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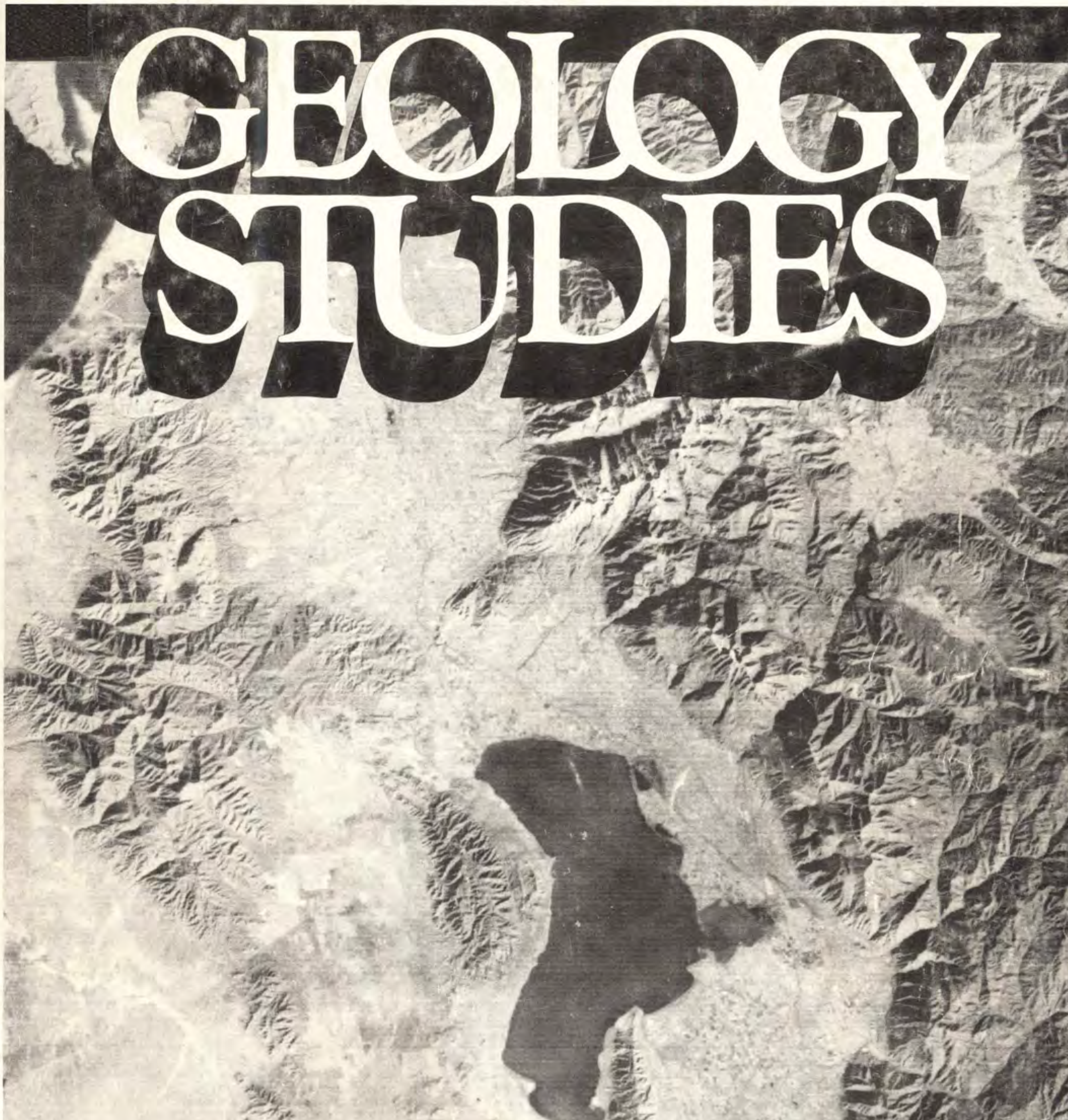

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THE GLORY OF GOD IS INTELLIGENCE

Cover: Aerial photo of Utah Valley and surrounding area.

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Structure and Stratigraphy of the Rex Peak Quadrangle, Rich County, Utah*

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ABSTRACT.—The Rex Peak Quadrangle includes one of the most complete and best exposed sections of Paleozoic and early Mesozoic strata associated with the Crawford Thrust. This report provides a more accurate and detailed description of the formational units and associated structure than previous publications. More than 1,500 m of marine sediments of Late Ordovician through Early Triassic age crop out in the quadrangle. Ordovician Fish Haven Dolomite, the oldest rock exposed, helps to define the location of the Crawford Thrust. Formations above the Fish Haven Dolomite include the Devonian Jefferson Dolomite and Three Forks Formation, the Mississippian Lodgepole Limestone and Brazer Dolomite (the type section is in Brazer Canyon of the Rex Peak Quadrangle), the Pennsylvanian Wells Formation, the Permian Phosphoria Formation, and the Triassic Dinwoody and Woodside Formations.

There was little structural deformation until after Lower Triassic deposition. Several thrust faults, large- and small-scale folds, and small-scale deformation features are related to Cretaceous thrusting. Most folding developed contemporaneously with thrusting. Normal faults postdate the thrusting. Thrusting occurred after Early Cretaceous but before Eocene time. Little evidence was found to clarify problems of amount of displacement and mechanics of thrusting.

The Rex Peak Quadrangle has good potential for hydrocarbon accumulations at depth; the best possiblity is in folded strata beneath the Crawford Thrust, where both source and reservoir rocks are present.

INTRODUCTION

One of the most complete Paleozoic and early Mesozoic stratigraphic sections in the Crawford Thrust system is exposed in the Rex Peak Quadrangle (fig. 1). The thrust system, genetically related to the Sevier orogeny, is a part of a larger arcuate thrust belt, convex to the east, that extends through southeastern Idaho, western Wyoming, and northeastern Utah. The upper plate of the Crawford Thrust contains Paleozoic through Triassic marine sediments that have been thrust over a thick wedge of Mesozoic continental rocks and subsequently folded, as a "piggyback" portion of the younger Absaroka, Darby, and other fault systems to the east.

This deformation has produced economic possibilities, both near the surface and deep in the buried strata. A synclinal fold along the Crawford Mountains has been the site of near-surface phosphate production from the Permian Phosphoria Formation. Subsurface structures may prove to be favorable hydrocarbon traps. Geologic data, obtained by detailed mapping of the stratigraphic units and structural trends, and measured stratigraphic sections, will help delineate the geology and economic potential of the area.

Acknowledgments

I express my sincere appreciation to many people and organizations who helped make this study possible. Financial assistance was received from Sigma Xi, Brigham Young University Geology Department, Marathon Oil Company, Chevron Oil Company, Gulf Oil Company, and Standard Oil of Indiana (Amoco).

Suggestions on fieldwork, illustrations, and manuscript revision, and many helpful hours in the field were received from James L. Baer, who served as committee chairman, and Lehi F. Hintze, who served as committee member. Val Ott and Earl Norris assisted measuring the several stratigraphic sections.

Especially, I am grateful to my loving wife who excused many extended absences from the family.

Previous Work

Published geological reports of northeastern Utah and the Crawford Mountains have followed economic interests. Initially, phosphate deposits were the main focus, but recent oil and gas discoveries have shifted geologic attention to the hydrocarbon potential. One of the earliest published geologic reports was that of Veatch (1907). His report describes mineral resources along the railroad right-of-way through southwestern Wyoming but lacks stratigraphic detail, showing the Crawford Mountains only as "undifferentiated Paleozoics."

In the 1890s a prospector, R. A. Pidcock, in a search for gold, discovered, instead, phosphate in a soft black formation

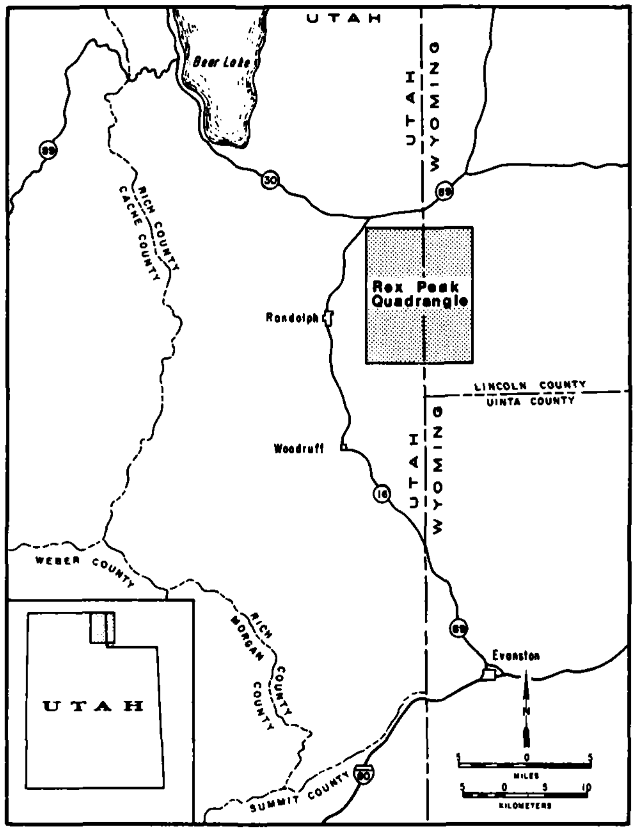

FIGURE 1.—Index map.

*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, April 1980. Thesis chairman: James L. Baer.

near Woodruff Creek, Rich County, Utah. Follow-up investigations conducted by Jones (1907, 1914) proved the existence of an extensive phosphate field in the Rocky Mountain region. Discovery of phosphate deposits in the area was described by Weeks and Ferrier (1906), Weeks (1907), Gale and Richards (1910), and Mansfield (1927). The stratigraphy of the Crawford Mountains was defined in Richardson's preliminary report (1913). Later Richardson (1941) provided the first detailed map (1:62,500) of the Crawford Mountains. No other detailed map of the Crawford Mountains has been published since Richardson's paper until the present report.

Petroleum interests in the Wyoming-Idaho-Utah overthrust belt have generated regional studies such as Eardley (1959, 1960, 1967), Armstrong (1953), Armstrong and Oriel (1965), and Royse and others (1975) that are pertinent to the Crawford Mountains. The Brazer Dolomite in its type section (Richardson 1913) in Brazer Canyon of the Crawford Mountains has been remeasured and redescribed by Sando, Dutro, and Gere (1959). Fossils collected from the northwest prong of the Crawford Mountains resulted in reassignment of dolomite, previously mapped as Silurian Laketown Dolomite (Richardson 1941), to the Ordovician (Berdan and Duncan 1955). To the immediate northeast, Rubey and others (1975) have mapped the 15-minute Sage and Kemmerer Quadrangles.

STRATIGRAPHY

A nearly complete section of Late Ordovician to Early Triassic strata (fig. 2) is well exposed in the Crawford Mountains. Mesozoic and Cenozoic rocks are less completely exposed in adjacent valleys and low hills. Sediments from the easily weathered Wasatch and Fowkes Formations and Quaternary colluvium cover Cretaceous clastic sediments in Dry Hollow Valley. West of the Crawford Range, Quaternary floodplain sediments cover most of the Bear River Valley.

Ordovician

Fish Haven Dolomite

In northern Utah and southeastern Idaho the massive, dark gray dolomite of Late Ordovician age has been called Fish Haven Dolomite. In Wyoming and Montana, equivalent massive, light gray dolomite and impure limestones have been named Bighorn Dolomite. Because of its closer proximity to Fish Haven exposures, the Late Ordovician dolomite in the study area has been assigned to the Fish Haven Dolomite.

The Fish Haven Dolomite in the Rex Peak Quadrangle is mostly thin bedded to massive, light to medium gray dolomite with interbeds of light gray dolomitic limestone. Poorly preserved corals and crinoid material were found both in the northeast prong of the Crawford Mountains and in the adjoining Woodruff Narrows Quadrangle, where a section of Fish Haven strata was measured (Ott 1980). The corals were identified by William A. Oliver, Jr., of the U.S. National Museum, as Late Ordovician *Deiracorallium* sp., possible fragments of Late Ordovician *Grewingkia* sp. and *Lobocorallium,* and Ordovician to Silurian *Catenipora* sp. Originally these rocks were mapped by Richardson (1941) as Silurian Laketown Dolomite. However, later study of fossils from the northeast prong of the Crawford Mountains (section 18, T. 20 N, R. 120 W) resulted in reassignment to the Late Ordovician (Berdan and Duncan 1955).

In the Rex Peak Quadrangle, the Fish Haven Dolomite dips west 25°-30°, except for two isolated exposures in section 30, T. 20 N, R. 120 W, that display nearly vertical bedding, and mark the boundary of the Crawford Thrust through the central portion of the mapped area. A section of Fish Haven Dolomite 236 m thick was measured in the central Crawford Range (Ott 1980).

Devonian

Jefferson Dolomite

Peale (1893) first described the Jefferson Dolomite from exposures near the Three Forks of the Missouri River in southwestern Montana. In the Rex Peak Quadrangle, Jefferson Dolomite lies unconformably on the Bighorn Dolomite and is conformably overlain by Three Forks Limestone.

Thrusting has placed Jefferson Dolomite over Mississippian Lodgepole Limestone in section 16, of T. 1 N, R. 8 E, but lesser displacement along the fault has displaced Jefferson Dolomite against itself both north and south of that area.

In the Rex Peak Quadrangle, the Jefferson Dolomite consists of 108 m of thin to medium bedded, fine-grained dark brownish gray dolomite, which weathers to a characteristic dark brown. Interbedded dolomitic limestone is found near the top of the section. No fossils were found during this investigation. Both Kindle (1908) and Richardson (1941) reported a scarcity of fossils in the Jefferson Dolomite. The dark resistant Jefferson Dolomite contrasts with the underlying light gray Fish Haven Dolomite, and physiographically, with the overlying, more easily eroded slope-forming Three Forks Limestone.

Three Forks Limestone

The Three Forks Limestone of Montana, western Wyoming, southeastern Idaho, and northern Utah was named by Peale (1893) for outcrops located near Three Forks, Montana. The Three Forks Limestone is underlain by Jefferson Dolomite and overlain by Lodgepole Limestone. Multicolored limestones, shales, and sandstones of the Three Forks Limestone weather to a characteristic orangish red soil that forms slopes and saddles between the more resistant carbonate formations above and below. This Three Forks soil is an excellent horizon marker. No outcrops of Three Forks were found in the quadrangle; however, a few buff, resistant sandstone lenses crop out in the Woodruff Quandrangle to the south where a section 87 m thick was measured (Ott 1980).

Mississippian

Lodgepole Limestone

The Lodgepole Limestone, the lower member of the Madison Group, is part of a thick carbonate sequence that extends from Montana into Idaho, Wyoming, and northeastern Utah and is a part of a greater carbonate sheet that once covered much of the western United States (Sando 1974). Lodgepole Canyon of the Little Rocky Mountains in Montana is the type area for the Lodgepole Limestone. In the Rex Peak Quadrangle, the thin- to medium-bedded, fine-grained, medium to dark gray fossiliferous Lodgepole Limestone lies conformably over the Three Forks Limestone and conformably under the Brazer Dolomite. Fossils are found throughout most of the section, but are more common toward the base. Large crinoids, several types of brachiopods, horn corals, and bryozoans were found in abundance, often silicified in layers in the dark gray limestone. Fossils in the Lodgepole Limestone include the following genera: *Chonetes, Composita, Dictyoclostus, Faberophyllum, Fenestrellina, Lithostrontionella, Spirifer,* and *Zaphrentites.* In most places, the Lodgepole Limestone is covered in its own debris,

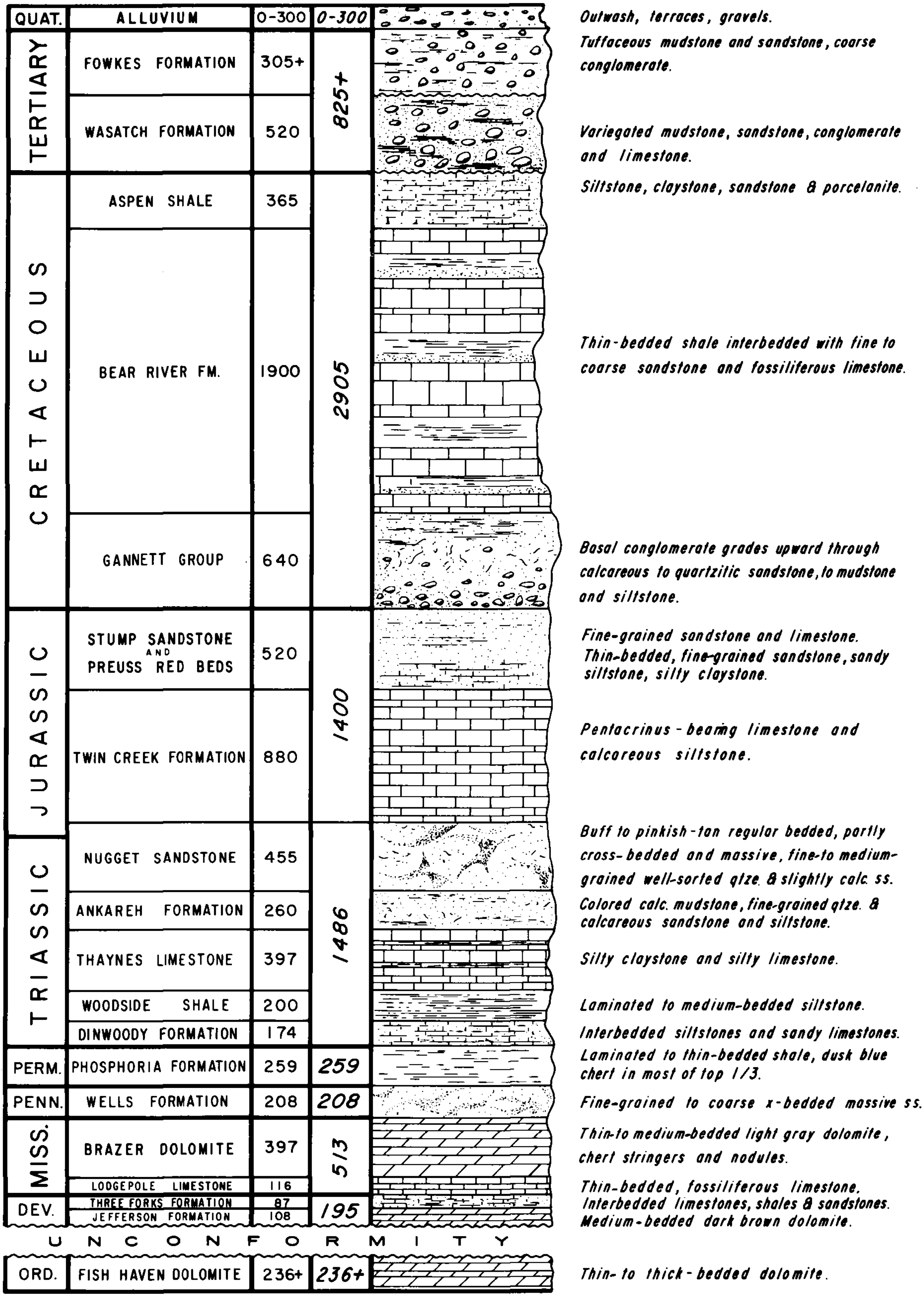

FIGURE 2.–Generalized stratigraphic column of the Crawford Mountain area.

but a section of relatively good exposures was measured in the adjacent Woodruff Narrows Quadrangle (Ott 1980). Toward the top of the section, the Lodgepole Limestone becomes dolomitic as it grades upward into the Brazer Dolomite.

Brazer Dolomite

Brazer Canyon in the Crawford Mountains of the Rex Peak Quadrangle is the type locality for the Upper Mississippian Brazer Dolomite (Richardson 1913). The type section was remeasured for this investigation in the northwest quarter of section 20, T. 11 N, R. 8 E (Ott 1980). Since its definition by Richardson (1913), usage of the term *Brazer* has been expanded elsewhere in northern Utah; but more recently Sando and others (1959) suggested that the term *Brazer* be restricted to the Crawford Mountains. In central northern Utah, where Deseret Limestone rests conformably on the Madison Group, faunal data indicate that the Deseret Limestone is correlative with the lower part of the Brazer Dolomite (Gilluly 1932). The Brazer Dolomite may also be considered a facies of the Madison Canyon Formation of the Madison Group (Sando and Dutro 1960). The formation was measured to be more than 396 m thick (Ott 1980).

Brazer Dolomite is light to medium light gray, thin- to medium-bedded, fine to coarse crystalline dolomite. Chert occurs as stringers, nodules, and beds, is darker toward the base, and is light gray toward the central portion of the section. The percent of chert decreases as the percent of sand increases toward the top of the section. Fossils are poorly preserved, but small crinoid material is abundant. Colonial corals and large spirifer brachiopods are found in the bottom half of the section. The 396-m-thick section of Brazer Dolomite grades upward to the sandstones of the Wells Formation.

Pennsylvanian

Wells Formation

The Wells Formation, named from Wells Canyon in Bannock County, Idaho (Richards and Mansfield 1912), rests there in apparent conformity upon limestone of Upper Mississippian age. In Utah, the basal contact of the Wells Formation may be unconformable (Blackwelder 1910).

The contact between the Brazer Dolomite and the Wells Formation, at the top of the Brazer type section, is marked by reddish silty sandstones and limestones. The reddish rocks do not appear elsewhere in the study area and do not provide the continuity necessary to form a good marker bed.

The Wells Formation consists of buff to light gray, fine-grained, cross-bedded to massive sandstone, and light gray quartzite. Interbedded chert nodules and stringers appear in the top half of the section and form resistant ledge-forming units. The formation is more calcareous toward the top where an intraformational calcareous sandstone conglomerate and a bleached sandstone appear. More than 208 m of Wells Formation (Ott 1980) underly the dark gray shales of the Phosphoria Formation.

Permian

Phosphoria Formation

Dark gray shales, oolitic phosphate, and dark chert of the Phosphoria Formation in Idaho, western Wyoming, and northeastern Utah have historically been of economic interest. In the Crawford Mountains, the Phosphoria Formation consists mostly of dark gray to grayish black laminated to thin-bedded shale with interbeds of black pisolitic to oolitic phosphate and occasional grayish orange, fine-grained sandstone. The shales are highly fractured, and crumble to rubble when they are excavated. The upper third of the formation contains abundant chert. The Rex Chert of the Phosphoria Formation is dusky blue to medium dark gray, medium-bedded chert with interbeds of thin-bedded, dark gray, phosphatic shale, and receives its name from Rex Peak, which is located at the head of Brazer Canyon. The top of the Phosphoria Formation is marked, in the study area, by a cherty, phosphatic, dolomitic, medium gray coquina of bryozoans, brachiopods, corals, and crinoids.

Triassic

Dinwoody Formation

Medium dark to medium gray, calcareous siltstone, greenish gray, calcareous, silty claystone, and argillaceous silty to sandy limestone make up the Dinwoody Formation of northeastern Utah. The Dinwoody Formation overlies the Phosphoria Formation unconformably on a regional basis (Love 1939, 1948; Newell and Kummel 1942).

The Dinwoody Formation is confined to the trough of a major syncline in Brazer Canyon. Roadcuts and mining operations have exposed siltstones and shales of the otherwise covered Dinwoody Formation. One of the best exposures is located along a road that leads to the Benjamin Mine in the center of section 18, T. 11 N, R. 8 E (figs. 7, 8). In Brazer Canyon, two sections of the Dinwoody Formation were measured with an average thickness of 172.5 m (Ott 1980). Regionally, the Dinwoody Formation thins to the east and is absent east of central Wyoming.

Woodside Formation

The Woodside Formation overlies the Dinwoody Formation in southwestern Montana, eastern Idaho, western Wyoming, and northern Utah. Unlike the Dinwoody Formation, the thickness of the Woodside Formation increases to the east but decreases rapidly to the west. In the Rex Peak Quadrangle, only a small portion of the Woodside Formation remains in the bottom of Brazer Canyon. It is pale reddish brown to light brown, thinly laminated to medium-bedded, fissile to flaggy, slope-forming siltstone.

Cretaceous

Bear River Formation

The Bear River Formation is found in southwestern Wyoming, southeastern Idaho, and northeastern Utah. It is named for the exposures near Old Bear River City, Wyoming.

In the Rex Peak Quadrangle, the Bear River Formation crops out along the west limb of an anticline located in the southeast corner of the study area, in sections 17 and 20, T. 20 N, R. 120 W, and as thin-bedded resistant sandstone beneath eroded Wasatch Formation. Except for a fault contact between Bear River clastics and a Mississippian Lodgepole Limestone klippe in section 17, T. 20 N, R. 120 W, and Lodgepole Limestone in section 31 of the same township and range, no Cretaceous formational contacts are exposed in the study area, but are covered by Quaternary deposits. The Bear River Formation consists of thin, cross-bedded, fine-grained sandstone ranging from grayish orange, light brown, to moderate brown, with interbedded dark claystone and fossiliferous limestone. Numerous ornate gastropods, *Pyrgulifera* (Yen 1954), weather out of a medium to very dark gray, calcareous coquina found on low hills in the easten half of section 5, T. 19 N, R. 120 W. Regionally, the formation ranges in thickness from 150 to 1500 m.

Differential erosion of sandstones and shales of the Bear River Formation has produced an irregular surface over which the Wasatch Formation was deposited. Some of the gullies and washes along the eastern slopes of the Crawford Mountains that drain into Dry Hollow Valley have small exposures of westward-dipping Cretaceous sandstones. A good exposure of the unconformity between the Bear River Formation and the Wasatch Formation is on the south-facing slope of a deep gully in the northern half of section 8, T. 10 N, R. 8 E, in the adjacent Woodruff Narrows Quadrangle (Ott 1980).

Tertiary

Wasatch Formation

Red, gray, and brown mudstones, siltstones, sandstones, and conglomerates of Eocene age extend over much of the central Rocky Mountain area. Thickness on a regional basis ranges from 90 to 3,350 m (Oriel 1962).

In the Rex Peak Quadrangle, the Wasatch Formation crops out as an orangish red weathering soil. Its color distinguishes it from recent colluvium and weathered tuffaceous mudstones of the Fowkes Formation. A light gray algal limestone, part of the Wasatch Formation, crops out along the north slope of an east-west trending wash in the northern half of section 8, T. 10 N, R. 8 E, of the Woodruff Narrows Quadrangle. Because of poor exposures, no section was measured.

Fowkes Formation

The late Eocene Fowkes Formation extends from southeastern Wyoming into northeastern Utah. The formation consists mainly of very pale gray, green, and pink tuffaceous mudstones, sandstones, siltstones, conglomerates, and calcareous claystones and limestones. The Fowkes Formation is present in two general areas within the Rex Peak Quadrangle. The exposures in Dry Hollow Valley of mostly light gray mudstones are the most extensive. The mudstone is highly weathered, rounded, and nearly covered by its own debris, which has produced covered or uncertain contacts with the Wasatch Formation and the surrounding pediment gravels and alluvium. The Fowkes Formation in Dry Hollow Valley dips moderately to the east and is best exposed along the larger washes. In the southeast corner of section 5, T. 11 N, R. 8 E, the Fowkes Formation consists of conglomerate and sandstone. The conglomerate is poorly sorted, well rounded, and clasts range in size from coarse sand to 20–30 cm, and are mainly composed of dark gray chert, light gray quartzite, grayish orange quartzite, and some limestone. This conglomerate is distinguished from the Wasatch Formation by interbedded tuffaceous sandstones. The Fowkes Formation rests unconformably over the Phosphoria (fig. 3) and Wells Formations. The thickness of the Fowkes Formation measured more than 83.8 m (Ott 1980).

FIGURE 3.–Eocene Fowkes conglomerate rests unconformably on the Permian Phosphoria Formation in a mine-cut in the northern part of the Crawford Mountains.

Quaternary

Quaternary deposits were mapped as alluvium, colluvium, or pediment gravels. Most of the Bear River Valley is a floodplain, marked with meander scars, oxbow lakes, and neck cutoffs, and composed mostly of soft silty clays and soils. Colluvium was shed from the steep west escarpment of the Crawford Mountains and small alluvial fans or bajadalike deposits which separate the Paleozoic rocks from the Bear River Valley alluvium. Pediment gravels occupy much of the stream and valley area on the east side of the Crawford Mountains. On most areas, the gravels are poorly sorted and mixed with soil to form a thin veneer which covers older bedrock, but toward the northern part of the area, where the Dry Hollow Valley and the Bear River Valley drainage merge, the gravels are better sorted. Road material is excavated from gravel pits located a few miles north of the Rex Peak Quadrangle.

STRUCTURE

Folding, high-angle faulting, and thrusting are very evident in the Rex Peak Quadrangle. Most structures trend northeasterly and control the present topography. The folding and thrusting are older than the high-angle faults that overprint them.

Folding

Folding consists of nearly parallel folds, the axes of which trend northeasterly. Two prominent synclines constitute the major features, but several minor folds are present. The most dominant syncline, the trough of which forms Brazer Canyon, extend northeastward from Rex Peak for more than 10 km. Phosphate was mined, conveniently, from both limbs of this syncline. To the north, this syncline is tightly folded with nearly vertical limbs, but near Rex Peak the limbs of the syncline flatten.

Another major syncline on the east side of the Crawford Mountains extends for more than 9 km from the northern half of section 33, T. 11 N, R. 8 E, to the southern half of section 7, T. 20 N, R. 120 W. This fold is associated with a thrust fault to the immediate west. Mississippian Lodgepole Limestone occupies the central two-thirds of the synclinal trough (fig. 4).

Folding was contemporaneous with thrusting in the area. Minor folds are associated with minor thrust faults, and serve to complicate the structure. Adjustments and plastic deformation within the strata due to thrusting are expressed as minor folds and faults, especially in the shaly beds of the Phosphoria and Dinwoody Formations (figs. 5, 6). Bedding-plane faults within the Phosphoria Formation are exposed by mine workings in the northern part of the Crawford Mountains.

Faulting

High-Angle Extensional Faulting

Two persistent, nearly parallel, high-angle faults trend northeasterly through the entire map area. Both are presumed to be listric faults, and may flatten and join a preexisting detachment zone at depth. The western listric fault marks the boundary between the Bear River Valley and the Crawford Mountains and extends to the north as far as Leefe. It may extend as far as Cokeville. Faceted spurs along the west front of the Crawford Mountains and small terracelike features in the colluvial cover along the base of the mountains suggest both that the Bear River Valley occupies a downdropped block and that there has been relatively recent movement.

FIGURE 4.–A synclinal fold in the northeastern part of the Crawford Mountains preserves the Mississippian Lodgepole Limestone above the Devonian Three Forks Formation.

The high-angle fault east of the Crawford Mountains separates west-dipping Cretaceous Bear River clastics on the east from the pediment gravels of Dry Hollow Valley on the west. An exposure of Fowkes Formation in section 6, T. 19 N, R. 120 W, dips moderately to the east and suggests that Dry Hollow Valley is also a downdropped block. Normal faults of minor displacement, located in the southeast corner of section 5, T. 19 N, R. 120 W, trend both parallel and normal to the major fault. High-angle extensional faulting began in this region as early as Eocene time and has continued to Recent (Armstrong and Oriel 1965).

Thrust Faults

Thrust faults extend the entire length, and along both east and west sides of the Crawford Mountains. The Crawford Thrust (Richardson 1941), located on the east side of the Crawford Mountains, strikes northeasterly through Dry Hollow Valley and displays the greatest stratigraphic displacement. Ordovician Fish Haven Dolomite along the leading edge of the Crawford Thrust rests against Cretaceous clastics. The Crawford fault is mostly covered by Quaternary and Tertiary deposits, but is exposed in the southwest corner of section 31, T. 20 N, R. 120 W. Its boundaries are defined by two Fish Haven outcrops, outcrops of resistant Cretaceous sandstone, Mississippian Lodgepole Limestone over Bear River clastics, and linear features that show on color aerial photographs. In section 30, T. 20 N, R. 120 W, nearly vertical outcrops of Fish Haven Dolomite help define the extension of the Crawford Thrust from its exposure in section 31. The trace of the Crawford fault in the southern portion of the area is defined by the covered contact of westward-dipping Cretaceous Bear River sandstones that crop out through the outlying cover of Tertiary Wasatch Formation, and Paleozoic carbonates. Highly fractured and folded Mississippian Lodgepole Limestone over Cretaceous clastics and a Lodgepole Limestone klippe faulted over Bear River clastics help define the extent of the Crawford fault through sections 31 and 17, respectively, of T. 20 N, R. 120 W. A linear feature on aerial photographs extends the mapping of the Crawford fault through the northern portion of Dry Hollow Valley toward the southwest corner of the Sage Quadrangle where the Crawford thrust was mapped by Rubey and others (1975).

FIGURE 5.–Minor fault within the Triassic Dinwoody Formation, located along a roadcut to the Benjamin Mine at the mouth of Brazer Canyon.

The Crawford Thrust is a compound fault, and other thrust faults intersect with the Crawford fault near section 32 and 33, T. 10 N, R. 8 E. A thrust of little stratigraphic displacement extends along the east central portion of the Crawford Mountains. The displacement ranges from slight thrusting within the Devonian Jefferson Dolomite to Jefferson Dolomite faulted against Mississippian Lodgepole Limestone. The other fault that splays northeast from its intersection with the Crawford fault has little exposure. Except for the abrupt termination of exposures of Mississippian Lodgepole Limestone against Cretaceous sandstones jutting out through Tertiary Wasatch cover in the southwestern corner of section 31, T. 20 N, R. 120 W, the inferred thrust fault is covered.

Another thrust fault of minor displacement is exposed along the west face of the Crawford Mountains. It is related to a parallel tightly folded, asymmetric anticline. The steeply dipping Brazer Dolomite and Lodgepole Limestone that form the west escarpment of the Crawford Mountains, are remnants of the west limb of this anticlinal fold. This thrust fault which displaces the Wells Formation in the north exposes the Devonian Jefferson Dolomite as it cuts downsection to the south along the mountain front (fig. 7).

The thrusting is post-Cretaceous Bear River Formation, but pre-Tertiary Wasatch Formation. From exposures to the north, Armstrong and Oriel (1965) estimate the Crawford Thrust to be mid-Cretaceous. Figure 8 shows a generalized diagram depicting the structural evolution of the study area.

The relatively simple structure of the northern part of the Crawford Mountains becomes more complex along the southern edge of the map area where several parallel anticlinal structures occur. These minor folds intersect a complex zone of thrust, shear, and normal faults to the south in the adjacent Woodruff Narrows Quadrangle (Ott 1980).

GEOLOGIC HISTORY

Geology of the study area is a result of (1) Paleozoic and early Mesozoic sedimentation, (2) Cretaceous and early Tertiary tectonism, and (3) Tertiary to Recent events. Figure 8 illustrates, in cross section, the interpretive structural history of the Rex Peak Quadrangle, from early Cretaceous to the present time. The structural style of the cross section illustrates the concept that upper plate strata and thrust surfaces may be folded as they are carried "piggy-back" by younger thrusts, and adheres to the principles of thrust belt structural geometry as related by Royse and others (1975).

Paleozoic and Early Mesozoic Sedimentation

The stable shelf margin of the Paleozoic and early Mesozoic Cordilleran geosyncline (Kay 1951) was the site of deposition for most of the rocks in the study area.

Late Ordovician Fish Haven Dolomite, the oldest strata in the area, is separated from the Devonian transgressive sequence by a period of nondeposition or erosion (Peterson 1977). Devonian chert and shale facies produced along the eastern margin

FIGURE 6.–Minor fold within the Triassic Dinwoody Formation, located along a roadcut to the Benjamin Mine at the mouth of Brazer Canyon.

of the Antler orogenic belt in central Nevada (Poole 1974) changes to carbonate, sandstone, and evaporite facies to the east, along the shelf margin in the area of this study. As evidence of Late Devonian regression, the carbonate buildup of Upper Devonian Jefferson Dolomite grades upward into sandy limestone and evaporite facies of the Three Forks Formation.

Lower Mississippian transgression is marked by widespread fossiliferous carbonate facies along the shelf margin (Rose 1976), particularly the Lodgepole Limestone in the study area. A period of regression produced the Late Mississippian Brazer Dolomite, a shelf carbonate, which grades upward into calcareous sandstones and gives further evidence of the regressive period.

The overlying calcareous sandstones, the Pennsylvanian Wells Formation, are a part of a transitional phase between the clean, cross-bedded Tensleep Sandstone facies of the Wyoming shelf and the thick basinal carbonate and quartzite facies of the Oquirrh Formation. Continuation of the shelf environment is evidenced by the shelf carbonate facies of the Permian Phosphoria Formation and its associated black shale and chert.

The carbonate and shale facies of the Triassic Dinwoody Formation extended over much of the shelf area. However, in contrast to Paleozoic units that thicken westward (McKee and others 1959), strata younger than Early Triassic thicken markedly to the east (McKee and Oriel 1956) and are characterized by emergent clastics.

Cretaceous and Early Tertiary Tectonism

The Mesozoic Sevier orogeny (Armstrong 1968) produced a significant change in the structure of the eastern Cordilleran region. Late Mesozoic orogenic pulses (Oriel and Armstrong 1966) resulted in a zone of thrust faults, concave to the west, 95 km wide and 320 km long that extends from southeastern Idaho, through western Wyoming, into northeastern Utah (Armstrong and Oriel 1965). The thrust belt consists of strata, originally deposited in western Utah and adjacent Idaho, that have been pushed or have slipped into Wyoming between the buttresses of Precambrian rocks of the Teton area to the north and the Uinta area to the south (Rubey 1955). Thrust faults of the Idaho-Wyoming-Utah belt dip moderately westward (Rubey and Hubbert 1959) and have an unmetamorphosed fault zone with little or no fault breccia or mylonite. Seismic evidence indicates that the faults have horizontal displacements of tens of kilometers and stratigraphic throws of 6,000 m or more (Armstrong and Oriel 1965, Crosby 1969, and Crittenden 1961). In latest Jurassic time, thrusting started in the west and progressed eastward through time to as late as early Eocene. Five major thrust systems dominate the present structure of the province. They are, from west to east, (1) Bannock-Paris-Willard (Monley 1971, Royse and others 1975), (2) Meade, (3) Crawford, (4) Absaroka, and (5) Prospect-Darby (Blackstone 1977). The upper plate of each successively more eastward thrust fault contains successively younger strata. The Crawford

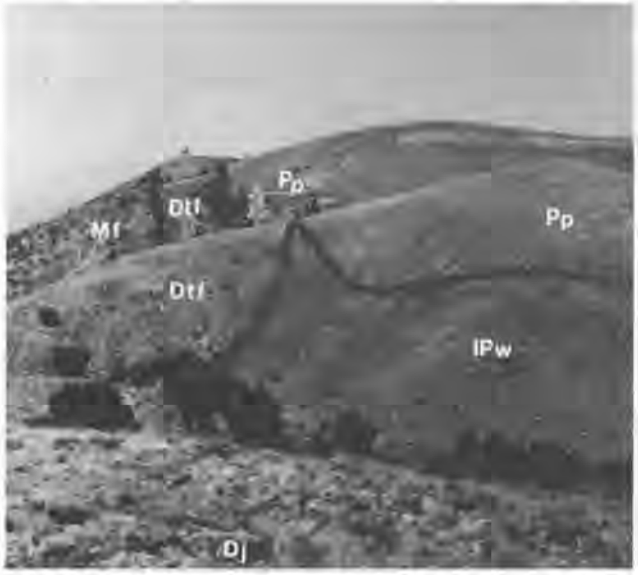

FIGURE 7.—A thrust fault along the Crawford Mountain front exposes Devonian strata south of Rex Peak as the fault cuts downsection to the south.

Thrust, the major thrust in the study area, places rocks as old as Late Ordovician over Cretaceous rocks.

Tertiary to Recent Events

The Eocene Wasatch and Fowkes Formations, unaffected by thrusting, mark the division between the earlier period of thrusting and a more recent period of extensional faulting and erosion. The Wasatch Formation in Dry Hollow Valley covers earlier thrust faults. An erosional surface separates the Fowkes Formation from the underlying Wasatch Formation in Dry Hollow Valley, and an angular unconformity separates the Fowkes Formation from Pennsylvanian and Permian units in section 5, T. 11 N, R. 8 E.

The eastern boundary of Dry Hollow Valley is marked by a high-angle fault that has placed older sediments of the Cretaceous Bear River Formation adjacent to and topographically above the Tertiary Wasatch and Fowkes Formations. The eastern boundary of the Bear River Valley is also marked by a high-angle fault. Gravimeter surveys of northward-trending block faults in a region to the north indicate a relief of 2,300 to 3,300 m between the crests of the flanking ranges and the bottom of the Tertiary fill in the valleys (Mabey and Armstrong 1962). Quaternary deposits of the Bear River Valley probably overlie several thousand meters of Tertiary valley fill on the down-dropped block. The present Bear River, which drains part of the north slopes of the Uinta Mountains, and winds past the Paleozoics of the Crawford Mountains as it travels northward, now flows atop several thousand meters of sediment which cover an older Tertiary erosional surface buried under its valley.

ECONOMIC GEOLOGY

Geology of the Rex Peak Quadrangle has produced an economic potential, only part of which has been exploited. Economic minerals can be divided into three categories: road gravel, phosphate, and hydrocarbons.

Road base material is derived from two sources in the area: (1) immediately north of the Rex Peak Quadrangle, pediment gravels, derived from eroded Tertiary conglomerates, are excavated from shallow gravel pits. (2) Within the study area, highly fractured rubble from the Phosphoria Formation, produced from mining operations, is also used for road base.

Discovery of phosphate in this area around the turn of the century caused mining activity for several years. The phosphate-bearing Phosphoria Formation is preserved along both limbs of a major synclinal structure, the axis of which is parallel with the trend of the Crawford Range. The ore was mined by stoping upwards from long drifts. The Phosphoria Formation is highly fractured and has formed unstable roofs. Roof caving was a major mining hazard, and accidents and deaths resulted from cave-ins. Even after mining was discontinued, roof caving has continued, extending to the surface in many areas. Two lines of surface depressions, caused from roof caving, outline on the surface the underground workings along both limbs of the

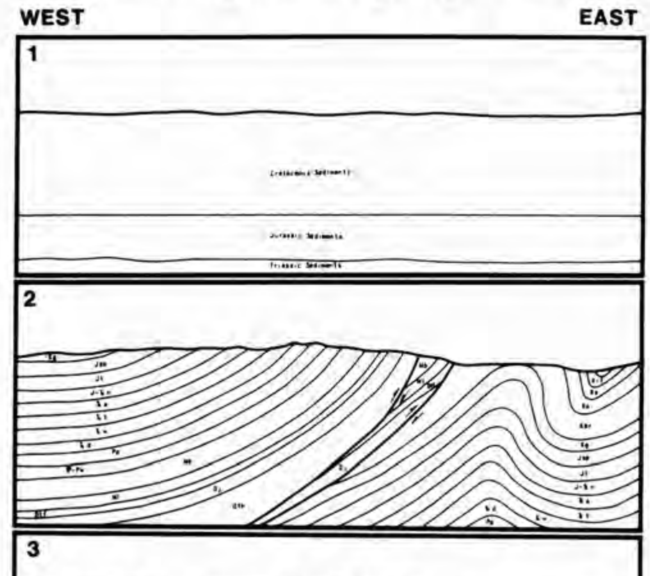

FIGURE 8.—Generalized diagram showing structural evolution of the study area.

synclinal structure (fig. 9). The phosphate in the trough of the syncline has not been removed, and at some future date economics may permit the extraction of this ore from under its hundred meters of overburden.

At the present time, oil and gas exploration efforts are directed towards determining the economic hydrocarbon potential of the Crawford Mountain region. Recent discoveries have revealed that the Overthrust Belt is favorable to hydrocarbon generation and migration (Royse and others 1975) and includes promising traps, source beds, and reservoir rocks. Discoveries east of the study area include Whitney Canyon, Ryckmen Creek, Yellow Creek, and Pineview (Hodgden and McDonald 1977). Moreover, the American Quazar Petroleum 20-1 Hodback Ridge wildcat (1977) located about 16 km northwest of the Crawford Mountains in section 20, T. 13 N, R. 7 E, discovered fifteen million cubic feet of gas per day on a drillstem test in the Triassic Dinwoody Formation (Powers 1977).

Requirements for hydrocarbon traps, source beds, and reservoir rocks exist in the Rex Peak Quadrangle. Tectonic developments and ancient sedimentary environments have, likely, generated reserves of oil and gas. Thrust faulting may have provided the proper mechanism for deeper burial of thermally immature source rocks and the creation of trapping structures for generated petroleum (Powers 1977). The most probable source beds are the Cretaceous marine shales of the Frontier Formation, Aspen Shale, and the Bear River Formation. The Jurassic Preuss Formation contains dark gray to black shales that may also be a hydrocarbon source (Maher 1976) and includes evaporites that may provide an upper-trapping seal. Other possible sources of hydrocarbons are the Triassic Thaynes, Woodside, and Dinwoody Formations, as well as the Permian Phosphoria Formation. The primary reservoir rocks are the Nugget Sandstone and the Twin Creek Limestone. Other possible reservoir rocks include lower Triassic and Permian porous carbonates, as well as the Pennsylvanian Wells, Mississippian Madison Limestone, Upper Cretaceous Frontier Formation, Lower Cretaceous Aspen Shale, and the Bear River Formation (Hodgden and McDonald 1977). Dark specks of "dead" oil were found in Cretaceous sandstone outcrops near the Crawford Fault in the southern portion of the Rex Peak Quadrangle.

FIGURE 9.—Collapsed features on the surface outline the old phosphate mine workings of subsurface drifts along the limbs of the Brazer Syncline.

SUMMARY AND CONCLUSIONS

The main significance of my research has been to provide a detailed geologic map and to investigate the area's potential for hydrocarbons.

From my study, the following conclusions are appropriate:

1. This report provides more detailed explanation and location of formational units as a result of using a 1:2,400 scale base map and an expanded explanation of several measured sections. Rocks formerly mapped as Silurian Laketown Dolomite (Richardson 1941) were more correctly mapped as Ordovician Fish Haven Dolomite. A conglomerate, previously mapped as part of the Wasatch Formation in the north central part of the Rex Peak Quadrangle, was reassigned to the Fowkes Formation. Formational boundaries along the west front of the Crawford Mountains were also mapped in more detail.

2. Greater structural detail and structural control are provided by this report. The location of the Crawford Thrust is substantiated with more detail. This report also provides a more complete fault pattern. A klippe of Mississippian Lodgepole Limestone over Cretaceous clastics is located in the northeastern part of the quadrangle.

3. The Crawford Thrust consists of a series of thrust faults that merge in plan view in the map area and probably merge at depth in cross-sectional view. Rocks as old as Ordovician carbonates have been thrust over Cretaceous Bear River clastics by the Crawford Thrust.

4. The west face of the Crawford Mountains is influenced by a thrust fault and an associated anticlinal fold and a subsequent normal fault that strikes nearly parallel with the thrust fault. Two major synclinal folds within the Crawford Mountains are other major structural features which resulted from the thrusting events.

5. Small-scale deformation such as slump folds and faults in the Phosphoria and Dinwoody shales, and bedding-plane faults in the Phosphoria Formation are evidence of adjustments both during and after the thrusting episodes.

6. The thrusting in the Rex Peak Quadrangle occurred after deposition of the Cretaceous Bear River Formation but before deposition of the Eocene Wasatch and Fowkes Formations.

7. The Rex Peak Quadrangle has good possibilities for hydrocarbon accumulations at depth. Regionally, there are several potential source and reservoir rocks, many of which may be found in the subsurface. Source beds include the Cretaceous Frontier, Bear River, and Aspen Formations, the Jurassic Preuss Formation, the Triassic Thaynes, Woodside, and Dinwoody Formations, and the Permian Phosphoria Formation. Reservoir rocks may incorporate Nugget Sandstone, Twin Creek Limestone, lower Triassic and Permian porous carbonates, Pennsylvanian Wells Sandstone, and Mississippian Lodgepole Limestone. Potential hydrocarbon buildups may exist in structural traps below the Crawford Thrust.

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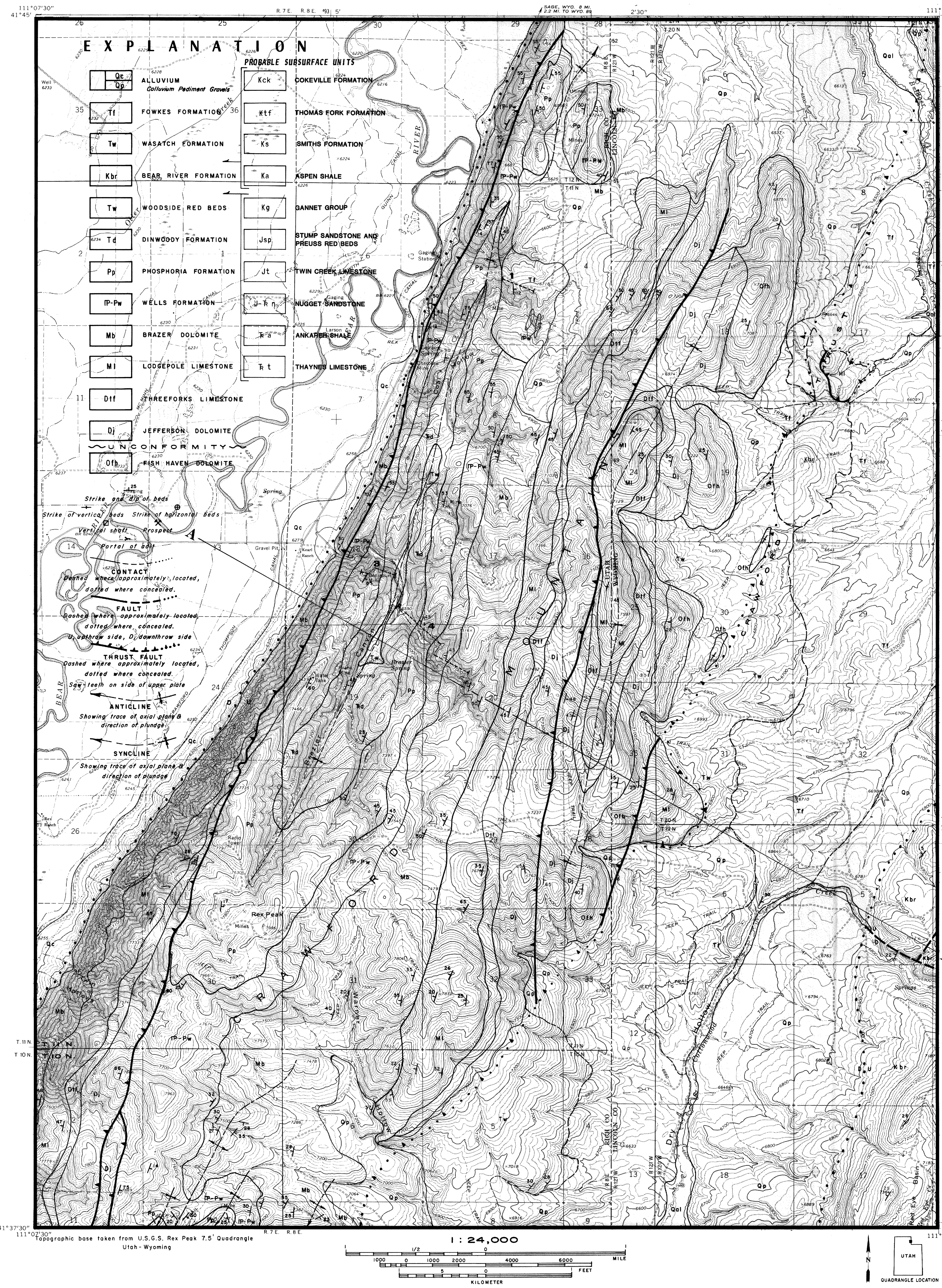

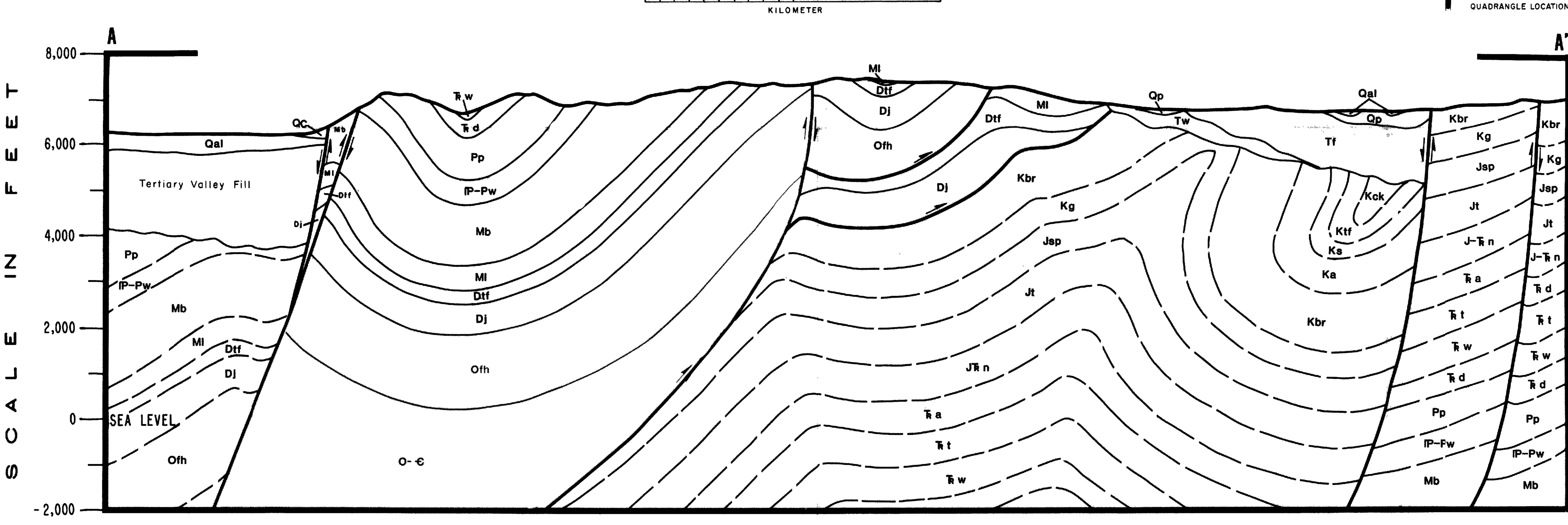

Geologic Map and Cross Section A-A'

of the

REX PEAK QUADRANGLE, UTAH-WYOMING

RANDY L. CHAMBERLAIN