THE GEOLOGICAL SURVEY OF WYOMING

Gary B. Glass, State Geologist

REPORT OF INVESTIGATIONS No. 21

THE SEARCH FOR OIL AND GAS IN THE IDAHO-WYOMING-UTAH SALIENT OF THE OVERTHRUST BELT

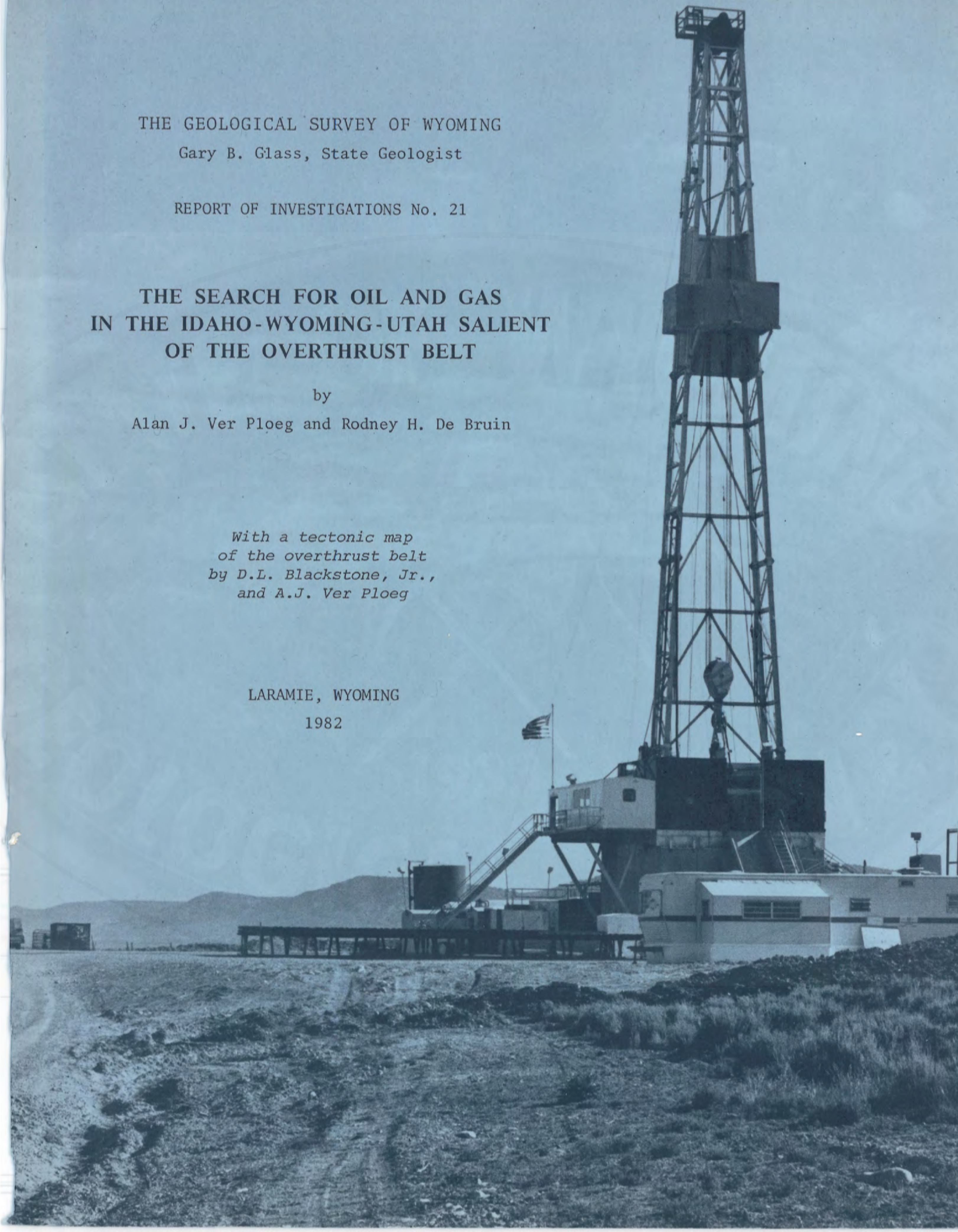
by

Alan J. Ver Ploeg and Rodney H. De Bruin

With a tectonic map of the overthrust belt by D.L. Blackstone, Jr., and A.J. Ver Ploeg

LARAMIE, WYOMING

1982



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Front Cover. Amoco's #1 Harry Moon well, a projected 13,500-foot Weber deep test in Yellow Creek Field, immediately southwest of the town of Evanston, Wyoming. Photograph by A.J. Ver Ploeg, June 1981.

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ERRATA

Page 15, Table 1, column under "Dip," 5th entry:

Sanke River *should read* Snake River.

Page 19, Table 2, column 8:

The column heading should read Average per well *and the column should not have been totalled.*

Page 20, Table 3, column 6:

The column heading should read Average per field.

LATE DEVELOPMENTS

¶Burton/Hawks has an indicated oil discovery in NW¼NW¼ sec. 28, T.3N., R.8E. in northeastern Utah's Summit County. Tests indicate production from the Cretaceous Kelvin Formation and the Jurassic Stump Formation. ¶In mid-October, 1981, Exxon completed the #4 Road Hollow Unit well in Lincoln County, Wyoming, as a gas well producing 10,000 MCFGPD and 440 BCPD. This discovery, recently named Road Hollow Field, produces from Ordovician Bighorn Dolomite at about 15,000 feet. It is in NW¼SE¼ sec. 4, T.19N., R.119W., approximately 4 miles northeast of the nearest producing well in Whitney Canyon-Carter Creek Field. ¶Early in 1982, Wainco Oil and Gas completed the B-1 Amoco-Champlin 370 as a discovery flowing 230 BOPD and 840 MCFGPD from the Triassic Ankareh Formation at about 12,500 feet. The discovery, in NW¼ SE¼ sec. 23, T.17N., R.119W., is in a separate structure immediately to the west of Ryckman Creek Field, in Uinta County, Wyoming. ¶Total production for the Idaho-Wyoming-Utah portion of the overthrust belt is listed at 23,703 BOPD and 139,900 MCFPD in the March, 1982 issue of Overthrust News [published by the Overthrust Industrial Association]. ¶Thomas Canyon Field has been abandoned by Chevron due to the high hydrogen sulfide content of the gas (over 35 percent) and proximity of the field to the town of Evanston (see Plate 1).

INTRODUCTION

The portion of the overthrust belt located in northeastern Utah, western Wyoming and southeastern Idaho is considered by the oil and gas industry to be the hottest new oil and gas province in the continental United States.

The Cordilleran fold and thrust belt extends from northern Alaska to southern Mexico (Figure 1). Very significant oil and gas reserves were identified in the Canadian thrust belt as early as 1913. However, until the Pineview success in 1975, most geologists felt that the Utah-Wyoming-Idaho salient probably retained very little oil and gas because of its long and complicated history of deformation, uplift, and erosion. Most did agree that sufficient thicknesses of sediments and the required facies for petroleum generation and migration did exist (Royse and others, 1975). Modern refinements of seismic exploration techniques have helped unravel the complex geology, and have led to the enormous successes that now characterize the area. This report catalogs the development of geologic knowledge of the area, describes its general geology and petroleum exploration history, profiles the important new oil and gas fields, and discusses some of the obstacles and problems faced by industry in developing this significant new oil and gas province.

HISTORY OF GEOLOGICAL INVESTIGATION

INITIAL WAVE OF EXPLORATION

Most early exploration in the area was tied either directly or indirectly to, first, the fur trade, then to the opening of the emigrant trail, and, finally, to the building of the first transcontinental railroad. Pioneer traders of the Rocky Mountain Fur Company - William Ashley, William Sublette, Robert Campbell, and their associates - provided the earliest knowledge of the geographic features of the region. The first reasonably accurate map of the area was compiled by Captain Bonneville as a result of his exploration in 1835 (Veatch, 1907).

In 1837, James Bridger and Louis Vasquez established the first permanent trading post, Fort Bridger, on the Blacks Fork of the Green River near present day Mountain View, Wyoming. It became a focal point on the Oregon Trail and later was associated with the overland stage route. In 1857, Fort Bridger was taken over by the U.S. Army as a military post, and thus became a natural jumping-off point for later scientific expeditions.

Earliest geographic and geologic contributions resulted from expeditions by Fremont in 1843, Clayton in 1847, Stansbury in 1849-50, Egloffstein (topographer for the Beckwith Expedition) in 1854, Lander and Wagner in 1857-58, and Simpson and Englemann in 1858. The earlier expeditions in the 1840's were military endeavors undertaken to identify routes and construct wagon roads through the area. The expeditions of the 1850's searched primarily for a route for the transcontinental railroad. These latter surveys correctly delineated most of the major geographic features of the region, but dealt little with the geology. Coal beds were identified on Sulphur Creek and Little Muddy Creek and tar or oil seeps were discovered on Sulphur Creek and at the head of Twin Creek (Veatch, 1907). Some Tertiary and Cretaceous fossils were described by James Hall of the Fremont Expedition and later in 1858 by Henry Engelmann. However, the complexity of the structural geology of the region is litte more than hinted at by these early explorers. For a more detailed discussion of early expeditions, see U.S. Geological Survey Professional Paper No. 56 by A.C. Veatch (1907).

POST-CIVIL WAR PERIOD

After the interruption of the Civil War, two large-scale scientific expeditions, the King Survey and the Hayden Survey, inaugurated the second wave of exploration in the western U.S. The King Survey, or "Fortieth Parallel Survey," was sponsored by the War Department to survey the lands along the route of the Union Pacific Railroad. Members of the King Survey worked in the report area in 1869, 1871, and 1872 (King, 1870; 1876; 1878). The coal deposits in the Bear River Valley were described by Arnold Hague, a Survey geologist, in 1869. In 1871, S.F. Emmons did reconnaissance geologic work farther to the east, working out of Fort Bridger. In 1872, these areas were re-examined by King Survey geologists.

Survey crews from the Department of Interior's Hayden Survey worked in the overthrust belt area between 1868 and 1872 (Hayden, 1869; 1870; 1871; 1872), and in 1877. Working out of Fort Bridger, they examined the upper reaches of Bear River, Muddy Creek, Blacks Fork and Smiths Fork. Geologists Meek and Bannister made detailed stratigraphic and paleontologic studies along the railroad right-of-way, and Lesquereux examined the coal deposits then being mined at Almy. In 1877, Gannett and Peale mapped the geology and topography of the area immediately north of the King Survey map. Gannett and Peale were the first to recognize and name the Absaroka thrust fault.

Between 1871 and 1875, the Land Office's topographic surveys established the exterior boundaries of most of the townships in the area, along with the western and southern boundaries of Wyoming Territory. Additional paleontological data were collected during the early 1870's by private parties, including Professor O.C. Marsh and Durkee and Cleburne of the Union Pacific Railroad.

This wave of exploration yielded considerable refinement in knowledge of the topography, and the King and Hayden Surveys produced geologic maps at a scale of 1 inch to 4 miles that covered much of the area. The mapping of the Hayden Survey, specifically the work of Peale, was the only really significant contribution to geologic knowledge. The King Survey provided no new information and was misleading in many ways (see Veatch, 1907). As a whole, these surveys were probably most important for the paleontological data they collected. As with the previous studies of the 1840's and 1850's, they failed to recognize complex structural relationships, and, as a result, confused age designations.

Also during this period, new coal mines were opened near Evanston, which flourished until about 1900. Small amounts of oil were collected and sold from the Carter and White Oil Springs and Brigham Young Spring. Extensive coal beds were discoverd in the Hodge Pass area, and Cope (1874) reported coals in the Frontier Formation near the present town of Frontier. Mines opened in the 1890's near the towns of Frontier, Diamondville, Oakley, Cumberland, and Glencoe. Mining is still going on in these areas; however, emphasis has shifted from the Frontier Formation coals to thicker Adaville Formation coals.

INVESTIGATIONS FROM 1881 TO THE PRESENT

Between 1880 and the present, additional significant studies which comprise the bulk of our present knowledge of the area were completed. Between 1881 and

1900, several scientists from the newly formed U.S. Geological Survey conducted studies in the overthrust belt area, again dealing primarily with coal deposits and paleontology.

Territorial and state officials examined the area during this same period. Territorial Geologist L.D. Ricketts (1888) visited the oil springs near Carter and Hilliard in 1887, and made a detailed study of the Evanston coal mines in 1889. Professor W.C. Knight of the University of Wyoming sampled the Evanston mines in 1893 and investigated the Hilliard, Carter, and Twin Creek oil springs in 1898 (Knight, 1893, 1899).

The first significant geological treatment of the area was completed by A.C. Veatch (1907) immediately following the turn of the century. He and his associates mapped nearly all of the area included in the Kemmerer and Sage quadrangles. The work was so perceptive and accurately done, that the major geological features and information have not been significantly altered by more recent detailed studies. Veatch recognized many of the thrust faults in the area and defined many of the stratigraphic units currently in use. For a detailed discussion of these early investigations, see Veatch, 1907.

In 1907, A.R. Schultz completed the first map of the northern portion of the overthrust belt. Schultz published a revised version with an expanded text in 1914. Additional important mapping projects in the early 1900's were completed by H.S. Gale and R.W. Richards (1910), E. Blackwelder (1910), R.W. Richards and G.R. Mansfield (1911; 1912), G.R. Mansfield (1916; 1927), and A.R. Schultz (1918). Many of these projects were initiated to classify public lands relative to the occurrence of phosphate and coal reserves in the area, and provided impetus for initial mapping in southeastern Idaho and northeastern Utah and for additional mapping in western Wyoming.

Recent mapping includes the work of W.W. Rubey (1958; 1973; 1980) in the central and northern portion of the Wyoming overthrust belt. Rubey has also clarified the mechanics of thrust faulting with a paper on pore fluid pressure, co-authored with M.K. Hubbert in 1959. In addition, several $7\frac{1}{2}$- and 15-minute quadrangles have been mapped by various U.S. Geological Survey investigators. Blackstone (1981) provides an excellent summary map of the strucutral geology of the overthrust belt and U.S. Geological Survey Hydrologic Atlas HA-539 (Lines and Glass, 1975) gives general geologic coverage of the area discussed in this report. Wyoming Geological Association Guidebooks for 1950, 1955, 1956, 1960, 1971, 1977, and 1979 provide additional information on the overthrust belt. Papers by Wanless, Belknap, and Foster (1955), Armstrong and Oriel (1965), Monley (1971), Royse, Warner, and Reese (1975), and Dorr, Spearing, and Steidtman (1977) also discuss the geology of the Utah-Idaho-Wyoming overthrust belt. Dr. D.L. Blackstone, Jr., of the University of Wyoming, has contributed extensively to the knowledge of the structural geology of the overthurst belt with several publications (1963; 1977; 1979) and by his supervision of more than twenty thesis projects in the overthrust belt.

GEOLOGIC SETTING

The area discussed in this report, commonly referred to as the "overthrust belt," is a part of a much larger tectonic province, defined by King (1969) as the Cordilleran fold belt, extending from northern Alaska to southern Mexico (Figure 1). The Cordilleran fold belt is divided longitudinally into at least

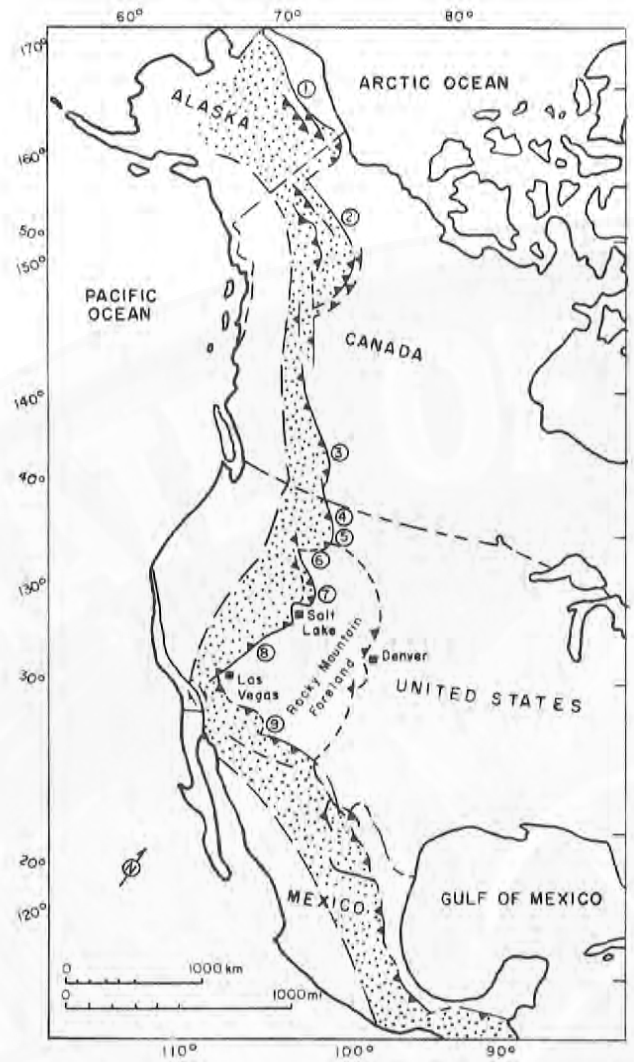


Figure 1. Longitudinal subdivisions of Cordilleran fold-and-thrust belt. From north to south, subdivisions are (1) Brooks Range and adjacent ranges in northern Yukon, (2) MacKenzie and Franklin Mountains, (3) Canadian Rocky Mountains, (4) Montana Disturbed Belt, (5) central Montana salient, (6) Medicine Lodge thrust system, (7) Idaho-Wyoming-Northern Utah salient, (8) Salt Lake City to Las Vegas segment, and (9) Las Vegas to Guatemala segment. Stippled area is outline of Cordilleran orogenic belt. Area west of Cordilleran orogenic belt is zone of younger deformation, volcanism, metamorphism and sedimentation. Modified from Drewes (1978) and Lageson (1980).

nine segments or "salients"; the Idaho-Wyoming-northern Utah salient is the topic of this report. This salient is a 200-mile-long, arcuate, easterly convex belt of faulted and folded rocks bordered on the north by the Snake River Plain and on the south by the Uinta Uplift. The eastern limit is defined by the Cliff Creek-Prospect-Darby fault trace and the western boundary is drawn in the vicinity of the Wasatch front, giving this salient a breadth of nearly 100 miles (Figure 2). Greater detail is provided on the tectonic map by Blackstone and Ver Ploeg which accompanies this report (Plate 1).

DEPOSITIONAL AND TECTONIC HISTORY

The depositional and tectonic history of the Idaho-Wyoming-northern Utah salient is closely related to the evolution of the Cordilleran geosyncline. During late Precambrian time (850 M.Y.B.P.), continental rifting created the Cordilleran geosyncline, which began receiving clastic sediments derived from the interior of the North American craton, to the east (Stewart, 1972). Initially, the western margin of the North American cratonic plate was probably at Atlantic-type or divergent plate margin which, in Middle or Late Ordovician time, changed to a convergent margin as the converging Pacific plate was subducted beneath the cratonic plate (Lageson, 1980). An extensive continental shelf or miogeosyncline developed along the entire cratonic margin. The hinge between the shelf and the trough in the miogeosyncline during Paleozoic and early Mesozoic time coincided roughly with the present Wyoming-Idaho border. Southcentral and southeastern Idaho served as the depocenter for essentially uninterrupted marine deposition, mostly limestone and dolomite, in this portion of the miogeosyncline from the late Precambrian to the Late Jurassic (Monley, 1971; Hintze, 1973). These carbonates

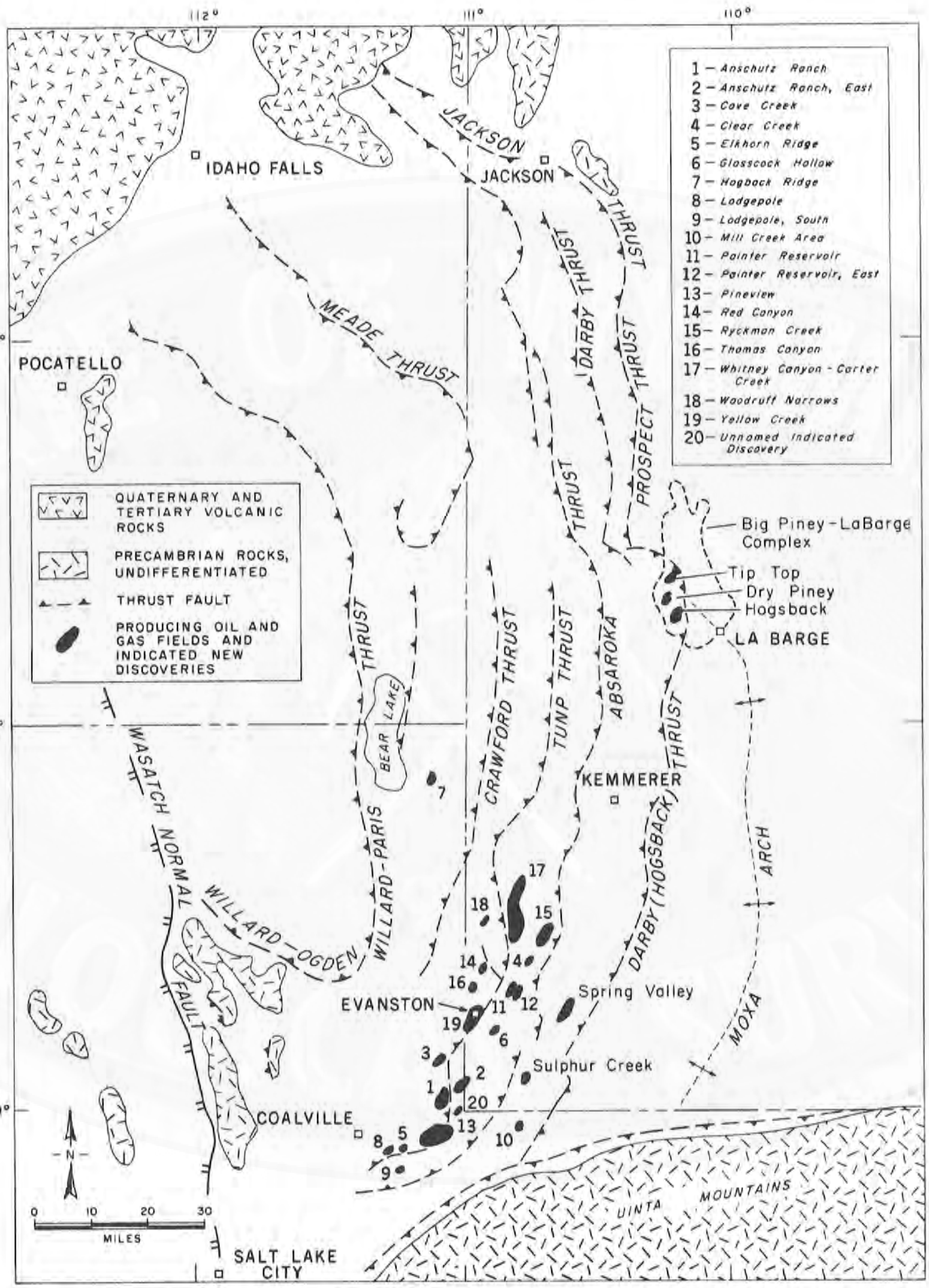


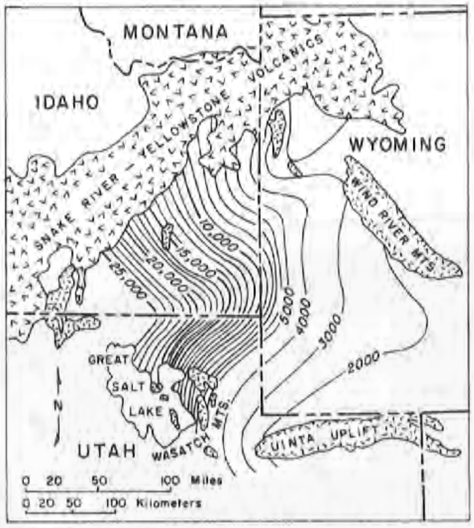
Figure 2. Index map showing oil and gas fields and major thrust faults in the Idaho-Wyoming-Utah salient of the overthrust belt. Modified from Powers (1977), Royse and others (1975), and Ver Ploeg (1979).

are interspersed with detritus eroded recurrently from both easterly and westerly source areas. Deposition, starting in late Precambrian time and continuing through the Cretaceous, produced rocks with an aggregate thickness between 50,000 feet (Crosby, 1968) and 100,000 feet (Armstrong and Oriel, 1965) within the trough. However, it should be pointed out that this entire thickness was not deposited at any one place since the site of maximum deposition migrated back and forth with time (Figure 3). Deposition on the shelf area immediately east of the hinge line was much thinner, ranging from 12,000 feet (Blackstone, 1977) to 16,000 feet (Monley, 1971). These sediments were, with a few exceptions, continuous with sediments of the same age deposited in the trough, but characterized by numerous unconformities and eastward thinning. Some depositional hiatuses resulted from truncation and depositional onlap (Monley, 1971). Some examples include Early Cambrian rocks which wedge out against the edge of the trough (depositional onlap) and Silurian age rocks which are quite thick to the west and are absent due to erosion or truncation on the shelf to the east (Figure 4).

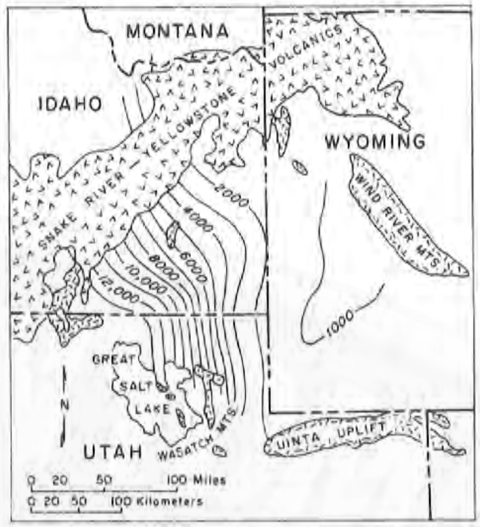
Initial pulses of uplift in the west, possibly related to the Permian-Triassic Sonoma orogeny further west, occurred in Triassic time, forcing the miogeosyncline to migrate eastward, and culminated in the Sevier orogeny, which began in Late Jurassic time. The area immediately to the west of the miogeosyncline began rising in Triassic time and, as a result, no Jurassic rocks were deposited in western Utah (Hintze, 1973). Continental deposition replaced the marine deposition in late Triassic time and continued into early Jurassic time when marine deposition returned and continued until late Jurassic time (Monley, 1971). The Sevier orogenic event in northeast Nevada and western Utah created a permanent "high" to the west and drastically changed the depositional pattern within the geosyncline beginning in the Late Jurassic (Blackstone, 1977).

With the advent of Lower Cretaceous time, the Sevier orogeny continued to expand throughout the Cordilleran geosyncline, producing the fold and thrust belt and breaking up the miogeosyncline which had persisted in the area since the late Precambrian time. Convergence of the oceanic and cratonic plates and concurrent subduction of the oceanic plate was largely responsible for the thrust faulting and folding (Burchfiel and Davis, 1975). Initial movement of the oldest and westernmost thrust system, the Willard-Woodruff-Paris system, resulted in deposition of the Ephriam Conglomerate (Figure 4) of Late Jurassic - Early Cretaceous age (Armstrong and Oriel, 1965). With each pulse of thrusting brought on by the Sevier orogeny, the site of maximum Cretaceous deposition shifted eastward. Monley (1971) places the average depocenter for the Lower Cretaceous immediately east of the Idaho-Wyoming border (Figure 3). As the "high" to the west had become the primary source of sediments, the proportion of continental strata deposited in the depocenter increased to the point of almost complete exclusion of the marine sedimentation which had characterized the miogeosyncline for so long. Maximum thickness for Lower Cretaceous sediments in the depocenter is 8,000 feet (Monley, 1971). To the east of the depocenter, sediments thin and grade into transitional marine sandstones and marine shales, totalling only 900 feet in the La Barge area (Monley, 1971).

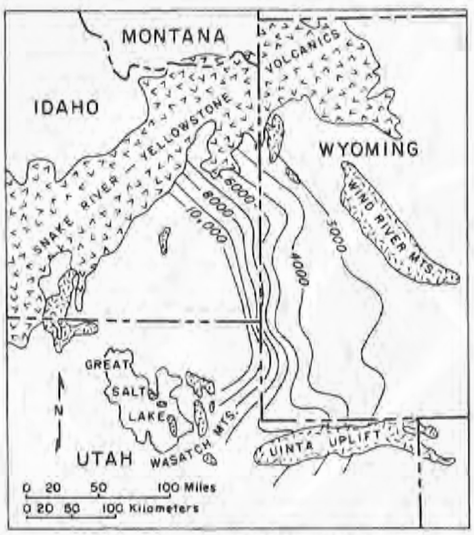
Upper Cretaceous time is characterized by the continued orogenic activity in the Sevier orogenic belt forcing the depocenter to migrate to 10-15 miles east of the Idaho-Wyoming border (Armstrong and Oriel, 1965). This depocenter or foreland deep was considerably narrower and deeper than the depocenter formed during Lower Cretaceous time (Figure 3), as subsidence and deposition rates increased (Monley, 1971). Once again, orogenic sediments were derived from the "high" located to the west almost exactly



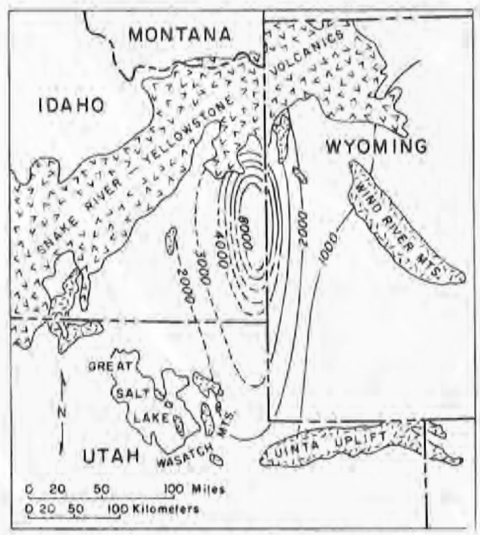
CAMBRIAN-MISSISSIPPIAN ISOPACH



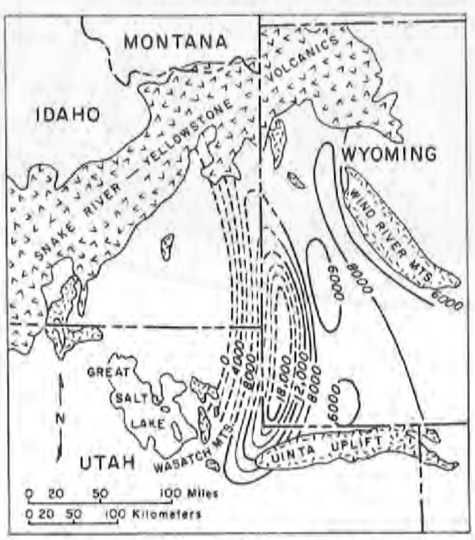
PENNSYLVANIAN-PERMIAN ISOPACH



TRIASSIC-JURASSIC ISOPACH



LOWER CRETACEOUS ISOPACH



UPPER CRETACEOUS ISOPACH

Figure 3. Isopach maps illustrating sediment thicknesses for Cambrian through Upper Cretaceous rocks. Taken from Monley (1971).

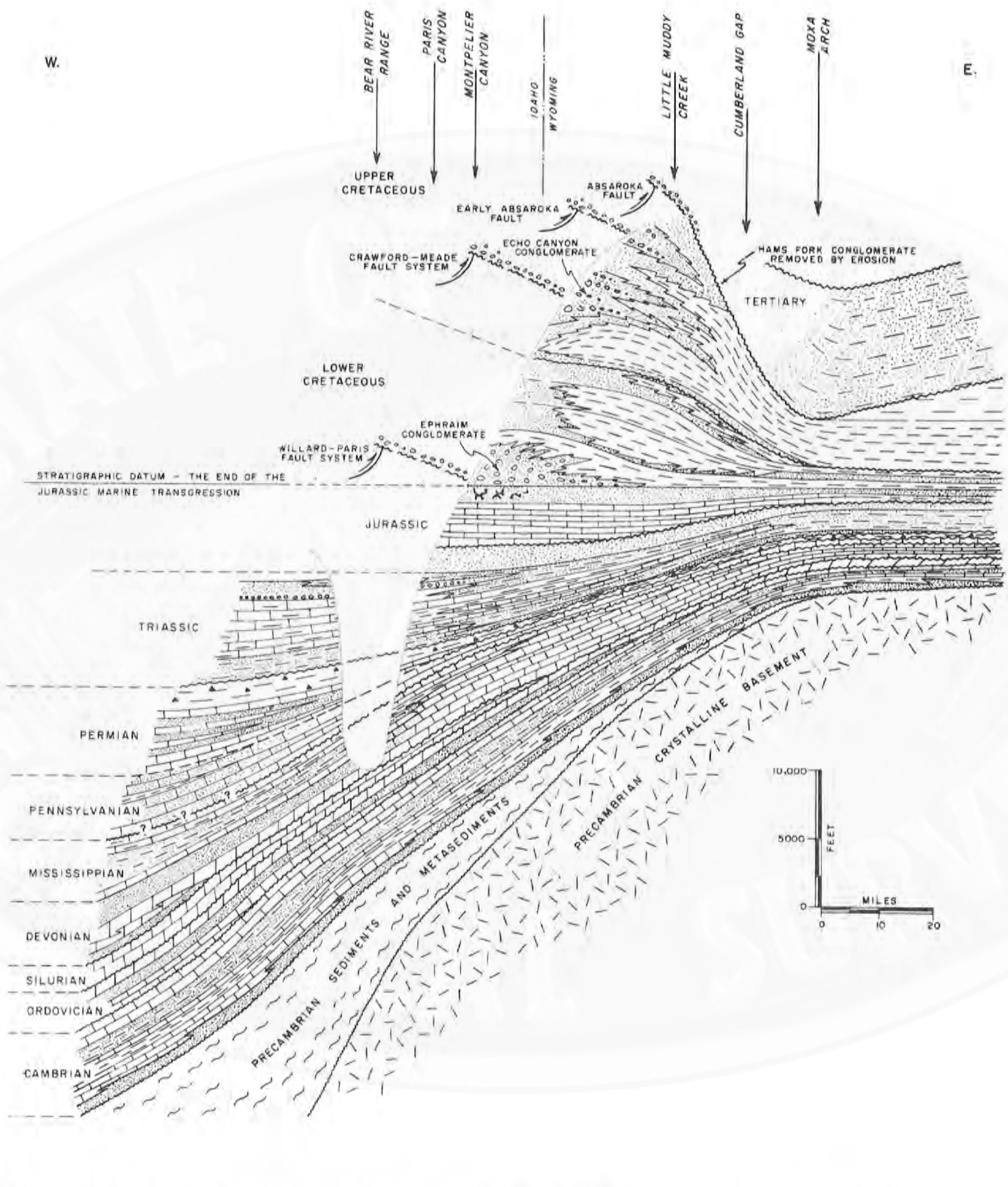


Figure 4. Regional cross section across the southeast Idaho and western Wyoming portion of the overthrust belt. Modified from Hayes (1976).

coincident with the former Paleozoic miogeosynclinal depocenter. Maximum thicknesses reached approximately 18,000 feet in the Upper Cretaceous depocenter (Monley, 1971). Syntectonic conglomeratic sequences once again serve to record initial movement on progressively younger thrust systems (Figure 4). Examples include the Echo Canyon Conglomerate [Crawford-Meade movement], the unnamed conglomerate in the Little Muddy Creek area [early Absaroka movement], and the Hams Fork Conglomerate [latest Absaroka movement] (Royse and others, 1975). As in the Lower Cretaceous, there is considerable thinning to the east along with a shift to transitional marine and marine sedimentation on the western edge of the Green River Basin. Preserved thicknesses to the east of the depocenter range from 8,000 feet to 5,600 feet on the western edge of the Green River Basin, near La Barge (Monley, 1971). However, preserved thicknesses, especially in the area immediately to the east of the depocenter, are quite variable due to erosion during the Tertiary (Monley, 1971).

The withdrawal of the Lewis seaway toward the end of the Upper Cretaceous initiated predominantly continental deposition which continued into the Tertiary throughout this area (Blackstone, 1977). Tertiary deposits unconformably overlie Upper Cretaceous rocks and for the most part are poorly preserved within the overthrust belt area. Paleocene and Eocene clastics are thickest in the vicinity of the easternmost faults and in the Fossil Basin (Monley, 1971). These sediments are both synorogenic and postorogenic, and are an excellent source of data for determining the age of deformational activity in the overthrust belt. Lacustrine deposits of Eocene age occur intertongued with the Eocene clastics on the eastern edge of the overthrust belt and within Fossil Basin. These Eocene lacustrine deposits are associated with the development of Lake Gosiute in the Green River Basin (Blackstone, 1977). Tuffs indicating volcanic activity appear interbedded with Eocene rocks and persisted through the rest of the Tertiary (Monley, 1971). Normal and block faulting superimposed on older thrust faulted terrain during late Tertiary time produced grabens and half-grabens which were in turn filled with coarse conglomeratic debris (Lageson, 1980), all of which provides a tool for dating the faulting.

In summary, the depositional and tectonic history of the area began with the development of the Cordilleran geosyncline as a result of continental rifting during Precambrian time. A miogeosyncline developed with a depocenter in southeastern Idaho and a gently sloping shelf in Wyoming with the hinge lying on the Idaho-Wyoming border. The miogeosyncline received relatively continuous marine deposition from Late Precambrian to Late Jurassic. The Sevier orogeny, beginning in Late Jurassic time, elevated the area to the west of the miogeosyncline and destroyed it, forcing the depocenter to migrate eastward and creating basins on what had been the shelf or stable platform in Paleozoic time. Initial movement on the oldest thrust system began in Late Jurassic time, and pulses of thrusting continued throughout the Mesozoic, moving the depocenter further east. The "high" to the west became the primary source of sediments for the depocenter as deposition changed from primarily marine carbonates to continental sediments. Marine deposition was much thinner and concentrated further to the east. By Tertiary time, deposition had become almost totally orogenically controlled and continental in nature. In all, during Paleozoic and Mesozoic time, 50,000 to 100,000 feet of sediments were deposited in the western portion of the area and between 12,000 and 16,000 feet in the eastern portion. Tertiary thicknesses are quite variable because deposition was much more local in nature and much of it has been removed by erosion. For more detailed discussions of the depositional history of the area, see articles by Armstrong and Oriel (1965) and Monley (1971).

STRUCTURAL GEOLOGY

The Cordilleran fold and thrust belt has been divided longitudinally into at least nine salients (Figure 1). In addition, the Cordilleran fold and thrust belt has been divided transversely into two parts, each having a different structural style. These are the frontal or eastern portion and the hinterland or western portion.

The frontal part is characterized by low-angle thrust faults, décollements, imbricate thrust faults, tear faults, listric normal faults, and folds that have concentric and kink geometries. Relative tectonic movement was from west to east, moving younger rocks eastward from their sites of deposition. Geometrically, the frontal portion has been described as thin-skinned and disharmonic with the allochthon or sedimentary section displaced eastward over the autochthon or Precambrian basement complex on a regional décollement in Cambrian strata (Lageson, 1980). Blackstone (1977) indicates that the Precambrian basement slopes gently westward with a regional dip of 2° to 5°, which must be the maximum dip of the deep-seated décollement thrust surfaces if it is assumed that the basement is not involved in the faulting. The overthrust belt does, however, differ from most other orogens of similar structure in that regional metamorphism and igneous intrusion are not significant (Armstrong and Oriel, 1965).

The hinterland or western portion of the Cordilleran fold and thrust belt is actually the "core" of the orogen and is characterized by syntectonic felsic to intermediate intrusive rocks, metamorphosed sedimentary rocks, and reconstituted basement complex (Lageson, 1980). Included in the normal assemblage of structures are thrust faults, similar folds, superposed folds, asymmetric recumbent folds, penetrative cleavage, and various igneous and metamorphic lineations and foliations. In the western United States, the hinterland is represented by the Mesozoic batholiths of Idaho and Montana and "core complexes" of eastern Nevada, southern Idaho, and Utah (Armstrong and Hansen, 1966; Armstrong, 1978).

TECTONIC DIVISIONS IN THE IDAHO-WYOMING-UTAH SALIENT

Major thrust faults in the salient are west dipping and progressively younger toward the east. From east to west, the northern portion of the salient includes the Prospect, Darby, Absaroka, Meade, and Paris-Willard thrust faults, and the southern portion includes the Darby, Absaroka, Tunp, Crawford, and Paris-Willard thrust fault.

Blackstone (1977) proposed six major structural units for the Idaho-Wyoming-Utah salient. These, from east to west, are the eastern unit, central unit, Meade Peak unit, Cache allochthon unit, Farmington Canyon complex, and Charleston-Strawberry unit (Figure 5).

The eastern unit is bounded on the east by the Darby-Hogsback thrust fault and on the west by the Baldy Mountain-Tunp-Medicine Butte thrust faults. The unit includes the Jackson-Prospect, Darby-Hogsback, and Absaroka thrust faults. The northwest boundary of the unit is the Grand Valley extensional fault (Plate 1).

The central unit lies between the western margin of the eastern unit and the Meade Peak thrust fault on the west. It is characterized by long, sinuous folds developed primarily in rock units of Mesozoic age and extending for tens of miles along strike with large structural relief. The Caribou Range in Idaho contains several good examples of this type

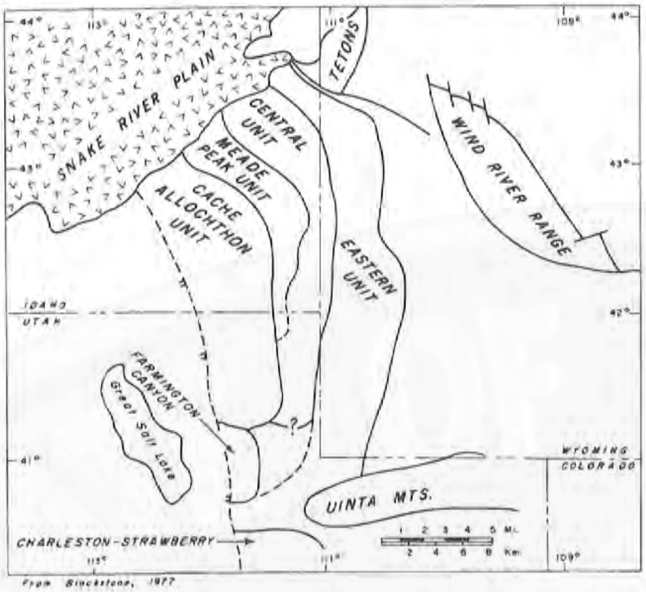


Figure 5. Location of major tectonic units within the Idaho-Wyoming-Utah salient of the overthrust belt as proposed by Blackstone (1977).

of structure (Black Mountain, Baldy Mountain, and Big Elk anticlines).

Bounding faults for the Meade Peak unit are the Meade Peak thrust on the east and the Paris thrust fault on the west. Broad, open folds in Paleozoic rocks characterize this unit. Commercial-grade phosphate deposits occur in the Permian Phosphoria Formation outlining the synclines of the unit.

The Cache unit is bounded on the east by the Paris-Willard-Woodruff thrust fault and probably underlies an area to the west beneath the Great Salt Lake. The unit is displaced downward in its western portion by the Wasatch normal fault. The rocks within the unit include a thin basal Precambrian schist, the overlying Huntsville Group (late Precambrian), a thick section of Early Cambrian rocks, and a relatively thick section of Paleozoic rocks. East of Ogden, Utah, in the southwest part of the unit, these rocks are broadly folded, while on the eastern margin they are more strongly folded, especially near Bear Lake, Utah.

Immediately south of the Cache unit is the Farmington Canyon complex. The unit is composed of Precambrian crystalline basement, and, like the Cache unit, the western portion is displaced downward by the Wasatch normal fault. Crittenden (1972) considers the unit autochthonous; however, a more recent investigation (Lageson, 1980) indicates that it may be an allochthon in the hanging wall of the Absaroka thrust fault.

The Charleston-Strawberry unit is south of the Uinta Mountain structural axis and geographically is outside of the Idaho-Wyoming-Utah salient, but the structural styles are very similar. The Charleston and Strawberry thrust faults have placed Pennsylvanian and Permian rocks in the hanging wall over Triassic and Jurassic rocks in the footwall.

STRUCTURAL FEATURES OF THE IDAHO-WYOMING-UTAH SALIENT

Work by Royse and others (1975), Dahlstrom (1970), Price and Mountjoy (1970), and Bally and others (1966) has established a series of models of basic structural features characteristic of the Idaho-Wyoming-Utah salient of the overthrust belt. According to Royse and others (1975), these models include: (1) concentric folds, (2) décollements, (3) reverse faults, (4) tear faults, and (5) younger normal faults. The overall structural geology of the overthrust belt can be interpreted using these models.

Concentric folding is characteristic of low strain deformation at relatively low temperature and pressure. Under these conditions there is no flowage and the thickness of any individual bed is constant whether it is on the crest, flank, or trough of a fold (Dahlstrom, 1970). If this model is correct, cross-sections can be constructed utilizing the concept of volumetric balance; i.e., profiles of deformed sediments can be restored to an undeformed state without creating large unexplained voids and excess rock. According to Blackstone (1977), folding in the Idaho-Wyoming-Utah salient is quite extensive, occurring in the rocks above the décollement surfaces only (i.e., not involving the basement). The intensity of folding varies according to the age of the rocks involved. For example, the folds in the Paleozoic rocks of the Meade Peak unit are more open and less sinuous than those in the Mesozoic rocks in the footwall.

With a few exceptions, the folds characteristic of the salient are asymmetric to the east. However, Blackstone (1977) and Rubey (1973) point out that in the Salt River Range near Afton, Wyoming, there are large folds which are asymmetric to the west, probably because a lack of space to expand to the east in this portion of the salient forces rock units to pile up to allow for stratal shortening.

On the basis of seismic, aeromagnetic and surface data, the older Precambrian crystalline basement underlying the salient is not deformed except for a broad warping and is, therefore, structurally detached from the sedimentary cover by regional "décollement" (Royse and others, 1975). Since, to date, no wells in the Idaho-Wyoming-Utah salient reach basement, the depth to basement can only be estimated on the basis of an inferred stratigraphic section still underlying the wells of deepest penetration or on geophysical data (Blackstone, 1977). For example, at Church Buttes Field on the Moxa Arch, the basement is estimated to be only 14,000 feet below sea level, sloping to the west at approximately 2 degrees at least as far as the Wyoming-Utah border, where it probably is approximately 23,000 feet below sea level. At that point, the slope angle steepens to possibly 5 degrees, putting the basement at a potential maximum depth of up to 60,000 feet below sea level beneath the western portion of the salient. Acceptance of this model for the surface of the Precambrian basement then puts constraints on the slope of all deep-seated décollement surfaces, since the dip of such surfaces cannot be greater than the western slope of the basement surface (Blackstone, 1977). The actual basal detachment zone over most of the area probably lies within Cambrian shale and carbonate near the top of the crystalline Precambrian basement (on the basis of well, seismic, and surface control; Royse and others, 1975).

Dahlstrom (1970) equates the term "thrust fault" with "low angle reverse fault" and indicates that regionally the faults are low angle; however, locally they can dip quite steeply as a result of post-fault folding or imbrication as they approach the surface. Major thrust faults bound large panels of rock, termed "thrust sheets" by Dahlstrom. These thrust sheets are named for the lowest bounding fault. Major thrust faults of the Idaho-Wyoming-Utah salient can have stratigraphic throws of several thousand feet and can be traced laterally for tens of miles. Each thrust sheet contains subsidiary thrusts and imbricates, more numerous near the leading edge of the sheet. These subsidiary faults and imbricates dip steeply near the surface but tend to flatten as they join the underlying major fault or "sole fault."

Generally, major thrust faults cut upsection in the direction of tectonic transport, which is east or northeast in the salient. They also normally cut parallel to bedding in incompetent rocks (treads) and oblique to bedding in competent rocks (ramps), according to the model proposed by Royse and others (1975) and illustrated in Figure 6. [However, Allmendinger (1981) cites some exceptions in the Meade thrust plate in the northern Blackfoot Mountains of southeastern Idaho, where imbricate faults,

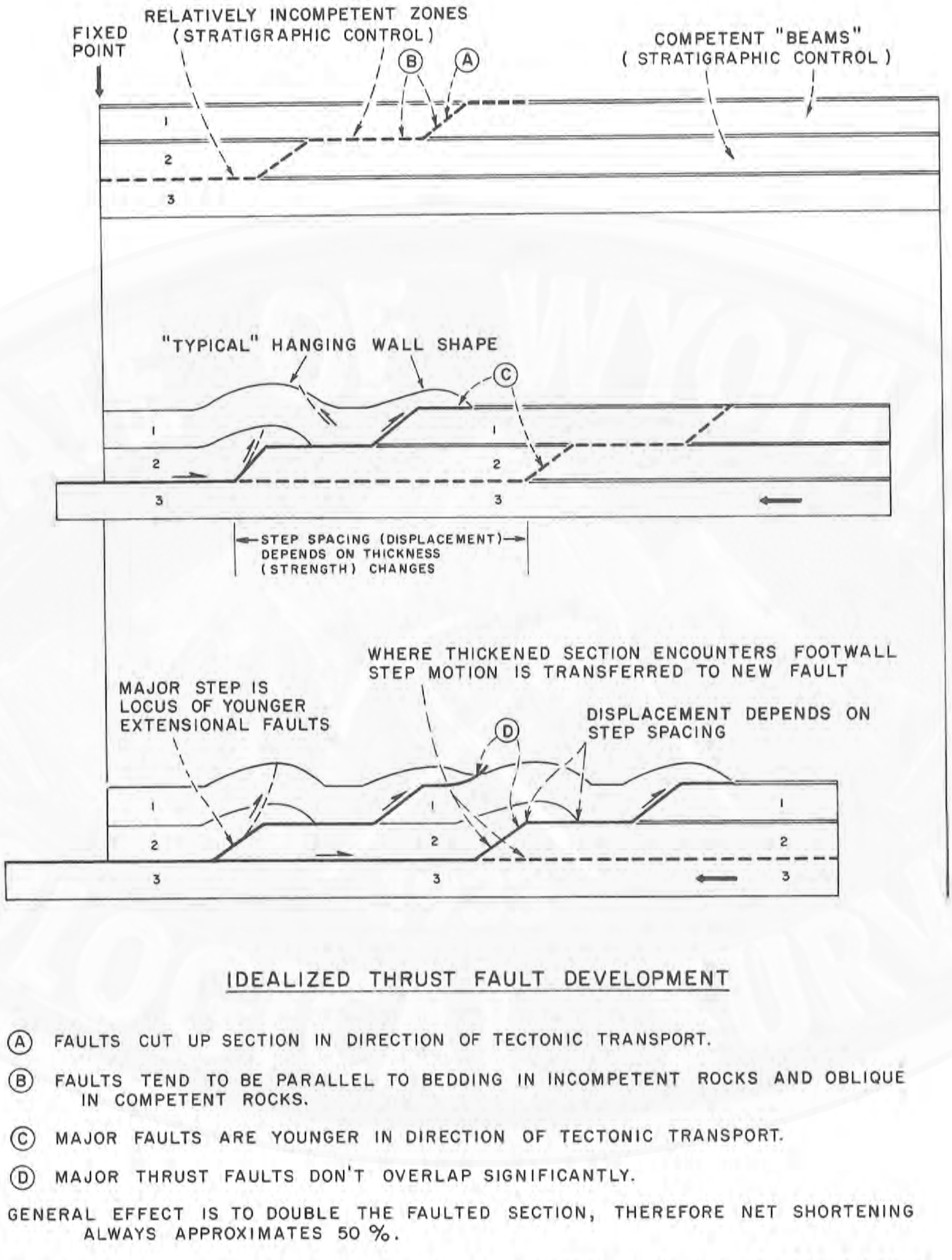


Figure 6. Model proposed by Royse and others (1975) to depict idealized thrust fault development.

formed in the later stages of deformation near the toe of the thrust sheet, locally cut down section in the direction of tectonic transport. In these examples, he also notes instances where relative competency of the rock units does not control stratigraphic levels of thrusting, as is normally the case. These exceptions probably resulted from responses to preexisting folds which tilted rocks steeply to the west on their western flanks.] The general effect of thrust faulting as shown in Royse's model is to double the faulted section, creating an overall stratal shortening which approximates 50 percent. In the central part of the salient, this acounts to about 50 to 60 miles of total tectonic transport by thrust faulting and folding (Blackstone, 1977). Thrust faults of the Idaho-Wyoming-Utah salient have been extensively mapped and details of fault attitude exist for many localities; these tend to support the model discussed above (see Table 1). Although the majority of the thrust faults dip to the west, Blackstone (1977) points out two examples of thrusts dipping to the east. A portion of the Meade thrust near Snowdrift Mountain dips to the east, probably as a result of folding of the original fault surface, and a portion of the Willard thrust dips to the east in the vicinity of Huntville, Utah, probably as a result of pre-Basin-Range folding and tilting of the Wasatch fault.

As mentioned previously, the major faults in the central and eastern structural units are considered to be décollements, with the sedimentary section detached from the Precambrian basement or younger sedimentary section detached from older sedimentary units (Blackstone, 1977). Royse and others (1975) indicate that, in addition to the major detachment in the Cambrian shales and carbonates immediately above the Precambrian basement, other preferred detachment positions exist in the incompetent Twin Creek Limestone and basal Mississippian rocks in the west, and within the Upper Cretaceous shale in the east. These zones of weakness most commonly occur in shales. Also, it appears that in the southwestern part of the salient in the Farmington Canyon complex, the crystalline basement may contain shear zones. The complex is bounded to the west by a fault which arises in the crystalline basement rather than as a décollement.

Dahlstrom (1970) defines a tear fault as "a species of strike-slip fault which terminates both upwards and downwards against movement planes that may be detachments or thrust faults or low angle normal faults." Tear faults can be divided into two major types within folded or thrust-filled terrain, (a) tears totally within one thrust sheet or group of thrust sheets and (b) tears that are part of the bounding surface of the deformed sheet. Blackstone (1977) and Royse and others (1975) note examples of the latter type of tear fault in the Idaho-Wyoming-Utah salient, referring to them as fault linkages or intersections. According to Royse and others (1975), thrust faults intersect where motion on a younger underlying thrust deforms and links with an overlying thrust across a transverse step or "tear." Examples following this model exist along the trace of the Absaroka fault zone (a) five miles west of Snider Basin (Absaroka-Commissary thrusts), (b) southeast of Alpine, Wyoming (Absaroka-Murphy-Firetrail thrusts), and (c) just north of Little Muddy Creek, south of Kemmerer, Wyoming. Blackstone (1977) speculates that a similar linkage may exist where the Mount Raymond-Absaroka fault surface possibly links up with the Charleston fault surface in the southern portion of the salient.

The youngest structural features in the Idaho-Wyoming-Utah salient are the normal or extension faults which were initiated by extensional forces beginning in the Eocene and active through the present (Armstrong and Oriel, 1965). Evidence indicates that there are two major types of normal faults within the

Table 1: Dips of major thrust surfaces.

Thrust Surface	Location	Dip
Absaroka Fault	Observation Peak Quadrangle U.S. Geological Survey GQ 1081	Dip varies from 70° to 18°
St. Johns Fault		Dip 23°W over large area
Darby Fault	Munger Mountain Quadrangle U.S. Geological Survey GQ 705	Dip 12°W at Munger Mt. Dip 36°W at Snake River
Absaroka Fault		Dip 20°W
Absaroka Fault	Ferry Peak Quadrangle U.S. Geological Survey GQ 1027	Dip 14°W at Snake River
Fire Trail Fault		Dip 36°W or less
Darby Fault	Blind Bull Mine- Mt. McDouglas Area	Dip 40° to 5°W at toe
Darby Thrust	Mt. Darby	Dip 12°W
Hogsback Thrust	Round Mountain Area	Dip 20° (subsurface data)

From Blackstone (1977)

salient, (a) normal faults restricted to individual thrust sheets and related to earlier thrust faults as propsed by Royse and others (1975), and (b) normal faults unrelated to individual thrust sheets in that they extend through the sedimentary section into the basement. Blackstone (1977) suggests that the model proposed by Royse and others (1975) may represent early response to extensional force with the second type becoming dominant when the frequency and magnitude of normal faulting increased, as in the Wasatch front fault. The model proposed by Royse and others (1975) is based on evidence that many of the major normal faults are high angle near the surface but tend to flatten with depth, soling into underlying older thrust planes. Movement occurs on a listric surface, concave upward, giving the hanging wall block rotational motion. The sediments in the rotated block retain original length and dip into the fault plane. The occurrence of these faults apparently coincides with the location of ramps or steps in the underlying thrust fault planes. Royse and others (1975) list examples, including the Grand Valley normal fault in the Alpine area and the Hoback fault south of Jackson, Wyoming, which appear to fit this model.

DATING MOVEMENT ON THE MAJOR THRUST FAULTS

Armstrong and Oriel (1965) estimate that deformation in the form of thrusting and concomitant uplift occurred episodically from Late Jurassic to early Eocene within the salient. Royse and others (1975) used a restored sedimentary section, emphasizing the age-dating of syntectonic conglomerates, as evidence of the time of thrusting for various major thrust faults.

Such evidence indicates that the Willard-Woodruff-Paris fault system, contained in the Cache allocthon unit, was the first fault system activated. Syntectonic basal conglomerates of the Ephraim Formation (see Figure 4) date the movement as Late Jurassic and Early Cretaceous.

Movement on the second set of faults, the Meade and Crawford Mountain, is documented by the Echo Canyon Conglomerate. However, data on the age are sparse, placing it as possibly late Niobrara (Williams and Madsen, 1959) or somewhat older and equivalent to the middle part of the Hilliard Shale (Royse and others, 1975).

Blackstone (1977) states that as deformation in the salient continued to shift eastward, a period of early movement on the Absaroka thrust is recorded by an unnamed coarse conglomerate in the Little Muddy Creek Area (Figure 4) considered equivalent to the upper Hilliard or lower Adaville Formation. Major movement on the Absaroka is documented by the Hams Fork Conglomerate Member of the Evanston Formation of late Late Cretaceous Lance age (Royse and others, 1975). Additional minor movement of the Absaroka probably occurred in the very late Late Cretaceous or early Paleocene (Dorr and others, 1977; Vietti, 1977; Worrall, 1977). Blackstone (1977) indicates that all movement during this period occurred on a single fault surface, the Absaroka and related faults, probably moving some older thrust faults eastward in a "piggyback" fashion on the younger fault surface.

The youngest thrust faults in the salient include the Jackson, Prospect, and Hogsback (Darby), which were dated by mapping by Oriel (1969), Rubey (1973) Rubey, Oriel, and Tracey (1975), Vietti (1977), and Worrall (1975). The Jackson-Prospect system initially moved during late Paleocene time and may have been active during middle early Eocene according to Armstrong and Oriel (1965). The Hogsback (Darby) thrust, according to Blackstone (1979) and Dorr and others (1977), moved during middle Paleocene time.

THE SOURCE OF ENERGY FOR THURST BELT DEFORMATION

The origin of the forces necessary to deform a geosynclinal rock succession into a fold and thrust belt remains a point of controversy which has been widely discussed in the geologic literature. Two basic concepts were originally proposed as driving forces for the deformation: (1) overthrusting by compression or "pushing" from the rear and (2) gravity sliding. However, beginning with Price (1971), less and less credence has been given to the concept of gravity sliding and the more recent concept of gravity spreading. Most workers feel that the dominant forces behind thrust belt deformation are compressional in nature, evolving around plate-boundary interaction. Lageson (1980) summarizes some of the more recent ideas and relates the deformation to plate convergence and west dipping, Benioff-type subduction, stating that although compressional forces dominate, the concepts of topographic slope and gravity spreading are also components of the convergent stress regime. This type of model also accounts for the total basement shortening of fold and thrust belt orogens.

OIL AND GAS EXPLORATION IN THE OVERTHRUST BELT

PRE-PINEVIEW EXPLORATION EFFORTS

The existence of petroleum in southwestern Wyoming has been recognized since the early 1800's. The first published account of the existence of oil was by W. Clayton in his "Latter Day Saints Emigrants' Guide," written in 1848, in which he describes a "tar" or "oil spring" in the Sulphur Creek area near Fort Bridger. The oil was sold in small quantities to the emigrants passing through on their way to Oregon and California. Veatch (1907) lists several oil springs associated with the Absaroka fault, including springs near Hilliard Flat, at Aspen Tunnel, the Carter Oil Spring three miles north of Aspen Tunnel, springs on the south branch of Twin Creek, and springs near Spring Valley.

The Union Pacific Railroad Company discovered the first oil field in the overthrust belt in 1900. While drilling a water well near one of their coal mines, they encountered oil in a sandstone unit at 491-493 feet, again at 573-581 feet, and at 1,148-1,170 feet (Veatch, 1907). This was the beginning of the Spring Valley-Aspen-Sulphur Creek area (Plate 1); and, to date, nearly 200 wells have been drilled, primarily shallow tests less than 2,000 feet deep. Unfortunately, these shallow fields have produced less than 250,000 barrels of oil over the years (Wyoming Oil and Gas Conservation Commission, 1980), and even counting some of the early production in Spring Valley Field which went unreported, these fields never really supplied much impetus for further exploration in the area. Recorded production came from the Frontier Formation, Aspen Shale, and Bear River Formation. It appears that some of the oil produced probably came from Eocene rocks, although no such production was reported.

The second wave of successful exploration occurred in what is termed the Big Piney - La Barge complex, which lies in a transition zone between the Green River Basin and the overthrust belt (see Figure 2). This producing area is located on a large anticlinal structure known as the La Barge Platform. La Barge Field was discovered in 1924. In 1952, an intensive gas development program was initiated by A.B. Belfer, founder of Belco Petroleum. Tip Top Field was discovered in 1951, Hogsback Field in 1959, and Dry Piney Field in 1970. These three fields are located on the edge of the overthrust belt, as shown in Figure 2, and are significant in that, to date, they have accounted for production totalling nearly 24 million barrels of oil and 581 million MCF (thousand cubic feet) of gas (Wyoming Oil and Gas Conservation Commission, 1980) from the Almy Formation (Evanston Formation), Adaville Formation, Frontier Formation, Aspen Shale, Bear River Formation, and the Nugget Sandstone. Discoveries of this size on the edge of the area logically stimulated interest in the overthrust belt proper.

Pre-Pineview oil and gas exploration in the Utah portion of the overthrust belt was relatively sparse: 15 unsuccessful wildcats were drilled. The first actual drilling in northern Utah's overthrust belt occurred in 1924 on a large surface anticline near Coalville (Plate 1). The Coalville anticline was found to be dry; however, the structure has been used by Mountain Fuel Supply Company as a gas storage area since 1960. Additional drilling occurred in the Cache Valley further north in Utah beginning in 1925, again with no success. In 1949, an interesting well was drilled near the Utah-Wyoming border on the Utah portion of the Yellow Creek anticline. It was deepened in 1952 into the Nugget Sandstone without shows; however, in 1976, Amoco drilled a higher position on the anticline in Wyoming and established gas and condensate production in the Twin Creek Limestone in what is now Yellow Creek Field (Hodgden and McDonald, 1977).

Idaho, at this time, has no oil and gas production; however, the overthrust belt of southeastern Idaho saw 26 unsuccessful tests drilled during the Pre-Pineview period. The majority of these wells were drilled during three periods, 1925-30, 1950-56, and 1963-66. These tests clustered around Driggs, Palisades Reservoir, east of Soda Springs, west of Soda Springs, and near Montpelier (see Plate 1). The first well drilled in Idaho, as well as the overthrust belt portion of Idaho, was drilled northwest of Driggs in 1903. It was the first in a series of wells drilled in the Teton Valley area. Although, to date, no successful wildcats have been drilled in Idaho, several of the early wells had significant enough oil and/or gas shows to sustain interest in the area. The area west of Driggs is an excellent example, with seven wells drilled between 1903 and 1974. One key to lack of success may be that most of the wells drilled were relatively shallow, with 16 of the 26 penetrating less than 5,000 feet and only one penetrating over 10,000 feet.

Note: The reader is referred to an excellent article on the history of exploratory drilling in the overthrust belt by Hodgden and McDonald (1977).

PRESENT WAVE OF EXPLORATION

As mentioned in the previous section, pre-Pineview exploration drilling was sparse and, with a few exceptions, quite shallow in the overthrust belt. Major oil companies showed limited interest after World War II; however, extensive exploratory efforts, especially by the "majors," did not commence until the discovery of Pineview Field in Utah in 1975. Activity quickly spread to adjacent Wyoming, and a series of spectacular discoveries in Wyoming and Utah resulted, dating from 1976 through the present (Figure 2 and Tables 2 and 3). To date, all discoveries have been found in similar geologic settings related to asymmetric folds in leading edges of major thrust plates. These relatively deep structures were not directly related to surface structures, and were discovered primarily with the aid of new high-resolution seismic techniques, including common depth point, digital

Table 2: Production statistics for Wyoming overthrust belt fields through December, 1980.

Field	Dis-covery date	Pro-ducing wells	Shut-in wells	Dec. 1980 production	1980 production	Cumulative production	Average per well	Incom-plete wells	Producing formations	Reserve esti-mate*
Ryckman Creek	1976	31	1	Oil-Bbls. 259,546 Gas-MCF 864,356	2,956,984 9,004,357	6,685,882 18,528,821	261 1,637	2	Nugget Thaynes	100 MM Bbls. 200 BCF
Yellow Creek	1976	21	1	Oil-Bbls. 34,467 Gas-MCF 172,621	419,520 5,265,476	1,056,116 20,257,139	52 265	28	Twin Creek Phosphoria	40 MM Bbls. 300 BCF
Clear Creek & Painter Reservoir	1977	32	13	Oil-Bbls. 354,294 Gas-MCF 1,989,857	3,349,400 17,311,104	5,234,528 26,252,127	357 2,005	26	Nugget	198 MM Bbls. 835 BCF
Red Canyon	1980	-	1	none	none	none	-	-	Weber	-
Whitney Canyon - Carter Creek	1978/ 1979	3	6	Oil-Bbls. 4,461 Gas-MCF 130,069	24,025 133,009	28,223 133,009	49 1,398	43	Thaynes Phosphoria Weber Mission Canyon Lodgepole Darby Bighorn	115 MM Bbls. 5,300 BCF
Glasscock Hollow	1980	1	-	Oil-Bbls 1,345 Gas-MCF 9,300	1,345 9,300	1,345 9,300	- -	8	Nugget	- -
Painter Reservoir East	1980	2	2	Oil-Bbls. 5,197 Gas-MCF 600	5,197 600	5,197 600	- -	7	Nugget	98 MM Bbls. 765 BCF
Anschutz Ranch East	1980	1	-	Oil-Gas -	-	-	-	-	Nugget	800-1,200 MM Bbls. oil equivalent
Thomas Canyon	1981	t	-	Oil-Gas -	-	-	-	-	Phosphoria Madison	-
Woodruff Narrows	1981	1	-	Oil-Gas -	-	-	-	-	Bighorn	-
TOTALS		92	24	829,310 Bbls. 3,166,803 MCF	6,756,471 31,623,846	13,011,291 65,181,006		114		

BOPD = Barrels of oil per day, MCFPD = 1,000 cubic feet per day, MCF = 1,000 cubic feet, t = testing, Bbls. = billion barrels, MM Bbls. = million barrels, BCF = billion cubic feet.

* For sources see discussion in text.

Modified from Wyoming Oil and Gas Conservation Commission

Table 3: Production statistics for Utah overthrust belt fields through September, 1980.

Field	Discovery date	Producing wells	Shut-in wells	Sept. 1980 production	Average per field	1979 production	Cumulative production	Incomplete wells	Producing formations	Reserve estimate*
Anschutz Ranch	1978	0	9	none reported				2	Twin Creek Nugget	15 MM Bbls. 49 BCF
Anschutz Ranch East	1980	0	1	none reported				4	Nugget	
Cave Creek	1980	0	1	none				0	Phosphoria Weber Madison	
Elkhorn	1977	1	1	Oil Bbls. 404	13	28,312	179,079	0	Twin Creek	14 MM Bbls. 6 BCF
				Gas-MCF 27		7,572	66,328			
Hogback Ridge	1977	1	0	Gas-MCF 64,689		2,418,839	5,258,202	0	Dinwoody Phosphoria	194 BCF
Lodgepole	1977	4	2	Oil-Bbls. 7,432	248	90,906	257,911	0	Twin Creek Nugget	18 MM Bbls. 6 BCF
				Gas-MCF 1,324		26,988	65,383			
Lodgepole South	1978		1	none					Kelvin	
Pineview	1975	30	9	Oil-Bbls. 241,670	8,056	3,872,304	16,247,955	0	Kelvin Stump Twin Creek Nugget	71 MM Bbls. 71 BCF
				Gas-MCF 298,449		4,213,109	16,567,596			
TOTALS		35	23	Oil-Bbls. 249,506	8,317	3,991,522	16,684,945	6		118 MM Bbls. 326 BCF
				Gas-MCF 364,489		6,666,508	21,957,509			

*Figures from Oil and Gas Journal, May 12, 1980. BOPD = barrels of oil per day, MCF = 1,000 cubic feet, BCF = billion cubic feet, MM Bbls. = million barrels.

Source: Ritzma (1981)

data recording, and computer processing techniques.

Pineview Field, Utah

Pineview Field is located in T.2N., R.7E., Summit County, Utah, approximately 40 miles east of Salt Lake City and seven miles from the southwest corner of Wyoming (Figure 2 and Plate 1). The first test of the seismically defined Pineview structure was drilled by the Oxy-Amoco-Sun group late in 1971. The Nugget Sandstone exhibited oil shows; however, a drillstem test of the zone recovered water and the well was abandoned. (American Quasar Petroleum reentered the well in 1977 and recompleted it as an oil well producing from the Twin Creek Limestone). The actual discovery well (#1 Newton Sheep Co.) was completed up-dip from the initial test, in NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 4, T.2N., R.7E., by American Quasar Petroleum, Energetics Incorporated, and North Central Oil Company on a farmout from the Oxy-Amoco-Sun group early in 1975. The well was drilled to a total depth of 14,500 feet and completed in the Jurassic(?) and Triassic(?) Nugget Sandstone at a depth of 9,928 feet for 540 barrels of oil and 270 MCF of gas per day. Subsequently, production was established in the Jurassic Twin Creek Limestone, Jurassic Stump Sandstone, and Cretaceous Kelvin Formation. A discussion of the petrology and regional character of these producing units appears below.

On the basis of development drilling within the field, the structure can be described as a faulted anticline, asymmetric to the east, in the hanging wall of the Tunp thrust fault (Figure 7). The structure above the Twin Creek and Nugget is considerably more complex as a result of faulting and salt diapirism associated with the Jurassic Preuss salt section. Immediately below the Triassic rocks in the hanging wall, Cretaceous rocks are encountered in the footwall, dipping west.

Structural closure is in excess of 1,000 feet, and the structure is nearly full of oil to a seismically defined spill point on the north flank (Conner and Covlin, 1977). In the main pool, the Twin Creek and Nugget share a nearly common oil/water contact which ranges from 3,400 to 3,500 feet below sea level. No information is available on the Kelvin and Stump oil/water contacts. The Nugget Sandstone reservoir has an average pay thickness of 160 feet, average porosity of 10 percent, and permeability averaging 3 millidarcies. The Twin Creek Limestone reservoir ranges from 16 to 100 feet in pay thickness, and has 3 percent porosity and an estimated 30 millidarcies permeability; the porosity and permeability result almost totally from fracturing of the limestone. The Stump Sandstone reservoir averages 40 feet in thickness, 13 percent porosity, and 30 millidarcies permeability. The Kelvin Formation sandstone reservoir has a pay thickness ranging from 21 to 48 feet, an average porosity of 6 percent, and an undetermined permeability related to fracturing in the sandstone. The productive area of the field is estimated at 1,600 acres (Blazzard, 1979c). Oil and gas analyses are shown for Pineview Field in Appendix A.

As of September 1980, 30 producing oil wells within the field accounted for cumulative production of 16,247,955 barrels of oil and 16,567,596 MCF of gas (Table 3). Pineview's reserves are estimated 71 million barrels of oil and 71 million MCF of gas (Ritzman, 1981). Earlier reserve estimates of 135 million barrels of oil and 135 million MCF of gas were projected by Petroleum Information Corporation in their 1978 publication on the overthrust belt. The primary operator in the field has been American Quasar Petroleum, although some of the wells were drilled by Champlin Petroleum. Other partners include Amoco Production, Energetics, Sun Oil,

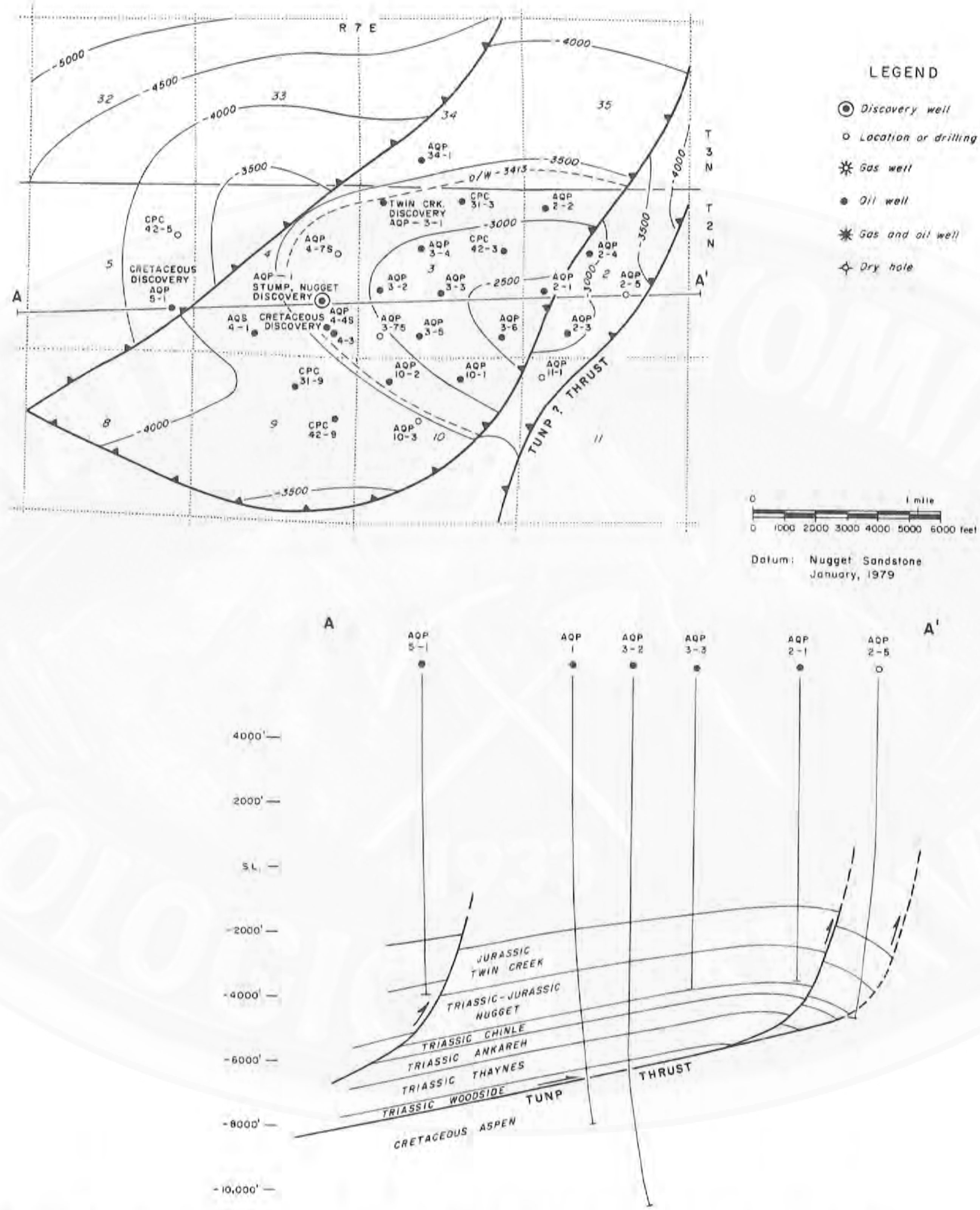


Figure 7. Structure contour map and cross section for Pineview Field. Map from Blazzard (1979) and cross section modified from Conner and Covlin (1977).

and North Central Oil (Petroleum Information, 1978). Oil produced in Pineview Field is purchased by Amoco Pipeline Company.

Ryckman Creek Field, Wyoming

Ryckman Creek Field is located in the southwestern corner of Wyoming, approximately 15 miles northeast of the town of Evanston (Figure 2 and Plate 1). Amoco Production Company began drilling the discovery well (Amoco No. 1, Champlin 224 Amoco A) in NW¼NW¼ sec. 19, T.17N., R.118W. in December 1975 on a seismically defined subthrust anticlinal feature. However, the well was completed in the hanging wall of the Absaroka thrust in September 1976, flowing 280 barrels of oil and 310 MCF of gas per day from the Jurassic(?) and Triassic(?) Nugget Sandstone at a depth of 7,860 feet, after plugging back from the total depth of 14,795 feet. Since that time, additional gas production has been established in the Triassic Thaynes Limestone in the #23 Ryckman Creek well which was dually completed in the Nugget and Thaynes in February, 1980.

The field is probably 90 percent developed, and the geometry of the structure is fairly well understood. The structure can be described as an overturned anticline, asymmetric to the east, involving Upper Triassic through Lower Cretaceous rocks in the hanging wall and leading edge of the Absaroka thrust. The fold is cut by at least three thrust faults, the basal Absaroka thrust and two smaller faults higher up in the fold, as illustrated in the cross section in Figure 8 (Kelly and Hine, 1977). Royse and others (1975) indicated that the Absaroka thrust is low angle with eastward displacement of over 17 miles as a result of movement in Late Cretaceous time. This movement was also responsible for the creation of the Ryckman Creek structure and the two associated thrusts. The lower minor thrust fault is probably an imbricate of the Absaroka thrust and is shown cutting the Nugget surface on the right or east side of the structure (see map in Figure 8). The upper minor fault, gliding in the basal Preuss salt, has much greater displacement than the lower minor fault, and is probably not an imbrication of the Absaroka thrust. The basal Pruess salt is absent at the crest of the structure, but present on the west flank. Its absence probably results from faulting, nondeposition, or flow of the salt off the crest (Kelly and Hine, 1977). Cretaceous rocks are present in the footwall of the Absaroka thrust immediately beneath the structure.

The Nugget Sandstone is the primary producing reservoir in the field. The oil/water contact is 450 feet below sea level and the gas/oil contact is 235 feet below sea level. Pay thickness averages 300 feet, porosity 15 percent, and permeability 34 millidarcies. A Cretaceous source is indicated for the oil (Kelly and Hine, 1977). Reservoir characteristics and oil and gas analyses for the Nugget are shown in Appendix A. No information is available concerning the Thaynes reservoir. A discussion of the petrology and regional character of these producing formations appears below. The overall productive area of the field is 1,000 acres (Kelly, 1979).

As of December, 1980, 31 producing wells and 1 shut-in well within Ryckman Creek had a cumulative production of 6,685,882 barrels of oil and 18,528,821 MCF of gas (Table 2). The gas produced has been re-injected in the reservoir to maintain reservoir pressure in an effort to maximize recovery. Eventually, nitrogen injection will replace the injection of the gas being produced. Reserves have been estimated at 100 million barrels of oil and 200 million MCF of gas (Cummings, 1978). Kelly (1979) estimates primary recovery at 40-50 million barrels of oil and 100-150

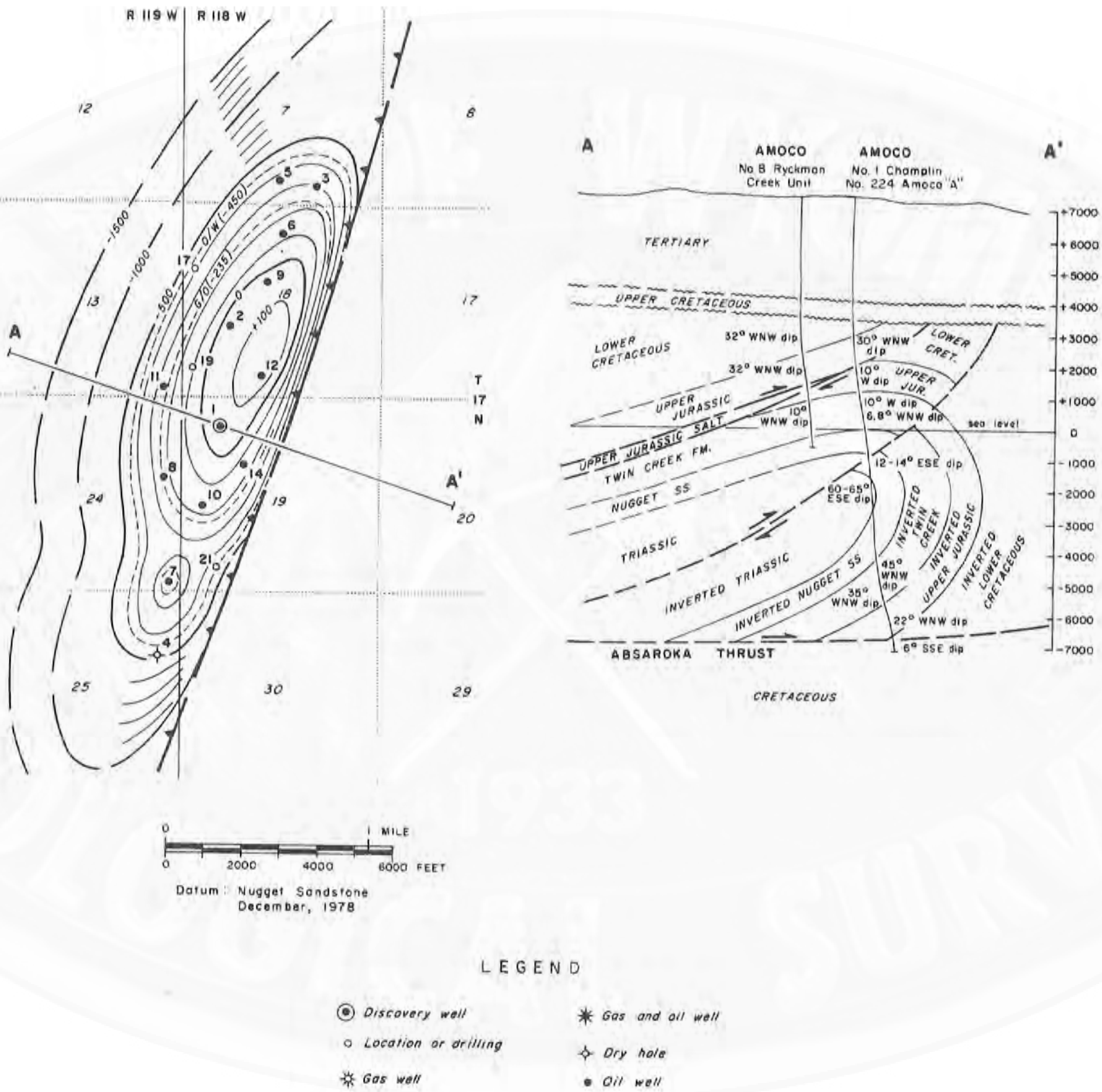


Figure 8. Structure contour map and cross section for Ryckman Creek Field. Map from Kelly (1979) and cross section courtesy of Amoco Production Company.

million MCF of gas. Amoco Production is the operator of the field with working interests split as follows: Amoco - 37.5 percent, Chevron - 50 percent, and Champlin 12.5 percent. Amoco Production Company purchases all oil produced in Ryckman Creek Field; 50 percent of the gas (Chevron's share) was recently purchased by Northwest Pipeline.

Yellow Creek Field, Wyoming

Yellow Creek Field is located in the southwest corner of Wyoming, immediately southwest of the town of Evanston (Figure 2 and Plate 1). The first well (#1 Hatch) on the Yellow Creek structure was drilled by Utah Southern in SE¼SW¼ sec. 28, T.6N., R.8E., in 1950, just across the Wyoming line in Summit County, Utah. It was re-entered and deepened in 1952 to test the Twin Creek and Nugget, again, without success, and was plugged after reaching a total depth of 8,637 feet. It wasn't until twenty-four years later, in 1976, that Amoco drilled the discovery well (#1 Amoco-Gulf WI Unit), higher on the structure in Wyoming in SW¼SW½ sec. 2, T.14N., R.121W. Amoco completed this discovery well in July 1976 for 2,750 MCF of gas and 120 barrels of condensate per day at 6,262 feet from the Jurassic Twin Creek Limestone. Subsequently, gas production has been established in the Jurassic(?) and Triassic(?) Nugget Sandstone (B-1 Evanston Townsite Unit Well), the Permian Phosphoria Formation, and Permian-Pennsylvanian Weber Sandstone (#1 Urroz WI Unit Well). Once again, the primary exploration method leading to the discovery was seismic.

Similar to the two previous discoveries, the Yellow Creek structure is an anticlinal fold, asymmetric to the east, in the leading edge of the Tunp thrust hanging wall. The Tunp thrust is shown on the right or east side of the structure in Figure 9. Trending northeast to southwest, the structure is over six miles long. There is no significant imbricate faulting.

The primary producing horizon in the field is the Twin Creek Limestone. According to available information, no gas/water or oil/water contact has been determined. The reservoir is fracture controlled, and as a result the most prolific wells have been located on the crest of the structure where the fracturing is most extensive. The Twin Creek has an average pay thickness in Yellow Creek Field of 158 feet, average porosity of 1.7 percent, and fracture-controlled permeability from 0.01 to 0.11 millidarcies (Moklestad, 1979). Since the Nugget, Phosphoria, and Weber reservoirs are relatively undeveloped, no information is available concerning reservoir properties. Reservoir properties and gas analyses for the Twin Creek reservoir are listed in Appendix A. A discussion of the petrology and regional character of the Twin Creek Limestone appears below.

As of December, 1980, Yellow Creek Field contained 21 producing wells and 1 shut-in well, accounting for cumulative production of 1,056,116 barrels of oil and 20,257,139 MCF of gas (Table 2). No recent estimate of recoverable reserves is available; however, Cummings (1978) estimated reserves at 40 million barrels of oil and 300 million MCF of gas. Moklestad (1979) estimated primary recovery at 53 million MCF of gas and 8 million barrels of oil. The major operators in the field are Amoco, Mountain Fuel, and Mesa Petroleum. Additional partners include Chevron, Gulf, Cities Service, and Burton/Hawks. Mountain Fuel is the purchaser of the gas produced in Yellow Creek Field.

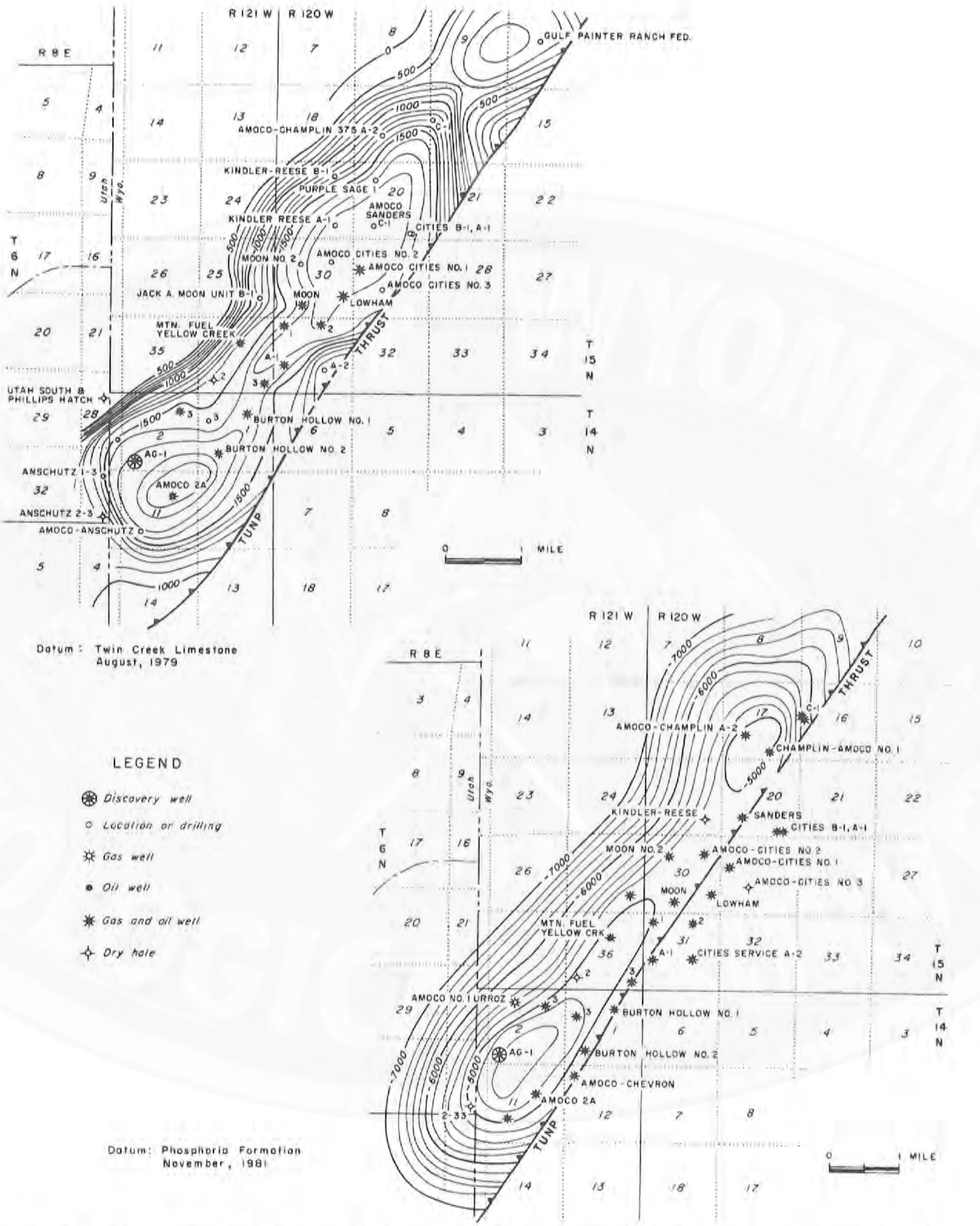


Figure 9. Structure contour maps drawn on the Twin Creek Limestone and Phosphoria Formation for Yellow Creek Field. Maps courtesy of Amoco Production Company.

Whitney Canyon - Carter Creek Field, Wyoming

Whitney Canyon - Carter Creek Field, probably the most significant discovery in the overthrust belt to date, is located approximately 13 miles north-northeast of Evanston, in Uinta and Lincoln Counties. Amoco Production completed the discovery well, #1 Amoco-Chevron-Gulf WI Unit ($SW\frac{1}{4}SE\frac{1}{4}$ sec. 18, T.17N., R.119W.), in August 1977 for 4,713 MCF of gas and 196 barrels of condensate per day at 9,178 feet from the Triassic Thaynes Limestone. The Carter Creek area, which has been combined with Whitney Canyon, was discovered by Chevron in July 1979 with completion of the #1-32 Chevron Federal well in $SW\frac{1}{4}SW\frac{1}{4}$ sec. 32, T.19N., R.119W., in Lincoln County. This well had initial production of 11,415 MCF of gas and 347 barrels of oil per day from the Pennsylvanian Weber Sandstone and Mississippian Madison Limestone. In addition, Whitney Canyon - Carter Creek Field now produces, or has indicated production, from the Triassic Dinwoody Formation, Permian Phosphoria Formation, Devonian Darby Formation, and Ordovician Bighorn Dolomite.

The Whitney Canyon - Carter Creek structural trend extends nearly north-south for almost 15 miles. As with previous discoveries, the structure has no surface expression and, as a result, was drilled primarily on the basis of seismic evidence (Figure 10). The anticlinal fold, involving Ordovician through Jurassic rocks, is asymmetric to the east and is located in the hanging wall of the Absaroka thrust. The fold is separated from the Ryckman Creek strucutre to the east by the Tunp thrust, as illustrated in Figures 10 and 11 (Judd and Sacrison, 1979). The folding and location of the

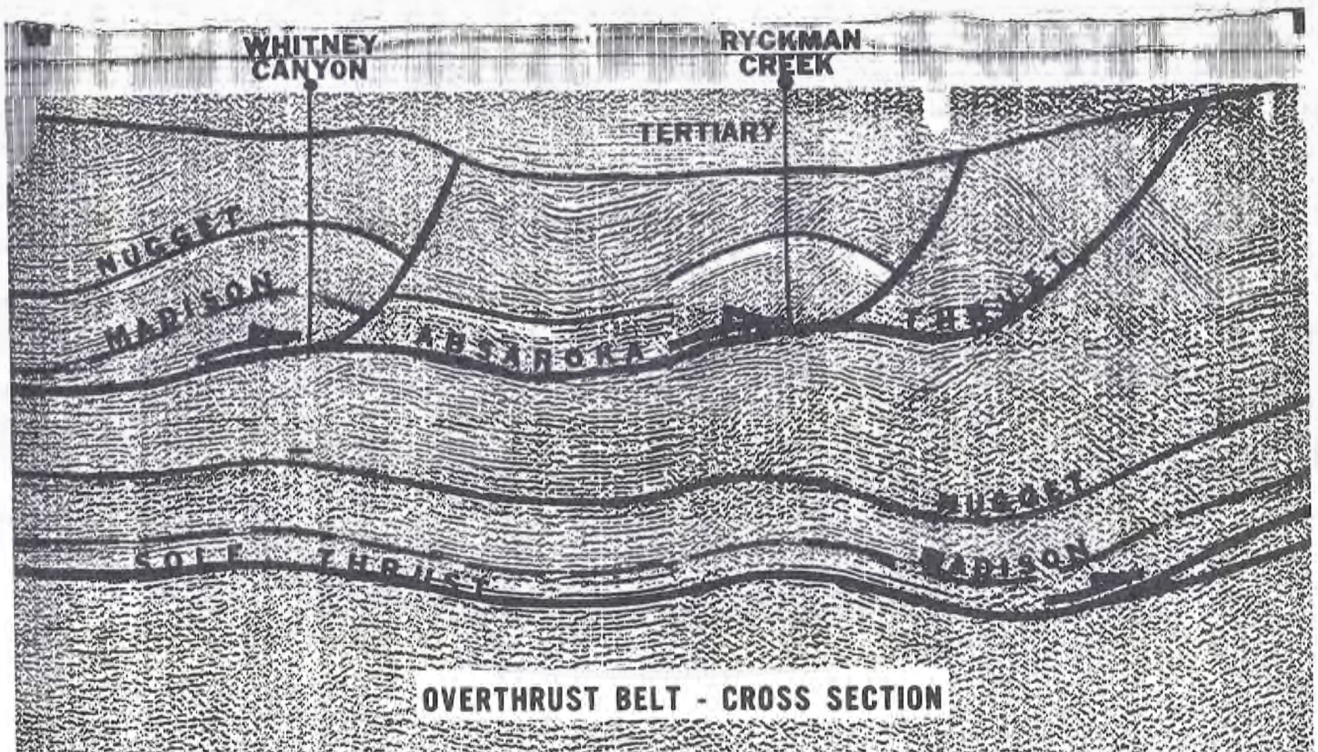


Figure 10. Seismic line through Whitney Canyon and Ryckman Creek Fields (courtesy of Amoco Production Company).

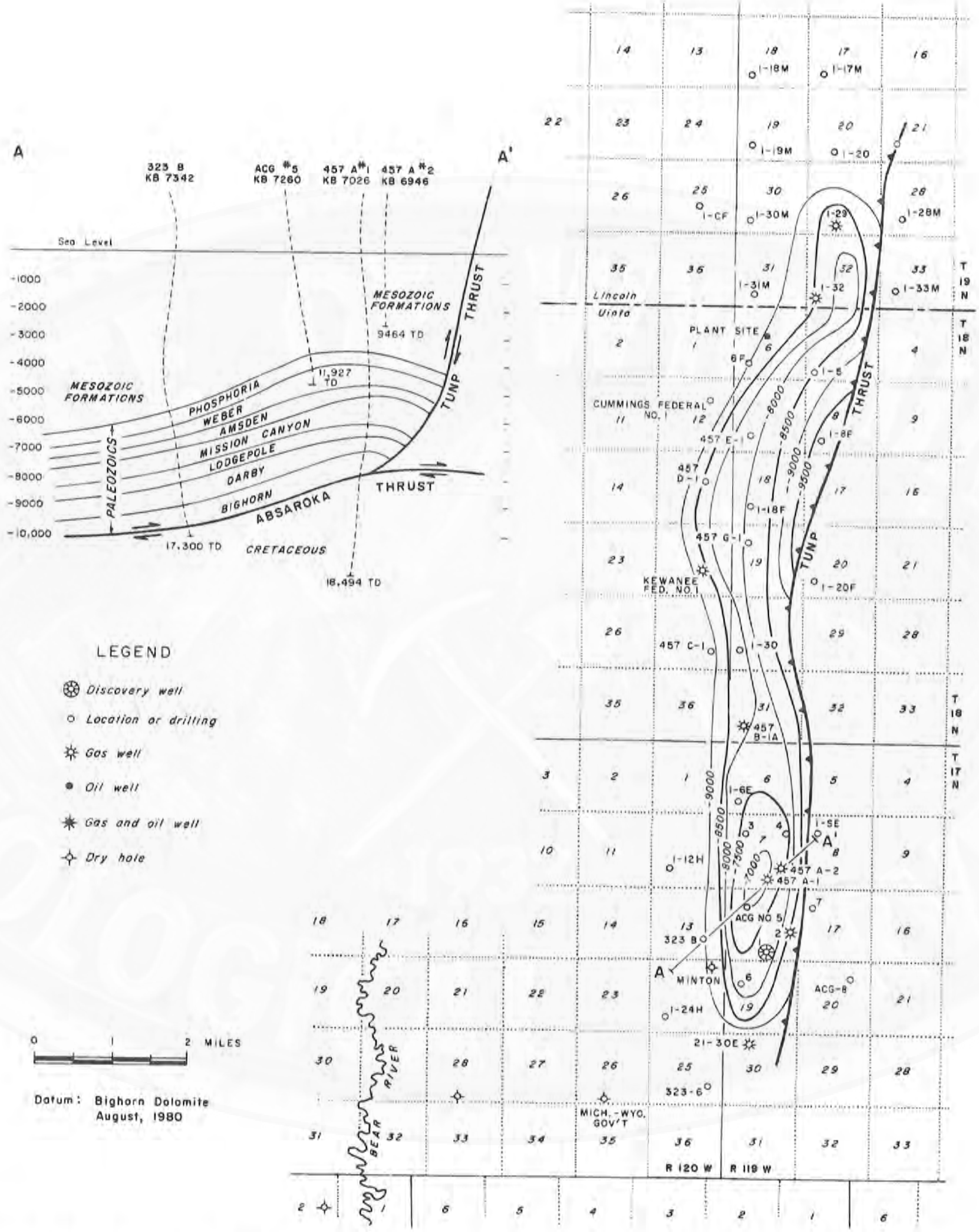


Figure 11. Structure contour map and cross section for Whitney Canyon Field. Map and cross section courtesy of Amoco Production Company.

Tunp thrust apparently is related to a "step" in the Absaroka thrust as it climbs upsection in the underlying Cretaceous rocks, an excellent example of the model proposed by Royse and others (1975; see p. 13). The carbonate reservoirs which include the Bighorn, Madison, Phosphoria, and Thaynes have average porosities from 2 percent in the Bighorn to 10 percent in the Madison. No permeability averages were available; permeability is dependent upon fracturing and is quite variable. Average pay thicknesses include 88 feet in the Thaynes, 100 feet in the Madison, and 30 feet in the Bighorn. The Weber Sandstone reservoir has an average porosity of 6 percent and permeability of 10-20 millidarcies. Additional reservoir parameters and representative gas analyses are included in Appendix A. No reservoir information was available on the Dinwoody and Darby reservoirs. A regional and petrographic discussion of the producing or potentially producing horizons appears below.

As of December 1980, Whitney Canyon - Carter Creek Field contained 3 producing and 6 shut-in wells with cumulative production of 133,009 MCF of gas and 28,223 barrels of oil or condensate (Table 2). The gas, except that produced from the Thaynes, is very high in H_2S, and production is for the most part shut in awaiting construction of a 250-million-cubic-feet-per-day sulfur treatment plant by Amoco and a 150-million-cubic-feet plant by Chevron (see discussion of transportation and treatment facilities below). Amoco conservatively estimated reserves for the Whitney Canyon - Carter Creek Complex at 5.3 billion MCF of gas and 115 million barrels of oil and gas liquids (Oil and Gas Journal, 1980b). These gas reserves, when added to the present total for all of Wyoming (4.7 billion MCF), will more than double the state's gas reserves. The major operators of the field are Amoco Production and Chevron, and Champlin and Gulf also hold owner interests. According to a January 1980 article in Petroleum Information's Rocky Mountain Region Report, Amoco has signed an agreement to supply 1.5 billion MCF of gas to Peoples Gas of Chicago over a 15 year period upon completion of the Amoco gas processing facility. No other information is available about purchasers of gas or liquids from the field.

Hogback Ridge Field, Utah

The most northerly discovery to date is Hogback Ridge Field, approximately 12 miles north of Randolph, Utah in Rich County (Figure 2 and Plate 1). The discovery well, #20-1 Hogback Ridge (NE¼SE¼ sec. 20, T.13N., R.7E.), was dually completed in October, 1977, flowing 22,400 MCF of gas per day from the Triassic Dinwoody Formation below 9,468 feet and 9,967 MCF of gas per day from the Permian Phosphoria Formation below 10,070 feet. The Phosphoria production is shut in awaiting construction of processing facilities for the high sulfur gas.

The Hogback Ridge structure is an anticlinal fold, asymmetric to the east, in the hanging wall of the Crawford thrust and bounded on the east by an imbricate thrust. Additional thrusting occurs in the Triassic Woodside above the productive portion of the structure (Figure 12).

Hogback Ridge Field contains only one producing well, with cumulative production of 5,258,202 MCF of gas through September 1980 (Table 3). Reserves are estimated at 194 million MCF of gas (Ritzma, 1981). The gas produced is purchased by Northwest Pipeline (50 percent) and Mountain Fuel Supply (50 percent). American Quasar Petroleum is the operator with working interest partners including Louisiana Land and Exploration, Cities Service, Ram Petroleum, Energy Reserves Group, W.R. Grace, Patrick Petroleum, and Gulf Oil (Petroleum Information, 1978).

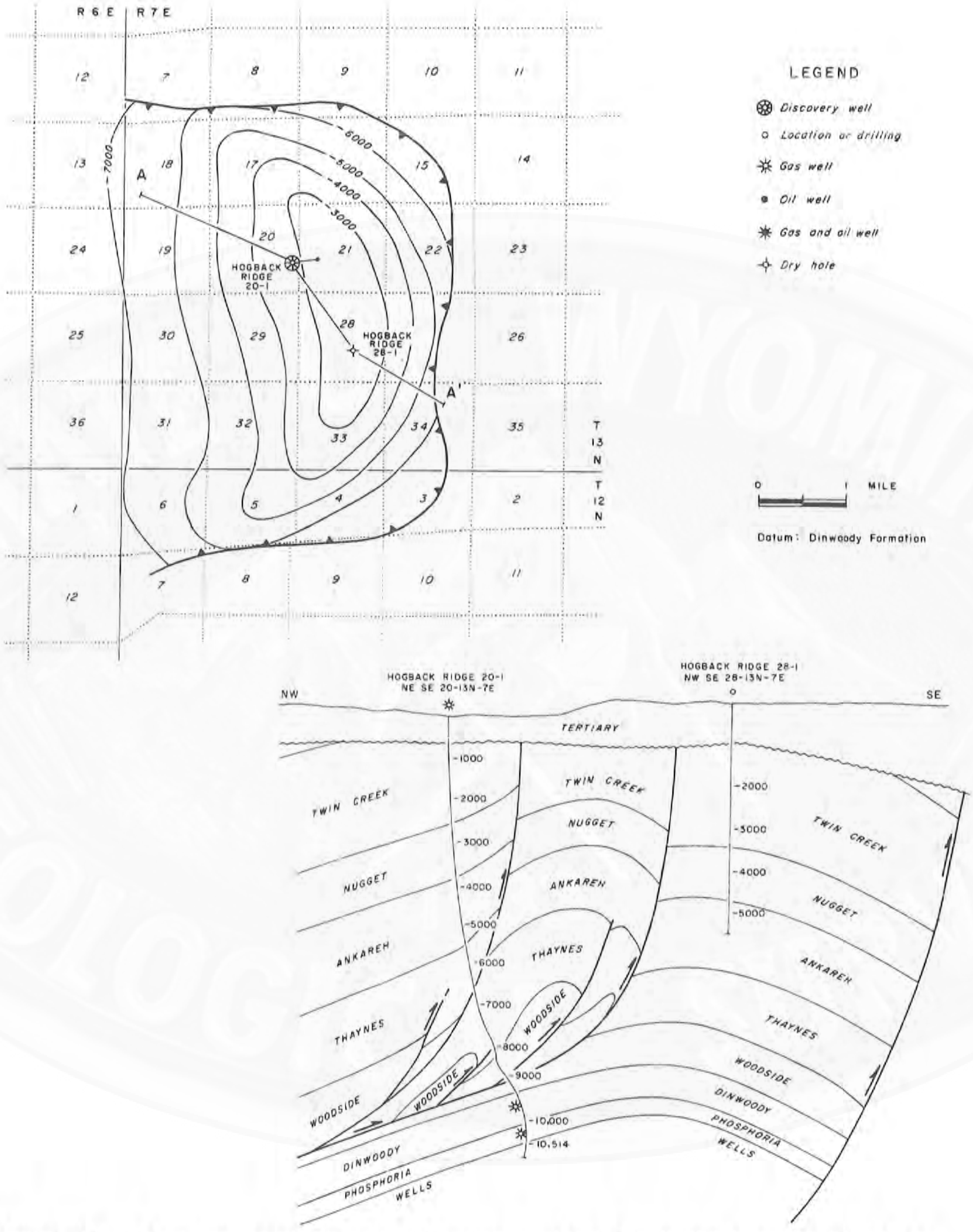


Figure 12. Structure contour map and cross section for Hogback Ridge Field, representing an early interpretation by American Quasar Petroleum. Taken from Petroleum Information Corporation (1978).

Elkhorn, Lodgepole, and Lodgepole South Fields, Utah

Three small discoveries were made in 1977 and 1978, south of Pineview Field in Summit County, Utah (Figure 2 and Plate 1). Lodgepole Field, the largest of the three, was discovered in March 1977, when American Quasar Petroleum Completed the #35-1 UPRR (SE¼NW¼ sec. 35, T.2N., R.6E.) for 128 barrels of oil and 76 MCF of gas per day in the Jurassic Twin Creek Limestone below 10,704 feet. Since then, production has also been established in the Jurassic(?) and Triassic(?) Nugget Sandstone. American Quasar completed the discovery well, #19-1 UPRR, for Elkhorn Field between Lodgepole and Pineview Fields in SW¼NE¼ sec. 19, T.2N., R.7E. in September of 1977. The well was completed for 1,506 barrels of oil and 452 MCF of gas per day from the Jurassic Twin Creek Limestone below 11,000 feet. Colorado Energetics completed the most recent discovery of the three, Lodgepole South Field, in September 1978 two miles south of Lodgepole Field. The discovery well (#33-11 UPRR), located in NW¼SE¼ sec. 11, T.1N., R.6E., was completed in the Lower Cretaceous Kelvin Formation for 370 MCF of gas per day from below 5,955 feet.

Lodgepole and Elkhorn Fields are on the same anticlinal trend as Pineview Field in the hanging wall of the Tunp thrust (Figure 13). The structures are underlain by Cretaceous rocks in the footwall. Lodgepole South Field, however, is apparently a small structure in the Absaroka thrust and is probably not related to the Pineview trend. Twin Creek reservoir data for Elkhorn Field include an average porosity of 3 percent, pay thickness of 30-150 feet, and permeability averaging 7 millidarcies (Blazzard, 1979a). Porosity and permeability are variable and fracture controlled. Lodgepole Field's Nugget reservoir is characterized by 10 percent average porosity, average pay thickness of 36 feet, and permeability averaging 229 millidarcies (Blazzard, 1979b).

As of September 1980, Lodgepole Field's 4 producing and 2 shut-in wells had produced 257,911 barrels of oil and 65,383 MCF of gas (Table 3). Reserves are estimated at 18 million barrels of oil and 6 million MCF of gas (Ritzma, 1981). Elkhorn Field has 1 producing and 1 shut-in well with cumulative production of 179,079 barrels of oil and 66,328 MCF of gas (Table 3). Reserve estimates for Elkhorn total 14 million barrels of oil and 6 million MCF of gas (Ritzma, 1981). The one well in Lodgepole South Field is shut in with no production, due to the lack of an outlet for the gas. No reserve estimates have been made for Lodgepole South. American Quasar is the operator for both Elkhorn and Lodgepole Fields. Colorado Energetics is the operator of Lodgepole South Field.

Painter Reservoir and Painter Reservoir East Fields, Wyoming

Painter Reservoir and Painter Reservoir East Fields are located approximately 4 miles northeast of Evanston in Unita County, southwest Wyoming (Figure 2 and Plate 1). Chevron U.S.A. completed the discovery well (#22-6A Chevron-Federal in SE¼SW¼ sec. 6, T.15N., R.119W.) for Painter Reservoir in October, 1977 in the Jurassic(?) and Triassic(?) Nugget Sandstone at 10,290 feet with initial flowing potential of 410 barrels of oil and 859 MCF of gas per day. After drilling two dry holes (#33-6A and #13-7A) in a fault block and structure separate from Painter Reservoir (Figure 14), Chevron moved up structure and drilled the Painter Reservoir East discovery well (#11-5A Painter Reservoir Unit) in NW¼ NW¼ sec. 5, T.15N., R.119W. The well was completed in August 1979 in the Nugget Sandstone at 11,874 feet for 169 barrels of oil and 933 MCF of gas per day.

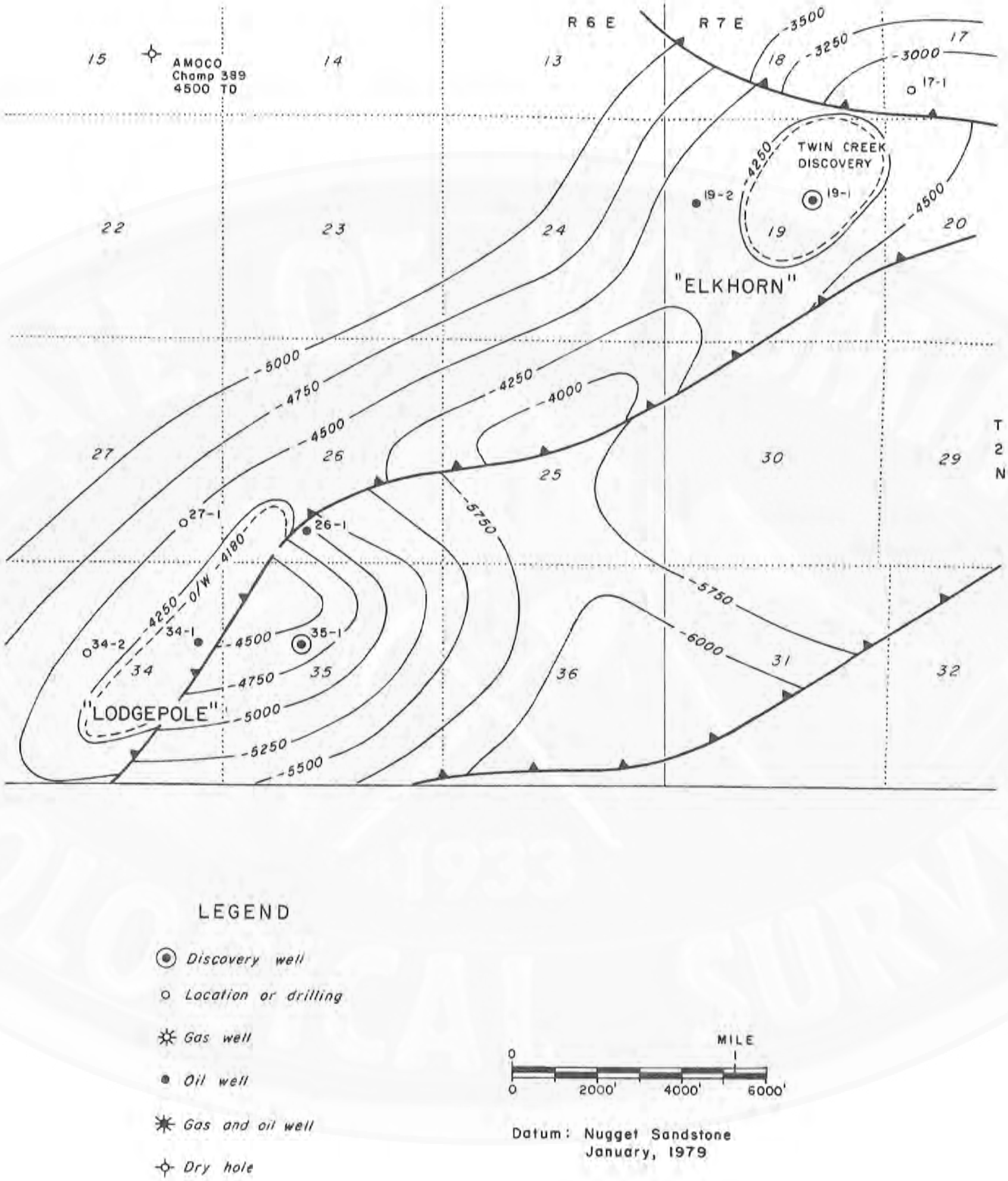


Figure 13. Structure contour map for Lodgepole and Elkhorn Fields. Taken from Blazzard (1979).

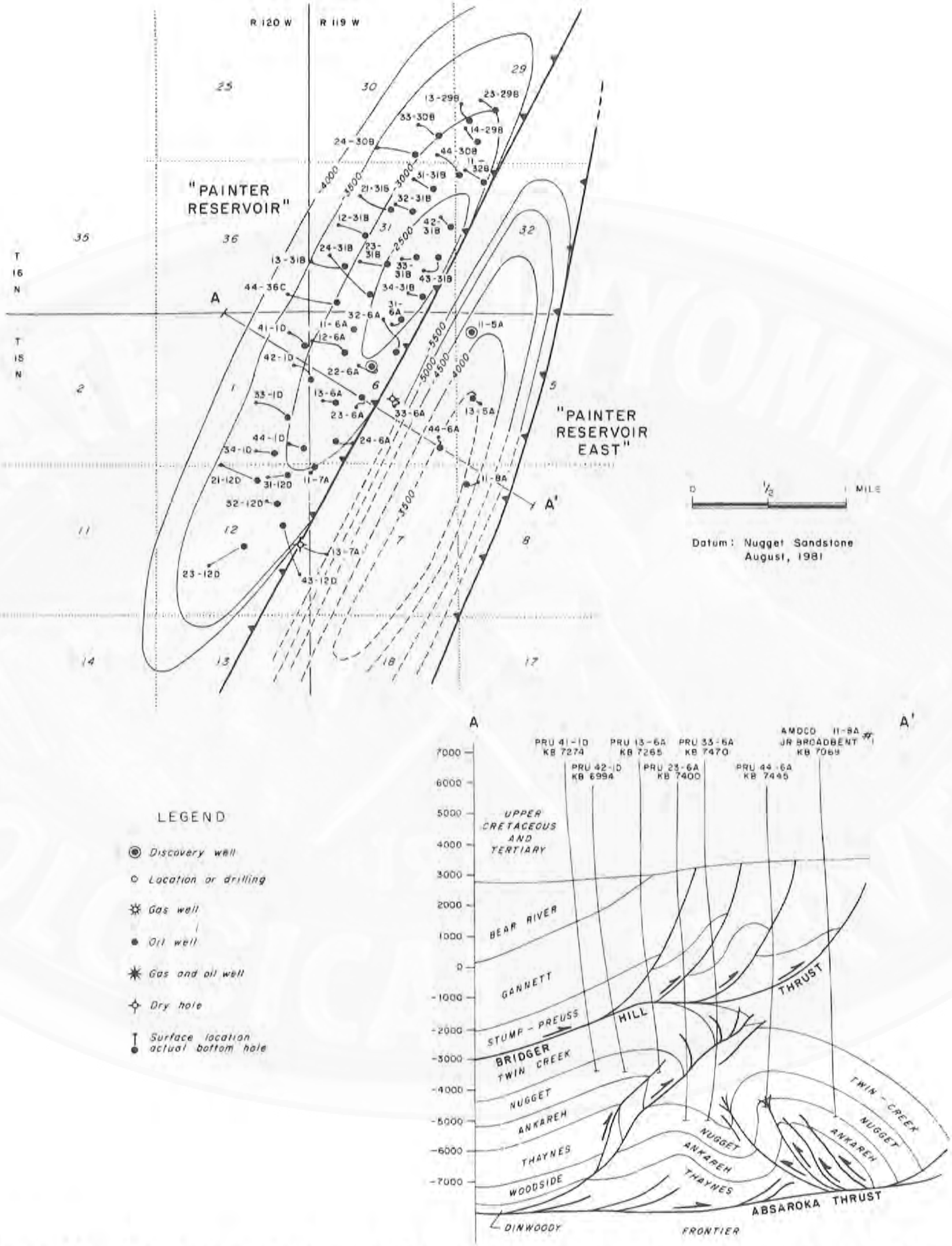


Figure 14. Structure contour map and cross section for Painter Reservoir and Painter Reservoir East Fields (courtesy of Chevron U.S.A.).

The two structures are northeast to southwest trending anticlines in the hanging wall of the Absaroka thrust. The Painter Reservoir structure is asymmetric to the east, while the Painter Reservoir East structure is asymmetric to the west. A small, symmetrical structure is sandwiched between the two producing structures and is apparently nonproductive. The Painter Reservoir structure is separated from the Painter Reservoir East structure by a minor imbrication above the main Absaroka thrust and by the minor structure described above (Figure 14). Painter Reservoir East is bounded on the east by another minor imbrication. Both structures contain Triassic through Lower Jurassic rocks and have been thrust over Cretaceous rocks in the footwall of the Absaroka thrust.

The Bridger Hill thrust glides in the lower Preuss salt and has produced a fold and fault sequence above, and totally separate from, the Painter Reservoir productive structure, involving Upper Jurassic through Lower Cretaceous rocks, as indicated in the cross section in Figure 14 (Lamb, 1980). The Nugget Sandstone is the only producing reservoir in both fields, although the Triassic Thaynes Limestone, which already produces in Ryckman Creek Field, is a likely candidate for future, deeper tests. In Painter Reservoir Field, the Nugget pay thickness averages 450 feet, with an average porosity of 14.1 percent and permeability averaging 22.8 millidarcies (Jones, 1979; Lamb, 1980). Additional reservoir parameters and oil and gas analyses are shown in Appendix A. Chromatographic analysis indicates that the source for the hydrocarbons trapped in the Nugget is the underlying Cretaceous rocks. Seismic data indicate that the Painter Reservoir structure has about 1,100 feet of closure, and the field is expected to eventually contain about 1,600 productive acres (Lamb, 1980). As at Ryckman Creek Field, the gas produced is being re-injected to maintain reservoir pressure. Eventually, Chevron plans to produce both the oil and gas and inject nitrogen into the reservoir to maintain pressure (Lamb, 1980). Very little information is available concerning Painter Reservoir East's reservoir parameters. They are probably quite similar, however, to the Nugget parameters in the Painter Reservoir Field.

Through December 1980, Painter Reservoir Field and Clear Creek Field, a smaller structure immediately north of Painter Reservoir, had 32 producing and 13 shut-in wells with cumulative production totalling 5,234,528 barrels of oil and 26,252,127 MCF of gas (re-injected) (Table 2). Painter Reservoir East has 2 producing and 2 shut-in wells and cumulative production totalling 5,197 barrels of oil and 600 MCF of gas. Recoverable reserves for Painter Reservoir are estimated by Frank and Gavlin (1981) at 165 million barrels of oil and 635 million MCF of gas. They estimate reserves for Painter Reservoir East at 89 million barrels of oil and 765 million MCF of gas. The major operators and interest holders in both fields are Chevron, Amoco, and Champlin. The oil produced from Painter Reservoir Field is purchased by Amoco Production Company, and 50 percent of the gas has been purchased by Northern Natural Gas. No information is available on the market for Painter Reservoir East production.

Anschutz Ranch Field, Utah

Anschutz Ranch Field is located in Summit County, Utah, approximately 4 miles north of Pineview Field and on trend with Yellow Creek Field, nearly 12 miles southwest of Evanston, Wyoming (Figure 2 and Plate 1). Anschutz Corporation discovered the field with the completion of the #34-1 Anschutz Ranch in NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 34, T.4N., R.7E. in October 1978. The well was completed in the Jurassic Twin Creek Limestone at a depth of 6,981 feet, producing 10,313 MCF of gas and 250 barrels of condensate per day. Jurassic(?) and Traissic(?) Nugget production was established in June 1980 in the #27-1 Anschutz Ranch (NE¼SE¼ sec. 27, T.4N., R.7E.) at 6,648 MCF of gas and 24 barrels of oil per day.

The Anschutz Ranch structure trends northeast—southwest and is approximately six miles long (Figures 15 and 16). Once again, the structure is a faulted anticlinal fold, asymmetric to the east, in the hanging wall on the leading edge of the Tunp or Medicine Lodge thrust. It contains Devonian through Jurassic rocks. Additional faulting is indicated on the interpretations shown in Figures 15 and 16. Imbrication of the Tunp thrust is shown in both interpretations; however, the Amoco interpretation (Figure 16) shows imbricate faulting that cuts the producing horizon immediately east of the crest of the structure. A fault is shown gliding through the lower Preuss salt, but the sense of the fault seems to be in question as Amoco shows it as a normal fault while Anschutz (Figure 14) calls it a thrust. Additional drilling of the structure will no doubt clear up interpretation of the structure.

The Twin Creek Limestone reservoir contains pay zones averaging 800 feet in thickness; however, since it is a fracture controlled reservoir, no good numbers are available for porosity and permeability. The Nugget Sandstone reservoir average pay thickness is 150 to 200 feet, and permeability is 37 millidarcies; no average porosity is available. Oil and gas analyses are shown in Appendix A.

As of October 1980, Anschutz Ranch had 3 producing wells with cumulative production of 93,095 barrels of oil and 3,691,260 MCF of gas (Table 3). Ritzma (1981) shows estimated reserves of 15 million barrels of oil and 49 million MCF of gas. The major operators of the field are Anschutz Corporation and Amoco Production. Amoco Production purchases the oil produced; Natural Gas Pipeline Company of America purchases the gas.

Clear Creek Field, Wyoming

Clear Creek Field is located on the structural trend of, and midway between, Painter Reservoir and Ryckman Creek Fields, about 8 miles northeast of Evanston in Unita County (Figure 2 and Plate 1). After extensive testing, Chevron U.S.A. completed the discovery well, 35-4B Painter Reservoir Unit (SW¼SE¼ sec. 4, T.16N., R.119W.), in late September 1979. The well flowed 240 barrels of oil and 1,386 MCF of gas per day from below 9,775 feet in the Jurassic(?) and Triassic(?) Nugget Sandstone.

The Clear Creek structure is an anticlinal fold, asymmetric to the east and bounded on the east by an imbrication of the Absaroka thrust (Figure 17). The structure contains Triassic through Lower Jurassic rocks and has been thrust over Cretaceous rocks in the footwall of the Absaroka thrust. No information is available on Nugget reservoir characteristics; however, they are probably very similar to those of the Nugget reservoir in Painter Reservoir Field.

Clear Creek Field is unitized with Painter Reservoir Field, so statistics for production and producing wells are combined with those of Painter Reservoir Field and are listed in the Painter Reservoir discussion. Frank and Gavlin (1981) estimate reserves at 33 million barrels of oil and 200 million MCF of gas. Chevron U.S.A. is the field operator; interest holders include Amoco, Champlin, and Reserve Oil and Gas.

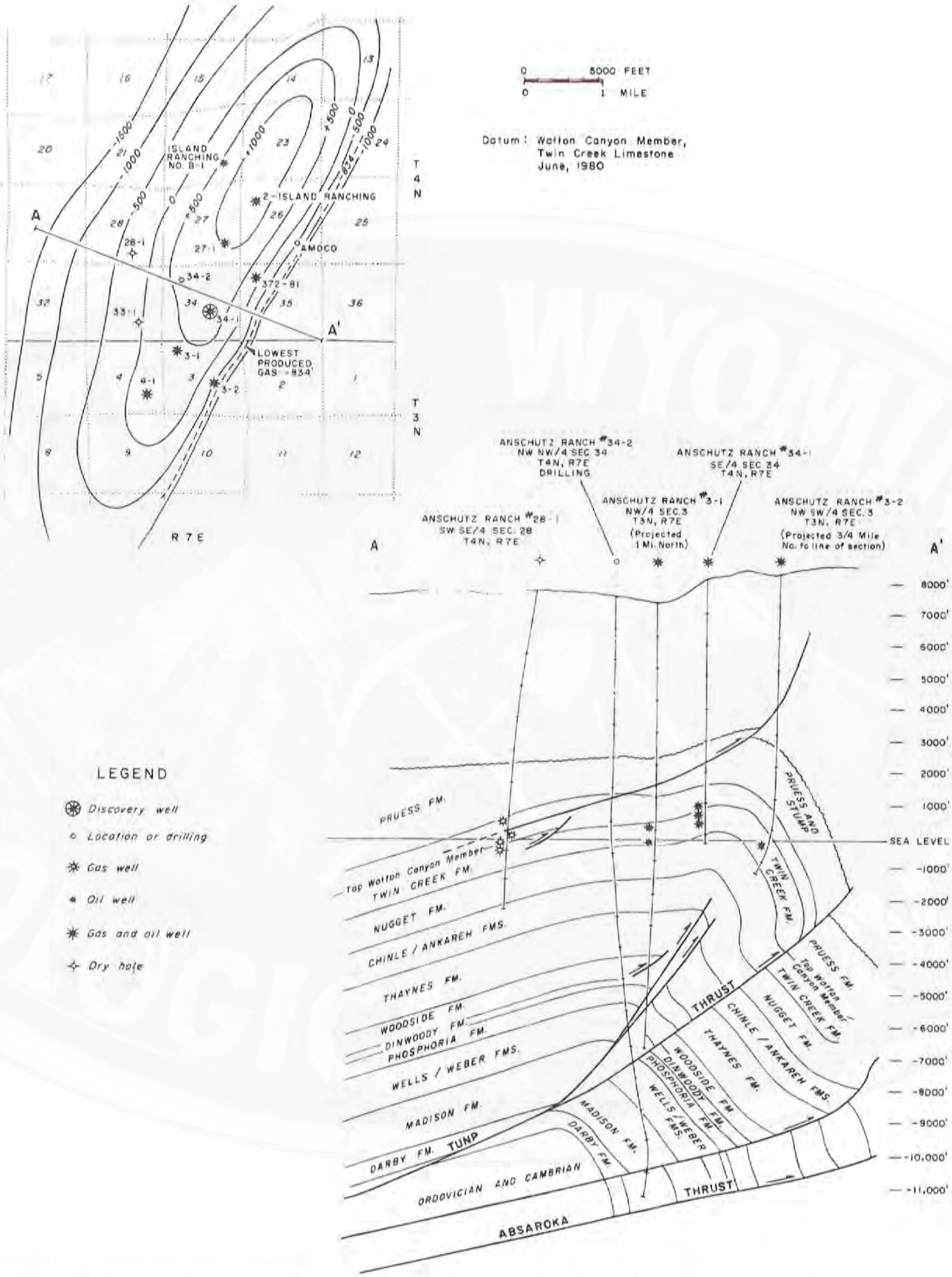


Figure 15. Structure contour map and cross section for Anschutz Ranch Field as interpreted by Anschutz Corporation.

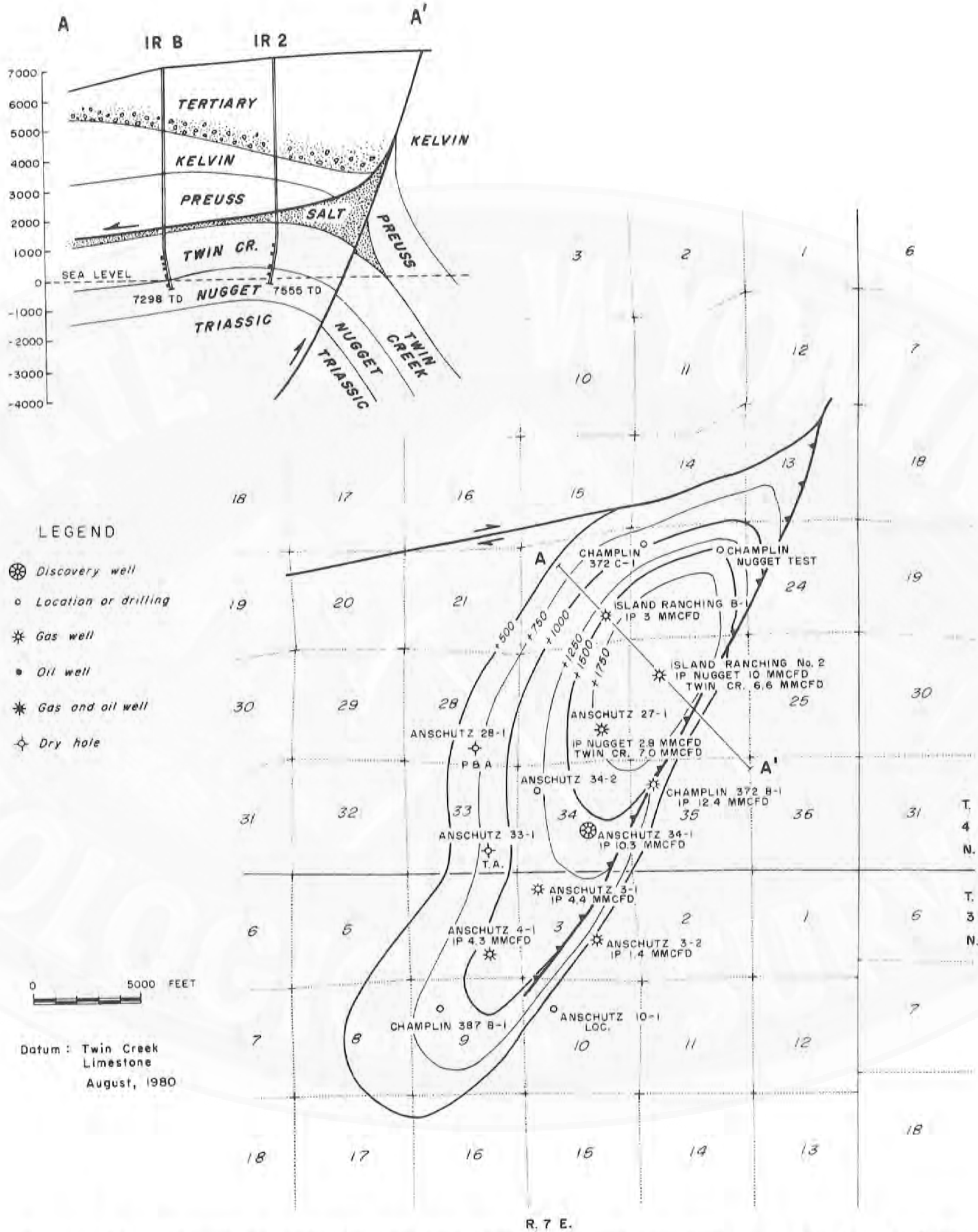


Figure 16. Structure contour map and cross section for Anschutz Ranch Field as interpreted by Amoco Production Company.

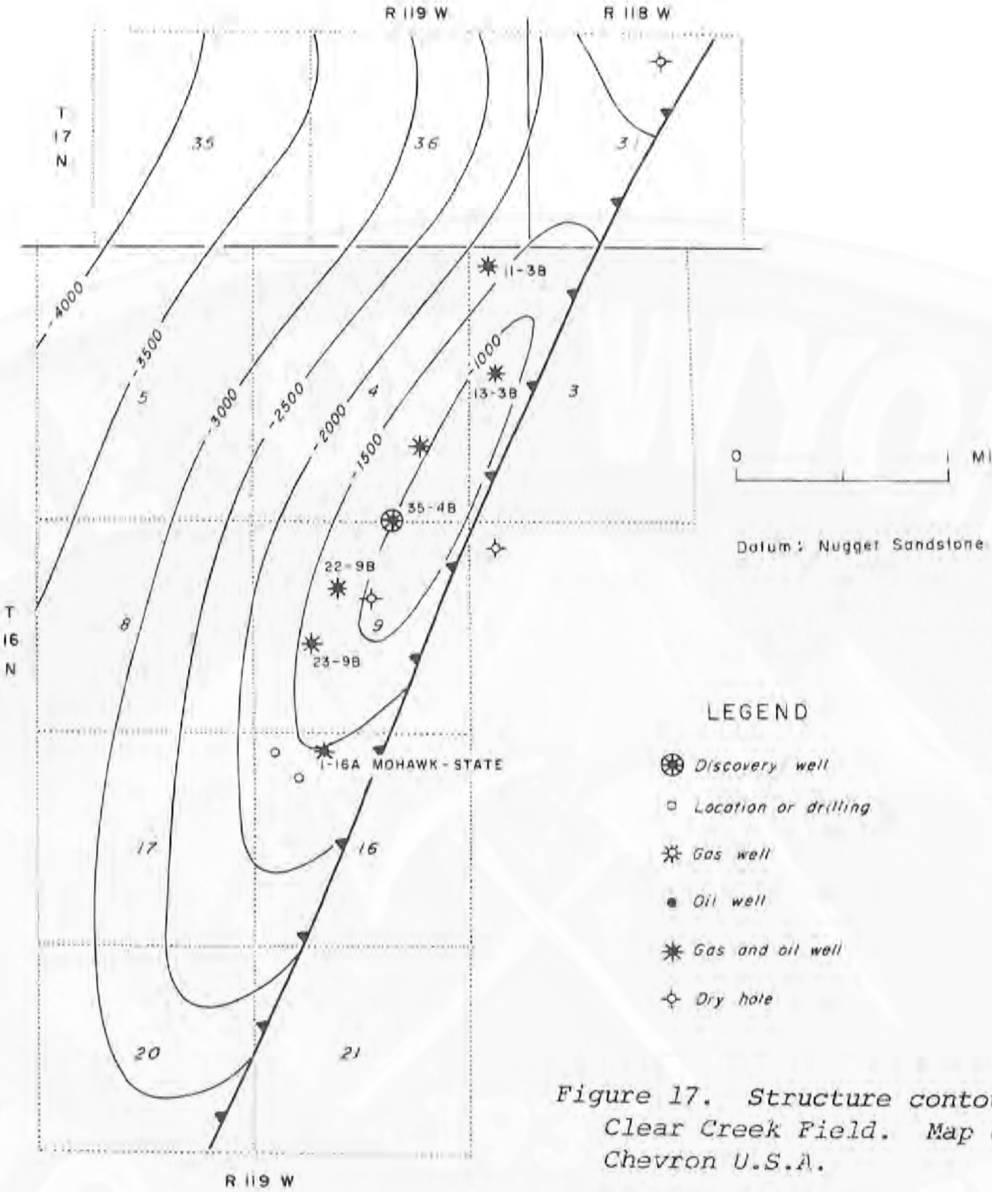


Figure 17. Structure contour map for Clear Creek Field. Map courtesy of Chevron U.S.A.

Anschutz Ranch East Field, Utah and Wyoming

Anschutz Ranch East Field is located on the Utah-Wyoming line approximately 14 miles southwest of Evanston, Wyoming (Figure 2 and Plate 1). Amoco completed the discovery well, #1 Bountiful Livestock, in NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 16, T.4N., R.8E. in late December, 1979. Initial production totalled 1,054 barrels of oil and 4,053 MCF of gas per day from the Jurassic(?) and Triassic(?) Nugget Sandstone below 13,172 feet.

The structure, although poorly defined at this time, appears to be roughly 7-8 miles long, trending northeast-southwest. Similar to other fields, the structure is a faulted anticlinal fold, asymmetric to the east, involving Triassic through Late Cretaceous rocks. The fold occurs in the hanging wall of the Absaroka thrust and is probably bounded on the east by an imbrication. An early interpretation by Mesa Petroleum, shown in Figure 18, portrays the fold as overturned. Information from recent drilling indicates the structure is probably much larger.

The imbricate fault may be flatter than indicated and the fold may not be overturned, putting the eastern boundary of the structure much further east. An additional thrust fault is shown gliding in the Preuss salt and creating a fold separate from and above the main fold, very similar to the secondary small structure shown for Painter Reservoir (Figure 14). Much more drilling is needed to define the structure fully, especially the eastern flank.

At this stage, very little information is available concerning the Nugget reservoir parameters, but indications are that the gross pay thickness may be over 700 feet, and net pay thickness averages approximately 125 feet in the first two completions (Petroleum Information Corporation, 1978). No averages were available for porosity and permeability, but they are probably similar to those for Anschutz Ranch.

As of October 1980, Anschutz Ranch East Field included only the discovery well, which had produced 218,228 barrels of oil and 966,007 MCF of gas. No published reserve figures are available for the field, but industry officials have hinted that this may be one of the major finds to date in the overthrust belt. In a recent address, the president of Amoco Production indicated discovered potential reserves could range between 800 million and 1.2 billion barrels of oil equivalent (Adams, 1981). Amoco Production is the operator of the Field, with Champlin; Anschutz; Tom Brown Company; Brownlie, Wallace, Armstrong and Bander; Mesa Petroleum; and Gulf holding working interests.

Red Canyon Field, Wyoming

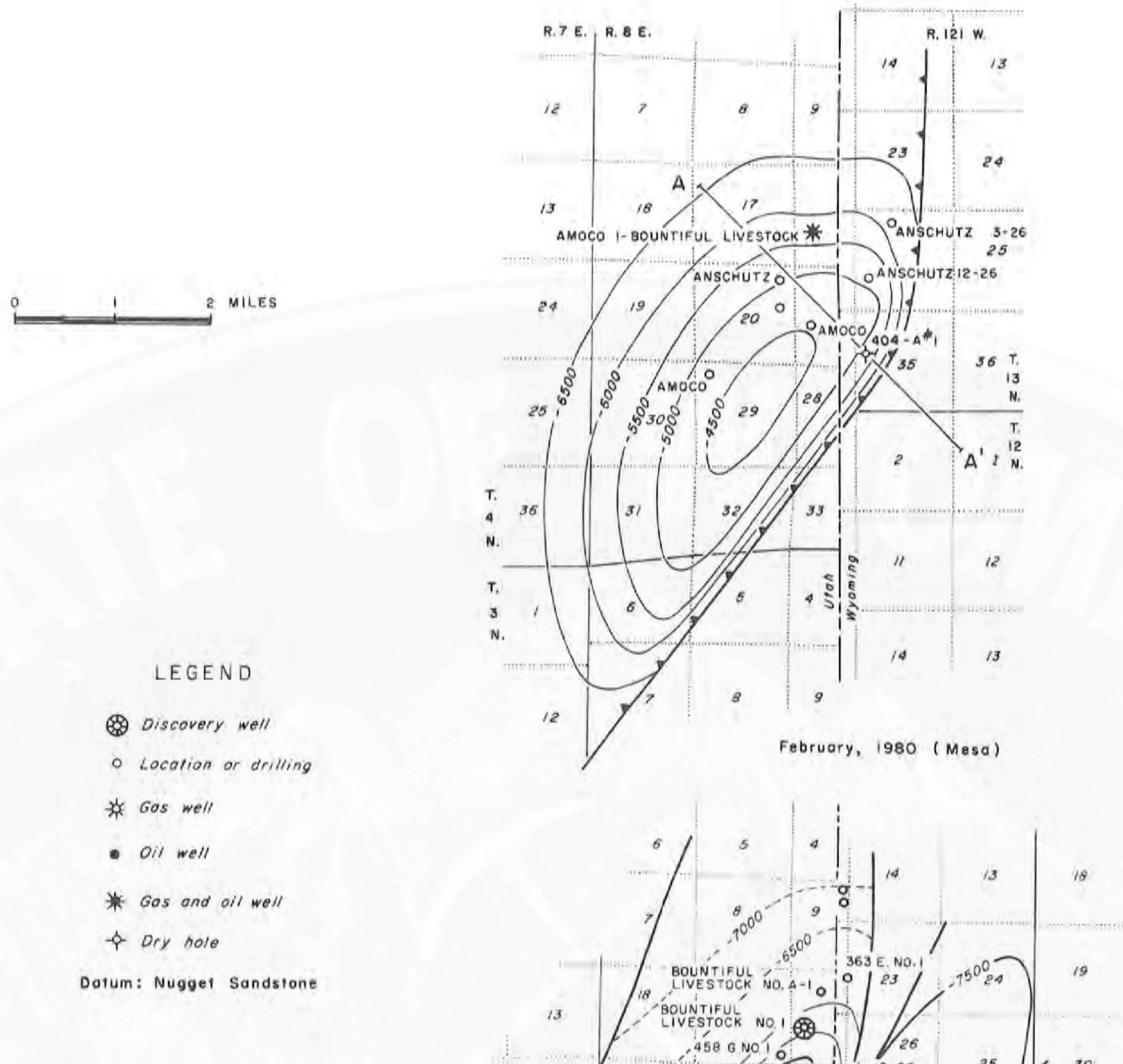
Amoco Production discovered Red Canyon Field, approximately 5 miles north of Evanston, Wyoming (Figure 2 and Plate 1), in January 1980. The discovery well, #1 Red Canyon WI Unit, in NE¼SE¼ sec. 21, T.16N., R.102W., was completed in the Pennsylvanian Weber Sandstone for 1,055 MCF of gas and 7.4 barrels of condensate per day from below 13,532 feet. The structure is apparently located in the hanging wall of the Tunp or Medicine Butte thrust. The discovery well is currently shut in, and no production is reported. The operator is Amoco, with Chevron and Champlin holding interests in the field.

Cave Creek Field, Utah

Cave Creek Field is located in Summit County, Utah, 4 miles north of Anschutz Ranch Field and 11 miles southwest of Evanston, Wyoming (Figure 2 and Plate 1). Amoco completed the discovery well, #1 Fawcett and Son, in NE¼NW¼ sec. 36, T.5N., R.7E. in June 1980. The well flowed at a combined rate of nearly 40,000 MCF of gas and 681 barrels of condensate per day from the Permian Phosphoria Formation below 11,461 feet, the Pennsylvanian Weber Sandstone below 11,914 feet, and the Mississippian Madison Limestone below 15,396 feet.

Very little information on the nature of the structure is available at this time, as only two wells have been drilled. The structure does, however, appear to be located in the hanging wall of the Tunp or Medicine Butte thrust. Pay thickness for the Phosphoria is 495 feet, porosity averages 6 percent, and no average permeability figure exists because of high variablity in the fractured carbonate reservoir. Gas and oil analyses are shown in Appendix A. No data have been released on the other two reservoirs.

As of September 1980, there was one shut-in well in Cave Creek Field and an offset well which is temporarily abandoned. No production has been reported because Amoco, the field oper-


R. 7 E.
R. 8 E.
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A
A'
AMOCO 1-BOUNTIFUL LIVESTOCK
ANSCHUTZ
ANSCHUTZ 3-26
ANSCHUTZ 12-26
AMOCO
404-A#1
T. 13 N.
T. 12 N.
T. 4 N.
T. 3 N.
Utah
Wyoming
February, 1980 (Mesa)
0 1 2 MILES
LEGEND
Discovery well
Location or drilling
Gas well
Oil well
Gas and oil well
Dry hole
Datum: Nugget Sandstone
363 E. NO. 1
BOUNTIFUL LIVESTOCK NO. A-1
BOUNTIFUL LIVESTOCK NO. 1
458 G NO. 1
12-26
6-20
8-20
458 F NO. 1
458 F 2
14-20
16-20
458 D NO. 1
404 A NO. 1
8-30
4-28
458 D NO. 2
14-30
458 D NO. 3
16-30
458 D NO. 4
HOWELL LIVESTOCK C NO. 1
458 E NO. 2
458 E NO. 1
HOWELL LIVESTOCK WIU NO. 1
ISLAND RANCHING E NO. 2
458 E NO. 3
HOWELL LIVESTOCK WIU NO. 2
ISLAND RANCHING E NO. 1
HOWELL LIVESTOCK B NO. 1
UTAH
WYOMING
R 121 W
458 B
R 7 E
R 8 E
April, 1981 (Amoco)

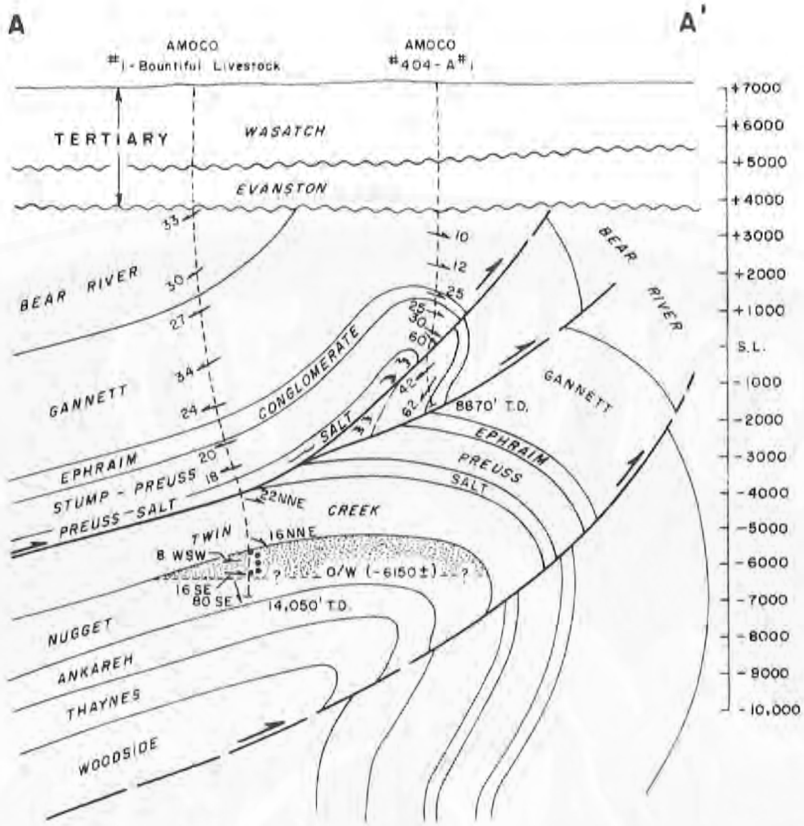


Figure 18 (this and facing page). Early structure contour map and cross section for Anschutz Ranch East Field (courtesy of Mesa Petroleum). Lower structure contour map represents a more recent interpretation by Amoco Production Company.

ator, is awaiting construction of gas treatment facilities to treat the high sulfur gas. No reserve estimates have been made.

Glasscock Hollow Field, Wyoming

Glasscock Hollow Field is located approximately 4 miles southeast of Evanston, Wyoming (Figure 2 and Plate 1). The discovery well, #1 Millis WI Unit, was completed by Amoco in $NW\frac{1}{4}NE\frac{1}{4}$ sec. 10, T.14N., R.120W. late in August 1980. The well initially flowed 1,290 barrels of condensate and 4,100 MCF of gas per day from below 13,784 feet in the Jurassic(?) and Triassic(?) Nugget Sandstone, the deepest Nugget production in the overthrust belt to date.

Little is known about the structure, with only one well drilled and completed. The structure appears to be in the hanging wall of the Absaroka thrust, and Amoco considers it probably part of the same producing trend as Anschutz Ranch East. No data are available on reservoir characteristics.

As of December 1980, only the discovery well was producing, with total cumulative production of 1,345 barrels of oil and 9,300 MCF of gas (Table 2). Reserve estimates have not been released. Amoco Production is the operator, with Chevron, Gulf, and Champlin holding interest in the field.

Woodruff Narrows Field, Wyoming

Woodruff Narrows Field is located approximately 4 miles west of Whitney Canyon - Carter Creek Field and about 14 miles north of Evanston, Wyoming (Figure 2 and Plate 1). Chevron U.S.A. completed the discovery well, #1-4H Amoco-Federal, in NW¼SE¼ sec. 3, T.17N., R.120 W. late in April 1981. Initial production from the well totalled 2,750 MCF of gas and 10 barrels of condensate per day from below 16,736 feet in the Ordovician Bighorn Dolomite, the deepest production to date in the overthrust belt.

Because it is a very recent discovery, no information is available concerning the structure. It appears to be in the hanging wall of the Absaroka thrust, overlying Cretaceous rocks in the footwall. No data are available on the producing reservoir.

Woodruff Narrows Field has one recently completed well and no reported production. Once again, it is too early in the developmental stage to have estimated reserve figures. Although, Chevron is the operator, interests in the discovery well are divided between Chevron (50%), Amoco (37.5%), and Champlin (12.5%).

Thomas Canyon Field, Wyoming

The most recent indicated discovery in the overthrust belt is located about five miles northwest of Evanston, Wyoming and is tentatively called Thomas Canyon Field (Figure 2 and Plate 1). The indicated discovery well, #1-35 Chevron Mesa-Amoco-Uteland-Federal, was drilled by Chevron in S½SW¼ sec. 35, T.16N., R.121W. Chevron is currently evaluating indicated sour gas production from the Permian Phosphoria Formation and the Mississippian Madison Limestone.

Very little information is available on the potential producing structure, except that it appears to be located in the hanging wall of the Medicine Butte thrust (Plate 1). In addition to Chevron, the operator, Mesa Petroleum, Amoco, and Uteland Oil have interests in the well.

Mill Creek Area, Utah

Another potential discovery well (#2 Mill Creek Unit-Federal) is currently being drilled by Exxon in the Mill Creek Area, approximately 18 miles east of Pineview Field and 2½ miles south of the Utah-Wyoming line in Summit County, Utah (Figure 2 and Plate 1). Exxon completed the initial well, #1 Mill Creek Unit-Federal, in SE¼NE¼ sec. 27, T.3N., R.10E. in July 1980 as a dry hole due to mechanical problems. However, they recovered 70 barrels of oil from the Devonian Darby Formation below about 11,450 feet during an 8 hour test. The potential discovery well, which is being drilled as an offset in NW¼SW¼ sec. 26, T.3N., R.10E., also recovered oil in the Darby section according to drillstem test data. If successful, the discovery would be the first recent find in the Darby thrust (Plate 1), the next main thrust plate east of the Absaroka, and would spur exploration in other portions of the Darby thrust.

Northeast Pineview Area, Utah

Amoco Production appears to have another gas discovery four miles northeast of Pineview Field (Figure 2 and Plate 1) in their 1-A Champlin-458-B (NW¼SE¼ sec. 19, T.3N., R.8E.). A zone in the Preuss Sandstone (Jurassic) was tested at 2,660 MCF of gas per day. The well is currently still being tested in other potential producing zones. If successful, this would represent the first production from the Preuss Sandstone.

* * * * * * * * * * * * * * * *

In summary, several similarities are evident when comparing the discoveries made in the overthrust belt, from the initial find at Pineview to the present. Where information is available, it appears that the producing structures can be characterized as anticlinal folds, asymmetric to the east, located in the hanging wall of a major thrust. The folds are normally found near the leading edge of the major thrust or imbricate thrust. Cretaceous rocks underlie the structures in the footwall, and, where data exist, it appears that the Cretaceous rocks are the source for the hydrocarbons trapped above. Wallem (1981) discusses this possibility with respect to the Bear River Formation.

To date, the production is divisible into two major trends. The more easterly trend produces primarily oil from structures involving Triassic through Cretaceous rocks. Except for the Pineview trend, they all occur in the Absaroka thrust plate. The more westerly trend produces mostly gas from structures containing Paleozoic and Mesozoic rocks related to the Tunp/Medicine Butte thrust plate. The Hogback Ridge producing structure is located in the Crawford thrust plate but is otherwise similar to those in the westerly trend.

With all the discoveries described above, activity and production have increased tremendously in the Idaho-Wyoming-Utah portion of the overthrust belt. Marketed production for the main "fairway" in the overthrust belt averages 34,361 barrels of oil and 158,000 MCF of gas per day as of late summer, 1981 (Overthrust Industrial Association, 1981a). Statistics for November 1980 listed 61 active rigs in the area. By comparison, a late summer 1981 count indicated 78 rigs active in the area including development and exploration tests. Amoco and Chevron are the most active companies, followed by Anschutz Corporation (Table 4). As illustrated in Table 2 a tremendous amount of development drilling remains to be done. For example, 43 locations were either drilling or planned for drilling in Whitney Canyon Field alone. Exploration continues around the discovered fields, as well as in frontier areas to the north and south of the 70-mile-long, 20-mile-wide main fairway. Chevron has indicated that they plan to expand exploration efforts to the west of Whitney Canyon - Carter Creek Field, into Utah, and into southeastern Idaho.

To date, no discoveries have been made in the Idaho portion of the overthrust belt, but it appears only a matter of time before a discovery is made. Several previous tests have contained good oil and gas shows, and it is evident that industry has not lost interest in the area, as it has two relatively deep tests currently drilling and two staked locations as of August 1981.

DESCRIPTIONS OF PRODUCING FORMATIONS

INTRODUCTION

Although sandstones in the Upper Cretaceous Frontier Formation and in the Lower Cretaceous Bear River Formation and Aspen Shale have produced in old fields in the eastern part of the overthrust belt, most of the newly discovered oil and gas occurs in formations

Table 4: Operating rigs in the Idaho-Wyoming-Utah overthrust belt by county and company.

	UINTA	LINCOLN	SUBLETTE	RICH	BEAR LAKE	SUMMIT	TOTAL
Amerada Hess		1					1
American Hunter			1				1
American Quasar			1			2	3
Amoco	13	1		1		8	23
Anschutz						4	4
Apache Corp.		1	1				2
Arco		1					1
Belco			1				1
Chevron	14	3			1		18
Cities Service					1		1
Down		1					1
Energetics			1				1
Energy Reserves		1					1
Exxon		1	2			1	4
Getty		1					1
Gulf	2						2
Hamilton Bros.	1						1
Industrial Gas		1					1
Marathon				2			2
Mesa Petroleum	1						1
Mobil			1				1
Natural Gas Corp.			1				1
Natural Gas of CA		1					1
Phillips						1	1
Sanchez-O'Brien	1						1
Santa Fe Energy			1				1
Sun Texas		1					1
Wainoco	1						1
TOTAL	33	14	10	3	2	16	78

Source: Overthrust Industrial Assoc. (1981a) of pre-Cretaceous age. Notable exceptions are in the Lodgepole South and Pineview Fields where gas is produced from the Lower Cretaceous Kelvin Formation. It is still likely that post-Jurassic rocks in the overthrust belt may contain economically recoverable quantities of hydrocarbons.

The producing formations of the overthrust belt are the Bighorn Dolomite, the Darby Formation, the Lodgepole Limestone and Mission Canyon Limestone of the Madison Group, the Wells Formation/ Weber Sandstone, the Phosphoria Formation, the Dinwoody Formation, the Thaynes Limestone, the Nugget Sandstone, the Twin Creek Limestone, the Stump Formation, and the Kelvin Formation (Plate 2).

ORDOVICIAN BIGHORN DOLOMITE

The Bighorn Dolomite was named by Darton (1904) from exposures on the east side of the Bighorn Mountains, Wyoming. Wanless and others (1955) call it one of the most massive and homogeneous formations in western Wyoming, although it thins to a zero edge in northeastern Utah and extreme southwestern Wyoming. Oriel (1969) describes it in the Fort Hill quadrangle of Lincoln County, Wyoming, as consisting of about 400 feet of subaphanitic, very-light- to medium-gray dolomite and dolomitic limestone that occurs in thick to massive beds. It weathers very light gray to white with very pitted surfaces. Some beds are buff to tan on fresh surfaces. Rubey and others (1975) describe it in the Sage and Kemmerer quadrangles of Lincoln County (about 10-15 miles north of Whitney Canyon - Carter Creek Field, where it produces sour gas from fractures) as consisting of about 600 feet of massive dolomite, mainly light-gray but partly mottled dark-gray.

The first well in Woodruff Narrows Field in Wyoming was completed in the Bighorn. The Bighorn was most likely deposited under fairly deep marine conditions. A representative log of the Bighorn is shown in Figure 19.

DEVONIAN DARBY FORMATION

The Darby Formation was described by Blackwelder (1918) as the sequence of shales and dolomites in many colors, from white to gray, green, lavender, buff, red, brown, and black, resting disconformably on the Bighorn Dolomite and separated from the overlying Madison by an erosion surface (Figure 19). Blackwelder derived the name from the canyon of Darby Creek on the west slope of the Teton Range, but he failed to designate a type section. He did describe a typical or reference section at Sheep Mountain in the Wind River Range, nearly 60 miles southeast of the canyon of Darby Creek. Benson (1966) assumes the reference section at Sheep Mountain is the type section and reasons that the Darby is not present in western Wyoming; he believes the Devonian sequence in that area is represented by the Jefferson and Three Forks Formations. Love and Keefer (1969) refute this assumption, stating that according to the Code of Stratigraphic Nomenclature, the type section of the Darby would have to be located at or near the type locality in the canyon of Darby Creek, not at Sheep Mountain. Therefore according to Love and Keefer (1969), there is Darby present in western Wyoming.

The Upper Devonian Darby Formation in the Cokeville quadrangle of western Wyoming, as described by Rubey and others (1980), consists of about 460 feet of dark-gray, buff- to dark-brown-weathering, massive to medium-bedded dolomite which has a fetid odor when it is freshly broken. It has interbeds of black, yellow, and red sandy calcareous siltstone in the upper part. It is described in much the same way by Rubey and others (1975) for the

Sage and Kemmerer quadrangles, and by Oriel (1969) for the Fort Hill quadrangle.

Wanless and others (1955), describe the upper shales as yellow brown with two or three bands of reddish shale, indicating occasional oxidizing conditions in a predominantly reducing environment.

The Darby Formation produces sour gas in the Whitney Canyon - Carter Creek Field in Wyoming. Figure 20 shows a log of the Darby Formation from this field.

MISSISSIPPIAN MADISON GROUP

The Mississippian Madison Group in western Wyoming is about 1,250 feet thick and includes the Mission Canyon Limestone and the underlying Lodgepole Limestone (Plate 2). According to Lageson and others (1979), in parts of western Wyoming the Lodgepole is divded into the Cottonwood Canyon, Paine, and Woodhurst Members (from the oldest to the youngest). There the basal member of the Lodgepole consists of about 60 feet of dark shale and is the upper tongue of the Cottonwood Canyon Member. The Paine Member of the Lodgepole conformably overlies the Cottonwood Canyon Member, is about 165 feet thick, and consists of 10-15 feet of silty, glauconitic, crinoidal limestone overlain by 150 feet of cherty, thin-bedded, silty, fine-grained limestone. The Woodhurst Member of the Lodgepole Limestone conformably overlies the Paine and consists of approximately 260 feet of cyclically interbedded thin-bedded, silty, fine-grained limestone and oolitic, crinoidal limestone. A log from Whitney Canyon Field, where the Lodgepole produces gas, shows it as almost 500 feet thick (Figure 21).

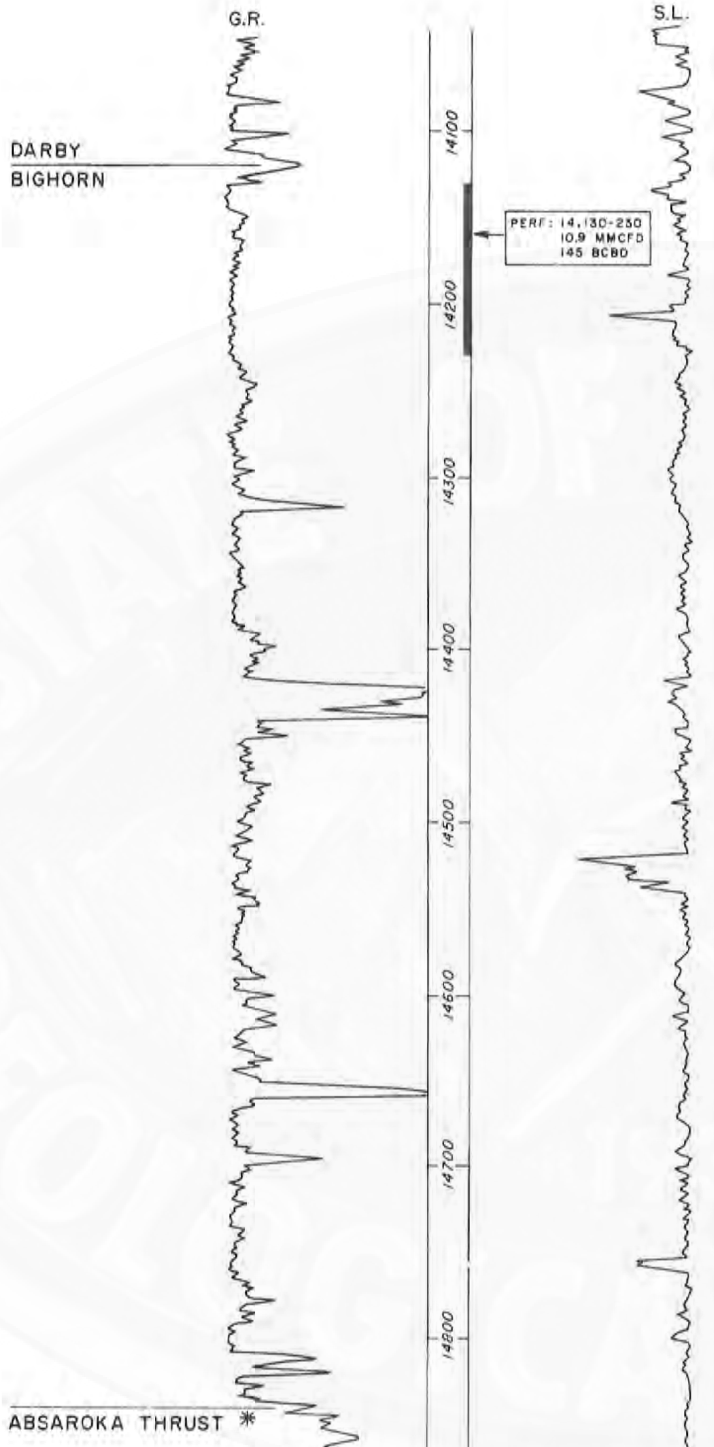
The Mission Canyon Limestone conformably overlies the Woodhurst and is made up of interbedded thick-bedded, crinoidal limestone and cherty, thin-bedded, fine-grained dolomite and dolomitic limestone in the lower part and dolomite and dolomitic limestone interbedded with cherty, fine-grained limestone in the upper part. Total thickness of the Mission Canyon in western Wyoming is about 800 feet (Lageson and others, 1979). A log from Whitney Canyon Field, where it produces gas, shows it as over 1,000 feet thick (Figure 22).

At Little Flat Canyon in the Chesterfield Range of southeastern Idaho, the Madison is only 259 feet thick and is represented by the Lodgepole Limestone. The Paine Member is 175 feet thick, the Woodhurst Member is only 84 feet thick, and the Cottonwood Canyon Member is absent. A drastic change in the lithology occurs above the Lodgepole in this vicinity (Sando, 1977). The Little Flat Formation overlies the Lodgepole, is 965 feet thick, and is composed of dominantly terrigenous strata with a basal 126-foot siltstone member, a 551-foot sandstone member, and an upper 288-foot sandy limestone member (Dutro and Sando, 1963). Rose (1977) believes that the Lodgepole Limestone and Little Flat Formation are probably represented in northeastern Utah.

The Madison Group in western Wyoming is interpreted by Lageson and others (1979) as predominantly consisting of shelf carbonate rocks. The Madison produces gas in Cave Creek Field in Utah and in Whitney Canyon - Carter Creek Field in Wyoming. The first well in Thomas Canyon Field in Wyoming is being completed in the Madison.

PERMIAN-PENNSYLVANIAN WELLS FORMATION / WEBER SANDSTONE

Most U.S. Geological Survey reports use the name "Wells" for the Upper Pennsylvanian - Lower Permian unit in the Idaho and Wyoming parts of the overthrust belt. Oil companies operating in the area apparently favor the



* This is most likely a full Bighorn section with the Absaroka Thrust bounding it on the bottom

Figure 19. Representative log of Bighorn Dolomite, Whitney Canyon Field, Champlin 457 Amoco A#1, SW¼SE¼ sec. 7, T.17N., R.119W., Uinta County, Wyoming. Courtesy of Amoco Production Company.

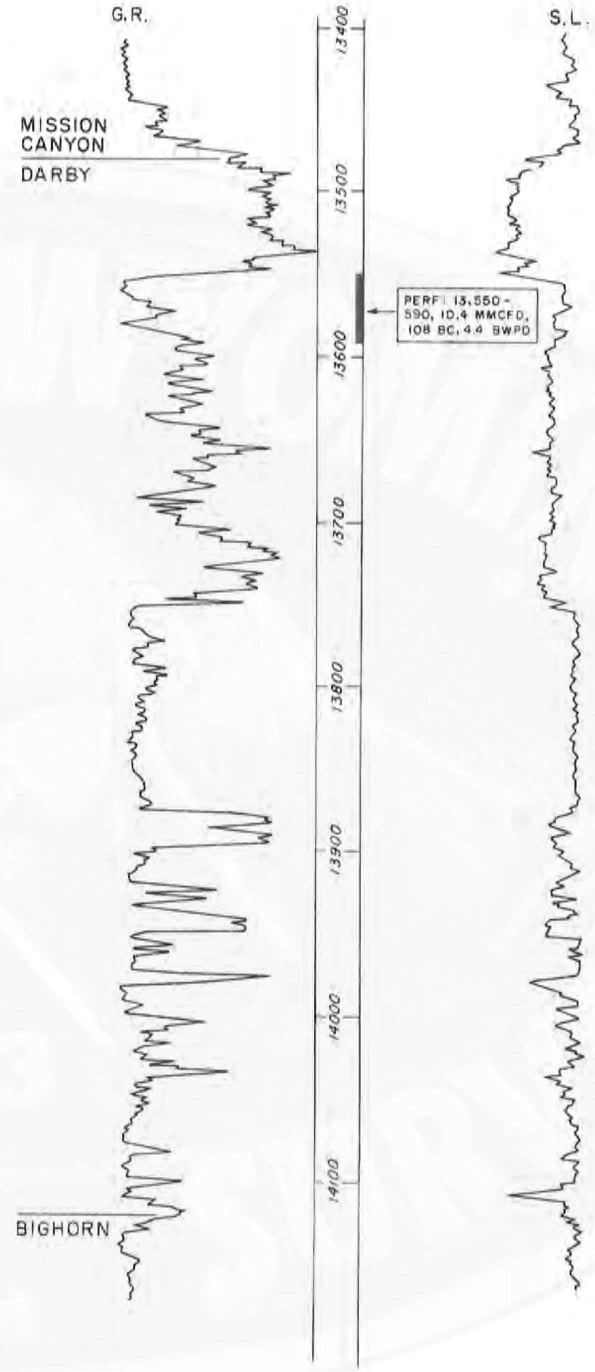


Figure 20. Representative log of Darby Formation, Whitney Canyon Field, Champlin 457 Amoco A#1, SW¼SE¼ sec. 7, T.17N., R.119W., Uinta County, Wyoming. Courtesy of Amoco Production Company.

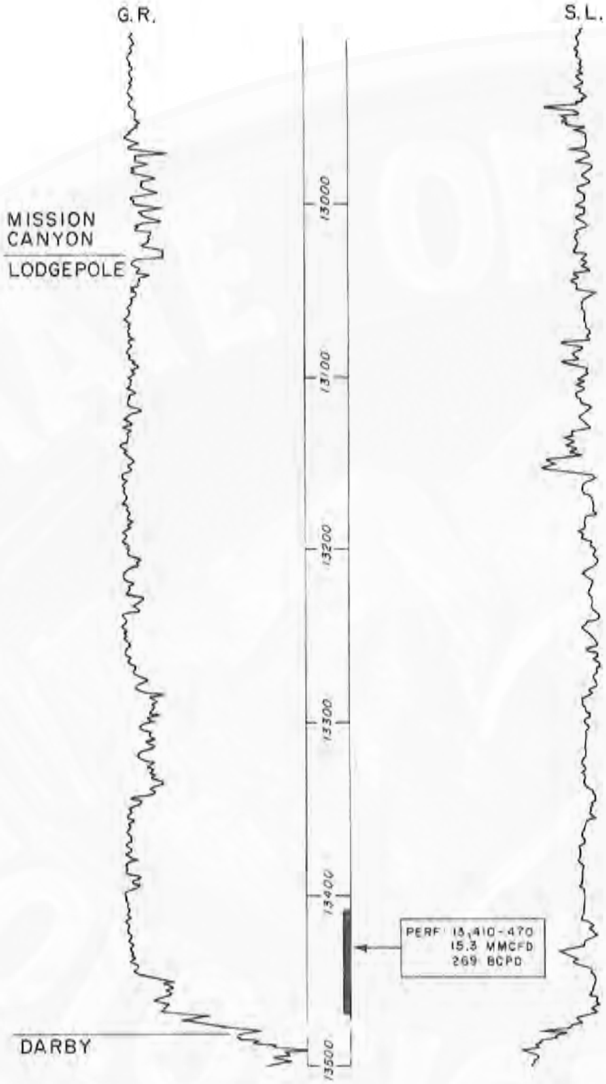


Figure 21. Representative log of Lodgepole Limestone of Madison Group, Whitney Canyon Field, Champlin 457 Amoco A#1, SW¼SE¼ sec. 7, T.17N., R.119W., Uinta County, Wyoming. Courtesy of Amoco Production Company.

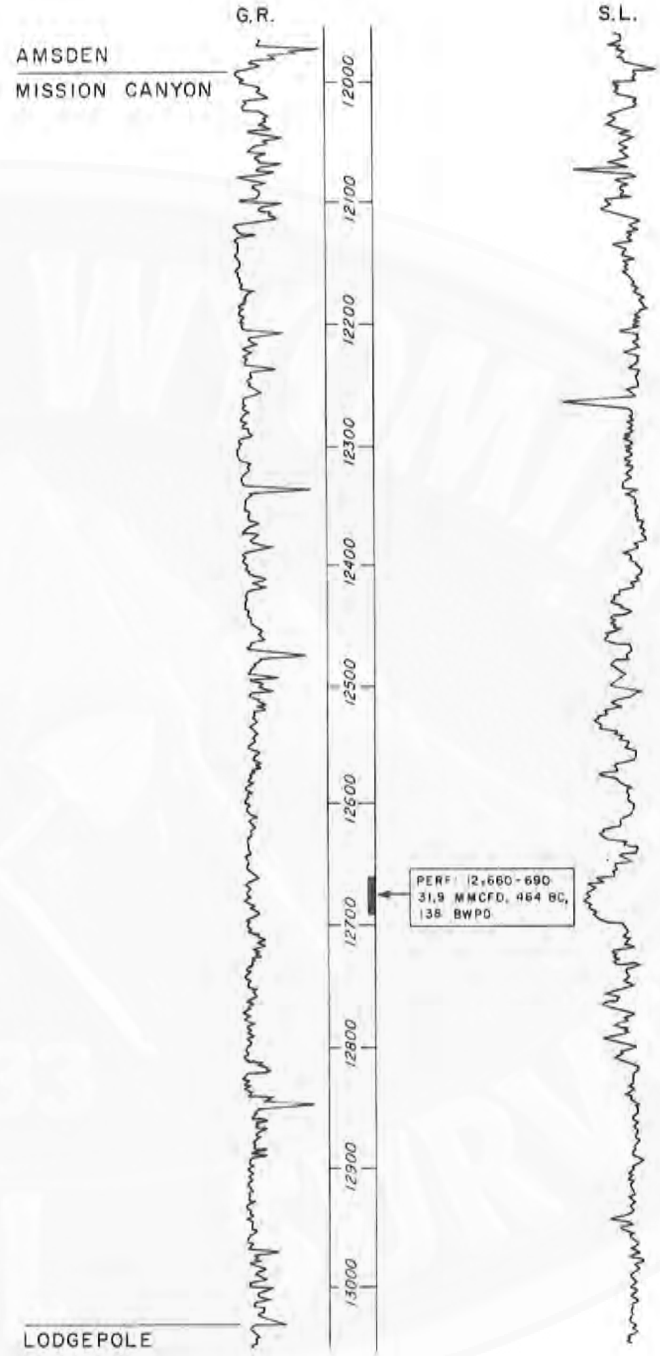


Figure 22. Representative log of Mission Canyon Limestone of Madison Group, Whitney Canyon Field, Champlin 457 Amoco A#1, SW¼SE¼ sec. 7, T.17N., R.119W., Uinta County, Wyoming. Courtesy of Amoco Production Company.

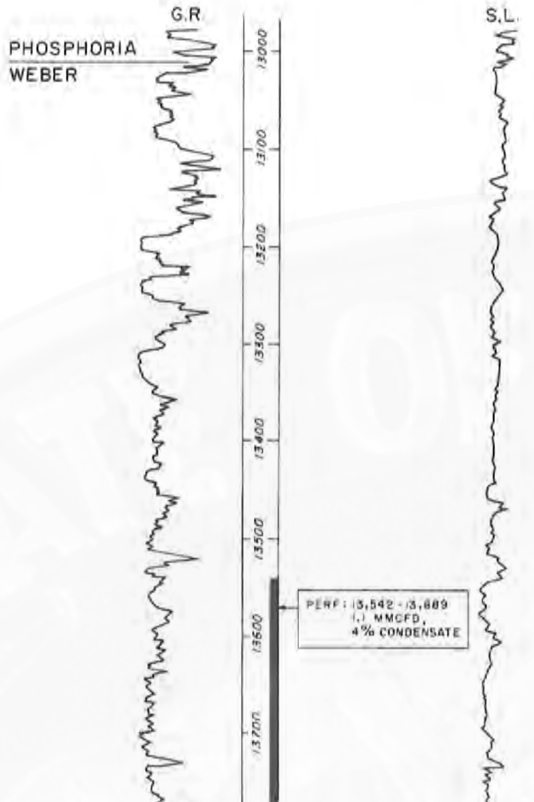


Figure 23. Representative log of Weber Sandstone, Whitney Canyon Field, Chevron Federal 21-30E, NW¼ sec. 30, T.17N., R.119W., Uinta County, Wyoming. Courtesy of Amoco Production Company.

name "Weber", for the Weber is listed as producing gas in Red Canyon and Whitney Canyon - Carter Creek Fields in Wyoming and Cave Creek Field in Utah. Amoco has recently announced a new pool discovery in the Weber in Yellow Creek Field in Wyoming. The term Weber is commonly used in Utah (Plate 2).

Rubey and others (1975) have divided the Wells formation in the Sage and Kemmerer 15-minute quadrangles into two distinct parts. The lower part consists dominantly of pale-buff and gray to white, well-sorted, fine-grained quartzite and partly calcareous sandstone. The upper part consists of interbedded siltstone, quartzite, and gray, finely crystalline dolomite. The Wells thickens from 600 feet on Commissary Ridge in the eastern part of the area to 1,000 feet on Dempsey Ridge in the western part, and continues to thicken westward (Mansfield, 1927; Cressman, 1964; Montgomery and Cheney, 1967) and northward (Rubey, 1958; Staatz and Albee, 1966). The Weber in Whitney Canyon Field is nearly 1,000 feet thick (Figure 23).

The Wells Formation in the Cokeville 30-minute quadrangle has been described by Rubey and others (1980) as a pale-buff, fine grained quartzite and sandstone with beds of gray dolomitic limestone alternating with hard siltstone in the upper part and containing a few thin calcareous beds in the middle and lower parts. It thins eastward from 1,100 feet near Cokeville to 600 feet in the eastern part of the quadrangle. Oriel and Platt (1980) describe the Wells in the Preston 1° x 2° quadrangle as interbedded gray limestone and pale-yellow, calcareous sandstone with minor gray dolomite, cherty in the lower part. It thins from 2,000 feet near Blackfoot Reservoir in Idaho to 600 feet on the eastern edge of Fossil Basin in Wyoming. The Wells was deposited in marine waters with much of the sediment probably derived from the Bannock Highland (Williams, 1962).

PERMIAN PHOSPHORIA FORMATION

The Permian Phosphoria Formation was named for Phosphoria Gulch in Bear Lake County, Idaho (Richards and Mansfield, 1912). Near its type locality it is 250 to 450 feet thick and consists mostly of dark chert, phosphatic and carbonaceous mudstone, phosphorite, cherty mudstone, and some dark carbonate rock (Plate 2). Sandstones and light-colored carbonate rocks are almost always present (McKelvey and others, 1959). The Phosphoria is typically developed in southeastern Idaho and adjacent parts of Utah and Wyoming. Portions of the Phosphoria Formation grade eastward into the Shedhorn Sandstone and the Ervay, Franson, and Grandeur Members of the Park City Formation, while other parts extend as tongues over the whole area (Figure 24). The Phosphoria thickens in south-central Idaho to nearly 1,300 feet. Four members are recognized at the type locality: the Meade Peak Phosphatic Shale Member, the Rex Chert Member, the cherty mudstone member, and the Retort Phosphatic Shale Member. There are two other members that are absent at the type locality: the lower chert member, which is laterally continuous with the lower beds of the Meade Peak, and the Tosi Chert Member, which is laterally continuous with the upper part of the Retort Member and the Cherty Shale Member.

The lower chert member consists of cherty and slightly phosphatic beds and is confined to a narrow, north-trending belt in the Wyoming, Snake River, Gros Ventre, and Teton Ranges and the eastern part of the Salt River Range. Its maximum thickness is 40 feet in the southern Wyoming Range, and it pinches out in northwestern Wyoming. The unit grades westward into phosphatic mudstone of the Meade Peak, eastward into sandy and cherty carbonate rock, and southward into phosphatic mudstone. This unit was probably deposited below wave base (McKelvey and others, 1959).

The Meade Peak Phosphatic Shale Member is composed of dark carbonaceous, phosphatic, and argillaceous rocks in its type area. In southeastern Idaho it is 125-225 feet thick, but thickens to the south. It thins to the north, east, southeast, and west. The Meade Peak changes to dark carbonate rock southward; the upper and lower parts change to chert and carbonate beds eastward; it thins northward, and changes to carbonaceous mudstone in south-central Idaho. The Meade Peak sediments probably accumulated on a gently shoaling bottom (McKelvey and others, 1959).

Richards and Mansfield (1912) described the Rex Chert Member of the Phosphoria at the type locality as 100 feet of gray limestone and black chert in the lower part, 60 feet of red-stained black chert in the middle, and 80 feet of dark cherty shale in the upper part. The upper unit is separated from the Rex Chert by McKelvey (1949) and termed the upper shale member. Northward, eastward, and southward from its type area, the upper part of the Rex Chert passes into carbonate rock of the Franson Member of the Park City Formation. The lower part of the Rex Chert passes into carbonate rock of the Franson Member in western Wyoming, southwestern Montana, and north-central Utah. The Rex Chert probably was deposited below wave base (McKelvey and others, 1959).

At the type locality, the cherty mudstone member is composed of nearly 500 feet of fine-grained quartzite and sandstone, mudstone, and argillaceous chert. The lower part intertongues with and grades into the Rex Chert eastward and westward from the type area. The upper part extends as a tongue over much of southeastern Idaho. It probably was deposited in deeper water than the Rex Chert (McKelvey and others, 1959).

The Retort Phosphatic Shale Member consists of 60 feet of thin-bedded, soft, dark, carbonaceous mudstone and pelletal

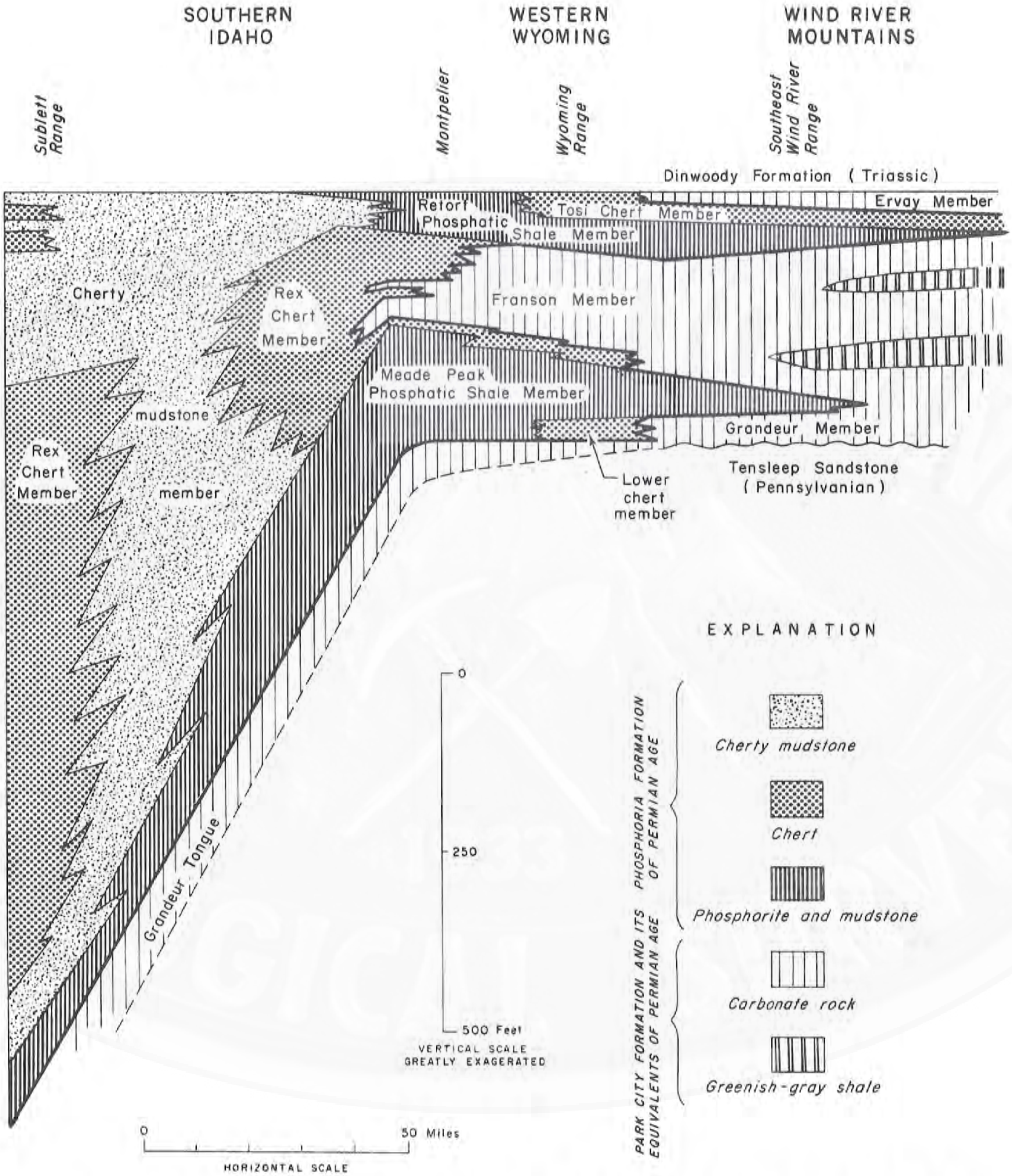


Figure 24. Stratigraphic relationship of the Phosphoria Formation to the Park City Formation in a portion of the overthrust belt. (Modified from McKelvey and others, 1959).

phosphorite at its type locality near Dillon, Montana. In southwestern Wyoming, it has a fairly constant thickness of 25 to 30 feet, but it thickens westward to about 60 feet near the Idaho border. The Retort was deposited under the same conditions as the Meade Peak (McKelvey and others, 1959).

Tosi Creek in Sublette County, Wyoming is the type locality for the Tosi Chert Member, where it is 33 feet thick. It consists of brownish chert some 25 feet thick with an upper sandy chert unit, 8 feet thick. Southwest of the type locality, the Tosi Chert Member grades into dark-gray mudstone which is included in the Retort Phosphatic Shale Member. The Tosi Chert Member extends to the Owl Creek and Wind River Mountains eastward; it is about 40 feet thick in northeastern Utah. The Tosi Chert was deposited under the same conditions as the Rex Chert (McKelvey and others, 1959).

The Phosphoria Formation produces gas in Cave Creek and Hogback Ridge Fields in Utah and in Yellow Creek and Whitney Canyon - Carter Creek Fields in Wyoming. The first well in Thomas Canyon Field in Wyoming is being completed in the Phosphoria. A representative log of the Phosphoria Formation is shown in Figure 25.

TRIASSIC DINWOODY FORMATION

The Dinwoody Formation crops out in southeastern Idaho, southwestern Montana, and western Wyoming. The Dinwoody thickens to the west with the addition of beds both above and below those at the type locality. Along a curving path starting in southwestern Montana, continuing along the Wyoming-Idaho border, and deviating westward in northern Utah, the Dinwoody intertongues with the red beds of the Woodside Formation (Kummel, 1954) (Plate 2).

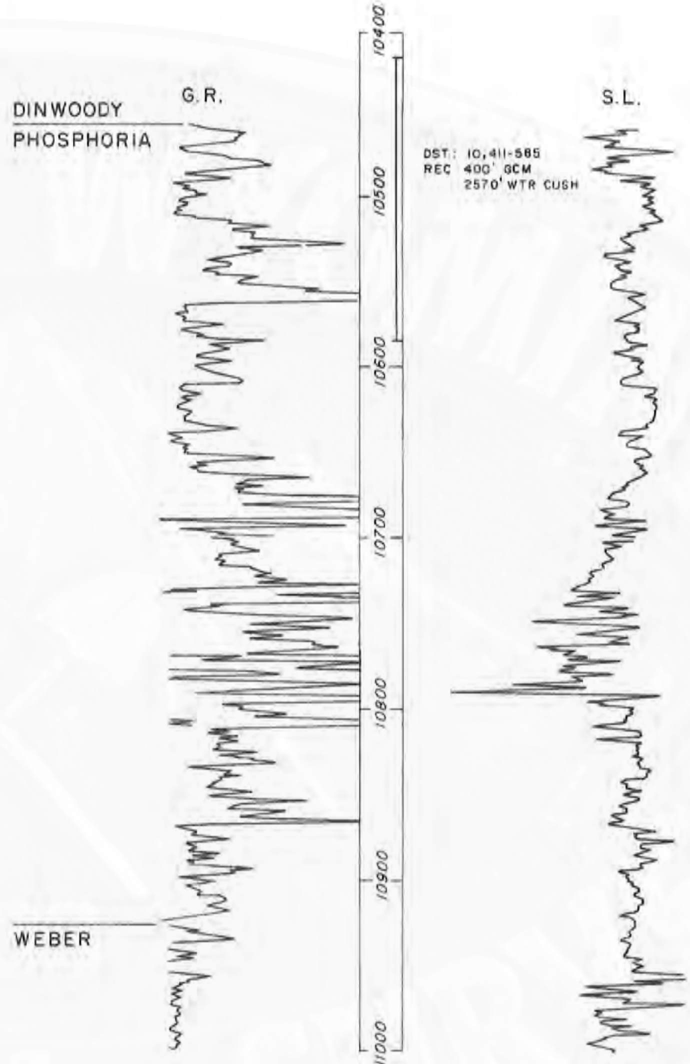


Figure 25. Representative log of Phosphoria Formation, Whitney Canyon Field, Champlin 457 Amoco A#1, SW¼ SE¼ sec. 7, T.17N., R.119W., Uinta County Wyoming. Courtesy of Amoco Production Company.

As originally defined by Blackwelder (1918) from outcrops in Dinwoody Canyon near Dubois, Wyoming, the Lower Triassic Dinwoody included everything between the red shales and siltstone of the Chugwater Formation above the Phosphoria Formation below. Because the color boundary between the Chugwater and Dinwoody was not a mappable boundary, Newell and Kummel (1942) redefined the Dinwoody at the type locality to include only the mainly silty beds between the Phosphoria and the top of the resistant siltstone about halfway to the top of the original Dinwoody. As redefined it is 90 feet thick and overlain by gray shales. Nearly everywhere else it is overlain by red shales and siltstones.

Newell and Kummel (1942) recognized three major lithologic units in the Dinwoody in western Wyoming. These are the basal silty limestone, the *Lingula* zone, and the *Claraia* zone. The basal, silty limestone consists of buff to tan, silty limestone or calcareous siltstone and is present only in the most western part of Wyoming. The *Lingula* zone consists of silty limestone, gray crystalline limestone, olive-buff to gray shales, and an abundance of well-preserved *Lingula*. The *Claraia* zone, the most extensive of the three units, is characterized by tan calcareous siltstone, silty limestone, gray crystalline limestone, a few beds of shale, and abundant molds of *Claraia*. The Dinwoody is considered potentially productive in Whitney Canyon - Carter Creek Field in Wyoming (Figure 26).

Kummel (1954) states that the Dinwoody Formation in southeastern Idaho and the Woodside Formation at its type locality near Park City, Utah have the same upper and lower stratigraphic boundaries. At Hogback Ridge Field in Utah, where it produces gas, the Dinwoody Formation is considerably thinner than it is in southwestern Idaho, and nearby outcrops consist of an upper unit of massive olive-buff to blue-gray calcareous siltstone and gray limestone and a lower unit of gray shale interbedded with tan to olive-drab calcareous siltstone and gray, finely crystalline limestone. The lower unit is correlative with the basal, silty limestone and part of the *Lingula* zone of western Wyoming. In general, the Dinwoody was deposited on the platform to the east and in a miogeosyncline to the west. The eastern edge of the miogeosyncline was in eastern Idaho (Kummel, 1954).

TRIASSIC THAYNES LIMESTONE

At the type locality in Thaynes Canyon, Park City Mining District, Utah, Boutwell (1907) described the Lower Triassic Thaynes as 1,190 feet of limestone, calcareous sandstone, sandstone, shale, and, in the middle, a red shale member. It is found over a wide area in northern Utah, eastern Idaho, southwestern Montana, and western Wyoming. Along its southern, eastern, and northern margins it intertongues with the red Ankareh Formation or the Chugwater Formation (Plate 2). The Thaynes in southeastern Idaho is differentiated into several lithologic units which can be traced over a wide area. In southwestern Montana, northern Utah, and most of western Wyoming the lithology of the Thaynes is more homogeneous (Kummel, 1954). The Thaynes produces gas in the Ryckman Creek and Whitney Canyon - Carter Creek Fields in Wyoming (Figure 27). Near these fields, just southeast of Sublette Ridge, Wyoming, Kummel (1954) describes the Thaynes as 1,165 feet of silty and sandy limestone interbedded with fine-grained sandstone.

The Thaynes thins eastward in western Wyoming by lateral change into the lithology of the overlying Ankareh Formation and the underlying Woodside Formation. The Thaynes completely disappears east of the Wyoming Range. In northern Utah eastward along the Uinta Mountains, the Thaynes thins and passes into the Ankareh and Woodside Formations.

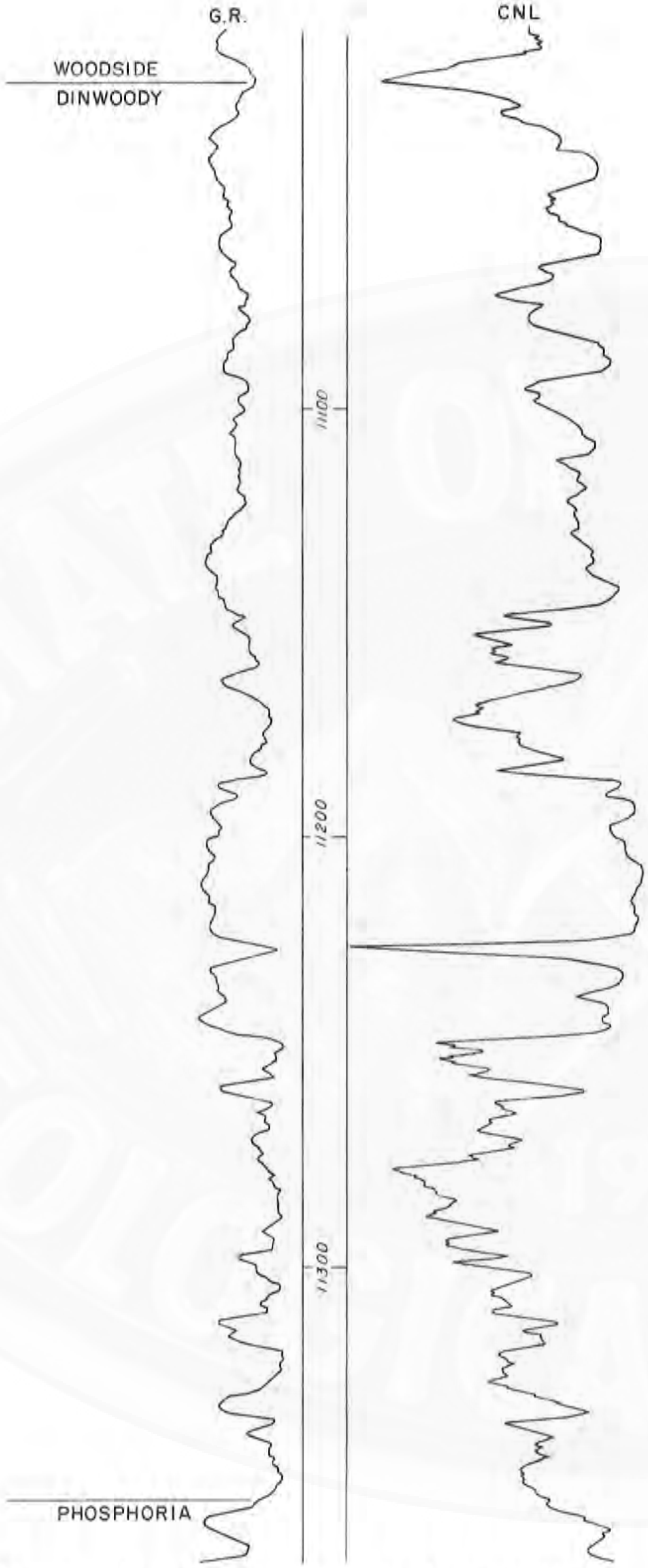


Figure 26. Representative log of Dinwoody Formation, Whitney Canyon Field, 2 Amoco-Chevron-Gulf WI Unit, NE¼SE¼ sec. 18, T.17N., R.119W., Uinta County, Wyoming. Courtesy of Amoco Production Company.

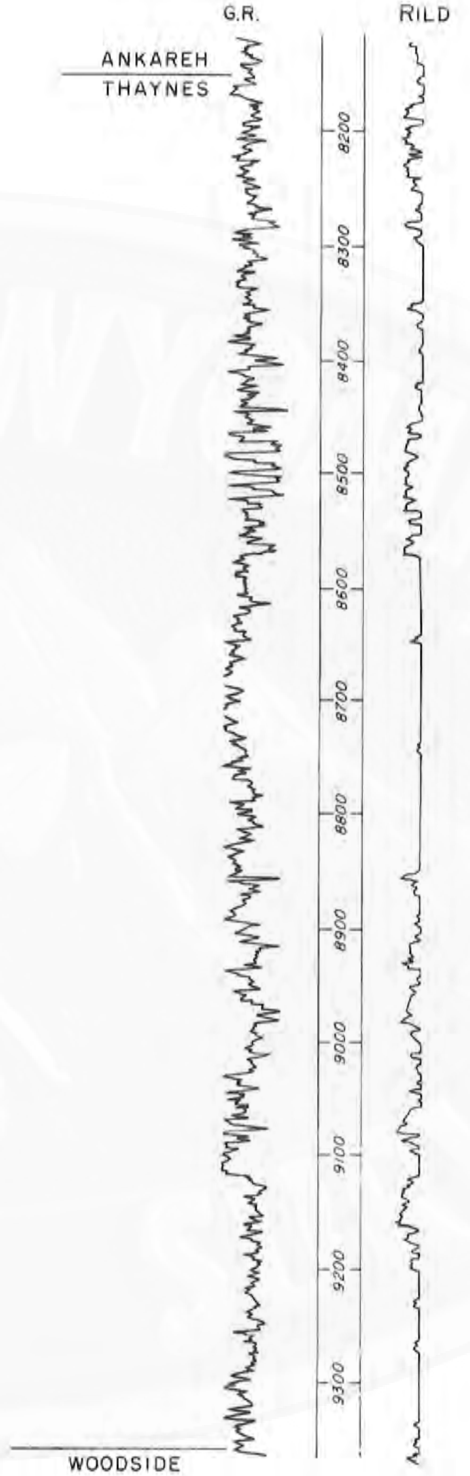


Figure 27. Representative log of Thaynes Limestone, Whitney Canyon Field, 1 Champlin 457 Amoco-A, SW¼SE¼ sec. 7, T.17N., R.119W., Uinta County, Wyoming. Courtesy of Amoco Production Company.

In southeast Idaho at Fort Hall, the Thaynes is 5,525 feet thick and contains seven major lithologic units. From bottom to top, these are (1) lower limestone, (2) lower black limestone, (3) tan silty limestone, (4) upper black limestone, (5) sandstone and limestone, (6) the Portneuf Limestone Member, and (7) the Timothy Sandstone Member (Kummel, 1954). The Thaynes was deposited in marine conditions on a shelf and into the contiguous eastern edge of a miogeosyncline present in eastern Idaho during Triassic time (Kummel, 1954).

JURASSIC(?) AND TRIASSIC(?) NUGGET SANDSTONE

The Nugget Sandstone is probably the most prolific oil producer of any formation in the overthrust belt. It is productive in Anschutz Ranch, Lodgepole, and Pineview Fields in Utah; in Ryckman Creek, Clear Creek, Glasscock Hollow, Painter Reservoir, and Painter Reservoir East Fields in Wyoming; and in Anschutz Ranch East Field in Utah and Wyoming.

The Nugget at Ryckman Creek Field is approximately 800 feet thick and consists of a fairly uniform, massive, cross-bedded to cross-laminated, white to pink to red-brown, porous sandstone. The Nugget is a quartzose sandstone, containing 90-95 percent quartz, 5-10 percent feldspar, and trace amounts of magnetite, pyrite, and pelletal glauconite. The sand grains are mostly very fine to medium, well-rounded and well-sorted. The grains are clear to pink, and locally have an iron oxide coating which has preceded any carbonate cementation that is present. This cementation occurs locally in minor amounts and consists of calcite with some dolomite. Authigenic silica is present to a minor degree and occurs as quartz overgrowths. Clays are rare and, where present, consist of illite and montmorillonite in trace amounts (see Figure 28). Fractures and microfaults are common. The fractures are open to tight, generally high angle, and include several varieties and orientations. Microfaults are slickensided, and have impermeable zones of microgouge or mylonite which form barriers that restrict or orient fluid flow (Kelly and Hine, 1977).

At Painter Reservoir Field, the Nugget is approximately 880 feet thick. It is white to pink, cross-laminated, and massive. Sand grains are mostly very fine to medium, well-sorted, and subrounded. Composition is 90-95 percent quartz, 5 percent feldspar, and minor amounts of calcite, dolomite, and illite clay in the form of authigenic overgrowths (Lamb, 1980).

Figure 28. Scanning electron micrograph of Nugget Sandstone from Ryckman Creek Field showing well-rounded quartz grains with illite clay coating. Porosity = 12.3 percent, permeability = 89 millidarcies (Kelly and Hine, 1977).

Picard (1977) describes two facies of the Nugget in southwest Wyoming and northeast Utah: (1) basal, thin-bedded facies consisting of clayey siltstone, siltstone, mudstone, silty claystone, sandstone, limestone, and dolomite, and (2) upper, cross-stratified facies composed almost entirely of sandstone and siltstone.

The depositional environment of the cross-stratified sandstones in the Nugget was dominantly eolian, while some of the associated beds were deposited in small lakes within dune areas or in inland sebkhas. There is a regional unconformity separating the Nugget from overlying rock units, and one separating it from underlying rock units (Picard, 1977). Pipiringos and O'Sullivan (1978) designate the unconformity above the Nugget Sandstone as J-1 and the one below as J-0.

Because paleontological data is lacking, the exact age of the Nugget Sandstone is still debated. It is considered by the U.S. Geological Survey (Pipiringos and O'Sullivan, 1978) to be Jurassic(?) and Triassic(?) (Figure 19). A representative log of the Nugget from Ryckman Creek Field is shown in Figure 29.

JURASSIC TWIN CREEK LIMESTONE

The Twin Creek Limestone at Painter Reservoir Field in Wyoming is 1,200 feet of gray limestones and shales with some glauconitic sandstones in the upper members. The Twin Creek is not productive in this field, although gas shows were found during drilling. It does produce at Yellow Creek Field in Wyoming as well as at Anschutz Ranch, Elkhorn, Lodgepole, and Pineview Fields in Utah.

Along the Idaho-Wyoming border and in northcentral Utah the Twin Creek Limestone crops out in an area of thrust faulting which extends from the southern end of the Teton Mountains to the south end of the central Wasatch Range. The axis of the trough in which it was deposited is west of the Twin Creek now exposed. The formation thickens from 665 feet in northwestern Wyoming to 2,720 feet near Idaho Falls, and from 440 feet in the Uinta Mountains to 2,850 feet near Salt Lake.

The members of the Twin Creek, from bottom to top, are Gypsum Spring, Sliderock, Rich, Boundary Ridge, Watton Canyon, Leeds Creek, and Giraffe Creek. The Gypsum Spring Member thickens westward, from 12 to 400 feet. It consists mostly of red to yellow siltstone and claystone that is interbedded with brecciated or vuggy or chert-bearing limestone. In Wyoming, a basal unit of brecciated limestone passes eastward into thick masses of gypsum. Chert-bearing limestone thickens westward from units a few feet thick in Wyoming to thick, cliff-forming units in Idaho. The topmost bed in many sections is a green tuff. This member was deposited in very shallow, warm marine waters and lagoons in a sea that was transgressing slowly eastward (Imlay, 1967).

The Sliderock Member thickens westward from 20 to 285 feet and is mostly a grayish-black, medium- to thin-bedded limestone. Its basal beds in Wyoming are oolitic; in Idaho they are sandy, glauconitic, cross-bedded, and pebbly; and in Utah, sandy and oolitic. The Sliderock grades upward into soft, shaly limestone. This member was deposited in a shallow, warm sea that either terminated a short distance east of the Twin Creek trough or passed eastward into lagoons and basins where red beds and gypsum were deposited (Imlay, 1967).

The Rich Member thickens westward from 40 to 500 feet and consists of gray, shaly, splintery limestone that becomes more clayey northward. The upper few feet grade into hard sandy limestone or soft red siltstone. It was deposited as soft calcareous mud in a shallow sea that transgressed eastward beyond the Twin Creek trough (Imlay, 1967).

The Boundary Ridge Member thickens westward from 30 to 285 feet and consists of soft, red, green, and yellow siltstone interbedded with silty to sandy or oolitic limestone. The member changes eastward into soft, gypsiferous, red siltstone and claystone and westward into cliff-forming, oolitic to dense limestone interbedded with red siltstone. It was deposited in a shallow, warm, retreating sea and in lagoons (Imlay, 1967).

The Watton Canyon Member thickens westward from 60 to 400 feet and consists mainly of gray, dense, brittle, medium- to thin-bedded limestone. Some oolitic beds occur. The Watton Canyon was deposited in a shallow sea that transgressed eastward to the Black Hills area (Imlay, 1967).

The Leeds Creek Member thickens westward from about 260 to 1,600 feet. It consists of soft, dense, light gray, shaly limestone. It contains some beds or units of oolitic, silty or sandy, ripple-marked limestone and becomes more clayey northeastward in Idaho and Wyoming and southward in Utah. It was deposited rapidly as soft, calcareous mud in a shallow sea that deepened westward (Imlay, 1967).

The Giraffe Creek Member thickens westward and southward from 25 to 295 feet. It is mostly yellow, green, pinkish-gray, silty to sandy, ripple-marked, thin-bedded limestone and sandstone, but includes some thicker beds of oolitic sandy limestone. It was deposited in a shallow marine to littoral environment in a sea retreating westward (Imaly, 1967). Figure 30 shows a representative log of the Twin Creek Limestone from Pineview Field.

JURASSIC STUMP FORMATION

Mansfield and Roundy (1916) named the Stump Formation after a sandstone sequence on Stump Peak in Idaho, but they did not designate a type section. Pipiringos and Imlay (1979) selected a location at Stump Peak as the principal reference section. This section was also illustrated by Mansfield and Roundy (1916), who described it as a typical exposure of the Stump Formation. The distribution of the Stump is mainly within the overthrust belt of western Wyoming, northeastern Utah, and southeastern Idaho, but it is also present in the Uinta Mountains (Plate 2). It ranges in thickness from 92 feet to over 390 feet and thins irregularly northward and eastward from Idaho.

The Stump is divided into the Curtis Member, similar to the Curtis Formation of east-central Utah, and the Redwater Member, similar to the Redwater Shale Member of the Sundance Formation of Wyoming. Some outcrops of the Stump are similar to both the Curtis Formation and the Redwater Shale Member (Pipiringos and Imlay, 1979). The Stump consists of marine rocks that change very rapidly within short distances (Mansfield and Roundy, 1916).

The Curtis Member of the Stump can be divided into two lithologic units. The lower unit consists of a cliff-forming sandstone containing glauconite and interbedded with sandy siltstone and silty shale. The upper unit is mostly soft, flaky to fissile claystone that contains some very thin sandstone beds and some fossiliferous, oolitic limestone slabs. The overlying Redwater Member of the Stump can also be divided into two lithologic units along the Wyoming-Idaho border and southward to Peoa, Utah. The lower unit is generally siltstone or claystone that

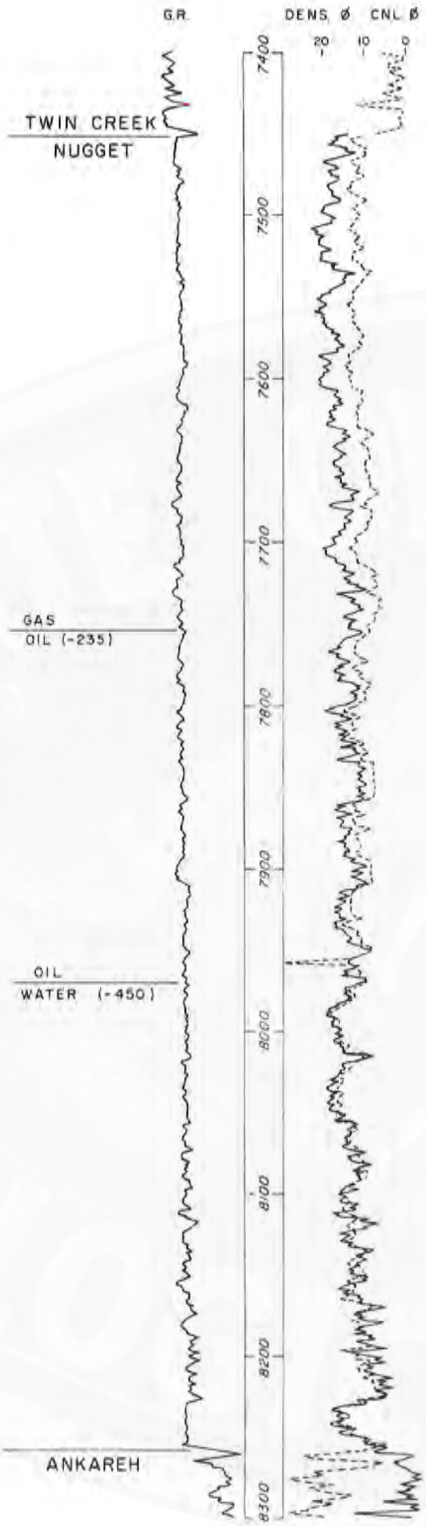


Figure 29. Representative log of Nugget Sandstone, Ryckman Creek Field, Amoco No. 1 Champlin 225 Amoco "A" (Ryckman Creek Unit No. 1), NW¼NW¼ sec. 19, T.17N., R.118W., Uinta County, Wyoming. Courtesy of Amoco Production Company.

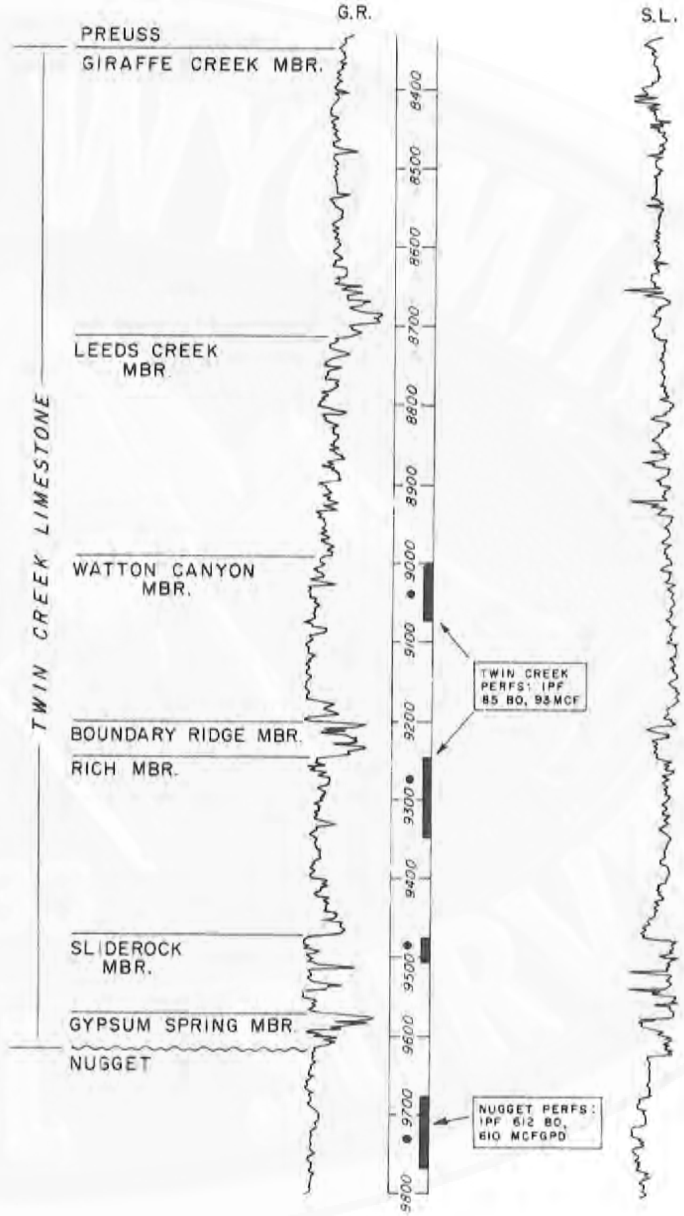


Figure 30. Representative log of Twin Creek Limestone, Pineview Field, 3-5 UPRR, SE¼SW¼ sec. 3, T.2N., R.7E., Summit County, Utah. Courtesy of American Quasar Petroleum.

may be sandy and usually contains belemnites. The upper unit consists of cliff-forming sandstone that is thin- to thick-bedded, crossbedded, calcareous, and glauconitic. There are usually interbeds of sandy siltstone or siltstone partings. Chert pebbles may be present, as well as sandy oolitic limestone beds. Belemnites, bivalves, and ammonites may all be present (Pipiringos and Imlay, 1979).

The Stump Formation produces gas at Pineview Field in Utah. A section described by Pipiringos and Imlay (1979) at Peoa, Utah, about 20 miles southwest of Pineview Field, contains the upper and lower units in both the Curtis and Redwater Members and is 220 feet thick. At a section near Evanston, Wyoming, nearly 30 miles northeast of Pineview Field, the lower or sandstone unit of the Curtis Member is missing but the Stump Formation is still 290 feet thick. A representative log for the Stump Formation was not available.

LOWER CRETACEOUS KELVIN FORMATION

The Lower Cretaceous Kelvin Formation (Plate 2) was named by A.A.L. Mathews (1931) for exposures at Kelvins Grove in Emigration Canyon, about eight miles east of Salt Lake City where it consists of interbedded shale, sandstone, and coarse conglomerate several hundred feet thick. The Kelvin varies rapidly in thickness and lithology from place to place. Owing to its rapid variation and irregular deposition, it can't be traced a great distance from the type locality. The size of the quartzite pebbles making up the conglomerate, one to eight inches in diameter, indicates that the source of the conglomerate, was fairly close. Chert is a minor constituent near the type section, but it becomes more common eastward (Stokes, 1944).

The Kelvin Formation produces gas at Pineview and Lodgepole South Fields in Utah. A representative log of the Kelvin was not available.

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The preceding discussion has dealt with the producing formations in the overthrust belt. For a description of the members, formations, and groups other than those producing oil and gas, see Appendix B. Lageson (1978) has a discussion of the petrography of selected rock samples from formations exposed in the northern Salt River Range, Wyoming.

OVERTHRUST BELT RESERVE ESTIMATES

UNDISCOVERED RECOVERABLE RESERVES

Early estimates of undiscovered recoverable reserves* in the Idaho-Wyoming-Utah salient of the overthrust belt, as defined earlier in the report, were understandably pessimistic. So little was known about the area, and the geology was so complex, that there was little data and no major discovery to offer an insight into the area's potential. However, with the discovery of Pineview Field in 1975, estimates were revised upward, and it is now believed that the overthrust belt is,

** Assumed to be equivalent to the U.S. Geological Survey "undiscovered recoverable resources."*

indeed, one of the top new petroleum producing provinces on the North American continent. Estimates of undiscovered recoverable reserves, made by various individuals and groups over the past 10 years, are summarized in Table 5.

The most optimistic estimate of reserves, made by the Rocky Mountain Oil and Gas Association (RMOGA), was based on a survey of 15 overthrust belt operators (Petroleum Information Corporation, 1978). This estimate covered only U.S. Forest Service RARE II tract nominations, and RMOGA estimates that this total may represent only 10 percent of the overall potential. The estimate made by Ken Cummings (1978) of Empire Resources in an unpublished report was also considered quite optimistic, and was based on a survey of industry people familiar with the overthrust belt. However, with the recent large discoveries and better definition of existing fields through development drilling, the most recent estimate by the U.S. Geological Survey Resources Appraisal Group (Petroleum Information Corp., 1981) in early spring, 1981 indicates that these early optimistic estimates may be fairly accurate. The Resource Appraisal Group put undiscovered recoverable reserves at 6.7 billion barrels of oil and 58.4 trillion cubic feet of gas, quite different from the 0-0.2 billion barrels of oil and 0-1.1 trillion cubic feet of gas estimated by a similar U.S. Geological Survey group in 1975 (Miller and others, 1975). This 1981 U.S. Geological Survey report estimates undiscovered recoverable oil in the United States at 82.6 billion barrels and gas at 593.9 trillion cubic feet.

The key to estimating reserves for a complex area like the overthrust belt lies with the information gleaned from fields already discovered within the area. Therefore, as the geologic parameters and reservoir characteristics of existing fields are better defined, trends can be identified and better exploration models developed, leading to more accurate reserve estimates. Table 5 illustrates this, in that, as additional discoveries were made, the estimates of undiscovered recoverable reserves increased both in size and reliability. However, many more discoveries in various parts of the overthrust belt, particularly the northern portion, are needed before a reliable overall reserve estimate is possible. The present numbers, although far more accurate and meaningful than the early estimates, are still only broad "ball park" numbers based on minimal data.

DISCOVERED POTENTIAL RESERVES

Discovered potential reserves differ from undiscovered reserves in that they represent only those reserves actually discovered in a given area; therefore, these data have more substance. Undiscovered reserve estimates are developed by projecting data from known areas into unknown areas and usually call for very broad assumptions and trend projection, a very subjective process.

The most recent published estimate of discovered potential reserves in the overthrust belt was made by Amoco Production (Oil and Gas Journal, 1980b). Amoco put discovered potential reserves for the overthrust belt at 9,725 billion cubic feet of gas and 914 million barrels of oil and gas liquids, numbers which many people consider quite conservative and probably now require revision. Only four months earlier, Amoco had estimated discovered potential reserves at 4-5 trillion cubic feet of gas and 500 million barrels of oil and gas liquids (Oil and Gas Journal, 1980a).

The newest estimate by Amoco is shown in Table 6, broken down by specific producing trends. The Pineview - Painter Reservoir - Cleark Creek - Ryckman Creek,

Table 5: Overthrust belt undiscovered oil and gas reserves estimates.

	UNDISCOVERED RECOVERABLE RESERVES	
	OIL (Billions Bbls.)	GAS (Trillion Cu. Ft.)
MONLEY (1971)	3.3	——
U.S.G.S. 1975 ESTIMATE Miller et al. (1975)	0-0.2	0-1.1
U.S.G.S. 1977 ESTIMATE POWERS (1977)	0.6-3.0	4.0-12.0
R.M.O.G.A. 1978 ESTIMATE (RARE II TRACTS ONLY) PETROLEUM INFORMATION CORP. (1978)	1.5-8.8*	6.0-51.5*
CUMMINGS (1978) UNPUBLISHED ESTIMATE	15	75
POTENTIAL GAS COMMITTEE 1979 ESTIMATE PETROLEUM INFORMATION CORP. (1979)	——	65
U.S.G.S. 1980 ESTIMATE PETROLEUM INFORMATION CORP. (1981)	7.5	30.5
U.S.G.S. 1981 ESTIMATE PETROLEUM INFORMATION CORP. (1981)	6.7(82.6)**	58.4(593.9)**

* R.M.O.G.A. estimated that reserves for the entire Idaho-Wyoming-Utah overthrust belt could be 10 times this amount.

** Estimates for the entire U.S. *in parentheses*.

Source: Modified from Ver Ploeg (1979)

Table 6: Discovered potential reserves in the Idaho-Wyoming-Utah overthrust belt.

FIELDS	GAS (BILLION CU.FT.)	LIQUIDS (MILLION BBLS.)
PINEVIEW, RYCKMAN CREEK, PAINTER RESERVOIR, CLEAR CREEK	600	147
YELLOW CREEK, ANSCHUTZ RANCH (JURASSIC PRODUCTION)	65	2
CARTER CREEK — WHITNEY CANYON	5,300	115
CAVE CREEK, YELLOW CREEK (DEEP PRODUCTION)	400	10
PAINTER RESERVOIR EAST, ANSCHUTZ RANCH EAST, GLASSCOCK HOLLOW	3,460	640
	9,725	914

Source: AMOCO Production Co.

Jurassic and Triassic oil and gas trend is credited with 600 million MCF of gas and 147 million barrels of oil. The Yellow Creek - Anschutz Ranch, Jurassic and Triassic gas trend is estimated at 65 million MCF of gas and 2 million barrels of liquids. To date, the largest structural trend involving primarily gas is the Whitney Canyon - Carter Creek, Triassic-Paleozoic trend, with 5.3 billion MCF of gas and 115 million barrels of liquids. The Cave Creek - Yellow Creek, Paleozoic structural trend is expected to contain 400 million MCF of gas and 10 million barrels of liquids. The largest oil-rich structural trend, to date, is the Anschutz Ranch East - Glasscock Hollow - Painter Reservoir East, Jurassic-Triassic trend, which contains an estimated 3,460 million MCF of gas and 640 million barrels of oil and natural gas liquids.

HIGH EXPLORATION AND DEVELOPMENT COSTS IN THE OVERTHRUST BELT

The important geological structures in the overthrust belt that have proven to be petroleum traps were not located as a result of surface expression as were many of the older fields in Utah and Wyoming. They all represent deeply buried anticlinal structures which had no surface expression and were located using seismic reflection techniques. Basically, seismic reflection is a process by which travel times of elastic waves, generated at or near the surface and reflected back from rock interfaces, are measured to determine the depth and configuration of specific rock units. The complex geology, including multiple thrust sheets and highly deformed rock strata, makes interpretation of overthrust belt seismic information extremely difficult.

As a result of the rugged terrain, elaborate equipment used, and problems with accessibility, costs associated with seismic exploration in the area are very high. Average costs can easily run over $400,000 per month for a helicopter-supported seismic crew. The number or miles shot per month averages 40-45 in rough terrain and about 70 in road areas. Costs can run as high as $30,000 per mile in extremely rugged areas. Three-dimensional seismic surveys used by several companies cost even more. By comparison, less complex and rugged areas outside the overthrust belt can be surveyed with crew costs closer to $300,000 per month with a typical crew covering closer to 90-100 miles per month (at a cost of about $3,000 per mile). Costs for all seismic crews working in the overthrust belt exceed $6 million a month with data processing costs adding at least another $2 million (Rountree, 1980). As a result of the high costs, it has become popular for companies to explore with group shoots; i.e., 10-12 companies share the cost for the seismic survey and all receive the same raw data. It is then up to each company's geologists and geophysicists to make their own interpretations.

Complex geology, rugged terrain with poor access, and seasonal working restrictions related to bad weather also have their effect on exploration drilling costs. These costs, first of all, include a flat fee for constructing the access road and drill site, which varies considerably depending on terrain. In addition, the costs of moving in and setting up the drill rig, tearing it down, and moving out can run over $125,000. Rental costs for a rig often exceed $7,000 per day. The cost of completing a production well varies from field to field: Anschutz Ranch wells average approximately 1.5 million dollars with an average depth of about 8,000 feet, Anschutz Ranch East wells average approximately 5 million dollars with an average depth of about 14,500 feet, and Whitney Canyon and Yellow Creek wells average approximately 7.5 million dollars with average depths of about 16,500 feet and 13,500 feet, respectively (personal communication, Doug White, Amoco Production Co., July 1981). From these figures, average price per foot can be calculated. These range from a low of $187/foot for a well in Anschutz Ranch Field to a high of $555/ foot for a well in Yellow Creek Field. These figures are for wells drilled without any problems; wells which encounter any type of problem can very well cost a lot more. The Preuss salt has been particularly troublesome during drilling, and one side track job can add $500,000 to the cost of the well.

After completing the well, the operator has the additional cost of constructing processing facilities and laying pipeline to carry the product to refineries or various markets. In some cases, expensive special equipment has to be installed to process "sour gas" (gas with high hydrogen sulfide content), Hogback Ridge and Whitney Canyon - Carter Creek Fields being notable examples. Many of the drilling and completion costs are based on an hourly rate, and it is evident that any type of delay can be financially devastating.

TRANSPORTATION AND PROCESSING FACILITIES

Once a new discovery has been identified in the overthrust belt, the additional expensive tasks of treating the product and transporting it to market must be undertaken. The sulfur-rich gas that has been found in such vast amounts must be treated to remove the sulfur before transportation. As a result, several sulfur treatment plants are under construction or have been proposed (Table 7). The largest of these are Amoco's 250-million-cubic-feet-per-day plant and Chevron's 150-million-cubic-feet-per-day plant. When completed, these plants will process the high-sulfur gas (15-17 percent) produced from the Paleozoic reservoirs in Whitney Canyon - Carter Creek Field. Construction cost for the Amoco facility is estimated at $120 million and the Chevron facility, which could eventually expand to triple the initial capacity, will cost approximately $350 million. Additional gas facilities for natural gas liquid recovery, nitrogen recovery, sweet (low sulfur) gas processing, etc., are also under construction or recently completed. The effects of these projects on local communities are obvious when the peak and permanent work force associated with the construction and operation of the facilities is considered (Table 7). As an example, the town of Evanston, Wyoming had a population of 4,721 according to a 1975 census; now, there are an estimated 18,000 people in and around the town.

In addition to the treatment facilities, transportation facilities in the form of in-field gathering lines and, most important of all, major pipelines for transporting oil, natural gas, natural gas liquids, and sulfur to market are also necessary. Four major pipelines are in various stages of proposal, planning, and permitting, and one was completed and on line in December 1980.

The Trailblazer Pipeline (Figure 31) will be an 800-mile, 36-inch, natural gas pipeline extending from fields near Evanston, Wyoming and Anschutz Ranch Field in Utah to Beatrice, Nebraska. Natural Gas Pipeline Company of America, Mountain Fuel, Northern Natural Gas, Colorado Interstate Gas, and Columbia

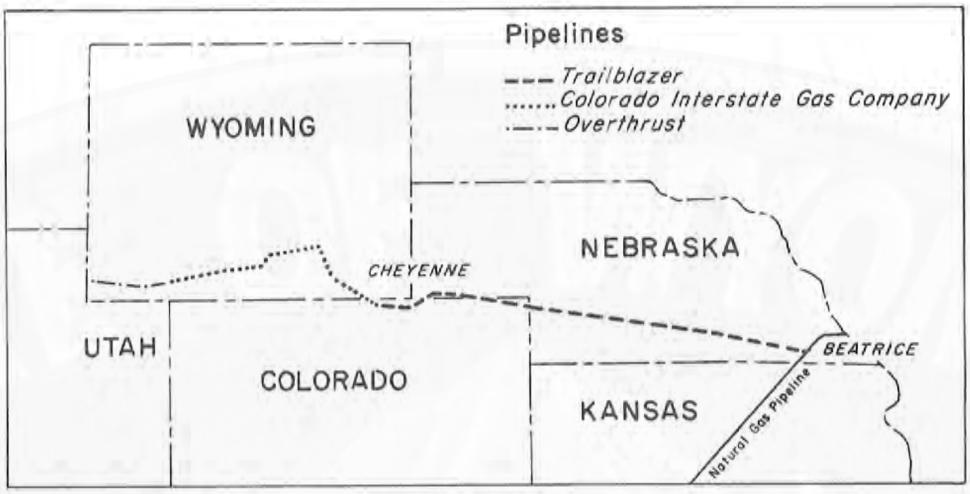
Table 7: Existing and planned overthrust belt gas processing facilities.

Plant, Operator, and Type of Facility	Size (million cu. ft./day)	Location	Current Status	Completion Date	Peak Construction Force	Permanent Employees
Whitney Canyon, Amoco, sour gas	250	8 miles NE of Highway 89 on Whitney Canyon Road	20% complete	second quarter, 1982	1,000	70
Carter Creek, Chevron, sour gas	150 (450)	16 miles NE of Highway 89 on Whitney Canyon Road	11% complete	July, 1982	1,160	120
Cave Creek, Amoco, sour gas	possibly 250	Summit County, Utah	design stage	1984?	?	?
Moxa Arch, Amoco, sweet gas	100	6 miles W of Granger	early construction	mid-1982	125	?
Yellow Creek, Champlin, sweet gas	80	Summit County, Utah	in operation	completed	---	18
Ryckman Creek, Amoco, recovers some condensate and recompresses gas	40	Ryckman Creek	in operation	completed	---	24
Painter Reservoir, Chevron, nitrogen recovery	44 MMCF/day nitrogen	Painter Reservoir N of Evanston	in operation	completed	---	12
NGL* recovery	35 MMCF/day natural gas & 70,000 gal./day NGL		in operation	completed	---	8

According to the Wyoming Oil and Gas Conservation Commission, gas plants are proposed at Glasscock Hollow and Anschutz Ranch East Fields.

Source: Overthrust News, Issue no. 1, fall, 1980, and issue no. 3, summer, 1981.

*NGL = natural gas liquid from a separate Chevron plant in the Painter Reservoir Field.



ROUTE OF THE TRAILBLAZER PIPELINE

ROUTE OF THE ROCKY MTN. PIPELINE PROJECT

ROUTE OF THE MAPCO PIPELINE

Figure 31. Recently proposed or completed pipelines serving the overthrust belt area. Taken from Overthrust Industrial Association (1980).

Transmission will construct and own the pipeline. The proposed Trailblazer System would move an initial volume of 617,400 MCF of gas per day from the overthrust belt to markets in the Midwest and East. Total cost of the pipeline and its facilities is estimated at $549 million (Overthrust Industrial Assoc., 1980).

The MAPCO Rocky Mountain Pipeline transports natural gas liquids through a 4-10-inch pipeline from Rock Springs, Wyoming, 1,196 miles to Seminole, Texas (Figure 31) and from there through existing lines to the Midwest (Overthrust Industrial Assoc., 1980). Initially, the line carries 35,000 barrels per day, expandable to 65,000 in late 1981, and eventually reaching total capacity of 100,000 barrels per day. No figures were available on construction cost. The pipeline went on line in late December, 1980.

Another natural gas pipeline, the Rocky Mountain Pipeline Project, is proposed to carry gas from Sage, Wyoming to the West Coast (Figure 31). The projected 30-inch-diameter line has been proposed by Pacific Gas Transmission Company, El Paso Natural Gas, and Northwest Pipeline Corporation (Overthrust Industrial Assoc., 1980).

The Trans-Anadarko Pipeline System is planned to extend 635 miles from the Texas Panhandle to Monroe, Louisiana. United Gas Pipeline Company and Southern Natural Gas will construct the line to carry gas from the Anadarko Basin as well as gas transported to that point from the overthrust belt through exising Colorado Interstate Gas pipelines (Overthrust Industrial Assoc., 1980).

Indications are that the two large gas treatment plants under construction by Amoco and Chevron at Whitney Canyon - Carter Creek Field will initially produce nearly 2,300 short tons of sulfur per day as a by-product of the process. Amoco and Chevron will haul their sulphur from the Whitney Canyon - Carter Creek facilities by truck to the Skull Point loading facility, 8 miles south of Kemmerer. The railroad load-out facility will cost approximately $20 million (Overthrust Industrial Assoc., 1981; Bureau of Land Management, 1981).

LAND AND MINERAL OWNERSHIP WITHIN THE OVERTHRUST BELT

Petroleum exploration in the overthrust belt and in many other areas of the western United States must contend with a complex land and mineral ownership pattern. First, much of the area is characterized by separation of surface and mineral ownership. Second, the overthrust belt area includes National Forest lands, public domain lands administered by the U.S. Bureau of Land Management (BLM), Union Pacific Railroad lands, State lands, and private lands. The policies under which exploration, leasing, drilling, and development occur vary considerably among these types. As demonstrated by the map in Figure 32, a very large portion of the land within the overthrust belt is federally controlled by either the U.S. Forest Service or the BLM. Of this federally controlled land, approximately 47 percent is reportedly closed or effectively withdrawn from mineral development (Kleppe, 1977).

Figure 33 depicts the areas in or immediately adjacent to the overthrust belt which are currently under study by various federal agencies. In January, 1979, the U.S. Forest Service under their Roadless Area Review and Evaluation (RARE III) recommended the 290,000-acre Gros Ventre tract for wilderness and the 135,000-acre Palisades tract for further planning. These two tracts will continue to be managed under temporary but restrictive guidelines until final disposition of the land is made by Congress. In addition, the BLM, under their roadless area evaluation program, had identified the 13,970-acre Lake Mountain study area and the 32,236-acre Raymond Mountains study area for further evaluation, placing these areas under a restrictive interim management policy. An interested reader is referred to Everett and Associates, 1980; General Accounting Office, 1981; Petroleum Information Corporation, 1978; Powers, 1977; Schumacher and others, 1980; and Ver Ploeg, 1979 for descriptions of these federal studies and their effect on exploration.

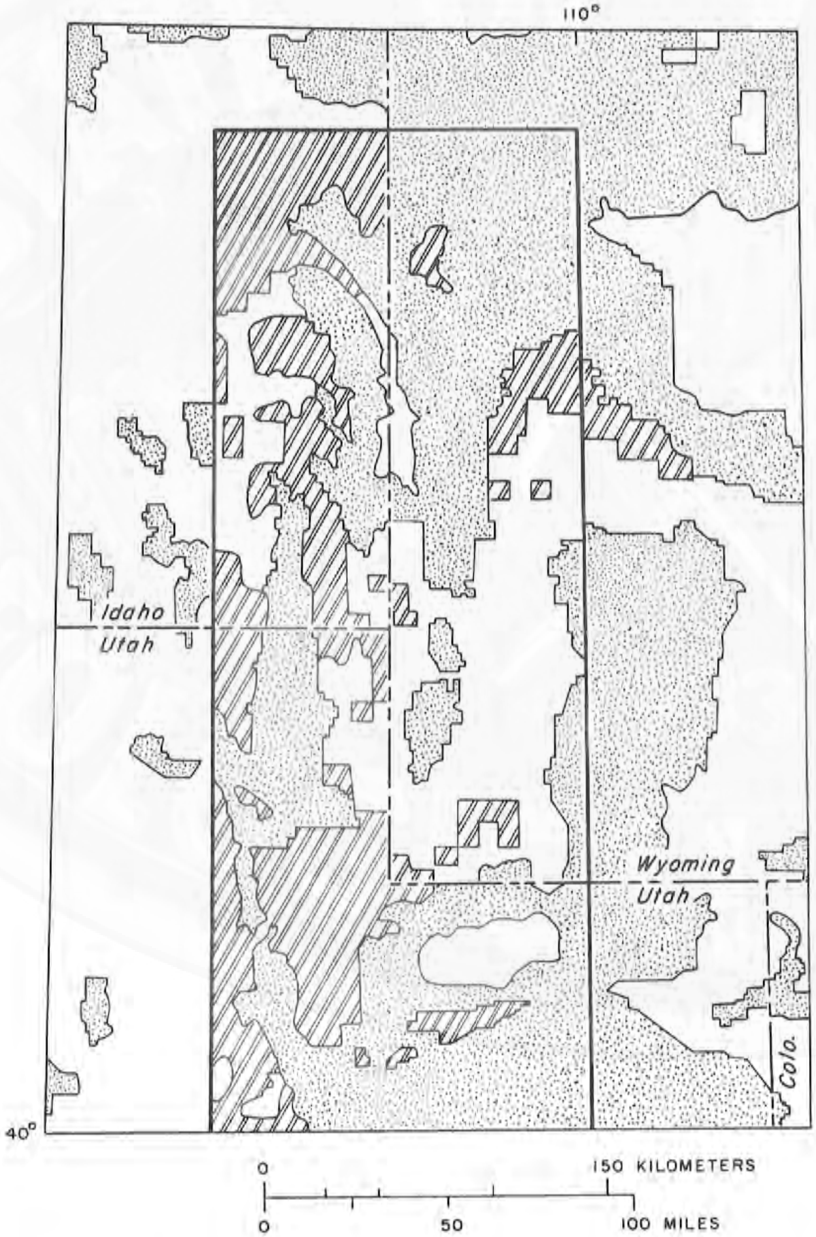


Figure 32. Map showing federal lands which are subject to mineral restrictions in the Idaho-Wyoming-Utah portion of the overthrust belt. Stippled and clear areas represent federal lands, 47 percent of which are effectively closed to oil and gas development. Diagonal patterned areas represent nonfederal lands. Taken from Powers (1977).

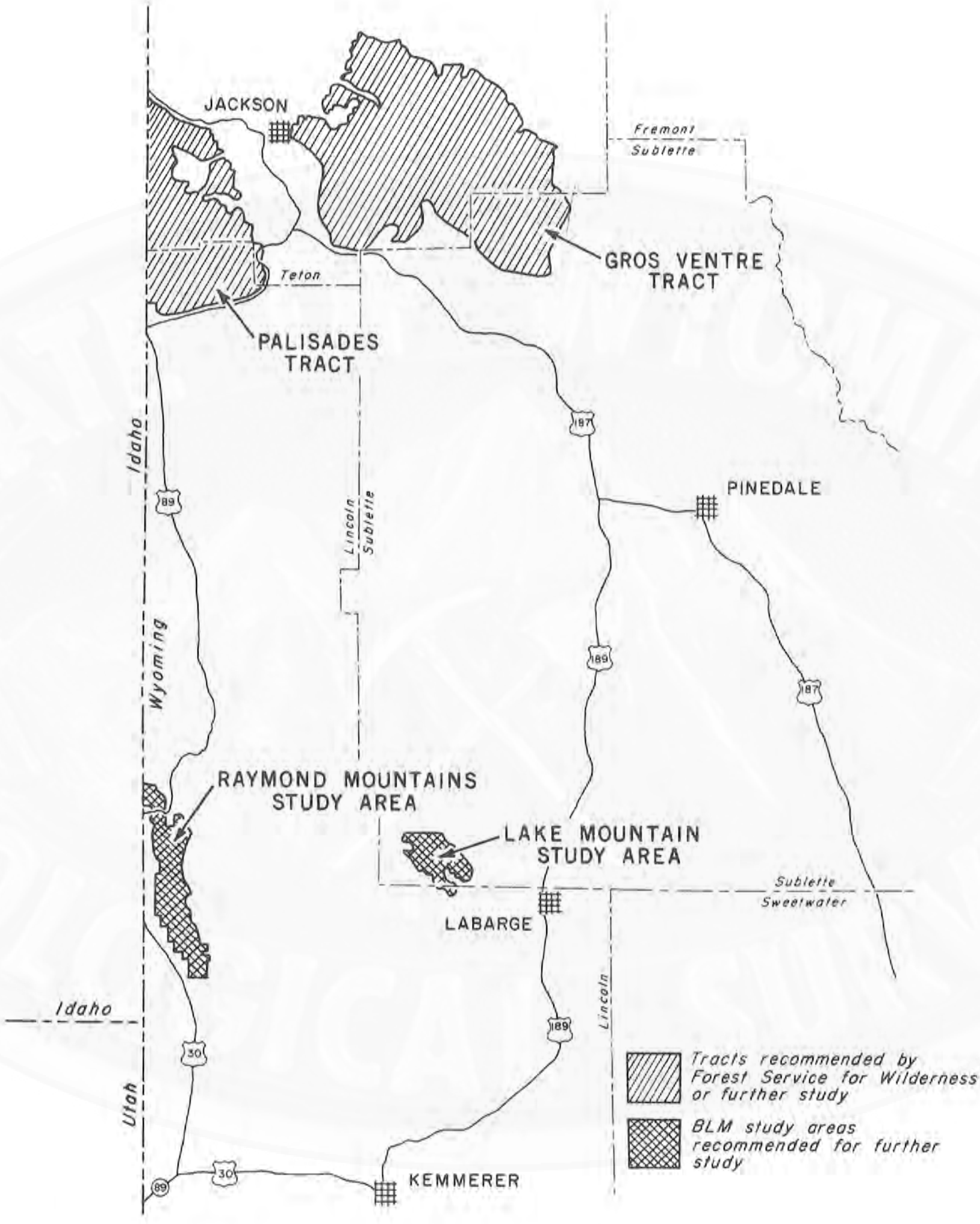


Figure 33. Wilderness study areas in or near the Wyoming portion of the overthrust belt. Modified from Ver Ploeg (1979).

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APPENDIX A
RESERVOIR CHARACTERISTICS AND GAS AND OIL ANALYSES FOR SELECTED OVERTHRUST BELT FIELDS*

Field: ANSCHUTZ RANCH

Formation:	Twin Creek
Depth (Top):	5,442'
Thickness (Gross):	1,618'
(Pay):	800'
Average Porosity:	NA
Permeability:	NA
Oil Gravity:	54° API
Gas BTU:	1,062

Typical Gas Composition:

	Mol%
Nitrogen	6.59
Carbon Dioxide	----
Hydrogen Sulfide	----
Methane	82.55
Ethane	7.33
Propane	2.43
Iso-Butane	0.47
Normal Butane	0.63
Iso-Pentane	0
Normal Pentane	0
Hexanes Plus	0

Source of Data: Amoco Production Co., 1981.

Field: ANSCHUTZ RANCH

Formation:	Nugget
Depth (Top):	8,312'
Thickness (Gross):	NA
(Pay):	150-200'
Average Porosity:	NA
Permeability:	37 md
Oil Gravity:	56.1° API
Gas BTU:	1,077

Typical Gas Composition:

	Mol%
Nitrogen	7.09
Carbon Dioxide	0.07
Hydrogen Sulfide	----
Methane	80.99
Ethane	7.55
Propane	2.56
Iso-Butane	0.57
Normal Butane	0.68
Iso-Pentane	0.25
Normal Pentane	0.24
Hexanes Plus	0

Source of Data: Amoco Production Co., 1981.

Field: ANSCHUTZ RANCH EAST

Formation:	Nugget
Depth (Top):	12,796'
Thickness (Gross):	NA
(Pay):	60' (perforated)
Average Porosity:	13.5%
Permeability:	12 md
Oil Gravity:	49.5° API
Gas BTU:	NA

Typical Gas Composition:

	Mol%
Nitrogen	----
Carbon Dioxide	----
Hydrogen Sulfide	----
Methane	2.26
Ethane	0.16
Propane	0.55
Iso-Butane	0.32
Normal Butane	0.58
Iso-Pentane	0.47
Normal Pentane	0.56
Hexanes Plus	95.10

Source of Data: Amoco Production Co., 1981

Field: CAVE CREEK

Formation:	Phosphoria
Depth (Top):	11,461'
Thickness (Gross):	495'

**Some of the analyses in this appendix represent average data for a whole field, while others pertain to only one well within a field and should be used with this in mind.*

(Pay): 495'
Average Porosity: 6% (Fractured reservoir)
Permeability: NA
Oil Gravity: 49.5% (heptanes+)
Gas BTU: 1,010
Typical Gas Composition:

	Mol%
Nitrogen	2.33
Carbon Dioxide	1.26
Hydrogen Sulfide	12.59
Methane	76.16
Ethane	5.32
Propane	1.41
Iso-Butane	0.29
Normal Butane	0.33
Iso-Pentane	0.13
Normal Pentane	0.09
Hexanes Plus	0.09

Source of Data: Amoco Production Co., 1981.

Field: PAINTER RESERVOIR

Formation: Nugget
Average Pay Thickness: 450'
Oil/Gas Column: 1,100'
Porosity: 10-20%
Permeability: 1-50 md
Gas-Oil Ratio: 3,500:1
Drive Mechanism: Water drive and expanding gas cap
Oil Gravity: 46-48° API
Sulphur: 0.26%
Typical Gas Composition:

	Mol%
Nitrogen	0.014
Carbon Dioxide	0.018
Hydrogen Sulfide	-----
Methane	68.80
Ethane	12.02
Propane	6.08
Butane	1.45
Other Hydrocarbons	11.60

Source of Data: Wyoming Geol. Assoc. Symposium, Wyoming Oil and Gas Fields, Greater Green River Basin, 1979 (American Quasar Petroleum Co.).

Field: PAINTER RESERVOIR

Formation: Nugget
Thickness (Gross): 880'
Average Porosity: 14.1%
Average Permeability: 22.8 md
Oil Gravity: 46° API
Gas BTU: 1,276
Typical Gas Composition:

	Mol%
Carbon Dioxide and Nitrogen	1.9
Hydrogen Sulfide	----
Methane	69.5
Ethane	11.5
Propane	6.0
Iso-Butane	3.3
Normal Butane	1.4
Iso-Pentane	0.9
Normal Pentane	5.5

Source of Data: Petroleum Information Corp., 1978.

Field: PAINTER RESERVOIR

Formation: Nugget
Gross Completed Interval: 10,290-10,318'
Average Porosity: 15%
Permeability: 1-1,000 md
Gas-Oil Ratio: 2,095:1
Drive Meachanism: Water and Gas Cap
Oil Gravity: 46-48° API
Source of Data: Mesa Petroleum Co., 1979

Field: PAINTER RESERVOIR

Formation: Nugget
Oil Column: 319'
Gas Column: 750'
Average Porosity: 14.1%
Average Permeability: 22.8 md
Gas-Oil Ratio: 2,133:1
Drive Meachanism: Expanding Gas Cap and Water Drive
Oil Gravity: 48.4° API
Gas BTU: 1,276
Source of Data: Lamb, V.F., Amer. Assoc. Petroleum Geologists, Bull., v. 64, no. 5, p. 643, 1980.

Field: PINEVIEW

Formation: Kelvin

Average Pay Thickness: 21-48'
Oil/Gas Column: Unknown
Porosity: 6%
Peremability: Unknown (fractured)
Gas-Oil Ratio: 1,125:1
Drive Mechansim: Water
Oil Gravity: 48.4° API
Source of Data: Wyoming Geol. Assoc. Symposium, Wyoming Oil and Gas Fields, Greater Green River Basin, 1979 (American Quasar Petroleum Co.).

Field: PINEVIEW

Formation: Stump
Average Pay Thickness: 40'
Porosity: 13%
Permeability: 30 md
Gas-Oil Ratio: 550:1
Drive Mechansim: Water
Oil Gravity: 46° API
Source of Data: Wyoming Geol. Assoc. Symposium, Wyoming Oil and Gas Fields, Greater Green River Basin, 1979 (American Quasar Petroleum Co.).

Field: PINEVIEW

Formation: Twin Creek
Average Pay Thickness: 16-100'
Oil Column: 500'
Porosity: 3%
Permeability: 30 md (est) fractured
Gas-Oil Ratio: 1,000:1
Drive Mechanism: Water
Oil Gravity: 46° API
Source of Data: Wyoming Geol. Assoc. Symposium, Wyoming Oil and Gas Fields, Greater Green River Basin, 1979 (American Quasar Petroleum Co.).

Field: PINEVIEW

Formation: Nugget
Average Pay Thickness: 160'
Oil Column: 1,069'
Porosity: 10%
Permeability: 3 md
Gas-Oil Ratio: 1,000:1
Drive Mechanism: Water
Oil Gravity: 46° API
Source of Data: Wyoming Geol. Assoc. Symposium, Wyoming Oil and Gas Fields, Greater Green River Basin, 1979 (American Quasar Petroleum Co.).

Field: PINEVIEW

Average Gas Analysis:

	Mol%
First Phase @ approx. 560#	
Nitrogen	1.14
Carbon Dioxide	2.52
Hydrogen Sulfide	----
Methane	75.36
Ethane	11.67
Propane	5.69
Iso-Butane	1.15
Normal Butane	1.38
Iso-Pentane	0.34
Normal Pentane	0.24
Hexanes	0.23
Hexanes Plus	0.26
Gas BTU	1,246
Second Phase @ approx. 70-90#	
Nitrogen	1.36
Carbon Dioxide	1.29
Hydrogen Sulfide	----
Methane	58.75
Ethane	18.33
Propane	11.35
Iso-Butane	2.40
Normal Butane	2.90
Iso-Pentane	0.72
Normal Pentane	0.54
Hexanes	1.50
Hexanes Plus	0.87
Gas BTU	1,557
Third Phase @ approx. 8#	
Nitrogen	0.74
Carbon Dioxide	0.10
Hydrogen Sulfide	----
Methane	14.36
Ethane	22.04
Propane	29.14
Iso-Butane	8.79
Normal Butane	12.05

Iso-Pentane	3.61
Normal Pentane	2.92
Hexanes	2.98
Hexanes Plus	3.26
Gas BTU:	2,578

Source of Data: Petroleum Information Corp., 1978.

Field: RYCKMAN CREEK

Formation: Nugget
Depth (Top): 7,450-7,700'
Thickness (Gross): 400'
(Pay): 150'
Average Porosity: 15%
Permeability: 35 md
Oil Gravity: 49° API
Gas BTU: (1,268 Associated)
(1,190 Gas Cap)
Typical Gas Composition:

Gas Cap

	Mol%
Nitrogen	2.28
Carbon Dioxide	----
Hydrogen Sulfide	----
Methane	79.66
Ethane	11.42
Propane	4.91
Iso-Butane	0.85
Normal Pentane	0.82
Iso-Pentane	0.04
Normal Pentane	0.02
Hexanes Plus	0

Associated Gas

	Mol%
Nitrogen	1.84
Carbon Dioxide	----
Hydrogen Sulfide	----
Methane	73.40
Ethane	15.44
Propane	7.05
Iso-Butane	1.10
Normal Butane	1.09
Iso-Pentane	0.05
Normal Pentane	0.02
Hexanes Plus	0.01

Source of Data: Amoco Production Co., 1981.

Field: RYCKMAN CREEK

Formation: Nugget
Average Pay Thickness: 300'
Oil/Gas Column: 380'
Porosity: 8-21%, average 15%
Permeability: 1.5-945, average 34 md
Gas-Oil Ratio: 1,108:1
Drive Mechanism: Active Water
Oil Gravity: 47.4° API
Gas BTU: 1,239
Typical Gas Composition:

	Mol%
Nitrogen	2.31
Carbon Dioxide	0.05
Hydrogen Sulfide	----
Methane	77.86
Ethane	11.27
Propane	5.25
Butane	1.11
Other Hydrocarbons	2.15

Source of Data: Wyoming Geol. Assoc. Symposium, Wyoming Oil and Gas Fields, Greater Green River Basin, 1979 (Chevron U.S.A. Inc.).

Field: RYCKMAN CREEK

Formation: Nugget
Gross Completed Interval: 7,804-7,880'
Average Porosity: 15%
Permeability: 1.5-934 md
Gas-Oil Ratio: 1,107:1
Drive Mechansim: Water
Oil Gravity: 47° API
Source of Data: Mesa Petroleum Co., 1979.

Field: WHITNEY CANYON - CARTER CREEK

Formation: Bighorn
Depth (Top): 15,580'
Thickness (Gross): 600'
(Pay): NA
Average Porosity: 2%
Permeability: NA
Oil Gravity: NA
Gas BTU 1,070
Typical Gas Composition:

	Mol%
Nitrogen	0.74
Carbon Dioxide	2.03
Hydrogen Sulfide	0.61
Methane	87.70
Ethane	6.64
Propane	1.72

Iso-Butane	0.30
Normal Butane	0.09
Iso-Pentane	0.04
Normal Pentane	0.02
Hexanes Plus	0.01

Source of Data: Amoco Production Co., 1981.

Field: WHITNEY CANYON - CARTER CREEK

Formation:	Madison
Depth (Top):	12,978'
Thickness (Gross):	1,500'
(Pay):	200'
Average Porosity:	10%
Permeability:	NA
Oil Gravity:	76° API
Gas BTU:	985

Typical Gas Composition:

	Mol%
Nitrogen	0.04
Carbon Dioxide	5.15
Hydrogen Sulfide	14.50
Methane	71.50
Ethane	5.91
Propane	1.60
Iso-Butane	0.30
Normal Butane	0.40
Iso-Pentane	0.15
Normal Pentane	0.10
Hexanes Plus	0.20

Source of Data: Amoco Production Co., 1981

Field: WHITNEY CANYON - CARTER CREEK

Formation:	Weber
Depth (Top):	11,960'
Thickness (Gross):	350'
(Pay):	NA
Average Porosity:	6%
Permeability:	10-20 md
Oil Gravity:	60° API
Gas BTU:	1,076

Typical Gas Composition:

	Mol%
Nitrogen	0.04
Carbon Dioxide	3.36
Hydrogen Sulfide	11.49
Methane	73.56
Ethane	7.18
Propane	2.38
Iso-Butane	0.54
Normal Butane	0.72
Iso-Pentane	0.36
Normal Pentane	0.11
Hexanes Plus	0.35

Source of Data: Amoco Production Co., 1981.

Field: WHITNEY CANYON - CARTER CREEK

Formation:	Phosphoria
Depth (Top):	11,350'
Thickness (Gross):	500'
(Pay):	NA
Average Porosity:	4%
Permeability:	NA
Oil Gravity:	70° API
Gas BTU:	1,064

Typical Gas Composition:

	Mol%
Nitrogen	2.60
Carbon Dioxide	4.80
Hydrogen Sulfide	6.70
Methane	73.52
Ethane	8.11
Propane	2.00
Iso-Butane	0.80
Normal Butane	0.80
Iso-Pentane	0.18
Normal Pentane	0.19
Hexanes Plus	0.30

Source of Data: Amoco Production Co., 1981.

Field: WHITNEY CANYON - CARTER CREEK

Formation:	Thaynes
Depth (Top):	8,240'
Thickness (Gross):	1,300'
(Pay):	70'
Average Porosity:	4%
Permeability:	NA
Oil Gravity:	76° API
Gas BTU:	1,037

Typical Gas Composition:

	Mol%
Nitrogen	9.35
Carbon Dioxide	----
Hydrogen Sulfide	----
Methane	74.46
Ethane	6.16
Propane	2.73
Iso-Butane	----
Normal Butane	----

Iso-Pentane	----
Pentane	----
Hexanes Plus	----

Source of Data: Amoco Production Co., 1981.

Field: WHITNEY CANYON - CARTER CREEK

Formation: Thaynes
Average Pay Thickness: 88'
Porosity: Less than 5% matrix, fractured
Permeability: Unknown
Gas-Oil Ratio: 24,054:1
Drive Mechanism: Gas Expansion
Condensate Gravity: 61.4° API
H_2S: 150 ppm
Source of Data: Wyoming Geol. Assoc. Symposium, Wyoming Oil and Gas Fields, Greater Green River Basin, 1979 (Gulf Oil Exploration and Production Co.).

Field: WHITNEY CANYON - CARTER CREEK

Formation: Bighorn
Average Pay Thickness: 30'
Porosity: 2% matrix, fractured
Permeability: Unknown
Gas-Oil Ratio: 89,558:1
Drive Mechansim: Gas Expansion
Condensate Gravity: 52.5° API
H_2S: 10,500 ppm
Source of Data: Wyoming Geol. Assoc. Symposium, Wyoming Oil and Gas Fields, Greater Green River Basin, 1979 (Gulf Oil Exploration and Production Co.).

Field: YELLOW CREEK

Formation: Twin Creek
Depth (Top): 5,700-6,500'
Thickness (Gross): 750'
(Pay): 125'
Average Porosity: 0.7%
Permeability: 0.028 md (air)
Oil Gravity: 54° API
Gas BTU: 1,075

Typical Gas Composition:

	Mol%
Nitrogen	1.15
Carbon Dioxide	0.10
Hydrogen Sulfide	----
Methane	28.37
Ethane	8.68
Propane	7.59
Iso-Butane	3.62
Normal Butane	4.99
Iso-Pentane	4.23
Normal Pentane	3.24
Hexanes Plus	38.03

Source of Data: Amoco Production Co., 1981.

Field: YELLOW CREEK

Formation: Twin Creek
Gross Completed Interval: 6,262-6,736'
Average Porosity: 1.7%
Permeability: 0.01-0.11 md
Gas-Oil Ratio: 22,917:1
Oil Gravity: 55-61° API
Source of Data: Mesa Petroleum Co., 1979.

Field: YELLOW CREEK

Formation: Twin Creek
Depth (Top): 5,536'
Porosity: 1.5%
Permeability: <0.01 md (fractured)
Gas BTU; 1,170

Gas Analyses:

	Mol%
Nitrogen	5.50
Carbon Dioxide	0.40
Hydrogen Sulfide	----
Methane	68.50
Ethane	12.10
Propane	6.40
Iso-Butane	2.20
Normal Butane	2.50
Iso-Pentane	1.00
Normal Pentane	0.60
Hexanes	0.40

Heptanes Plus 0.40

Source of Data: Petroleum Information Corp., 1978.

Field: YELLOW CREEK

Formation: Twin Creek

Average Pay Thickness: 158' (av. perf. interval)

Oil/Gas Column: 669' minimum

Porosity: 1.7% av., 3.4% max.

Permeability: 0.01-0.11 md

Gas-Oil Ratio: 6,852:1

Drive Mechanism: Gas Expansion

Condensate Gravity: 59-61° API

Gas BTU: 1,170-1,250

Gas Analysis:

	Mol%
Nitrogen	5.50
Carbon Dioxide	0.20
Hydrogen Sulfide	----
Methane	77.70
Ethane	0.40
Propane	4.60

Source of Data: Wyoming Geol. Assoc. Symposium, Wyoming Oil and Gas Fields, Greater Green River Basin, 1979 (Gulf Oil Exploration and Production).

APPENDIX B:*
CATALOG OF ROCK NAMES FOR THE OVERTHRUST BELT

These names are in common use within the overthrust belt. Each rock unit has the following information provided where possible:

A) regional distribution
B) reference for further description
C) type locality or section
D) generalized lithology
E) general remarks

ADAVILLE FORMATION (4,000 feet)
Upper Cretaceous

A) Southwestern Wyoming.
B) Veatch, A.C., 1907, U.S. Geol. Survey Prof. Paper 56.
C) Adaville Coal Mine 3½ miles west of Kemmerer, Wyoming.
D) Yellow, black, and gray carbonaceous shale interbedded with brown and buff sandstones. Contains abundant amounts of coal.
E) Overlies Hilliard Shale and is equivalent to lower Mesaverde members. Unnamed conglomerate in Little Muddy Creek area records initial movement on Absaroka thrust fault.

ALLAN HOLLOW SHALE MEMBER (780 feet)
Upper Cretaceous

A) Northeastern Utah.
B) Hale, L.A., Wyoming Geol. Assoc. 15th Ann. Field Conf. Guidebook, p. 137-146.
C) Allan Hollow northeast of Coalville, Utah.
D) Dark gray shales with thin interbeds of marine sandstone.
E) Member of Frontier Formation overlying Coalville Member. Represents first marine transgression over northeastern Utah after Aspen time.

AMSDEN FORMATION (200-900 feet)
Upper Mississippian - Lower and Middle Pennsylvanian

A) Central and western Wyoming and southern Montana.
B) Darton, N.H., 1904, Geol. Soc. America Bull., v. 15, p. 394-401.
C) Amsden branch of the Tongue River, west of Dayton, Sheridan County, Wyoming.
D) Gray dolomite, brownish limestone, red shale, and sandstone.
E) Equivalent in part to the Morgan Formation.

ANGELO MEMBER (0-200 feet) lower Eocene

A) Southwestern Wyoming.
B) Oriel, S.S., and Tracey, J.I., Jr., 1970, U.S. Geol. Survey Prof. Paper 635, p. 31-32, 45-46.
C) Bluff overlooking Angelo Ranch, Lincoln County, Wyoming.
D) Limestone,calcareous shale, mudstone, chert, minor sandstone, and oil shale beds.
E) Conformably overlies Fossil Butte Member of the Green River Formation; conformably underlies Bullpen Member of the Wasatch Formation. The Angelo is a member of the Green River Formation.

ANKAREH FORMATION (200-1,000 feet)
Middle-Upper Traissic

A) Northeastern Utah, southeastern Idaho, and southwestern Wyoming.
B) Boutwell, J.M., 1907, Jour. Geol. v. 15, p. 439-458.
C) Ankareh Ridge, Park City District, Utah.
D) Deep red, maroon, and yellowish to orange shale, snadstone, and siltstone.

Appendix B was modified from Keroher, 1970; Keroher and others, 1966; Olson, 1977; Pattison, 1977; and Wilmarth, 1938.

E) In western Wyoming the name applies to all strata between the Thaynes Limestone and the Nugget Sandstone.

ASPEN SHALE (250-2,000 feet) Lower Cretaceous

A) Southwestern Wyoming, southeastern Idaho, and northeastern Utah.
B) Veatch, A.C., 1907, U.S. Geol. Survey Prof. Paper 56.
C) Near Aspen Station, Uinta County, Wyoming.
D) Gray to dark gray shale, hard, siliceous, fissile, and occasionally bentonitic. Frequently contains white siliceous inclusions.
E) Equivalent to Mowry Formation.

BANCROFT LIMESTONE (500 feet) Middle Cambrian

A) Southeastern Idaho and northeastern Utah.
B) Oriel, S.S., and Armstrong, F.C., 1971, U.S. Geol. Survey Prof. Paper 394, 52 p.
C) Center sec. 7, T.10S., R.39E., southwest quarter of Bancroft quadrangle, Idaho.
D) Thin-bedded, silty to oolitic limestone with thin green shale parting in the lower part.
E) Overlies Lead Bell Shale. An eastern equivalent, the Ute Formation, overlies the Langston Dolomite.

BEAR RIVER FORMATION (500-5,000 feet) Lower Cretaceous

A) Southwestern Wyoming, southeastern Idaho, and northeastern Utah.
B) Hayden, F.V., 1869, U.S. Geol. Survey, Colorado and New Mexico, 3rd Ann. Rept., p. 91-92.
C) Bear River City, Wyoming.
D) Tan, red, gray, and variegated sandstones; black shales; coals; and fresh-water limestones.
E) Partially equivalent to the Dakota Formation.

BECHLER CONGLOMERATE (1,775 feet) Lower Cretaceous

A) Western Wyoming and southeastern Idaho.
B) Mansfield, G.R., and Roundy, P.V., 1916, U.S. Geol. Survey Prof. Paper 98.
C) Bechler Creek, Bannock County, Idaho.
D) Reddish salt and pepper sandstone, shale, and mudstones with interbedded conglomerates.
E) Member of Gannett Group.

BEIRDNEAU FORMATION (? feet) Upper Devonian

A) Northern Utah and southeastern Idaho.
B) Williams, J.S., 1948, Geol. Soc. America Bull., v. 59, no. 11, p. 1139-1140.
C) Exposures about the base of Beirdneau Peak, Logan quadrangle, Cache County, Utah.
D) Medium-gray to pale-brown dolomite, commonly argillaceous, silty, and sandy, with halite casts and mud cracks.
E) Equivalent to the Logan Gulch and Trident Members of the Three Forks Formation (see Benson, A.L., 1966, Am. Assoc. Petroleum Geologists Bull., v. 50, no. 12, p. 2566-2603). Areally restricted to the upper plates of the Willard and Paris thrust faults.

BIGHORN DOLOMITE (0-800 feet) Upper Ordovician

A) Wyoming and southern Montana.
B) Darton, N.H., 1904, Geol. Soc. America Bull., v. 15, p. 394-401.
C) Exposures in the Bighorn Mountains, Wyoming.
D) Light-gray, massive, homogeneous dolomite.

E) Zero edge in northeastern Utah and southwestern Wyoming. Western equivalent is the Fish Haven Dolomite.

BLACKSMITH LIMESTONE (450 feet) Middle Cambrian

A) Northeastern Utah and southeastern Idaho.
B) Deiss, C., 1938 (amended definition), Geol. Soc. America Bull., v. 49, no. 7, p. 1112-1113,1117.
C) A spur west of the first western tributary of North Cottonwood Creek, Blacksmith Fork Canyon, Logan quadrangle, Cache County, Utah.
D) White-gray to dull- to steel-gray. In the upper 60 feet it is dark-lead-gray, fine- to medium-grained, usually thick-bedded dolomite and interbedded magnesium limestone.
E) Pinches out to the west.

BLIND BULL FORMATION (6,000 feet) Upper Cretaceous

A) Southwestern Wyoming.
B) Rubey, W.W., 1973, U.S. Geol. Survey Bull. 1372-I, p. 25-34.
C) Eight miles north of Blind Bull coal mine, Afton quadrangle, Lincoln County, Wyoming.
D) Gray to buff sandstone and siltstone with coal beds.
E) Divided into upper and lower units by tongues of Hilliard Shale. Overlies Aspen Shale and is correlative with Frontier Formation and Hilliard Shale.

BLOOMINGTON FORMATION (1,000-1,500 feet) Middle Cambrian

A) Southeastern Idaho and northeastern Utah.
B) Walcott, C.D., 1980, Smithsonian Misc. Coll., v. 53, no. 1804, p. 6-7.
C) About 6 miles west of Bloomington, Bear Lake County, Idaho.
D) Gray to bluish-gray, thin-bedded to massive limestone, locally argillaceous.
E) Hodges Shale Member is tawny-olive shale and interbedded thin layers of light- to dark-gray limestone, about 330 feet thick at base of formation. Middle unit is of thinly to thickly bedded, light- to dark-gray limestone about 720 feet thick, overlain by the Calls Fort Member. The Calls Fort is a tawny-olive shale with some interbedded, platy limestone.

BOUNDARY RIDGE MEMBER (30-285 feet) Middle(?) Jurassic

A) Southeastern Idaho, northeastern Utah, and southwestern Wyoming.
B) Imlay, W.R., 1967, U.S. Geol. Survey Prof. Paper 540, p. 36-41.
C) About 1 mile southwest of Pegram in NW$\frac{1}{4}$ sec. 12, T.15S., R.45E., Bear Lake County, Idaho. Named after Boundary Ridge which lies east and southeast of type locality.
D) Interbedded siltstone, silty to finely sandy limestone, oolitic limestone, and claystone.
E) Grades downward into the shaly limestone of Rich Member. Overlain sharply by cliff-forming limestone of Watton Canyon Member of Twin Creek Limestone.

BRAZER DOLOMITE (850 feet) Upper Mississippian

A) Northeastern Utah and eastern and south-central Idaho.
B) Richardson, G.B., 1913, Am. Jour. Sci., 4th, v. 36, p. 407, 413.
C) Rich County, Utah, NW$\frac{1}{4}$ sec. 20, T.11N., R.8E. Named for exposures in Brazer Canyon.
D) Medium- to dark-gray and yellowish-gray, interbedded with oolitic

dolomites, cherty.

E) Correlates with the Mission Canyon Formation of the Madison Group. Principal outcrops occur in the Crawford Mountains, Utah. Has been redescribed as the Chesterfield Range Group in southeastern Idaho.

BRIGHAM QUARTZITE (4,800 feet+) Precambrian - Lower and Middle Cambrian

A) Northeastern Utah and southeastern Idaho.
B) Walcott, C.D., 1908, Smithsonian Misc. Coll., v. 53, no. 1804, p. 6-7.
C) West front of Wasatch Range, northeast of Brigham City, Box Elder County, Utah.
D) Basal transgressive sequence of buff, gray, purple, and pink massive quartzite and sandstone, locally conglomeratic with micaceous shale beds near the top.
E) In areas to the east and northeast the basal Cambrian equivalents are the Flathead Sandstone and the Tintic Quartzite. Lowest members are probably Precambrian.

BULLDOG HOLLOW MEMBER (200-2,000 feet) Eocene

A) Southwestern Wyoming and Utah.
B) Oriel, S.S., and Tracey, J.I., Jr., 1970, U.S. Geol. Survey Prof. Paper 635, p. 35-37, 41, 46-47.
C) Named for extensive exposures along Bulldog Hollow, south of Sage, Wyoming.
D) Green, white, and brown tuffaceous and ash sandstone and mudstone.
E) Gradationally overlies Sillem Member and underlies Gooseberry Member of the Fowkes Formation.

BULLPEN MEMBER (200-400 feet) Eocene

A) Southwestern Wyoming.
B) Oriel, S.S., and Tracey, J.I., Jr., 1970, U.S. Geol. Survey Prof. Paper 635, p. 21-22, 28, 43-44.
C) Named for exposures capping bluffs south of Bullpen Creek, Lincoln County, Wyoming.
D) Varicolored and banded mudstone, limestone, and sandstone.
D) Conformably overlies Angelo Member of Green River Formation; grades laterally to the west into Tunp Member of Wasatch; disconformably underlies Sillem Member of Fowkes Formation. Member of Wasatch Formation.

CALLS FORT SHALE MEMBER (190-200 feet) Middle Cambrian

A) Northeastern Utah.
B) Maxey, G.B., 1958, Geol. Soc. America Bull., v. 69, no. 6, p. 649, 651-652, 659-660, 672.
C) West side of Wellsville Mountain, near Calls Fort Monument, about 7 miles north of Brigham City, Box Elder County, Utah.
D) Limestone and shale.
E) At or near top of Bloomington Formation.

CAMP DAVIS FORMATION (0-5,000) Upper Miocene - lower Pliocene

A) Western Wyoming near Jackson.
B) Eardley, A.J., et al., Hoback-Gros Ventre-Teton Field Conf., geol. map, private printing.
C) Camp Davis, Hoback Canyon, Wyoming.
D) Conglomerates and agglomerates with thin, fresh-water limestones.
E) Local source.

CHALK CREEK MEMBER (3,000 feet) Upper Cretaceous

A) Northeast Utah.
B) Hale, L.A., 1960, Wyoming Geol.

Assoc., 15th Ann. Field Conf. Guidebook, p. 137, 146.
C) Chalk Creek Valley, Utah.
D) Gray, pink, maroon, and green claystones with gray to tan conglomeratic sandstones.
E) Member of Frontier Formation overlying Spring Canyon Member. Frequently mistaken for Kelvin Formation.

CHESTERFIELD RANGE GROUP (1,900 feet)
Lower-Upper Mississippian

A) Southeastern Idaho.
B) Dutro, J.T., Jr., and Sando, W.J., 1963, Am. Assoc. Petroleum Geologists Bull., v. 47, no. 11, p. 1963-1986.
C) Southwest-trending spur in NW$\frac{1}{4}$ sec. 20, T.7S., R.40E., Chesterfield Range, Bannock County, Idaho.
D) Lower part is pale-red siltstone and fine-grained sandstone with two cherty limestone units. Middle part is fine-grained, calcareous sandstone and quartzose limestone in thin, platy beds.
E) Upper members are the Little Flat Formation and the overlying Monroe Canyon Formation, a massive-bedded, ridge-forming limestone. The Chesterfield Range Group overlies the Wells Formation. The Little Flat Formation is correlative with the upper portion of the Madison Group and the Monroe Canyon correlates with the Great Blue Formation of north-central Utah.

COALVILLE MEMBER (75-225 feet)
Upper Cretaceous

A) Northwestern Utah.
B) Hale, L.A., 1960, Wyoming Geol. Assoc. 15th Ann. Field Conf. Guidebook, p. 137-146.
C) Ridge northeast of Coalville, Utah.
D) Coals and marine sandstone locally conglomeratic.
E) Member of Frontier Formation overlying Chalk Creek Member.

COKEVILLE FORMATION (1,600 feet)
Lower Cretaceous

A) Southeast Idaho and western Wyoming.
B) Rubey, W.W., 1973, U.S. Geol. Survey Bull. 1372-I, 35 p.
C) Two miles northeast of Cokeville along the north side of Smiths Fork, Lincoln County, Wyoming.
D) Fossiliferous sandstone and sandy siltstone, claystone and mudstone, calcareous concretions, very fossiliferous limestone with some beds of bentonite and porcelanite. There are a few beds of coal in the upper part.
E) The Cokeville intertongues with and grades into the overlying Quealy Formation and the underlying Thomas Fork Formation. Both of these formations thicken northward at the expense of the Cokeville.

COTTONWOOD CANYON MEMBER (0-80 feet)
Lower Mississippian

A) Montana, northern and western Wyoming.
B) Sandberg, C.A., and Klapper, G., 1967, U.S. Geol. Survey Bull. 1251-B, 70 p.
C) Named for Cottonwood Canyon on west side of northern Bighorn Mountains, 16 miles east of Lovell.
D) Dark shale unit.
E) In western Wyoming the Cottonwood Canyon Member lies at the base of the Lodgepole Limestone.

DARBY FORMATION (0-500 feet)
Upper Devonian

A) Western Wyoming.
B) Blackwelder, E., 1918, Washington Acad. Sci., Jour., v. 8, p. 420.
C) Canyon of Darby Creek on the western slope of the Teton Range
D) Dark, fine- to medium-crystalline dolomite ledges separated by beds of shale, mudstone, siltstone, and sandstone.

DEADMAN LIMESTONE (150 feet) Upper Triassic

A) Southeastern Idaho and northwestern Wyoming.
B) Mansfield, G.R., 1915, Washington Acad. Sci. Jour., v. 5, p. 492.
C) Deadman Creek in northeastern part of T.4S., R.38E., Paradise Valley quadrangle, Idaho.
D) Light colored, dense, nodular limestone.
E) Grades eastward to red beds of the Ankareh Formation. Overlain by the Wood Shale Tongue of the Ankareh.

DEATH CANYON LIMESTONE (207-368 feet) Middle Cambrain

A) Western Wyoming.
B) Miller, B.M., 1936, Jour. Geology, v. 4,, no. 2, p. 119.
C) Along Divide between Death and Teton Canyons in the Teton Range.
D) Massive, dull blue-gray limestone in two beds of unequal thickness with an intervening fossiliferous shale.
E) Middle unit of Gros Ventre Formation. Overlies Wolsey Shale and underlies Park Shale.

DINWOODY FORMATION (400-2,000 feet) Lower Triassic

A) Western Wyoming, southeastern Idaho, southwestern Montana, and northeastern Utah.
B) Condit, D.D., 1916, U.S. Geol. Survey Prof. Paper 98, p. 263-270.
C) Dinwoody Canyon in the Wind River Mountains near DuBois, Wyoming.
D) Buff to tan, olive-colored, silty limestone and calcareous siltstone, olive-buff to gray shale.
E) Intertongues with the Woodside Formation red beds.

DRANEY LIMESTONE (0-200 feet) Lower Cretaceous

A) Southeastern Idaho and western Wyoming.
B) Mansfield, G.R., and Roundy, P.V., 1916, U.S. Geol. Survey Prof. Paper 98.
C) $1\frac{1}{4}$ miles east of Draney Ranch, Idaho.
D) Gray, massive limestone.
E) Formation in Gannett Group.

DRY HOLLOW MEMBER (100-1,220 feet) Upper Cretaceous

A) Northeastern Utah.
B) Hale, L.A., 1960, Wyoming Geol. Assoc., 15th Ann. Field Conf. Guidebook, p. 137-146.
C) Dry Hollow - $1\frac{1}{2}$ miles northeast of Coalville, Utah.
D) Basal - conglomerate; middle red to brown sandstones, shales, and coals; upper - white sandstone.
E) Member of Frontier Formation unconformably overlying Oyster Ridge Member. Locally, an unconformity has angular discordance, and a hiatus spanning Middle and Late Carlile time is believed to exist.

DU NOIR LIMESTONE (40 feet) Upper Cambrian

A) Western Wyoming.
B) Miller, B.M., 1936, Jour. Geology, v. 44, no. 2, p. 124-127.
C) Along Warm Springs Creek, 2 miles west of Du Noir, in the northwestern part of the Wind River Moun-

tains.
D) Glauconitic flat-pebble limestone near base.
E) Underlies the Open Door Limestone; overlies Park Shale. Lower member of the Gallatin Limestone.

DURST GROUP (1,100-4,500 feet) Permian-Pennsylvanian

A) Northeastern Utah.
B) Sadlisk, W., 1957, Intermountain Assoc. Petroleum Geologists Guidebook, 8th Ann. Field Conf., p. 62.
C) Durst Mountain, 7 miles north of Morgan, Morgan County, Utah.
D) See reference for description.
E) Includes type Morgan and Weber Formations. Unconformable above the Round Valley Formation. In the Uinta Mountains to the east it includes the Hells Canyon Formation which is a facies of the Morgan.

ECHO CANYON CONGLOMERATE (0-3,100 feet) Upper Cretaceous

A) Northeastern Utah.
B) Williams, N.C., and Madsen, J.H., Jr., 1959, Intermountain Assoc. Petrol. Geol. Guidebook, 10th Ann. Field Conf., p. 122-125.
C) Echo Canyon, Utah.
D) Conglomerate with lenticular sandstone and mudstone interbeds.
E) Unconformably overlies the Henefer Formation.

EPHRAIM CONGLOMERATE (0-1,000 feet) Lower Cretaceous

A) Southeastern Idaho and western Wyoming.
B) Mansfield, F.R., and Roundy, P.V., 1916, U.S. Geol. Survey Prof. Paper 98.
C) Ephraim Creek, Idaho.
D) Reddish and purplish conglomerate, sandstone, siltstone, and shale, Thins and becomes finer grained northeast of type section.
E) Lowermost formation of the Gannett Group.

ERVAY TONGUE (30-40 feet) Upper Permian

A) Northwestern Wyoming.
B) Thomas, H.D., 1934, Am. Assoc. Petroleum Geologists Bull., v. 18, no. 12, p. 1664-1666.
C) Ervay, Natrona County, Wyoming, near the north end of Rattlesnake Hills.
D) Mostly limestone in the western area of occurrence and dolomite in the eastern area.
E) Underlies Dinwoody Formation; member of Park City Formation

EVANSTON FORMATION (1,500 feet) Upper Cretaceous - Paleocene

A) Evanston, Wyoming.
B) Lesquereux, L., 1876, U.S. Geol. and Geog. Survey Terr. Bull. 5, 2nd Ser., p. 244-248.
C) North of Evanston, Wyoming.
D) Yellow, gray, and black carbonaceous clays and shales with interbedded sandstones.
E) Partially equivalent to the Fort Union and Lance Formations. Also partially equivalent to the Almy, a local term used in the Big Piney - La Barge area.

FISH HAVEN DOLOMITE (500 feet) Upper Ordovician

A) Southern Idaho and northern Utah.
B) Richardson, G.B., 1913, Am. Jour. Sci., 4th v. 36, p. 406-416.
C) Fish Haven Creek 5 miles north of the Idaho-Utah State line in southeastern Idaho.
D) Massive, dark-gray dolomite.

E) Unconformably overlies the Swan Peak Quartzite. Its eastern equivalent is the Bighorn Dolomite.

FLATHEAD SANDSTONE (300 feet) Middle Cambrian

A) Central and western Wyoming and Montana.
B) Peale, A.C., 1893, U.S. Geol. Survey Bull. 110, p. 20-22; and Weed, W.H., 1900, U.S. Geological Survey 20th Ann. Rept., pt. 3, p. 285-286.
C) Flathead Pass near Three Forks, Montana.
D) Red and gray sandstone and quartzite, usually arkosic at base.
E) Equivalent to portions of the Brigham Quartzite and the Tintic Quartzite.

FOSSIL BUTTE MEMBER (200-270 feet) Eocene

A) Southwestern Wyoming.
B) Oriel, S.S., and Tracey, J.I., Jr., 1970, U.S. Geol. Survey Prof. Paper 635, p. 30-32.
C) South-facing scarp of Fossil Butte, Lincoln County, Wyoming.
D) Mudstone, limestone, and shale.
E) Conformably overlies Wasatch Formation; conformably underlies Angelo Member of the Green River Formation.

FOWKES FORMATION (0-2,500 feet) upper Eocene

A) Southwestern Wyoming.
B) Tracey, J.I. and Oriel, S.S., 1959, Intermountain Assoc. Petrol. Geol. 10th Ann. Field Conf. Guidebook, p. 126-130.
C) Fowkes Ranch north of Evanston, Wyoming.
D) Light gray sandstone and shale composed primarily of volcanic material. Occasional fresh-water limestone interbeds.
E) Originally thought to separate the Almy and Knight Formations, but now believed younger than both. Made up of Gooseberry, Sillem, and Bulldog Hollow Members.

FRANSON MEMBER (235 feet) Permian

A) Eastern Utah, northwestern Colorado, eastern Idaho, southwestern Montana and western Wyoming.
B) Cheney, T.M., *in* McKelvey, V.E., and others, 1956, Am. Assoc. Petroleum Geologists Bull., v. 40, no. 12, p. 2842-2843; 1959, U.S. Geol. Survey Prof. Paper 313-A, p. 15-19, 31, 37.
C) North side of Franson Canyon near the mouth in $S\frac{1}{2}SE\frac{1}{4}$ sec. 15 and $N\frac{1}{2}NE\frac{1}{4}$ sec. 22, T.1S., R.6E., Summit County, Utah.
D) Light-gray and grayish-brown carbonate rock, cherty or sandy carbonate rock, and calcareous sandstone. Overlies Meade Peak Tongue of the Phosphoria Formation.
E) Member of Park City Formation. Probably laterally continuous with Mackentire Tongue of Woodside Formation, lower contact gradational.

FRONTIER FORMATION (100-8,500 feet) Upper Cretaceous

A) Western and central Wyoming and Montana.
B) Knight, W.C., 1902, Eng. and Mining Jour., vol. 73, p. 721.
C) Frontier, Wyoming.
D) Buff, brown to tan sandstones interbedded with brown to dark-gray shales, local coal beds.
E) This formation thickens rapidly westward and is broken into members in northeastern Utah as fol-

lows in ascending order: Longwall, Spring Canyon, Chalk Creek, Coalville, Allan Hollow Shale, Oyster Ridge Sandstone, Dry Hollow, Grass Creek, Judd Shale, and Upton Sandstone.

GALLATIN LIMESTONE (200-400 feet) Upper Cambrian

A) Western Wyoming and southern Montana.
B) Peale, A.C., 1893, U.S. Geol. Survey Bull. 110, p. 20-23; 1896, U.S. Geol. Survey Geologic Atlas, Folio 24.
C) Gallatin Range, Montana.
D) Glauconitic flat-pebble limestone, thin interbedded calcareous shale, limestone, and flat-pebble conglomerates.
E) Consists, in ascending order, of: Du Noir Limestone and the Open Door Limestone.

GANNETT GROUP (360-4,200 feet) Lower Cretaceous

A) Southeastern Idaho and southwestern Wyoming.
B) Mansfield, G.R., and Roundy, P.V., 1916, U.S. Geol. Survey Prof. Paper 98.
C) Gannett Hills, Bannock County, Idaho and Lincoln County, Wyoming.
D) Variegated claystone, sandstones, shales, conglomerates and freshwater limestones.
E) Includes in ascending order: Ephraim Conglomerate, Peterson Limestone, Bechler Conglomerate, Draney Limestone, and the Smoot Formation. Generally the Gannett Group is considered to be the nonmarine sequence of rocks overlying the Stump Formation and underlying the Bear River Formation.

GARDEN CITY FORMATION (0-1,800 feet) Lower-Middle Ordovician

A) Northern Utah and southeastern Idaho.
B) Richardson, G.B., 1913, Am. Jour. Sci., 4th, v. 35, p. 407-408.
C) Garden City Canyon, Rich County, Utah.
D) Interbedded and interlensed intraformational conglomerates and crystalline, aphanitic and muddy limestones; upper part has high chert content, nodules, stringers, and interbeds in irregularly laminated limestone and dolomitic limestone.
E) Grades to fine quartz sandstone and siltstone along the Utah-Wyoming state line. Wedges out to the east, most likely removed by erosion.

GIRAFFE CREEK MEMBER (25-295 feet) Middle(?) Jurassic

A) Southeastern Idaho, northeastern Utah, and southwestern Wyoming.
B) Imlay, W.R., 1967, U.S. Geol. Survey Prof. Paper 540, p. 50-53.
C) North side of Thomas Fork Canyon, Lincoln County, Wyoming.
D) Mainly silty to finely sandy ripple-marked, thin-bedded limestone interbedded with sandstone. Some shaly limestone and medium-bedded limestone.
E) Uppermost member of the Twin Creek Limestone.

GOOSEBERRY MEMBER (200 feet) Eocene(?)

A) Southwestern Wyoming.
B) Oriel, S.S., and Tracey, J.I., Jr., 1970, U.S. Geol. Survey Prof. Paper 635, p. 35-37.
C) Five miles northeast of Sage, near Gooseberry Springs, Lincoln County, Wyoming.
D) Gray to white conglomerate interbedded with calcareous rhyolitic ash and limestone.
E) Overlies Bulldog Hollow Member of the Fowkes Formation. Upper member of Fowkes.

GRANDEUR MEMBER (0-350 feet) Permian

A) Utah, Idaho, Montana, and Wyoming.
B) Cheney, T.M., *in* McKelvey, V.E., and others, 1956, Am. Assoc. Petroleum Geologists Bull., v. 40, no. 12, p. 2842-2843; 1959, U.S. Geol. Survey Prof. Paper 313-A, p. 15-19, 31, 37.
C) One mile southwest Grandeur Peak in sec. 36, T.1S., R.2E., on north side and near mouth of Mill Creek Canyon, Salt Lake County, Utah.
D) Interbedded, cherty carbonates, carbonaceous sandstone and siltstone.
E) Member of Park City Formation.

GRASS CREEK MEMBER (875-1,025 feet) Upper Cretaceous

A) Northeastern Utah.
B) Hale, L.A., 1960, Wyoming Geol. Assoc. 15th Ann. Field Conf. Guidebook, p. 137-146.
C) Grass Creek Valley near Echo Reservoir, Utah.
D) Basal unit - reddish claystones and lenticular sandstones; upper part - gray shales and thin-bedded tan sandstones.
E) Member of Frontier Formation overlying Dry Hollow Member.

GREEN RIVER FORMATION (0-1,500 feet) lower-middle Eocene

A) Southwestern Wyoming, northwestern Colorado, and northern Utah.
B) Hayden, F.V., 1869, Preliminary field report of the U.S. Geol. Survey of Colorado and New Mexico, U.S. Geol. Survey, p. 89-92.
C) Green River Valley, southwestern Wyoming.
D) Brown to yellowish-gray chalky shales, buff-brown sandstones, algal limestones and oil shales.
E) These lacustrine beds are interfingered with tongues of the Wasatch Formation.

GROS VENTRE FORMATION (0-700 feet) Middle-Upper Cambrian

A) Western Wyoming and southern Montana.
B) Blackwelder, E., 1918, Washington Acad. Sci. Jour., v. 8, p. 417.
C) Doubletop Peak in Gros Ventre Range, Wyoming.
D) Glauconitic red sandstone, green and red shale, dark gray, massive, resistant, mottled limestones, green shales, and beds of thin limestone and flat-pebble limestone conglomerates.
D) Wedges out to the east.

GYPSUM SPRING MEMBER (12-400 feet) Middle(?) Jurassic

A) Southeastern Idaho, northeastern Utah, and southwestern Wyoming.
B) Imlay, R.W., 1950, *in* Wyoming Geol. Assoc. Guidebook, 5th Ann. Field Conf., called this Member A of Twin Creek. Oriel, S.S., 1963, U.S. Geol. Survey Oil and Gas Inv. Map OM-212, renamed it Gypsum Spring Member.
C) Named for the gypsum spring on Red Creek, Fremont County, Wyoming.
D) Mostly siltstone and claystone interbedded with brecciated, or vuggy, or chert-bearing limestone.
E) Lowermost member of the Twin Creek Limestone.

HAMS FORK CONGLOMERATE MEMBER (450-1,000 feet) Upper Cretaceous

A) Southwestern Wyoming.
B) Oriel, S.S., and Tracey, J.I., Jr., 1970, U.S. Geol. Survey Prof. Paper 635, p. 6-9.
C) Five miles northwest of Elkol, Lincoln County, Wyoming. Named for Hams Fork River.

D) Brown boulder conglomerate, sandstone, and mudstone.
E) Hams Fork Conglomerate Member records latest major movement on the Absaroka thrust fault. Member of the Evanston Formation.

HENEFER FORMATION (2,400-2,500 feet) Upper Cretaceous

A) Northeastern Utah.
B) Eardley, A.J., 1944, Geol. Soc. America Bull., v. 55, no. 7, p. 819-894.
C) Named for exposures in Harris Creek Canyon northeast of Henefer, Summit County, Utah.
D) Brown to gray sandstone with occasional lenticular conglomerate.
E) This formation lies between the Frontier and the Echo Canyon Formations. Partially equivalent to the Adaville Formation.

HILLIARD SHALE (2,500-7,000 feet) Upper Cretaceous

A) Southwestern Wyoming.
B) Knight, W.C., 1902, Eng. and Mining Jour., vol. 73, p. 721.
C) Hilliard, Wyoming.
D) Drab to pale-gray shales with rare silty sandstone.
E) Equivalent or partially equivalent to the Baxter, Steele, Mancos, Cody, Pierre, and Niobrara Formations.

HODGES SHALE MEMBER (540 feet) Middle Cambrian

A) Northeastern Utah and southeastern Idaho.
B) Maxey, G.B., 1958, Geol. Soc. America Bull., v. 59, no. 6, p. 649, 651-652, 659-660, 672.
C) Hodges Canyon, Rich County, Utah.
D) Basal tawny-olive shale and interbedded layers of light- to dark-gray limestone.
E) Member of Bloomington Formation; overlies Blacksmith Limestone.

HYRUM DOLOMITE (840-1,200 feet) Upper-Middle-Upper Devonian

A) Northern Utah and southeastern Idaho.
B) Williams, J.S., 1948, Geol. Soc. America Bull., v. 59, no. 11, p. 1139, 1140.
C) Named for exposures in the mouth of Blacksmith Fork Canyon, east of town of Hyrum, Logan quadrangle, Utah.
D) Black dolomite and limestone with minor amounts of calcareous sandstone.
E) Disconformably overlies the Water Canyon Formation in northeastern Utah and the Laketown Dolomite in southeastern Idaho.

JUDD SHALE (0-760 feet) Upper Cretaceous

A) Northeastern Utah.
B) Hale, L.A., 1960, Wyoming Geol. Assoc. 15th Ann. Field Conf. Guidebook, p. 137-146.
C) Judd Canyon, 6 miles east of Coalville, Summit County, Utah.
D) Gray marine shale.
E) Member of Frontier Formation overlying Grass Creek Member. This unit is a tongue of the Hilliard Shale of southwestern Wyoming.

KELVIN FORMATION (1,500-2,700 feet) Lower Cretaceous

A) Northeast Utah.
B) Crittenden, M.D., 1963, U.S. Geol. Survey Prof. Paper 475-B, p. 95-98.
C) Kelvin's Grove Resort, Emigration Canyon, Utah.
D) Pale-red siltstone, sandstone, and conglomerates with lower lavender-gray siltstone and lenticular sandstone unit containing pale-

gray to white limestone nodules.

KNIGHT FORMATION (500-5,000 feet) lower Eocene

A) Western Wyoming, northern Utah, and southeastern Idaho.
B) Veatch, A.C., 1907, Jour. Geol., vol. 15, p. 547-949.
C) Knight Station, Uinta County, Wyoming.
D) Red, yellow, and white conglomeratic sandstone, shale and sandy claystone.
E) Overlies the Evanston Formation unconformably in some areas; indivisible from Almy Formation in others.

LAKETOWN DOLOMITE (0-1,500 feet) Middle-Upper Silurian

A) Northeastern and western Utah, southern Idaho, southwestern Wyoming (?).
B) Richardson, G.B., 1913, Am. Jour. Sci., 4th, v. 36, p. 406-416.
C) Laketown Canyon, Rich County, northeastern Utah.
D) Light-gray massive dolomite.
E) Thins rapidly eastward; extends into extreme western Wyoming.

LANGSTON DOLOMITE (450 feet) Middle Cambrian

A) Southeastern Idaho and northeastern Utah.
B) Walcott, C.D., 1908, Smithsonian Misc. Coll., v. 53, no. 1804, p. 6-7.
C) Blacksmith Fork Canyon, Cache County, Utah, and Langston Creek, Bear County, Idaho.
D) Limestone and dolomite interbedded with shale and siltstone. Tan-weathering dolomite with intermediate limestone.
E) Current usage is the northern and eastern transition of the Lead Bell Shale into a carbonate section in eastern Idaho and Utah. (Oriel, S.S., and Armstrong, F.C., 1971, U.S. Geological Survey Prof. Paper 394, 52 p.).

LAZEART SANDSTONE (200-300 feet) Upper Cretaceous.

A) Overthrust of southwestern Wyoming.
B) Veatch, A.C., 1907, U.S. Geol. Survey Prof. Paper 56.
C) Lazeart coal mine, Uinta County, Wyoming.
D) White, resistant sandstone.
E) Lowermost member of Adaville Formation and partially equivalent to Henefer Formation.

LEAD BELL SHALE (500 feet) Middle Cambrian

A) Southeastern Idaho and northeastern Utah.
B) Oriel, S.S., and Armstrong, F.C., 1971, U.S. Geol. Survey Prof. Paper 394, 52 p.
C) Northeast of abandoned Lead Bell mine, NW$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 18, T.10S., R.39E., Idaho.
D) Argillaceous, dark-gray and black shale, interbedded with siltstone in the lower part, green and tan shale interbedded with thin limestones in the upper part.
E) Previously part of the Langston Dolomite. The Spence Shale is now considered to be the upper shale tongue of the Lead Bell Shale.

LEATHAM FORMATION (80 feet) Lower Mississippian

A) Northeastern Utah.
B) Holland, F.D., Jr., 1952, Am. Assoc. Petroleum Geologists Bull., v. 36, no. 9, p. 1719-1720, figs. 1-17.
C) North wall of Leatham Hollow, sec. 34, T.11N., R.2E., Salt Lake base and meridian, Utah.

D) Shales, sandy shales, and nodular limestones.

LEEDS CREEK MEMBER (260-1,600 feet) Middle(?) Jurassic

A) Southeastern Idaho, northeastern Utah, and southwestern Wyoming.
B) Imlay, W.R., 1967, U.S. Geol. Survey Prof. Paper 540, p. 45-50.
C) North side of Leeds Creek, Lincoln County, Wyoming.
D) Mainly soft, dense shaly limestone with some beds of oolitic silty or sandy, ripple-marked limestone.
E) Member of Twin Creek Limestone. Giraffe Creek Member lies above, Watton Canyon Member lies below.

LITTLE FLAT FORMATION (290 feet) Upper Mississippian

A) Southeastern Idaho.
B) Dutro, J.T., Jr., and Sando, W.J., 1963, Am. Assoc. Petroleum Geologists Bull., v. 47, no. 11, p. 1963-1986.
C) Bannock County, Idaho, NW$\frac{1}{4}$ sec. 20, T.7S., R.40E., in Chesterfield Range.
D) Sandy limestone.
E) An upper unit of Chesterfield Range Group, it underlies the Monroe Canyon Formation.

LODGEPOLE LIMESTONE (200-800 feet) Lower Mississippian

A) Southwestern Montana, western Wyoming, and southeastern Idaho.
B) Collier, A.J., and Cathcart, S.H., 1922, U.S. Geol. Survey Bull. 736-F, p. 173.
C) Lodgepole Canyon, Little Rocky Mountain region, Montana.
D) Massive, cliff-forming limestone.
E) Lower formation of Madison Group. Average thickness in western Wyoming is 800 feet. Basal thin, dark shale separates the Mississippian carbonates from the underlying Devonian strata

LOGAN GULCH MEMBER (111 feet) Upper Devonian

A) Montana and Wyoming.
B) Sandberg, C.A., 1965, U.S. Geol. Survey Bull. 1194-N, p. 8, 10-12.
C) Included in type section of Three Forks Formation in gulch and on bluffs on north side of Gallatin River, northeast of Logan, in S$\frac{1}{2}$ sec. 25, T.2N., R.2E., Gallatin County, Montana.
D) Evaporitic, nonfossiliferous, yellowish-gray and grayish-red argillaceous limestone breccia and shale breccia. Interbedded with dolomitic shale and siltstone and silty dolomite, capped by a lenticular bed of brownish-gray limestone and limestone breccia.
E) Member of Three Forks Formation. Underlies Trident Member. Extends into Yellowstone Park. Truncated eastward along west side of Bighorn Basin.

LONGWALL SANDSTONE MEMBER (70-100 feet) Lower Cretaceous

A) Northeastern Utah.
B) Hale, L.A., 1960, Wyoming Geol. Assoc. 15th Ann. Field Conf. Guidebook, p. 137-146.
C) North of Coalville, Utah.
D) Light gray to white sandstone.
E) Lowermost member of the Frontier, has been correlated to Bear River Formation by some authors.

MACKENTIRE REDBEDS TONGUE (100 feet) Lower Triassic

A) Northern Utah.
B) Williams, J.S., 1939, Am. Assoc. Petroleum Geologists Bull., v. 23, no. 1, p. 91-93.
C) Mouth of MacKentire Draw in sec.

27, T.2N., R.5W., Unita base and meridian, Duchesne County, Utah.
D) Gray and red sandstones, siltstones, and shales.
E) Appears between the calcareous sandstones and the main body of the Woodside Shale.

MADISON GROUP (1,800 feet) Mississippian

A) Montana, Colorado, Wyoming, and Utah.
B) Peale, A.C., 1893, U.S. Geol. Survey Bull. 110, 56 p.
C) Madison Range, central part of Three Forks quadrangle, Montana.
D) Gray, interbedded limestone, dolomite, and shale.
E) Includes (in ascending order) the Lodgepole Limestone and the Mission Canyon Formation. Designated as a Group by Collier, A.J., and Cathcart, S.G., 1922, U.S. Geological Survey Bull. 736-F, p. 171-178. Madison Formation in Utah.

MEADE PEAK PHOSPHATIC SHALE MEMBER (80-300 feet) Permian

A) Eastern Idaho, southwestern Montana, eastern Utah, and western Wyoming.
B) McKelvey, V.E., *in* McKelvey, V.E., and others, 1956, Am. Assoc. Petroleum Geologists Bull. v. 40, no. 12, p. 2832, 2936, 2845-2847.
C) Meade Peak, about 2½ miles south of Phosphoria Gulch, Bear Lake County, Idaho.
D) Dark carbonaceous phosphatic and argillaceous rocks; mudstone and phosphorite are shelf end-member rock types, and dark dolomite and limestone are subordinate types.
E) Member of Phosphoria Formation. About 300 feet thick in central Wasatch Mountains where it is split by the Franson Member of the Park City Formation; thins toward the north, east, and southeast, and pinches out in southwestern Montana, western Wyoming, and eastern Utah.

MISSION CANYON FORMATION (200-300 feet) Mississippian

A) Montana and western Wyoming.
B) Collier, A.J., and Cathcart, S.H., 1922, U.S. Geol. Survey Bull. 736-F, p. 171-178.
C) In canyon of St. Paul's Mission along west flank of the Little Rocky Mountain uplift, Little Rocky Mountain region, Montana.
D) Lower member light-gray and brownish-gray, bedded siliceous limestone and dolomite, upper member gray massive limestone and dolomite, limonite-stained limestone breccia. Solution-collapse brecciation common. In western Wyoming it is predominantly dolomite and dolomitic limestone with evaporite zones (see Houlik, C.W., Jr., 1973, Am. Assoc. Petroleum Geologists Bull., v. 57, no. 3).
E) Underlies Amsden Formation, overlies Lodgepole Limestone.

MOFFAT TRAIL LIMESTONE MEMBER (65-115 feet) Upper Mississippian

A) Western Wyoming.
B) Sando, W.J., Gordon, M., Jr., and Dutro, J.T., Jr., 1975, U.S. Geol. Survey Prof. Paper 848-A, p. A27-A31.
C) Ridge north of Moffat Trail, sec. 3, T.33N., R.117W., Lincoln County, Wyoming.
D) Light-gray limestone containing chert nodules.
E) Member of the Amsden Formation.

MONROE CANYON LIMESTONE (925 feet) Upper Mississippian

A) Southern Idaho.
B) Dutro, J.T., Jr., and Sando, W.J., 1963, Am. Assoc. Petroleum Geologists Bull., v. 47, no. 11, p. 1963-1986.
C) Bannock County, NW¼ sec. 20, T.7S., R.40E., Chesterfield Range, Idaho.
D) Massive ridge-forming limestone.
E) Upper unit of Chesterfield Range Group. Overlies the Little Flat Formation.

MORGAN FORMATION (900-1,500 feet) Lower-Middle Pennsylvanian

A) Northeastern Utah, northwestern Colorado, and southern Wyoming.
B) Blackwelder, E., 1910, Geol. Soc. America Bull., v. 21, p. 519, 529-542.
C) East of Morgan, Morgan County, Utah.
D) Cherty carbonates intercalated with red shale beds in the lower part and interbedded red shales and carbonates in the upper part.
E) In part equivalent to the Amsden Formation. Member of the Durst Group (see Sadlich, W., 1957, Intermountain Assoc. of Petroleum Geologists Guidebook, 8th Ann. Field Conf.).

MORRISON FORMATION (200 feet) Upper Jurassic

A) Widespread over Rocky Mountain region.
B) Eldridge, G.H., 1896, U.S. Geol. Survey Mon. 27.
C) Morrison, Jefferson County, Colorado.
D) Dull to variegated shales with interbedded and lenticular sandstones, siltstones, and thin limestones.
E) Partially equivalent to Gannett Group and Beckwith Formation.

NAOMI PEAK LIMESTONE MEMBER (30-40 feet) Middle Cambrian

A) Southeastern Idaho and northern Utah.
B) Maxey, B.G., 1958, Geol. Soc. America Bull., v. 69, no. 6, p. 671.
C) North side of North Fork of High Creek, approximately 6½ miles northeast of Richmond, Cache County, Utah.
D) Light- to medium-neutral-gray, finely crystalline arenaceous limestone with numerous lenses of coarsely crystalline, very fossiliferous limestone. A few thin beds of gray, medium-grained, brown-weathering calcareous or dolomitic sandstone occur near base.
E) Member of Langston Formation.

NORWOOD TUFF (50-2,000 feet) Eocene-Oligocene

A) Northeastern Utah and southwestern Wyoming.
B) Eardley, A.J., 1944, Geol. Soc. America Bull., v. 55, no. 7, p. 845-846.
C) Norwood Canyon, Morgan County, Utah.
D) Dominantly light-colored tuff with lenses of volcanic conglomerate.

NOUNAN FORMATION (1,000 feet) Middle-Upper Cambrian

A) Southeastern Idaho and northeastern Utah.
B) Walcott, C.D., 1908, Smithsonian Misc. Coll., v. 53, no. 1804, p. 6-7.
C) East slope of Soda Peak, west of Nounan, Bear Lake County, Idaho.
D) Light-gray to dark-lead-colored, massive limestones and dolomites.
E) assic(?) amd Kirassoc(?)

eastward equivalents include Open Door Limestone, Dry Creek Shale, and DuNoir Limestone.

NUGGET SANDSTONE (0-1,500 feet) Triassic(?) and Jurassic(?)

A) Southern Wyoming, southeastern Idaho, and northeastern Utah.
B) Veatch, A.C., 1907, U.S. Geol. Survey Prof. Paper 56.
C) Nugget Station, Wyoming.
D) Light-brown to white sandstone, cross-bedded, frosted quartz grains, and locally calcareous or dolomitic.
E) Thins eastward and is equivalent to Navajo sandstone westward.

OPEN DOOR LIMESTONE (? feet) Upper Cambrian

A) Southwestern Wyoming.
B) Shaw, A.B., and DeLand, C.R., 1955, Wyoming Geol. Assoc. Guidebook, 10th Ann. Field Conf., p. 38-39.
C) East wall of Granite Canyon in Gros Ventre Mountains, just below topographic feature known as the Open Door, Teton County, Wyoming.
D) Limestone, calcareous shales, and flat-pebble conglomerates. Dry Creek Shale Member at base.
E) Overlies the DuNoir Limestone. Upper member of Gallatin Limestone.

OYSTER RIDGE SANDSTONE (0-280 feet) Upper Cretaceous

A) Overthrust belt.
B) Veatch, A.C., 1906, U.S. Geol. Survey Bull. 285.
C) Oyster Ridge, Lincoln County, Wyoming.
D) Yellow-brown to white sandstones with rare lenticular conglomerates.
E) Widespread member of the Frontier Formation. Late Carlile sediments are missing from the section in the overthrust belt and the Dry Hollow Member unconformably rests on the Oyster Ridge Member of the Frontier.

PAINE MEMBER (165 feet) Lower Mississippian

A) Montana and western Wyoming.
B) Weed, W.H., 1899, U.S. Geol. Survey Geol. Atlas, Folio 55.
C) Paine Gulch, Little Belt Mountains, Montana.
D) Limestones and silty limestones with some chert.
E) Member of the Lodgepole Limestone.

PARK CITY FORMATION (300-1,000 feet) Middle-Upper Permian

A) North-central and northeastern Utah, southwestern and west-central Wyoming, with tongues extending into Idaho and Montana.
B) Boutwell, J.M., 1907, Jour. Geology, v. 15, p. 434-458.
C) Park City District, Utah.
D) Carbonates; cherty, interbedded, calcareous sandstones and siltstones.
E) Three members (in ascending order): Grandeur Member, Franson Member, and Ervay Tongue. Intertongues with Phosphoria Formation. The Franson Member intertongues with the Rex Chert and Meade Peak Members of the Phosphoria and separates them from the Retort Phosphatic Shale Member. The Ervay Tongue grades northwestward to the sandstones of the Shedhorn Formation.

PARK SHALE (0-700 feet) Upper(?) Cambrian

A) Western Wyoming and southern Montana.

B) Blackwelder, E., 1918, Washington Acad. Sci. Jour., v. 8, p.417.
C) Doubletop Peak in the Gros Ventre Range, Wyoming.
D) Glauconitic green shales with minor interbeds of thin limestone and flat-pebble limestone conglomerates.
E) Upper unit of Gros Ventre Formation.

PETERSON LIMESTONE (20-205 feet) Lower Cretaceous

A) Southeastern Idaho and extreme western Wyoming.
B) Mansfield, G.R., and Roundy, R.V., 1916, U.S. Geol. Survey Prof. Paper 98.
C) Peterson Ranch along Tygee Creek, Bannock County, Idaho.
D) Gray limestone.
E) Formation in Gannet Group. Thins eastward.

PHOSPHORIA FORMATION (250-1,300 feet) Middle-Upper Permian

A) Idaho, western Montana, northeastern Utah, and western Wyoming.
B) Richards, R.W., and Mansfield, G.R., 1912, Jour. Geology, v. 20, p. 681-709.
C) Exposures in Phosphoria Gulch, which joins Georgetown Canyon $2\frac{1}{2}$ miles northwest of Meade Peak, Idaho.
D) Phosphorite, pelletal phosphatic mudstone, chert, pelletal, oolitic, pisolitic dolomite, nodular and bioclastic phosphorite, and limestone.
E) Includes (in ascending order): Meade Peak Phosphatic Shale Member, lower chert member, Rex Chert Member, cherty shale member, Retort Phosphatic Shale Member, and Tosi Chert Member. Intertongues with Park City Formation. Retort Phosphatic Shale Member may be a good hydrocarbon source bed.

PORTNEUF LIMESTONE MEMBER (200-1,000 feet) Lower Triassic

A) Southeastern Idaho.
B) Mansfield, G.R., 1915, Washington Acad. Sci. Jour., v. 5, p. 492.
C) Named for Portneuf River, in Fort Hall Indian Reservation.
D) Limestone containing a well-developed red-bed unit which consists of interbedded red sandstone and shale.
E) Member of Thaynes Limestone. Unconformably underlies Timothy Sandstone Member of the Thaynes.

PREUSS SANDSTONE (0-1,300 feet) Upper Jurassic

A) Southeastern Idaho and eastern Utah.
B) Mansfield, G.R., and Roundy, P.V., 1916, U.S. Geol. Survey Prof. Paper 98.
C) Preuss Creek, 12 miles northeast of Montpelier, Idaho.
D) Reddish-gray to dull-red sandstone and sandy siltstones.
E) Equivalent to Entrada Formation.

QUEALY FORMATION (1,000 feet) Lower Cretaceous

A) Southeastern Idaho and southwestern Wyoming.
B) Rubey, W.W., 1973, U.S. Geol. Survey Bull. 1372-I, 35 p.
C) About $1\frac{1}{4}$ miles south of Quealy Reservoir, Lincoln County, Wyoming.
D) Mudstones and sandstones with some siltstones.
E) Probably equivalent to the lower part of the Aspen Shale.

RETORT PHOSPHATIC SHALE MEMBER (55-90 feet) Permian

A) Southwestern Montana, eastern Idaho, northeastern Utah, and western Wyoming.
B) Swanson, R.W., 1956, *in* McKelvey,

V.E., and others, Am. Assoc. Petroleum Geologists Bull. v. 40, no. 12, p. 2832, 2850-2851; 1959, U.S. Geol. Survey Prof. Paper 313-A, p. 29-30.

C) Small Horn Canyon just northwest of Retort Mountain in sec. 23, T.9S., R.9W., about 10 miles south of Dillon, Beaverhead County, Montana.

D) Lower phosphatic zone; middle zone of calcareous mudstone, including oil shale beds; and upper phosphatic zone.

E) Member of Phosphoria Formation. In the Garrison, Montana, area, it is almost wholly phosphorite. To the southwest in Idaho it intertongues with the cherty shale member. Underlies the Tosi Chert Member; overlies Rex Chert Member. Also intertongues with the Franson Member of the Park City Formation.

REX CHERT MEMBER (100 feet) Permian

A) Northeastern Utah, eastern Idaho, southwestern Montana, and southwestern Wyoming.

B) Richards, G.B., and Mansfield, G.R., 1912, Jour. Geology, v. 20, p. 683-689.

C) Phosphoria Gulch, $2\frac{1}{2}$ miles northwest of Meade Peak, Bear Lake County, Idaho, sec. 12, T.10S., R.44E.

D) Gray limestone and black chert in lower part, red-stained black chert in the middle, and dark-gray cherty shale in the upper part.

E) Member of Phosphoria Formation. Upper part grades into the Franson Tongue of the Park City Formation to the northeast and south. Lower part maintains its identity into southwestern Montana, western Wyoming, and north-central Utah.

RICH MEMBER (40-500 feet) Middle Jurassic

A) Southeastern Idaho, southwestern Wyoming and northeastern Utah.

B) Imlay, R.W., 1967, U.S. Geol. Survey Prof. Paper 540, p. 30-36.

C) North side of Birch Creek about 8 miles west of Woodruff, Rich County, Utah.

D) Mostly medium-gray shaly limestone.

E) Ovelies the Sliderock Member and underlies the Boundary Ridge Member of the Twin Creek Limestone.

SAGE JUNCTION FORMATION (2,300 feet) Lower Cretaceous

A) Southeastern Idaho and southwestern Wyoming.

B) Rubey, W.W., 1973, U.S. Geol. Survey Bull. 1372-I, 35 p.

C) South end of Boulder Ridge on the north side of U.S. Highway 30 at Sage Junction.

D) Siltstone, sandstone, and quartzite with some porcelanite, limestone, conglomerate, and coal.

E) Correlative in part with much of the Aspen Shale. Uppermost several hundred feet may be equivalent to parts of the Frontier Formation.

SALT LAKE FORMATION (0-3,700 feet) Miocene-Pliocene

A) Northern Utah, southeastern Idaho, and southwestern Wyoming.

B) Hayden, F.V., 1869, U.S. Geol. Survey Terr., Report on Colo. and N. Mex., 3rd Ann. Report, p. 92.

C) Named for extensive outcrops in Weber and Salt Lake Valleys, Utah.

D) Conglomerates with beds of marls, clays, sandstones, and grits.

E) Probably partly lacustrine but mainly of fluviatile origin.

SILLEM MEMBER (100-400 feet) Eocene

A) Southwestern Wyoming.
B) Oriel, S.S., and Tracey, J.I., Jr., 1970, U.S. Geol. Survey Prof. Paper 635, p. 34-36, 41, 46-47.
C) Named for good exposures on Sillem Ridge south of Sage, Wyoming.
D) Pale-varicolored to gray mudstone and claystone, partly tuffaceous, basal conglomerate, minor marlstone, limestone, and sandstone.
E) Basal member of the Fowkes Formation.

SLIDEROCK MEMBER (20-285 feet) Middle Jurassic

A) Southeast Idaho, and southwest Wyoming.
B) Imlay, R.W., 1967, U.S. Geol. Survey Prof. Paper 540, p. 22-30.
C) The west side of Grade Creek at the junction with Sliderock Creek, Lincoln County, Wyoming.
D) Mostly medium- to thin-bedded limestone.
E) Overlies Gypsum Spring Member and underlies Rich Member of the Twin Creek Limestone.

SMITHS FORMATION (750 feet) Lower Cretaceous

A) Southeastern Idaho and southwestern Wyoming.
B) Rubey, W.W., 1973, U.S. Geol. Survey Bull. 1372-I, 35 p.
C) About 1½ miles northwest of the Smiths Fork Guard Station, Lincoln County, Wyoming.
D) Ferruginous black shale and tan quartzitic sandstone.

SMOOT FORMATION (? feet) Lower Cretaceous

A) Southwestern Idaho and western Wyoming.
B) Eyer, J.A., 1965, Dissert. Abs. 25, no. 10, p. 5860.
C) Near town of Smoot, Lincoln County, Wyoming.
D) Mudstones, siltstones, and calcareous nodular beds.
E) Uppermost formation in Gannett Group.

SPENCE SHALE MEMBER (? feet) Middle Cambrian

A) Southeastern Idaho and northeastern Utah.
B) Walcott, C.D., 1908, Smithsonian Misc. Coll., v. 53, no. 1804, p. 5, 6, 8.
C) Spence Gulch, about 5 miles west-southwest of Liberty, Bear Lake County, Idaho.
D) Dark reddish-brown shale.
E) Member of the Langston Dolomite.

SPRING CANYON MEMBER (0-375 feet) Lower Cretaceous

A) Northeastern Utah.
B) Hale, L.A., 1960, Wyoming Geol. Assoc. 15th Ann. Field Conf. Guidebook, p. 137-146.
C) Spring Canyon southeast of Coalville, Utah.
D) Carbonaceous shale, sandstone, and thin coals.
E) Member of Frontier Formation and possibly equivalent to Mowry Formation.

ST. CHARLES FORMATION (0-800 feet) Upper Cambrian

A) Southeastern Idaho and northeastern Utah.
B) Walcott, C.D., 1908, Smithsonian Misc. Coll., v. 53, no. 1804; Williams, J.S., 1948, Geol. Soc. America Bull., v. 49, no. 11 (Logan quadrangle, Utah), p. 1121-1123.
C) West of St. Charles, Bear Lake County, Idaho.

D) Basal quartzite (Worm Creek Member, 170 feet thick) overlain by thin-bedded limestone and massive dark-gray dolomites.
E) Overlies Nounan Formation.

STUMP FORMATION (0-600 feet) Upper Jurassic

A) Southeastern Idaho, eastern Utah, and southwestern Wyoming.
B) Mansfield, G.R., and Roundy, P.V., 1916, U.S. Geol. Survey Prof. Paper 98.
C) Stump Peak, Idaho.
D) Gray, calcareous, glauconitic sandstone with some shale and sandy limestones.
E) Equivalent to the Curtis Formation and upper part of Sundance Formation.

SWAN PEAK QUARTZITE (0-720 feet) Middle Ordovician

A) Northeastern Utah and southeastern Idaho.
B) Richardson, G.B., 1913, Am. Jour. Sci., 4th, v. 36, p. 406-416.
C) Swan Peak, Rich County, Utah, 4 miles northwest of Garden City, Utah.
D) Lower member, limestone and interbedded dark shale; upper member, massive quartzite and thin-bedded quartzitic sandstone.
E) Referred to as the Kinnikinic Quartzite in central Idaho. Thins rapidly to a zero edge to the east.

TEEWINOT FORMATION (500 feet) Middle Pliocene

A) Northwestern Wyoming.
B) Love, J.D., 1956, Am. Assoc. Petroleum Geologists Bull., v. 40, no. 8, p. 1899, 1907-1911, fig. 1.
C) In and adjacent to Jackson Hole National Elk Refuge, Teton County, Wyoming. Name derived from Mount Teewinot.
D) Succession of white limestone, tuff, pumicite, claystone, and conglomerate.
E) Unconformably overlies rocks ranging in age from Cambrian to Miocene.

THAYNES LIMESTONE (500 feet) Lower Triassic

A) Northeastern Utah, southeastern Idaho, southwestern Montana, and southwestern Wyoming.
B) Boutwell, J.M., 1907. Jour. Geology, v. 15, p. 434-458.
C) Thaynes Canyon, Park City District, Utah.
D) Black to tan, silty limestone and sandstone.
E) Thaynes subdivisions are (in ascending order): lower limestone, lower black limestone, tan silty limestone, upper black limestone, sandstone and limestone, Portneuf Limestone, and Timothy Sandstone. The Thaynes Formation intertongues with the red beds in the lower portion of the Ankareh Formation.

THOMAS FORK FORMATION (1,000 feet) Lower Cretaceous

A) Southeast Idaho and southwest Wyoming.
B) Rubey, W.W., 1973, U.S. Geol. Survey Bull. 1372-I, 35 p.
C) North bank of Thomas Fork, Lincoln County, Wyoming.
D) Mudstone and some sandstone which is conglomeratic in part.

THREE FORKS FORMATION (0-200 feet) Upper Devonian

A) Northwestern Wyoming, Montana, and northern Utah.
B) Peak, A.C., 1893, U.S. Geol. Survey Bull. 110, p. 20-22.
C) North side of Gallatin River at Logan, Montana.

D) Evaporites, sandstone, and shale.
E) The Logan Gulch and Trident Members are equivalent to the Beirdneau Formation in the upper plates of the Willard and Paris thrust faults.

TIMOTHY SANDSTONE MEMBER (160-1,300 feet) Lower Triassic

A) Southeastern Idaho, central northern Utah, and central western Wyoming.
B) Mansfield, G.R., 1920, Am. Jour. Sci., 4th, v. 50, p. 62; 1920, U.S. Geol. Survey Bull. 713, p. 29, 50.
C) Timothy Creek in Lanes Creek and Freedom quadrangles, Idaho.
D) Red shales and siltstones with interbedded reddish-purple and reddish-brown sandstone.
E) Member of Thaynes Limestone. Overlies Portneuf Limestone.

TOSI CHERT MEMBER (25-40 feet) Permian

A) Western Wyoming, eastern Idaho, southwestern Montana, and eastern Utah.
B) Sheldon, R.P., *in* McKelvey, V.E., and others, 1956, Am. Assoc. Petroleum Geologists Bull., v. 40, no. 12, p. 2830, 2832, 2836, 2851-2852; 1959, U.S. Geol. Survey Prof. Paper 313-A, p. 3031.
C) Tosi Creek in SE$\frac{1}{4}$ sec. 17, T.39N., R.110W., Sublette County, Wyoming, 8$\frac{1}{2}$ miles east-northeast of Tosi Peak on east nose of small anticline.
D) Thick dark- to light-colored chert beds.
E) Member of Phosphoria Formation. Underlies Dinwoody Formation; overlies Retort Phosphatic Shale Member. It is the most extensive tongue of the Phosphoria into the Park City Formation and the Shedhorn Sandstone.

TRIDENT MEMBER (73-225 feet) Upper Devonian

A) Montana, Idaho, northern Wyoming, and Utah.
B) Sandberg, C.A., 1965, U.S. Geol. Survey Bull. 1194N, p. 2,8,12-14.
C) Included in type section of Three Forks Formation in gulch on bluffs at north side of Gallatin River northeast of Logan in S$\frac{1}{2}$ sec. 25, T.2N., R.2E., Gallatin County, Montana.
D) Greenish-gray, light-olive-gray, and yellowish-gray calcareous to slightly calcareous fossiliferous clay shale.
E) Member of Three Forks Formation.

TUNP MEMBER (100-500+ feet) Eocene

A) Southwestern Wyoming.
B) Oriel, S.S., and Tracey, J.I., Jr., 1970, U.S. Geol. Survey Prof. Paper 635, p. 22-28.
C) Dempsey Ridge in Tunp Range, Lincoln County, Wyoming.
D) Diamictite, consisting chiefly of conglomeratic mudstone and blocky breccia in mudstone matrix.
E) Member of Wasatch Formation.

TWIN CREEK LIMESTONE (800-3,000 feet) Middle Jurassic

A) Southeast Idaho, southwest Wyoming, and northeast Utah.
B) Veatch, A.C., 1907, U.S. Geol. Survey Prof. Paper 56.
C) Twin Creek between Sage and Fossil, Lincoln County, Wyoming.
D) Black and gray calcareous shale and thin-bedded, shaly limestone.
E) Underlain by Nugget Formation throughout area. Members are (in ascending order): Gypsum Spring, Sliderock, Rich, Boundary Ridge, Watton Canyon, Leeds Creek, and Giraffe Creek.

TYGEE SANDSTONE (400-700 feet) Lower Cretaceous

A) Southeastern Idaho and southwestern Wyoming.
B) Mansfield, G.R., and Roundy, P.V., 1916, U.S. Geol. Survey Prof. Paper 98.
C) Tygee Creek, Idaho.
D) Black shales and tan sandstones.
E) Member of the Bear River Formation.

UPTON SANDSTONE (450 feet) Upper Cretaceous

A) Northeastern Utah.
B) Hale, L.A., 1960, Wyoming Geol. Assoc. 15th Ann. Field Conf. Guidebook, p. 137-146.
C) Upton, Utah.
D) Light yellow to bluish-gray calcareous sandstones.
E) Uppermost member of Frontier Formation overlying the Judd Shale. Represents beginning deposition in regressive phase of Hilliard sediments.

UTE LIMESTONE (685 feet) Middle Cambrian

A) Northeastern Utah and southeastern Idaho.
B) Amended definition, Deiss, C., 1938, Geol. Soc. America Bull., v. 49, no. 7, p. 1112-1113, 1117.
C) A spur west of the first western tributary of North Cottonwood Creek, Blacksmith Fork Canyon, Logan quadrangle, Cache County, Utah.
D) Lower 175 feet is alternating drab-green to buff shales interbedded with dark-gray to green thick-bedded limestone. Upper 510 feet is thin- and thick-bedbed dark-blue-gray limestones with stringer of tan- and reweathering siliceous clay.
E) Eastern equivalent of the Bancroft Formation. It overlies the Langston Dolomite, and wedges out along the Utah-Wyoming State line.

WASATCH FORMATION (300-11,000 feet) Eocene

A) Widespread in Rocky Mountain area.
B) Hayden, F.V., 1873 reprint, First, second and third ann. repts. of the U.S. Geol. Survey of the Territories for the years 1867, 1868, and 1869, p. 191.
C) Wasatch Station, Echo Canyon, Utah.
D) Red, gray, brown mudstones, siltstones, sandstones, and conglomerates.
E) The Wasatch intertongues with the Green River Formation.

WATER CANYON FORMATION (550 feet) Lower Devonian

A) Northern Utah and south-central Idaho.
B) Williams, J.S., 1948, Geol. Soc. America Bull., v. 59, no. 11, 1121-1123.
C) Tributary of Green Canyon, Logan quadrangle, Cache County, Utah, well exposed in sec. 3, T.21N., R.3E.
D) Lower member is fine-grained, medium- to thin-bedded, light gray dolomite, which weathers to grayish-orange or pink hues. Upper member is a cross-bedded light-brown sandstone.
E) Unconformably overlies Laketown Dolomite.

WATTON CANYON MEMBER (60-400 feet) Middle Jurassic

A) Southeast Idaho, southwest Wyoming, and northeast Utah.
B) Imlay, R.W., 1967, U.S. Geol. Survey Prof. Paper 540, p. 41-45.
C) North side of Birch Creek about 8 miles west of Woodruff, Utah.

D) Mostly medium- to thin-bedded limestone; oolitic beds occur throughout.
E) Overlies Boundary Ridge Member and underlies Leeds Creek Member of the Twin Creek Limestone.

WAYAN FORMATION (7,000 feet) Cretaceous

A) Southeastern Idaho.
B) Mansfield, G.R., and Roundy, R.V., 1916, U.S. Geol. Survey Prof. Paper 98, p. 82.
C) Wayan, Bannock County, Idaho.
D) Red mudstones, siltstones, and sandstones with some fresh-water limestones.
E) Partially equivalent to Bear River, Aspen, and possibly Frontier.

WEBER SANDSTONE (200-3,000 feet) Permian-Pennsylvanian

A) Northeastern Utah and western Colorado.
B) King, C., 1876, Am. Jour. Sci., 3rd, v. 11, p. 477-479.
C) Upper Weber Canyon, east of Morgan, Morgan County, Utah.
D) White, light-gray, buff quartzite, interbedded with thin limestone and/or dolomite, smoke-gray to dark-blue.
E) Equivalent to the Wells Formation and in part to the Tensleep Sandstone. Thins to the east.

WELLS FORMATION (1,500-1,800 feet) Permian-Pennsylvanian

A) Eastern Idaho, Montana, northeastern Utah and southwestern Wyoming.
B) Richards, R.W., and Mansfield, G.R., 1912, Jour. Geology, v. 20, p. 681-709.
C) Wells Canyon, T.10S., R.45E., Caribou County, Idaho.
D) Brecciated, fine-grained sandstone, intercalated limestone and sandy limestone, some oolitic, and with chert nodules and stringers.
E) Thins to the east. Equivalent at least in part to the Weber Sandstone and the Tensleep Sandstone.

WOLSEY SHALE (150-360 feet) Middle Cambrian

A) Western Montana and northwestern Wyoming.
B) Weed, W.H., 1899, U.S. Geol. Survey Geologic Atlas, Folio 55; 1900, U.S. Geol. Survey, 20th Ann. Rept., pt. 3, p. 285-286.
C) Named for exposures at dam on Sheep Creek near Wolsey, Meagher County, Montana.
D) Lower part dull-green to greenish-gray shale, interbedded with thin lenses of sandstone. Middle part is micaceous, paper-thin shale and occasional thin platy intercalated beds of rust-weathering sandstone. Upper part is fissile shale, chocolate- to maroon-brown, thin beds of gray crystalline limestone with iron and glauconite.
E) Member of Gros Ventre Formation. Underlies Park Shale and overlies Flathead Sandstone.

WOODHURST MEMBER (260 feet) Lower Mississippian

A) Montana and western Wyoming.
B) Weed, W.H., 1889, U.S. Geol. Survey Geol. Atlas, Folio 56.
C) Woodhurst Mountain, Montana.
D) Interbedded silty fine-grained limestone and oolitic crinoidal limestone.
E) Upper member of Lodgepole Limestone.

WOOD SHALE TONGUE (250-400 feet) Upper Triassic

A) Southeastern Idaho, central northern Utah, and central western Wyoming.

B) Mansfield, G.R., 1915, Washington Acad. Sci. Jour., v. 5, p. 492; 1916, Washington Acad. Sci. Jour., v. 6, p. 41.

C) On Wood Creek in T.3S., R.38E., less than 2 miles west of Paradise Valley quadrangle, Idaho.

D) Bright-red, sandy shale of shaly sandstone. Locally contains purplish and green shale in addition to red beds.

E) Unit considered to be the westward-extending tongue of the Ankareh Formation in western Wyoming and southeastern Idaho.

WOODSIDE SHALE (300-1,000 feet)
Lower Traissic

A) Northeastern Utah, southeastern Idaho, southwestern Montana, and southwestern Wyoming.

B) Boutwell, J.M., 1907, Jour. Geology, v. 15, p. 434-458.

C) Woodside Gulch, Park City District, Utah.

D) Red to maroon, shaly, nonfossiliferous siltstone.

E) Red beds grade westward to limestone and siltstone. Intertongues with the Dinwoody Formation. The red beds section is called the MacKentire Redbeds Tongue.

WORM CREEK QUARTZITE (6-75 feet)
Upper Cambrian

A) Southeastern Idaho and northeastern Utah.

B) Richardson, G.B., 1913, Am. Jour. Sci., 4th, v. 36, p. 407-408.

C) Worm Creek, Bear Lake County, Idaho.

D) Drab fine- to medium-grained, medium-bedded quartzite.

E) Basal unit of St. Charles Formation. Overlies Nounan Formation.

LATE DEVELOPMENTS

¶Burton/Hawks has an indicated oil discovery in NW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 28, T.3N., R.8E. in northeastern Utah's Summit County. Tests indicate production from the Cretaceous Kelvin Formation and the Jurassic Stump Formation. ¶In mid-October, 1981, Exxon completed the #4 Road Hollow Unit well in Lincoln County, Wyoming, as a gas well producing 10,000 MCFGPD and 440 BCPD. This discovery, recently named Road Hollow Field, produces from Ordovician Bighorn Dolomite at about 15,000 feet. It is in NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 4, T.19N., R.119W., approximately 4 miles northeast of the nearest producing well in Whitney Canyon-Carter Creek Field. ¶Early in 1982, Wainco Oil and Gas completed the B-1 Amoco-Champlin 370 as a discovery flowing 230 BOPD and 840 MCFGPD from the Triassic Ankareh Formation at about 12,500 feet. The discovery, in NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 23, T.17N., R.119W., is in a separate structure immediately to the west of Ryckman Creek Field, in Uinta County, Wyoming. ¶Total production for the Idaho-Wyoming-Utah portion of the overthrust belt is listed at 23,703 BOPD and 139,900 MCFPD in the March, 1982 issue of Overthrust News [published by the Overthrust Industrial Association]. ¶Thomas Canyon Field has been abandoned by Chevron due to the high hydrogen sulfide content of the gas (over 35 percent) and proximity of the field to the town of Evantson (see Plate 1).

STATE OF WYOMING

1933

GEOLOGICAL SURVEY