the formation is bounded above and below by conformable contacts with the Colton and North Horn Formations respectively. The contacts are gradational in nature; the varicolored, lacustrine shales and mudstones of the Colton and North Horn Formations grade into the red calcareous beds of the Flagstaff. In Gooseberry Valley there is no change of color between the formations above and below but in the southern part of the area there is an abrupt change from the red beds of the North Horn Formation to the grays and greens of the shales and mudstones which occur at the base of the Flagstaff Formation. In this southern area the Flagstaff is usually overlain unconformably by Tertiary lavas, but at one locality, sec. 11, T. 24 S., R. 2 E., the Flagstaff is overlain by the Colton (?) Formation.

Distribution and Topographic Expression. The Flagstaff Formation crops out extensively in central Utah. Exposures occur in

FIGURE 12. Red Flagstaff (left center) overlying west dipping varicolored North Horn beds in Gooseberry Valley. This is the only complete section of the Flagstaff exposed in the area. Green River beds on the skyline.

the Valley Mountains, Pavant Range and in the Gunnison, Wasatch and Fish Lake Plateaus. The formation is one of the most prominent cliff-formers in the Wasatch Plateau and because of its regional persistence is an excellent marker unit.

South of Salina Canyon, the Flagstaff has largely been removed by erosion and crops out in limited exposures. The only complete section is exposed west of Gooseberry Creek (Plate 3) where the formation forms a prominent cliff about 80 feet in height. Three miles west of the mapped area, in Salina Canyon, this section thins and laps out on a topographic high that formed an island in the Flagstaff lake (23, p. 87). In the central and southern parts of the district the formation generally crops out in limited and isolated exposures where it has been preserved from erosion in down-dropped fault blocks and later disturbed by extensive landsliding. The most complete section in this area is exposed on the west side of Niotche Creek, in sec. 35, T. 23 S., R. 2 E., where the formation forms a 300 foot cliff.

Lithology and Thickness. The Flagstaff Formation is composed of limestones, shales, mudstones, siltstones and sandstones which locally become conglomeratic. There are two distinct lithologic types found within the region. In Gooseberry Valley the formation is a red colored cliff-former and is composed of red argillaceous limestone, calcareous siltstone and a few beds of sandstone. In the central and southern part the formation consists predominantly of white and gray limestone interbedded with green mudstone and a few sandstone beds.

The sandstones of the Gooseberry Creek section are yellow, brown and red when fresh and weather to a light brown and gray. They are composed of fine- to medium-grained quartz grains which are sub-rounded to rounded and are cemented by calcium carbonate. The sandstones are massive to irregularly-bedded and generally occur in beds from 5 to 20 feet thick. The beds commonly contain lenses of gray and yellow gray siltstone and are interbedded with mudstone, siltstone and limestone. Where the sandstones are in contact with siltstones the boundary between them is gradational; however, where the sandstones are in contact with mudstones or limestones the contacts may be either gradational or sharp.

The limestones in the Gooseberry Creek section are dark red, purple, and light gray in color and occur in massive beds less than two feet thick. The limestones contain a high percentage of argillaceous material and they grade into calcareous mudstones and siltstones. The argillaceous sediments are gray, red, brown, purple, and mottled. They are both even- and irregularly-bedded and occur in beds between one and five feet thick. The argillaceous sediments grade into one another and into the interbedded limestones and sandstones.

In the south-central and extreme southern parts of the area the Flagstaff crops out in small limited exposures and the complete section is nowhere exposed. The thickest section exposed is on the west side of Niotche Creek (Plate 3). At this location the formation is composed predominantly of gray to white limestones intercalated with thin-bedded gray and green shales and mudstones. A few cross-bedded sandstones are present. The limestones are micritic containing large amounts of clay-size material. Some beds have been partly replaced by chert. The limestones are both evenly-bedded and irregularly-bedded and occur in thin, one half to one inch, discrete beds which form three to five foot thick intervals. These limestone intervals are interbedded with 8 to 12 inch layers of light gray calcareous mudstone and shale and form units as thick as 50 feet.

The mudstones and shales are gray, grayish green and brown in color and occur in beds ranging in thickness from a few inches to 50 feet. The thinner units are intercalated with the limestones and the thicker layers separate the thick limestone units.

Only two sandstone units occur in this sequence. One is less than a foot thick and the other is about 50 feet thick. The sandstones are brown to red in color and are cross-bedded. They are composed of fine- to medium-grained, sub-angular to sub-rounded quartz and chert grains which are weakly cemented with calcium carbonate. The thick unit of sandstone becomes intricately intercalated with siltstone about 20 feet above the base and is predominantly green siltstone in the upper ten feet.

About 1.5 miles south of the Niotche Creek section is another isolated outcrop of the Flagstaff Formation (Plate 3). The outcrop is at least 50 feet thick and forms a rounded hill. The exposed section is composed predominantly of limestone but contains intercalated siltstone and mudstone (Figure 13). The section does not correlate lithically with any of the other exposed sections. The limestones are micritic and contain a high proportion of argillaceous material. Chert is a common constituent and may replace as much as 50 percent of some limestone beds.

FIGURE 13. An outcrop of the Flagstaff Formation composed of thin- to medium-bedded limestone intercalated with thin units of mudstone and shale. Near Salina Reservoir.

Because the carbonates are noticeably argillaceous acid residue analyses were made of two samples (JBA-46, JBA-87) from this locality in an attempt to determine the amount and composition of the detrital material. These analyses indicate a clay-size fraction of 30 percent by weight for sample JBA-46 and 16 percent for sample JBA-87. Petrographic studies of the insoluble residue suggest that the argillaceous fraction is composed of cryptocrystalline silica. X-ray analysis of the residue from sample JBA-46 also suggests the presence of cryptocrystalline silica.

The limestones at this locality are interbedded with dark gray and green evenly-bedded siltstones and mudstones which range in thickness from a few inches to 15 feet. Some of the contacts are gradational but in some cases the contacts between the limestone and overlying siltstones are sharp.

Another outcrop, in sec. 12, T. 24 S., R. 2 E., (Plate 2), is significant because the base of the formation is exposed. The red mudstones and sandstones of the underlying North Horn Formation give way to slopes covered by flaggy, micritic and cherty limestone and green siltstone and mudstone. The section is about 100 feet in thickness and is composed predominantly of green siltstone and mudstone. Interbedded with the mudstones are a few thin beds of limestone, not exceeding five feet in thickness, which crop out as thin ridges on the steep slope formed on the weaker argillaceous rocks. The individual beds are one half to one inch in thickness. Near the top of the section, which is overlain unconformably by Tertiary volcanics, is a 15 to 20 foot outcrop of cross-bedded sandstone.

The sandstone is light green to gray when fresh and weather to light green. The sandstone unit is composed of fine- to coarse-grained, sub-angular quartz grains and a few rock fragments and is cemented by clay and calcium carbonate. The contact relations between the various lithologies of the section are obscured because of limestone and mudstone float which covers the surface.

In the southern part of sec. 11, T. 24 S., R. 2 E., the upper part of the Flagstaff Formation is exposed. The lithology changes abruptly from a sequence of limestones and mudstones to one of pebble conglomerate. The contact is concealed but the pebble conglomerate. The contact is concealed but the pebble conglomerate is believed to be the basal part of the Colton Formation in this area. The Flagstaff at this locality is composed of white to cream colored beds of cherty, micritic limestone which do not exceed five feet in thickness and are interbedded with units of green mudstone ranging from 10 to 20 feet in thickness. The limestones occur in discrete, fissile beds about one quarter to three inches thick and crop out as thin resistant ridges in slopes formed on the mudstone units. The contacts between the limestone and mudstone units are sharp where they can be observed. The exact thickness of the exposed section cannot be determined because of slumping at the base of the outcrop, but it is at least 100 feet thick.

X-ray analyses were made of two samples of carbonate material from outcrops of the Flagstaff Formation in the south-central part of the area. The analyses, made by Mr. Tracy Vallier of the Oregon State University Geology Department, indicated that the two samples are composed of nearly 100 percent dolomite. Thin-sections of the samples were prepared and studied with a petrographic microscope. No textures which would suggest that the dolomite had been formed by the replacement of limestone were observed. The samples fit Folk's description (6, p. 14) of a dolomicrite. Further studies are necessary to determine the origin of the dolomites but the writer believes that they may be of primary origin. Graf et al, (7) report unlithified magnesium carbonate deposits in the Great Salt Lake and believe that they were formed by chemical precipitation or by diagenetic alteration. Alderman and Skinner (1), in studies of dolomitic sediments in some lake deposits in southeast Australia, conclude that the dolomite is a primary precipitate. As only two samples were analysed the writer does not know how many of the limestone units, described within the Flagstaff Formation, are actually composed of dolomite.

Age. On the basis of molluscan faunas collected by La Rocque, the age of the Flagstaff is suggested to be Late Paleocene for the lower part and Early Eocene for the upper part (13, p. 140-141). F. M. Swain (28) collected ostracods from the base of the red Flagstaff section exposed west of Gooseberry Creek. These suggest that the base of the formation was correlative with the upper Colton or lower Green River Formations of the Uinta Basin. This would indicate a late Early Eocene age for the base of the formation. McGookey (16) believes that the Flagstaff beds along Gooseberry Creek can be physically traced to the part of the section identified by La Rocque as Paleocene. It is not known if the top of the formation is of Paleocene age or if it is of Eocene age as is the case in the Wasatch Plateau (14, p. 73). The exposures near the top of the Flagstaff Formation in the southern part of the mapped area are lithologically similar to the upper units of the Flagstaff found in the Wasatch Plateau. The latter have been dated as Eocene in age by La Rocque.

Source Rocks and Depositional Environment. The limestone and limy argillaceous units within the Flagstaff Formation, as well as the field relations, indicate deposition in a lacustrine environment. La Rocque (14, p. 11) states that the Flagstaff Formation of central Utah was deposited in a shallow lake of great extent which covered a minimum area of 2,800 square miles and possibly a maximum area of 7,000 square miles.

The predominantly red argillaceous limestones, calcareous shales and mudstones, and sandstones which comprise the red Flagstaff section in Gooseberry Valley suggest deposition near the edge of the Flagstaff lake where the supply of detrital material was high. The red color of the detrital material suggests that the sediments were derived from the red beds of pre-existing Cretaceous and Jurassic units which cropped out along the edge of the lake. Rocks of this type occur three miles west of the thesis area where the red Flagstaff section thins over folded Late Jurassic and Late Cretaceous beds which formed an island in the Flagstaff lake (Figure 14).

The dense micritic limestones alternating with limy shales and mudstones which are characteristic of the formation in the southern and central parts of the area suggest deposition farther from the shore of the lake. Mud cracks and ripple marks found within the

FIGURE 14. Three miles west of the mapped area the nearly horizontal Flagstaff Formation laps out westward on east dipping strata of the Indianola Group.

limestone units indicate that the lake was shallow and that the lake bottom was at times exposed to the atmosphere. A few medium- to coarse-grained cross-bedded sandstones which occur locally within the formation indicate deposition in a high energy environment, possibly analogous to a paralic environment.

The alternation of the limestones and limy argillaceous units which are characteristic of the Flagstaff Formation in the central and southern parts of the area has been explained by La Rocque (14, p. 78) as the result of changes in the depth of the lake rather than changes in the supply of sediment to the basin. These changes in depth were brought about by small periodic movements on faults which are believed to have existed in and around the lake basin. The dense micritic nature of the limestones suggests precipitation of calcium carbonate from solution (14, p. 78). The calcium carbonate was probably brought into the lake basin by streams which drained areas adjacent to the lake. Some finely brecciated limestones were observed within the Flagstaff and suggest that some of the limestones were produced by plants. Pettijohn (18, p. 410) states that plants such as Chara precipitate calcium carbonate on their leaves and stems and that these deposits when sloughed off collect on the lake bottom. Limestones formed in this way are characterized by a pseudobrecciation produced by small angular chips or flakes of calcium carbonate embedded in a fine-grained matrix of similar composition. Float on one outcrop of Flagstaff limestone yielded what appear to be fragments of algal growths that have been silicified. No algal growths were observed in place.

Colton Formation

The Colton Formation was first defined by Spieker and Reeside (26) to be the upper member of the Wasatch Formation and was later redefined by Spieker (21, p. 139) and given formational rank. The type locality is in Price Canyon, two miles east of Colton, Utah. The type section consists of 1,500 feet of irregularly-bedded gray sandstone, greenish buff sandstone, and deep red to varicolored shale, all of fluviatile origin. In the mapped area the formation consists of about 500 feet of evenly-bedded brownish red shales, mudstones and siltstones which are intercalated with mottled gray and purplish gray mudstones. In contrast to the type section there is no evidence of fluviatile deposition and the formation appears to be of lacustrine origin.

The only complete section of the Colton Formation is located on the west side of Gooseberry Valley in the northwestern part of the area (Plate 3). At this locality the formation lies between the overlying Green River and the underlying Flagstaff formations. The contacts are gradational in nature; the lacustrine shales and mudstones of the Colton grade into the red calcareous beds of the Flagstaff below and into the grayish green shales and mudstones of the overlying Green River Formation (Figure 15).

Distribution and Topographic Expression. Westward and southward from the type locality the Colton Formation is exposed along the west edge of the Wasatch Plateau, in the Gunnison Plateau, the Valley Mountains, and in the northwestern part of the Fish Lake

FIGURE 15. A view to the northwest from the center of Gooseberry Valley showing the gradational contact between the varicolored mudstones of Colton Formation and the overlying green mudstones of the Green River Formation. Strata of the Colton Formation form the slopes at the base of the cliff and underlie the valley in the foreground.

Plateau; elsewhere it has been removed by erosion. The only prominent exposures of the Colton within the mapped area are on the west side of Gooseberry Valley where the formation lies at the base of a cliff formed by the Green River Formation. The formation is nonresistant and forms part of the valley floor. The outcrop is continuous along the west side of the valley until it becomes covered by alluvium and landslides about four miles south of Utah Highway 10.

Isolated outcrops of the Colton (?) Formation occur south of the Gooseberry Creek Ranger Station where it has been preserved in fault blocks (Plate 3). Extensive landsliding obscures the contacts with adjacent outcrops of the Flagstaff and Green River formations, but these isolated sections of the Colton Formation are lithologically similar to those found in Gooseberry Valley. In the extreme south central part of the area (Plate 3) a discontinuous section of varicolored conglomerates, sandstones and siltstones, which lies between the Flagstaff Formation and overlying Tertiary volcanics, has been assigned to the Colton Formation. The contact relations with the underlying Flagstaff Formation are concealed and an erosional unconformity separates the overlying Tertiary volcanics from the Colton Formation.

Lithology and Thickness. The Colton Formation is typically composed of even-bedded brownish red mudstones and siltstones that are generally mottled with patches of gray and purple. A few thin beds of shale, sandstone and limestone are present at some localities. A conglomerate and sandstone unit overlies the Flagstaff Formation in sec. 11, T. 24 S., R. 2 E. and is believed to be part of the Colton

Formation.

Mudstones and argillaceous siltstones are the predominant rocks of the formation. They are generally brownish red to gray, are mottled with patches of grayish yellow, gray and purple, are evenly- to unevenly-bedded, and occur in units ranging from a few inches to over 100 feet in thickness. The siltstones and mudstones grade into each other and into the interbedded sandstones.

The sandstones are gray, yellow gray to grayish green and weather to shades of light brown. They are evenly-bedded and occur in one eighth to one half inch beds which form units ranging in thickness from one to three feet. The sandstones are fine-grained and are composed predominantly of sub-angular to sub-rounded, well-sorted quartz grains weakly cemented by calcium carbonate. The units are gradational with the enclosing siltstones or mudstones.

The conglomerate and sandstone unit which overlies the Flagstaff Formation in the extreme south-central part of the area ranges in thickness from 0 to 40 feet, the variation a result of erosion. The unit is yellow brown, brown and orange and weathers to shades of dark red brown and dark gray. The clasts of the conglomerate are sub-rounded to well-rounded and range in size from 0.2 cm to 7.5 cm though most are between 1 and 3 cm. in diameter. The clasts are 75 percent light colored quartzite and 25 percent dark quartzite, chert and argillite. They are weakly cemented by a dark brown matrix of coarse sand and grit containing clay and iron oxide. Interbedded with the conglomerates are sandstones ranging in thickness from six inches to six feet. They are composed mainly of fine- to coarse-grained quartz grains and are cross-bedded and friable (Figure 16). They are the same color as the enclosing conglomerate beds and are gradational with them. Within one-quarter mile along strike the conglomerate and sandstone unit reaches a maximum observable thickness of 40 feet and the color changes from dark red brown to light gray. This is a function of a change in the matrix as the clasts remain the same. It appears to be caused by a marked decrease in the iron oxide content of the matrix. At this locality the conglomerate and sandstone unit is overlain by at least 30 feet of gray siltstone containing beds of sandstone which grade into red argillaceous siltstone and mudstone. The two units are separated by a minor erosional unconformity and the entire sequence is overlain unconformably by Tertiary lava. This unconformable contact is undulating and it appears that the volcanics were extruded on an erosional surface of considerable relief. The contact between the Colton (?) beds and the underlying Flagstaff Formation is obscured but it appears to mark a disconformity. This is based on the observation that the contact seems to undulate and that the beds above and below the contact are parallel. It is believed that the contact marks a minor erosional unconformity.

These conglomerates and sandstones cannot be correlated lithologically with any other units within the area but because of stratigraphic position the unit is believed to be a part of the Colton Formation. Because of the limited exposures and the fact that the upper part of the unit has been eroded away it cannot be determined if the conglomerate and sandstone unit is correlative with the upper

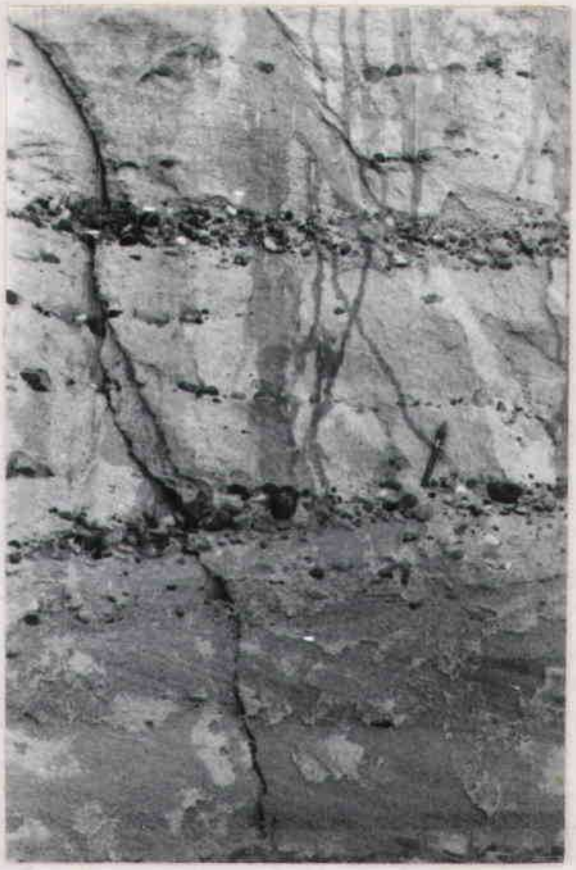


FIGURE 16. An outcrop of the Colton (?) Formation composed of cross-bedded sandstones with thin beds of conglomerate.

or lower part of the Colton Formation exposed in Gooseberry Valley. More detailed mapping might indicate that the unit belongs to one of the later Tertiary formations which crop out to the west of the mapped area and have been described by McGookey (16). However, at present the unit in question does not compare with the published descriptions of these later Tertiary formations.

In thickness the Colton Formation ranges between 1,500 feet at the type locality and zero feet where the formation loses its identity by intertonguing with the Green River Formation west of Soldier Summit in the northern part of the Wasatch Plateau (23, p. 34). As a rule, however, it is between 300 and 1,000 feet thick. Within the mapped area the formation is 530 feet thick where the complete section is exposed in Gooseberry Valley. In other exposures within the area only part of the formation is exposed and none of the sections are over 100 feet thick.

Age. Ostracods collected from the Colton Formation in Gooseberry Valley and identified by Swain (28) suggest a correlation with the uppermost Colton or lower Green River of the Uinta Basin. This indicates an early to middle Eocene age for the formation. Fresh water mollusks collected in the Wasatch Plateau were identified by Reeside (21, p. 139) as members of the traditional Wasatch fauna. It appears that an early Eocene age designation for the formation in the thesis area is permissible but Spieker (21, p. 139) states that because of the lack of diagnostic vertebrate fossils the Eocene designation is not completely supported by fossil evidence. A sample of limestone collected from the Gooseberry Valley section of the formation contains some ostracod fossils. The age of these fossils was not determined by the writer. No other fossils were collected.

Source Rocks and Environment of Deposition. In the type area Spieker has described lithologies which represent deposition in flood-plain and channel environments but within the mapped area lithologies of this type were not observed. The predominance of even-bedded argillaceous units and the interbedded limestone units containing fresh water ostracods indicate that the Colton Formation was deposited in a lacustrine environment. A cross-bedded conglomerate and sandstone unit that has been described from one locality appears to indicate that fluviatile conditions existed at least locally within the basin of deposition. This unit may represent deltaic deposition near the margin of the lake or it may record a pulse of orogeny in areas adjacent to the site of deposition and a temporary supply of coarse debris.

Green River Formation

The Green River Formation was named by Hayden (10, p. 89-92) for outcrops near Green River, Wyoming. Bradley (3, p. 9) later described the type section in greater detail. At the type locality the formation consists of finely laminated marlstones, limy and sandy shales, and oil shales. In central Utah the Green River Formation differs both from the rocks at the type locality and from the well known facies of the Uinta Basin and western Colorado. In the thesis area the formation consists of two members, a lower green-gray to light green shale and an overlying unit of cream to tan limestone. In central Utah the formation is transitional with the underlying Eocene Colton Formation and is overlain unconformably by the Crazy Hollow Formation (23, p. 36). The lower contact is well exposed within the mapped area but the overlying Crazy Hollow beds have been removed by erosion. McGookey (16) has described the upper contact from areas immediately west of the thesis area. He states that the Green River Formation wedges out south of Gooseberry Creek in T. 23 S., R. 2 E. due to differential uplift and erosion that took place prior to the deposition of the Crazy Hollow beds. The fluviatile varicolored clastic beds of the Crazy Hollow Formation were deposited disconformably over the eroded Green River limestones and older beds.

Distribution and Topographic Expression. In central Utah the Green River Formation is exposed at the base of the north and west flanks of the Wasatch Plateau, in the Gunnison Plateau, Valley Mountains and Pavant Range, and in the extreme northern part of the Fish Lake Plateau. Within the mapped area the formation crops out along the western side of Gooseberry Valley (Figure 15). The outcrop extends south from Utah State Highway 10 to the southern edge of T. 23 S., R. 2 E. where it wedges out. In other parts of the area the formation has been removed by erosion except for one isolated outcrop in sec. 28, T. 23 S., R. 2 E. where it has been preserved in a fault block. Typically the formation is an impressive cliff-former and forms the western boundary cliff of Gooseberry Valley. The upper part of the cliff is nearly vertical and is formed by the resistant upper limestone member of the formation. The lower shale member forms a steep slope beneath the limestone cap.

Lithology and Thickness. The Green River Formation in the mapped area consists of two members: a lower green to grayish green mudstone and shale member and an upper white to tan limestone member. The lower member, about 430 feet thick, is composed mainly of green to grayish green mudstones and shales but contains many thin layers and lenses of limestone, siltstone, and sandstone. The mudstone and shale beds are evenly-bedded and form units ranging from 5 to 125 feet in thickness. Thinner units are composed entirely of shale or mudstone but the thicker units contain thin interbedded limestones, siltstones and sandstones. The sandstones range in thickness from three to ten feet and are finely cross-bedded. Some units are conglomeratic at their base and contain small pebbles of the underlying mudstones and limestone. Generally the sandstones are fine- to medium-grained and are composed of sub-angular to sub-rounded quartz grains cemented by calcium carbonate. Some of the contacts are sharp but others are gradational, both above and below, from sandstone into siltstone and mudstone. The interbedded siltstones are grayish green in color and generally less than one foot in thickness. They are usually cemented by calcium carbonate and contain small ferruginous concretions which are less than 1 cm. in diameter. The siltstones have gradational contacts with the adjacent sandstones and mudstones. The interbedded limestones range in thickness from 3 to 12 feet and are white to gray in color. The limestones are dense and resistant and form minor ledges on the steep mudstone and shale slopes.

The upper limestone member, of which about 300 feet is exposed in the mapped area, is characterized by both thin-bedded platy limestone and massive dense limestone that locally is oolitic. The thin-bedded limestones, which are the most common, are white to light brown in color and occur in discrete one to three inch beds which are fissile. The massive limestones are also white to light brown in color and occur in beds ranging from a few feet to over 100 feet in thickness. These limestones are especially resistant because of partial to locally complete replacement by chert.

Age. McGookey (16) reports that ostracods collected from limestones near the top of the Green River Formation in Soldier Canyon, four miles west of the mapped area, have been identified by F. M. Swain and indicate a correlation with the middle part of the Green River Formation of the Uinta Basin. Bradley (3, p. 9) considers the Green River Formation of Wyoming and northeastern Utah to be of middle Eocene age. Inasmuch as the fossil assemblages found in the vicinity of the mapped area correlate with those described by Bradley there seems to be no doubt that, in this area, the Green River Formation is of middle Eocene age.

Source Rocks and Depositional Environment. The limestones, the even-bedded shales and mudstones, and the fresh water fossils found within the Green River Formation indicate deposition in a lacustrine environment. Bradley (3, p. 54), who has studied the Green River deposits in northeastern Utah and Colorado, pictures the lake as a broad sheet of water flooding a large plain on which the Colton

Formation was being deposited, and enclosed by mountains or high hills. The depth of the lake near the shore was not more than 10 or 15 feet and the deepest part of the basin was 50 or 60 feet deep and may have been as deep as 75 to 100 feet.

West of the thesis area McGookey (16) has reported biostromal growths of Chlorellopsis coloniata in the massive limestone units and indicates that this alga grows in water depths of less than 15 feet. The factors which determine the precipitation of the carbonates, both organic and chemical, are outlined in detail by Bradley (2, p. 641-643). The presence of lensing cross-bedded sandstones, some of which are conglomeratic and contain wood fragments, in the lower mudstone and shale member of the formation indicates deposition in a sub-aerial or shallow water high energy environment.

The limestones and argillaceous rocks are considerably different from the marls and oil shales which are characteristic of the Green River Formation in the Uinta Basin and in Colorado. This difference is either a function of the faunal productivity of the lake in this area or the lack of that thermal or chemical stratification which induces reducing conditions on lake bottoms and is a prerequisite for the preservation of organic material.

The large accumulation of carbonates and argillaceous material was mainly a function of the available source areas. Harris (9), discussing Mesozoic positive areas in western Utah, states that thrust faulting during the Late Cretaceous exposed Paleozoic and Early Mesozoic carbonates and clastic rocks in areas west of the present Sevier Valley. Post-thrusting erosion supplied fine sediments to the fresh water lakes of Central Utah where they were deposited as calcareous and argillaceous beds.

Gray Gulch Formation

Within the mapped area the Gray Gulch Formation is the next higher stratigraphic unit after the Green River Formation because the Crazy Hollow Formation, which lies between them in areas to the west (16), is not exposed.

The lacustrine tuffaceous sediments which unconformably overlie the Crazy Hollow Formation in the Salina district were provisionally named the Gray Gulch Formation by Spieker (23, p. 37-38). No type section was named but McGookey (16) indicates that Spieker had in mind a section in Crazy Hollow (sec. 32, T. 21 S., R. 1 E.). McGookey proposes subdividing the unit into two distinct formations: 1) The "Bald Knoll Formation" would be the lower part of the Gray Gulch Formation, and would consist of evenly-bedded light gray to white shale, some of which is bentonitic; 2) The "Dipping Vat Formation" would be the upper coarse interval of the Gray Gulch Formation and would include evenly-bedded tuffaceous sandstones that contain varying amounts of glass and other pyroclastic fragments interbedded with white clay and silty limestone. Because of limited exposures of the Gray Gulch Formation within the mapped area the writer has not attempted to subdivide the formation. However, comparisons of type sections and written descriptions indicate that the outcrops within the area are correlative with McGookey's "Dipping Vat Formation". Spieker (23, p. 38) states that the formation is bounded above and below by erosional unconformities, but the contacts are concealed within the mapped area.

Distribution and Topographic Expression. McGookey (16) and Spieker (23, p. 37) have correlated the Gray Gulch Formation with strata exposed in the southern Wasatch Plateau, Pavant Range, Gunnison Plateau, Tushar Mountains and possibly in Iron County in southwestern Utah. Within the mapped area exposures are limited to a few outcrops in the south-central part of T. 23 S., R. 2 E. The strata are resistant and form minor cliffs 20 to 40 feet high (Figure 17) which stand out from landslide areas. At one location a resistant limestone forms a minor dip slope.

Lithology and Thickness. Within the mapped area the Gray Gulch Formation consists of interbedded limestones, shales, siltstones and sandstones. The limestones are white to dark gray in color and weather to white and gray and in some cases to light brown. They are even-bedded and occur in beds one-eighth to two inches thick which form units less than two feet thick. They are both micritic and fossiliferous. One dark gray limestone unit contains abundant gastropod tests and exudes a fetid odor when struck by a hammer. The limestones are sharply separated from the interbedded clastic sediments and are resistant to erosion, forming thin ledges in otherwise steep slopes.

A few reddish brown, thinly-laminated shales are present and occur in units about six feet thick. The shales are gradational with the interbedded siltstones but are sharply defined from the sandstone units. The siltstones are light brown in color, are evenly-

FIGURE 17. An outcrop of interbedded limestone, shales, mudstones and tuffaceous sandstones of the Gray Gulch Formation.

bedded, occur in discrete one-half inch beds, and form units ranging from two to four feet in thickness. The siltstones are gradational into interbedded shales and sandstones.

The sandstones are tuffaceous, are gray to white in color and weather to reddish brown. They are both massive and finely cross-laminated and occur in units ranging in thickness from a few inches to four feet. They are coarse- to medium-grained, poorly sorted and are composed of angular- to sub-angular grains of dark gray chert, quartz, and rock fragments in a matrix of glass shards and clay. They are classified as volcanic sandstones. Some of the sandstones are conglomeratic at their bases and include pebbles of the underlying shale and siltstone units.

McGookey (16) has measured a section of the Gray Gulch Formation immediately west of the mapped area and reports a thickness of over 1,250 feet for the formation. Within the mapped area the isolated outcrops have been disturbed by faulting and landsliding this thickness is not representative of the actual thickness of the formation.

Age. McGookey (16) states that Charophytes collected from the lower part of the formation were tentatively determined to be of a late Eocene or Oligocene age. Gastropods of the family Lymnaeidae and ostracods of the genus *Heterocypris* collected from the upper part of the formation suggest a correlation with the uppermost Green River or Uinta formations of the Uinta Basin. These facts suggest a late Eocene and possibly an early Oligocene age for the formation. Planorbid gastropod fossils were collected by the writer but were not identified.

Source Rocks and Depositional Environment. The limestones, the presence of fresh water fauna, and the even-bedded nature of the fine-grained sediments indicate that the formation was deposited under lacustrine conditions. Charophytes, reeds, air-breathing gastropods and algae, reported by McGookey in areas adjacent to the mapped area, indicate that the lake in this area was very shallow during part of its history. The interbedded finely cross-laminated sandstones and conglomeratic sandstones also indicate sub-aerial or shallow water high energy conditions. The size of the lake in which the formation was deposited is not known but considering the known extent of the outcrops it appears to have been smaller than the Uinta Lake in which the Green River Formation was deposited.

The fine-grained nature of the clastic sediments and the interbedded limestones suggest that the sedimentary materials were derived from pre-existing sedimentary rocks. The high percentage of tuffaceous material within the clastic sediments and particularly within the sandstones indicates that volcanic activity had been initiated in areas adjacent to the basin of deposition. Neither the direction nor the distance to the volcanic source areas could be determined by studying the few exposures of the formation that are present within the area studied.

Tertiary Lavas

The Tertiary lavas exposed in the thesis area represent the northern edge of a great mass of flows which covers more than

3,000 square miles of the High Plateaus of Utah. The extrusives within and adjacent to the area were first studied by Dutton (5, p. 265) in the late 1870's and he mapped them as "...700 feet of hornblendic trachytes in massive sheets alternating with augitic andesites, which are much thinner." McGookey (16) has applied the term "Bullion Canyon volcanics, lava flows" to the sequence of extrusives because they appear to be correlative with a sequence of Early Tertiary tuffs, volcanic breccias, and latite flows that are exposed near Marysville, Utah, and which have been named the "Bullion Canyon volcanics". Because the lavas were not studied in detail by the writer there has been no attempt to subdivide the extrusive volcanic rocks exposed in the mapped area or to correlate them with other volcanic rocks in adjacent regions. The volcanic rocks have been deposited on an erosional surface of considerable relief and overlie sedimentary rocks of Early Tertiary age.

Distribution and Topographic Expression. The lavas within the area are part of a volcanic cover which extends over 80 miles to the south. At present the flows are continuously exposed across the southern part of the area (Figure 18). It is possible that they originally extended north into the southern part of the Wasatch Plateau, and that they were subsequently removed by erosion. Spieker (23, p. 38) states that the northern-most lobe of the lava fields of the central High Plateaus extends a few miles into the foothills of the Wasatch Plateau in the vicinity of Salina, Utah. The sequence of lava flows in the southwestern and southeastern parts of the mapped area forms nearly vertical cliffs over 300 feet high rising above

FIGURE 18. A view south from near Salina Reservoir toward the cliff and steep talus slope formed by Tertiary lavas.

steep talus slopes. In the central part of the region the volcanic cover is much thinner and the flows cap steep slopes formed on Late Cretaceous and Early Tertiary sedimentary rocks. In the east-central part of the area the volcanic cover has been preserved in a fault block, the UM Plateau (Plate 2), and forms a steep cliff over 300 feet high. The surface of the lava-covered plateau in the extreme southern part of the area is one of very low relief and slopes gently to the south.

Lithology and Thickness. The Tertiary volcanics are composed predominantly of lava flows. In sec. 34, T. 23 S., R. 2 E. some tuffaceous sandstones and pumice tuffs are exposed at the base of the lava sequence. These probably correlate with McGookey's (14) "Bullion Canyon volcanics, clastics". This unit includes mudflows, conglomeratic tuffaceous sandstones and tuffs that disconformably overlie the Gray Gulch Formation in areas west of the mapped area. The tuffaceous sediments were not mapped as they are exposed at only one locality and have been disturbed by landsliding.

The flow rocks are dark bluish black to light gray and weather to light gray, dark brown and pinkish brown. The flows range in thickness from a few feet to over 40 feet. Individual flows can be discerned by changes in color and texture. Some of the flows are massive and others contain flow lines and vesicles which are elongated in the direction of flow. Four rock samples were collected and sectioned. The rocks examined, on the basis of the phenocrysts, may be classified as augitic andesites. Andesine and augite are the predominant phenocrysts and iddingsite, as pseudomorphs after olivine, is a common accessory mineral. There are probably other kinds of rocks in the flows that were not sampled as Dutton (5) has classified the flows as trachytes with subsidary augitic andesites and McGookey (14) reports the presence of andesites and latites.

The thickness of the volcanic sequence within the thesis area is difficult to determine because the base is covered by talus slopes, rock glaciers and landslide debris. In general it appears that the unit ranges in thickness from less than 50 feet in the south central part of the area to over 700 feet in the southeastern and southwestern parts of the area. The differences in thickness across the southern part of the area are due to: 1) extrusion on a surface of relief, 2) faulting which has protected parts of the unit from erosion, and 3) subsequent erosion which has modified the surface of the volcanic sequence. McGookey (14) indicates that in areas south and east of the mapped area the volcanics attain thicknesses in excess of 1,000 feet.

Age. The extrusive rocks of the northern part of the Fish Lake Plateau unconformably overlie Late Eocene sedimentary rocks and pre-date the period of pediment development in the region. They also pre-date the Late Tertiary normal faulting which was probably initiated in the Late Miocene. These stratigraphic and structural relationships indicate a Middle Tertiary, possibly Oligocene age, for the lava flows.

Unconsolidated Sediments

Much of the thesis area is covered by deposits of unconsolidated sediments. Quaternary alluvium, pediment gravels, and landslide deposits occur in the area.

Quaternary alluvium, in the form of unconsolidated gravel, sand and silt, is found along some of the larger streams within the area (Plate 3). Deposits in the smaller and steeper stream valleys are composed of angular boulders and cobbles of sandstone, limestone or lava rock, depending on the available rock type, in a matrix of sand- and silt-size material. These deposits are of a colluvial nature and the sedimentary materials have undergone little or no stream transportation.

The terrace, pediment, and landslide deposits occurring in the mapped area have been discussed in the Geomorphology section.

STRUCTURAL GEOLOGY

The High Plateaus of central Utah are a structural transition zone between the block faulted, thick geosynclinal sedimentary rocks of western Utah and the less-deformed and thinner shelf sequences of the Colorado Plateau.

Regional Structure

The dominant structural features of the geosynclinal area west of the High Plateaus are block faults of Tertiary age which have been superimposed on Late Jurassic to Late Cretaceous faults and folds. The shelf folds to the east are broad anticlinal and monoclinal flexures which are characteristic of the Colorado Plateau. These flexures were formed at some time between the middle and late part of the Paleocene (24, p. 13).

The Pavant and Canyon Ranges (Plate 2) are large uplifted blocks on the eastern edge of the geosynclinal area which are typical of the Basin and Range fault blocks. Within the Canyon Range thrust faulting of early Late Cretaceous age is exposed disclosing Precambrian rocks overlying Late Cretaceous conglomerates of the Indianola Group. The Gunnison Plateau and the Valley Mountains, located west of the Sevier and Sanpete Valleys, are smaller uplifted fault blocks (Plate 2).

The most prominent structural feature east of the High Plateau is the San Rafael Swell. The Swell is an elongate northeast-trending anticline with a steep east flank and a gently dipping west flank. The Book Cliffs which circle the northern part of the San Rafael Swell form the east side of the High Plateaus.

The outstanding structural features of the central and northern High Plateaus are the Wasatch monocline and the normal faults which are superimposed on it. On the eastern side of the Wasatch Plateau the strata dip gently westward from the San Rafael Swell and on the western side the strata dip more steeply into the Wasatch monocline. The Wasatch monocline forms the west front of the Wasatch Plateau from north of Fairview, Utah to south of Salina Canyon where it is masked by Tertiary volcanic rocks. Superimposed on the monoclinal structure are numerous normal faults with displacements as great as 3,000 feet. The major faulting was initiated in the Early Tertiary and continued into the Pleistocene.

Four major periods of deformation have been recognized in the region. The first occurred between the Late Jurassic and early Late Cretaceous (prior to Colorado time), and formed the Sevier Arch. The second happened during the middle Late Cretaceous (middle Montana time). This has been named the Early Laramide orogeny by Spieker (23, p. 79). The third, between the Late Eocene and the Miocene, produced the Wasatch monocline. The last, during the Late Miocene, initiated the normal faulting of the High Plateaus. Spieker (23, p. 77-81) has outlined the sequence of deformation in the region and presents evidence for 14 distinct periods of crustal movement.

Thesis Area Structure

The northern part of the Fish Lake Plateau lies in a transition zone between the simple domal uplift of the San Rafael Swell of the Colorado Plateau Province on the east and the highly faulted, structurally complex region of the Great Basin Province on the west. Because of its transitional location the Fish Lake Plateau has structural elements characteristic of both bordering areas.

The central and western parts of the mapped area are dominated by a homoclinal sequence of west-dipping Late Cretaceous and Early Tertiary strata which are modified by Late Tertiary normal faults. The homoclinal structure is the gently dipping limb of the Wasatch monocline and is similar to the monoclinal folds of the Colorado Plateau. The Gates Creek monocline, located in the west-central part of the region (Plate 3) is a minor flexure of the same type.

Folds

Wasatch Monocline

The Wasatch monocline is the dominant feature of the northern High Plateaus of Utah. It forms the western front of the Wasatch Plateau between Milburn, Utah and Salina Canyon, a distance of 55 miles. South of Salina Canyon the monocline becomes less pronounced due to a lesser structural development and to an overlapping by Tertiary volcanics. The difference in structural elevation between the flat-lying strata at the top of the High Plateaus to where the gently dipping beds of the Green River Formation pass under the alluvium of Sevier and Sanpete Valleys (Figure 19) exceeds 6,000 feet.

The strata are generally horizontal in the eastern part of the area and the beds begin to dip to the west on the western side of Brown's Hole (Plate 3). The strata are gently inclined to the west with dips that are only locally greater than 10°. In the northern part of the area the monocline is well developed but in the southern part the monocline cannot be recognized. This is partly because of the volcanic cover in the extreme southern part of the area, and partly because of a lesser structural development.

Spieker (23, p. 44-48), in discussing the monocline, suggests that it is a tensional rather than a compressional feature, and that its origin is distinctly different from that of the typical Colorado Plateau monoclines which were caused by deep-seated compression. Spieker believed that the Wasatch monocline and the associated grabens of the High Plateaus were the result of regional uplift that took place after the deposition of the Late Eocene Crazy Hollow Formation and before the deposition of the Tertiary lavas of probable Oligocene age. Because the age of the volcanics is uncertain Spieker (23, p. 80) places the time of folding between the Late Eocene and the Miocene and suggests that an early date in this interval is likely. McGookey (16), however, states that relationships observed in regions immediately west of the thesis area indicate that the folding followed the deposition of the "Bullion Canyon volcanics, clastics", and that this indicates a probable early Oligocene age for the folding. No data within the mapped area was observed which could establish the time of folding any closer than that suggested by Spieker.

Gates Creek Monocline

In T. 22 and 23 S., R. 1 and 2 E. (Plate 3) is another monoclinal flexure which McGookey (16) has named the Gates Creek monocline. The monocline has been developed en echelon to the southern end of the Wasatch monocline and was probably formed at the same time. The dips east of the shoulder range from 4° to 10° west. At the steepest part, farther west in the vicinity of Gates Creek, the dips increase and range from 18° to 36° west. The toe of the fold is located west of the thesis area and is characterized by dips of less than 10°. To the north the fold dies out, but to the south the bedrock is covered by landslide debris. The origin and time of folding of the structure are believed to be the same as those of the Wasatch monocline.

Other Folds

At the head of Porcupine and Hoodoo Creeks in T. 22 S., R. 2 E. there is a half-dome-shaped structure. From south to north the strikes of the strata change from N 40° W to N 50° E, and the dips range from 8° to 15° west. To the west the fold dies out in Gooseberry Valley by merging with the regional homoclinal structure, and to the east it is bounded by a normal fault. All indications suggest that the structure is a pre-faulting flexure and it is believed to have been formed by the same forces that produced the Gate Creek monocline.

Local reversals of dip, associated with normal faults, are common in the area. A number of these dip reversals are associated with the Water Hollow graben. These reversals are drag folds which are a result of differential movement along fault planes. An excellent example of a drag fold is exposed in Salina Canyon (NE 1/4, SE 1/4, sec. 13, T. 22 S., R. 2 E.) where beds of the Blackhawk Formation are seen to dip steeply into a north-trending fault (Figure 20).

Faults

The Wasatch and Fish Lake Plateaus are characterized by groups of north- and northeast-trending high angle normal faults. These faults are considered to represent the easternmost extension of the Basin and Range type of faulting. Five major grabens have been developed in the Wasatch Plateau and three of these extend southward into the Fish Lake Plateau (23, p. 42-44). Of these three only the Water Hollow graben is entirely within the thesis area. The western boundary fault of the Musinia graben forms the eastern boundary of the mapped area.

The age of the faulting can only be determined by structural and geomorphic relations. There is no evidence in the area of faulting prior to the extrusion of the Tertiary lavas which are considered to be of Early Oligocene age. Pediments which have been affected by the faulting also aid in the dating of the structures as

FIGURE 19. A view toward the west front of the Wasatch Plateau. The hogbacks in the center background are formed on limestones of the Green River Formation and represent the toe of the Wasatch monocline.

FIGURE 20. A drag fold in sandstones of the Blackhawk Formation. Salina Canyon.

they were formed after the extrusion of the lavas but prior to the faulting. Between Yogo and Niotche Creeks in T. 23 S., R. 3 E. a perched pediment forms Flat Top Mountain. At the base of the west boundary fault of the Musinia graben there is a pediment which is believed to correlate with the pediment of Flat Top Mountain. This correlation is based on the following facts: 1) the present difference in elevation between the pediments is about the same as the displacement of the fault, 2) the pediments are both formed on strata of the Late Cretaceous and Early Tertiary North Horn Formation, and 3) only one period of pediment development, during the Quaternary, has occurred in the area. The fact that Niotche and Yogo Creeks cut diagonally across the faults indicate that the major drainages were established prior to the faulting.

Taking all of the data into consideration it appears that the normal faulting was initiated after the extrusion of the lavas and sometime after the present drainage pattern was well developed, probably in the late Miocene. Faulting has continued into the Recent in the region, but no positive evidence of this was found in the mapped area.

Musinia Graben

The north-trending west boundary fault of the Musinia graben forms the east boundary of the thesis area. At the eastern end of Salina Canyon (Plate 3) the fault has a displacement of at least 1,000 feet (23, p. 44) and possibly as much as 2,000 feet. The fault forms a cliff composed of sandstones of the Price River Formation

(Figure 21). This cliff forms the western boundary of a broad valley formed by the erosion of the less resistant North Horn Formation. To the north the fault continues into the Wasatch Plateau and to the south the displacement becomes progressively less until the fault trace disappears under landslide debris in the southern part of T. 23 S., R. 3 E.

Water Hollow Graben

The Water Hollow graben occupies a fault zone approximately one and one-half to two miles wide in the north-central part of the area. The zone is separated from the Musinia graben by two and one-half miles of relatively unbroken terrain. The graben is formed by one main fault on the east side and by three subsidiary faults to the west. As fault surfaces are rarely visible because of erosion and sliding the fault traces were mapped by photo interpretation. The fault planes are generally nearly vertical or dip steeply to the east. The westernmost fault, as seen in Salina Canyon, has a 60^{o} dip to the east but becomes nearly vertical to the south. The faults which were photo interpreted apparently have dips ranging from 60^{o} east to vertical.

Displacement along the easternmost fault is about 1,000 feet. The eastern block in the graben has had the greatest displacement, and the blocks to the west have progressively less displacement. Brown's Hole (Plate 3) is a distinctive topographic feature formed on the easternmost block as a result of the differential erosion of the less resistant North Horn Formation (Figure 22). The cliffs on

FIGURE 21. A view west down Salina Canyon showing the fault-line scarp of the western boundary fault of the Musinia graben. The cliffs in the background are formed by strata of the Blackhawk and Price River Formations. The valley in the foreground has been formed on less-resistant strata of the North Horn Formation.

FIGURE 22. A view to the north into Brown's Hole, a topographic basin formed by erosion of the North Horn Formation in the Water Hollow graben.

either side of Brown's Hole are composed of the sandstones of the Price River Formation. South of Brown's Hole the graben is difficult to recognize as the displacement decreases and there is no longer a prominent physiographic expression.

From Salina Canyon to about two miles south, the Water Hollow graben is cut by a number of smaller faults. These faults have no consistent trend and form small fault blocks with strata dipping in a variety of directions. Only the more prominent of these faults have been included on the geologic map because of scale limitations. These smaller fault blocks as well as the three major fault blocks appear to be foundered blocks formed by tensional release rather than by differential uplift.

Many other normal faults occur in the mapped area (Plate 3) and they are believed to be the result of the same forces which formed the major grabens. The isolated faults may be later than the major graben faulting but no evidence to this effect has been observed in the mapped area.

GEOMORPHOLOGY

Stream Erosion

This region, largely mountainous, is highly dissected by stream erosion. In the northern part the streams have cut steep walled canyons and have narrow, flat, interstream divides, while in the southern part the streams have cut broader valleys and have rounded interstream areas. In the northwestern part of the area, Gooseberry Creek has formed a relatively wide valley attaining a maximum width of about one mile near its junction with Salina Creek. Farther south Gooseberry Valley narrows rapidly and the gradient of the creek increases. In general, it appears that the thesis area is in the late youth to early maturity stage of stream erosion.

Many of the streams flow to the north and are subsequent to the north-trending regional structure. Their courses have been determined either by differential erosion of the predominantly north-trending and west-dipping strata or by north trending normal faults. Other streams, such as the northeast-flowing Niotche Creek and the west-flowing Salina Creek, are antecedent streams cutting across the north-trending normal faults. The antecedent drainages appear to have been well established as early as the Late Miocene when the normal faulting, which strongly affected the area, began.

Terraces indicate that there were at least two periods of stream erosion during the Late Cenozoic, prior to the deposition of Quaternary alluvium. Arroyos now being cut into the Quaternary alluvium, indicate that a new cycle of erosion has begun. The down-cutting is probably due to a lowering of a temporary base level or to recent uplift.

Terraces

Alluvial terraces occur along two stream valleys within the mapped area. They are composed of boulders and cobbles of andesite, latite, and sandstone in a matrix of quartzite and chert pebbles and coarse sand. A discontinuous terrace, about 15 to 20 feet above the present stream level, lies along Gooseberry Creek in the northwestern part of the area (Plate 3). The terrace is first noticed at the Gooseberry Creek Ranger Station where it is about one-half mile long, a few hundred yards wide, and is restricted to the west side of the creek.

About a mile downstream the terrace again occurs on the west side of the creek and widens as the creek enters the southern end of Gooseberry Valley. In the valley the terrace is found along both sides of the creek and attains a width of one-half mile (Plate 2). The surface of the terrace is relatively flat and slopes to the north at the same gradient as the creek. One-half mile east of Gooseberry Creek, at the mouth of the canyon formed by Porcupine Creek (Plate 3), a deposit of cobbles and gravel has been interpreted by the writer to be an erosional remnant of the Gooseberry Creek terrace.

Another terrace, about two miles long and one-half mile wide, occurs on both sides of the northeast-flowing Yogo Creek in the extreme east-central part of the mapped area (Plate 3).

The terrace deposits within the area record an earlier period of sedimentation during which the stream valleys were partially filled with coarse-grained deposits. These deposits were nearly completely removed during a later period of erosion. This episode of valley filling was post-normal faulting and pre-Quaternary alluvium, suggesting a Pleistocene age for the terraces.

Pedimentation

Pediments, which are formed as gently sloping plains eroded at the foot of steep slopes or cliffs, are found in the southeastern and eastern parts of the mapped area (Plate 3) at elevations ranging from 7,000 to 10,000 feet. The steep slopes or cliffs which are associated with pediment development have been removed by erosion and the pediments remain as the only indication of these previous topographic highs.

The pediments are formed predominantly on the sedimentary rocks of the Late Cretaceous North Horn Formation, but in the extreme southern part of the region a pediment is formed in part on strata of the Early Tertiary Flagstaff Formation. The pediments are covered by 5 to 20 feet of gravel composed of rounded pebbles of chert and quartzite and angular to sub-angular cobbles and boulders of andesite and latite. The pediment surfaces are generally inclined to the northeast with slopes of four to eight degrees.

The largest pediment surface in the area forms Flat Top Mountain, a distinctive topographic feature lying between Niotche and Yogo Creeks in the southeastern part of the area (Figure 23).

FIGURE 23. A pediment surface between Niotche and Yogo Creeks which forms Flat Top Mountain. The pediment surface is formed on strata of the North Horn Formation.

This pediment trends in a northeastern direction, is nearly four miles long and varies in width from one-eighth to three-quarters of a mile. The southwestern end of the pediment has been displaced by a fault associated with the Water Hollow graben. Numerous smaller pediments occur as isolated topographic highs within the extensive area of landsliding between Table Mountain and the steep cliffs of the lava-covered plateau to the south (Plate 3).

Narrow pediment surfaces lie at the base of the western boundary fault of the Musinia graben along the eastern edge of the mapped area. The pediments are terminated upslope by the fault and are formed on strata of the North Horn Formation. They must have been formed at a higher elevation, later being displaced to their present position by normal faulting.

The pediment surfaces are covered by cobbles and boulders of volcanic material indicating that the pediments were formed after the extrusion of the Oligocene lavas. Since faulting the pediments have been extensively dissected by stream erosion.

Landsliding

Extensive landsliding has occurred within the thesis area, particularly south of the Gooseberry Ranger Station where three quarters of the land surface is covered by landslide debris. The landslide areas are characterized by hummocky topography, interrupted drainages and by numerous closed depressions, some of which form small ponds and lakes. Below 9,000 feet the landslides typically are covered by growths of aspen, while above 9,000 feet the slide areas are open, grass-covered slopes (Figure 24) with aspen growing in profusion along the creeks.

Though landslide scars are common and a few minor slump blocks are present, there is little evidence of recent landsliding of the scale necessary to account for the extensive slide areas that are present. The writer believes that at the present time landsliding is a minor feature and that the major landsliding took place in the late Pleistocene when the amount of precipitation in the area was much greater.

Most of the slides involve the Late Cretaceous North Horn Formation and the Early Tertiary Flagstaff Formation. In one area (sec. 27, T. 23 S., R. 2 E.) the Colton and Green River (?) Formations have also been affected by sliding, and it is possible that later Tertiary formations are also involved in the landsliding though they cannot be identified in the rubble of the landslide debris.

A major factor that influenced the sliding was the Tertiary lava flows which covered the southern part of the thesis area and capped the weaker underlying sedimentary rocks. Differential weathering and erosion of these weaker rocks caused oversteepening of the slopes and sapping of the lava cliffs which resulted in rock falls and slumping.

Talus creep, caused by frost heaving, is a common feature at the base of the lava cliffs in the southern part of the area. Rock glaciers, composed of sinuous streams of angular blocks of lava, extend over three-quarters of a mile from the base of the lava cliffs.

FIGURE 24. A view to the north from the head of Niotche Creek. The topography in the central part of the photograph has been formed by landsliding. Tertiary lavas form the cliff in the left background.

HISTORICAL GEOLOGY

During the Late Mesozoic a northeast-trending positive area known as the Sevier Arch was formed in western Utah. The arch is believed to be the third in a series of major upwarps which were developed by the eastward progression of Paleozoic and Mesozoic orogenies. The structural history of the Sevier Arch is described in detail by Harris (9). After the initial uplift of the arch the orogenic deposits of the Late Jurassic Morrison Formation and the Late Cretaceous Indianola Group were deposited in a geosynclinal foredeep east of the arch. The deposits of the Indianola Group become progressively finer eastward and are believed to grade into the shales which were being deposited in the shallow Mancos Sea of central and eastern Utah. As the highland source areas to the west were worn down finer grained sediments were deposited in the Fish Lake Plateau area. These deposits of fluviatile, swamp, lagoonal and marine origin formed the Blackhawk Formation of middle Montana age. Outcrops of this formation are not found west of the thesis area but it is probable that they extended much farther to the west and were subsequently removed during the Laramide folding and erosion that took place between middle and late Montana time.

The Laramide orogeny was initiated by thrust faulting in the area of the Sevier Arch and by folding in the area of the Sevier and Sanpete Valleys. The folding is well exposed at the mouth of Salina Canyon and at other localities along the west front of the Wasatch Plateau. Within the Fish Lake Plateau area this episode of folding and subsequent erosion is represented by the disconformity between the middle Montana Blackhawk Formation and the late Montana Price River Formation. To the west and northwest the Price River Formation is highly conglomeratic but in the Fish Lake Plateau area the formation is predominantly sandstone which becomes finer to the east. The Castlegate Member of the formation was deposited as a great sandstone tongue which extends eastward across Utah into Western Colorado where it disappears by intertonguing with the Mancos Shale. The finer grained sediments of the Late Cretaceous and Early Tertiary North Horn Formation were deposited conformably over the Price River Formation as the highland source areas to the west were worn down. The lower varicolored beds of the North Horn Formation were deposited in fluviatile environments and the upper beds were deposited under lacustrine conditions which were initiated in this area in the Early Paleocene and prevailed until Middle Eocene time.

The post-North Horn, pre-Flagstaff regional compression which formed the monoclines of the Colorado Plateau and deformed areas to the north along the west front of the Wasatch Plateau did not affect the Fish Lake Plateau area, or at least this effect does not appear in the stratigraphic record.

During the Late Paleocene and Early Eocene red silts and clays with some calcareous beds were deposited under lacustrine conditions in the northern part of the area and graded southward into the typical grayish green argillaceous beds and white limestones of the Flagstaff Formation. Following the deposition of the Flagstaff

Formation the lacustrine varicolored siltstones and mudstones of the Colton Formation were deposited and were subsequently followed without break by the green shales and white limestones of the Green River Formation.

The deposition of the Green River Formation was followed by a period of erosion which probably lasted until the early Late Eocene. Following this erosion, which removed a considerable amount of the Green River Formation, the conditions changed from lacustrine to fluviatile and the varicolored muds and sandstones of the Crazy Hollow Formation were deposited unconformably over the eroded surface of the Green River Formation. Renewed downwarping in the area caused the formation of a second great lake in which the Gray Gulch Formation was deposited. At the same time volcanic activity was initiated in adjacent areas, supplying volcanic ash to the lake basin. The amount of ash was sufficient to form the tuffaceous siltstones and sandstones found within the Gray Gulch Formation.

Lacustrine conditions were terminated in the area in latest Eocene time when large volcanoes appeared in areas to the south and southwest. Streams from the volcanic areas carried huge quantities of volcanic material into the region immediately west and possibly into the mapped area proper. The volcanic debris was deposited as mudflows which compose the "Bullion Canyon volcanics, clastics" of McGookey (16).

A period of uplift followed the deposition of the "Bullion Canyon volcanics, clastics", and associated forces caused the formation of the Wasatch monocline and the much smaller Gates Creek monocline located on the western edge of the mapped area. The uplift and folding were followed by a period of erosion which removed a considerable amount of strata from the central and eastern parts of the area. After the period of erosion a thick series of lava flows from sources in the Fish Lake and Sevier Plateaus covered the southern and possibly the central part of the mapped area. The flows were part of a great volcanic sequence which presently covers over 3,000 square miles of the High Plateaus.

A period of erosion and pediment formation followed the extrusive activity. During the Late Miocene the whole region was uplifted and normal faulting began. The faulting continued into the Pleistocene and possibly into the Recent. Extensive landsliding and at least two cycles of stream erosion have modified the topography during the Late Cenozoic. At the present time erosion is the dominant process as arroyos are now being cut into Quaternary alluvium.

ECONOMIC GEOLOGY

Limited exploration has been conducted in the northern part of the Fish Lake Plateau in the search for oil and gas. This exploration has been concentrated in the north-central part of the area along Salina Canyon. In the past coal has been produced from mines within Salina Canyon.

Oil and Gas

Stratigraphic and possibly structural conditions in the area are apparently favorable for the formation and accumulation of petroleum and gas. Both source and reservoir rocks are present in the subsurface. However, two dry oil and gas test holes have been drilled in the area. The locations and descriptions of these dry holes are given in Table 3.

F. M. Christianson (4) includes the Fish Lake Plateau in a report concerning the oil and gas possibilities of central Utah.

Possible Reservoir Rocks

About 7,000 feet of Cretaceous sedimentary rocks are known to underlie the area studied. Earlier Mesozoic strata outcrop both east and west of the mapped area and an undetermined thickness of these rocks is believed to be present in the subsurface. An additional 6,000 feet of Late Cretaceous and Early Tertiary nonmarine rocks are exposed in the area.

Several of the Cretaceous formations contain possible reservoir rocks. From electric log data it appears that permeable

TABLE 3. Summary of oil and gas test holes in the thesis area.

Name	Location	Date	Total Depth	Spudded in	Bottomed in
Pan American Petroleum Corporation Porcupine Ridge Unit #1	C, NW, NW, Sec. 30 T. 22 S., R. 3 E.	1963	6299	Price River (?) Formation	Tununk Shale
El Paso Natural Gas Company Unit #1	SW, NE, NE, Sec. 15 T. 22 S., R. 2 E.	1953	6116	Blackhawk Formation	Morrison Formation

sandstone beds occur in the Late Cretaceous Sanpete, Ferron and Star Point formations. The Late Cretaceous and Early Tertiary Price River and North Horn formations also contain many permeable sandstone beds but they are exposed within the mapped area. It is very probable that other reservoir rocks are present in units of the Indianola Group in areas to the west which have not been drilled and at deeper horizons in strata of earlier Mesozoic age. The Mancos Shale of Late Cretaceous age is a known source rock for petroleum and gas in areas farther east.

Structural and Stratigraphic Traps

This area does not seem suitable for the structural entrapment of oil. The region is dominated by a homoclinal sequence of west-dipping Late Cretaceous and Early Tertiary strata which are modified by normal faulting. The major homoclinal structure and some local flexures appear to be the result of regional uplift and deformation during the Early Oligocene. Normal faulting, initiated during the Late Miocene, was superimposed on the earlier structures and locally caused displacements of over 1,000 feet. The faulting in the central part of the area has formed a closure on a half-dome-shaped structure located at the head of Porcupine and Hoodoo Creeks (Plate 3), and has formed many local reversals of dip due to drag along the fault planes. Though there have been structures with closure formed by the faulting the writer believes that these possible structural traps have been formed too late in the geologic history of the region to act as traps for the accumulation of oil and gas.

Stratigraphic traps in the form of updip pinchouts may be present in the area. If present they would be best developed in the western part of the area where the writer believes that there is extensive intertonguing between the Late Cretaceous Indianola Group and the Mancos Shale. This idea is based on the fact that stratigraphic relations and paleontologic evidence (12) indicate that the Indianola Group, which outcrops on the west front of the Wasatch Plateau and is last seen in Salina Canyon, is correlative in age to the Mancos Shale. Three miles west of the mapped area the Indianola Group lies with angular unconformity beneath Early Tertiary strata. Spieker (23, p. 66) indicates that eastward from the unconformity 5,000 to 7,000 feet of Late Cretaceous beds, including the Indianola Group, flatten out and the unconformity passes into a disconformity that can be observed in the mapped region between the early Montana Blackhawk Formation and the late Montana Price River Formation. The El Paso Natural Gas Company test hole located in Salina Canyon recorded 365 feet of the Sanpete Formation of the Indianola Group and the Pan American test hole three miles southeast of the El Paso Natural Gas well recorded no strata of this unit. Likewise the two test holes indicated a thickening of the Blue Gate Shale Member of the Mancos Shale eastward. It appears that within a distance of ten miles the continental facies of the Indianola Group passes transitionally into the marine facies of the Mancos Shale. It is probable that many littoral marine sandstone tongues are present in the subsurface and that these units have formed stratigraphic traps capable of accumulating oil and gas.

Oil and Gas Possibilities

Though two test holes have been drilled in the mapped area with no success, the northern part of the Fish Lake Plateau is still virgin territory for oil and gas exploration. The possible occurrence of oil and gas in the area is strengthened by the fact that gas is produced in nearby areas. Gas is produced from the Ferron Sandstone in the Clear Creek and Flat Canyon fields located in the northern part of the Wasatch Plateau. In the Clear Creek field gas is also produced from the Early Cretaceous Dakota Sandstone (29). Gas has been discovered in the Early Triassic Moenkopi Formation on the Last Chance Anticline located approximately eight miles southeast of the thesis area (8).

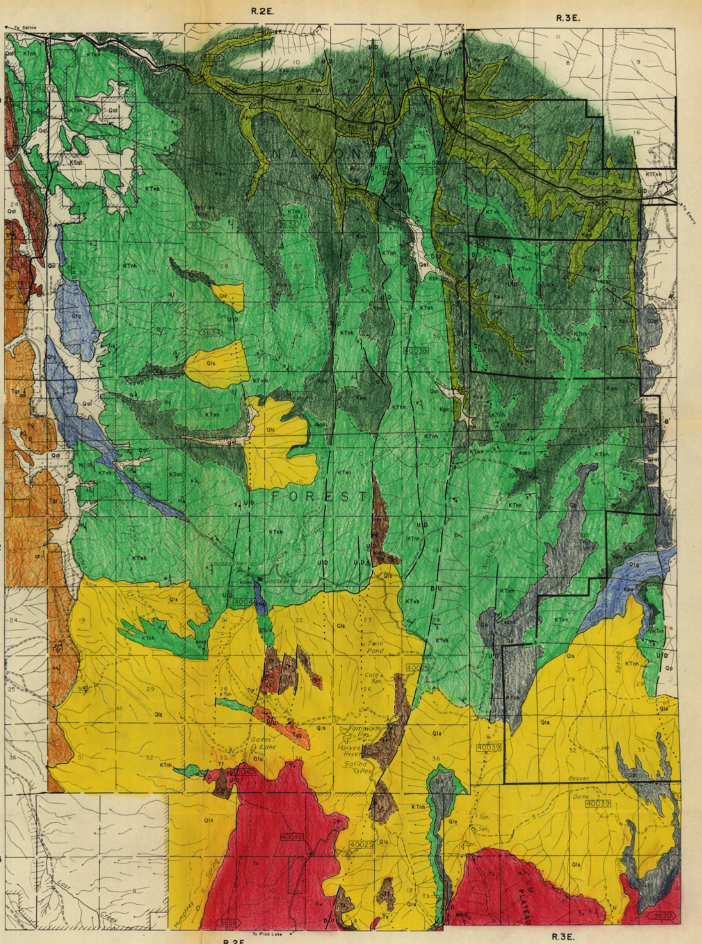
As production has already been established for the Moenkopi, Dakota and Ferron Formations in nearby areas there seems to be little reason to doubt the potential of these units in this area. Further study and drilling within the Fish Lake Plateau may very possibly locate stratigraphic traps in the form of updip sand pinchouts.

Coal

Many thin coal beds occur in the area within the Blackhawk Formation. These deposits, which are best exposed in Salina Canyon, have been investigated and described by Spieker and Baker (25). During the 1920's some small prospects and coal mines were operated in Salina Canyon and one, the Sevier Valley Coal Company mine, located in sec. 12, T. 22 S., R. 3 E. remained in operation until 1940. Currently there are no mines operating in the area but a few miles to the east coal is being mined from both the Blackhawk and Ferron Formations. The Pan American Petroleum test hole penetrated a few thin coal beds in the Ferron Sandstone.

Since most of the coal beds in the area studied are thin and local in nature it is doubtful that coal mining will ever become an important industry.

PLATE 3



EXPLANATION

RECENT

- **Qal** — Alluvium: Unconsolidated silt and sand in valley fill and terrace deposits.
- **Qls** — Landslide deposits: Unsorted rock debris.
- **Qtg** — Terrace gravels: Boulders and cobbles of lava and sandstone, pebbles of quartzite and chert, and coarse sand.
- **Qp** — Pediments: Veneer of cobbles and boulders of vesicular andesite and latite and pebbles of chert and quartzite.

Unconformity

OLIGOCENE

- **Tv**: Andesite and latite lava flows.

Unconformity

EOCENE

- **Tgg** — Gray Gulch Formation (In fault block only): Tuffaceous sandstone and siltstone, gray to white, even-bedded, with subordinate black to light gray fossiliferous limestone.
- **Tgr** — Green River Formation: Upper part: lacustrine limestone, white to gray, thick-to thin-bedded, in part replaced by chert. Lower part: lacustrine shale, mudstone and siltstone, green.
- **Tc** — Colton Formation: Lacustrine shale, mudstone and siltstone, red to orange.

PALEOCENE

- **Tf** — Flagstaff Formation: Northwest part of area: lacustrine calcareous siltstone and argillaceous limestone, red, thin-to medium-bedded. Elsewhere: argillaceous limestone, gray to white, with siltstone and mudstone, gray to green.
- **KTnh** — North Horn Formation: Upper part: lacustrine mudstone and siltstone, red, orange and gray with subordinate fluviatile, fine-to medium-grained, cross-bedded sandstone. Lower part: lacustrine mudstone and siltstone, gray, alternating with fluviatile, fine-to medium-grained, cross-bedded, sandstone.

UPPER CRETACEOUS

Price River Formation

- **Kpu** — Upper Member: Fluviatile sandstone, gray to light brown, fine-to coarse-grained cross-bedded sandstone.
- **Kpc** — Castlegate Member: Fluviatile sandstone, gray to white, medium-to coarse-grained, in part conglomeratic, cross-bedded, prominent cliff former.

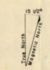
Disconformity

- **Kbh** — Blackhawk Formation: Fluviatile sandstone, gray to brown, fine-to medium-grained, cross-bedded, with subordinate gray shale and thin coal seams.

(Base not exposed)

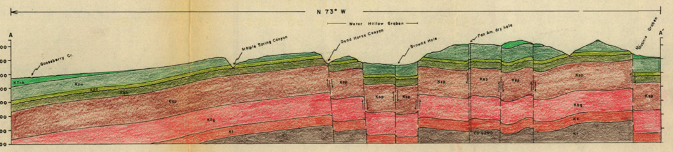
LEGEND

- Attitude (field obtained)
- Attitude (photo interpreted)
- Dip component
- Fault, high angle normal, dashed where approximately located
- Fault, inferred
- Formation contact, dashed where approximately located
- Line of section
- Abandoned coal mine
- Dry hole, oil and gas
  1. Pan. Am. Petr. Corp., Porcupine Ridge Unit 1
  2. El Paso Nat. Gas Co., Salina Canyon Unit 1
  3. Ellis A. Hall-Gordon Gray 1 Federal
- Sample locality
- Drainage
- Lake
- Highway, paved
- Road, gravel
- Road, dirt
- Trail
- Boundary, Fish Lake National Forest
- Boundary, private property



Approximate mean declination 1964

STRUCTURAL CROSS SECTIONS



Subsurface Formations

- Ksp — Star Point Sandstone
- Kbg — Blue Gate Shale
- Kf — Ferron Sandstone
- Kt — Tununk Shale

(no vertical exaggeration)

GEOLOGIC MAP OF PART OF THE FISH LAKE PLATEAU SEVIER COUNTY, UTAH

John B. Alexander
Oregon State University
Dec. 23, 1964

Based on USFS Planimetric Series Maps: Mt. Terril 1 and 4, Fish Lake National Forest, 1962

BIBLIOGRAPHY

1. Alderman, A. H. and H. C. W. Skinner. Dolomitic sediments in the southeast of Australia. American Journal of Science 255:561-567. 1957.

2. Bradley, W. H. Limnology and the Eocene lakes of the Rocky Mountain Region. Geological Society of America Bulletin 59: 635-648. 1948.

3. ________________ Origin and microfossils of the oil shale of the Green River formation of Colorado and Utah. 168 p. 1931. (U. S. Geological Survey Professional Paper 168)

4. Christiansen, F. W. Oil and gas possibilities of the transition zone in central Utah. Utah Geological and Mineralogical Survey Bulletin 54:327-338. 1963.

5. Dutton, E. E. Geology of the high plateaus of Utah. Report of the U. S. Geographic and Geologic Survey of the Rocky Mountain Region. Washington D. C., 1880. 307 p.

6. Folk, R. L. Practical petrographic classification of limestones. American Association of Petroleum Geologists, Bulletin 43:1-38. 1959.

7. Graf, D. L., A. J. Eardley and N. F. Shrimp. Preliminary report on magnesium formation in glacial Lake Bonneville. Journal of Geology 69:219-223. 1961.

8. Hager, Dorsey. Gas and oil developments on the Last Chance and the Caineville anticlines, Sevier, Emery, and Wayne Counties, Utah. Intermountain Association of Petroleum Geologists Guidebook 4:96-98. 1954.

9. Harris, H. D. Mesozoic positive area in western Utah. American Association of Petroleum Geologists, Bulletin 43:2636-2652. 1959.

10. Hayden, F. V. Preliminary field report in the United States Geologic Survey of Colorado and New Mexico. Washington D. C., 1869. 155 p. (Geologic and Geographical Survey of the Territories. Third Annual Report)

11. Ingram, Roy L. Fissility of mudrocks. Geological Society of America Bulletin 64:869-878. 1953.

12. Katich, Philip J. Jr. Source directions of the Ferron Sandstone in Utah. American Association of Petroleum Geologists, Bulletin 37:858-862. 1953.

13. LaRocque, A. Tertiary mollusks of central Utah. Intermountain Association of Petroleum Geologists Guidebook 7:140-145. 1956.

14. ________________ Molluscan faunas of the Flagstaff Formation of central Utah. Geological Society of America Memoir 78. 1960. 100 p.

15. Mackin, Hoover J. Structural significance of tertiary volcanic rocks in southwestern Utah. American Journal of Science 258: 81-131. 1960.

16. McGookey, Donald P. Early tertiary stratigraphy of part of central Utah. American Association of Petroleum Geologists 44:589-615. 1960.

17. McKee, Edwin D. and Gordon W. Weir. Terminology for stratification and cross-stratification in sedimentary rocks. Geological Society of America 64:381-390. 1953.

18. Pettijohn, F. J. Sedimentary rocks. 2d ed. New York, Harper, 1957. 417 p.

19. Richardson, G. B. Underground water in Sanpete and central Sevier Valleys, Utah. 1907. 63 p. (U. S. Geological Survey Water-Supply Paper 199)

20. Robbins, Carl and W. D. Keller. Clay and other noncalcareous minerals in some limestones. Journal of Sedimentary Petrology 22:146-152. 1952.

21. Spieker, Edmund M. Late Mesozoic and Early Cenozoic history of central Utah. U. S. Geological Survey Professional Paper 205-D:117-161. 1946.

22. ________________ Sedimentary facies and associated diastrophism in the Upper Cretaceous of central and eastern Utah. Geological Society of America Memoir 39:55-82. 1949.

23. ________________ The transition between the Colorado plateaus and the Great Basin in central Utah. Salt Lake City, Utah Geological Society, 1949. 106 p. (Guidebook to the Geology of Utah no. 4)

24. ________________ Structural history. Intermountain Association of Petroleum Geologists Guidebook 5:9-14. 1954.

25. Spieker, Edmund M. and A. A. Baker. Geology and coal resources of the Salina Canyon District, Sevier County, Utah. U. S. Geological Survey Bulletin 796:125-170. 1928.

26. Spieker, Edmund M. and J. B. Reeside. Cretaceous and tertiary formations of the Wasatch Plateau, Utah. Geological Society of America, Bulletin 36:435-454. 1925.

27. Stokes, William L. and Robert E. Cohenour. Geologic atlas of Utah, Emery County. Salt Lake City, University of Utah, 1956.

28. Swain, F. M. Early tertiary Ostracoda from the western interior United States. Journal of Paleontology 23:172-181. 1949.

29. Walton, Paul T. Wasatch Plateau gas fields, Utah. Intermountain Association of Petroleum Geologists Guidebook 5:79-85. 1954.

30. Williams, H., F. J. Turner and C. M. Gilbert. Petrography. San Francisco, Freeman, 1958. 406 p.

31. Woolley, R. R. and E. Callaghan. Utilization of surface water resources of Sevier Lake Basin, Utah. 1907. 393 p. (U. S. Geological Survey Water Supply Paper 920)

32. Young, Robert G. Sedimentary facies and intertonguing in the Upper Cretaceous of the Book Cliffs, Utah-Colorado. Geological Society of America, Bulletin 66:177-202. 1955.