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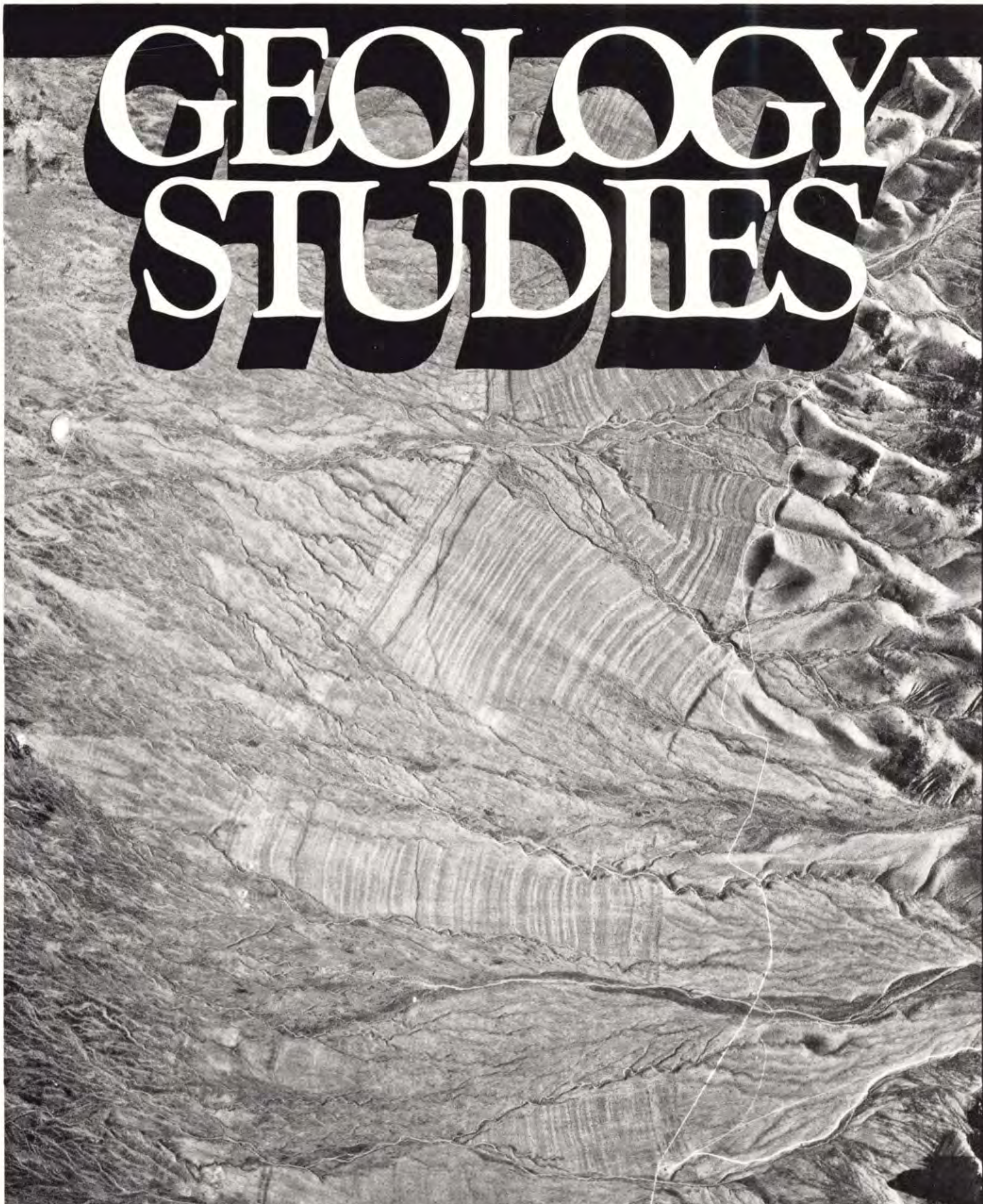

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Cover: Air photo of House Range fault scarp. Courtesy of Lee Piekarski.

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Geology of the Woodruff Narrows Quadrangle, Utah-Wyoming*

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ABSTRACT.—The Woodruff Narrows Quadrangle lies in the heart of the Utah-Idaho-Wyoming Overthrust Belt. The following formations crop out within the study area: Ordovician Fish Haven Dolomite (+236.4 m), Devonian Jefferson Formation (108 m) and Three Forks Formation (87 m), Mississippian Lodgepole Limestone (167 m) and Brazer Dolomite (397 m), Pennsylvanian-Permian Wells Formation (208 m), Permian Phosphoria Formation (259 m), Triassic Dinwoody Formation (174 m), Woodside Shale (100–200 m), and Thaynes Limestone (+30 m), Cretaceous Bear River Formation (+800 m), and Tertiary Wasatch Formation (+50 m) and Fowkes Formation (+50 m). Structural geology is dominated by folding and thrusting of the mid-Mesozoic Sevier orogeny. Major folds are generally asymmetric with west-dipping axial planes. The largest fold covers about 22 k^2. Faulting includes thrust faults, tear faults, and extensional faults. The Crawford Thrust puts Mississippian through Triassic rocks on Cretaceous strata. The tear faults are all left-lateral.

Potential for economic accumulations of hydrocarbons is favorable within the study area. Potential for economic deposits of metals and nonmetals is much less favorable.

INTRODUCTION

One of the best exposed Paleozoic and Mesozoic sections in the Utah-Idaho-Wyoming Overthrust Belt is found in the Crawford Mountains of northeastern Utah where the stratigraphic sequence from Ordovician Fish Haven Dolomite to Triassic Thaynes Limestone is present. Some Cretaceous rocks and several Tertiary units are also exposed. Lower Cretaceous and older strata in the Woodruff Narrows Quadrangle were folded and faulted during the Sevier orogeny. Later extensional faulting has further complicated the geologic structure.

Geologic mapping at a scale of 1:24,000 and interpretive cross-sections included in this report show the major geologic relationships. Stratigraphic sections have been measured; however, no attempt has been made to detail the petrology or paleontology of each formation.

Location

The Woodruff Narrows 7½-minute quadrangle is located east of Woodruff in northeastern Utah (fig. 1). The Southern Crawford Mountains along the western side of the quadrangle extend southwards to the Bear River Valley. Woodruff Narrows are in a shallow canyon in the southeast corner of the map area where the Bear River changes course from north to west. Dirt roads and jeep trails provide excellent access during summer months to within 1.6 km of most points in the quadrangle.

Geologic Setting

The Woodruff Narrows Quadrangle lies in the heart of the Utah-Idaho-Wyoming Overthrust Belt. This region is characterized by north-south mid-Mesozoic Sevier orogenic thrust faults with associated Sevier orogenic folds. In Paleozoic time the quadrangle was situated along the eastern edge of the Cordilleran geosyncline and in Cretaceous time along the western edge of the Rocky Mountain geosyncline.

Previous Work

Hayden, Peale, and Gannett of the Hayden Survey and King, Emmons, and Hague of the Fortieth Parallel Survey examined the Bear River region between 1869 and 1878. They assessed the general nature and age of the rocks. Veatch (1907) reported on the phosphate deposits in northeastern Utah, southeastern Idaho, and western Wyoming. However, he did little with the rocks below the Permian phosphate beds except to map them as undifferentiated Paleozoics. Richardson (1913) subdivided the Paleozoic rocks of northern Utah into mappable formations. Later (1941), he published a geologic map and report on the Randolph 30-minute quadrangle which includes the study area.

Until the present study was undertaken, Richardson's work provided most of the geologic information for the Woodruff Narrows Quadrangle. Regional studies by Armstrong and Oriel (1965), Eardley (1967), and Royse, Warner, and Reese (1975) discussed the study area only in a general way. At present, Earl Norris, a graduate student at Brigham Young University, is conducting a biostratigraphic study of the Brazer Dolomite at the type section to the north in Brazer Canyon. Randy Cham-

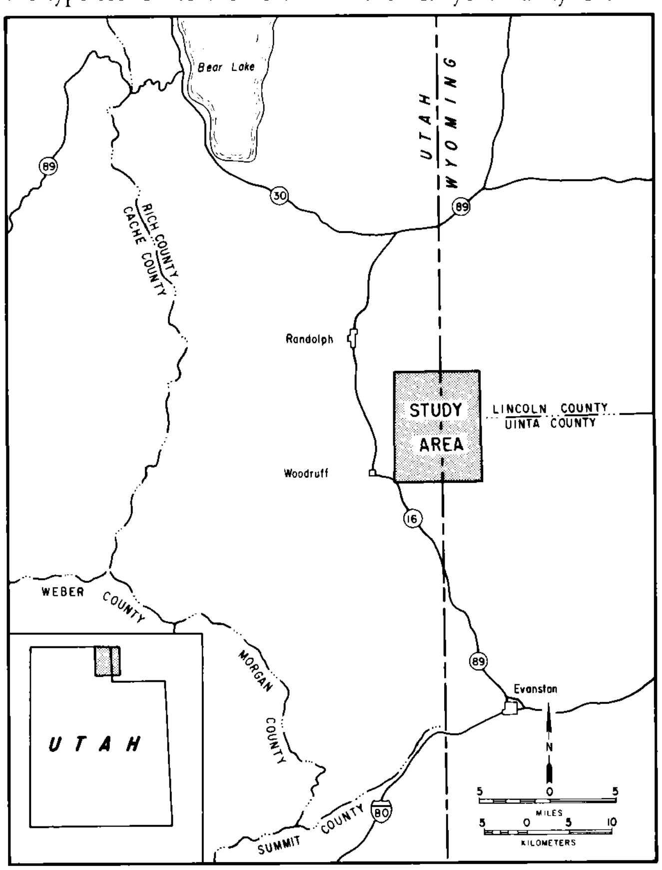

FIGURE 1.—Index map showing the location of the Woodruff Narrows Quadrangle.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, December 1979. Thesis chairman: James L. Baer.

berlain, also a graduate student at Brigham Young University, is mapping the Rex Peak Quadrangle immediately north of the study area. James L. Baer, professor of geology at Brigham Young University, is currently mapping the Woodruff Quadrangle immediately west and additional quadrangles to the north.

Fieldwork was conducted in the spring and summer of 1979. Mapping was done on aerial photographs (scale 1:24,000 and 1:36,000) and later transferred to the topographic base. Stratigraphic sections were measured using a 100-foot tape and a Brunton compass.

Acknowledgments

I gratefully acknowledge the guidance, counsel, and assistance of my committee chairman, Dr. James L. Baer. He spent many hours both in the field and back at the office reviewing my interpretations and editing my manuscript. Dr. Lehi Hintze's expertise and timely comments are also greatly appreciated. Special thanks are given to Marathon Oil Company, Chevron Oil Company, Gulf Energy and Minerals, and Amoco Production Company for funding a regional study of which this investigation was a part. In addition, Marathon Oil Company provided valuable surface and subsurface data. My greatest appreciation goes to my dear wife Robyn for her help with typing and editorial corrections and for her patience with my many extended absences from home.

STRATIGRAPHY

Stratigraphy exposed in the Woodruff Narrows Quadrangle ranges from upper Ordovician carbonates to Tertiary (Eocene) volcanic tuffs (fig. 2). Paleozoic and lower Mesozoic rocks are restricted to the southern Crawford Mountains along the western side of the study area (fig. 3). Upper Mesozoic and Tertiary rocks occur throughout the rest of the quadrangle but are mostly covered by Quaternary deposits. Earlier mapping by Richardson (1941) was generally accurate. Nevertheless, several outcrops were misnamed because of facies changes, or not mapped altogether.

Ordovician System

Fish Haven Dolomite

The Fish Haven Dolomite was named by Richardson (1913), from Fish Haven Creek, Bear Lake County, Idaho. In the map area this formation is exposed in sections 11 and 14, T. 10 N, R. 7 E (fig. 3), where it is unconformably overlain by the Jefferson Formation and consists of massive to thick-bedded crystalline, light to medium gray dolomite. It is remarkably uniform in color and texture throughout but occasionally may be thin bedded or have thin, white discontinuous limestone lenses. Locally it may show white and gray mottling.

Overall the Fish Haven Dolomite is a dense crystalline rock with low porosity and permeability. Secondary porosity may be excellent near fault contacts where the brittle rock has been highly fractured (fig. 4). Along the thrust fault in section 11 the Fish Haven is so intensely brecciated that some of the bedding is indistinguishable. A section was measured westward from this fault to the top of the Fish Haven (see appendix). Total thickness for the sequence is 236.4 m.

Because of its resistant nature the Fish Haven Dolomite forms well-exposed ledges and cliffs. The formation viewed from a distance appears as a homogeneous, massive, light-gray-weathering rock beneath the darker units above. Closer inspection reveals that bedding is fairly common even though the rocks generally are massive. Chert is rare in the Fish Haven. This characteristic, as well as color and texture, makes it readily distinguishable from younger dolomites in the study area.

Several corals were collected from a horizon near the top of the Fish Haven in the NE ¼ of section 11, T. 10 N, R. 7 E. William T. Oliver of the U.S. Geological Survey identified them as follows:

Deiracorallium sp.	Late Ordovician
Catenipora sp.	Ordovician-Silurian
Lobocorallium (?)	Late Ordovician
Grewingkia sp. (?)	Late Ordovician

These corals clearly mark the late Ordovician Bighorn–Red River fauna which is equivalent in age to the Fish Haven Dolomite–a change from Richardson's (1941) map. He called these outcrops Mississippian Brazer Dolomite thrust over Jefferson Formation to the east. His "thrust" is actually an unconformity between the Fish Haven and Jefferson Dolomites.

Richardson (1941) mapped exposures of Silurian Laketown Dolomite to the north in the Rex Peak Quadrangle at the same stratigraphic position below the Jefferson Dolomite. Berdan and Duncan (1955) confirmed a late Ordovician age for these rocks. Thus it appears that the light to medium gray dolomite beneath the Jefferson Formation, both in the study area and in the Rex Peak Quadrangle, is actually Ordovician Fish Haven Dolomite.

Devonian System

Jefferson Formation

The Jefferson Formation was named by Peale (1893) for exposures along the Missouri and Jefferson Rivers in the Three Forks Quadrangle, Montana. The upper member, called the Birdbear Member in Montana and Wyoming and the Hyrum Dolomite in Utah, is a thick, cliff-forming dolomite. The lower member, equivalent to the Darby Formation of western Wyoming, is brownish gray, dark brown, or dark gray dolomite. Only the lower member is present in the Woodruff Narrows Quadrangle. The upper member either was eroded off or was not deposited.

The Jefferson in the study area is a dark brownish gray, thin- to thick-bedded or massive, sugary dolomite about 108 m thick. A few thin reddish limestone units may be interbedded with the dolomite (see appendix). It is considered to be Late Devonian despite the fact that fossils well enough preserved for dating are rare. In the study area the Jefferson Formation, without exception, weathers to a dark brownish gray ledge or cliff. It is easily distinguished from the lighter Fish Haven Dolomite below, and the reddish Three Forks Formation above. Like the Fish Haven, the Jefferson has very little chert.

Three Forks Formation

The Three Forks Formation was named by Peale (1893) for exposures near Three Forks, Montana. The type section was established by Sloss and Laird (1947) at Logan, Montana. Where it crops out in the study area, the Three Forks is a poorly exposed, nonresistant, reddish weathering unit (see appendix). Reddish, calcareous shale interbedded throughout gives the entire sequence a bright reddish color. Thus, a marked contrast exists between the Three Forks above and the Jefferson Formation below. The Three Forks in the study area is only about 87 m thick.

System	Formation	Thickness	Total	Description
QUAT.	ALLUVIUM	0-300	0-300	Outwash, terraces, gravels.
TERTIARY	FOWKES FORMATION	305+	825+	Tuffaceous mudstone and sandstone, coarse conglomerate.
TERTIARY	WASATCH FORMATION	520		Variegated mudstone, sandstone, conglomerate and limestone.
CRETACEOUS	ASPEN SHALE	365	2905	Siltstone, claystone, sandstone & porcelanite.
CRETACEOUS	BEAR RIVER FM.	1900		Thin-bedded shale interbedded with fine to coarse sandstone and fossiliferous limestone.
CRETACEOUS	GANNETT GROUP	640		Basal conglomerate grades upward through calcareous to quartzitic sandstone, to mudstone and siltstone.
JURASSIC	STUMP SANDSTONE AND PREUSS RED BEDS	520	1400	Fine-grained sandstone and limestone. Thin-bedded, fine-grained sandstone, sandy siltstone, silty claystone.
JURASSIC	TWIN CREEK FORMATION	880		Pentacrinus - bearing limestone and calcareous siltstone.
TRIASSIC	NUGGET SANDSTONE	455	1486	Buff to pinkish tan regular bedded, partly cross-bedded and massive, fine-to medium-grained well-sorted qtze. & slightly calc. ss.
TRIASSIC	ANKAREH FORMATION	260		Colored calc. mudstone, fine-grained qtze. & calcareous sandstone and siltstone.
TRIASSIC	THAYNES LIMESTONE	397		Silty claystone and silty limestone.
TRIASSIC	WOODSIDE SHALE	200		Laminated to medium-bedded siltstone.
TRIASSIC	DINWOODY FORMATION	174		Interbedded siltstones and sandy limestones.
PERM.	PHOSPHORIA FORMATION	259	259	Laminated to thin-bedded shale, dusk blue chert in most of top 1/3.
PENN.	WELLS FORMATION	208	208	Fine-grained to coarse x-bedded massive ss.
MISS.	BRAZER DOLOMITE	397	513	Thin-to medium-bedded light gray dolomite, chert stringers and nodules.
MISS.	LODGEPOLE LIMESTONE	116		Thin-bedded, fossiliferous limestone.
DEV.	THREE FORKS FORMATION	87	195	Interbedded limestones, shales & sandstones.
DEV.	JEFFERSON FORMATION	108		Medium-bedded dark brown dolomite.
UNCONFORMITY				
ORD.	FISH HAVEN DOLOMITE	236+	236+	Thin- to thick-bedded dolomite.

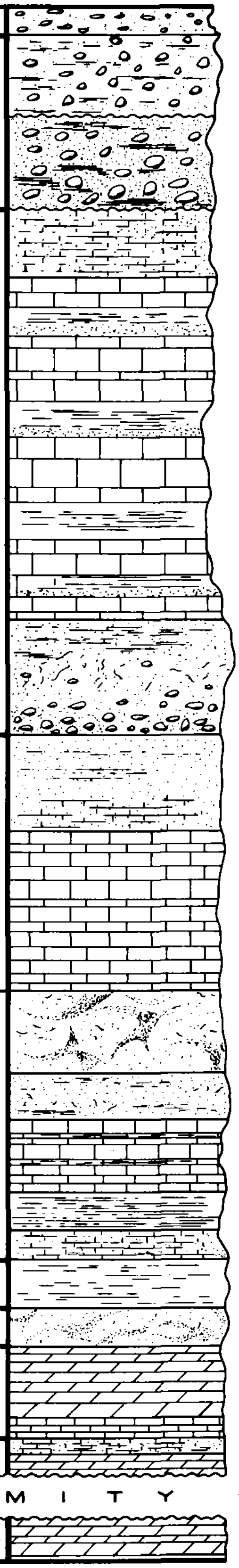

FIGURE 2.–General stratigraphic column for the Crawford Mountain area. Paleozoic and Tertiary thicknesses in meters from measured sections (see appendix). Mesozoic thicknesses in meters from Ruby, Oriel, and Tracy (1975).

Mississippian System

Lodgepole Limestone

The Lower Mississippian Lodgepole Limestone of the Madison Group was named by Collier and Cathcart (1922) from exposures in Lodgepole Canyon, Little Rocky Mountain region, Montana. A type section was designated at the same location by Sloss and Hamblin (1942).

In the northwest corner of the Woodruff Narrows Quadrangle, the Lodgepole Limestone overlies the Three Forks Formation and is in turn overlain by the Brazer Dolomite. The Lodgepole consists of 167 m of mostly thin-bedded, blocky, medium gray limestones. The lower 91 m contain occasional siliceous carbonate nodules which weather moderate brown (see appendix). The formation is fairly resistant and forms ledges where exposed. It usually weathers into medium gray blocky talus covering the underlying nonresistant Three Forks Formation. Fossils are abundant in the Lodgepole and include the following genera:

FIGURE 4.–Strongly fractured Fish Haven Dolomite.

Fenestrellina
Chonetes
Spirifer
Composita
Dictyoclostus
Lithostrontionella
Zaphrentites
Faberophyllum

Crinoid columns and gastropods are also common.

Brazer Dolomite

The type section of the Brazer Dolomite was named by Richardson (1913) from exposures in Brazer Canyon northeast of Randolph, Utah. The Brazer crops out at several locations in the study area (see fig. 3) and is a medium-bedded to massive, medium gray to dark brownish gray crystalline dolomite overlain by the Wells Formation. Black chert stringers are common, particularly in the dark gray dolomites. They occasionally show light and dark zebra-stripe bands a few millimeters in width. Locally, thin limestone, sandstone, or quartzite beds may be found. The sandstone and quartzite tend to increase toward the formation top. Fossils are not common in the Brazer, but a few brachiopods and corals may be found. Earl Norris, a graduate student at Brigham Young University, has identified (personal communication 1979) the following Osagean conodonts in the Brazer:

Eotaphrus burlingtonensis
Polygnathus communis communis
Bispathodus aculetus
Bispathodus stabilis
Pelekysgnathus bultyncki
Scaliognathus n. sp. A. (Chauffand and Klapper, 1978)
Pseudopolygnathus nudus
Polygnathus longiposticus

A complete section of Brazer is not exposed in the study area. A section measured in the Rex Peak Quadrangle to the north (see appendix) shows the formation to be about 397 m thick. It is quite resistant to erosion and generally weathers into a medium dark gray cliff.

Pennsylvanian and Permian Systems

Wells Formation

The white to brown well-sorted sandstones and quartzites above the Brazer Dolomite and below the Phosphoria Formation belong to the Wells Formation. It was first referred to by Richards and Mansfield (1912). It was named from exposures in Wells Canyon, T 10 S, R. 45 E, Bannock County, Idaho. The Wells Formation crops out in the western half of the quadrangle as a result of several structural elements. The Wells is exposed along the overturned eastern limb of the Southern Crawford Anticline (fig. 3). It is also well exposed along both limbs of the adjacent syncline to the northwest. Locally, thin gray limestone or dolomite units may be interbedded with the sandstones and quartzites. Where exposed the Wells Formation weathers white or tan with frequent hematite stains It almost always forms a resistant ledge or cliff up to 210 m thick. In adjacent areas it is roughly equivalent to the Weber Quartzite of Utah, the Quadrant Quartzite of Montana, and the Tensleep Sandstone of Wyoming.

Phosphoria Formation

The first reference to the Phosphoria Formation was by Richards and Mansfield (1912). The type section is in Phosphoria Gulch northwest of Meade Park, Idaho. Originally it was called the Phosphoria Group, but later work by McKelvey and others (1956) formalized the Phosphoria as a formation and described the Meade Peak Phosphatic Shale, Rex Chert, and Cherty Shale Members. In the Woodruff Narrows Quadrangle the Cherty Shale Member is quite thin and not easily distinguished from the Rex Chert Member.

Good exposures of Phosphoria Formation occur along the overturned eastern limb of the Southern Crawford Anticline (fig. 3). Northwest of this anticline the Phosphoria crops out in the trough of an adjacent syncline. The formation is also well exposed to the north in the Wood Pass Syncline. The Meade Peak Member is generally covered, but many prospect pits reveal its position along both limbs of the syncline.

In contrast the Rex Chert Member is almost always well exposed. In the Rex Peak Quadrangle north of the study area the Rex Chert normally occurs as a massive dark gray to black chert a few tens of meters thick. A dramatic facies change of this member takes place south of Rex Peak. In the northern part of the Woodruff Narrows Quadrangle it consists of massive light gray carbonate lenses interbedded with light gray to tan chert, sandstones, and siltstones, highly fractured. Farther south, along the eastern limb of the Southern Crawford Anticline the chert gives way to tan quartzites and coarse cross-bedded sandstones. Locally, thin carbonate beds may be present, and the member as a whole may be mistaken for Wells Formation. It can be recognized, however, by its stratigraphic position above the Meade Peak Member. Float from the Meade Peak in the study area will generally show an easily recognizable phosphatic bloom.

Triassic System

Dinwoody Formation

Blackwelder (1918) formalized the name and described a type section at Dinwoody Canyon in the Wind River Mountains of Wyoming. In the study area the formation unconformably overlies the Phosphoria Formation in the Wood Pass Syncline and in a small area to the south in section 24, T 10 N, R. 7 E. It consists of greenish gray shale and siltstone with interbedded, thin, buff sandstone. Locally, thin gray limestone units can be found. The formation is nonresistant and weathers into a tan or greenish gray slope. The Dinwoody is 171 m thick in the map area.

Woodside Shale

The type section of the Woodside Shale is in Woodside Gulch, Park City district, Utah. It was first described by Boutwell (1907) In the northwestern part of the study area it is exposed in the trough of the Wood Pass Syncline and to the south in section 36, T. 10 N, R. 7 E. It consists mostly of nonresistant red shales and thin siltstones. In the Wood Pass Syncline the Woodside weathers to rounded, hummocky slopes covered with red sandy soil. Outcrops are poor with gradational contacts The Woodside is about 90 m thick.

Thaynes Limestone

The Thaynes Limestone was named by Boutwell (1907) for exposures at Thaynes Canyon, Park City district, Utah. The largest outcrop of Thaynes in the map area is above the Woodside Shale in the trough of the Wood Pass Syncline. Other smaller outcrops were found in sections 24, 25, and 36 of T. 10 N, R. 7 E. and in section 18 or T 10 N, R. 8 E. These exposures consist of medium gray to reddish gray resistant, ridge-forming limestones with thin, tan sandstone beds. The limestones range from coarsely crystalline units to sandy coquinas of broken brachiopod and pelecypod shells. Small pectins can be found locally, but recrystallization has generally destroyed all but the largest morphologic features. No complete section of Thaynes crops out in the study area, but approximately 30 m are exposed.

Cretaceous System

Bear River Formation

The Lower Cretaceous Bear River Formation was named by Hayden (1869) for exposures near Bear River City, Wyoming. Rubey is credited by Moritz (1953) with subdividing the formation into informal units A through E. His descriptions are worth repeating here: (A) thin sequence of black shales and tan quartzitic sandstones; (B) series of essentially nonfossiliferous red and variegated mudstones and sandstones; (C) series of light colored gray and tan sandstones, limestones, and shales, with numerous coal beds; (D) a second series of red and variegated mudstones and sandstones; and (E) gray shales, tan sandstones, and numerous porcellanite beds (like those of the Aspen Shale) throughout. In its lower part unit E contains coal beds; its upper part contains red mudstones and conglomerates. Later, Rubey (1973) formalized these units into the Smiths, Bear River, Thomas Fork, Cokeville, and Sage Junction Formations.

Cretaceous rocks in the Woodruff Narrows Quadrangle have all been mapped as undivided Bear River Formation for several reasons. No complete section of Bear River is exposed anywhere in the map area. Structure and Quaternary cover further compound the problem of assigning each outcrop to a specific unit in the Cretaceous section. Most outcrops fit the description of more than one of Rubey's informal Bear River units. With the data available it was not feasible to subdivide the Bear River Formation in the Woodruff Narrows Quadrangle.

Bear River Formation in the Woodruff Narrows area is dark gray shale with interbedded thin, resistant sandstone and limestone coquinas that weather brown. Gastropods and bivalves are abundant in the limestone. North of the Lower Narrows the Bear River is unconformably overlain by the Wasatch Formation. In the hills just south of Session Pass and at the Narrows Reservoir, the dark gray shales are underlain by a sandstone-redbed sequence. This distinct change in lithology has been mapped at Session Pass to show offset on several normal faults in the area. North of Session Pass, along what Veatch (1907) called the Narrows Anticline, the same sandstone-redbed sequence continues to the northern quadrangle boundary. Sandstone outcrops at Mud Spring, in section 18, T. 10 N, R. 8 E, also belong to the Bear River Formation. Similar outcrops also appear in sections 17, 19, and 20 to the southeast.

FIGURE 5.—Cretaceous sandstones and conglomerates near Mud Spring.

All consist of coarse, gray, poorly sorted sandstone and conglomerate (fig. 5). Rocks of about the same lithology crop out along the northern quadrangle boundary just east of the Crawford Thrust. Several other exposures too small to map at a scale of 1:24,000 also occur along the edge of Warner Hollow to the east.

An angular unconformity between tan Bear River sandstones below and the Wasatch Formation above (fig. 6) is exposed along the north side of Warner Hollow. The Bear River dips west and the Wasatch dips east. More than 317 m of Cretaceous were measured at this location (see appendix). In addition, a small patch of Cretaceous rocks is exposed east of the Crawford Thrust near the southern tip of the Crawford Mountains. This exposure also consists of poorly sorted sandstone and conglomerate. Some of the larger clasts can be identified as Wells, Brazer, or Phosphoria rocks.

Eocene Series

Wasatch Formation

The Wasatch Formation was named by Hayden (1869) for outcrops in Echo Canyon near Echo, Utah. In the Woodruff Narrows Quadrangle the Wasatch, with two minor exceptions, unconformably overlies the Bear River Formation. The friable reddish sandstone, siltstone, and conglomerate above the dark gray shales in sections 17 and 20, north of the Lower Narrows, belong to the Wasatch Formation. The only other exposures of Wasatch in the map area are near Warner Springs at the northern quadrangle boundary and immediately west along the Crawford Thrust. These exposures are quite different lithologically from the Wasatch Formation in sections 17 and 20. They are mainly white, red, or brown algal limestone interbedded with variegated calcareous sandy or silty units. The outcrops have the appearance of coarse conglomerate interbedded with nonresistant slope formers. Closer inspection reveals the conglomerates are algal limestone balls (fig. 7). The Wasatch in this area is less than 60 m thick.

Fowkes Formation

The Fowkes Formation was named at Fowkes Ranch near Evanston, Wyoming, by Veatch (1907). In the Woodruff Narrows Quadrangle it covers large areas from Session Pass to Warner Spring and southwest of the Lower Woodruff Narrows. Where exposed the Fowkes Formation consists of interbedded gray green tuffs, sandstones, siltstones, and shales rich in magnetite and biotite. Locally it may contain pink and red tuffaceous siltstones and shales. The formation is nonresistant to erosion, is seldom well exposed, and weathers into low, rounded hills.

Quaternary Deposits

Quaternary deposits in the Woodruff Narrows Quadrangle are four basic types as follows: (1) pediment gravels covering most of Dry Hollow, (2) alluvium and valley fill along Cottonwood Creek and the Bear River Valley, (3) colluvium composed of talus and alluvial fan debris, and (4) Recent sand dunes along the west side of the Crawford Mountains. The pediment gravels consist mostly of boulders, cobbles, pebbles, and sand derived from Paleozoic rocks in the area. Alluvium and valley fill are primarily sand, silt, and clay. Colluvium is generally angular to subrounded cobbles and boulders found at the base of many cliffs or in several alluvial fans. The Recent sand dunes along the west side of the Crawford Mountains consist mostly of pinkish medium-grained, subrounded, quartz sand. It probably is derived from reddish Wasatch Formation outcrops to the west.

STRUCTURAL GEOLOGY

Structural geology in the Woodruff Narrows Quadrangle is strongly dominated by folding and thrusting of the mid-

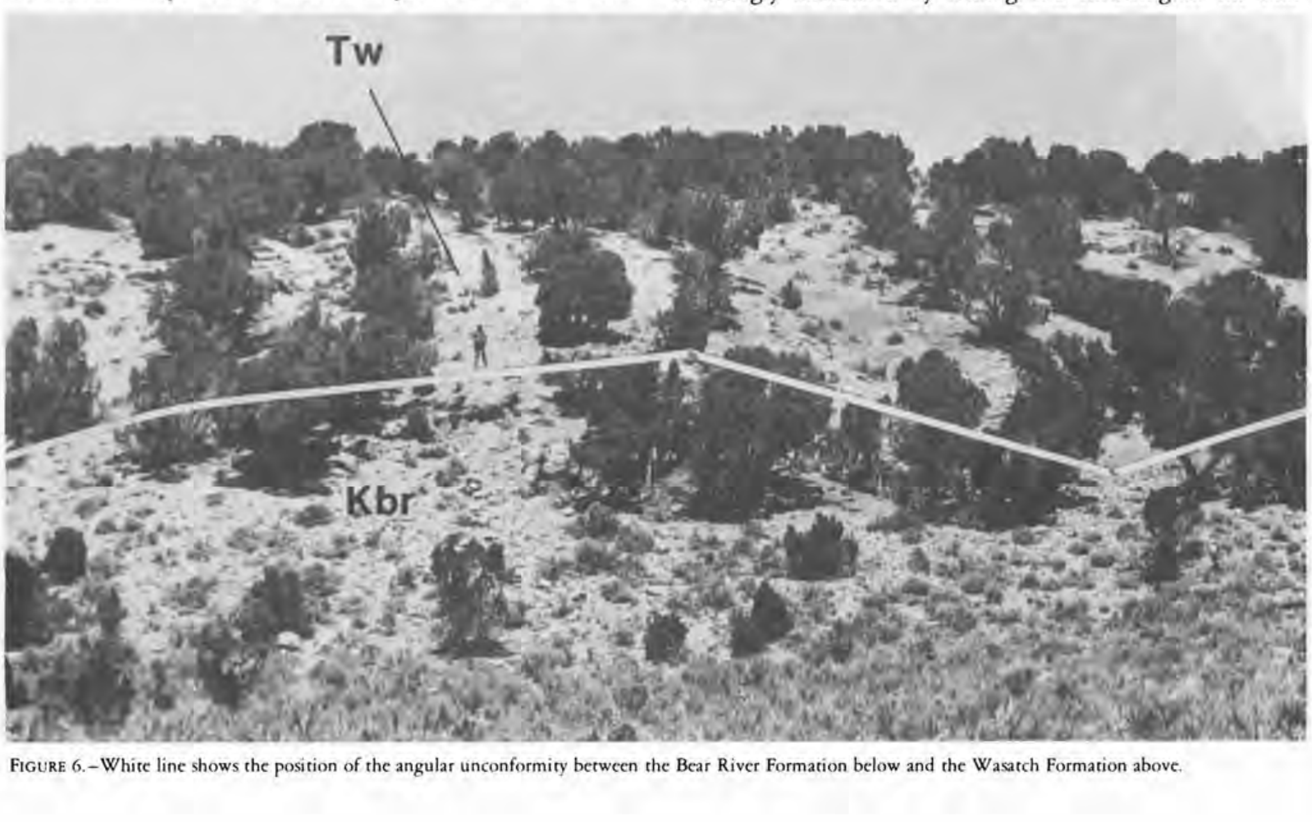

FIGURE 6.–White line shows the position of the angular unconformity between the Bear River Formation below and the Wasatch Formation above.

Mesozoic Sevier orogeny. Five steep anticlines and synclines are clearly expressed. Thrusts place Paleozoic strata on younger Paleozoic or Mesozoic strata. Later extensional faulting has cut earlier geologic structure. Six unconformities add further complexity.

Folds

Sevier folding and thrusting began in the region during late Early Cretaceous time (Armstrong and Oriel 1965). The resulting deformation produced the Wood Pass Syncline (fig. 3), the Southern Crawford Anticline, the Narrows Anticline, and numerous smaller folds. The Wood Pass Syncline is an asymmetric closed fold (see cross-section A-A′) plunging southwest. The western limb is generally more steeply inclined than the eastern limb except in the northwest quarter of section 12, T. 10 N, R. 7 E, where minor folding flattens it somewhat. In the southwest quarter of the same section the syncline has been bent eastward so that it now plunges to the southeast. In section 13, T. 10 N, R. 7 E, the western limb is partly truncated by a thrust. The fold finally ends near the center of section 13, where it is cut by an east-west striking tear fault. Beds deformed by the syncline include Mississippian Brazer Dolomite through Triassic Thaynes Limestone.

The Southern Crawford Anticline is an asymmetric overturned fold several kilometers long, oriented roughly north-south along the west central quadrangle boundary. The western limb has gentle dips of less than 25°, and the eastern limb is overturned by as much as 30°. This combination produced an axial plane inclined to the west. The structure is doubly plunging north and south from a point in the east central part of section 35, T. 10 N, R. 7 E. The southward plunge steepens near the southern tip of the anticline where it is buried by alluvium of the Bear River Valley. Northwest of the Southern Crawford Anticline is a smaller open syncline plunging to the southwest. This structure is a gentle symmetric fold much less complicated than the Wood Pass Syncline.

The Narrows Anticline, named by Veatch (1907), is situated along the eastern quadrangle boundary in the vicinity of Session Pass. The fold is divided by faulting at this pass. The northern part plunges northeast and the southern part plunges southwest. The fold is fairly simple with no overturning found in the map area. The graben at Session Pass shows the axial plane to be nearly vertical or inclined slightly westward. The Narrows Anticline is complemented by a syncline to the southeast with its axis located along the Woodruff Lower Narrows. This structure is a broad, gentle fold plunging northeast off the map area.

Faults

Faults in the study area can be categorized as thrust faults, tear faults, and extensional faults. Most of the thrusts increase in dip upward and may surface at a high inclination. Tear faults are associated with thrusting, and both are the same age as the Sevier orogenic folding in the area.

FIGURE 7.—Wasatch Formation consisting almost entirely of algal limestone balls.

Thrust Faults

The Crawford Thrust was first mapped by Richardson (1941) along the east side of the Crawford Mountains. This study indicates Richardson was correct in placing the Crawford Thrust where he did. However, it is not a single thrust as he mapped it but is actually a compound fault. In section 24, T. 10 N, R. 7 E, it branches. To the northeast Mississippian Brazer Dolomite has been thrust over Cretaceous Bear River Formation. This is the fault Richardson mapped. A second branch continues northwest from section 24, then west, and finally north along the western limb of the Wood Pass Syncline. The variation in strike of this branch is caused by interaction with the tear fault system at Wood Pass. This interaction will be explained in detail in a later section. The thrust puts Mississippian rocks in contact with Pennsylvanian, Permian, and Triassic rocks along this limb of the Wood Pass Syncline Where the strike of this thrust changes from west to north in the southeast quarter of section 11, it is paralleled on the west by a thrust of large stratigraphic displacement. This western thrust puts Ordovician Fish Haven Dolomite against Mississippian Brazer and Pennsylvanian-Permian Wells. The two faults join together north of the map area and become one thrust.

Two small thrusts have also been mapped in the study area The first is southwest of Wood Pass in the northeast quarter of section 14. This short fault strikes north and offsets two left-lateral tear faults in a steplike manner. The thrust puts Devonian Three Forks Formation over Mississippian Brazer Dolomite. The second thrust is along the eastern limb of the overturned Southern Crawford Anticline. The fault occurs along the Brazer-Wells contact in sections 1 and 12, T. 9 N, R 7 E, and section 36, T. 10 N, R. 7 E; as a result part of the Wells is cut out. Several intermittent streams show disrupted drainages where they cross the fault plane. Initial movement on this thrust probably occurred during formation of the Southern Crawford Anticline.

Tear Faults

High-angle tear faults occur in the structurally complex area near Wood Pass This left-lateral system consists of several short strike-slip faults which begin and end at a thrust contact in a steplike manner. Apparent offset on individual faults suggests displacements of more than 0.8 km to 1.6 km Total displacement on the complete system, however, is difficult to determine Considerable dip-slip movement may have occurred making net slip impossible to calculate without some pre-faulting markers. A northern continuation of the strata found in the Southern Crawford Anticline has not been located to the west. This fact suggests a minimum left-lateral displacement for the system of at least 4.8 km. These faults strike roughly east-west with the exception of a northeast striking fault in section 13, T. 10 N, R. 7 E.

Extensional Faults

High-angle extensional faulting began in this region as early as Eocene time and has continued to the Recent (Armstrong and Oriel 1965). Two persistent north-south normal fault systems roughly parallel each other on the western and eastern sides of the map area. The western system can be traced northward at least as far as Leefe. No name has been given to it; therefore it is proposed that this fault system be called the Leefe Fault It has downdropped the Bear River Valley on the west a minimum of 425 m and probably much more In the study area it generally cuts Paleozoic rocks at a high angle to bedding. In the Wood Pass area repeated movement on the tear fault system has offset the Leefe Fault to the west. To the south the fault dies out at the southern tip of the Crawford Mountains.

The eastern system extends north from the Woodruff Narrows Reservoir to beyond the quadrangle boundary. It is composed of a series of short normal faults of varying displacement almost approaching an en echelon pattern. The pattern, however, is broken by a northwest striking graben at Session Pass. On the cross-sections accompanying this report (fig. 3) most of the normal faults have been shown as listric in nature It is presumed that they flatten and join a pre-existing thrust system at depth.

Proposed Model

A proposed structural model for the Woodruff Narrows Quadrangle is shown in figure 8. The model is modified from an interpretation of the Darby-Hogsback-Prospect thrust system by Royse, Warner, and Reese (1975). Two wells in progress within the quadrangle (Marathon, Mud Springs 1-8; Chevron-Getty, Narrows South 29-15) have supplied some well control. Additional information was obtained from seismic interpretations by Marathon Oil Company. However, some of the subsurface features in figure 8 are inferred. Nevertheless, the diagrams are not casually drawn; considerable surface evidence exists to support them

Diagram A shows the footwall block just after movement on the Crawford Thrust. The overlying hanging wall has been removed to show the general geometric shape of the fault plane. Diagrams B and C show the shape of the fault plane after movement on two successively younger thrusts. These thrusts did not extend as far south as the older Crawford Thrust. Consequently, two transverse footwall "steps" were formed in the footwall block. The present surface geology is shown in Diagram D. The hanging-wall block has now been added to show the surface expression when three successively younger thrusts link up. The transverse footwall "steps" have a profound effect upon the original thrust sheet riding "piggyback" on younger thrusts Because of stacking, a tear occurs in the overlying sheets producing extensional and strike-slip faults. This effect is well displayed near Wood Pass. The complex structure in the Wood Pass area is easily explained by three thrust sheets stacked one on top of each other. If the model shown in figure 8 is accurate, the westernmost thrust fault is part of the original Crawford Thrust.

The fault now mapped as the Crawford Thrust is a younger feature and belongs to the second sheet in the stack. A third fault—the youngest—is some distance to the east. Seismic data from Marathon Oil Company gives evidence for a thrust beneath Cottonwood Creek in Dry Hollow and some related deformation immediately west. This fault is shown in figure 8 as the Dry Hollow Thrust. The deformation may have resulted from ramping in the fault plane. The tear seen at Wood Pass could well extend this far east beneath the overlying pediment gravels The overturned Southern Crawford Anticline can be explained by the model as the upper sheet in a two-sheet stack. The original Crawford Thrust has been wrinkled as it was carried "piggyback" by the younger fault now mapped as the Crawford Thrust. The southern tip of the anticline plunges steeply south and is truncated by inferred extensional and strike-slip faults associated with a transverse step in the subsurface. The Leefe Fault also may end there if it is in fact a listric fault. The Bear River changes course east-west in a peculiar manner between Woodruff Narrows Reservoir and Wood-

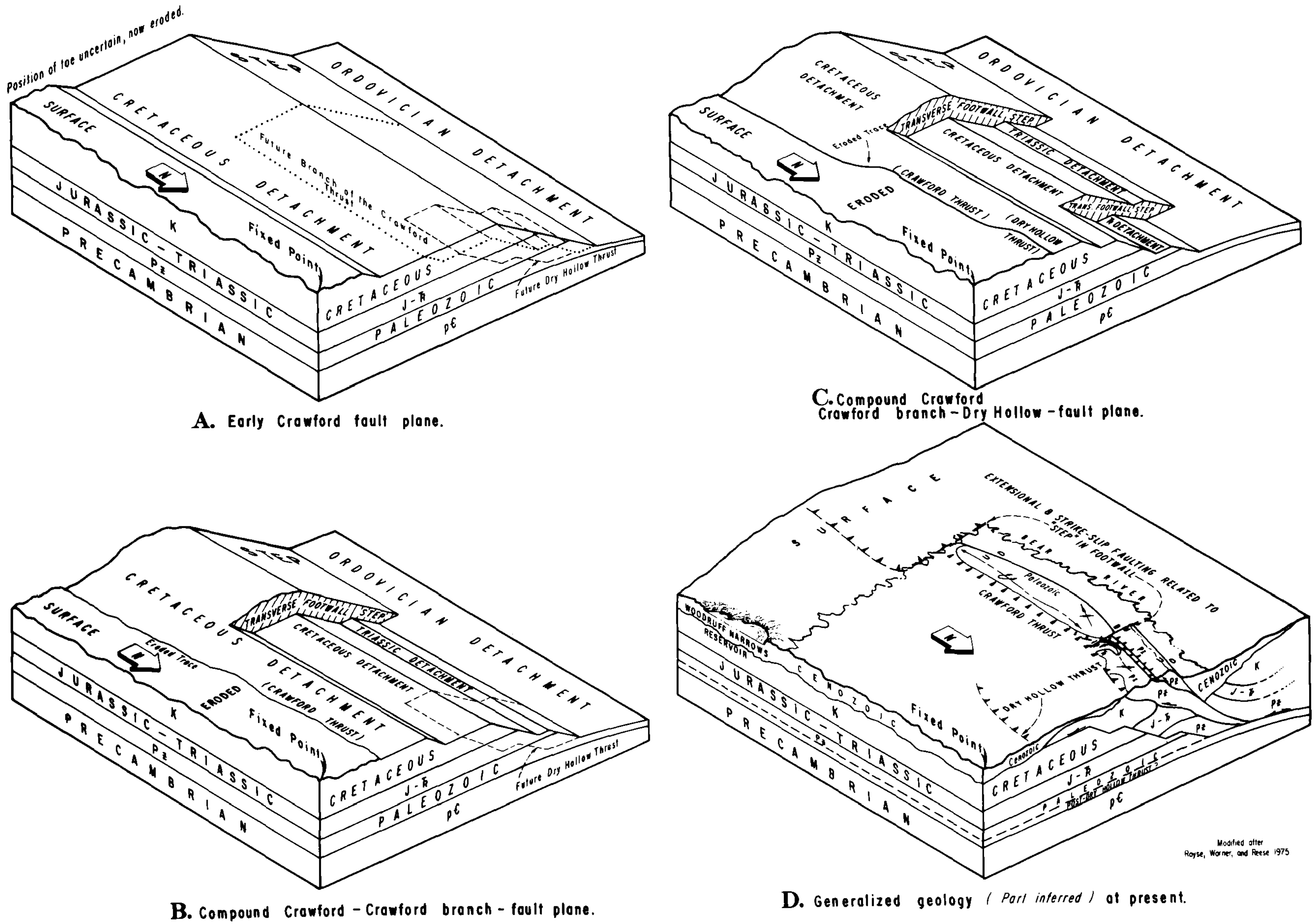

FIGURE 8.–Proposed model showing the structural evolution of the study area (see text for explanation). In order to show steps in the footwall, the north orientation does not follow the usual convention.

ruff, Utah. The river may well be down-cutting through bedrock made less resistant by prior tear faulting along both branches of the Crawford Thrust. Seismic data suggests the Crawford Thrust at the Bear River is offset eastward about 2.4 km (2 mi).

In summary, the evolution of structural elements in the Woodruff Narrows Quadrangle can best be explained by a proposed model shown in figure 8. The model explains many surface features as follows: (1) the obvious difference in age between the thrust faults near Wood Pass, (2) the presence of tear faults in the same area, (3) the difference in elevation between the Crawford Mountains north and south, (4) structural deformation of Cretaceous beds near Warner and Mud Springs, (5) the position of Cottonwood Creek, (6) the overturned Southern Crawford Anticline, (7) the sudden southward plunge near the Bear River of the Southern Crawford Anticline, (8) an end to the surface expression of the Leefe Fault, and (9) peculiar east-west change in course of the Bear River In addition, interpretation of seismic data indicates a thrust in Dry Hollow and east-west offset on the Crawford Thrust. Structural events from oldest to youngest include the following: (1) movement on the early Crawford fault plane, (2) movement on the present Crawford fault plane with development of a transverse step and tear faulting in the allochthonous block, (3) movement on the Dry Hollow fault plane with development of another transverse step at Wood Pass and tear faulting in two sheets riding piggyback on the allochthonous block, and (4) Eocene to Recent extensional faulting.

UNCONFORMITIES

The unconformities present in the Woodruff Narrows Quadrangle are between the following units· (1) Fish Haven Dolomite–Jefferson Formation, (2) Three Forks Formation–Lodgepole Limestone; (3) Brazer Dolomite–Wells Formation, (4) Phosphoria Formation–Dinwoody Formation, (5) Bear River Formation–Wasatch Formation, and (6) Fowkes Formation–pediment gravels. The first four unconformities all have the same general characteristics. None of them show an angular discordance between the beds above and the beds below. They are all disconformable relationships. The erosional vacuity represented by each is difficult to determine. However, all the Silurian is missing between the Fish Haven and Jefferson Dolomites. Apparently there was only gentle uplift and subsidence during development of any one individual unconformity. No paleosols, lag sands, conglomerates, or buried erosional surfaces with substantial relief were found associated with any of the disconformities

The unconformity between the Bear River and Wasatch Formations shows a good angular discordance at Warner Spring. The Bear River below dips 19° to 24° west; the Wasatch above is nearly horizontal. The resistant sandstones in the tilted Bear River Formation formed paleoridges during the erosional period after Sevier orogenic thrusting and before the Wasatch Formation was deposited. Near Warner Spring these paleoridges can be clearly seen with Wasatch Formation filling the intervening paleovalleys. The unconformity between the Fowkes Formation and the overlying pediment gravels may not be fully developed The gravels are not yet lithified and may be removed in the future allowing future erosion of the Fowkes

GEOLOGIC HISTORY

The earliest recorded geologic events in the study area began with Ordovician sedimentation along the Cordilleran shelf. It continued throughout the Paleozoic Era and into Mesozoic time with only occasional gentle uplift and subsidence. From then until the Recent, tectonic activity has dominated the major geologic events in the Woodruff Narrows Quadrangle.

Sedimentation

Ordovician and Devonian strata in the study area were deposited in a shallow marine environment along the eastern Cordilleran miogeoclinal shelf (Stewart and Poole 1974). The Silurian strata have all been removed by erosion but were probably deposited in the same environment. Mississippian sedimentation along the eastern Cordilleran miogeoclinal belt was dominated by the Madison-Brazer basin (Bissell 1974). The Lodgepole Limestone and Brazer Dolomite now found in the study area were deposited in shallow marine waters along the eastern edge of this basin. Later erosion removed any Late Mississippian and Early Pennsylvanian strata deposited. The Madison-Brazer Basin was the forerunner of the Oquirrh and Sublette Basins of Pennsylvanian and Permian times. The Wells and Phosphoria Formations were deposited on an eastern shelf of these two depocenters. Latest Permian and earliest Triassic time is represented by an unconformity above the Phosphoria Formation. By early Triassic time these basins were more or less joined and somewhat smaller Sediment laid down in this later depocenter became the Thaynes and other formations found in the map area.

Tectonics

The Late Triassic was a time of great change for the Cordilleran region. Armstrong (1968), in discussing the Cordilleran, feels that about mid-Triassic time uplift was initiated in the area, and the marine seas began to withdraw. By Middle Jurassic the region was undergoing orogenic deformation and supplying sediment to the newly formed Rocky Mountain geosyncline to the east. This marked the end for a time of marine deposition in the Woodruff Narrows Quadrangle that had been going on almost continuously since the late Precambrian.

The orogenic activity which took place in the former Cordilleran region eventually culminated in the Sevier orogeny. Sediments deposited there during the late Triassic, Jurassic, and Cretaceous consist of both marine and continental strata. Rocks in the map area as young as the Lower Cretaceous Bear River Formation were involved in the Sevier orogenic folding and thrusting. Figure 9 shows the generalized evolution of the study area during and after the Sevier orogeny. Extensional faulting in the Utah-Idaho-Wyoming thrust belt began as early as Eocene time and has continued until the Recent (Armstrong and Oriel 1965).

ECONOMIC POTENTIAL

The economic potential for hydrocarbons within the Woodruff Narrows Quadrangle is good. On the other hand, the potential for metals and nonmetals is meager at present.

Hydrocarbons

The Crawford Thrust has been the focus of intense hydrocarbon exploration in the last few years. Several promising structures in the area have been tested. American Quasar's Hogsback well to the northwest is presently producing gas from the Dinwoody Formation. At present (September 1979) Marathon Oil Company has a wildcat test underway in section 8, T. 10 N, R. 8 E (Mud Springs 1-8), and Getty Oil Company has one underway in section 29, T. 19 N, R. 120 W (Narrows South 1-29). Favorable structures may also exist in the autochthon beneath the Crawford Thrust The strata in the area contain abundant source and reservoir rocks. Source beds include the Lodgepole Limestone, Phosphoria Formation, Thaynes Limestone, Twin Creek Limestone, and Bear River Formation. Possible reservoir rocks are the Wells Formation, Phosphoria Formation, Dinwoody Formation, Thaynes Limestone, Woodside Shale, Nugget Sandstone, Twin Creek Limestone, Stump Sandstone, and Bear River Formation. It is hoped that future exploration in the map area will discover commercial quantities of oil and gas.

Metals

Igneous rock in the study area is restricted entirely to the volcanic tuffs of the Fowkes Formation. The chance of finding an economic metallic deposit associated with igneous rocks is quite small. Similarly, no metallic sedimentary occurrences have yet been found in the quadrangle.

Nonmetals

Gravel and phosphate are the only two nonmetals that have been quarried or mined in the map area. However, their economic contribution has been limited. Several quarries in the area have supplied gravel, mainly as local road material. Gravel is plentiful and therefore does not command a respectable price. Phosphate has been widely prospected in the Phosphoria Formation. Nevertheless, only a few tons at most have been produced within the quadrangle. The Phosphoria in the study area is thin and the phosphate poor. It is unlikely that in the future any large deposits will be found.

CONCLUSION AND RECOMMENDATIONS FOR FUTURE STUDIES

One of the best exposed Paleozoic sections in the Overthrust Belt is found in the Crawford Mountains of northeastern Utah. Fish Haven Dolomite, Jefferson Dolomite, Three Forks Formation, Lodgepole Limestone, Brazer Dolomite, Wells Formation, and Phosphoria Formation are exposed within the Woodruff Narrows 7½-minute quadrangle. In addition, the Mesozoic and Cenozoic deposits found there include the following: Dinwoody Formation, Woodside Shale, Thaynes Limestone, Bear River Formation, Wasatch Formation, Fowkes Formation, pediment gravels, colluvium, alluvium, and Recent sand dunes. All the major geologic time periods since the Cambrian have at least one time stratigraphic unit exposed in the study area, except the Silurian and the Jurassic. The Silurian strata were eroded away during Paleozoic uplift. The Jurassic rocks probably exist at depth beneath overlying Cretaceous units.

The structure found in the study area is dominated by Sevier folding, thrusting, and strike-slip tear faulting. Later Eocene to Recent extensional faults add further complexity to the structure. Major events leading to development of the present geology found in the map area began with the Cordilleran miogeocline and its associated basins. Later, evolution of the Rocky Mountain geosyncline affected the area during early and middle Mesozoic times. Intense structural deformation followed in Cretaceous time with the Sevier orogeny. Eocene to Recent extensional faulting has been the last major event recorded. Economic potential for hydrocarbons in the study area shows some promise. The potential for metals and nonmetals is meager.

A pollen analysis of the Cretaceous strata within the Woodruff Narrows Quadrangle would probably accomplish two things. First, it would determine more accurately the age of thrusting on the Crawford Thrust. Secondly, it would help determine the relative position of each outcrop in the Cretaceous section. A paleoecology-petrology study could be done on the Rex Chert to determine why it changes facies from the

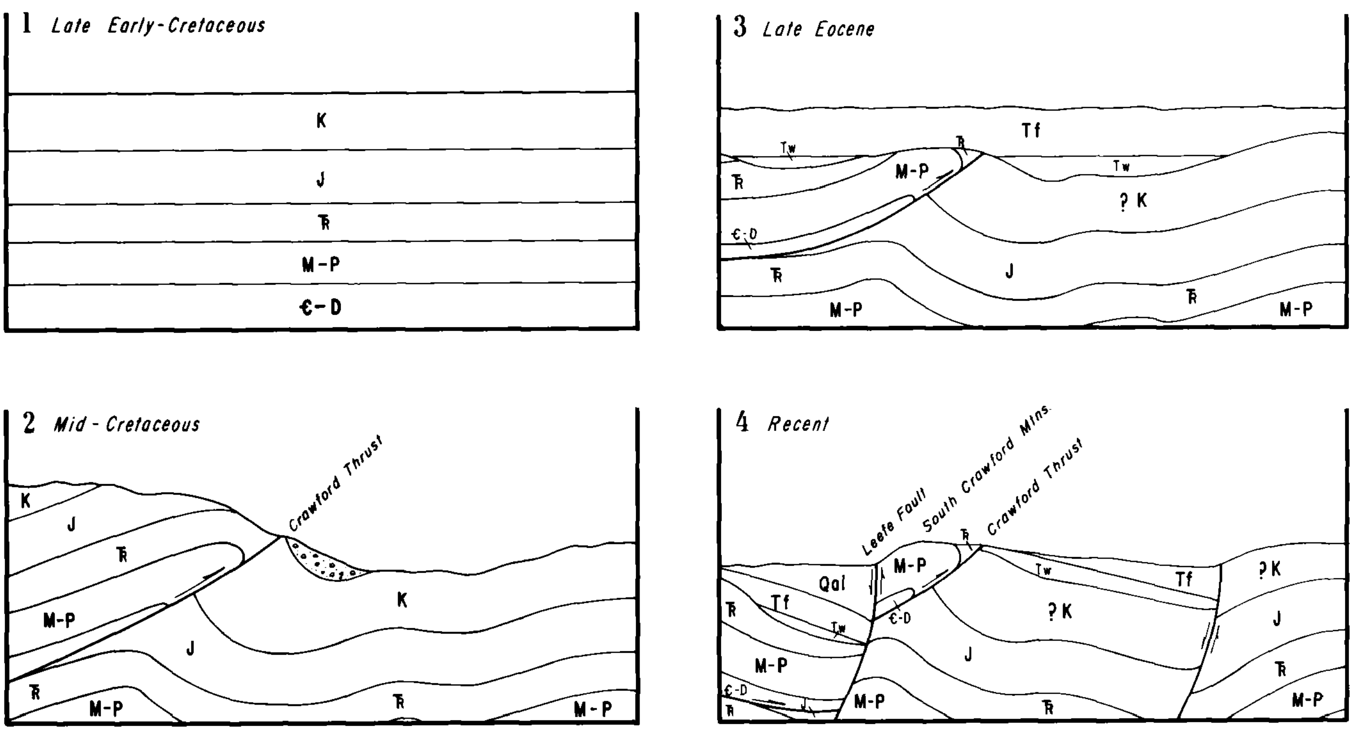

FIGURE 9.–Generalized diagram showing major episodes in development of the study area since early Cretaceous times: (1) nearly horizontal beds, (2) Sevier thrusting, (3) Eocene sedimentation, (4) extensional faulting.

typical dark gray chert to cross-bedded sandstone. This sort of study might help to increase our understanding of late Paleozoic sedimentation and tectonics in the area.

APPENDIX

Measured Stratigraphic Sections

Section 1

A mine cut near the center of section 5, T. 11 N., R. 8 E., in the Rex Peake Quadrangle exposes the base of the Eocene Fowkes Formation resting unconformably on the Permian Phosphoria. A section was measured from the base of the formation eastward along a dirt road to the eroded top of the formation.

Fowkes Formation

The top is an erosional surface.

Unit No.	*Unit Thickness (meters)*	*Description*
6	13.3	Conglomerate, weathers moderate brown, poorly sorted, well-rounded dark gray chert, light gray quartzite and grayish orange chert pebbles range in size up to 5 cm in diameter, matrix is poorly sorted, subrounded, poorly cemented sandstone, ledge forming, weathered pebbly surface
5	8.1	Sandstone, medium gray, weathers moderately brown, fine grained, well-rounded quartz and chert grains, well cemented, thin bedded, well sorted, ledge forming
4	24.8	Conglomerate, weathers moderate brown, poorly sorted, pebbles range up to 5 cm in diameter, well-rounded dark gray chert, light gray quartzite and grayish orange chert pebbles, matrix is poorly sorted, subrounded, poorly cemented sandstone, ledge forming, weathered pebbly surface
3	33.1	Conglomerate, poorly sorted, poorly cemented, cobbles and pebbles range up to 0.5 m in diameter, cobbles and pebbles are composed of dark gray chert, light gray quartzite, and grayish orange quartzite, matrix varies from grayish orange to light gray poorly cemented coarse sandstone, slope forming
2	3.0	Sandstone, coarse grained, poorly cemented, dusty yellow and yellowish gray, thin bedded, poorly sorted, subrounded to subangular, sand grains include quartz, chert, biotite, some clay matrix, slabby, slope forming
1	1.4	Conglomerate, poorly sorted, well rounded, cobbles range up to 0.5 m in diameter, coarse, poorly cemented, salt and pepper colored sand matrix, cobbles, pebbles, and sand grains are composed of dark gray chert, light gray quartzite, grayish orange quartzite, and phosphate, slope forming
Total	83.8 meters	
		Underlain by the Permian Phosphoria Formation

Section 2

Bear River Formation

An incomplete section of Bear River Formation was measured at two locales within the Woodruff Narrows Quadrangle. The upper part was measured beginning at a fork in the road just east of Warner Spring in section 8, T. 10 N., R. 8 E., and commencing west.

The lower part was measured from a point at the base of the ridge just west of the Woodruff Narrows Reservoir Dam in section 32, T. 18 N., R. 120 W. From here the section was measured northwest and north. Because of structural complications the section was offset until the top was finally reached in section 20, T. 18 N., R. 120 W., where it is overlain by the Wasatch Formation.

Section 2a

Bear River Formation

Unconformable contact with overlying Wasatch Formation

Unit No.	*Unit Thickness (meters)*	*Description*
12	5.0	Sandstone, medium grained, pale yellowish brown, weathers pale yellowish brown, laminated to thin bedded, ledge, subrounded grains, sorting poor, calcareous, dirty
11	31.8	Covered slope
10	20.3	Sandstone as above
9	63.6	Covered slope
8	35.0	Sandstone, medium grained, dark yellowish orange, weathers moderate yellowish brown, very thin to thick bedded, slabby, ledge, calcareous, subrounded, poor sorting, dirty
7	25.6	Sandstone, fine grained, grayish yellow, weathers grayish yellow, calcareous, laminated to medium bedded, ledge, spherical to subrounded grains, sorting average, ripple marks
6	6.2	Sandstone, same as unit 7 except cross-bedded and ripple marks
5	53.6	Covered slope
4	6.0	Sandstone, coarse grained, grayish yellow, weathers grayish yellow, calcareous, massive, ledge, spherical grains, sorting good, cross-bedding, porosity good
3	35.5	Covered slope
2	17.4	Sandstone as above in unit 4 except weathers yellowish brown
1	18.0	Sandstone, medium grained, grayish orange, weathers dark yellowish brown, calcareous, laminated to thick bedded, flaggy, cliff forming, subangular grains, sorting average, cross-bedded, dirty
Total	318.0 meters	

Section 2b

Bear River Formation

Unconformable contact with overlying Wasatch Formation

Unit No.	*Unit Thickness (meters)*	*Description*
38	20.5	Shale, dark gray, weathers dark gray, slope
37	1.2	Sandstone, fine grained, gray, weathers brown, thin bedded, ledge
36	11.3	Shale, dark gray, weathers dark gray, slope
35	20.5	Sandstone, fine grained, gray, weathers brown, thin-bedded ledge
34	0.5	Limestone, coquina, dark brown, weathers tan, assorted gastropods and bivalves
33	25.8	Shale, dark gray, weathers dark gray, slope forming
32	8.5	Sandstone, coarse grained, light gray, weathers brown, very thin bedded, flaggy, ledge forming, rounded grains with hematite spots, calcareous, weathers blocky
31	22.0	Shale, dark gray, weathers dark gray, slope forming
30	0.3	Sandstone, fine grained, light gray, weathers dark brown, very thin bedded, flaggy, ledge forming, rounded grains with hematite spots, calcareous, ripple marks, weathers blocky
29	13.4	Shale, dark gray, slope forming
28	7.0	Sandstone, fine grained, light gray, weathers dark brown, very thin bedded, ledge forming, weathers blocky
27	32.3	Shale, dark gray, weathers dark gray, slope forming
26	6.2	Sandstone, fine grained, light gray, weathers dark brown, very thin bedded, calcareous, hematite spots
25	65.5	Shale, dark gray, weathers gray, slope

24	10 4	Sandstone, fine grained, light gray, weathers brown, very thin bedded, flaggy, calcareous, ripple marks
23	14 3	Shale, dark gray, weathers dark gray, slope
22	1 2	Sandstone, fine grained, light gray, weathers dark brown, very thin bedded, flaggy, ledge, rounded grains with hematite spots, calcareous, ripple marks near top, weathers blocky
21	11 7	Shale, dark gray, weathers dark gray, slope
20	0 6	Limestone coquina, brownish gray, weathers grayish tan, sandy, thick bedded, flaggy, ledgy slope, interbedded with thin dark gray shale, some areas weather whitish, assorted gastropods and bivalves
19	89 1	Shale, dark gray, slope
18	2 1	Limestone coquina similar to 20
17	9 3	Shale, dark gray, weathers dark gray, slope
16	10 9	Limestone coquina similar to 20
15	27 5	Shale, dark gray, slope
14	10 0	Limestone coquina similar to 20
13	73 0	Shale, dark gray, slope
12	1 5	Limestone coquina, brownish gray, weathers grayish tan, sandy, thick bedded, ledge
11	2 0	Shale, dark gray, slope
10	5 7	Sandstone, white to brown, medium grained, weathers tan to dark brown, thin bedded, cliff, hematite spots, plant fragments, weathers pitted
9	13 6	Shale, light to dark gray, carbonaceous, sandy, slope former
8	3 7	Sandstone, similar to unit 9 except no plant fragments
7	13 0	Covered slope of gray soil
6	2 0	Sandstone as above
5	8 0	Covered slope
4	3 2	Sandstone, fine grained, light gray, weathers dark brown, very thick bedded, ledge, calcite crystals on joint surfaces
3	12 5	Covered slope
2	4 2	Sandstone as above
1	11 3	Covered slope of light gray soil
Total	575 8 meters	

Section 3

A roadcut leading to the Benjamin Mine near the mouth of Brazer Canyon provides a good exposure of otherwise covered Triassic Dinwoody and Permian Phosphoria Formations The section was measured from the west end of the Benjamin Mine road near the center of section 18, T 11 N, R. 8 E, of the Rex Peak Quadrangle along the road toward the east, to the base of the Triassic Woodside Formation

Dinwoody Formation

Unit No	*Unit Thickness (meters)*	*Description*
9	12 1	Shale, and siltstone, medium dark gray, weathers moderate brown, thin bedded, slabby, ledge forming, interbedded dusky yellow, light brown weathering siltstone
8	66 3	Siltstone, sandy, medium gray to greenish gray, thin bedded, slabby to blocky, slope forming, interbedded olive gray and moderate brownish laminated shale
7	4 6	Shale, brownish gray, laminated, shaly splitting, slope forming, interbedded greenish gray thin-bedded siltstone
6	6 1	Siltstone, medium gray, thin bedded, slabby to blocky, slope forming, interbedded olive gray laminated shale
5	12 0	Shale, brownish gray, laminated shaly splitting, slope forming, interbedded greenish gray thin-bedded siltstone
4	19 7	Siltstone, medium gray to greenish gray, thin bedded, blocky, slope-ledge, interbedded olive gray laminated shale
3	37 3	Covered
2	10 2	Siltstone, medium gray, thick bedded, blocky, ledge forming, calcareous, interbedded moderate brown laminated shale, and light olive gray shale
1	2 6	Shale, moderate, yellowish brown, laminated, slope forming, calcareous
Total	170 9 meters	

Underlain by the Phosphoria Formation

Phosphoria Formation

Unit No	*Unit Thickness (meters)*	*Description*
13	4 3	Coquina, medium light gray chert (more than 80%), phosphatic, fossils include bryozoans, brachiopods, fenestrate bryozoans, crinoids, ledge former, thick bedded
12	6 7	Chert, dark gray to greenish black, thin bedded, blocky weathering, ledge forming
11	1 3	Shale, moderate yellowish brown to moderate brown, phosphatic laminated, shaly, slope forming, interbedded dark gray chert, about 10 percent
10	1 3	Chert, medium gray, thin bedded, highly fractured, ledge forming, weathers dark yellowish orange, over 90 percent chert of which less than 10 percent is interbedded dark gray chert
9	7 6	Chert, dark gray, thin to medium bedded, highly fractured, ledge forming, interbedded dark yellowish orange, thin bedded, fractured shale Chert has about 5 percent white silica stringers along bedding plane
8	16 7	Shale, medium dark gray, weathers pale yellowish orange on surface, very thin bedded, slabby, sloped-ledge forming, dark gray 3 2 mm by 6 4 mm pelletlike shale interbedded
7	5 8	Shale, dark gray, thin bedded, slabby, white silica stringers about 3 2 mm wide range in length from 5 to 25 cm along the bedding plane, slightly mottled bedding, ledge-forming
6	9 2	Shale, olive gray, thin bedded, slabby, slope-ledge forming, interbedded brownish black, phosphatic, thin-bedded shale
5	1 3	Shale, olive black, laminated, shaly splitting, slope former, interbedded dark greenish gray, thin-bedded shale
4	5 5	Shale, moderate yellowish brown, thin bedded, flaggy weathering, slope-ledge forming, interbedded phosphatic, oolitic, olive black thin-bedded shale
3	2 0	Shale, olive black, laminated, shaly parting slope former, interbedded dark greenish gray thin-bedded shale
2	22 5	Shale, dark gray, weathers medium dark gray, thin bedded, slabby parting, sloped-ledge forming, calcareous, phosphatic
1	176 5	Covered
Total	255 0 meters	

Underlain by the Wells Formation

Section 4

A continuous section from the top of the Mississippian Lodgepole Limestone to the top of the Pennsylvanian-Permian Wells Formation was measured from a saddle near the center of the east half of section 20, T 11 N, R 8 E, (of the Rex Peak Quadrangle) and in a northwesterly direction down a small canyon toward the mouth of Brazer Canyon. The section ends in this small canyon about 4 km east of the Brazer Canyon road The strata measured includes the type section of Mississippian Brazer Dolomite

Wells Formation

Conformable contact with the overlying Phosphoria Formation

Unit No.	Unit Thickness (meters)	Description
18	11 0	Sandstone, very light gray, fine grained, friable, thin bedded, cliff forming, calcareous cement, basal 0 2 m intraformational calcareous sandstone conglomerate, medium dark gray to medium gray, sandstone appears bleached, interclasts of very angular conglomerate of gray cherty sandstone
17	42 8	Sandstone, very light gray, weathers light gray, thin bedded, fine grained, calcareous cement, quartz grains, blocky weathering, ledge former, less than 2 percent chert
16	14 6	Covered
15	8 8	Sandstone, very light gray, weathers light gray, thin bedded, fine grained, cross-bedded, jointed along bedding plane and vertical to bedding plane, quartz sandstone, blocky weathering, ledge forming, light bluish gray chert interbeds, 01 m thick, comprises less than 5 percent
14	12 0	Covered
13	1 8	Sandstone, very light gray, weathers light gray, very thin to thin bedded, joint weathering pattern produces small (01 to 03 m) blocky fragments, very fine quartz grains, ledge forming, light blue gray chert in very thin layers (less than 10 percent chert)
12	8 0	Covered
11	1 8	Chert, light blue gray, white, thin bedded, ledge forming, overlying sandstone
10	24 8	Covered
9	12 6	Sandstone, fine to medium grained, very thin bedded, light gray, grayish yellow sandstone, light bluish gray chert (10–15%), layered 05 to 1 m thick, cliff forming
8	8 6	Covered
7	2 2	Sandstone, medium grained, calcareous cement, thin bedded, sloped-ledge forming, chert interclasts (10–15%), light bluish gray, irregular shaped
6	11 2	Covered
5	1 1	Sandstone, very fine grained, cement slightly calcareous, hard, ledge forming, light gray, weathers light gray, medium bedded, weathers with small light brown spots
4	10 0	Covered
3	6 5	Sandstone, fine grained, calcareous cement, very light gray, weathers light gray, thin, cross-bedded, some weathers grayish orange, cliff forming, weathers friable, broken bedding, appears like small blocks of intraformational conglomerate
2	16 4	Sandstone, fine grained, calcareous cement, very light gray, laminated with pale orange, weathers light gray and dark yellowish orange, laminated to thin bedded, cross-bedded, cliff forming, friable
1	14 4	Sandstone, fine grained, calcareous cement, very light gray, weathers light gray and grayish yellow, thin bedded, cliff forming, solution weathering produces a rough surface, cross-bedded
Total	208 5 meters	

Underlain by the Brazer Dolomite

Brazer Dolomite

Unconformable contact with the Wells Formation

Unit No	Unit Thickness (meters)	Description
37	4 6	Sandstone, dolomitic, coarse grained, yellow gray, weathers yellow gray to light gray, thin bedded, laminated slope, small ledge former, weathers easily
36	6 9	Covered
35	2 3	Dolomite, fine crystalline, medium light gray white, weathers medium gray, thin bedded, massive, slope
34	3 5	Dolomite, very coarse, light olive gray-patchy, brecciated, thick bedded, massive, 2 percent chert, slope-small ledge former
33	13 4	Covered
32	9 2	Dolomite, fine-medium crystalline, medium gray, weathers light gray, thin bedded, massive, slope former, darker near top, top has calcite stringers
31	11 5	Covered
30	8 0	Sandstone, medium grained, light gray, weathers grayish orange, thin bedded, slope former, flaggy
29	10 4	Dolomite, fine crystalline, light gray to white gray, thin bedded, massive slope former, grades into sandstone
28	3 0	Dolomite, medium crystalline, medium gray, weathers light olive gray, oolitic near top, medium bedded, massive, cliff former, 8-cm chert layer in middle
27	8 7	Dolomite, fine crystalline, yellow gray, weathers light olive gray, thin bedded, massive, oolites and pisolites, ledge former, gastropods at base, burrows
26	3 8	Dolomite, fine crystalline, light olive gray, thin bedded, massive, small ledge, nodules of chert are rare
25	16 5	Dolomite, fine crystalline, medium light gray, weathers light gray, thin bedded, massive, slope, slightly laminated at base
24	8 0	Dolomite, medium crystalline, medium dark gray, weathers light olive gray, medium bedded, massive, cliff former, crinoids are rare, gastropods are common, calcite stringers, burrows, no chert, small oolitic layer in middle of unit
23	3 8	Dolomite, fine crystalline, medium dark gray, weathers light gray, thin bedded, massive, slope former, no fossils or chert
22	9 8	Dolomite, medium fine crystalline, medium gray, weathers light olive gray, dark olive at the top, medium bedded, massive, ledge-slope former, gastropods are common, syringospora corals are rare, black chert layer near top (5 cm), horn corals and crinoids are common
21	9 5	Dolomite, coarse crystalline, medium gray, weathers light olive gray, medium bedded, massive, ledge-slope former, crinoids are rare, chert is rare
20	4 0	Dolomite, fine crystalline, medium light gray, weathers light gray, thin bedded, massive, vertical parting, no fossils or chert, ledge former
19	0 3	Quartz sandstone, calcareous to dolomitic, very fine grained, light gray, weathers gray yellow, slope former, thin bedded, slabby erosional base
18	4 6	Dolomite, fine crystalline, medium light gray, weathers light gray, thin bedded, massive, vertical partings, no fossils or chert, ledge former
17	4 2	Dolomite, fine crystalline, medium dark gray, weathers medium gray, thin bedded, massive, slope former, crinoid debris is common, small nodules or white chert are rare

16	14.7	Covered.
15	5.2	Dolomite, medium crystalline, medium dark gray, weathers medium light gray, thin bedded, massive, ledge former, syringopora corals are common, horn corals are rare, chert is white to brown and rare.
14	3.8	Dolomite, medium to coarse crystalline, medium gray, weathers yellow gray, medium bedded, massive, cliff former, crinoids are rare, syringopora corals are common, chert nodules are rare.
13	8.4	Dolomite, coarse crystalline, light olive gray, weathers yellow gray, thin bedded, massive ledge former, syringopora corals are common, large spirifer brachiopods and crinoid stems are rare but common at the base, chert is white brown.
12	14.4	Dolomite, coarse crystalline, medium gray, weathers yellow gray, thin bedded, massive, cliff former, crinoid debris is abundant, 5 percent white to dark gray chert, layered with a few nodules; syringopora corals are rare.
11	6.3	Dolomite, coarse crystalline, gray yellow, weathers yellowish gray, thin bedded, massive, ledge former, crinoid debris is common, chert in lenses and nodules that are white gray.
10	17.6	Dolomite, medium crystalline, yellow gray, weathers light gray (slight tint of yellow), thin bedded, massive ledge former, abundant cri
9	28.3	Dolomite, fine crystalline, light gray, medium bedded, massive, slope former, abundant crinoids, brachiopods are common (spirifers?), horn corals are rare; black chert weathers dark brown to dark red with some white.
8	14.4	Dolomite, medium crystalline, yellow gray, weathers yellow gray, thin bedded, massive ledge former, crinoids are common to abundant, chert is nodular 4 percent, black to brown color.
7	21.2	Covered.
6	15.0	Dolomite, fine crystalline, light gray color, weathers yellow gray, thin bedded, massive, slope former, syringopora corals are rare, horn corals are common, crinoids and brachiopods are common; 10 percent chert, black, weathers dark brown to dark orange.
5	16.4	Dolomite, medium crystalline, medium gray, weathers light gray, medium bedded, massive, bottom half of unit is slope, top half is ledge, abundant crinoids, bioclastic, spirifer brachiopods are common, bryozoans are rare, syringopora corals are common near top of unit, nodular chert (syringopora corals inside nodules) 5 to 10 percent.
4	8.5	Dolomite, medium to coarse crystalline, medium gray, weathers yellow gray, thin bedded, massive ledge former, abundant crinoids, fetid odor, 5 percent nodular white to gray chert.
3	12.6	Dolomite, medium crystalline, medium gray, weathers yellow gray, medium bedding, massive, slope-ledge former, bioclastic in part, abundant crinoids and bryozoan-cryptostomata(?); nodular chert white to gray, 10 percent.
2	6.5	Dolomite, medium to coarse crystalline, light gray, weathers medium light gray, thin bedded, massive cliff-ledge former, spirifer brachiopods (large, rare), bioclastic in part, abundant crinoids, horn corals are rare; 5 percent chert, layered, light gray to white.
1	33.9	Dolomite, fine crystalline, medium gray, weathers light to medium gray, thin bedded, massive slope-ledge, crinoidal, chert-lenticular, grades into dolomite, medium stained, medium gray, weathers light gray, thin bedded, massive, ledge, abundant crinoids, cryptostomata bryozoans are rare, lenticular and nodular chert which weathers dark brown to reddish, 30 percent chert.
*Total	396.7 meters	

Underlain by the Devonian Three Forks Formation.

*Note: This section was measured previously by Sando, Dutro, and Gere (1959). They position several faults within the section on the basis of paleontological evidence. The author could find no evidence of these faults at the outcrop. If they do indeed exist, the total thickness of the Brazer Dolomite is somewhat less than the measured value.

Section 5

Section 5 was measured on the north side of a small east-west canyon in the northeast ¼ of section 14, T. 10 N, R. 7 E. The section was measured west along the south-facing side of the hill and ended at the base of the Brazer Dolomite located in a saddle 100 m east of a small hill identified as 6,942 feet on the Woodruff Narrows Quadrangle map.

Lodgepole Limestone

Unit No.	*Unit Thickness (meters)*	*Description*
15	3.0	Limestone, medium gray, weathers light olive gray, massive, slope forming.
14	30.0	Covered.
13	1.0	Limestone, medium gray, weathers olive medium gray, thin bedded, slabby, slope former; fossils include crinoids, brachiopods, corals; occasional white calcite in fractures.
12	26.0	Covered.
11	10.0	Limestone, dark gray, weathers dark gray and light olive gray, thin bedded, slabby, slope forming, weathers to rubble with some soil; fossils include horn corals, spirifer brachiopods, and twiggy bryozoans.
10	14.5	Covered.
9	1.5	Limestone, dark gray, weathers medium dark gray, thin bedded, slabby, slope forming, occasional white calcite in fractures.
8	10.4	Covered.
7	14.1	Limestone, medium dark gray to dark gray, weathers light dark gray and moderate yellowish brown, thin bedded, slabby, slope forming, weathers to rubble; abundant fossils include horn corals and syringopora corals, spirifer and other assorted brachiopods, and crinoids; occasional nodules, white calcite in fractures, 1.0 to 4.0 cm reddish bands at base.
6	19.7	Covered.
5	3.2	Limestone, dark gray, weathers dark yellowish brown to dark gray, thin bedded, slope forming, slabby; fossils include brachiopods, crinoids, bryozoans.
4	4.3	Covered.
3	7.0	Limestone, light gray, weathers light gray to medium dark gray, thin bedded, slabby, ledgy slope, weathers to rubble, occasional carbonate nodules with some silica which weathers moderate brown, white calcite in fractures; fossils include corals, gastropods, crinoids, and bryozoans; layered chert, dark gray 1.0 to 3.0 cm thick near base.
2	18.3	Covered.
1	3.8	Limestone, crystalline, dark gray, weathers dark gray, thin bedded, white calcite filling in fractures, weathers to rectangular blocks, ledgy slope.
Total	166.8 meters	

Stratigraphic contact with the underlying Three Forks Formation.

Section 6

The Three Forks Formation and the Jefferson Formation were measured in the north central part of section 11, T. 10 N, R. 7 E. Measurements were taken west of a ridge top about .4 km south of a jeep trail near the northern boundary of section 11.

Three Forks Formation

Stratigraphic contact with the overlying Lodgepole Limestone.

Unit No.	*Unit Thickness (meters)*	*Description*
2	62.5	Covered. Float is reddish sandstone, limestone, and sandy limestone.
1	24.6	Sandstone, medium coarse, moderate reddish orange to dark yellowish orange; thin bedded, flaggy, grains are spherical to rounded, good sorting, alternating light to moderate red bands.
Total	87.1 meters	

Gradational contact with the underlying Jefferson Formation.

Jefferson Formation

Unit No.	*Unit Thickness (meters)*	*Description*
10	21.8	Dolomite, crystalline, dark gray, weathers dark yellowish brown, massive, ledge forming, white dolomite stringers along fractures.
9	9.5	Covered.
8	1.2	Limestone, crystalline, moderate red, weathers pale red, thick bedded, blocky, slope forming.
7	5.2	Covered.
6	1.6	Dolomite, crystalline, dark gray, weathers brownish gray, thin bedded, slope forming.
5	21.5	Covered.
4	3.0	Dolomite, medium gray, weathers light gray, crystalline, blocky, thick bedded, slope-ledge former.
3	13.7	Covered.
2	17.3	Dolomite, ledgy slope former.
1	13.5	Dolomite, crystalline, dark gray, weathers dusky brown, massive ledge former, weathers to soil and rubble, contact with underlying unit is good.
Total	108.3 meters	

Unconformable contact with the underlying Ordovician Fish Haven Dolomite.

Section 7

The Fish Haven Dolomite was measured northwest from the Fish Haven-Brazer thrust contact near the southern boundary of section 11, T. 10 N, R. 7 E. The beginning point was in a saddle along the ridge just south of a resistant knob of Brazer Dolomite.

Fish Haven Dolomite

Unconformable contact with the overlying Jefferson dolomite.

Unit No.	*Unit Thickness (meters)*	*Description*
11	4.0	Limestone, medium coarse crystalline, sandy, white at base and gray at top, massive, ledge-slope, upper part has dark gray angular dolomite clasts which average 1 cm.
10	33.5	Dolomite, medium crystalline, gray, weathers light gray, very thick bedded to massive, cliff.
9	1.6	Dolomite similar to unit 10 except fine crystalline.
8	34.9	Dolomite, coarse crystalline, gray, weathers gray, very thick bedded to massive, cliff, poorly preserved crinoidal debris.
7	52.8	Dolomite, fine crystalline, light gray, weathers light gray, medium thick bedded, ledge, fractures have calcite crystals and iron oxide stains.
6	25.3	Dolomite similar to unit 7 except gray on fresh surface.
5	13.9	Dolomite, medium coarse crystalline, pinkish gray to light gray, weathers light gray to reddish gray, thin bedded, ledge-slope.
4	0.1	Limestone, very light gray, weathers reddish yellow, very thin bedded, some fractures have spots of green copper(?) mineralization.
3	28.9	Dolomite, fine to coarse crystalline, light gray, weathers light gray, thick to very thick bedded, cliff.
2	22.4	Dolomite, coarse crystalline, dark gray, weathers medium gray, massive, cliff.
1	19.0	Dolomite, medium crystalline, gray, weathers light gray, massive, ledge-slope, tight breccia recemented with calcite.
Total	236.4 meters	

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