STATE OF IDAHO
C. C. MOORE, Governor
BUREAU OF MINES AND GEOLOGY
FRANCIS A. THOMSON, Secretary

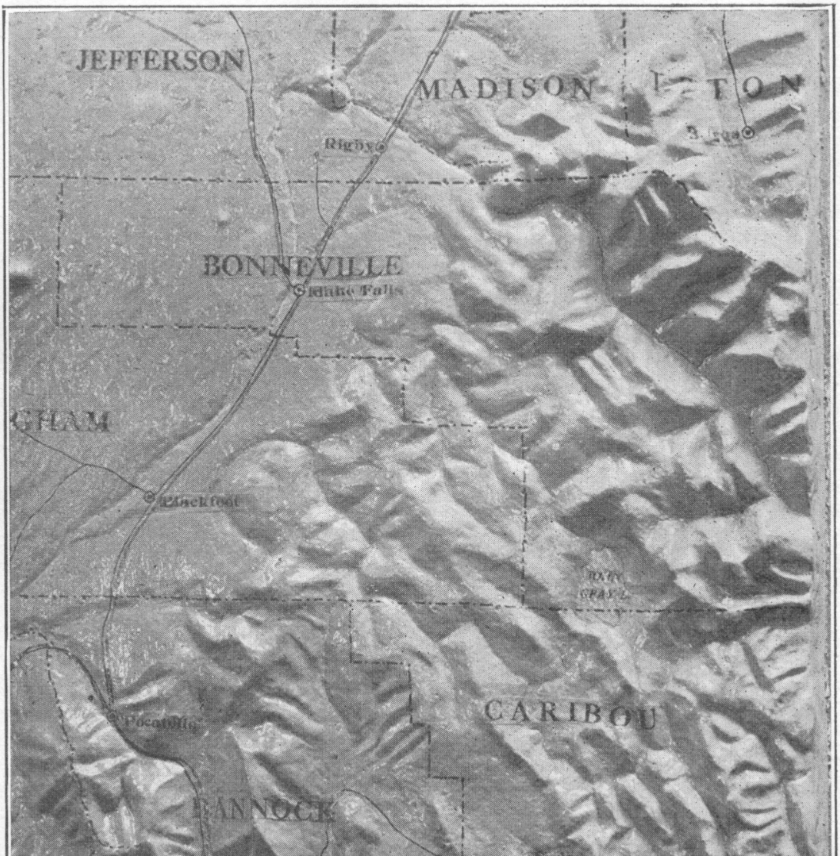
IDAHO BUREAU OF MINES AND GEOLOGY BULLETIN
ISSUED QUARTERLY. PRICE 50 CENTS
NO. 8 SEPTEMBER 1924

GEOLOGY AND OIL POSSIBILITIES OF BINGHAM, BONNEVILLE, AND CARIBOU COUNTIES, IDAHO

BY
VIRGIL R. D. KIRKHAM

UNIVERSITY OF IDAHO
MOSCOW, IDAHO

Entered as second-class matter August 11, 1924, at the postoffice at Moscow, Idaho, under the act of March 3, 1879.



RELIEF MAP OF SOUTHEASTERN IDAHO.

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CONTENTS.

ILLUSTRATIONS.

PREFACE.

This bulletin presents the results of a study of additional areas in southeastern Idaho which lie within the so-called "petroliferous province" of the state.

The reception accorded to Bulletin 4—*Petroleum possibilities of certain anticlines in southeastern Idaho*—by the same author, indicates that the people of Idaho are disposed to accept and to act upon competent geologic advice. This is further evidenced by the fact that, so far as known, drilling in impossible and ridiculous places in the state has practically ceased.

Nothing could be of greater value to the state of Idaho at the present time than the discovery therein of areas capable of commercial oil production, and efforts to this end in likely areas are to be commended; nevertheless it is thought wise to point out that in most instances in a "wildcat" area no test well should be started without sufficient financial backing to go to at least 2500 feet depth. Neglect of this precaution in adjacent areas has led to the abandonment of wells before structures have been adequately tested, resulting not only in total financial loss but also in undesirable and unjustified reflection on the area involved.

The Bureau of Mines and Geology is endeavoring in this and other similar publications to bring before the people the potential or possible mineral resources of the state and to do so in such manner as to enable an intelligent estimate to be made of the risk involved in their development.

FRANCIS A. THOMSON,
Secretary.

GEOLOGY AND OIL POSSIBILITIES OF PARTS OF BINGHAM, BONNEVILLE, AND CARIBOU COUNTIES, IDAHO.

BY VIRGIL R. D. KIRKHAM.

INTRODUCTION.

PURPOSE OF THE INVESTIGATION.

A reconnaissance examination of a part of southeastern Idaho and a small strip of western Wyoming lying between longitudes 111° and 111° 45′ W., and latitudes 43° and 43° 30′ N., comprising an area of approximately 1330 square miles, was undertaken during the summer of 1923 for the collection of data regarding the oil possibilities of the region.

Previous to this examination considerable local excitement over oil possibilities had been manifested. Thousands of acres of patented lands in the western part of the area had been leased. The data collected during the examination indicate, however, that only a part of the region examined can justifiably be suspected of having possibilities of petroleum production to a commercial extent.

The field work was accomplished by two parties. The first, composed of four persons, entered the field about June 1, 1923, under the supervision of Mr. Arthur M. Piper, a geologist of the State Bureau of Mines and Geology. The work of this party was to establish stations in a secondary control that would serve to facilitate the accurate mapping of geological outcroppings and structures throughout the region. This work was extended over four of the six quadrangles herein reproduced. The writer joined this party on July 8, 1923. The control work was finished about July 17, and Mr. Piper left shortly thereafter for another part of the state.

The geological examination proceeded from that date until Sept. 9, 1923, under the supervision of the writer. Progress over the mountainous region was slow, due to lack of roads, trails, and navigable streams. All work was accomplished with the aid of a pack outfit and was of such a strenuous character as to necessitate frequent changes of horses. No camp was made for longer than five days; most stops were much shorter. The plan of attack was to cross and recross the Caribou Range and to follow the Snake River and other major streams of the area. The geological mapping was facilitated by the use of Forest Service topography in three quadrangles and the use of the U. S. Geological Survey topographic sheet for the Cranes Flat quadrangle. Formations in other areas were located by drainage and by resection and intersection with plane table, alidade, and compass.

PREVIOUS GEOLOGICAL WORK IN THE AREA.

The entire area was examined in 1877 by geologists of the Hayden Survey and was described in the report for that year. [12]

This examination was conducted by Orestes St. John. His report, which includes a fund of accurate information, represents reconnaissance work of high standard. The area was covered in one field season. It may be said, however, that the written report considerably excels the geologic maps which accompany it and that many localities were not visited either by St. John or by members of his geological staff.

About one-third of the area was covered in a reconnaissance examination for phosphate lands in 1911. [39] This examination, which lasted about three weeks, was made by A. R. Schultz and R. W. Richards of the U. S. Geological Survey. Their work established more accurate boundaries for the phosphate lands and caused 141,000 acres of withdrawn phosphate land to be restored to agricultural entry.

An earlier expedition by Schultz was made through the Snake River valley of this area in 1906.*

A similar expedition traversed the Salt River valley to Snake River and thence to Irwin and across the Snake River range in 1910.[1] This party was headed by Eliot Blackwelder of the U. S. Geological Survey.

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12. See reference No. 12, Bibliography p. 10.

39. See reference No. 39, Bibliography.

* Schultz, A. R.—Geology and geography of a portion of Lincoln County, Wyo: U. S. Geol. Survey Bull. 543, 1914.

1. See reference No. 1, Bibliography.

Another examination for phosphate was made by Schultz in the summer of 1912.[38] This reconnaissance covered parts of the Snake River valley and irregular areas on each side.

An examination for coal was conducted in the summer of 1917 by G. R. Mansfield of the U. S. Geological Survey.[22] A part of the two months consumed in the investigation was spent in the western portion of the area discussed in this bulletin. The report on coal prospects was negative.

ACKNOWLEDGMENTS.

The writer takes pleasure in acknowledging his deep indebtedness to the following members of the United States Geological Survey: to Mr. G. R. Mansfield (who has done the most recent and exhaustive work in southeastern Idaho) for personal conferences which have greatly aided the writer in properly describing many formations and faults in the area; to Dr. Francis B. Laney, professor of geology, University of Idaho, for many valuable suggestions and criticisms advanced during the preparation of this manuscript and the accompanying maps, and also for editorial supervision; to Dr. Francis A. Thomson, dean of the School of Mines, University of Idaho, for valuable counsel in preparing the maps and format of this report, and for a critical reading of the manuscript. The writer also wishes to express gratitude for the able assistance given in the field by Mr. Arthur M. Piper, geologist of the Idaho Bureau of Mines and Geology, and Mr. Felix A. Plastino, in charge of geologic instruction at the Idaho Technical Institute, Pocatello.

The writer wishes to acknowledge to Mr. Alfred L. Anderson, graduate assistant in geology, University of Idaho, his appreciation for the petrographic analyses of many of the igneous rocks described in this bulletin. He is also grateful for the care and cooperation given by Mr. A. S. Swanson and Mr. Fred Crandall in the preparation of the maps accompanying this publication.

38. See reference No. 38, Bibliography.
22. See reference No. 22, Bibliography.

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Many of the formations discussed and described in this bulletin extend into adjacent areas which have already been mapped and described. Those publications which are thought likely to be of value to the reader in making a thorough study of this area are listed below.

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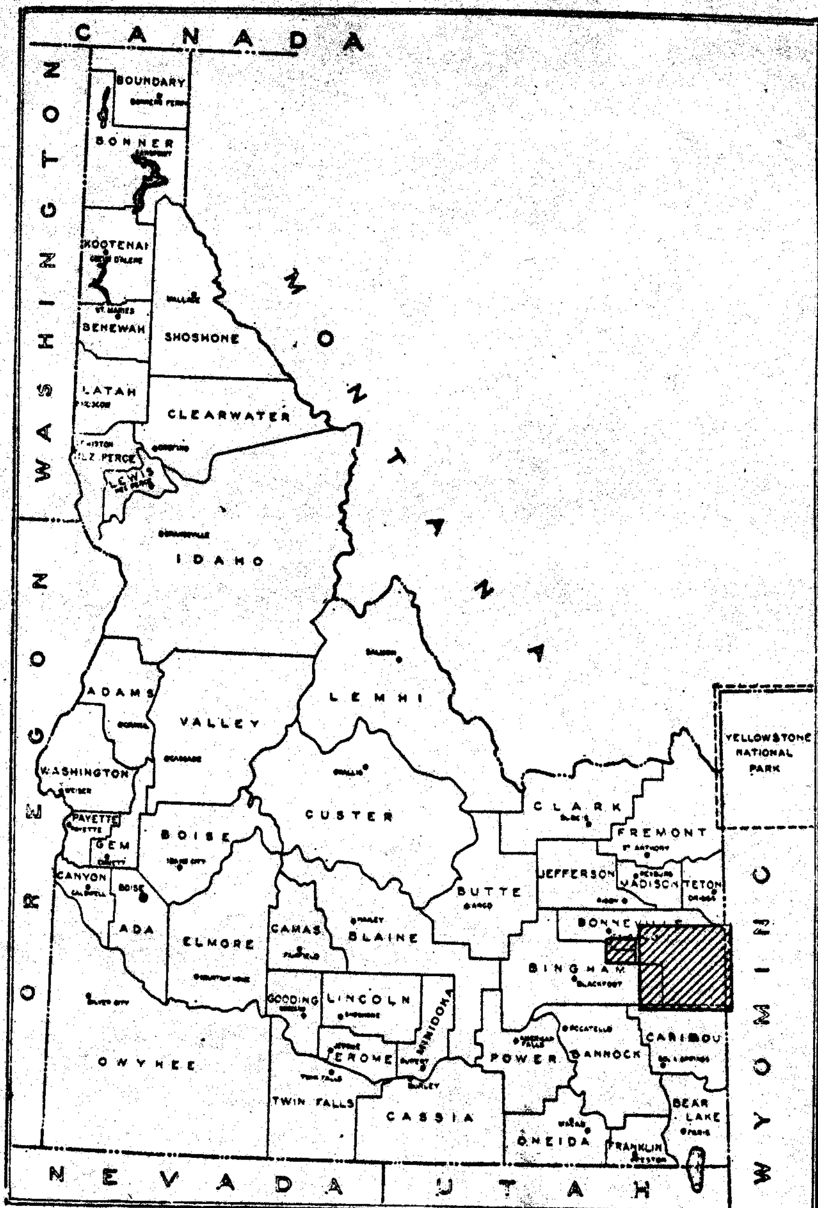

KEY MAP OF IDAHO SHOWING AREA COVERED IN THIS BULLETIN.

GEOGRAPHY.

LOCATION.

The area examined and mapped constitutes six 15-minute quadrangles lying between meridians 111° and 111° 45′ W., and parallels 43° and 43° 30′ N. It comprises an area of approximately 1330 square miles located chiefly in Idaho but extending over the state line into Wyoming for a distance slightly in excess of two miles. The above-mentioned area is divided as follows: Bonneville county, 1025 square miles; Bingham county, 160 square miles; Caribou county, 55 square miles; the State of Wyoming, 90 square miles. An area comprising 520 square miles lies in the Caribou National Forest, 260 square miles are in the Targhee National Forest, and the remaining 550 square miles are public domain, privately owned lands, or state property.

TOPOGRAPHY.

The entire area lies within the upper Snake River drainage basin. Snake River flows through the northeastern and eastern part of the area in a northwesterly direction. The largest tributaries are: Salt River, flowing north, which receives in turn the drainage of Tincup and Jacknife creeks in the area; McKoy, Bear, Indian, Fall, Pritchard, Garden, Granite, and Antelope creeks, flowing northeasterly to join the Snake at a right angle; and Indian, Elk, Palisade, Rainy and Pine creeks, flowing southwesterly to the Snake and joining it at a similar angle.

The western half of the area is drained by Grays Lake Outlet and its tributaries: Willow Creek, with its tributaries Crane and Homer creeks, Meadow, Indian Fork, Bull Fork, Hell, Lava and Brockman creeks. Grays Lake Outlet drains Grays Lake (in the southern part of the area) and enters the Snake about three miles north of the city of Idaho Falls. The Snake at this point has made a great curve and is flowing directly south through the Snake River lava plains.

The entire drainage system has been controlled by the structure of the sedimentary beds in the area, which exhibit numerous alternations of hard and soft strata with consequent unequal erosion. The headwaters of the most important streams, as well as many others, flow in a northwesterly or southeasterly direction along any soft, easily eroded bed, or between and parallel to dominant anticlinal axes until a depression or downward undulation in the main anticline permits them to break across at a right angle to join the Snake River. This striking and common relationship between structure and drainage is typified by the course of Fall Creek and its tributaries as shown in the Fall Creek and Hell Creek quadrangles.

Grays Lake is the largest body of water in the area, being about 35 square miles in extent. It is little more than a vast marsh. From the summit of Caribou Mountain, immediately to the east, it presents a tangled skein of open, stream-like waterways making a veritable maze in the midst of the marshy growth. Its elevation is approximately 6390 feet above sea level. Two islands lie in the central eastern part of the lake.

A portion of the lower end of the Blackfoot River reservoir enters the Grays Lake quadrangle. This quadrangle also contains the Little Valley reservoir.

Three types of topography are included in the area: (1) Lava plateaus, (2) alluvium covered basin plains, and (3) rugged, mountainous provinces made up for the most part of tilted, folded, or faulted sediments, chiefly sandstones, conglomerates, shales, and limestones. The first type is found in the Hell Creek, Fall Creek, and Cranes Flat quadrangles. The second type is represented by Swan Valley in the Fall Creek quadrangle, Star Valley in the McKoy Creek quadrangle, and Little Valley, Long Valley and Outlet Valley in the Cranes Flat quadrangle. The third type is found mainly in the Fall Creek, Palisade Creek, McKoy Creek and Grays Lake quadrangles.

The highest point in the area is Caribou Mountain, reaching an elevation of approximately 9800 feet. It presents a truly scenic spectacle due to its isolation and serrated outlines of cirques and spurs, scars from a past period of glaciation. It is easily the most commanding landmark in the southern part of the area.

The lowest point in the area lies in the Fall Creek quadrangle, being slightly more than 4300 feet above sea level. This is where the Snake River passes out of the area examined.

The mountainous areas include the Caribou Range, which traverses parts of all the quadrangles except Cranes Flat quadrangle, and the Big Hole or Snake River Range which is found in Palisade Creek quadrangle. In these ranges many peaks exceed 8000 feet, and a few reach a height of 9000 feet or above.

The most notable eminences in that part of the Caribou Range discussed here are Caribou Mountain, Big Elk Mountain, Little Elk Mountain, Black Mountain, Bald Mountain, Poker Peak, Tincup Mountain, Red Ridge, Fourth of July Ridge, Mahogany Ridge, Congress Knob and Point Lookout. Prominent peaks in that part of the Bighole and Snake River ranges included in the area are Atkinson, Thompson, Elkhorn, Palisade, Starvation, and Powder peaks.

The regions occupied by the two ranges are composed of sedimentary rocks representing many geologic periods and varying greatly in their resistance to the various weathering agencies and erosion processes to which they have been exposed throughout millions of years. These mountains, which have a northwest and southeast trend, have been subjected to a number of cycles of uplift and consequent active erosion, and have been elevated altogether several thousand feet. This does not mean, however, that they probably existed at any time at an elevation much in excess of the present high points.

The harder sediments form the prominent peaks and ridges and the softer beds have been excavated along their strikes.

In many places structural eminences are likewise topographic high points. In other words, structural anticlines and domes are often, respectively, ridges and oval-shaped mountains.

Some of the region has been rejuvenated a number of times, and is now in a youthful period of erosion exhibiting deep V-shaped valleys, vertical lava cliffs, and many other criteria of physiographic youth.

SETTLEMENT, OCCUPATIONS, AND ACCESSIBILITY.

The chief centers of habitation are in the Snake River valley, around Grays Lake, and in Long Valley. Sheep raising and hay growing are essentially the industries of the area.

The abundance of alluvium supplied by the erosive work of the stream makes the Snake River bed attractive for agriculture, but in some localities early or late frosts limit agricultural pursuits to the raising of stock and of hay for feed. Many of the basin valleys employ irrigation when it is needed. Much of the bench land above the Snake channel is used for dry farming and produces considerable wheat and many hardier grains.

Much of Cranes Flat, Grays Lake, and Hell Creek quadrangles is dotted with homesteads, but these are now chiefly used by sheep men for late range when the bands are brought out of the national forests. The Caribou National Forest serves as a great grazing area for several hundred thousand sheep each season. A few herds of cattle also graze here during the grass season.

The north and east sides of the larger mountains are heavily timbered with red fir, cedar, juniper, pine, and other conifers. The valleys and remaining sides of the mountains generally contain dense thickets of aspen, sagebrush, and chaparral growth. An occasional sawmill operates to supply the local demand for rough lumber, but the dressed article generally comes from other forests by rail transportation.

Considerable trapping is done in both the Caribou and Targhee National Forests, and the latter has become a celebrated game country noted for elk and big-horn sheep. Alpine, a post office and supply point in the McKoy Creek quadrangle, serves as a starting point for many "dude parties" during the summer season. The hot baths of the Alpine Hot Springs are also sought each year by a goodly number of tourists.

Towns and post offices in the area, in order of size, are Irwin, Etna, Gray, Alpine and Dehlin. Mail arrives at Irwin each day from Idaho Falls, and each day at Gray from Soda Springs. All other postoffices have alternate-day service.

An excellent highway enters the area from the north and extends through the Snake River valley along the eastern edge to Freedom by way of Salt River valley. Another main artery of travel is a sagebrush road from Idaho Falls to Soda Springs which traverses Cranes Flat and Grays Lake quadrangle by way of Gray. A number of private roads wander aimlessly to all parts of the bench lands but are in doubtful condition for auto transportation. The Caribou Range can be crossed by auto at only one place in the area—on a road from Gray to Freedom along Tincup Creek. In spite of the lack of good roads all the area can be reached by pack outfits or sheep camp equipment.

During the summer months Idaho Falls serves the western part of the area with rail transportation, supplies, and in the winter with schooling facilities. Soda Springs, to the south, similarly serves that region which is nearest it. Soda Springs is approximately 30 miles by road from the nearest part of the area and Idaho Falls lies less than 25 miles from several points in the northwestern portion.

GEOLOGY.

STRATIGRAPHY.

The rocks of the region range in age from Carboniferous to Quaternary, inclusive, and exhibit six evident unconformities and sediments to a thickness of approximately 27,000 feet. These include all the usual types of clastic deposits.

CARBONIFEROUS SYSTEM (MISSISSIPPIAN SERIES).

Madison Limestone (*Lower Mississippian*)—This formation, occurring in the northeastern portion of the area along the Snake River, is dark bluish-gray in color, fairly thin bedded in places and massive elsewhere. It is a notable cliff maker where tilted, and contains comparatively little shale. Its age has been determined by the finding of numerous recognizable cup corals. Although a complete section was unavailable, its thickness is thought to be approximately 1000 feet.

Brazer Limestone (*Upper Mississippian*)—This limestone appears to overlie the Madison conformably where observed. It is massive in occurrence, forming rugged cliffs or ridges where tilted and levelled. It has a dark gray color when fresh, but weathers to almost white or gray. A notable feature is a series of dark chert zones where banding, nodules, and irregular forms abound. Fossils are abundant and consist of distinctive cup corals. Calcite and siderite veins fill many of the fissures. The thickness of this limestone is approximately 1000 feet, and the formation appears to thin toward the north.

CARBONIFEROUS SYSTEM (PENNSYLVANIAN SERIES).

Wells Formation—The lower member, lying conformably immediately above the Brazer, is a thin bedded series of fossiliferous limestones and calcareous sandstones, and is probably about 100 feet thick. The central member is the prominent one of the formation, and is made up of white and yellow sandstones and quartzites. Occasional thin beds of limestone are also found in this member. The quartzitic member varies notably from south to north, where it decreases rapidly to a thickness of less than 80 feet.

The upper member is a massive gray siliceous limestone, which weathers into prominent white cliffs. Numerous bands and nodular zones of dark chert occur throughout and especially near the base of this limestone. Its average thickness rarely exceeds 200 feet.

Both the upper and lower members of this formation are fossiliferous, containing abundant Brachiopods and Bryozoa.

CARBONIFEROUS SYSTEM (PERMIAN SERIES).

Phosphoria Formation—The formation in this area is made up of the Rex chert member at the top, overlying softer phosphatic sandstones, shales and limestones of a yellowish, greenish, to gray color, and black oolitic phosphate rock at the base. The Rex chert is a cliff-maker and forms the crest of minor ridges, whereas the underlying shales, to the contrary, generally weather to a depression. The formation varies from 80 to 400 feet within the area, with the Rex chert making up about one-sixth of the thickness. A number of attempts were made to secure a good section but due to lack of success none will be given here. Only one horizon is believed to contain commercial phosphate in this area although contiguous areas contain more than one workable bed.

This formation bears the rich and immensely valuable phosphate deposits of southeastern Idaho, and its stratigraphy has been worked out in great detail in other parts of southeastern Idaho by a large corps* of U. S. Geological Survey geologists.

An unconformity with the underlying formation is reported in some localities, but if one exists in this area it was not detected.

* See references No. 6, 21, 34, 38, and 39, Bibliography.

TRIASSIC SYSTEM.

Woodside Shale—No angular unconformity between this formation and the underlying Phosphoria formation was noted in this area, although Mansfield believes a stratigraphic break to exist, from evidence found in other localities of southeastern Idaho.[21]

The formation as found here is composed chiefly of russet-brown and variable olive-green calcareous and arenaceous shales, containing impure fossiliferous limestone members. A series of limestones which makes up the top of the formation was difficult to distinguish from higher calcareous formations of the Triassic system. There is present in this region also a red shale member, wash from which gives the limestone cliffs a slightly reddish tinge throughout most of the exposures. As this formation is not clearly distinguishable from the overlying one, it was not actually measured, but it is thought to be approximately 800 feet thick at the exposures.

Thaynes Group—Mansfield has differentiated the remaining Triassic formations in a number of southeastern Idaho quadrangles and in the Fort Hall Indian Reservation. The description of the formation in the latter area is published,[21] but the findings in the areas adjacent to this region were not available to the writer. He describes a Thaynes group containing the Ross Fork limestone, the Fort Hall formation, Portneuf limestone and Timothy sandstone, the last-named being the youngest formation. Above these come in order, the Higham grit, Deadman limestone and Wood shale. The writer was able to recognize some of the above-listed formations but, because the Fort Hall Indian Reservation is relatively distant, and lithologic changes are not only possible but likely, he could not be certain of the correlation.

For convenience, the remaining Triassic formations also were mapped as the Thaynes group. One or more members of this group may be missing and some of the subsequent formations may be included in this grouping. Detailed paleontological identification, which alone can determine the sequence here, was lacking in the present field examination.

The Thaynes group thus indicated is made up of a series of thick-bedded limestones of a bluish-gray color, and a reddish limestone highly fossilized with a form thought to be *meekoceras*. Limestones of another series are thin-bedded and of brown color. Still another series contains yellowish sandstones and cherty limestones, which in turn are overlain by another massive limestone, gray to brown in color, and siliceous in character. The formation is probably less than 1200 feet thick in most of the localities studied.

JURASSIC SYSTEM.

Nugget Sandstone—This formation is believed to lie unconformably on the underlying Triassic formation. The Nugget has a light and generally white-colored zone of sandstone or grit near its base. In many places this is changed to quartzite, much of which is pink. The main part of the Nugget is a brick-red fine-grained sandstone in fairly thin platy beds, with cross-bedding evident in many places. The color of this phase changes in places to a deep purple and the entire member weathers to blocks and slabs which cover extensive talus slopes. The uppermost member again changes to a white or light pink sandstone, grit, or quartzite, varying locally. The entire formation is highly resistant and because of its general occurrence it appears in high, bold ridges, and broad, rounded slopes. The Nugget maintains a thickness of approximately 1000 feet in every locality where it was studied but appears to be thinning slightly to the northward.

Twin Creek Limestone—This formation appears to lie conformably on the underlying Nugget formation, although the stratigraphic change suggests an unconformity. This limestone exhibits a lithology peculiar to the Twin Creek, and the following section made on Fall Creek is designed to make the formation readily recognizable. The section given presents a thickness of 970 feet but the formation attains a thickness of approximately 1200 feet in parts of the area. It appears to decrease toward the north. The section is as follows:

Twin Creek Formation.

No. of Member	Thickness in Feet	Description
1 (bottom)	38	An impure, yellow, sandy limestone.
2	7	An impure calcareous sandstone with limestone inclusions. This weathers to a rusty brown, and being erosion-resistant, forms ridges where steeply inclined.
3	135	A gray, platy, soft limestone containing calcite seams. This weathers in small, irregularly shaped cliffs, presenting soft, yellowish slopes from a distance.
4	140	A dark blue, compact, fine-grained limestone which presents a splintery surface. The fragments are generally less than one inch in any dimension. This weathers yellow and forms splintery talus slopes.
5	50	A massively bedded, oolitic limestone, dark gray in color, which weathers to a gray-brown. It is ridge-making where steeply inclined and ledge-making where gently inclined.
6	100	A massive, dark blue limestone containing a few thin-bedded, platy members, weathering to a dirty yellowish-white color. It is fossiliferous.
7 (top)	500	A thin-bedded platy limestone with distinctly shaly structure. Its fresh color is dark blue; its weathered color, greenish-yellow. It breaks into minute scales and flakes, varying from 1-16 to 1 inch in thickness. This formation forms soft, rounded slopes, easily eroded, presenting a greenish to a yellowish dirty-gray appearance.
	970 feet	

Preuss Formation—This formation is separated from the underlying Twin Creek limestone by a minor unconformity. The formations differ so greatly throughout most of the area, from the brief description set forth by Mansfield in his only published description of its occurrence in southeastern Idaho,[30] that the writer sets forth here a detailed description of a section examined on Fall Creek. As the line of demarcation between the Preuss and the overlying Stump formation could not be determined, the exact thickness is in doubt. The formation as observed here can be said to be less than 425 feet. Mansfield has described it with a thickness of 1300 feet in other localities. The formation shows slightly different characteristics in the southern portion of the Cranes Flat quadrangle, where it consists of fine, even-grained sandstones of a reddish-gray to deep red color, alternating with an occasional shaly phase. The Fall Creek section is as follows:

Preuss Formation.

No. of Member	Thickness in Feet	Description
1 (bottom)	170	A dark red or maroon shale. It is very soft and erodes in rounded slopes.
2	18	A massive limestone. The lower part is platy and extremely cross-bedded. The texture is fine grained. It has a gray color slightly tinted with red, while weathered surfaces are reddish-gray to brown.
3	35	A reddish-chocolate shale, which is thin-bedded and weathers to soft slopes.
4	50	A greenish shale inter-bedded with reddish, soft shales similar to No. 3 This weathers to soft slopes.
5	12	A massive, light gray, pepper-and-salt sandstone. It is intensely ripple-marked and platy in places. It weathers to a light, pale-green color and is a ledge maker.
6	15	Green and red shales, thin and platy, showing abundant ripple marks.
7	25	A massive, fine-grained sandstone, generally a dark chocolate brown in color, containing in the center a zone of gray-brown pepper-and-salt sandstone, very platy and exceedingly cross-bedded. This member is extensively ripple-marked and is a ledge maker.
8 (top)	90	A thin-bedded, shaly sandstone, containing sandy shales and shales which vary from red to green in color, occurring in soft, easily eroded beds. Ripple marks are abundant.
	415 feet	

Stump Formation—This formation is of marine origin and seems to indicate a change in deposition from the underlying Preuss formation. However, no unconformity was established during the examination. Its thickness and lithology vary greatly from those presented in localities previously mentioned, examined by Mansfield in adjacent areas; consequently a detailed section studied on Fall Creek is presented here. The thickness in the Cranes Flat area is considerably greater than the 220 feet displayed on Fall Creek. This formation is combined in a map unit with the underlying and overlying formations. The section is as follows:

Stump Formation.

No. of Member	Thickness in Feet	Description
1 (bottom)	60	A dark, blue-gray, fine-grained, massive sandstone, extensively ripple-marked and containing numerous calcite seams. It weathers to a brownish-green and yellowish-gray color.

2	30	A green, shaly sandstone that is ripple-marked and easily eroded.
3	50	A massive, coarse-grained calcareous sandstone. It is dark gray in color when fresh, and weathers to a yellow surface. It contains a very large number of calcite seams varying in width up to 1½ inches. The entire formation shows extensive cross-bedding.
4	75	A soft, shaly sandstone, very platy and weathering to thin green fragments.
5 (top)	5	A sandstone similar to No. 4, except weathering white.
	220 feet	

CRETACEOUS SYSTEM.

Gannett Group—This group is composed of five distinct members. In order from bottom to top they are the Ephraim formation, Peterson limestone, Bechler formation, Draney limestone and Tygee sandstone.

The formations of the group appear to be conformable, although some are marine formations and others are of fresh water origin. The entire thickness as measured on Fall Creek approximates 1750 feet but each of the members varies notably throughout the area.

Ephraim Formation— This formation is the lowest of the Gannett group and is apparently conformable with the underlying Stump formation. Its similarity to the underlying Stump and Preuss has caused it to be incorporated in the same map unit with them.

The Ephraim in the Grays Lake and Cranes Flat quadrangles is several hundred feet thick, and is dominated by the third member of the following section, which is the most distinctive member of the series. It varies in color from purple to red to yellow but is constant in containing a large quantity of black chert pebbles of an inch or less in diameter.

Another unusual member is the purplish-red limestone. The bright crimson-red soil which is a product of its weathering is easily recognizable and aids in distinguishing this formation from others of the large number of red formations in the area. The Fall Creek section shows 360 feet of Ephraim, but other localities outside the area present a thickness of 1000 feet. The section on Fall Creek is as follows:

Ephraim Formation.

No. of Member	Thickness in Feet	Description
1 (bottom)	10	A massive, pepper-and-salt, reddish-lavender sandstone, containing alternate dark and light-colored streaks, which weathers to a deep purple.
2	25	A reddish-purplish shale, very soft and thin-bedded.
3	12	A very massive conglomerate, with a reddish-purple matrix. The included pebbles are predominately green, and include sandstone, quartz, chert, limestone, etc. The pebbles are generally less than one inch in any dimension.
4	100	A reddish-chocolate shale, very soft.
5	10	A gray, pepper-and-salt sandstone, weathering light gray, and containing alternate light and dark streaks throughout. It is similar to No. 1.
6	30	A massive, fine-grained, maroon and chocolate-red sandstone. It contains alternate light and dark streaks and is an important ledge maker.
7	12	A coarse-grained, gritty, pepper-and-salt sandstone. It is light gray on fresh fracture, weathering to dark gray. This is notably cross-bedded and massive. It is a ledge maker.
8	50	A purplish-reddish limestone. This is siliceous in character and contains great quantities of chert, flint, and agate inclusions. It weathers to a bright crimson-red soil and gentle slopes. It is fossiliferous.
9	25	A lavender-red, platy sandstone with alternate light and dark bands.
10	35	A very massive, gritty, coarse-grained, pepper-and-salt sandstone. It is cross-bedded and contains alternate light and dark bands. The quartz fragments included are both angular and round. It is a ledge maker.
11 (top)	50	A light pink, shaly sandstone which weathers to a light red soil, forming saddles between the above-mentioned member and the lower member of the Peterson limestone. It is very soft and easily eroded.
	359 feet	

Peterson Limestone—This formation is fairly uniform throughout the area. It contains fresh water fossils of lower Cretaceous age but appears to be conformable with the contiguous formations. It is a massive, fine-grained limestone, dark gray in color, and contains an abundance of calcite seams and dark chert nodules, in most of the localities where a study was made. It weathers to dirty-white massive ledges from one to three feet thick. These massive phases form prominent ridges which persist throughout the region where the formation is steeply tilted. The thickness varies from about 180 feet in the southern part of the area to 50 feet on Fall Creek. This formation is combined in a map unit with the two immediately overlying formations.

Peterson Formation.

No. of Member	Thickness in Feet	Description
1	50	A massive fine-grained limestone, dark gray in color and containing an abundance of calcite seams and dark chert nodules. It weathers to dirty-white massive ledges from one to three feet thick. It is fossiliferous.

Bechler Formation—This formation presents an aspect so different from that described by Mansfield in its type section on Bechler Creek, Bannock County, Idaho, that its identity was uncertain until the latter part of the field season.

In the type section it is 1700 feet thick and is known as the Bechler conglomerate where it exhibits a profusion of "salt and pepper" sandstones and interbedded conglomerates. Throughout the area examined by the writer, the thickness varied from 225 feet on Fall Creek to 450 feet in the southernmost quadrangles. The formation invariably was made up of soft red shales which weather to a red soil in soft, rounded slopes and saddles between the Peterson and Draney limestones. So different are its characteristics from those of the type locality, and so constant are these features as found over a range of 35 miles, that the writer suspects them to be more typical of the formation than those described in the type locality. Only its position between the Draney and Peterson limestone causes it to be recognized as the equivalent of the Bechler conglomerate. This formation is included with the contiguous formations in a map unit.

Bechler Formation.

No. of Member	Thickness in Feet	Description
1	225	Soft reddish shales which weather to a red soil in soft round slopes or in saddles.

Draney Limestone—This formation lies conformably over the Bechler formation and is made up of a light grayish limestone so fine-grained as to be lithographic in texture in most of the sections examined. It weathers to a dirty-white color and generally forms ridges where tilted at a high angle. It is not so massive as the Peterson limestone and consequently not so resistant. It contains numerous small and simple fossil forms. The thickness varies from about 300 feet in the southern part of the area to 175 feet on Fall Creek, where the top member is an impure, dark-colored, coarse-grained, siliceous limestone, which weathers to a dirty-brown color and forms large talus blocks averaging three feet in their greatest dimensions. This member is also fossiliferous and presents a thickness of about 25 feet. The whole formation differs very little from the section described at the type locality. This formation is combined with the Peterson and Bechler formations to form a convenient map unit.

Draney Limestone.

No. of Member	Thickness in Feet	Description
1 (bottom)	150	Light grayish limestone, very fine-grained and lithographic in texture. It weathers to a dirty white and generally forms ridges, although not so resistant as the Peterson. It is fossiliferous.
2 (top)	25	An impure, dark-colored, coarse-grained, siliceous limestone. It weathers brown in color. In large blocks, averaging 3 ft. in greatest dimensions. It is fossiliferous.
	175 feet	

Tygee Formation—At the type locality in the Freedom quadrangle Mansfield's description of the Tygee sandstone is as follows: "The rock is gray to buff, even-grained, and without the greenish or reddish tinges of some of the higher sandstones. The top is not exposed, and in much of the region this sandstone, with part or all of the limestone below it, has been eroded before the deposition of Wayan formation. At the type locality about 100 feet of this sandstone is exposed."[30]

The Tygee formation of this area, however, differs greatly from the above description. Part of this difference is apparently due either to the great amount of erosion, which seems to have removed all of the formation at the type locality except the lowest member, or else to decidedly different conditions of deposition. The formation has suffered erosion to varying degrees throughout this area and in other localities. The notable unconformity with the overlying Wayan has concealed much of its upper portion. A section measured on Fall Creek, conformable with the underlying formations and unconformable with beds definitely known to be Wayan, measures 1020 feet in thickness and is as follows:

Tygee Formation.

No. of Member	Thickness in Feet	Description
1 (bottom)	15	A fine-grained brown sandstone, weathering to reddish-brown. It contains numerous calcite seams varying up to ½ inch in thickness.
2	30	Red shales, which are very soft.
3	4	A gray, pepper-and-salt sandstone, massive in character and containing calcite seams.
4	60	A red and green shaly sandstone which weathers to soft red slopes.
5	6	A very fine-grained, greenish-gray sandstone, in plates about 4 inches thick. It weathers to a dirty green color.
6	50	Carbonaceous shales and a carbonaceous, shaly sandstone, varying from black to dark green in color. It is thin-bedded and platy, with an irridescent staining on the surface.
7	110	A dark-colored shaly sandstone, very soft, and eroding into depressions.
8	75	A dark, very thinly bedded and brittle carbonaceous shale, immediately beneath a massive ridge-making sandstone, which constitutes the chief horizon marker for recognizing the Tygee.
9	30	A massive, hard, very fine-grained sandstone, mentioned above. Its color on fresh fracture is yellowish-gray. Some of the isolated talus fragments weather to a pinkish-white, while massive ledges and many talus slopes weather to a brownish-black. It is a notable ridge maker.
10	150	A sandy shale and shaly sandstone of a lavender color. It is very soft, making rounded hills and depressions. It weathers to a light pink color and can be easily confused with many Wayan members.
11	5	A yellow-green sandstone, making subordinate ridges.
12	60	A shaly sandstone and sandy shale. It is lavender-pink in color and weathers to a pale pink soft slope, easily confused with members of the Wayan group.
13	25	A semi-massive sandstone, dark-greenish to dark brown in color. It contains much carbonaceous material which has irridescent staining, as in No. 6. It weathers to light brown with pinkish and reddish tints.
14	150	Soft, fine-grained, yellowish sandstone, which weathers into rounded slopes. It exhibits a black tarnish upon weathered surfaces.
15	40	A dark, fine-grained massive sandstone. It is a ledge maker but has interpolated carbonaceous shales of varying thicknesses not to exceed 6 ft. The member weathers to a dirty brown color.

16	70	Pinkish, reddish, purplish and greenish shales. They are very soft, making depressions, and are easily confused with members of the Wayan group.
17	10	A medium-fine grained, greenish gray sandstone. It is a subordinate ridge maker which weathers to a dirty green color.
18	60	A soft, light-colored, shaly sandstone which makes up depressions and is easily confused with the members of the Wayan group.
10	40	A coarse-grained, light gray, pepper and gray sandstone, with alternate light and dark streaks. It is platy and cross-bedded in places and weathers to a rusty brown. It is extensively calcite seamed and is a ledge maker.
	1020 feet	

As mentioned in the foregoing section, many of these members assigned to the Tygee are very similar in lithology and color to members known to be in the Wayan group. Only an obvious unconformity between these beds and similar Wayan beds caused the writer to group them with the Tygee. The hypothesis that the apparent unconformity was a fault failed to satisfy the problem, and the presence of a similar unconformity between the Tygee and Wayan formations, equally evident in several localities throughout the region, was persuasive evidence that the locality where this section was taken also exhibited an unconformity.

The probability of the occurrence of such similar beds in both of these contiguous formations is further strengthened by the occurrence in the Wayan of limestone lithologically similar to the Draney and Peterson limestone of the Gannett group. Conglomerates, shales, and sandstones almost identical lithologically with the Bechler, Ephraim, Stump, and Preuss formations are also abundant in the Wayan formation. In no case, however, were the interrelations of these confusing beds observed to be the same as in the Gannett group and Stump and Preuss formations.

Wayan Formation—This group of formations lies unconformably on the underlying Gannett in numerous localities throughout this area. Similar unconformities are found in Freedom quadrangle, contiguous on the south, and Mansfield has published a description of another instance.[23]

This group of formations is composed of sandstones, grits, conglomerates, shales, limestones, and ash beds, of fresh water and continental origin. Mansfield has divided the group into an upper and a lower unit.[30] The lower unit contains eight members, including four red beds, three limestones with shaly phases, and one sandstone. He estimated the thickness of this unit to be 2800 feet, which thickness together with the lithology was corroborated by the writer in the southern part of the area examined.

The upper unit is made up of red and gray sandstones; grits, characteristically cross-bedded; vari-colored shales; and some limestones. The only good outcrops are afforded by some of the sandstones, grits, and limestones, because the remaining beds weather into tinted soil devoid of indications of dip or strike. This condition requires the structure to be deduced from isolated and widely scattered outcrops, and also prevents positive recognition of duplication by faulting and folding. Mansfield estimates a thickness of 9000 feet for this upper unit as exposed in the limb of a vast syncline located in an adjacent area, but on account of the smaller folds and more disturbed condition of this area the writer experienced difficulty in measuring more than 6000 feet of sediments in the upper unit. No attempt was made to differentiate these formations; they are mapped as a unit throughout the region.

In age these formations appear to be only slightly younger than the Gannett group as shown by similarities in fossil fauna. Evidence is present, however, which indicates a rather strenuous period of movement and erosion in the Gannett group during the brief interval before the deposition of the Wayan.

TERTIARY SYSTEM (PLIOCENE SERIES).

Salt Lake Formation—This formation lies unconformably on all older formations. It is made up of calcareous conglomerates (light gray to buff colored, with a white matrix), fine-grained lithographic limestones, marls, clays, sandstones, and grits. Most of the exposures occur in the Snake River valley along both sides of the river and in the Palisade Creek and Fall Creek quadrangles. More than 1000 feet of these beds are exposed in the channel of the Snake River near Alpine post office, where they have been tilted, eroded, and masked by alluvium. In many places they are concealed by later lavas and show only where streams have cut through the igneous flows.

QUATERNARY SYSTEM (PLEISTOCENE SERIES).

Hill Wash—This material is generally tinted similar to the eroded rocks of the locality but frequently tends to display a pinkish, greenish, or yellowish color. It is commonly made up of shales and pebbles of sandstones and limestones. Its origin was in alluvial fans, cones, and stream deposits, aided in a few cases by glacial action.

Spring Deposits—Several extensive areas of travertine, tufa, and sinter are found throughout the region bordering the Snake River. Some of the hot springs are now depositing tufa.

QUATERNARY SYSTEM (RECENT).

Alluvium—This material, made up of a mixture of sediments derived from the mountains of the region, occupies the larger valleys and basins and successfully masks rock exposures except in gorge-like channels where the alluvium is cut through. Entrenchment has removed all but an occasional remnant of it in some localities. In a few places the stream deposits are being washed for gold.

STRUCTURE.

GENERAL STRUCTURAL FEATURES OF THE AREA.

The region is traversed by a series of folds consisting of anticlinoria and synclinoria. The axes of some of the anticlines, which were traced to the extremities of the area and beyond, are probably more than 50 miles long.

Relatively few of the synclines or anticlines are symmetrical. A number of the folds are overturned either to the northeast or to the southwest. Transverse folds cause undulations along the major folds, thus forming well defined domes and cross synclines along the dominant axes.

The whole arrangement presents a series of long, nearly parallel folds sweeping across the entire area and possessing structural features similar to those of the southern Appalachian regions.

The most notable faults are quite extensive. Their overthrust character persuades one to connect some of them with the Bannock overthrust which is the principal fault of southeastern Idaho. A few normal faults were also observed but with a few exceptions these produced no unusual effect on topography or outcrop.

SPECIAL STRUCTURAL FEATURES.

Marked Unconformities—The unconformity between the Wayan formation of lower Cretaceous age and the underlying Gannett group of slightly earlier Cretaceous age is a striking and unusual structural and stratigraphic feature. Observation and proof of this unconformity throughout the area was one of the first important findings of the season. Until this examination the beds of the region occupied by the Wayan formation had been thought to be of a different age and were believed to be the Bear River formation. The formation was assumed to lie conformably upon what has been described here as the Gannett group. Evidences of an angular unconformity are found in Fall Creek basin and on Meadow Creek in the Hell Creek quadrangle, north of the head of Bear Creek in the Fall Creek quadrangle, on Jacknife, Trail, and Trout creeks in the McKoy Creek quadrangle, and in several localities of the Grays Lake and Cranes Flat quadrangles.

Another notable unconformity exists between the Salt Lake formation of Pliocene age and all underlying formations. This angular unconformity is strikingly exhibited along the Snake River in Palisade Creek and Fall Creek quadrangles.

An attempt is made to include some instance of each unconformity in the geologic cross-sections portrayed on the various quadrangle maps.

Fan Folds—This unusual type of structure occurs in both the upright and inverted forms in the Cretaceous and Jurassic beds of the area. In all cases these folds have been deeply eroded, but conclusive evidence of their original form still remains.

The best example of the upright fan fold exists in the Fall Creek quadrangle, being represented by the region known as Fourth of July Ridge. The Tygee and Draney formations are overturned on each side of this ridge, forming a fan fold containing two definite crests. The fold is about four miles wide where the beds are now eroded but the upper part once was wider.

An equally important but inverted fan fold is found in McKoy Creek quadrangle near its southwestern extremities. The Draney and Tygee formations are here overturned on the sides of a syncline and two overturned anticlines. This fan fold is less than one mile wide at the neck but as deduced from the dip must be more than twice that wide beneath the surface.

Another inverted fan fold was observed in Cranes Flat quadrangle near Sugar Loaf Mountain and Long Valley. This occurs in the Wayan formation. It is about a mile and a half wide at the neck and nearly two miles wide at a distance beneath the surface. This fold has been described by Mansfield in a recent publication.[29]

The attitudes of these structures are illustrated in the geologic cross-sections accompanying the maps.

"Swallowtail" Folds—In some places the orogenic forces exerted in developing the Caribou Range have created cross folds along the main axes and subsequent erosion has left outcrops of various formations in a pattern resembling a swallow's tail. In practically all instances the Tygee and Draney formations form the distinctive pattern of these unusual folds.

The best examples are illustrated by branching synclines with a complementary intervening and plunging anticline. Localities where these may be observed on the maps are in the northeastern part of Hell Creek quadrangle, the southern portion of the Fall Creek quadrangle just north of Bear Creek, and the northern part of the McKoy Creek quadrangle.

Bannock Overthrust—The Bannock overthrust fault is the major fault of the region but only a small part of it is represented in this area. The overthrusts occurring in the Little Valley Hills are, however, believed to be two branches of it. The one farther east brings the Preuss formation of Jurassic age, the Thaynes group of Triassic age, and members of the Lower Cretaceous Gannett group against the Wayan formation of still later Cretaceous age. Another branch about two and one-half miles to the southwest approximately parallels the one first mentioned. This one brings the Brazer formation of Carboniferous age against the Preuss and Twin Creek formation of Jurassic age.

Three more faults of considerable vertical displacement enter and leave the area still farther to the southwest. They represent block faulting, and the writer is unable to say whether or not these should be considered as branches of the Bannock overthrust.

This great overthrust was first described in 1912.[36] Further work by geologists of the United States Geological Survey and especially by Mansfield has furnished much information for publications.*

This overthrust is credited with a length of more than 270 miles and a horizontal displacement of from 12 to 35 miles. The thrust is to the northeastward.

The underlying block is generally composed of folded Mesozoic rocks somewhat less resistant than the Paleozoic rocks which generally make up the more competent overlying block. In some places the overthrust constitutes a single fault plane but more commonly it is branched and shows as many as six distinguishable branches in some localities.

Snake River Fault—This fault appears to be nearly vertical in many places, and assumes an overthrust attitude in others, although in two localities it has the appearance of a normal fault. It can be traced for approximately 30 miles within the area but its displacement is very small compared with that credited to the Bannock overthrust. This fault has been described as an overthrust by federal geologists[x] as a result of former brief reconnaissances.

Absaroka Fault—This is a large fault which enters the area for a short distance in the eastern edge of the Palisade Creek quadrangle. Its displacement is unknown but is less than that of the Bannock overthrust and greater than that of the Snake River fault. It has been described by Schultz,[38] as the result of an earlier reconnaissance.

St. John Fault—This large overthrust fault is apparently the west branch of Absaroka overthrust fault, which it parallels throughout its extent in the Palisade Creek quadrangle. Like the

* See references No. 16, 23, 24, and 35, Bibliography.
x See references No. 24, 38, and 39, Bibliography.

Absaroka it never has been worked out in detail but has horizontal and vertical displacements much greater than the Snake River fault. It has also been described by Schultz[38] although not under this name.

Meadow Creek Graben—Block faulting in the southwestern part of the Cranes Flat quadrangle has produced what appear to be two grabens* and an intervening horst. One of the grabens lies in the vicinity of Meadow Creek and has been described by Mansfield as the Meadow Creek graben.[23] The extension of the faults in this quadrangle is masked by superficial deposits of later extrusives and hill wash. A transverse fault which barely enters the quadrangle has permitted down faulting of the block south of it. Limerock and Meadow Creek mountains, made up of Carboniferous strata, represent the horst. Little Gray Ridge, made up of the same strata, and its extension to the north found in the Little Valley Hills, make up another horst-like block on the northeast side of the graben. Mansfield finds exposures of the graben rocks that are Triassic in their extension to a quadrangle farther south, but no graben rocks are exposed within this area. This graben structure is exposed for about nine miles as it crosses the southwestern corner of the Cranes Flat quadrangle.

IGNEOUS GEOLOGY.

Each of the quadrangles, except the McKoy Creek quadrangle, discussed in this report contains evidence of igneous activity and a variety of igneous rocks. Because of their possible influence upon the accumulation of petroleum in the associated sediments, a discussion of their occurrence will be included here.

The general forms of occurrence are varied and include exhumed plugs, dikes, laccoliths, and sills, as well as craters, cones, flows, and ash beds.

The relationships of these various igneous occurrences to the several sedimentary formations, make it possible to estimate their relative age and with some degree of accuracy. Practically all of the igneous episodes are believed by the writer to have occurred within Tertiary time although some of the sills may

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* For the benefit of the layman: a horst is a section of the crust separated by faults from adjacent areas known as grabens which have been relatively depressed.

have been intruded in late Cretaceous time and some of the late eruptions and flows which are obviously younger than Pliocene sediments may be as young as Quaternary.

The types vary in chemical and mineral composition from gabbro, olivine and fayalite basalt to rhyolite and pegmatitic granite. Several intermediate types of an unusual character are found between these extremes.

In texture is found an equally wide range represented by graphic granite, coarsely crystalline gabbro, andesite, basalt, trachyte porphyry, rhyolite porphyry, felsite of varying types and several unusual examples of perlite, glass, and obsidian.

Many of the basalt and trachyte flows show an extraordinary development of vesicles which range in size from microscopic cavities to those large enough to contain a man.

MODES OF OCCURRENCE.

Laccoliths—At Sugarloaf Mountain in sec. 25, T. 2 S., R. 41 E., in Cranes Flat quadrangle, is an intrusion which has followed the bedding planes of the sediments in the manner of a sill but has thickened locally so as to present many of the characteristics of a laccolith. Owing to its present state of denudation, it is impossible to determine whether or not the overlying strata were arched to any appreciable extent. This igneous body makes up the crest of the higher part of the eminence and encloses remnants of highly metamorphosed sediments along its top which exist as erosional remnants of the immediately overlying bed.

This intrusion is oriented along the axis of a minor anticline in Wayan sediments, and suggests the hypotheses (1) that the intrusion could be the cause of the folding; (2) that the anticline existed before the intrusion; and (3) that the folding of the anticline occurred later than the intrusion.

It should be obvious to the reader, after noting the description of igneous phenomena which will follow, and after a realization of the large number of anticlines and domes in the area, that much importance is to be attached to theories which would reveal that igneous activity in the form of laccoliths had, or had not, caused the folds. If igneous intrusion has caused much of the folding the heart of these folds would be very unlikely reservoirs for commercial petroleum. On the other hand, if it can be shown that the folding occurred before or since the intrusion, such structures can be regarded as decidedly more attractive, provided other necessary factors for the accumulation of petroleum are present.

The laccolith, or thickened sill, is composed of hornblende andesite porphyry, the phenocrysts of which produce a striking pattern: a microscopic examination of thin sections of this rock shows prominent crystals of hornblende, andesine, and biotite, along with many minor minerals in varying amounts. Since these phenocrysts show no evidence of strain it is believed that the folding could not have occurred later than the intrusion of the hornblende andesite porphyry. This deduction appears to eliminate one of the three hypotheses.

To disprove the two remaining hypotheses is much more difficult. Support for the hypothesis of simultaneous intrusion and deformation is found in the words of one of America's foremost economic geologists.* He says:

> Everywhere intrusions correspond to uplifts, and the evidence, it seems to me, is entirely favorable to simultaneous uplift and intrusion. Can we doubt that uplift was one of the consequences of batholithic intrusion? Is it not also probable that large areas of elevation in the Cordilleras are underlain by concealed batholiths?

A great many phenomena presented in this district may be thought to contribute evidence to this view: the common occurrence of dikes, sills, craters, and cones scattered over a large area offer persuasive evidence for an underlying igneous mass batholithic in proportions. A further argument for this point may be found in the relationship of the Sugarloaf intrusion, Brockman Creek vent and lava flow, and the Caribou Mountain intrusions.

All of these intrusions, although separated by many miles, lie in a direct line along the strike of the same sediments in the Wayan formation. Hornblende andesite porphyries, almost identical in character, occur at Sugarloaf Mountain and Caribou Mountain. It is interesting to note that the axial strike of many of the major anticlines is approximately parallel to a line drawn through the Caribou Mountain intrusion, Brockman Creek vent, Sugarloaf intrusion, and Pine Creek vent. In summing up the

* Waldemar Lindgren: The igneous geology of the Cordilleras and its problems: Yale University, Silliman Foundation, 1913. Problems of American Geology. pp. 282-284. New Haven, 1915.

evidence there seems to be a weighty argument in favor of simultaneous intrusion and folding.

Arguments for the remaining hypothesis are equally convincing. A number of dikes composed of hornblende andesite porphyry occur adjacent to the Sugarloaf intrusion. Some of them lie parallel to it and others are transversely related. These dikes are made up of essentially the same rocks as is found in Sugarloaf and Caribou mountains. All of them are cross-cutting in their relationships to the sediments and are obviously later than the folding. This circumstance leads to the belief that these intrusions of similar magma may probably be of the same age and presumably younger than the folding of the area. Another large intrusion in the southern part of the Grays Lake quadrangle is made up of the same igneous material and appears to have entered the beds after folding. At Caribou Mountain, where several successive intrusions have occurred, the hornblende andesite porphyry appears to have been the first lava intruded and also makes up the major portion of the igneous types represented. It occurs here in a multitude of sills, variable in thickness and extent, emerging from a feeder, laccolithic in proportions, but more like a dike in its apparently cross-cutting relations to the Wayan sediments. Such relations would also substantiate the belief that folding and tilting preceded the intrusion. Another argument in favor of the latter hypothesis is the fact that this intrusion exists midway along the dip of a vast monocline in the Wayan sediments rather than along the axis of an anticline or dome where it would be expected to exist had laccolithic pressure been exerted.

The evidence, as a whole, persuades the writer to believe that much of the folding of the area, probably all of the Wayan folding, occurred previous to the intrusion of the hornblende andesite porphyry found at Sugarloaf Mountain, Caribou Mountain and other places in the area where this rock type has invaded tilted and folded sediments. Accepting this theory, the writer believes that the sill at Sugarloaf Mountain followed structure lines already established in the fold at that locality. No other intrusions that could be called laccoliths were recognized by the writer.

Sills—Caribou Mountain, the highest peak in the region, owes its superior resistance to a series of sills, composed of various types of intrusions, which are interleaved with the Wayan sediments. A ground plan of these intrusive masses is displayed on the Grays Lake map, (Pl. VII, in pocket) and a suggestion of their relations to the sediments is shown in one of the geologic cross-sections. Due to the scale of the geologic map and cross-section it was found impossible to show the actual number of sills and dikes making up this unusual intrusive area, and no attempt will be made in this report to describe it in any great detail because of its lack of especial significance to the economic problem involved in the investigation.

The Wayan sediments and sills dip in a general direction toward the southwest at an average angle of 40°, making up an uninterrupted monocline more than six miles wide.

The sills, approximately 50 in number, emerge from central wedge-shaped intrusions whose cross-cutting relationships appear to classify them as dikes. These in turn have been intruded a number of times by successive lava types. The larger number of sills are to be found east of the feeders and are well exposed in the precipitous cliffs of the many cirques developed by mountain glaciation. These cliffs are, however, so steep as to prevent any significant areal mapping of sills with a thickness equal to those on the western side. Ten or a dozen sills are exposed west of the feeder, and erosion along the dip slope of some of them has exposed areas of the intrusives wide enough to be shown on the geologic map. Because of this dip slope exposure these outcrops are very deceiving, giving the impression, in some instances, of great thicknesses.

The sills are fairly uniform in extent and thickness and the larger number are made up of andesite porphyry displaying notable hornblende and plagioclase phenocrysts. Other types are chiefly trachyte porphyry, dacite porphyry, or similar types.

The associated sedimentary groups include shales, limestones, sandstones, and conglomerates. The whole sedimentary mass has been pretty generally metamorphosed by the intrusives into slaty argillites, siliceous marbles, and quartzites. Because of the change in lithology and physical characteristics due to the intrusions, it is very difficult in places to decide in what sedimentary series these altered rocks belong. Structural relations, however, make clear that the greater part of the metamorphosed series belongs to the Wayan group. Sills other than those found in the vicinity of Caribou Mountain were not recognized elsewhere.

Dikes—Several large blunt and wedge-shaped masses appear along the crest of Caribou Mountain. These are granitic in texture and show hornblende and plagioclase as dominant minerals. These dioritic masses have the characteristics of dikes and appear to have served as feeders to a majority of the associated sills. Other dike-like intrusions of granular texture appear to be syenite, pegmatic or graphic granite, gabbro and diabase.

Fragments of still more basic types were found on talus slopes near the summit but were not observed in place. The magnitude of most of these feeders appears to have been sufficient to provide enough heat, aided by a heavy covering of sediments, to prevent rapid cooling which resulted in these partly or wholly crystallized rock types. The same magma, intercalated with the sediments in flat, relatively thin sheets, cooled more rapidly into porphyritic types.

Other typical dikes are found in the extreme southeastern corner of the Grays Lake quadrangle and near Sugarloaf Mountain in Cranes Flat quadrangle. The latter groups occur respectively about one mile south and west and four miles northeast of that eminence. All of these dikes are hornblende andesite porphyry.

Plugs—Castle Rock is the name locally applied to an intrusion which has some of the characteristics of a plug. It appears, however, never to have reached the surface and has been revealed only by erosion. Large quantities of included country rock are found throughout the mass but the intruded sediments show no quaquaversal tilting.

This rock has the appearance of basalt, having a black fine-grained ground mass with huge glassy plagioclase phenocrysts. A thin-section determination revealed about equal amounts of plagioclase and magnetite as its mineral composition. The ground mass is predominantly magnetite and it has been tentatively classified as an andesite. No remnants of any possibly associated lava flow were found. This plug is located in sec. 5, T. 2 S., R. 42 E., in the Hell Creek quadrangle.

Vents—A number of localities give evidence of being vents or fissures of limited dimensions from which non-explosive eruptions of lava occurred. Each of these is associated with an attached lava flow which makes their relationships seem obvious. Typical examples of such occurrences are: the Pine Mountain vent, located in sec. 6, T. 2 S., R. 41 E., in Hell Creek quadrangle; Brockman Creek vent, secs. 30 and 31, T. 2 S., R. 43 E., in Grays Lake quadrangle; and a vent in the Little Valley Hills located in the northwest corner of the unsurveyed T. 4 S., R. 42 E. All of these vents have produced flows of olivine or fayalite basalt.

Craters—The most noteworthy craters of the area are distinguished in most places by the red-colored scoriaceous lava which surmounts the old cones. Associated with these craters are attached lava flows with obvious relations.

Typical basaltic craters are Sheep Mountain, located in sec. 32, T. 2 S., R. 41 E., in the Cranes Flat quadrangle, and Castle Rock crater in sec. 5, T. 2 S., R. 42 E., in the Hell Creek quadrangle. A rhyolite crater is situated in T. 4 S., R. 42 E., in the Cranes Flat quadrangle.

Lava Flows—Lava flows of considerable extent and variety are abundant in many of the quadrangles.

Cranes Flat quadrangle displays flows of olivine and fayalite basalt which cover more than half of the area. Several different flows are found here but no very great thickness of basalt exists, even where flows are overlapping. Craters, vents, and fissures located along fault lines have been identified as the source of individual flows. Three relatively small patches of rhyolite were found in the Little Valley Hills and are represented on the map. This rhyolite shows a fluidal and perlitic structure, and phenocrysts of quartz, orthoclase, and a little plagioclase. The thickness has been measured in excess of 200 feet.

Grays Lake quadrangle has a small basalt flow from the Brockman Creek vent, and a strip of basalt along the western part of the area representing extensions of flows from Cranes

Flat quadrangle and from a source immediately west of Grays Lake.

Hell Creek quadrangle contains basalt flows identified with crater and vent eruptions from within the quadrangle, as well as extensions of basalt flows from Cranes Flat quadrangle. About one-eighth of the quadrangle is covered with basaltic lava.

A rather unusual series of perlitic, glassy, and porphyritic trachyte flows exists in this area and extends beyond to the north and east.

From one to three flows of trachyte, no one of which appears to be more than 35 feet thick, are exposed in different parts of the area. Each flow shows widely different megascopic characteristics in different localities. On Bull Fork is a flow of dense, brownish-gray, porphyritic type, showing equal amounts of plagioclase and orthoclase under the microscope. Many of the orthoclase crystals are very glassy but have a marked cleavage. These crystals are probably sanidine and, as observed in the hand specimen, greatly resemble quartz. Quartz phenocrysts are rare.

Another flow in the same vicinity appears as a grayish-blue rock, slightly porphyritic in texture. Plagioclase of the oligoclase type is more abundant than the orthoclase feldspar; and quartz, although prominent, is less abundant than the feldspar. This rock could be classed as a dacite at this locality but appears as a trachyte in other parts of the area. The rock shows a microspherulitic ground mass under the microscope.

Other trachytes show large quantities of glassy sanidine phenocrysts much more abundant than the associated plagioclase. Spherulites, crystallites, and fluidal lines are common in many of the samples.

In general, sanidine, orthoclase, andesine and oligoclase feldspar with minor varying amounts of quartz, make up the dominant minerals of these trachytes.

The descriptions of these rocks have been given considerable space due to the fact that they have been described and mapped as basalts and rhyolites in U. S. Geological Survey Bulletins 530[39], 680[38], and 716[22]. The above mentioned surveys were reconnaissance in character and if field determinations only were made the glassy quartz-like appearance of the feldspar phenocrysts could easily account for the classification as rhyolite.

The oldest flow in the area appears to be a rusty brown, highly vesicular trachyte which was identified and ably described by St. John[12] in his early reconnaissance of the area. This ancient flow appears to have covered vast areas previous to the last major uplift and is now found tilted away from the tectonic axes as well as in isolated patches on some of the higher summits in the region. The arrangement of these erosional remnants is such as to furnish persuasive evidence of its former blanket-like extent. The writer was unsuccessful in finding any point of origin for it within the limits of the area studied.

An obsidian of unusual color was found in connection with the rusty brown, highly vesicular rhyolite near Point Lookout. Specimens were collected in sec. 21, T. 1 N., R. 42 E. This rock is a typical obsidian except for its gray color, which is not unlike that styled "battleship gray." Typical black obsidian is also found at the same locality.

Fall Creek quadrangle contains small patches of trachyte representing the flows extending into the area from Hell Creek quadrangle.

More than one-sixth of the area is covered with a group of formations which could not be differentiated for mapping purposes in the limited time spent in the investigation. Sections taken along the Snake River show the succession to be as follows:

The lowermost member is the Salt Lake formation made up of calcareous conglomerates. This is overlain by 35 feet of dark gray trachyte. This in turn is overlain by 25 feet of black to dark green vesicular basalt. Next in order comes 35 feet of pink trachytic tuff and agglomerate; above this occurs 100 feet of a conglomeratic deposit, cemented by pink volcanic ash in some places and by travertine spring deposits in other localities. Rounded pebbles of variegated country rocks are found within this matrix. Succeeding this is a red trachyte, a red andesite, a gray trachyte and a hard black basalt, making a total thickness of approximately 230 feet for the series.

In many places the basalt has failed to cover the entire series or has been removed by erosion. Differing degrees of erosion have exposed different members of the series at various places in the area indicated. The entire group appears to be conformable and has been tilted away from the Snake River fault, suggesting its existence previous to the last movement along that plane.

The Palisade Creek quadrangle contains an extension of the same lava series along the east side of the Snake River valley. Pyramid Peak at the mouth of Bear Creek, although possibly an erosion remnant, has some appearance of being a source for certain flows which extend down the river valley. At the palisades in the river are two lava masses which also appear to have been the sources for some of the lava in the area. As no time was available for examining these questionable lava masses in detail, they have been mapped with the rest of the undifferentiated series.

The trachytes of Fall Creek and Palisade Creek quadrangles have essentially the same megascopic and microscopic characteristics as those in Hell Creek quadrangle.

One trachyte on Indian Creek shows considerable quartz but it is decidely subordinate to the orthoclase. The orthoclase shows the glassy phenocrysts common throughout the trachytes of the area. Most of the quartz is present in eutectic or graphic intergrowth with the orthoclase. Plagioclase feldspar occurs rarely.

The andesite flow which appears in the undifferentiated series is a dull red porphyritic and vesicular rock. A plagioclase feldspar and an amphibole which appear to be respectively andesine and katomorphite are the dominant minerals and appear to be present in about equal amounts. Pyroxene occurs as a minor mineral. The feldspars show carlsbad twinning. Fluidal structure is found in the ground mass.

The succession of igneous rocks in the area appears to have begun with the intermediate andesitic type, which was followed by alternate eruptions of basalt, trachyte, and rhyolite. Three periods of trachyte eruptions are believed to be present, with two eruptions of basalt and one of rhyolite. The age of the intrusive andesite appears to be anywhere between Eocene and Pliocene inclusive. The basalt and rhyolite appear to be of Pliocene age.

FACTORS GOVERNING ACCUMULATION OF OIL AND NATURAL GAS.

Petroleum geologists in searching the earth for oil have learned that many parts of the world can be considered favorable for its accumulation, whereas, for a variety of reasons, other regions are unsuitable for oil occurrence. They believe, for instance, that no petroleum will be found in great expanses of the earth's crust where rocks of Archean or Algonkian age are exposed at the surface. Other unsuitable areas are those occupied by the vast batholithic intrusions of granular igneous rocks or by masses of intensely metamorphosed sediments. By thus limiting the search for oil we may rule out half the land surface at the very beginning. The remaining areas are known to many geologists* as "petroliferous provinces" until detailed study of the component parts pronounces them to be unfavorable. Of the remaining sedimentary areas, possible petroliferous districts may be defined as follows:

(1) Cambrian and Ordivician sediments so slightly folded as not to produce faulting and metamorphism which would permit distillation and escape of the hydrocarbons.

(2) Highly folded and slightly metamorphosed marine or brackish water deposits from Cretaceous age to Recent. Distillation and escape of petroleum in such occurrences may not in some places have been complete owing to lack of time.

(3) Some deposits of slightly saline lakes where kerogen was developed and is now found in rich oil shales of undoubtedly continental origin. Although no commercial production of petroleum is known to occur in these beds the presence of kerogen coupled with other essential conditions may yet lead to discovery of an oil field in such an area.

Favorable "petroliferous provinces" may be defined as those made up of marine or brackish water sediments from Ordivician age to the present which show proper folding and

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* Woodruff, E. G., Petroliferous provinces. Trans. Am. Inst. Min. Eng. Vol. 65, pp. 199-204, 1921. Discussion: Schuchert, Charles, pp. 204-216.

which contain certain amounts of thin-bedded sediments common to shallow water deposition. Thin-bedded sandstones, conglomerates, dark-colored or fossiliferous limestones, and dark-colored shales are all considered highly favorable to a "petroliferous province." All strata typical of shore line conditions are more favorable than deep sea types, since in shallow water deposits are more apt to appear the results of oscillations such as a true sedimentary sequence of alternating conglomerates, sandstones, shales, and limestones.

Petroleum geologists recognize also the existence of "petroleogenic epochs"—periods in the past when beds that contain oil were deposited. Although petroleum has been found in strata ranging in age from the Cambrian to the Recent, ages such as Carboniferous, Cretaceous, and Tertiary have been the most productive in the largest number of areas.

These facts make it clear that oil-prospecting, to hold promise, must proceed in a "petroliferous province" and in sediments of a "petroleogenic epoch."

A careful examination of sedimentary rocks which have contained, or now contain, commercial concentrations of natural gas and petroleum has been made during many years and in all the widely separated oil fields of the world. This examination has resulted in responsible geologists recognizing certain essential conditions visible at the surface, other than those already discussed, as controlling the commercial concentration of oil and natural gas in rocks. Various geologists disagree as to the number of such factors and also as to the relative importance of some of them, but each factor which is advanced by the writer has the sponsoring of a number of successful petroleum geologists.*

The essential controlling factors of commercial accumulation as advanced by the writer are:

1. Presence of sedimentary rocks of marine origin.
2. Absence of intense metamorphism or deformation.
3. Presence of an organic source for oil.
4. Presence of a porous reservoir or containing rock.

* The writer recommends that anyone wishing to go deeper into this subject read the following authors: Clapp, Frederick G., The Occurrence of Petroleum, Handbook of the petroleum industry. David T. Day, Editor-in-chief. Vol. 1, pp. 1-166, 1922. Emmons, William Harvey, Geology of Petroleum, p. 595, 1921.

5. Presence of a suitable cover or impervious capping.
6. Presence of a suitable structure for trapping oil.
7. Presence or absence of water in reservoir rock.
8. Presence of closure.
9. Presence of a sufficiently large drainage area.

A brief explanation of each of these factors is given here.

PRESENCE OF SEDIMENTARY ROCKS OF MARINE ORIGIN.

As practically all of the petroleum fields of the world are associated with marine strata, the general belief has arisen that deposits other than marine cannot furnish a source of petroleum, although the presence of oil shales in continental deposits may be classed as an exception to the rule. Deposits of petroleum may exist in overlying continental sediments or, in rare instances, in a reservoir in associated igneous rocks, to which petroleum has migrated from its source in marine strata.

THE ABSENCE OF INTENSE METAMORPHISM OR DEFORMATION.

Oil is not commonly found in rocks which have suffered intense metamorphism. In most mountain-making processes sufficient dynamic metamorphism and intense faulting occur to dissipate any oil present. Commercial deposits of petroleum may yet exist in regions where such action has occurred during Cretaceous times or since, under a deep cover. This condition is true in California, Galicia, and Rumania.

Until recently the amount of metamorphism that sedimentary rocks could withstand, and still be productive, was unknown. At the present, however, in regions where coal exists in the sedimentary series a measure of metamorphism is afforded by examination of the amount of fixed carbon in any coal present. A careful examination of all the oil fields in the United States which contain coal shows that most of the oil occurs where the coal shows from 50% to 55% of fixed carbon. Oil is known to occur where the fixed carbon is as high as 60% and gas is found where it reaches 70%.

In general, metamorphism which permits oil to remain in the rocks distills such oil into a high-grade product. Rocks in mountain ranges which have been metamorphosed for a comparatively long geologic period are decidedly unfavorable for petroleum prospecting.

PRESENCE OF AN ORGANIC SOURCE FOR OIL.

Petroleum and natural gas are mixtures of different compounds of the elements hydrogen and carbon and of various impurities. These hydrocarbons vary in chemical content and each series is given a generalized formula. No two petroleums are exactly alike.

Theories have been advanced accounting for the origin of oil by certain inorganic reactions or by fractional distillation of organic material. As the inorganic theory is generally conceded to be untenable, this discussion will be confined to theories of organic origin. Many such theories have been advanced by various authorities, most of them supported by persuasive evidence, and as a consequence we find three well defined theories:

(1) That petroleum is derived from animal remains.

(2) That petroleum is derived from vegetable remains.

(3) That some particular oils are derived from plants, others from animals and many others probably from both sources. A thorough study, by the writer, of publications devoted to these theories leads to the conclusion that the third is the most popular with reputable geologists of practical experience.

It is quite generally accepted that there are two stages in the development of petroleum from organic matter. One is a biochemical process; the other is geo-chemical. In the first, fats of animals and cellulose of plants are acted upon by anaerobic bacteria present in the mud of the sea bottom. Geo-chemical action appears to have developed kerogen into petroleum, in other instances, by some metamorphic action.

Some geologists suggest that oil and coal are derived from a parent source. Although they are often found in proximity and the distillation products of the two are very similar, geologic evidence for this belief is not wholly conclusive. If they were of common origin, we should find coal in the oil series and oil in the coal measures. In general it may be said that the coal-producing strata are not the oil-producing strata.

In many localities petroleum and natural gas have been found closely associated with vegetal remains, particularly in diatomaceous shales. In an equally large number of cases the oil is directly associated with the shells of animals such as mollusks or formaminifera. The beds providing the oil sources are often black muds hardened to shales, or beds of limestone containing many molluscan remains.

The fact that petroleum and gas accumulate in such large quantities indicates that migration has been very extensive to provide such a concentration. Because of this movement it becomes difficult to say definitely whether the oil originated where tapped by drilling, or whether it was derived from other localities and migrated to its present residence due to certain chemical, physical, and gravitational processes normal to the rocks of the earth's crust.

PRESENCE OF POROUS RESERVOIR OR CONTAINING ROCK.

The reservoir is a rock that acts as a sponge to retain the oil. It is commonly known as an "oil sand" but may be any one of a number of rock types. The chief requirements for a reservoir rock are porosity and thickness. These will ensure space for a large accumulation of petroleum. The reservoirs that contain oil are pore spaces in sandstones, conglomerates, sands, sandy marls, sandy limestones, and sandy shales. Other reservoirs are pores and solution cavities in limestones, dolomites, and other calcareous deposits. Fissures in shales, limestones, and igneous rocks act as petroleum reservoirs in rare instances.

The quantity of oil in such a rock depends on the size, shape, and number of the openings. In every field, oil will migrate to these more porous reservoirs. Generally the movement is upward but it is sometimes lateral or downward.

PRESENCE OF A SUITABLE COVER OR IMPERVIOUS CAPPING.

The capping rock is an impervious rock layer that overlies and seals the reservoir rock, thus preventing the upward escape of oil and gas. This rock is usually of an argillaceous type such as a shale, clay, or marl. Shaly limestones or igneous layers are exceptional types. Any impervious layer may act as a capping rock. Capping rocks are often ineffective on account of faults or fractures which may permit a complete drainage of the oil reservoir previous to drilling. Faults do not always drain the reservoir and are often an aid to the sealing of a reservoir rock.

PRESENCE OF A SUITABLE STRUCTURE FOR TRAPPING OIL.

From the 32 types of structure known to produce oil, one may choose certain of them which are likely to be productive more often than the others. The best structures are those produced by folding of the rock layers into traps. These assist in the accumulation of oil and gas at some points near the crests due to the differences in specific gravities of oil, gas, and water. The oil and gas migrate to the more suitable structures from more extensive areas of adjoining beds that are less favorably situated for their retention. The very best structures are conceded to be domes of all types—where of course the beds dip in all directions from the center—anticlinal folds, structural terraces and noses, monoclinal forms and sealed faults. It should be kept in mind that many of these types are unproductive, this usually being due to lack of closure. Other types should not be tested in an unproven area until oil has been proven to exist in the more favorable structures.

PRESENCE OR ABSENCE OF WATER IN RESERVOIR ROCK.

Water in the reservoir rock, along with the attitude of the strata, is responsible for a good concentration of oil and gas. A knowledge of the amount of water in the reservoir rock of a dome or anticline is very essential. If water is absent the oil would be found in the adjoining synclines or low on the flanks of the dome, where it can easily be missed by the drill if water is not taken into account. A medium saturation of the oil sand by water would force the oil into an intermediate position on the flanks of the structure and a high saturation would force the greatest concentration of the oil so that it would be found near the crest.

PRESENCE OF CLOSURE.

Closure is a condition in which the oil is completely trapped, as in a dome, by an impervious capping above and is completely surrounded by water lying below it in the reservoir rock. Closure may also be effected by a sealed fault or other factors. If closure is not complete, oil may escape from an otherwise favorable structure and migrate horizontally to a more favorable structure. A knowledge of closure is necessary to determine the place where the test well is to be drilled. In an anticline without undulations but with high water-saturation, oil may exist anywhere along the crest and is just as likely to be at one place as another. Where closure exists the uncertainty is removed.

PRESENCE OF A SUFFICIENTLY LARGE DRAINAGE AREA.

Since the quantity of oil and gas within a trap is dependent on the size of the area tributary to that particular structure, this factor is important. In a region covered with small folds crowded closely together, one is not likely to have a drainage area sufficient to guarantee a large concentration of oil. An anticline or dome standing alone or in a great anticlinorium would be more likely to repay prospecting with a large production. In general the larger the drainage area the more productive and long-lived is the field.

The foregoing discussion sets forth the factors and conditions which the geologist must keep in mind when investigating a region believed to have oil-bearing possibilities. If the area lacks any one of these it has apparently small chance of producing oil or gas in commercial quantities.

The foregoing evidences of oil occurrence which are so important to the oil geologist or petroleum engineer are likely to be overlooked or not comprehended by the layman. Besides these, however, exist other evidences known as "surface indications" which have a definite, relative, or coincidental relation to the existence of oil and which are comprehensible to anyone unversed in the study of petroleum prospecting.

A list of surface indications is as follows:

1. Oil seeps, oil springs, and oil ponds.
2. Natural gas seeps and springs.
3. Bituminous rocks:
4. Bituminous lakes.
5. Bituminous dikes.
6. Mud volcanoes.
7. Burnt clays and shales.
8. Mud dikes.
9. Salt and salt-water seeps.

10. Sulphur and sulphur springs.
11. Oil shales.

Any one of the above is frequently associated with oil but oil is very likely to occur at a great distance from places where these evidences occur at the surface. Probably only the first six of the list presented can be accounted as good indications. The latter group may occur where no oil is present and oil is commonly known to occur where they are absent. Their occurrence with oil is probably a coincidence in most of the cases.

Surface indications are valuable inasmuch as some of them offer evidence that petroleum has existed or does exist in the rocks of the area and by this means a source can be accounted for. It is not necessary to believe however, that any one of the listed indications must be present in any oil field, since many of the larger producing fields in the United States have offered none of these surface indications. Needless to say, before the science of petroleum prospecting developed, all of the early fields were discovered as a result of some "surface indications." A well-known authority[1] on petroleum geology says:

> The importance of surface indications of oil is often very much overestimated. They may be evidence that *some* oil or gas exists in or near the localities where they are found, but they do not tell us whether such oil or gas is here in commercial quantities. As a matter of fact, seepages are excellent witness to the fact that the oil has been escaping, perhaps for long periods of time. Under these circumstances it is the business of the geologist to search, in the region where the seepages occur, for structures which may have caused the *retention* of oil. He will be less interested in these particular places where, on account of peculiar structural conditions, original accumulations of petroleum may have been depleted by seepage.

Numerous localities exhibiting oil and gas seeps and bituminous rocks have proven barren of commercial petroleum when prospected. The lack of oil seeps in some localities may be explained by the unbroken folds present in some cases, and by erosion, which carries away the evidence as fast as it is formed, in other instances.

Iridescent films or scums produced by the development of iron oxide from marshy plant growth occur in many swampy places along streams and ponds and are usually mistaken for oil seeps. Upon being penetrated with a stick these scums break up into flakes which remain apart. An oil film subjected to the same treatment will not break up, but closes together again.

1. Lahee, Frederic H., Handbook of the Petroleum Industry, pp. 167-200, 1922.

Methane or marsh gas escapements are likewise the sources of many false alarms, being mistaken for natural gas seepages from a petroliferous origin.

In conclusion it may be said that surface indications are not essential and that the occurrence of oil is found to be dependent on the geological factors mentioned at first rather than on the existence or non-existence of surface indications, even though these may have led to the discovery of productive fields in some regions in earlier days.

The reader is invited to keep the foregoing discussion in mind to facilitate a clear understanding of the writer's conclusions in regard to the oil possibilities in the region examined.

HELL CREEK QUADRANGLE.

(Plate III in Pocket).

LOCATION.

This quadrangle lies between parallels 43° 15′ and 43° 30′ N., and meridians 111° 31′ and 111° 45′ W. It is the northwestern member of the group of six quadrangles mapped and described in this report. Several well traveled roads make the area accessible during the summer months. Idaho Falls is the chief distributing point for this and adjacent quadrangles. Fall Creek quadrangle lies immediately east, Cranes Flat quadrangle lies south, and Grays Lake quadrangle lies to the southeast.

The northeastern part of the quadrangle is extremely rough and mountainous. It is heavily timbered on the eastern and northern slopes and well watered by several large streams which drain into the Snake River. The rest of the area is made up of rolling, rounded ridges where sediments are exposed, and of mesas, buttes, and table lands where igneous lava flows cover the surface. Grays Lake Outlet and Willow Creek have developed scenic gorges where they cut through these lava plateaus.

GEOLOGY.

AREAL GEOLOGY.

The lithology and other characteristics of the various formations in this quadrangle as named below have been described in an earlier part of this bulletin. Formations found at the surface are in order of age as follows: The Nugget sandstone, Twin Creek limestone, Preuss and Stump sandstones of Jurassic age; the Ephraim formation, Peterson limestone, Bechler formation, Draney limestone, Tygee sandstone, and Wayan formation of Cretaceous age; and the Salt Lake formation, and several trachyte and basalt flows of Tertiary age.

DISTRIBUTION OF THE FORMATIONS.

Nugget Sandstone (*Jurassic*)—This formation occurs at only one place in the quadrangle. It shows in the eastern part of sec. 34, T. 2 N., R. 42 E., where it is exposed on the west side of a fault.

Twin Creek Limestone (*Jurassic*)—Two patches of this formation are exposed by the erosion of the folds in the eastern part of the area. This limestone is found in secs. 21, 22, 27, 28, and 34, at the heads of Granite and Garden creeks in T. 2 N., R. 42 E., and also north of Fall Creek in secs. 3, 20, 21, 27, 28, 34, T. 1 N., R. 42 E. Most of this exposure occurs in the heart of an overturned anticline.

Preuss Sandstone (*Jurassic*).
Stump Sandstone (*Jurassic*).
Ephraim Formation (*Cretaceous*).

These three formations are mapped together and are exposed in a thin band to the west of the Twin Creek limestone in T. 2 N., R. 42 E., and completely surround the same formation in T. 1 N., R. 42 E., where they are shown in the flanks of an overturned fold.

Peterson Limestone (*Cretaceous*).
Bechler Formation (*Cretaceous*).
Draney Limestone (*Cretaceous*).

These formations are grouped into one map unit and make up the crests and flanks of the three important anticlines in the northeastern part of the quadrangle. The formations occur in the eastern half of T. 2 N., R. 41 E., and in the northeastern part of T. 1 N., R. 42 E.

Tygee Sandstone (*Cretaceous*)—This formation occupies the flanks and troughs of all synclines in the northeastern part of the quadrangle and occurs in long exposures adjacent to, and in the same localities with, the Peterson limestone, Bechler formation, and Draney limestone mentioned above.

Wayan Formation (*Cretaceous*)—This formation lies unconformably on the formations named before and occupies the rest of the quadrangle although overlain in places by various lava flows. Every township in the quadrangle, with the exception of T. 2 N., R. 42 E., contains exposures of this characteristic formation.

Salt Lake Formation (*Tertiary*)—Only one area of this formation lies within the quadrangle. This occurrence is in secs. 16, 17, 18, 19, 20, and 21, T. 2 N., R. 42 E.

Trachyte (*Tertiary*)—Flows of trachyte lava are believed to have extended over the entire quadrangle at an earlier period. Erosion has left isolated remnants as well as lava plains and plateaus over nearly all of the area. This lava lies unconformably over the older underlying sediments but has also been considerably disturbed and tilted since its outflow. Areas in T. 2 S., Rs. 40, 41, and 42 E., are the only parts of the quadrangle where trachyte mesas do not occur.

The structure of the Wayan formation in the northwestern part of the quadrangle is greatly masked by the widespread occurrence of the trachyte flows.

Igneous Intrusives (*Tertiary*)—Andesitic and basaltic plug and vent intrusions younger than the trachytes are found at Pine Mountain in sec. 6, T. 2 S., R. 41 E., and at Castle Rock in sec. 5, T. 2 S., R. 42 E.

Basalt (*Tertiary*)—Basalt flows originating at the Castle Rock, Pine Mountain, and Sheep Mountain vents are found in the southern and southwestern portions of the quadrangle. These flows overlie the trachyte in many places and also lie unconformably over the Wayan in other localities.

STRUCTURE.

Faults—Two small faults were recognized and mapped near the heads of Granite and Garden creeks. These faults are normal and display a vertical throw of about 500 feet each. They disappear beneath the Salt Lake formation to the north but extend out of the quadrangle into the Fall Creek quadrangle at sec. 34, T. 2 N., R. 42 E. They have no economic importance whatever but are responsible for a variety in the arrangement of the formations found in that corner of the quadrangle.

Anticlines—Although many anticlines exist within this area only a relatively few have economic significance so far as petroleum possibilities are concerned. Three long, well-marked anticlines exist in the Wayan formation as indicated on the map of this quadrangle. The northern extremities of these structures are covered by trachyte flows and hill wash, while the southern extremities in the case of two of them are covered by a basalt flow from the Castle Rock vents. The geologic cross-section at B B′ (Pl. III in pocket) shows the attitude of the strata in two of these folds and the magnitude of the folding. Although these folds are unbroken and show marked closure in places, they are not recommended for testing until petroleum has been found in other folds of the area.

Two anticlines with petroleum possibilities lie in the northeastern part of the quadrangle. One of these lies northeast of Meadow Creek and is cut by the head of Antelope Creek. Its axis is found in the Cretaceous formations known as the Draney limestone, Bechler formation, and Peterson limestone. The Tygee sandstone is found along its flanks. The northern end disappears beneath trachyte and Wayan sediments which rest unconformably upon it. Closure to the north seems fairly certain, due to the abrupt slope of these formations, which dip under the Snake River plains. Dips from 10° to 35° are found along the flanks, the more gentle dips being found near the axis. Closure to the south is certain, being forced by the junction of two flanking synclines in the Tygee sandstone. The axis of this anticline can be traced from sec. 21, T. 2 N., R. 41 E., to where it plunges in sec. 8, T. 1 N., R. 42 E. The surface of this structure is well watered but poorly timbered. This latter condition makes it easily accessible from a number of good roads which traverse the neighborhood.

The other anticline within the area possessing petroleum possibilities is an extension of a long overturned fold which extends through many of the quadrangles. The fold as it appears here is the extension of the Fourth of July Ridge, north of Fall Creek. The attitude of the strata is shown in the geologic cross-section A A′ of the Hell Creek map (Pl. III in pocket.) At many places along the axis the dips are gentle and normal but on the western flank reverse dips of 75° are found in the Tygee sandstone. Erosion by Fall Creek has exposed the Twin Creek limestone, Preuss and Stump sandstones, and the Ephraim formation. The axis lies in the Draney, Bechler, and Peterson group in its northern extremity, where closure is produced as the anticline plunges beneath the unconformable Wayan formation. The axis of this anticline extends from sec. 1, T. 1 N., R. 41 E., to sec. 27, T. 1 N., R. 42 E., where it leaves Hell Creek quadrangle and enters Fall Creek quadrangle.

Synclines—None of the several synclines found within the quadrangle is believed to have petroleum possibilities and consequently this type of structure will receive no discussion here. However, each syncline is delineated on the map together with the anticlines discussed.

FALL CREEK QUADRANGLE.

(Plate IV in Pocket).

LOCATION.

Fall Creek quadrangle lies between meridians 111° 15′ and 111° 30′ W. and parallels 43° 15′ and 43° 32′ N. Hell Creek quadrangle lies to the west, Palisade Creek quadrangle is situated to the east, and Grays Lake quadrangle joins it on the south. Several well traveled roads in the Snake River valley make the northeastern part of the area accessible during the summer months, but a great part of this quadrangle is reached only by pack outfit or sheep camp and then only during the best weather.

The southwestern part of the quadrangle is dominated by Fall Creek basin, drained by Fall Creek flowing northwest into Hell Creek quadrangle, where it breaks across the Caribou Mountains to join the Snake River in this quadrangle. A broad area extending across the northeastern portion of the quadrangle lies in the valley of the Snake River. This valley consists of terraces and bench lands of lava and a lower portion covered with meadows and alluvium near the stream.

The foot hills of the Snake River Mountains rise in the extreme northeastern part of the quadrangle, where the immense canyon and alluvial fan of Rainy Creek open upon the depression occupied by the Snake River.

The central part of the quadrangle is covered by the Caribou Mountains, which lie in high parallel ridges trending to the northwest, cut at right angles by steep canyons of the streams flowing into the Snake River.

All of the mountainous areas are well watered and covered with heavy timber on the eastern and northern slopes. The entire region is underlain by sedimentary rocks which show at the surface, except in the bench lands along the Snake where trachytes and basalt flows predominate.

The settlement is entirely within the Snake valley. It centers around the village of Irwin, which receives its supplies from

Rigby and Idaho Falls and distributes the mail and supplies for the area.

GEOLOGY.

AREAL GEOLOGY

Because of the relief, erosion, and structure of this quadrangle, more formations are exposed here than in any other quadrangle of the area. Since the lithology and detailed descriptions of all these formations have been set forth elsewhere, they will not be repeated.

Formations found at the surface in this quadrangle are in order of age as follows: Madison and Brazer limestones, Wells and Phosphoria formations of Carboniferous age; Woodside formation and Thaynes group of Triassic age; Nugget sandstone, Twin Creek limestone, Preuss and Stump sandstones of Jurassic age; Ephraim formation, Peterson limestone, Bechler formation, Draney limestone, Tygee sandstone, and Wayan formation of Cretaceous age; Salt Lake formation and various lava flows of Tertiary age; and travertine, hill wash, and alluvium of Quaternary age.

DISTRIBUTION OF THE FORMATIONS.

Madison Limestone (Lower Mississippian)—One small area of this formation is exposed in the canyon of Fall Creek in sec. 8, T. 1 N., R. 43 E. This formation also occurs in the area mapped as undifferentiated Carboniferous in T. 2 N., R. 44 E.

Brazer Limestone (Upper Mississippian)—This formation is better exposed here than in any other quadrangle. A long strip extends along the west side of the Snake River fault for more than 10 miles and then becomes the formation along the axis of the Snake River anticline. This outcrop extends from a point north of Pritchard Creek to sec. 24, T. 1 S., R. 44 E., where it leaves the quadrangle. The formation is completely cut at only one place, which is in Fall Creek canyon near the fault. More of this formation occurs in the mountains northeast of Irwin.

Wells Formation (Pennsylvanian)—Both members of this formation are well exposed along the west side of the Snake River fault and in the flanks of the Snake River anticline. This formation disappears under the unconformable Salt Lake beds in the northwestern corner of the quadrangle but extends along the entire eastern front of the Caribou Range until it leaves the quadrangle. The massive limestone and quartzite of this formation are easily recognized. Although the same pattern is used for the limestone and quartzite members on the map, the location of each member is shown by a contact line and the proper map symbol.

Phosphoria Formation (*Permian*)—A narrow strip of this shale, limestone, and chert flanks the Wells formation along its western side for the entire length of the range within the quadrangle. The Phosphoria occupies a saddle and forms minor ridges between the more resistant formations. When one stands on the outcrop and looks along the strike of the formation it is like gazing at a gun sight. This relationship is of great help in tracing the formation along the ridges. The formation contains great quantities of commercial phosphate rock throughout southeastern Idaho. Evidences of high-grade phosphate rock were noted in the valleys of many of the streams cross-cutting the formation.

Woodside Formation (*Triassic*)—This formation is found wherever the Phosphoria is exposed and in a narrow outcrop of about the same width. It is exposed in a monocline which is one flank of the broken Snake River anticline. Its outcrop parallels the other formations revealed in this eroded fold.

Thaynes Group (*Triassic*)—This group of formations occurs in two parallel strips, one in the monocline to the west of the fault and the other in a short outcrop on the east side of the fault in the northeastern part of T. 1 S., R. 44 E. The exposure of the Thaynes in this quadrangle is better than in any other area of the entire region. The limestone members of the group serve as ridge makers throughout the quadrangle and aid in locating the formation from a distance.

Nugget Sandstone (*Jurassic*)—This red sandstone appears in a number of places. One small strip is exposed east of the Snake River fault in the northeastern part of T. 1 S., R. 44 E. Another small outcrop is in the axis of Big Elk dome in secs. 10 and 15, T. 2 S., R. 44 E. Four exposures are revealed by the erosion along the Fourth of July Ridge anticline. Two of these are just north of Bear Creek where it cuts the Ridge. Another lies just west of Rash Canyon, and a small one is in sec. 9, T. 1, S., R. 43 E.

The greatest outcrop of Nugget forms the dominating physiographic feature of the quadrangle. This is Red Ridge, which extends parallel to the Snake River, the Snake River fault, and all other structural features of this area. The Nugget here is very resistant to erosion and with its high coloration forms a bright ridge traversing the quadrangle which can be seen from nearly all parts of the region. This ridge of Nugget extends transversely of the quadrangle for its whole length. The Nugget is not entirely cut in Big Elk dome or in Fourth of July Ridge anticline.

Twin Creek Limestone (*Jurassic*)—This formation appears in long parallel strips in the flanks of every structure in the area. One narrow band appears in the east flank of the Caribou Range and can be seen on Deer and Yeaman creeks. A very long and wide exposure flanks the Nugget on the west side of Red Ridge throughout the length of the quadrangle. The crest and upper flanks of Big Elk dome and Fourth of July Ridge anticline are composed of this limestone.

Preuss Sandstone (*Jurassic*).
Stump Sandstone (*Jurassic*).
Ephraim Formation (*Cretaceous*).

This group of formations occurs only in the central part of the quadrangle. One long exposure is shown in the Red Ridge monocline, another outcrop completely encircles Big Elk dome, and Fourth of July Ridge contains a wide occurrence along each side parallel to the axis of the fold.

Peterson Limestone (*Cretaceous*).
Bechler Formation (*Cretaceous*).
Draney Limestone (*Cretaceous*).

This red and white group of Gannett formations occurs in three long, narrow outcrops which traverse the quadrangle obliquely as they are revealed in the flanks of Red Ridge, Big Elk dome, and Fourth of July Ridge. A small tongue separates Big Elk dome from Little Elk Mountain at the southern extremity of the quadrangle. The two limestones make chalky white ridges, with the Bechler occupying a bright red depression between. These formations, coupled with the red Nugget, yellow to white Twin Creek, red, brown, green, and purple Preuss, Stump, and Ephraim, all lying in parallel outcrops and in regular sequence on each side of Fourth of July Ridge, present a spectacle of color unequalled even in the gorges of the Yellowstone and Colorado rivers. The ridge takes its name from this variety of colored sediments.

Tygee Sandstone (*Cretaceous*)—This formation occupies the overturned syncline lying between Red Ridge and Fourth of July Ridge, and its continuation between Red Ridge and Big Elk. A tongue of this formation extends into the syncline between the end of Big Elk and Fourth of July Ridge. The western flank of the latter ridge also contains an exposure of the Tygee sandstone where it occurs in reverse dips of the overturned fold.

Wayan Formation (*Cretaceous*)—This group of sediments covers the entire Fall Creek basin and takes up the southwestern part of the quadrangle. Although it is much disturbed and folded, the folds are in no place congruent with the folds in the older Cretaceous and Jurassic formations. This formation appears to have been deposited in already existing structural depressions in the older sediments. These old depressions appear to have been subsequently deepened when the Wayan was folded.

Salt Lake Formation (*Tertiary*)—This formation is widespread in its occurrence in the foothills and bench lands on each side of the Snake River valley. In many places it is covered with basalt, trachyte, and andesite but its presence is revealed in the canyons of many streams that have cut through it.

Trachyte (*Tertiary*)—This lava occurs in the extreme northwestern part of the quadrangle, where it overlies the Salt Lake formation and all older sediments. Small isolated patches occur as erosional remnants and are scattered over many high points in the northern parts of the area. Such occurrences are found in sec. 21, T. 1 N., R. 43 E., and sec. 1, T. 1 N., R. 42 E.

Trachyte, Andesite and Basalt (*Tertiary*)—These undifferentiated lavas have been represented by the *Tlu* symbol. Because of the extent of erosion, various flows are exposed at the surface in the area bearing this symbol. Lack of time and lack of importance prevented the mapping of this material in separate map units. The area between Yeaman and Deer creeks is basalt at the surface but has trachyte and other formations underlying it. In general the basalt does not extend up the slopes as far as the underlying trachyte or andesite and in many places has been entirely removed by erosion.

Travertine and Sinter (Quaternary)—These spring deposits occur in small spots at many places in this quadrangle and in other areas. Only one such occurrence, however, was large enough to be shown on the maps. This deposit is found south of Fall Creek in sec. 8, T. 1 N., R. 43 E. It has a thickness of several hundred feet in places and a width and length of more than one-half mile. Several smaller deposits of travertine are scattered along Fall Creek for a mile or more above this large deposit.

Hill Wash and Alluvium (Quaternary)—This material is entirely confined to the Snake River valley and the mouths of its various tributaries such as Rainy, Granite, Pritchard, and Fall creeks.

STRUCTURE.

Faults—The Snake River fault which extends along the entire base of the Caribou Range in this quadrangle is nearly vertical as it appears here. In some places it tends to be overthrust whereas in others it is to all appearances normal. The horizontal displacement is only a few hundred feet and the vertical displacement is probably never in excess of 2,000 feet. The northern end of this fault disappears beneath the Salt Lake formation north of Garden Creek and the other extremity enters Palisade Creek quadrangle in sec. 13, T. 1 S., R. 44 E.

The Snake River fault has economic significance inasmuch as it appears for much of its course as a break along the crest of the Snake River anticline. This break probably would have drained any oil that might have existed in this anticline although no signs of such an escapement were noticed.

Two small normal faults with a vertical and horizontal displacement of less than 500 feet enter the quadrangle in sec. 34, T. 2 N., R. 42 E. They run nearly parallel for a few miles and then converge to disappear in Sec. 12, T. 1 N., R. 42 E.

Domes and Anticlines—Big Elk dome extends into this quadrangle in the southeastern part of the area. It is a rough, almost inaccessible mountain, oval in shape, and has the greatest altitude of any point in the quadrangle.

This dome has the greatest amount of closure and gathering ground of any dome examined in the region. The dips are steep and the fold is normal, with a slight inclination to the east. Erosion has exposed the Nugget sandstone along its highest points and annular outcrops of every younger formation up to the Tygee sandstone surround it. The oil possibilities of this structure would have to lie in Triassic and Carboniferous formations which have not been cut by erosion.

Fourth of July Ridge anticline extends transversely of the quadrangle and is the westernmost fold of the anticlinorium that make up the Caribou Range. This fold extends into Hell Creek quadrangle to the west and into Grays Lake quadrangle to the south where it terminates in Little Elk Mountain. Bald Mountain dome in McKoy Creek quadrangle appears to be an undulation on the axis of this major structural feature. This anticline takes on the characteristics of an upright fan fold throughout most of its length in this quadrangle. Its characteristic attitude is shown by the geologic cross-section A A′ on the Fall Creek quadrangle map (Pl. IV in pocket). At two places the axis splits to form two minor folds which join again into a single axis. Dips along the axis are gentle, but vertical; reverse dips are common farther out on the flanks of the structure. The anticline is completely closed on each end but neither of these plunges is within this quadrangle. Erosion has exposed the Nugget sandstone at four places along the crest of this anticline and all younger formations including the Gannett group are exposed in proper sequence in parallel outcrops along the flanks and ends.

Fourth of July Ridge anticline has less closure than Big Elk dome, and at many places the vertical attitude of the strata would make testing of the underlying formations very difficult. Except for these differences this anticline is as favorable for testing as Big Elk dome. It is easily accessible from Fall Creek basin. Only Triassic and Carboniferous strata could hold promise in this structure, since all younger formations have been eroded from the crest.

The Snake River anticline just south of the Snake River fault is believed to be without petroleum possibilities, since only the Madison is uneroded on the fold and the fault is in a position to have drained any existing oil. Should the Madison produce oil in other folds in the region, this structure would eventually deserve testing but should not receive attention before that contingency occurs.

A small terrace has been formed in the Carboniferous strata in the vicinity of Pritchard and Garden creeks. The structure is believed to be unfavorable for exactly the same reasons assigned to the Snake River anticline. This structure is shown in geologic cross-section B B′ of the Fall Creek quadrangle map.

Two narrow anticlines exist in the Wayan formation in the southwestern part of the quadrangle. These are believed to have little, if any, chance of producing commercial petroleum, chiefly because the Wayan formation is not believed to contain a source for petroleum and its non-conformity with underlying formations prevents recognition of structures in more favorable formations. Its tremendous thickness would seem to prevent the exploration by drilling of any lower formations considered to be favorable. Extensive migration of oil from older, underlying formations would be the only cause that could make this formation favorable for prospecting. The great thickness of shales in its column would seem to nullify that possibility.

Synclines—A great overturned syncline lying between the Snake River monocline and Fourth of July Ridge and a branch lying between the latter structure and Big Elk dome are not believed to have any economic significance in this region. Other unimportant synclines were noted in the area occupied by the Wayan formation. These also are considered unlikely structures for trapping petroleum.

PALISADE CREEK QUADRANGLE.

(Plate V in pocket).

LOCATION.

This quadrangle lies between parallels 43° 15′ and 43° 30′ N., and meridians 111° 00′ and 111° 15′ W. It is the northeastern member of the group of six 15-minute quadrangles mapped and described herein. Fall Creek quadrangle lies to the west and McKoy Creek quadrangle lies directly to the south.

This is the roughest and most inaccessible quadrangle of the group. The valley of the Snake River provides the only line of travel through the area. The rest of the region can be penetrated only by pack outfit, and during the summer months. Many peaks of this quadrangle rise above 9,000 feet altitude and the relief of many of the stream valleys approximates 2,000 feet. The region is entirely mountainous with the exception of the valley of the Snake which traverses the southeastern portion of the area. It contains lava terraces and narrow, alluvium covered plains which, along with the alluvial fans found at the mouths of the creeks, form the only low relief of the area. The entire region is well watered and well timbered and is underlain by tilted sedimentary formations. A narrow strip of lava forms bench lands on the east side of the river. Palisade, Elk, and Bear creeks are the largest streams draining into Snake River, which flows northwesterly in this region.

GEOLOGY.

AREAL GEOLOGY.

The formations exposed at the surface in this quadrangle are listed as follows in order of age: Madison and Brazer limestones, Wells, and Phosphoria formations all of Carboniferous age; Woodside formation, and Thaynes group of Triassic age; Nugget sandstone, Twin Creek limestone, Preuss, and Stump sandstones of Jurassic age; Ephraim formation, Peterson limestone, Bechler formation, Draney limestone, and Tygee sandstone of Cretaceous age; Salt Lake formation, undifferentiated lavas, and basalt of Tertiary age; and hill wash and alluvium of Quaternary age.

DISTRIBUTION OF THE FORMATIONS.

Madison Limestone (*Lower Mississippian*)—This formation is included in the area mapped as *Cu* and is found in a broad strip of the high mountainous area lying east of the Snake River. Inaccessibility and lack of time prevented detailed mapping of this and other formations to the east of the river.

Brazer Limestone (*Upper Mississippian*)—A narrow strip of this formation is exposed in sec. 24, T. 1 S., R. 44 E., in the axis of an anticline, and a considerable exposure is found in the mountains of undifferentiated Carboniferous age lying immediately east of the Snake valley and marked *Cu* on the map.

Wells Formation (*Pennsylvanian*)—This formation shows both limestone and quartzite members in the axis of an eroded anticline along the west side of the Snake River fault in secs. 13, 24, and 25, T. 1 S., R. 44 E., and in secs. 19, 29, 30, 31, and 32, T. 1 S., R. 45 E. This formation occurs in the broad strip of undifferentiated Carboniferous lying in the central part of the quadrangle and appears also in the narrow strip of *Cu* which extends along the west side of the Absaroka overthrust fault located in the northeastern portion of the quadrangle. Two of these exposures are due to erosion on the western up-throw sides of these prominent overthrust faults.

Phosphoria Formation (*Permian*)—This phosphate-bearing formation is found in secs. 24 and 25, T. 1 S., R. 44 E., and secs. 30, 31, and 32, T. 1 S., R. 44 E. Small specimens of high-grade, black phosphate rock have been collected in sec. 32, in the valley of Bear Creek. This formation also appears in the overthrust or western side of the Absaroka overthrust fault in the northeastern townships of this quadrangle.

Woodside Formation (*Triassic*)—This formation occurs in a parallel strip to the west of the Phosphoria where the latter is exposed.

Thaynes Group (*Triassic*)—This group of formations is to be found flanking the anticline in the southeastern townships and is the formation making up the up-throw side of the Snake River fault in its southern part and the down-throw side in its northern part in this quadrangle. It also makes up the larger part of the *Tru* area which lies between the Absaroka fault and its west branch, which are in the northeastern part of this area.

Nugget Sandstone (*Jurassic*)—Thick and prominent exposures of this formation flank the Thaynes group in parallel strips at all places where the latter is exposed southwest of the Snake River. It is to be found on both sides of the fault.

Twin Creek Limestone (*Jurassic*)—This limestone appears in a wide, irregular outcrop adjacent to the Nugget, southwest of the Snake River fault, and occurs in a narrow strip parallel to the fault and the adjacent formations on the down-throw side.

Preuss Sandstone (*Jurassic*).
Stump Sandstone (*Jurassic*).
Ephraim Formation (*Cretaceous*).

These formations included in the area mapped as *KJesp* occupy a narrow strip in the extreme southwestern part of the quadrangle and an extensive area designated *KJu* in the northeastern townships.

Peterson Limestone (*Cretaceous*).
Bechler Formation (*Cretaceous*).
Draney Limestone (*Cretaceous*).

These formations making up the map unit *Kdbp* are found in two strips flanking a syncline in the southwestern corner of the quadrangle and in the area marked *KJu* in the extreme northeastern corner.

Tygee Sandstone (*Cretaceous*)—This formation shows in one small exposure where it occupies the axis of a syncline in the southwestern sections of the area.

Salt Lake Formation (*Tertiary*)—This formation lies unconformably on all underlying formations and is exposed at numerous places along each side of the Snake River valley. It is sometimes covered with lavas but erosion reveals its presence by exposures in the faces and cliffs of the terraces and benches along the river.

An exposure of this formation lying in secs. 27 and 28 of T. 1 S., R. 45 E., has previously been mapped, as a result of two former geologic reconnaissances, as Carboniferous age and Cretaceous age.

Trachyte, Andesite, and Basalt (*Tertiary*)—These lavas, undifferentiated for mapping, are to be found in the valley of the Snake making terraces from the mouth of Elk Creek extending down the river on each side.

Hill Wash and Alluvium (*Quaternary*)—This material makes up the valley of the Snake below the level of the lava and the Salt Lake terraces which flank the depression. These lava cliffs are broken where tributaries of the Snake have cut through them and have built alluvial fans and cones which extend down to meet the alluvium-covered valley.

STRUCTURE.

Faults—Four overthrust faults are found within this quadrangle. Three of these are of major size and have been mentioned in the general discussion of structure in another part of this bulletin.

The Snake River fault which is found southwest of Snake River is an overthrust fault in this quadrangle although it is nearly vertical and perhaps normal at other places. The vertical throw as displayed here is between 1,000 and 2,000 feet, but the horizontal displacement is only a few hundred feet. This fault lies approximately parallel to the Snake River depression and also parallels structural features found in this and other nearby quadrangles. This fault has significance in this quadrangle since it has served to nullify the petroleum possibilities of the parallel anticline lying adjacent to it. Although no seeps or signs of gas or oil escapement were noticed along the fault zone it is hardly likely that such an avenue of escape would be sealed along its entire length.

The Absaroka overthrust fault, its west branch, the St. John fault, and a minor branch all extend through the northeastern and eastern part of the quadrangle but were not examined in detail. The vertical and horizontal displacement each amounts to several thousand feet, being in all places greater than that of the Snake River fault. These faults are effective in causing great thicknesses of strata to be duplicated at the surface but have no apparent economic significance.

Anticlines—A long and persistent anticline extends transversely of the quadrangle from its southeastern to its northwestern corner. It is made up of Carboniferous strata at the surface and consequently all of these formations have been truncated, thus permitting any petroleum to escape which may have existed within them. Since the nature of the underlying formations is unknown nothing can be suggested as to their petroleum possibilities. Detailed work on this anticline might show areas with closure and with uncut Carboniferous formations which might constitute a source and trap for petroleum.

The southern end of a large anticline appears in the southwestern part of the area adjacent to and southwest of the Snake River fault. This anticline plunges south of Bear Creek providing closure at that extremity but it is cut by the Snake River fault on the east and north in such a manner as probably to permit drainage of any oil which might exist in underlying formations. The Madison is the only formation, known to have oil bearing possibilities, that is not exposed and consequently truncated in this fold. Any formations underlying the Madison limestone constitute an entirely unknown factor and are excluded from consideration. This anticline has the Carboniferous formations along its axis, with Triassic, Jurassic and Cretaceous beds exposed in a vast monocline along its southwestern flank and southern extremity. This condition would preclude oil possibilities in beds from the Brazer limestone to the Tygee sandstone inclusive which are found in this structure.

Evidence of two narrow anticlines in the Carboniferous strata was noted southwest of the St. John fault on Elk Creek but the oil possibilities are no better than in the long persistent anticline first described.

Synclines—Parts of three small synclines were mapped in the rough mountainous area of undifferentiated Carboniferous in the central part of the area but none of these is believed to have any economic significance. Another syncline with its axis in the Tygee sandstone appears in the southwestern part of the quadrangle but is not believed to have any significance as an oil structure.

McKOY CREEK QUADRANGLE.

(Plate VI in Pocket).

LOCATION.

This quadrangle is the southeastern one of the group of six quadrangles mapped and described in this report, and lies between parallels 43° 00′ and 43° 15′ N., and meridians 111° 00′ and 111° 15′ W. The entire quadrangle is rough, mountainous and of great relief, except that portion occupied by Snake River and its important tributary, Salt River, which flows into it from the south. These river valleys furnish the only opportunity for transportation since they contain the only traveled roads. The rest of the region is accessible only by pack trains and sheep camp outfits during the summer months. The distributing point for this area is the town of Freedom, Wyoming, which lies a few miles south of the eastern part of the quadrangle.

The valleys of Snake and Salt rivers are fertile and broad plains from which the mountains flanking them rise precipitously. These plains constitute the only low relief in the quadrangle. A number of hot springs are distributed along the west side of Snake River at Alpine Hot Springs and at Spring Creek and Sulphur Bar Creek in the northern part of the quadrangle. All of these springs are apparently along the plane of the Snake River fault.

The area is plentifully watered and is well forested on the eastern and northern slopes of the ridges. The largest streams are: Salt River, which dominates the eastern part of the region, and Tincup and Jackknife creeks, which flow into this river from the west. After Salt River the next important tributary of the Snake is McKoy Creek, which drains the central part of the quadrangle.

GEOLOGY.

AREAL GEOLOGY.

The formations present at the surface in this quadrangle are as follows in order of age: Madison limestone, Brazer limestone, and Wells formation of Carboniferous age; Thaynes group of Triassic age; Nugget sandstone, Twin Creek limestone; Preuss and Stump sandstone of Jurassic age; Ephraim formation, Peterson limestone, Bechler formation, Draney limestone, Tygee sandstone, and Wayan formations of Cretaceous age; and hill wash and alluvium of Quaternary age.

DISTRIBUTION OF THE FORMATIONS.

Madison Limestone (Lower Mississippian).
Brazer Limestone (Upper Mississippian).
Wells Formation (Pennsylvanian).

These formations are included in the map unit *Cu* and make up the mountains flanking Snake and Salt River valleys on the east.

Thaynes Group (Triassic)—This formation lies in a wide belt in the valley wall west of Snake River in the north-central part of the area.

Nugget Sandstone (Jurassic)—This standstone appears in two localities in this area. It is exposed in a narrow strip, flanking the Thaynes group just west of Snake River, for a distance of nearly five miles, and also in the heart of the fold which forms Big Elk Mountain in secs. 24 and 25, T. 2 S., R. 44 E.

Twin Creek Limestone (Jurassic)—This formation is well exposed at four places in the area, where the overlying beds have been eroded. A narrow strip extends from Palisade Creek quadrangle in the great monocline to the west of Snake River, to a point nearly a mile south of the mouth of McKoy Creek. Another excellent exposure of Twin Creek appears near the summit of Big Elk Mountain where the limestone completely encircles the red Nugget sandstone in the northwestern part of the quadrangle.

It appears again in the axis of the dome which forms Black Mountain. This mountain is the highest eminence in this quadrangle, west of Salt River. The formation is only partly cut in this structure and appears in a wide strip surrounded by varicolored beds along the flanks and ends of the dome. This strip extends from sec. 25, T. 3 S., R. 45 E., to sec. 20, T. 4 S., R. 46 E.

The fourth outcrop is in the overturned fold that is found in the southwestern part of the area and which extends into Grays Lake quadrangle as far as Caribou Mountain. This limestone occupies the axis of the fold and is not completely cut in this structure.

Preuss Sandstone (*Jurassic*).
Stump Sandstone (*Jurassic*).
Ephraim Formation (*Cretaceous*).

These three formations are shown on the map by *KJesp* symbol and are in evidence on the flanks or in the axis of every dome and monocline in the area with the exception of Bald Mountain dome. A large expanse of these highly colored formations lies in and around Poker Peak and in a long strip flanking the Twin Creek limestone in the Snake River monocline. This strip disappears about two miles south of the point where McKoy Creek enters the Snake. A wide band of these formations completely surrounds that part of Big Elk dome which appears in this quadrangle. It makes up the buttress-like lower-lying peaks of this mountain.

These same red sandstones and shales make up most of the summit of Black Mountain dome in the central part of the area. The remaining exposure is a narrow strip in each flank of the overturned anticline that lies in the southwestern portion just north of Tincup Mountain. This formation is cut in each structure except Bald Mountain dome. One small exposure lies in sec. 2, T. 5 S., R. 46 E.

Peterson Limestone (*Cretaceous*).
Bechler Formation (*Cretaceous*).
Draney Limestone (*Cretaceous*).

These formations grouped together under the map symbol *Kdbp* are exposed in every structure in the area. The two white limestone layers with the red Bechler between them are easily recognized in the lower flanks of the Snake River monocline, in Big Elk dome, in Black Mountain dome, in the overturned fold north of Tincup Mountain, and at the head of Jacknife Creek. This group makes up the crest of Bald Mountain dome but the Peterson member is uncut on this structure. Because of their striking contrast in color they are easily recognized. A small exposure of Peterson limestone is shown north of Tincup Creek in secs. 2 and 3, T. 5 S., R. 46 E.

Tygee Sandstone (*Cretaceous*)—This massive sandstone occupies the axis and flanks of each syncline in the area and the west flank of Bald Mountain dome, as well as the east flank of the overturned fold to the southwest. It is completely cut on all domes and monoclines within the area. It is easily recognized by its lithologic peculiarities and the dike-like or wall-like outcrops where it is steeply inclined. The Tygee sandstone occupies a large area in this quadrangle.

Wayan Formation (Cretaceous)—This highly colored formation occupies the foothills of the range west of Salt River and much of the area in the southern part of the region. Tongues of this formation occupy the valleys of Squaw, Trail, Taylor, and Box Canyon creeks and a small area is found in McKoy Creek valley between Black and Bald mountains in T. 3 S., R. 44 E. This formation in each case has the appearance of having been deposited in depressions formed by folding of the older sediments. It is in turn folded and lies uncomformably on the older folds. At no place in this area is the full thickness exposed.

Hill Wash and Alluvium (Quaternary)—The broad flat plains making up the valleys of Salt and Snake rivers are covered by this material. Tongues of alluvium extend up Tincup, Jacknife, and McKoy creeks and small patches are found along the course of the latter streams.

STRUCTURE.

Faults—The Snake River fault described on previous pages is believed to extend through the entire length of this area. It has been mapped as an inferred fault paralleling the course of Snake River to the mouth of McKoy Creek, and from there it is believed that its trend is approximately the same as the contact between the Wayan formation and all the older formations as far south as Jacknife Creek. The escarpment caused by the older Cretaceous and Jurassic sediments along this line offers persuasive evidence that they have been sliced off by this fault. The small patches of formations designated *Kdbp*, and *KJesp*, lying north of Tincup Creek may also mark the west side or escarpment of the fault, but the alluvium and the Wayan formation prevent this from being proven. At no place is the actual fault plane visible as it is in other quadrangles but the escarpment to the west breaks so sharply as to be construed only as one side of the fault. The presence of hot springs along this line is a further proof of the existence here of the Snake River fault.

Two very small but unusual breaks are found in the extreme north end of the Bald Mountain fold. They are revealed clearly on the north side of McKoy Creek valley. Although Bald Mountain is an overturned fold it attempts here to straighten up into a normal fold as found in Little Elk Mountain. These breaks are caused by compression as the fold changed direction and inclination. The displacement amounts to less than 50 feet on each of these minor faults and they die out quickly in length.

Domes and Anticlines—Two large anticlinal domes are wholly within this quadrangle and part of another large dome lies in the northeastern part. Bald Mountain dome, located along the west central part, offers some favorable aspects because of its complete closure, large drainage area and relatively gentle dips. Throughout much of its length it is overturned to the west but the eastern slope is so gentle as to offer a suitable place for accumulation in the reservoir rocks. Another factor that makes this structure favorable is the large number of uncut beds which lie beneath its surface. The structure is one of the most accessible of all the favorable structures in the region. It is sparsely timbered and has fairly gentle slopes from both McKoy and Jacknife creeks. The Draney and Bechler formations make up most of its crest with a wide exposure of the Tygee formation completely surrounding them. The dips to the east are very gentle, varying from 5° to 18° while to the west the dips are gentle at the axis but soon become vertical and finally the beds overturn to dips of 85° east in many places on the western flank. A large amount of closure is provided in the underlying beds by the rapid plunge at each end of the structure.

Black Mountain dome is slightly higher and more rugged than Bald Mountain but is a normal anticlinal dome with fairly steep dips in all directions. Closure on this structure is assured on all sides except in the southeastern part, where the end may be cut by the Snake River fault. At any rate the fault is overlain by the Wayan formation, affording an impervious cover at that locality. Since faults are as often causes of trapping as they are causes of drainage, it may be said that conditions for closure are not unfavorable at this point. This structure presents the rest of the factors which would appear to make it a favorable place for the accumulation of any petroleum which might be present. It has, however, fewer uncut formations than the structure to the west since the Twin Creek limestone appears in the axis along the southern part of the structure and none of the younger formations could be considered because of their truncated condition in the flanks and extremities. Prospecting for oil in this structure should be confined to the Nugget sandstone and Triassic and Carboniferous formations.

Big Elk dome offers complete closure: a large gathering ground; normal dips, although steep in many places, and all the factors apparently necessary to a favorable structure. Erosion has cut all the Cretaceous and Jurassic formations and any oil in the dome would have to be trapped in the older sediments. Approximately oval outcrops of all the formations from Nugget sandstone to Tygee sandstone appear in regular sequence on this mountain. Big Elk Mountain is the highest point in the area west of Snake and Salt rivers except Mount Caribou. It is excessively rugged and difficult of access. Dips along the side are often 50° and the plunge is sudden at each end. It has the largest closure and gathering ground of any dome in the region.

The overturned fold at the head of Jacknife Creek and north of Tincup Mountain is too closely folded and too greatly overturned to furnish opportunity for successful prospecting. It offers the same geologic column as Black Mountain dome and has assurance of closure on all sides except the north where it has been intruded by the andesitic sills of Mount Caribou. At that place the Cretaceous and Jurassic sediments have become highly metamorphosed and since they occupy the highest place on the structure, it is doubtful whether any oil exists or could exist within them now.

The Twin Creek limestone is exposed along the crest of this fold, and parallel strips of all formations to the Tygee sandstone occur in proper sequence on each flank. Both northern and southern extremities are concealed by the unconformable Wayan formation.

Another anticline plunges to the south just east of Jensen Creek and north of McKoy Creek. It extends beyond Poker Peak to the north and appears to be a continuation of the Snake River anticline which flanks the Snake River fault to the west in the Palisade Creek quadrangle. Its apparent lack of closure classes it as an unfavorable structure for testing although all the other necessary factors may be present.

Synclines—A large syncline was mapped in the Carboniferous formations in the northeastern part of the quadrangle. Other synclines separate Big Elk dome from Poker Peak anticline, Big Elk dome from Bald Mountain dome, Black Mountain dome from Bald Mountain dome, and Tincup Mountain anticline from Bald Mountain dome. Another syncline extends to the east and parallel to Poker Peak anticline and to the axis of Black Mountain dome. None of these is believed to possess petroleum possibilities.

GRAYS LAKE QUADRANGLE.

(Plate VII in Pocket).

LOCATION.

This area lies west of McKoy Creek quadrangle, south of Fall Creek quadrangle, and east of Cranes Flat quadrangle, described in this report. Lanes Creek quadrangle joins it on the south. The quadrangle is bounded by parallels 43° 00′ and 43° 15′ N., and meridians 111° 15′ and 111° 30′ W.

The two rough and mountainous districts are separated by one of less relief formed by the wide rolling depressions occupied by Clear and McKoy creeks. The extreme northeastern portion of the map is occupied by parts of Little Elk and Big Elk Mountains, while the eastern central region is dominated by Mount Caribou and its tributary ridges and spurs. This area offers the greatest relief of any of the quadrangles described in this report. The elevation increases over 2500 feet in the short space of three and one half miles, between Grays Lake and the summit of Mount Caribou. Over a third of the quadrangle is covered by Grays Lake and the marshy and alluvium-covered plains adjoining it. This part of the area offers the mildest relief in the quadrangle, and is also the chief center of settlement. Most of the population is concentrated around Gray post office, which receives mail and supplies from Soda Springs to the south. A well travelled highway also makes connection with Idaho Falls to the northwest.

The area is drained to the west by Grays Lake Outlet and its tributary, Brockman Creek, and to the east by Tincup, Bear, and McKoy creeks and their various tributaries. Little Elk, Big Elk, and Caribou mountains are well clothed with aspen, juniper and fir, and carry snow banks for at least ten months of the year. Caribou Mountain was at one time the scene of considerable gold mining, and placer mining is carried on at the present time, during the open months. Much deserted equipment and a number of mills are mute evidence of the attempted development of the gold bearing ledges near the summit of the peak.

The summit is easily accessible—two good roads leading up its sides to the deserted millsites, whereas Little Elk and Big Elk Mountains to the northeast, although lower in altitude, can be approached only by pack train.

GEOLOGY.

AREAL GEOLOGY.

The formations which are exposed in this quadrangle are listed according to age as follows: Brazer limestone and Wells formation of Carboniferous age; Nugget sandstone, Twin Creek limestone, Preuss and Stump sandstones of Jurassic age; Ephraim formation, Peterson limestone, Bechler formation, Draney limestone, Tygee sandstone and Wayan formation of Cretaceous age; igneous intrusives and lava flows of Tertiary age; and hill wash and alluvium of Quaternary age.

DISTRIBUTION OF THE FORMATIONS.

Brazer Limestone (*Upper Mississippian*)—Faulting has exposed a small outcrop of this formation which extends into this area from adjacent quadrangles. This exposure is in the extreme southwestern corner of the area.

Wells Formation (*Pennsylvanian*)—Two very small areas of this formation are found within this quadrangle. They are shown in the corner of the map southwest of Grays Lake, where they enter from Cranes Flat quadrangle.

Nugget Sandstone (*Jurassic*)—This was seen only in the center of Big Elk Mountain in T. 2 S., R. 44 E.

Twin Creek Limestone (*Jurassic*)—The Twin Creek appears in four places in the area. Two strips outcrop on the flanks of Big Elk dome and a small patch appears in the crest of Little Elk Mountain, and on the overturned anticline southeast of Mount Caribou. The limestone is nowhere completely eroded in the latter exposures.

Preuss Sandstone (*Jurassic*).
Stump Sandstone (*Jurassic*).
Ephraim Formation (*Cretaceous*).

These highly colored sandstones and shales show on each side of Big Elk dome, and make up the crests of Little Elk Mountain, and of the high ridge southeast of Mount Caribou. One other exposure is located southwest of the lake on the edge of the quadrangle.

Peterson Limestone (*Cretaceous*).
Bechler Formation (*Cretaceous*).
Draney Limestone (*Cretaceous*).

This red and white group of Gannett sediments surrounds Little Elk Mountain and extends along the southwestern foothills of Big Elk. Two more exposures of the *Kdbp* group are shown on opposite sides of the overturned anticline in T. 4 S., R. 44 E.

Tygee Sandstone (*Cretaceous*)—A border of this formation extends along the western and southern sides of Big and Little Elk Mountains. Another outcrop of this sandstone extends northward along the east side of Mount Caribou, until it disappears beneath the Wayan formation. A small outcrop which may be the Tygee sandstone was noted in sec. 19, T. 3 S., R. 44 E., where the erosion of McKoy Creek appears to have washed away the overlying Wayan formation. The full thickness of this formation is concealed throughout the area by the overlapping Wayan sediments.

Wayan Formation (*Cretaceous*)—This formation is easily the dominant one of the area, as it covers nearly all of the quadrange. It shows a number of soft rounded, brightly colored hills clothed chiefly in aspen and with much less relief than the older formations. The unconformable relations of these sediments to the Gannett group is shown in the geologic cross-sections, A A′ and B B′ of the accompanying map. (Pl. VII in pocket.) No attempt was made to differentiate the large number of members in this formation, because of the limited time, the tremendous thickness and great lithologic similarity of the different beds. Where the sediments have been metamorphosed by igneous invasions their appearance is notably different, and makes identification even more difficult. A large area along the summit and eastern side of Caribou Mountain is made up of metamorphosed Wayan sediments and igneous intrusions. These could be differentiated and shown only on a large scale map. This problem has been reserved for another field season and consequently only the limits of the area occupied by these sills and metamorphic rocks are shown. The igneous intrusions are described under the discussion of igneous geology.

Igneous Intrusives (*Tertiary*)—The areas marked by the *Ti* symbol are basaltic, andesitic and dioritic dikes and sills, but the area marked *Tiu* contains various igneous rock types, as well as interbedded metamorphosed sediments. Several exposures of andesite represented by *Ti*, are sills cut by the western slopes of Caribou Mountain (See geologic cross-section C C'). Only the largest and most important of the exposures could be mapped and shown on the scale used.

The small area in the extreme southeastern corner of the quadrangle appears to be a dike of andesitic rock identical with the sills at Mount Caribou. The intrusive at Brockman vent is a fayalite basalt, which shows a peculiar flow structure. The rocks included in the *Tiu* area can best be illustrated by a section taken from the summit along the spur reaching to the northeast. This section does not extend far enough down the mountain side to include all the sills on the northern or eastern sides but was taken only to show the typical relationships encountered in this *Tiu* area. The section is as follows:

Lithologic cross section on Caribou Mountain from summit along main spur, traversing due north, to escarpment.

Note—All metamorphosed sediments are believed to represent the Wayan formation. All descriptions of igneous rocks were made in the field and the names used are field names and do not represent the conclusions of final laboratory study.

No. of Member	Thickness in Feet	Description
1 (top)	50	Andesite with greenish ground mass and an abundance of black hornblende crystals.
2	5	Argillite. This is mottled, greenish-brown and gray in color.
3	75	Crystalline limestone or marble. It is massive and bluish-white in color and highly metamorphosed and silicified.
4	35	Andesite with a greenish ground mass and an abundance of black hornblende crystals.
5	225	Limestone. It is massive and siliceous and weathers blue-white to white.
6	75	Argillite. This is massive, black to green in color, and extensively calcite-seamed and fractured.
7	150	Diorite. It is very dark and fine-grained.
8	50	Andesite. This rock is dark colored and contains an abundance of small perfectly shaped hornblende crystals.
9	10	Diorite. It is fine-grained and generally dark in color but becomes lighter near contact with No. 10.
10	20	Quartzite. This rock is greenish to red in color.
11	15	Diorite. It is dark and has a fine-grained texture.
12	35	Quartzite which is greenish to white in color.

13	45	Andesite. This is light colored and contains large feldspar phenocrysts.
14	15	Quartzite. It is gray in color.
15	15	Trachyte porphyry. This is pink in color and contains large clouded feldspar phenocrysts.
16	2	Limestone. This is a highly altered rock exhibiting large cavities filled with specular hematite. The entire member is copper-stained and fissured with malachite.
		Argillite. This is siliceous and greenish-red in color. It weathers gray and is extremely fractured and brittle.
18	5	Andesite. This rock is green to gray in color.
19		Shale or argillite. It is highly indurated and black to gray to white in color.
20	15	Andesite. It is green to gray in color.
21	250	Argillite and indurated shales. They are pinkish-white to gray in color.
22	75	Limestone. It is highly indurated and white to mottled in color and includes cherty and agate-like nodules.
23	50	Argillite. This member is massive and very hard and is purple in color.
24	300	Argillite. This formation is platy and greenish to white in color.
25	90	Quartzite. This rock is greenish-gray when fresh, and pink to red when weathered.
26	15	Andesite.
27	90	Argillite. The rock is reddish-brown on weathered surface but black to dark blue on fresh fracture.
28	225	Argillite. It is gray to violet in color, containing a small bed of gray quartzite.
29	90	Syenite. This intrusion is pinkish to gray in color.
30 (bottom)	100	Argillite. It is very brittle and fragile, and blue to green in color.
	2315 feet	

Basalt (*Tertiary*)—This type of lava is found in two places in the area. One flow extends from Brockman vent southwest for about two miles, and two more flows which overlap, extend into the area along the western edge from sources in Cranes Flat quadrangle. This material is a fayalite basalt described in the pages devoted to igneous geology.

Hill Wash and Alluvium (*Quaternary*)—This material is found in the valleys of Brockman Creek and its tributaries, and in the flat region adjacent to Grays Lake. The areas to the north and to the east of this lake represent part of the old lake bottoms, and are now adapted to hay growing and stock raising.

STRUCTURE.

Domes and Anticlines—This quadrangle, like others of this group, contains a part of Big Elk dome. It is a rough, almost inaccessible structure, oval in shape, and presents the greatest amount of closure and gathering ground of any dome in the region examined. The high point as well as the "structural high" of this mountain occurs within the limits of this quadrangle, in the extreme northeastern part. The fold is almost normal, but the dips are very steep along the flanks. The Nugget sandstone is exposed along the axis, and the younger formations up to the Tygee are shown successively along the sides. The oil possibilities of this structure would be confined to the Triassic and Carboniferous formations, since they are the only ones remaining untouched by erosion.

Little Elk Mountain is the southern end of Fourth of July Ridge anticline and affords a perfect closure to the south for this long structure. The dips on this part of the structure are fairly steep, but much more gentle than on Big Elk dome (see geologic cross-section A A′). Although the Twin Creek limestone is cut in this structure north of the point where it leaves the quadrangle, it is possible that it might still serve as a reservoir rock for petroleum along the southern extremity of this fold, because of a slight undulation along the axis south of Bear Creek. The normal attitude of the fold at this point, makes it one of the most desirable places for testing the possibilities of Fourth of July Ridge anticline. Little Elk Mountain presents several more beds for testing than does Big Elk Mountain.

The overturned anticline southeast of Caribou appears less favorable than the ones just discussed. The closeness of the folding, and its overturned attitude would make a test of the underlying beds difficult and expensive (see geologic cross-section B B′). The presence of large igneous intrusions near the structural high point of the fold, along with the metamorphosed condition of the rocks, is likely to nullify any petroleum possibilities. Should petroleum be discovered in the same rocks in other structures of the area, then this structure would perhaps deserve a test in its southern extremities near the edge of this quadrangle.

Three well defined anticlines are shown in the area covered by the Wayan sediments, but none of these is advised for testing because of the origin of this formation and its unfavorable relationships to the older beds which are considered more likely for petroleum production. In the event that the large structures of the region, such as Big Elk, Little Elk, Fourth of July Ridge, Black Mountain, and Bald Mountain, produce commercial petroleum, then it is fitting and proper that some of the Wayan anticlines which show proper structure and closure should receive exploration by the drill.

Synclines—A syncline between Big and Little Elk Mountains and a few minor folds in the Wayan formation comprise typical examples of this type of structure in this region. They appear to have no economic significance.

CRANES FLAT QUADRANGLE.

(Pl. VIII in Pocket).

LOCATION.

This is the southwestern one of a group of six 15-minute quadrangles mapped and discussed in this bulletin. It is bounded by parallels 43° 05′ and 43° 15′ N., and by meridians 111° 30′ and 111° 45′ W. Hell Creek and Grays Lake quadrangles of this report join it on the north and east, and Henry quadrangle lies to the south. The geology of both the Henry and Cranes Flat sheets has been mapped by the U. S. Geological Survey but it is not available, being, as yet, unpublished. Paradise Valley quadrangle joins this area on the west.

This quadrangle has less relief than any of the group described, and is made up of alluvium covered valleys, lava plateaus, gently sloping hills and a few steep-sided ridges. The chief centers of population are in Cranes Flat and Long Valley, where a few homesteaders spend the summer months and stock raising is the principal industry. Idaho Falls is the trading point for this and adjacent areas, and is reached by a well travelled road through Long Valley. Some timber is found on the slopes of Sheep Mountain and Meadow Creek Mountain, but the rest of the area is relatively open, or covered with sagebrush and aspen. Blackfoot River reservoir and a small reservoir north of Little Valley Hills are the largest bodies of water in the region. Important streams draining north are Grays Lake Outlet, Brockman Creek and Homer Creek. Drainage to the west is carried by Cranes Creek and Willow Creek and to the south by Meadow Creek.

GEOLOGY.

AREAL GEOLOGY.

The formations in order of age are as follows: Brazer limestone, Wells, and Phosphoria formations of Carboniferous age; Thaynes group of Triassic age; Nugget sandstone, Twin Creek limestone, Preuss and Stump sandstones of Jurassic age; Ephraim formation and Wayan formation of Cretaceous age; rhyolite and basalt flows, and igneous intrusives of Tertiary age; and hill wash and alluvium of Quaternary age.

DISTRIBUTION OF THE FORMATIONS.

Brazer Limestone (*Upper Mississippian*)—The largest exposure of this formation occurs in the axis of the fold which makes up Limerock Mountain and Meadow Creek Mountain in the southern part of the area. A continuation of this outcrop shows in sec. 21, T. 4 S., R. 40 E.

Four small outcrops have been produced by faulting and erosion east of Meadow Creek in the southeastern corner of the quadrangle. The limestone here makes up several prominent hills.

Wells Formation (*Pennsylvanian*)—This formation flanks the Brazer in Meadow Creek Mountain and Limerock Mountain, and extends into two patches along the western edge of the area. Four small outcrops show along with the Brazer east of Meadow Creek in the southern edge of the Little Valley Hills.

Phosphoria Formation (*Permian*)—This formation was recognized at only one locality. A narrow outcrop of it appears in secs. 34 and 35, T. 4 S., R. 40 E.

Thaynes Group (*Triassic*)—This group of formations appears on the west side of a large fault in the central part of the area and east of Cranes Flat. It is possible that the Woodside or other formations are included in this exposure, which has been mapped as Thaynes. If such were present they could not be recognized in the limited time spent in the examination.

Nugget Sandstone (*Jurassic*)—One area of this formation outcrops east of Cranes Flat adjacent to the Thaynes group in the northeastern part of T. 4 S., R. 41 E.

Twin Creek Limestone (*Jurassic*)—The Twin Creek occurs in two small irregular outcrops on the west side of a fault in the northwestern end of the Little Valley Hills and just southeast of the outcrop of Nugget sandstone.

Preuss Sandstone (*Jurassic*).
Stump Sandstone (*Jurassic*).
Ephraim Formation (*Cretaceous*).

These formations have been grouped together in the same map symbol throughout the other quadrangles of this report. Because of greater thickness here along with a gentler inclination of the strata it was possible to differentiate these strata on the map of this quadrangle. Although the same pattern is used, the contact lines are shown and the letters *Jp* indicate an outcrop of Preuss, *Js* represents exposures of the Stump sandstone and *Ke* marks the areas of Ephraim sediments. These three formations are exposed in irregular outcrops in the central part of the Little Valley Hills. The writer noted considerable evidence of faulting in these hills, but was able to determine and map only a few of the more obvious breaks. Other lines of inferred faults should be included at places where only contact lines exist, but lack of time prevented the accurate working out of these breaks. The structure of these hills is very complex, and detailed study of this area will probably required some changes in this mapping. A small area in the eastern part of T. 4 S., R. 42 E., was thought to be Ephraim and mapped as such but a certain determination of this formation was not made.

Wayan Formation (*Cretaceous*)—Wayan sediments cover the entire northeastern side of the quadrangle, except where they are masked by a thin covering of hill wash or basalt. Outcrops of limestone and variegated shales on typical rounded slopes are prominent throughout this part of the quadrangle, and the attitude of some of these beds is very deceiving. What at first appeared to be a broad anticline with one flank dipping west at Sheep Mountain and another dipping east at Sugar Loaf finally proved to be part of the complexly folded, inverted fan fold illustrated in geologic cross-section A A′. These deceiving structures have resulted in considerable leasing activity in this region, and much of the land lying in the central, eastern and northern part of the quadrangle is being held by a number of companies with the expectation of testing these structures.

Rhyolite (*Tertiary*)—Three patches of this lava are found on the southern slopes of the Little Valley Hills chiefly in T. 4 S., R. 42 E. These rocks are described more fully in the pages on igneous geology.

Igneous Intrusives (*Tertiary*)—One intrusion of andesite occurs as a laccolith or thickened sill at Sugarloaf Mountain in the northeastern part of the quadrangle. This and the accompanying andesite dikes in the same area are described in the discussion of igneous geology in another part of the bulletin. Their relations to the invaded strata are shown in geologic cross-section A A′ of the Cranes Flat map. (Pl. VIII in pocket.) Basaltic intrusions occur at Sheep Mountain and at the north end of the Little Valley Hills where the lava cores of old craters and vents are exposed. These intrusions are the sources of lava flows extending down the slopes near them. A rhyolitic intrusion was identified in connection with one of the rhyolite areas in the Little Valley Hills. Other sources of this rhyolite may be present in the rhyolite area to the northwest of this vent, but none was recognized. The typical relations of the basaltic intrusives to the lava flows and sediments are represented by geologic cross-section B B′ on the map of this quadrangle.

Basalt (*Tertiary*)—Flows of basalt cover more area in Cranes Flat quadrangle than any other formation. The western side of the quadrangle displays flows from Sheep Mountain, and the country south of Meadow Creek Mountain shows an extension of a flow from Henry quadrangle. The eastern and central part of the area is covered with basalt from local vents or fissures, and a small area on the northern edge of the quadrangle is part of a flow from Castle Rock vent in the Hell Creek quadrangle.

Hill Wash and Alluvium (*Quaternary*)—Large quantities of hill wash tinged with the color of the sediments from which it has formed, have been deposited in all the flats and depressions in the area. This material is instrumental in concealing much of the structure in the area and in many places is easily confused with the Wayan formation, where it has been derived from that source.

STRUCTURE.

Faults—Two large normal faults, discussed under structure in another part of this bulletin, extend transversely of the southwestern townships of the area. These faults bound on the northeast and southwest the high Carboniferous ridges known as Meadow Creek, and Limerock mountains. Dot-and-dash lines have been used to illustrate their inferred path to the point where they leave the quadrangle on the west. Much of their length is masked by the Tertiary basalt and hill wash, and the relationships of the various ridges are the only criteria in some instances, upon which to determine their course. The vertical throw of these faults is believed to be as much as 3,000 feet in some places. These normal faults have caused the anticline in the Carboniferous sediments to be raised in a huge horst which extends out of the quadrangle both to the west and to the south. A transverse normal fault cuts across the south end of Limerock Mountain and probably extends across the intervening area of hill wash to appear again at the southernmost contact of the Wells and Brazer in the ridges of the southeastern part of the quadrangle. The vertical throw of this fault appears to be as great or even greater than those mentioned above. Evidence of another fault, too indistinct to be described in any detail, was found west of Blackfoot River reservoir and south of the exposure of the Phosphoria formation. Part of its course seems to lie in the depression occupied by the reservoir.

The east side of the graben which is complementary to the horst is delineated by another normal fault which extends from a point in sec. 25, T. 4 S., R. 41 E., to sec. 5, T. 5 S., R. 42 E., where it is masked by hill wash. The vertical throw here appears to be 2,000 feet or more. This horst and the two graben-like blocks which flank it are believed to be blocks in the overthrust lip of the Bannock fault. A branch of this overthrust appears at the contact of the Carboniferous formations with the Preuss, Stump and Ephraim strata to the east. The Wells and Brazer have been thrust up over the Jurassic and Cretaceous formations along a line extending from Sec. 2, T. 5 S., R. 42 E. to a point in T. 4 S., R. 42 E., where the fault is masked by a rhyolite flow.

Both the vertical and horizontal displacements here may be in excess of 5,000 feet. Evidence of another branch of this branch fault is found in the Preuss, Stump, and Ephraim formations and extends from sec. 2, T. 5 S., R. 42 E., to a point east of the largest rhyolite flow. The outlines of this break were very difficult to determine and lack of time prevented this fault from being mapped. A large branch, or the main branch of the Bannock overthrust itself, extends transversely of the central part of the quadrangle. It separates the Jurassic and Triassic sediments from the younger Wayan formation to the northeast. The overthrust from the southwest has placed the Thaynes group, Twin Creek limestone, Preuss and Stump sandstones and Ephraim formation in a position overlying the Wayan formation which is much younger than any of them. This fault splits up into several branches in secs. 26 and 35, T. 3 S., R. 41 E., but only the two outside branches were mapped because the others were practically indistinguishable in the soft rolling hills of Wayan sediments. One branch extends along the edge of Cranes Flat until concealed by hill wash and lava from Sheep Mountain. The other branch can be traced along the east side of Sheep Mountain beyond the summit, where it is concealed by lava. Several minor faults were mapped along the contacts of small patches of Twin Creek limestone, Ephraim formation and Preuss sandstone in the northwest corner of T. 4 S., R. 42 E., and south of the Bannock fault line. A number of small faults were mapped in the basalt covered area northeast of the Little Valley Hills and many other places showed relationships probably produced by faults which could not be recognized and mapped for lack of certainty.

The writer feels that detailed mapping of this area will clear up the confusion that appeared to him to exist in some localities, and will show faulting and complex structure which were not recognized by him in the brief time spent in the reconnaissance of this quadrangle.

Anticlines—The largest anticlines in the area that are unbroken by block faulting on a large scale are the two tightly folded, overturned anticlines which are responsible for the formation of the inverted fan fold described under the discussion of unusual structure and portrayed in geologic cross-section A A′ of the map of this quadrangle. Much of the westernmost anticline is concealed by lava and hill wash and no attempt was made to plot its axis. The eastern anticline lies along the northeastern slopes of Sugar Loaf Mountain and parallel to the axis of the minor fold which extends along the crest of that eminence.

These folds in themselves are not of the best type to serve as good traps for petroleum, and the fact that they are in the Wayan formation, which is composed of fresh water and continental sediments of vast thickness, coupled with the further fact that they lie unconformably on any possible favorable structures below, does not make their chances of producing commercial petroleum appear very bright.

Tentative Correlation of Oil-producing Formations in Montana with Equivalent Formations in Southeastern Idaho.

o—oil *g*—gas *—seeps or small production of oil and gas.

SYSTEM OR SERIES	GROUP	Southeastern Idaho generalized	Crow Indian Reservation Montana	Judith Basin Montana	Cat Creek Montana	Sweetgrass Arch Montana	Crazy Mountains Montana
		FORMATION NAMES					
Cretaceous	Lower Cretaceous	Wayan	Fuson	Kootenai *g*	Kootenai *o*	Kootenai *og*	Kootenai *g*
		Unconformity	Lakota				
		Tygee	Morrison	Morrison	Morrison		Morrison
		Draney					
		Bechler					
		Peterson					
		Ephraim					
Jurassic	Upper Jurassic	Stump	Sundance*	Ellis	Ellis	Ellis *og*	Ellis
		Preuss					
		Unconformity					
	Lower Jurassic	Twin Creek					
		Nugget					
Triassic	Upper Triassic	Wood	Chugwater				
		Deadman					
		Higham					
		Unconformity					
	Lower Triassic	Thaynes Group					
		Woodside					
Carboniferous	Permian	Phosphoria	Embar	Quadrant	Quadrant *o*		Quadrant
	Pennsylvanian	Wells	Tensleep*				
	Mississippian	Brazer	Amsden *o*	Madison	Madison	Madison	Madison
		Madison	Madison*				

Tentative Correlation of Oil-producing Formations in Wyoming With Equivalent Formations in Southeastern Idaho.

o—oil *g*—gas *—seeps or small production of oil and gas

SYSTEM OR SERIES	GROUP	Southeastern Idaho generalized	Southwestern Wyoming generalized	Northern Wyoming	Central Wyoming	Salt Creek Powder River Teapot Wyoming	Lander Shoshone River Wyoming
		FORMATION NAMES					
Cretaceous	Lower Cretaceous	Wayan		Lower Cloverly	Cloverly*	Cloverly*	Cloverly *g*
		Unconformity	Unconformity				
		Tygee					
		Draney					
		Bechler	Beckwith *o*	Morrison	Morrison*	Morrison*	Morrison *g*
		Peterson					
		Ephraim					
Jurassic	Upper Jurassic	Stump					
		Preuss					
		Unconformity	Unconformity	Sundance*	Sundance *o* *	Sundance*	Sundance
	Lower Jurassic	Twin Creek	Twin Creek				
		Nugget	Nugget				
Triassic	Upper Triassic	Wood					
		Deadman	Ankareh				
		Higham					
		Unconformity	Unconformity	Chugwater *o*	Chugwater *og**		Chugwater **o*
	Lower Triassic	Thaynes Group	Thaynes				
		Woodside	Woodside				
Carboniferous	Permian	Phosphoria		Embar *o*	Embar *o*		Embar *o*
	Pennsylvanian	Wells	Weber and Wells	Tensleep	Tensleep*		
				Unconformity			
				Amsden	Amsden		
	Mississippian	Brazer	Brazer	Unconformity			
		Madison	Madison	Madison			

Tentative Correlation of Oil-producing Formations in Utah With Equivalent Formations in Southeastern Idaho.

o—oil g—gas *—seeps or small production of oil and gas.

SYSTEM OR SERIES	GROUP	Southeastern Idaho generalized	Green River Utah	San Rafael Utah	San Juan Utah	Vivian Utah	Castle Valley Utah
		FORMATION NAMES					
Cretaceous	Lower Cretaceous	Wayan					
		Unconformity					
		Tygee					
		Draney					McElmo
		Bechler					
		Peterson	McElmo				
		Ephraim					
Jurassic	Upper Jurassic	Stump					
		Preuss					
		Unconformity					
	Lower Jurassic	Twin Creek	La Plata	La Plata	La Plata	Jurassic Unnamed	La Plata
		Nugget					
Triassic	Upper Triassic	Wood		Vermilion Cliff	Dolores		Vermilion Cliff*
		Deadman					
		Higham				Triassic Unnamed	
		Unconformity					
	Lower Triassic	Thaynes Group		Undifferentiated	Moencopie		
		Woodside					
Carboniferous	Permian	Phosphoria		Permian o		Permian o	Permian
	Pennsylvanian	Wells			Goodridge o		
	Mississippian	Brazer				Upper Carboniferous	
		Madison					

OIL POSSIBILITIES OF THE AREA.

The foregoing tables represent an attempt at a correlation of oil-bearing beds and others in the geological column, ranging from the Lower Cretaceous to the Carboniferous in Utah, Montana, and Wyoming, with beds in the same stratigraphic sequence in that part of southeastern Idaho considered in this bulletin. Such a correlation under the most favorable conditions presents a difficult task, and when it is realized that even the correlation of many oil yielding horizons in these states is still in doubt, although the various areas have been worked in detail, one may comprehend how tentative this correlation must be. In Wyoming, Montana, and Utah the oil fields are often widely separated by unmapped areas, or by areas masked by unconformable lake-bed and continental sediments of Tertiary age, which absolutely prevent the continuous tracing of certain productive formations.

A correlation such as this must of necessity be made up from published data pertaining to the oil-bearing formations of the different fields. The publications of the United States Geological Survey, and of the various state geological surveys, as well as papers by geologists of responsible oil companies, have been the sources of the information used. Most of this material contains information concerning formations producing oil, their thickness, the stratigraphic position and age, and a description of the lithology and physical characteristics of the oil-bearing beds. Some of the correlations between adjacent fields seem quite positive, but others need verification and are presented tentatively.

The beds found in this area in order of age are correlated with other Rocky Mountain States as follows:

POSSIBLE OIL BEARING FORMATIONS.

Madison Limestone (Lower Mississippian).

This formation has been definitely correlated with many occurrences of Madison limestone in Montana and Wyoming. It furnishes seeps and a small production of oil in the Crow

Indian Reservation of Montana; and many reliable geologists believe that it is the source-rock of the oil found in the Cat Creek and Sweetgrass Arch fields of the same state. Geologists* for some of the largest producing companies in the Sweetgrass Arch field consider that some of the production attributed to the Ellis formation of Jurassic age, actually comes from the top of the Madison limestone which immediately underlies the Ellis. A core-drill test in this field penetrated the Madison and found numerous horizons where the fissures and cavities were filled with hydrocarbons. A similar occurrence is reported in Wyoming.[1]

Brazer Limestone (*Upper Mississippian*).

This formation is of the same age and has many of the physical characteristics of the Amsden formation which occurs in many localities of Montana and Wyoming. The lower part of the Quadrant formation is also assigned to this and may be correlated with the Brazer limestone. The Amsden produces commercial oil in the Crow Indian Reservation[4] of Montana, and the Quadrant formation produces commercial oil in the Cat Creek field[2] of the same state.

Wells Formation (*Pennsylvanian*).

This formation is correlated with the Tensleep formation of Wyoming and Montana, and is also correlated with a part of the Quadrant formation of the latter state. The Quadrant produces commercial oil in the Cat Creek field, and the Tensleep formation produces small amounts of oil in the Crow Indian Reservation of Montana and in central Wyoming[3]. Part of the Goodridge formation which produces oil at San Juan, Utah, is also correlated with the Wells.

Phosphoria Formation (*Permian*).

This formation, in both Idaho and Montana, contains large quantities of black carbonaceous shales from which oil has been

* Gerlough, Gene, and Stewart, Irvine; personal communication.

1. Washburne, Chester W., Gas fields of the Big Horn Basin. U. S. Geol. Survey Bull. 340, p. 361, 1908.
2. Freeman, O. W., Oil Fields in Central Montana, Eng. and Min. Jour., Vol. 109, pp. 936-938, 1920.
3. Hares, C. J., Anticlines in Central Wyoming. U. S. Geol. Survey Bull. 646, pp. 233-279, 1917.
4. Thom, W. T., Oil and gas prospects in and near the Crow Indian Reservation, Montana. U. S. Geol. Survey Bull. 736-b, pp. 35-53, 1922.

distilled. These shales may be the source of some oil which might be restricted from normal upward migration by the capping the Rex chert which is often impervious. In such a case the underlying sandy limestone might become a reservoir rock for this oil. In speaking of this formation a federal geologist, Dr. Schultz,[38] says

> Another source of oil that promises to be of some value occurs at the same horizon as the phosphate deposits in Montana, Idaho, and Wyoming, that is, the Phosphoria formation. The phosphate on applying heat to the rock is not driven off by distillation, but remains in the ash. Evidence of petroleum or bituminous compounds in rocks of this age has been observed over wide areas by the writer, who has worked on phosphate deposits, but few if any tests have heretofore been made to ascertain the quantity of oil.

In a further discussion he says,

> It may therefore be possible that commercial accumulations of oil have been formed in these older Paleozoic rocks. Thus far the Lander oil field of Wyoming seems to be the only place where oil has been obtained in commercial quantities from rocks of the same age, though indications of oil at this horizon have been noted, at several other places in Wyoming and Utah.

Distillation of oil from these shales has also been reported by the United States Geological Survey.[3]

The Phosphoria formation is correlated in age with the Embar formation which produces commercial oil in fields of northern and central Wyoming, as well as in the Shoshone River and Lander[2] fields, of the same state. This formation is correlated with the upper part of the Goodridge formation, which produces oil in the San Juan field of Utah, and with the formations of Permian age, that are oil-bearing in the Virgin and San Rafael fields of that state.

Woodside Formation (*Triassic*).
Thaynes Group (*Triassic*).

These formations are correlated with the Chugwater of Wyoming and Montana, and probably are equivalent to the lower part of that formation in physical characteristics. The Chugwater produces commercial oil and gas in various fields of northern and central[1] Wyoming, as well as commercial oil and seeps in the Lander[2] and Shoshone River fields of the same state.

The Vermilion Cliff formation which has a small produc-

1. Hares, C. J., Anticlines in Central Wyoming, U. S. Geol. Survey Bull. 646, pp. 233-279, 1917.
2. Woodruff, E. G., The Lander Oil Field, Fremont County, Wyoming, U. S. Geol. Survey Bull. 452, 87 pp., 1911.
3. See Reference No. 3 Bibliography.

tion of oil at Castle Valley, Utah, is thought to be partly equivalent to the Chugwater formation.

Nugget Sandstone (Jurassic).
Twin Creek Limestone (Jurassic).
Preuss Sandstone (Jurassic).
Stump Sandstone (Jurassic).

These Jurassic formations are of the same age as the Sundance formation of Wyoming and Montana, and of the Ellis formation of the latter state. The Sundance formation produces commercial oil in central Wyoming; seeps, and small production of oil and gas, are found therein in northern Wyoming; and in the Poison Spider,[1] Salt Creek[2] and Powder River[3] fields of that state. The Ellis formation produces commercial oil and gas in the Sweetgrass Arch of Montana. The Vermilion Cliff formation which has a small production at Castle Valley, Utah, is also correlated with the Nugget and Sundance formations.

Ephraim Formation (Lower Cretaceous).
Peterson Limestone (Lower Cretaceous).
Bechler Formation (Lower Cretaceous).
Draney Limestone (Lower Cretaceous).
Tygee Sandstone (Lower Cretaceous).

These formations are equivalent to the Beckwith or Morrison formation of Wyoming. Oil is produced in the Beckwith in southwestern Wyoming, natural gas in commercial quantities issues from the Morrison formation in the Shoshone River[4] field of Wyoming, and seeps and small production of oil and gas are found in Morrison beds in the Salt Creek[2] and Powder River[3] fields of Wyoming, and in the Florence[5] field of Colorado.

Wayan Formation (Lower Cretaceous).

This formation is of the same age and has many of the

1. Heald, K. C., Personal communication.
2. Wegemann, C. H., The Salt Creek oil field, Natrona County, Wyoming, U. S. Geol. Survey Bull. 452, pp. 37-83, 1911.
3. Wegemann, C. H., The Powder River oil field, Wyoming, U. S. Geol. Survey Bull. 471, pp. 56-75, 1912.
4. Hewitt, D. F., The Shoshone River section, Wyoming, U. S. Geol. Survey Bull. 541, pp. 89-113, 1914.
5. Washburne, C. W., The Florence oil field, Colorado, U. S. Geol. Survey Bull. 381, pp. 517-544, 1910.

same physical characteristics as the Kootenai, Fuson and Lakota of Montana, and the Cloverly of Wyoming. Its thickness in southeastern Idaho, however, far exceeds that attained by any of the latter formations.

The Cloverly produces commercial natural gas in the Shoshone River[1] field of Wyoming, and seeps or small production in central Wyoming and in the Powder River, Salt Creek, and Teapot fields. The Kootenai in Montana[2] produces commercial oil in the Cat Creek and Sweetgrass Arch fields, and commercial gas in Judith Basin, Crazy Mountain, and Sweetgrass Arch fields, and commercial gas in Judith Basin, Crazy Mountain and Sweetgrass Arch fields. A carbonaceous shale in the Wayan was tested for oil, and distilled about 20 gallons to the ton. This may be considered as a possible source for oil where it is folded and under a sufficient cover.

CONCLUSION.

From the foregoing discussion it can be readily seen that this area is underlain by numerous beds, accessible to the drill, of the same age as, and otherwise similar to, many formations which contain productive oil and gas-bearing horizons in areas comparatively near in adjacent Rocky Mountain states.

An important factor to be considered in determining the proper rating of a new area thought to have petroleum possibilities, is its distance from other producing fields. If other conditions are equal, an area that is relatively close to, and therefore geographically as well as geologically related to other oil fields, would appear more promising than an area not so situated. The oil fields of Wyoming, Montana, and Utah are scattered promiscuously over their respective states and separated in many instances by distances far greater than the distance between this area and several oil fields of Wyoming. Many producing beds in the various fields of Wyoming are of the same age as those in Montana fields and both are equivalent in age to those in this area. It has been found that the beds which carry oil in one field, are very likely to carry oil in a number of

1. Hewitt, D. F., the Shoshone River section, Wyoming, U. S. Geol. Survey Bull. 541, pp. 89-113, 1914.

2. Bauer, Max C., and Robinson, Ernest Guy, Comparative stratigraphy in Montana: Am. Assoc. of Petroleum Geologists Bull. Vol. 7, No. 2, March-April, 1923.

other fields in a region where structure is favorable, even though separated by great distances.

Parts of the area when measured by the factors and conditions considered essential to a commercial accumulation of oil and natural gas stand up fairly well.

The area is undoubtedly in a "petroliferous province" made up chiefly of marine sediments, which are favorably folded, and show in many places evidence of shallow water deposition, as well as abundant organic life. The rocks themselves are within two of the most productive "petroleogenic epochs" that are recognized.

The region is entirely underlain by sediments of marine and brackish water origin, and by others which are interbedded or overlying in such a manner as to be capable of acting as reservoir or capping rocks for any oil that may be present.

The only metamorphism in the region is localized at those points where contact with igneous invasions has indurated small areas of sediments. No metamorphism has been produced by severe folding or deformation. Although the folding is fairly complex in places, several structures are only moderately inclined, and relatively few have been fractured in the movement.

Many of the limestones in the Carboniferous and Triassic formations are highly fossiliferous, and appear to present a competent source for petroleum. Carbonaceous shales in the Phosphoria, Woodside, Tygee, and Wayan formations afford a source of petroleum if sufficient distillation has occurred at the proper places.

Suitable reservoir or containing rocks are plentiful from the Madison limestone to the top of the column, and the large number of interbedded shales gives assurance of an impervious capping rock overlying every conceivable reservoir rock in the area.

Suitable structures for trapping oil are fairly common in both the Wayan formation and in the older formations. The most favorable structures are domes such as Bald Mountain dome situated mainly in Tps. 3 and 4 S., R. 45 E, in McKoy Creek quadrangle; Big Elk dome, located in T. 2 S., Rs., 44 and 45 E., in Fall Creek, Grays Lake, and McKoy Creek quadrangles; Black Mountain dome found in Tps. 2 and 3 S., R. 45 E., in McKoy creek quadrangle and anticlines such as Fourth of July Ridge anticline which extends from T. 1 N., R. 41 E., in Hell Creek quadrangle through T. 1 N., R. 42 E., T. 1 S., Rs. 42 and 43 E., to T. 2 S., Rs. 43 and 44 E., in Fall Creek and Grays Lake quadrangles and the Meadow Creek anticline located in T. 2 N., Rs. 41 and 42 E., and T. 1 N., R. 42 E., in Hell Creek quadrangle. The Wayan anticlines are looked upon as being less favorable than those mentioned because of the improbability of their containing a source of origin, and their apparent lack of congruency with structures in the formations which contain more likely sources of petroleum. Should oil be produced from any of the above mentioned structures some of the better Wayan structures will undoubtedly be tested. Fault-type structures similar to structures that have produced oil in many western states exist along the Snake River fault which extends through Fall Creek, Palisade Creek, and McKoy Creek quadrangles. In no event should these fault-type structures be drilled unless the domes and anticlines have been proven productive.

The reservoir rocks of the various structures are not filled with water to a very high degree of saturation, and for this reason, should oil exist in any of these structures, it seems probable that it will be found on the upper flanks and ends of the domes and anticlines rather than in the high points along their crests.

Sufficient closure for trapping oil is thought to be present in Meadow Creek and Fourth of July Ridge anticlines, and in Big Elk, Bald Mountain, Little Elk and Black Mountain domes. Little Elk dome is a part of Fourth of July Ridge anticline, and presents only a small amount of closure to the north, but insures closure for the entire anticline on its southern end.

All of the above mentioned structures have a sufficiently large drainage area to insure commercial accumulation provided oil exists in the underlying rocks in quantities frequently found in similar fields.

None of the surface indications listed in another part of this bulletin were noted in this area with the exception of carbonaceous shales which gave up relatively small amounts of liquid hydrocarbons upon distillation. The absence of surface indications, however, does not appear to the writer to be necessarily unfavorable to the area because many of the more recent oil fields of the western states have shown few, if any, of them. These surface indications, as has been said before, often show that oil has been escaping from such structures for a long enough time to dissipate much of the reserve.

In writing of the oil possibilities of southeastern Idaho, Mr. K. C. Heald,[13] a petroleum geologist of the United States Geological Survey, says:

> Oil, if present in southeastern Idaho, will probably be in Jurassic, Triassic or Carboniferous formations, although there is also a chance for oil in the Cretaceous. The southeastern part of Idaho is intensely folded and faulted and the fear that alteration of the oil has destroyed chances of success probably has deterred some prospectors from seriously considering operations in the State. However, such evidence as is available does not indicate that alteration has progressed so far as to seriously injure the chances for the persistence of oil. But few analyses of coals from southeastern Idaho have been published and these analyses are all of the Cretaceous coals. The average fixed carbon ratio appears to be about 56, but this may indicate little regarding the extent of alteration in the pre-Cretaceous formations.
>
> In short, Idaho contains enormous areas where there is no proof that oil is absent. In parts of the state anticlinal structure is known to exist in beds equivalent in age to strata that yield oil in the adjacent state of Wyoming. This folded region apparently has not been too far altered to prohibit the existence of oil in paying quantities.

In conclusion, the writer wishes to state that it is his belief that if oil is found in Idaho, it will be found in the southeastern part of the state, in the area described in this report, or in similar areas, adjacent to these quadrangles, many of which have been described in other publications. Most of the area described herein is underlain by formations at varying depths, accessible to the drill, which are equivalent in age, and correlated with, productive oil and gas horizons in areas throughout various fields of the adjacent Rocky Mountain states. The region may be rated as a prospective, or "wild cat" area, containing localities which justify testing but in which the business risk is relatively high, compared with that involved in drilling within a mile or two of producing wells on equally favorable structures. Such tests as the latter are not typical "wild cat" tests, and although presenting less risk may also return proportionately smaller gains.

Areas below the crests and along the upper flanks of the following structures are considered the most advisable for testing: Black Mountain, Bald Mountain, Little Elk Mountain and Big Elk Mountain domes and Fourth of July Ridge, and Meadow

Creek anticlines. Unless oil is found in some of these localities, drilling should not be prosecuted on other structures of the area.

It should be emphasized that in no case can the writer state with any degree of certainty that petroleum or natural gas will be found in any of the above mentioned structures. Observation and experience make certain, however, that the chance of failure, in an unproven area such as this, is greatly reduced by a selection of localities for drilling, based on proper geologic investigation. With this latter in mind, this bulletin has been prepared to point out to leaders of legitimate development, some of the areas in Idaho considered most likely, or certainly least unlikely, for the production of commercial petroleum.

THE IDAHO FALLS-BLACKFOOT PEAK AREA.

LOCATION.

This area comprises four townships lying adjacent to the city of Idaho Falls and to Blackfoot Peak of the Blackfoot Mountains; namely T. 1 N., Rs. 38 and 39 E., and T. 1 S., Rs. 38 and 39 E., lying in Bonneville and Bingham counties. The southern two-thirds of the two latter townships lie in the northern extremity of the Blackfoot Range and are consequently fairly rough and mountainous. Several high points in these townships exceed 7,000 feet in altitude. The rest of the area represents a sloping lava plateau dissected by rapid erosion, exposing lava covered mesas and table lands which tilt toward the great Snake river valley under which the lava flows dip. The mountainous areas are sparsely timbered and much of the region is a lava desert except where alluvium filled stream valleys offer an opportunity for small farms. All of the area lies within 20 miles of Idaho Falls, while some of it reaches within three miles of the city limits. Several well travelled roads make the area easily accessible from that city. Wolverine and Sand creeks, with their tributaries, drain the area and flow southwesterly to the valley of Snake River.

GEOLOGY.

Three reconnaissance surveys of this area have been made by geologists of the United States Geological Survey [12, 30, 22].

The field work in the present examination covered the first week of May, 1924.*

AREAL GEOLOGY.

The formations found at the surface in these four townships are included in the group of formations described in the six quadrangles discussed in other parts of this bulletin.

The formations exposed here are, in order of age, Madison limestone, Brazer limestone and Wells formation of Carbonifer-

*The general observations herein set forth have been submitted to, and accepted by, G. R. Mansfield in a personal communication.

ous age; Wayan formation of Cretaceous age; trachyte and basalt flows of Tertiary age and hill wash and alluvium of Quaternary age. Their lithologic and physical characteristics are as already described.

DISTRIBUTION OF THE FORMATIONS.

Madison Limestone (Lower Mississippian).
Brazer Limestone (Upper Mississippian).
Wells Formation (Pennsylvanian).

Great thicknesses of Carboniferous strata lie in certain parts of this area. No attempt was made to differentiate these formations for mapping purposes and only the outlines of the group were delineated. The determination of the Madison was not certain but the Brazer and Wells were definitely recognized. Although the Phosphoria has been reported and mapped as out-cropping in this area, it could not be recognized in the brief search for it made by the writer in this reconnaissance. The Carboniferous strata above mentioned lie to the west of the plane of an overthrust fault of considerable magnitude which is thought, by the writer, to represent the northernmost extremity of the Bannock overthrust fault, described in other parts of this bulletin. The areas where the Carboniferous strata out-crop are in the southwestern third of T. 1 S., R. 39 E., and the south half of T. 1 S., R. 38 E. The northern edge of these strata in the latter township is covered by overlapping trachyte flows, the southeastern edge is concealed by an embayment of basalt, and the slope of the country to the west takes the Carboniferous formations beneath the alluvium-covered basalt flows that make up the valley of Snake River at this point. In the former township the Carboniferous strata are masked by the encroaching trachyte flows from the north, and are terminated on the northeast and east by the fault plane which brings them into contact with the highly colored Wayan sediments. At the fault plane the Carboniferous strata dip to the southwest and west at angles varying from 35° to 45°. The Wayan sediments dip in the opposite direction at approximately the same angle.

Wayan Formation (Cretaceous).

This formation appears extensively throughout the eastern and northern part of T. 1 S., R. 39 E. and in three small areas along the southern edge of T. 1 N., R. 39 E., where it joins the former township. It is bounded on the west by the fault plane of the Bannock overthrust and the overlying Carboniferous sediments, on the north by overlying trachyte flows, and to the east, outside of the area, it disappears beneath the basalt of the Willow Creek lava field. The Wayan dips consistently in the same direction for a distance of approximately five miles. Near the fault the inclination approaches 40° to 45°, but at the eastern edge of the area the angle of dip averages about 30°. This vast monocline shows a thickness of this formation as great as that measured by Mansfield [30], in Caribou County, where he found a thickness of Wayan sediments, calculated to be 11,800 feet. Some of the higher ridges in this formation are capped by small patches of trachyte, which appears at one time to have covered the entire area.

No fossils were found in any member of this formation, but its lithologic peculiarities and the sequence of varicolored limestones, shales, and cross-bedded coarse sandstones is identical with the vast exposures of Wayan in the quadrangles lying adjacent to this area on the east. This area of Wayan is separated from the Wayan of Hell Creek quadrangle by a basalt flow of a few miles in width which appears to occupy a great syncline in these sediments.

Trachyte (Tertiary)—This lava shows the same rusty brown color and exhibits identical physical characteristics, including the variously sized vesicles, as the trachyte of the areas in the quadrangles to the east. It is obviously part of the same series of flows described there. It occupies all of the foothill region not covered by sediments already described and presents a typical mesa and "bad-land" topography throughout the area.

Basalt (Tertiary)—This lava occurs in the southwestern part of T. 1 S., R. 38 E., where it appears as part of the flow which occurs in the Blackfoot River valley outside the area. It was not studied in any detail.

Hill Wash and Alluvium (Quaternary)—This material is scattered along the bottoms of Sand, Henry, and Taylor creeks and covers the northwestern half of T. 1 N., R. 38 E., which lies in the Snake River plains. The small part of T. 1 S., R. 38 E., which is covered with this material, is included in these plains.

STRUCTURE.

Faults—The Bannock overthrust fault is believed to extend through T. 1 S., R. 39 E., of this area and has thrust Carboniferous strata, on the west side, into a position overlying the Cretaceous Wayan sediments. The vertical displacement here is several thousand feet and the horizontal displacement may be many miles.

Folds—The obscure end of one small anticline in the Wayan is covered with trachyte in its northern extremity and disappears under Carboniferous strata about a mile to the south. The rest of the structures in the area are monoclines.

CONCLUSION.

The discussion of oil possibilities and conclusions reached concerning these beds and these types of structures found elsewhere in this bulletin can be applied here without change.

SUMMARY.

The area examined comprises forty-six townships and is located in eastern Bonneville county, northwestern Bingham County, and northern Caribou County; it includes also a narrow strip in Wyoming. The railway points best serving the area are Idaho Falls on the west and Soda Springs to the southwest.

The topography is generally rough and mountainous with elevations ranging from 4300 to 9800 feet above sea level. The major part of the Caribou Range extends diagonally across the center of the area and accounts for the main structural features studied. The area also includes parts of the Blackfoot, Snake River and Bighole ranges. The country is fairly well drained and forested and contains among its most notable water bodies Gray's Lake, a part of Snake River, and numerous large streams and reservoirs.

A large portion of the region lies within the boundaries of the Caribou National Forest, and the remaining portion is open land used for stock grazing or dry-farm homesteads.

STRATIGRAPHY.

The sedimentary column of the area includes a large number of important and well-known formations, reaching the immense thickness of over 27,000 feet in many places, and including an almost uninterrupted sequence of sedimentation from the Carboniferous to the Cretaceous inclusive.

The formations are as follows: Madison limestone, Brazer limestone, Wells formation, and Phosphoria formation of Carboniferous age; Woodside formation, and Thaynes group of Triassic age; Nugget sandstone, Twin Creek limestone, Preuss sandstone, and Stump sandstone of Jurassic age; Ephraim formation, Peterson limestone, Bechler formation, Draney limestone, Tygee sandstone, and Wayan formation of Cretaceous age; Salt Lake formation of Tertiary age; and hill wash and alluvium of Quaternary age.

There is also evidence of considerable igneous activity.

Dikes, sills and central vents are found occasionally in the western part, and the northwestern portion of the area is overlain by rhyolite, trachyte, andesite, and basalt flows.

Intrusions of andesite, trachyte, diorite, syenite, gabbro, pegmatitic granite, and divers porphyritic types of the above occur at Mount Caribou. These intrusions have affected only small areas of sediments and are of Tertiary age.

STRUCTURE.

The structure of the area presents the most interesting features. A series of almost parallel anticlines and synclines extend throughout the region from the southeastern boundary to the northeastern limits and represent the dominant ridges and valleys of the Caribou Mountain system, thus making this group a structural range.

Many of these long anticlines are broken up into oval-shaped domes by undulations along their axes, whereas other anticlines and synclines are overturned, forming many fancifully shaped structures such as fan folds, isoclines and "swallow-tail" folds.

Because of the unevenness of erosion in this mountainous country, different beds make up the crests of the various folds; consequently each separate dome has an independent group of oil possibilities. Many of these folds are considered as having favorable conditions, but others are distinctly unfavorable in character.

The most likely of the favorable structures occur in rocks older than the Wayan formation. Some of these are Black Mountain dome, Bald Mountain dome, Big Elk dome, Little Elk dome, Fourth of July Ridge anticline, and Meadow Creek anticline. Anticlines in the Wayan are considered less favorable since that formation is of a thickness unlikely to be completely penetrated by a drill, has little chance of being a source for oil, and lies uncomformably on the older formations in such a fashion that structures in it are unlikely to coincide with underlying folds.

Four notable overthrust faults lie within the area, as well as a number of normal faults of great magnitude. Some of these have affected the oil possibilities in the area in a few places but are chiefly interesting from a scientific standpoint.

The country lies within a "petroliferous province" and the rocks were formed in "petroleogenic epochs". Much of the area conforms to the factors and conditions considered essential to a commercial accumulation of oil and natural gas. However, no oil seeps or saturated sands were noted throughout the entire examination. This may or may not be construed as an unfavorable indication. Most of the area is underlain by formations at varying depths, accessible to the drill, which are correlated with productive oil and gas series in areas throughout the various fields of Wyoming, Montana, and other Rocky Mountain states.

The area may be rated as a prospective or "wildcat" area. It includes structures which deserve testing, in which the business risk is relatively high but where there are good speculative chances. The chances for loss as well as the amount of gain would probably be much greater here than those involved in drilling on similar structures in a proven field.

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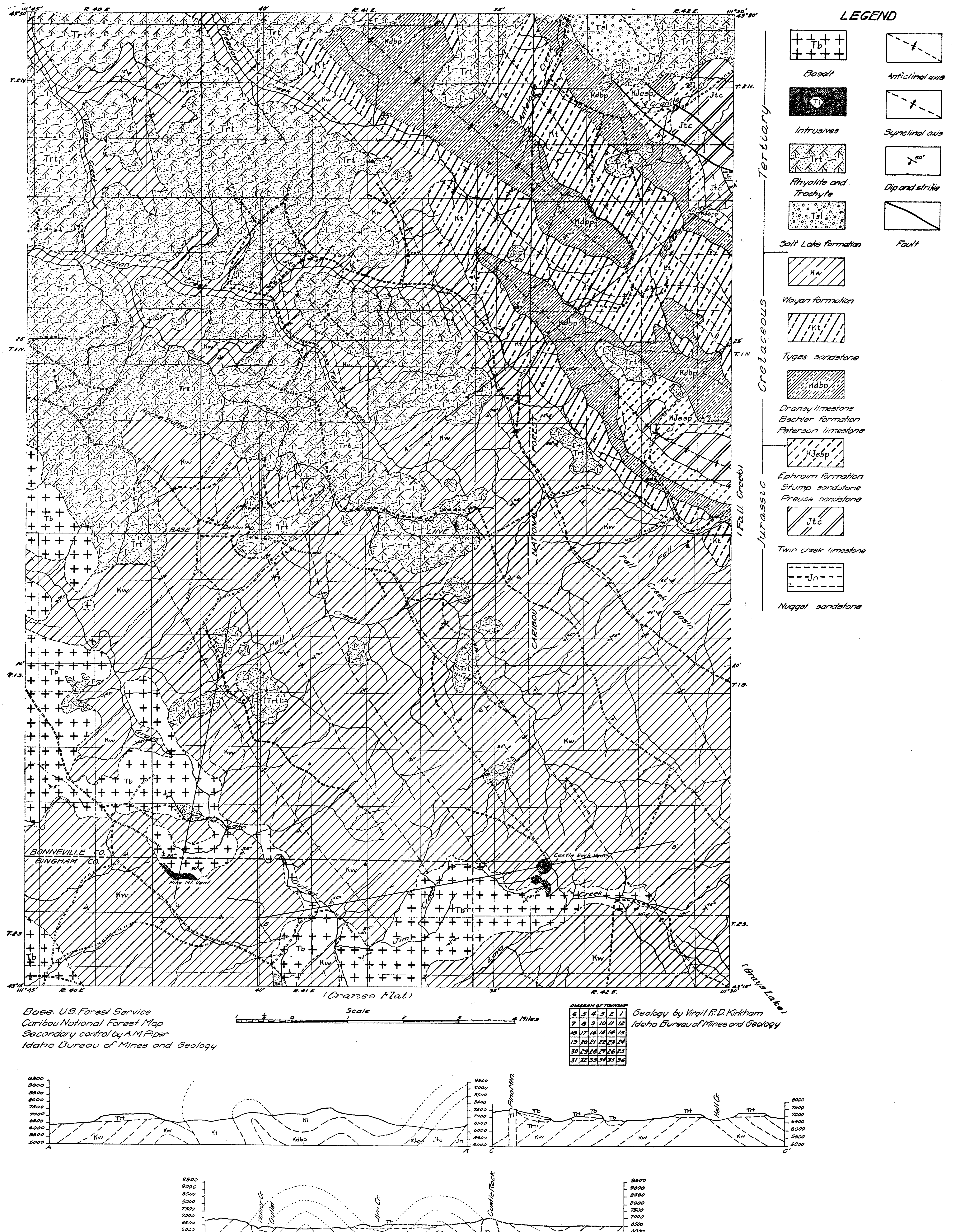

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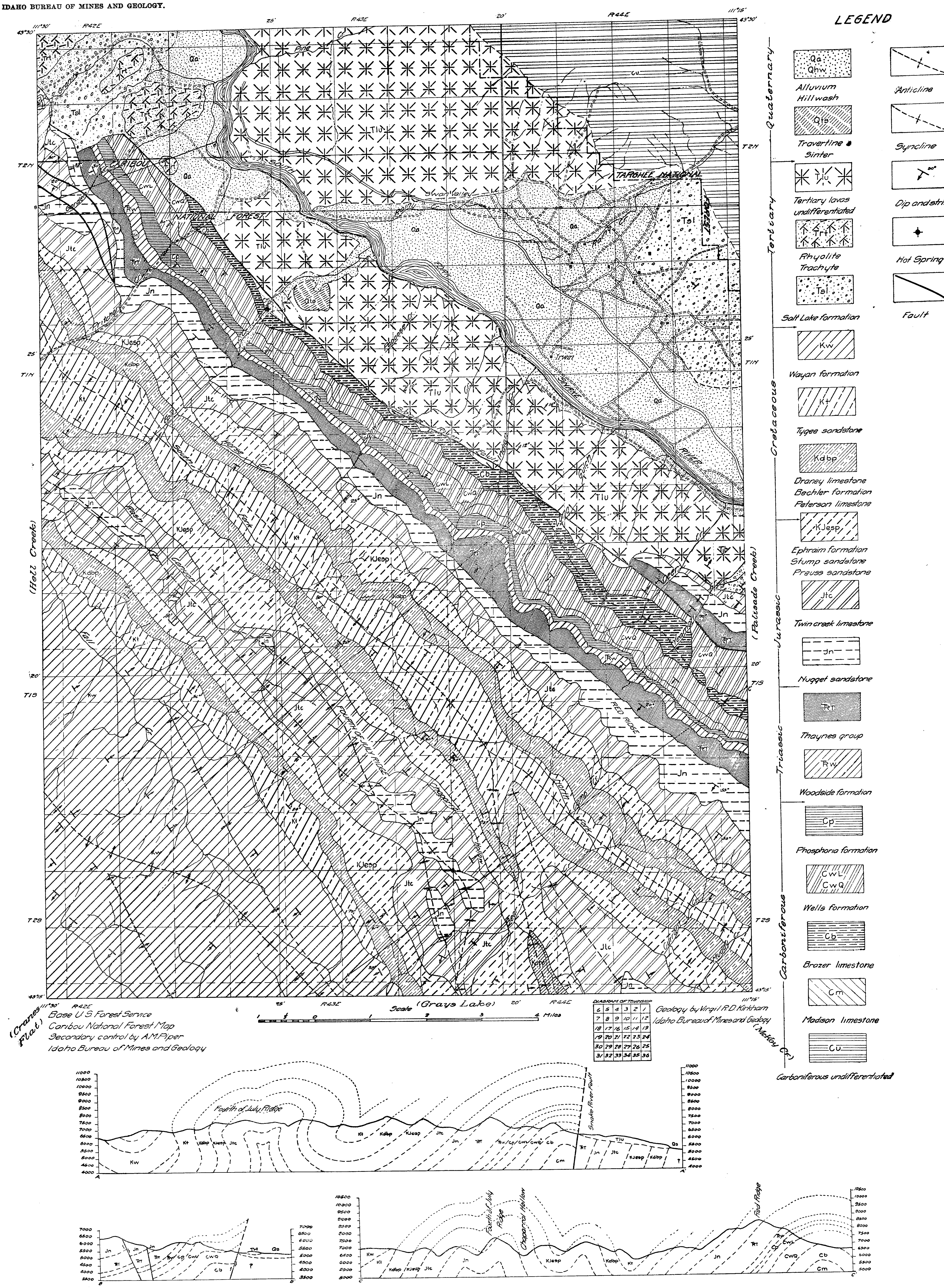

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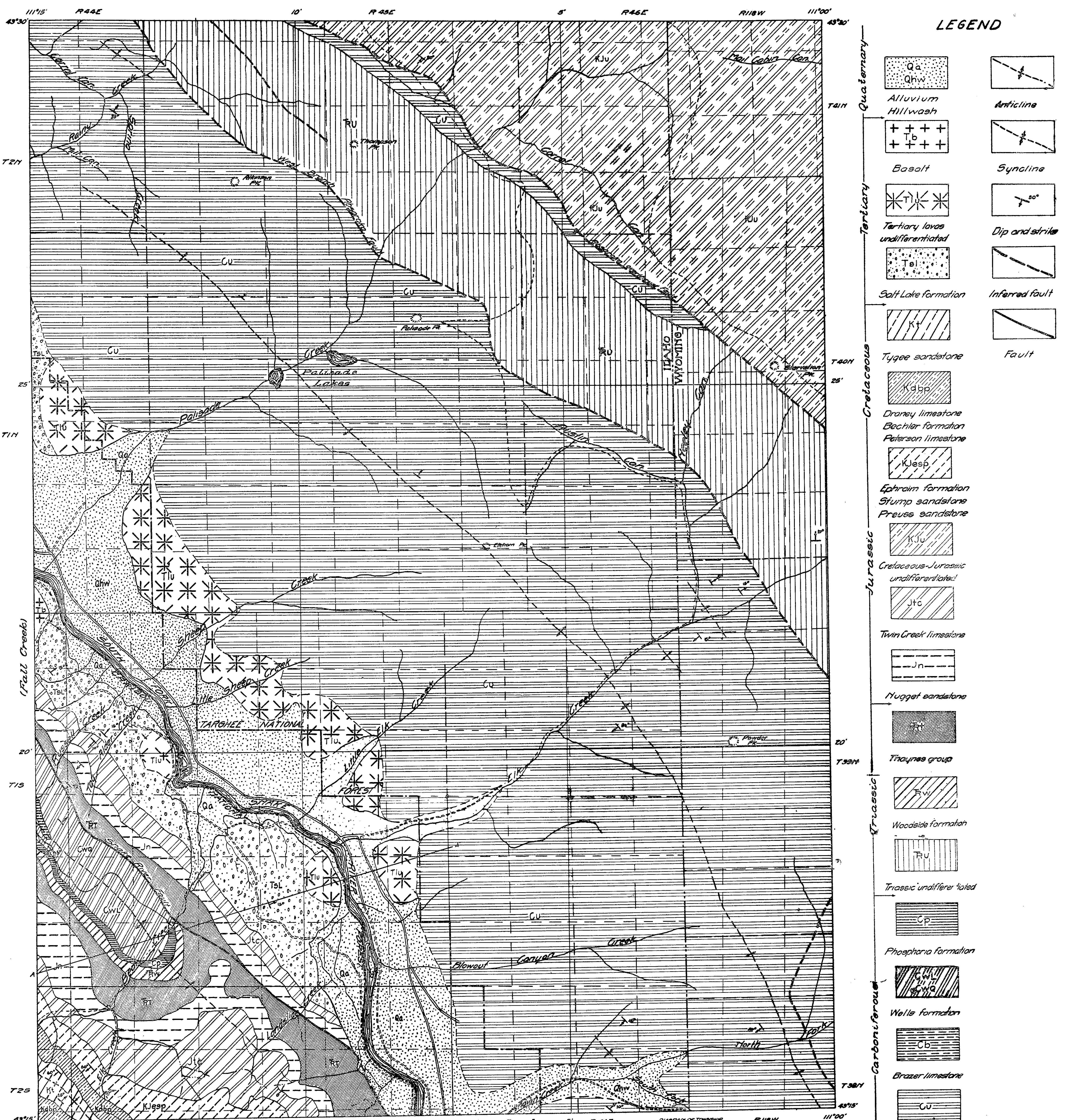

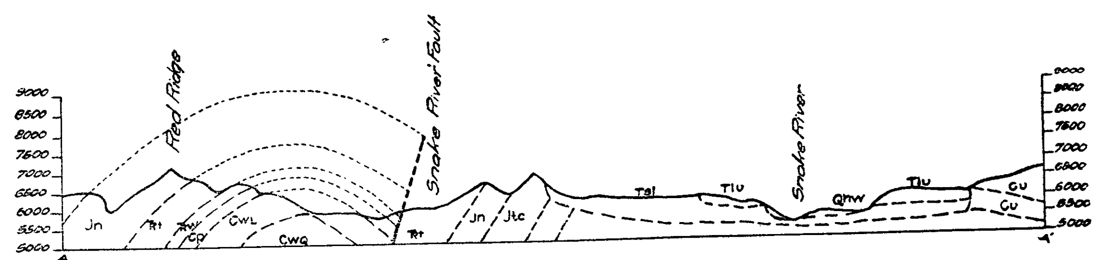

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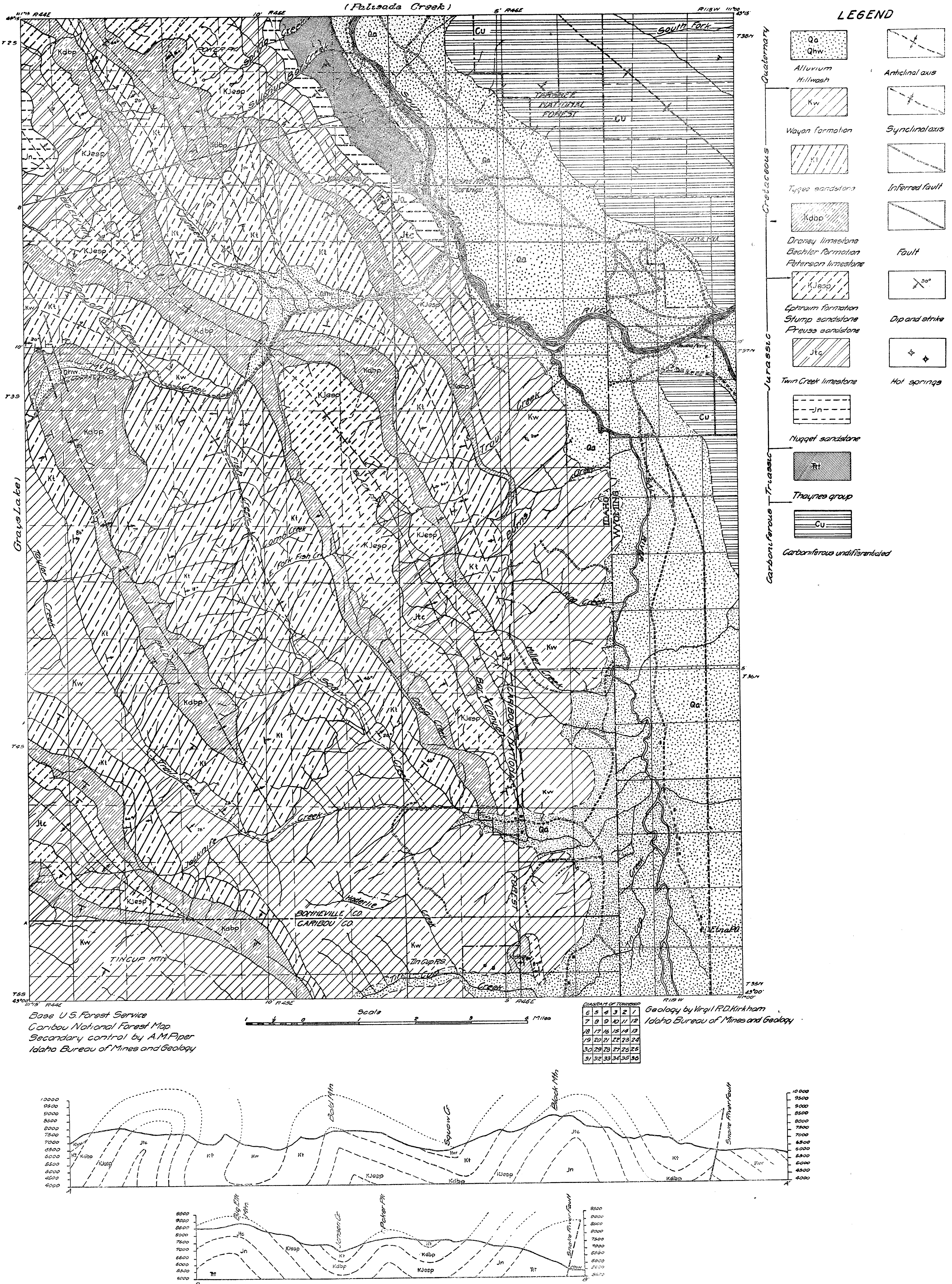

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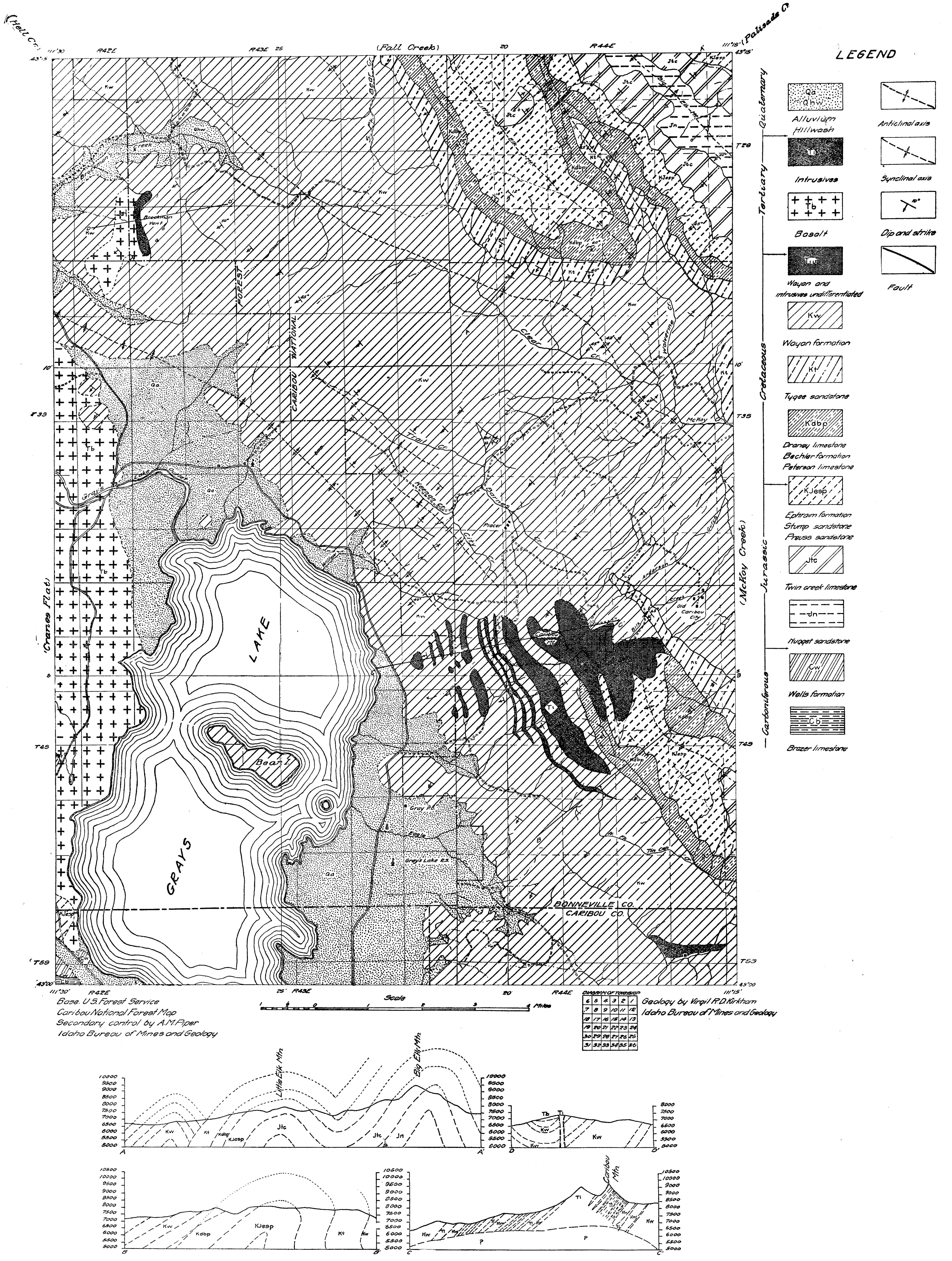

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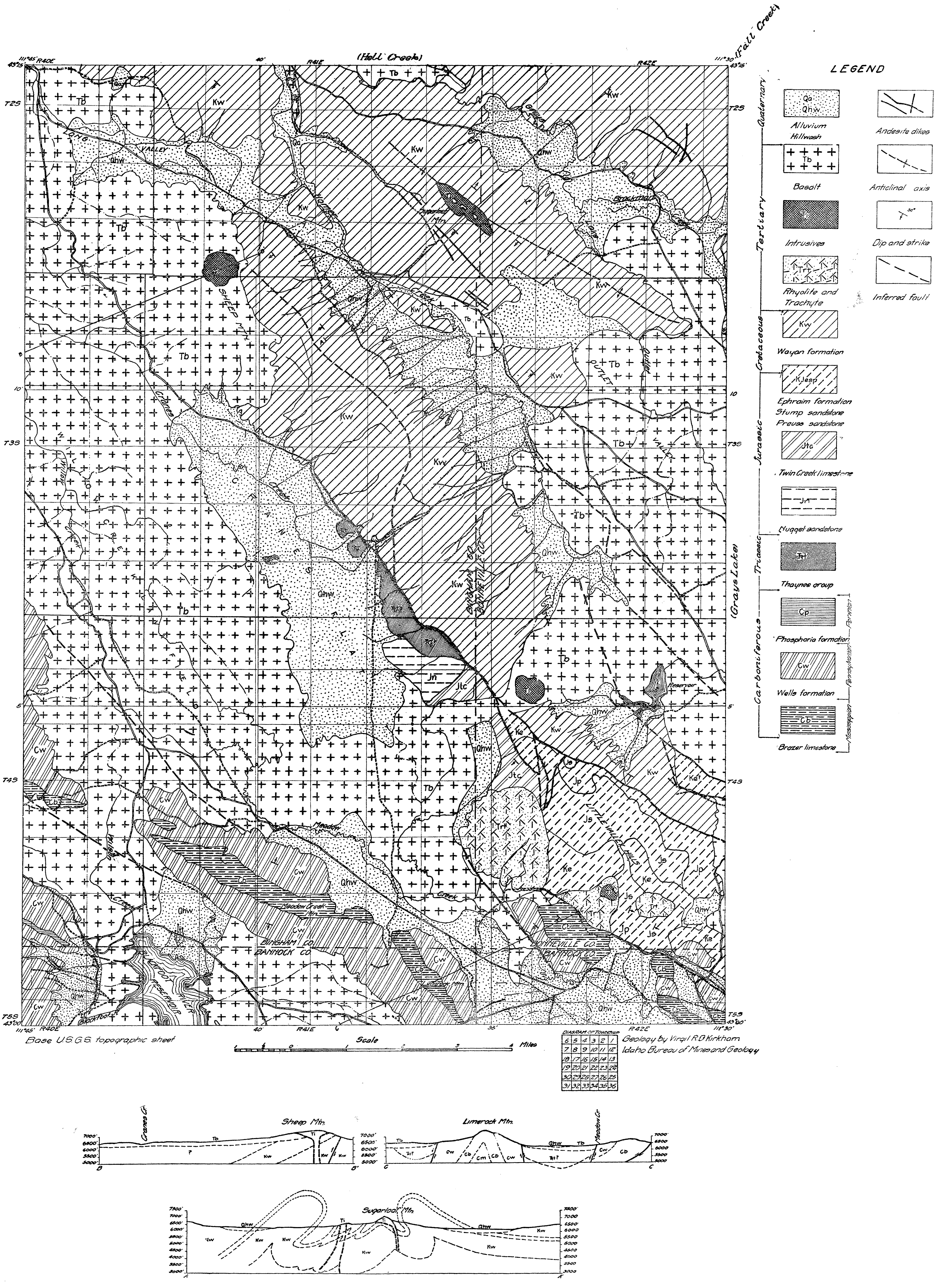

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