STATE OF MONTANA
J. Hugo Aronson, *Governor*

BUREAU OF MINES AND GEOLOGY
E. G. Koch, *Director*

BULLETIN 15
February, 1960

OIL AND GAS IN MONTANA

Revision of 1959

By

EUGENE S. PERRY

MONTANA BUREAU
of
MINES AND GEOLOGY

Butte, Montana

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ARTCRAFT PRINTERS

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By

EUGENE S. PERRY

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ABSTRACT

Montana has been self-supporting in her needs for oil and gas for many years, and the present reserves are far from being depleted. Furthermore, large areas still remain to be tested. Although not one of the major oil and gas producing states, Montana in 1959 produced 29,857,226 barrels of oil and 31,740,260 cubic feet of natural gas. Oil has been produced from 66 different fields as delineated by the State Oil and Gas Conservation Commission. Gas has been produced from 20 fields. The fields are widely scattered in the plains area of Montana east of the Rocky Mountains.

This report gives a brief history of oil development in Montana. The general geology and stratigraphy of central and eastern Montana are covered, and occurrence of oil and gas are described. Principal reservoir rocks are sandstone and limestone (or dolomite). Oil and gas have accumulated in anticlinal or domal structures, but the largest deposits occur in stratigraphic traps caused by lensing in sandstones, by decrease of porosity in sandstone, or by local development of porosity in limestone (or dolomite). Producing depths range from 400 feet (gas) near Havre to 12,600 feet (oil) in the Brorson field near Sidney. Descriptions of individual fields comprises the greater part of the report.

The report is a complete revision of a previous report issued as Memoir 35 in 1953.

PART 1. GEOLOGY OF OIL AND GAS OCCURRENCE

INTRODUCTION

Montana is 556 miles from east to west and 322 miles from north to south, and it has an area of 147,138 square miles, larger than the six New England states and New York and Pennsylvania combined. Its population in 1950 was 591,024. The western one-third is highly mountainous, geologically most complex, and has yielded metals valued at over four billion dollars; but most of this area is not considered even remotely favorable for oil and gas occurrence.

Central and eastern Montana lie in the western part of the northern Great Plains of North America. This part of the State is underlain by nearly horizontal strata favorable for oil and gas occurrence; excepting that, in central Montana, island-like mountain areas, in part of igneous origin, interrupt the continuity of the plains and the potential oil territory. The surface of the plains is not entirely flat or level, even though the underlying strata may be. Several large rivers and their tributaries have cut deeply (100 to 1,000 feet) into the rolling uplands, forming broad valleys bordered by gullied badlands. Only part of it has been critically examined, but most areas considered structurally favorable have been tested by the drilling of wells. However, obscure structures or possible stratigraphic traps remain to be found.

The purpose of this report is (1) to describe the general geologic conditions which influence oil and gas occurrence in Montana, and (2) to describe the different localities from which oil and gas have been produced in this State. It is hoped that such information will aid land owners who desire to lease or promote development of their lands for oil and gas prospecting, and also that it will aid producers, particularly producers from other states unfamiliar with Montana, in their search for oil and gas.

ACKNOWLEDGMENTS

Needless to say, much of this report is a compilation. The information was gained through a review of literature, through the courtesy of the many operating oil and gas companies and the practicing geologists within the State, all of whom have been most gracious. The writer would like to thank each contributor individually, but

space does not permit. Free use has been made of the many publications of the U. S. Geological Survey and the Billings Geological Society, and of articles in technical journals. Much information gained by personal observations of the writer is included, and it has been supplemented by references and personal interviews with other workers in Montana. Effort has been made to cite reference to vital information in the bibliography at the end of this report.

HISTORY OF MONTANA OIL DEVELOPMENT

The presence of oil in Montana was first made known in 1892 through oil-seepages found around Kintla Lake near the North Fork of Flathead River about 4 miles south of the Canadian border. This is on the west side of the first main range of the Rockies in what is now Glacier National Park, at that time in Missoula County. Oil was skimmed from pools of water. Many leases were taken in the next several years, and in 1901 a well was started. It ended in disappointment.

Again in 1901, strong seeps of oil were discovered along Swift Current Creek near the present site of Many Glaciers Hotel in Glacier National Park. Again an "oil boom" developed, and a well reported to have yielded 60 barrels per day was brought in during the spring of 1904. By 1906, it is reported, an area 60 miles long and 15 miles wide had been leased or claimed. Twelve wells were said to have been in operation of which five were said to have produced "Montana's first commercial oil" described as "high grade paraffin base." Production soon declined, wells were lost due to penetrating water, interest lagged, funds became exhausted, and the field was abandoned. Lake Sherburne, an artificial reservoir, now covers most of the well site.

These occurrences of oil were in an area directly underlain by the Precambrian Belt series of quartzites and argillites. However, the Belt in this area is thrust many miles eastward over Mesozoic and Paleozoic strata (Lewis overthrust); the fault plane, sloping westward at a low angle (perhaps 10 to 20 degrees), lies in the lower slopes west of Glacier Park station. The source of oil probably lies somewhere beneath the fault plane in Mesozoic or Paleozoic strata.

The history of Montana commercial oil and gas production dates from 1915, when oil was found in the Elk Basin field; Devil's Basin was discovered in 1919, Cat Creek in 1920, and Kevin-Sunburst in 1922. (See Description of Fields for the history of individual fields.) Oil production, of course, followed soon after discovery in each of the fields, the oil being refined into commercial products in or near the fields, or else shipped away in trucks or tank cars. Marketing of natural gas followed the building of pipe lines, most of which were laid between 1928 and 1931, to most of the larger cities in Montana and to adjacent areas in North and South Dakota. Between 55 and 60 percent of the people in Montana are supplied with natural gas, the remaining population being either rural or living to a large extent in smaller towns. The production of major oil and gas fields is shown in figures 2, 3, and 4.

Oil production in Montana prior to 1950 was confined essentially to three general areas: the northern fields, which lie between Great Falls and the Canadian border; the central fields, which lie within 50 miles east and southeast of Lewistown; and the southern fields, mainly south of Billings. Beginning with 1952, commercial amounts of oil were found in five widely spaced areas near the eastern margin of the State. By 1958 the number of producing areas in eastern Montana had been increased to 23, and this region now is being developed into a major oil-producing region. Between the areas of oil production are extensive areas, 50 to 150 miles across, in which some prospecting has been carried on, but in which commercial deposits have, as yet, not been found; still many areas of 500 to 1,500 square miles have had no test wells drilled within them. (See plate 15.)

Gas production in Montana has been confined to the northern fields, the southern fields, and the eastern fields; and of this in 1958, about 63 percent came from the northern fields. No commercial gas has been found in the central fields. (The Big Coulee-Hailstone gas field is considered as in southern Montana.) Of the grand total of all oil produced in Montana to 1959, 57.5 percent has come from the northern fields, 11.4 percent from the central fields, 11.5 percent from the southern fields, and 19.6 percent from the eastern fields. Geologically, 38 percent came from Mesozoic strata, 49.8 percent from Pennsylvanian and Mississippian strata, and 11.5 percent from Silurian and Ordovician strata (oil occurring in these formations only in the eastern fields).

In most of the oil fields, oil and gas are closely associated, either in the same geological formation or in different formations. In five fields gas occurs without known occurrences of oil, and in ten fields oil occurs without known occurrences of commercial amounts of free gas. In many fields gas dissolved in the oil escapes on production of oil, and in two fields such gas is marketed. Where dissolved gas is small in amounts, it is generally consumed in oil field operations.

Pertinent information concerning the different oil and gas fields is summarized in Tables 1 and 2, and the general location of the fields is shown on the accompanying map (fig. 1). The graphs (figs. 2, 3, and 4) show the growth and relative importance of the larger fields, and of this industry in the State as a whole.

Of course, oil and gas fields inevitably become depleted, and without new discoveries, the

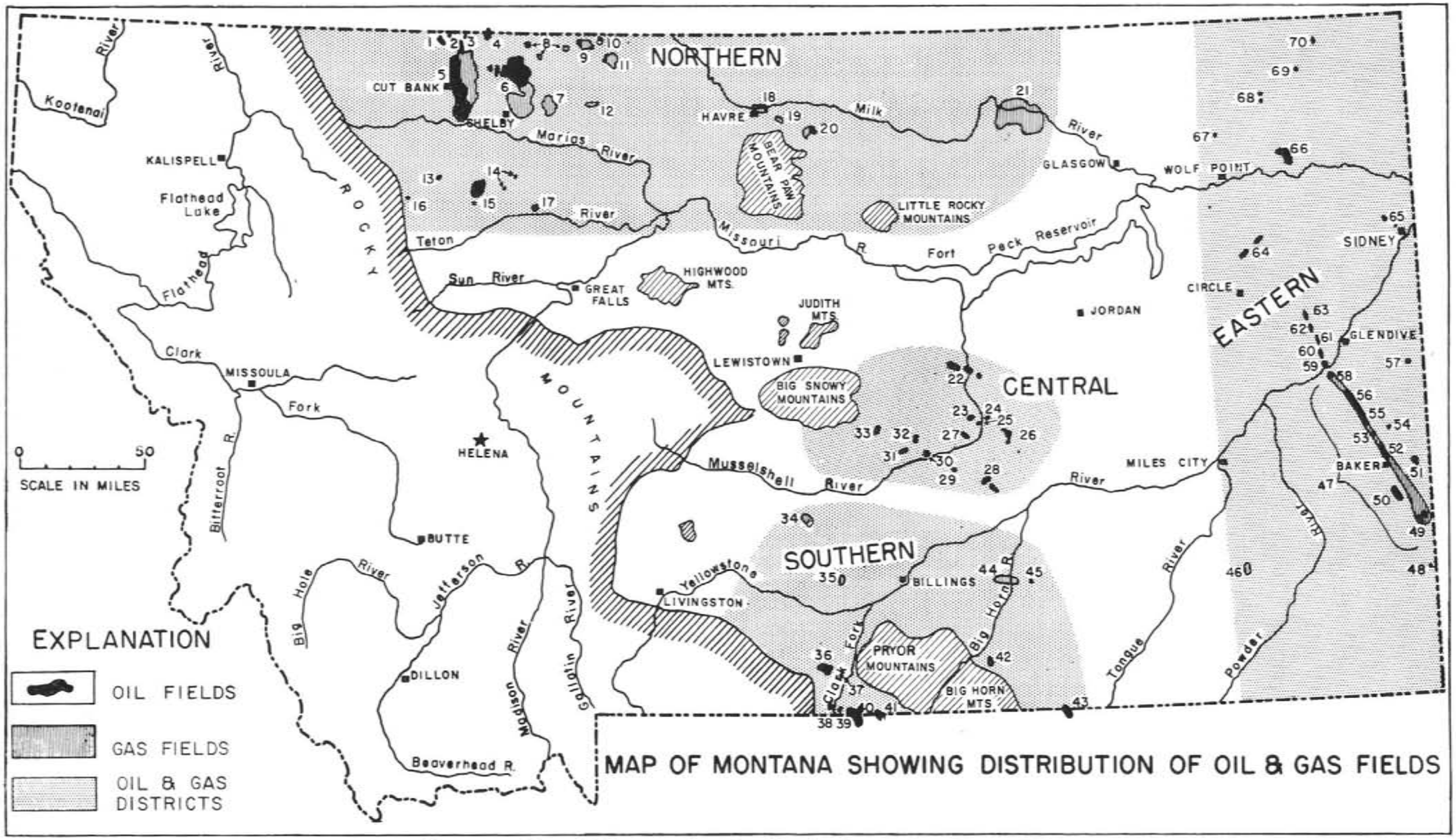

Figure 1.—Map of Montana showing distribution of oil and gas fields.

NUMERICAL

NORTHERN: 1 Reagan, 2 Blackfoot, 3 Red Creek, 4 Border, 5 Cut Bank, 6 Kevin-Sunburst, 7 Devon, 8 Bow and Arrow, Kicking Horse, and Apex, 9 Whitlash, 10 Flat Coulee, 11 Bears Den and Keith Block, 12 Utopia, 13 Gypsy Basin, 14 Brady-Midway, 15 Pondera and Bynum, 16 Blackleaf, 17 Bannatyne, 18 Havre, 19 Boxelder, 20 Bowes, 21 Bowdoin. CENTRAL: 22 Cat Creek, 23 Ragged Point, 24 Stensvad, 25 Ivanhoe, 26 Sumatra, 27 Melstone, 28 Wolf Springs, 29 Hawk Creek, 30 Delphia, 31 Gage, 32 Big Wall 33 Devil's Basin. SOUTHERN: 34 Big Coulee, 35 Lake Basin, 36 Dry Creek, 37 Golden Dome, 38 Belfry, 39 Clarks Fork, 40 Elk Basin, 41 Frannie, 42 Soap Creek, 43 Ash Creek, 44 Hardin, 45 Snyder. EASTERN: 46 Pumpkin Creek, 47 Cedar Creek, 48 Repeat, 49 Little Beaver, 50 Plevena, 51 Fertile Prairie, 52 Pennel, 53 Monarch, 54 Cupton, 55 Cabin, 56 Pine, 57 Wibaux, 58 Gas City, 59 Yellowstone, 60 Glendive, 61 Sand Creek, 62 Woodrow, 63 Deer Creek, 64 Richey, 65 Brorson, 66 Poplar, 67 Wolf Creek, 68 Bredette, 69 Red Stone, 70 Outlook.

ALPHABETICAL

Apex 8, Ash Creek 43, Bannatyne 17, Bears Den 11, Belfry 38, Big Coulee 34, Big Wall 32, Blackfoot 2, Blackleaf 16, Border 4, Bow and Arrow 8, Bowes 20, Bowdoin 21, Boxelder 19, Brady-Midway 14, Bredette 68, Brorson 65, Bynum 15, Cabin Creek 55, Cat Creek 22, Cedar Creek 47, Clarks Fork 39, Cupton 54, Cut Bank 5, Deer Creek 63, Delphia 30, Dry Creek 36, Devil's Basin 33, Devon 7, Elk Basin 40, Fertile Prairie 51, Flat Coulee 10, Frannie 41, Gage 31, Gas City 58, Glendive 60, Golden Dome 37, Gypsy Basin 13, Hardin 44, Havre 18, Hawk Creek 29, Ivanhoe 25, Keith Block 11, Kevin-Sunburst 6, Kicking Horse 8, Lake Basin 35, Little Beaver 49, Melstone 27, Monarch 53, Outlook 70, Pennel 52, Pine 56, Plevna 50, Poplar 66, Pumpkin Creek 46, Ragged Point 23, Reagan 1, Red Creek 3, Red Stone 69, Repeat 48, Richey 64, Sand Creek 61, Stensvad 24, Soap Creek 42, Snyder 45, Sumatra 26, Utopia 12, Whitlash 9, Wibaux 57, Wolf Creek 67, Wolf Springs 28, Woodrow 62, Yellowstone 59.

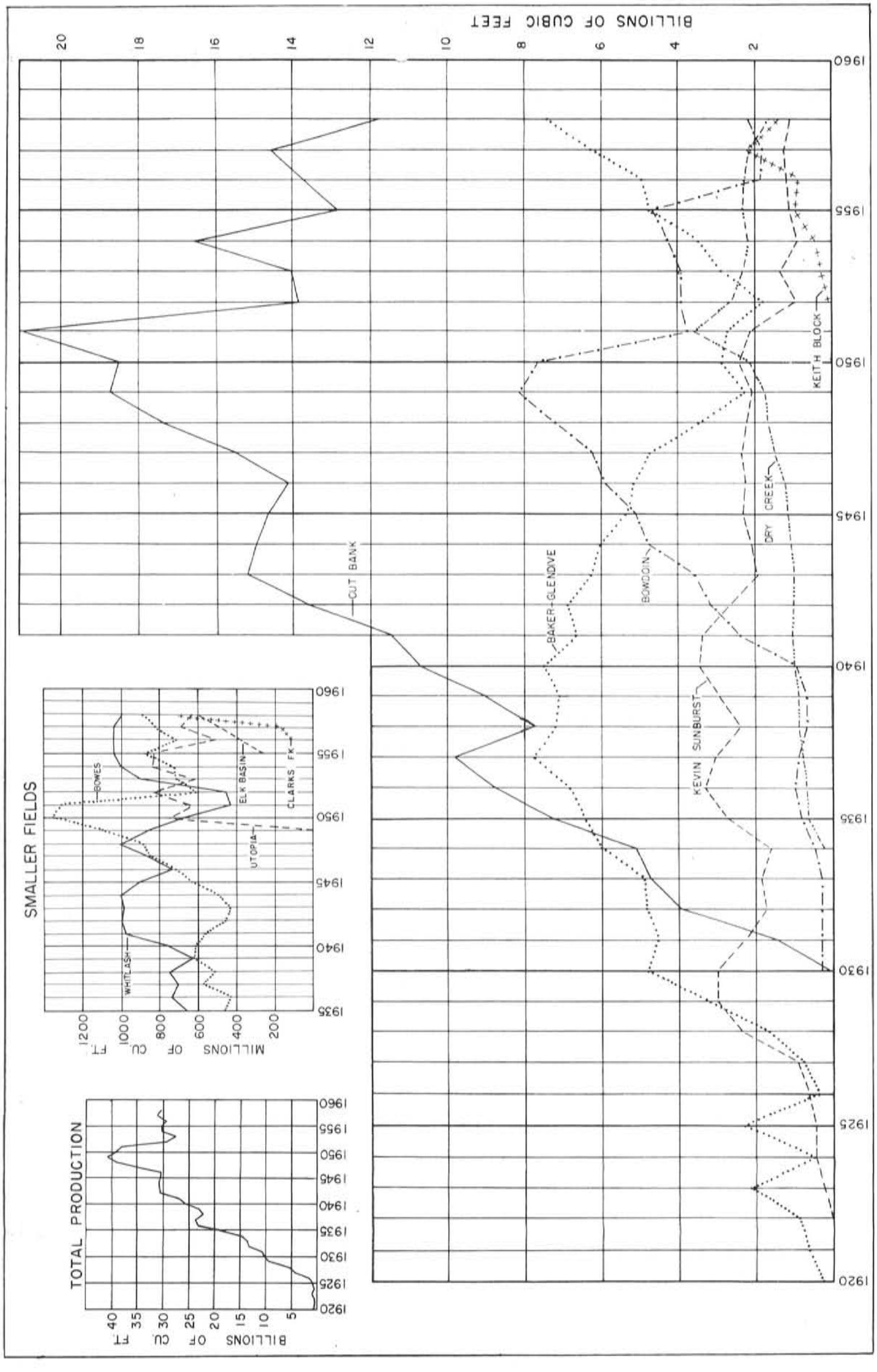

Figure 2.—Chart showing Montana's production of natural gas by years.

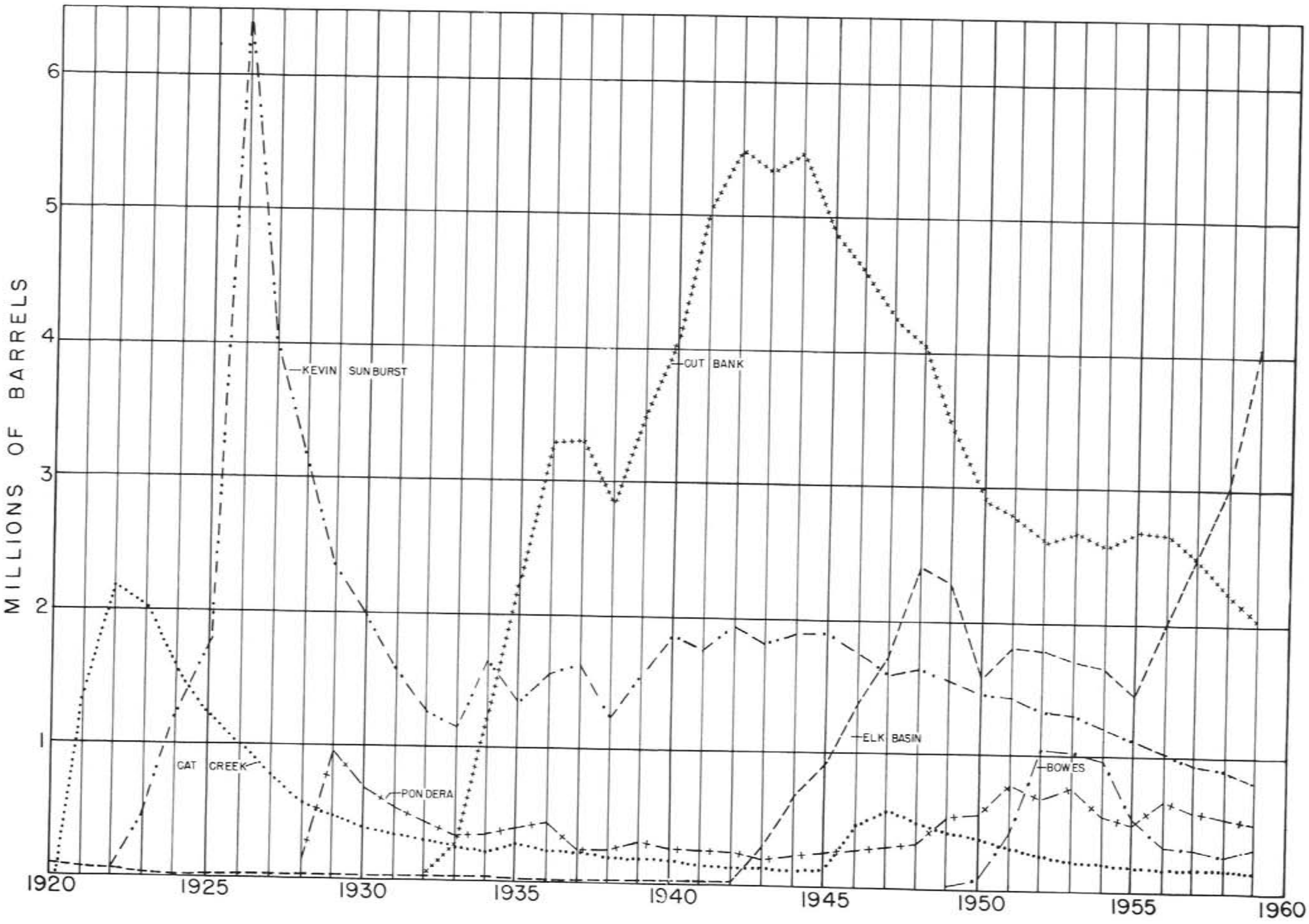

Figure 3.—Chart showing oil production of Montana fields that were principal producers prior to year 1950.

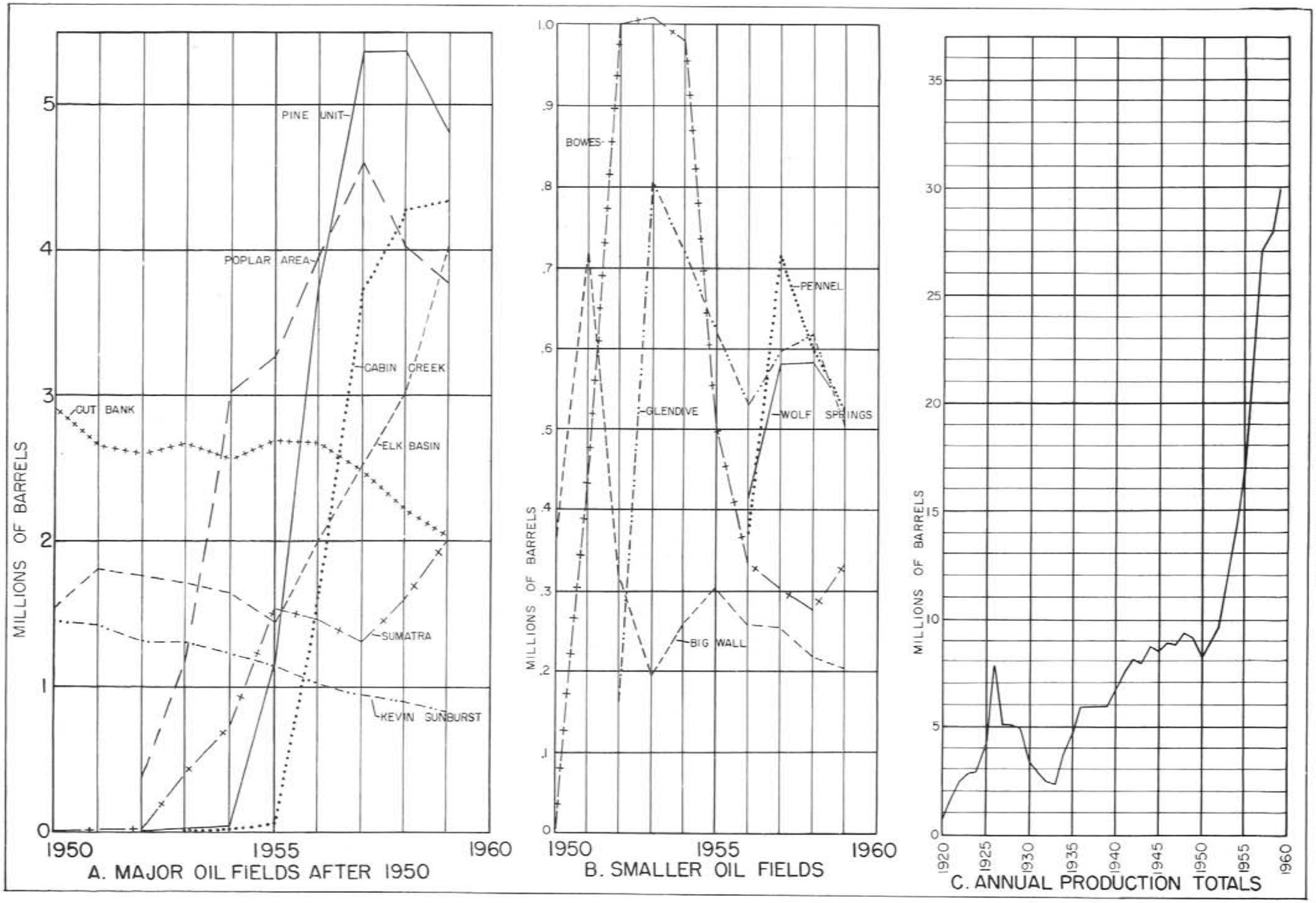

Figure 4,—Chart showing oil production of Montana fields after 1950.

time of need may possibly be within the lifetime of people now living. We may hope for new discoveries, such as those made in easternmost Montana in 1952. However, with the eventual exhaustion of the known oil and gas deposits, the potential manufacture of gas and oil products from the vast coal deposits of Montana is indeed comforting to the consumers of oil and gas as well as an alluring vision for the future to the coal producers of this region. Likewise, enormous quantities of oil shale are present in this State, and some will yield 20 gallons of oil per ton of shale. Coal deposits in Montana mainly east of the mountains, are estimated to exceed 222 billion tons.

GENERAL GEOLOGY OF MONTANA PLAINS

GEOLOGIC HISTORY

The geologic history of Montana prior to the Cambrian period has little or no bearing on the occurrence of oil or gas, excepting as structural features in the basal complex may be reflected into overlying strata, such as by movements in the basal complex after the younger strata had been deposited (Cedar Creek anticline, Big Snowy-Porcupine uplift). With renewed movements in fault zones or zones of weakness in the complex, the flexible shaly Mesozoic strata were bent into folds, and the more brittle Paleozoic limestones and dolomites were fractured as well as bent and folded.

The Cambrian sediments of Montana's plains were laid down on a metamorphic complex during the middle and upper parts of the period. Cambrian sediments in western Montana lie on quartzites, argillites, and impure limestone of the Precambrian Belt series and Precambrian gniesses and schists. Lower Cambrian strata are not recognized within the State. This condition indicates a widespread land surface in Montana at the beginning of Paleozoic time. The Cambrian seas, although of a transcontinental type, were widespread; and in them were deposited about 1,000 feet of sediments which occur with changing characteristics from carbonate rocks in western Montana to sandstones and shales in the east. (See figs. 6 and 7.) Cambrian sediments become thinner eastward. Near the close of the period the seas withdrew, and most, if not all, of Montana became a low-lying land mass which persisted into Ordovician time. The seas returned again in the middle part of the Ordovician period apparently coming in from the east and north, rather than from the west as did the Cambrian seas. Some Lower Ordovician strata (Whitewood formation) may be present in easternmost Montana. At first sands and muds were deposited (Winnipeg formation), to be followed by deposition of about 400 feet of dolomite (Red River and Big Horn formations). Ordovician strata have not been recognized in western Montana; if they were deposited there, and they probably were, erosion removed them prior to the Devonian period. Much of Montana, excepting the eastern part, appears again to have been a land surface throughout the Silurian period and the early part of the Devonian period because sediments of these ages have not been found, excepting that the Interlake formation of Silurian age extends about 100 miles west of the Montana-Dakota state line.

In Middle Devonian time most, if not all, of Montana was again submerged, and about 1,000 feet of limestone and dolomite known as the Jefferson formation was deposited. In eastern Montana about 1,000 feet of similar equivalent strata have been subdivided into several formations. (See plate 1, in pocket). Deposition of dark shale occurred at the end of the period (Three Forks formation). In northcentral Montana upper Devonian dolomite is interbedded with thick beds of anhydrite (Potlatch formation).

The Mississippian period began with all of Montana submerged, and the great thickness of crystalline limestone of the Madison group of formations was deposited during the first half of the period. In late Mississippian time, a large gulf or inland sea extended in a general east-west direction across central and esatern Montana and into the Williston basin, and the shales and sandy sediments of the Big Snowy group (Heath, Otter, and Kibbey formations) were laid down. In westernmost Montana a thick series of limestones (Brazer formation) was deposited at about the same time. The Mississippian period closed with widespread deposition of limestone (Amsden and Alaska Bench formations), and this condition persisted into the beginning of Pennsylvanian time in such a manner that the resulting carbonate rocks appear from fossil evidence to be of Mississippian age in the lower part and of Pennsylvanian age in the upper part. Although lithologically the upper and lower parts resemble one another, the lower part has been designated as Alaska Bench formation of Mississippian age, and the upper part designated as Amsden formation of Pennsylvanian age. An erosional unconformity occurs above the Heath formation and beneath the Alaska Bench formation in central Montana, and on this surface stream and/or shore-line deposits accumulated. These deposits have been important in oil production since 1950 (Tyler formation).

Sedimentation in Montana during Pennsylvanian time took place only in the first half of the period; and so far as known, it occurred essentially in the southern part of the State, except that the Amsden formation was laid down widespread over most of Montana. After the carbonate Amsden was deposited a notable change in type of sediments occurred; a widespread influx of clean white quartz sand resulted in the Tensleep and Quadrant formations of south-central and western Montana. In southern Montana wind-blown types of cross-bedded sands suggest nearness of shore line. In eastern Montana equivalent strata are limy and contain red beds (Minnelusa formation). After an interval of nondeposition the unique phosphate-bearing seas of Permian time spread over western Montana, but they are not believed to have reached the central or northern parts of the State. Permian sediments of a different type are found in south-central and eastern Montana.

The Paleozoic era ended with most of Montana a land mass, a condition which continued until the middle part of the Jurassic period. How-

TABLE 1—Montana Gas Production Data
(from Montana Oil and Gas Conservation Commission)

Field	County	No. of Wells	Producing Formation	1958 Production MCF
Bears Den	Liberty	2	Kootenai	31,933
Big Coulee	Golden Valley	6	Lakota-Morrison	659,287
Bowdoin	Phillips & Valley	367	Colorado	2,143,347
Bowes	Blaine	19	Eagle	886,086
Box Elder	Blaine & Hill	2	Eagle	19,551
Cabin Creek	Fallon	—*	Siluro-Ordovician	789,456
Cedar Creek	Fallon & Wibaux	232	Judith River & Eagle	5,387,597
Clarks Fork, North	Carbon	4	Lakota & Dakota	360,744
Cut Bank, incl. Reagan	Glacier & Toole	219	Kootenai	11,800,595
Devon	Toole	21	Colorado	191,518
Dry Creek	Carbon	6	Cretaceous	1,627,297
Elk Basin	Carbon	2	Tensleep	590,846
Flat Coulee	Liberty	4	Kootenai	309,301
Golden Dome	Carbon	1	Greybull	37,596
Hardin	Big Horn	48	Frontier	50,502
Keith Block	Liberty	5	Sawtooth-Madison	1,451,141
Kevin-Sunburst	Toole	72	Kootenai	1,003,600
Pine	Wibaux & Prairie	—*	Siluro-Ordovician	993,045
Plevna	Fallon	29	Judith River	216,589
Utopia	Liberty	6	Sawtooth-Ellis	619,537
Whitlash	Liberty	42	Colorado	1,058,633
Miscellaneous				737,052
TOTAL all Fields		1,087		30,965,253

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*-Gas produced from oil wells

ever, early in Triassic time marine seas reached northward from the south into southwestern and southeastern Montana. In the south-central part of the State, desert conditions left the brillant-red sandy beds of the Chugwater formation, the lower portion of which may be considered late Permian in age.

Preceding the marine submergence of Montana in Late Jurassic time when the Ellis (Sundance) strata were deposited, this region was subjected to slight upward tilting upward to the north, and strata from Mississippian (Madison) to Middle Triassic age were beveled by erosion. For this reason the Ellis group, which lies on the upper part of the Madison limestone in northern Montana, lies on successively younger strata southward until near the Wyoming line it lies on the red beds of the Chugwater formation of Triassic age. This erosion surface has had a profound influence in oil and gas occurrence and exploration, as will be discussed later.

Jurassic time ended with all of Montana a land surface which persisted on through much of Early Cretaceous time. River-laid sands and muds, much of which are distinctly red, accumulated, thereby forming the Morrison formation of Jurassic age. The Kootenai (Cloverly) formation of Early Cretaceous age overlying the Morrison appears to be near-shore deposits, land-laid to the west, but probably lagoonal, estuarine, or beach deposits over much of Montana, under conditions formed by advancing seas coming in from the south and east. Extensive lacustrine limestone in the upper part of Kootenai strata of western Montana tells of a large fresh-water lake. A highland, perhaps mountainous, lies to the west, perhaps in Idaho, as indicated by the presence in western Montana of coarse Kootenai conglomerates in which cobbles 6 or 8 inches in diameter may be present. The advent of these Early Cretaceous seas initiated the deposition of the great thickness of black shales of the Colorado group, the lower part of which is now considered Early Cretaceous in age (up to and including Mowry).

With the beginning of Late Cretaceous time, all of eastern and central Montana was covered by this inland sea which extended from the Gulf of Mexico to the Arctic Ocean. About 2,000 feet or more of shaly sediments of the Colorado group of formations accumulated. A short line, no doubt irregular in pattern, extended in a north-south direction across western Montana; however, the position of the shore was not constant throughout the period. The latter half of Late Cretaceous time, during which 2,000 to 3,000 feet of the Montana group of sediments were deposited was characterized by eastward recessions and westward advances of this great sea across central Montana. During retreats the sandy Eagle and Judith River formations were laid down largely as terrestrial deposits, and during advances the Claggett and Bearpaw marine shales were deposited. The shore lines alternately migrated from about the central part of the State to the western part of the State. It is noteworthy that during this time sediments accumulated regardless of whether land or sea conditions prevailed. Thus the Eagle and Judith River formations are terrestrial or coast line deposits in west-central Montana and their equivalents in eastern Montana are marine.

Uplifting of the Rocky Mountains began near the close of the Cretaceous period and continued into early Teritary time (Late Cretaceous, Paleocene, and early Eocene). This was the first major deformation of the strata since Precambrian time. It is noteworthy that all Paleozoic and Mesozoic strata are so nearly parallel that angularity between beds cannot be readily observed, notwithstanding erosional gaps which may involve one or more geologic periods. With the advent of the mountains in western Montana the Cretaceous seas withdrew from all Montana, never to return again. Central and eastern Montana remained a monotonously level lowland, a piedmont plain on which outwash from the mountains accumulated, resulting in the development of the Hell Creek (Lance)*, Fort Union, and Wasatch formations. Coal swamps were numerous, extensive, and occurred repeatedly with the upbuilding of the plain. This land surface, although interrupted by the rising of the localized mountains of central Montana, eventually matured into the surface of Montana of today. From place to place the surface is blanketed by high-level stream gravel, by outwash from late-rising mountains, and by glacial drift.

The geologic history of the Rocky Mountains is indeed complex, and involves more than one period of deforation. The early stages of mountain making were compressional, and the Paleozoic and Mesozoic strata were intensely folded and faulted. During a later stage (mid Tertiary), huge blocks of the earth many miles across were shifted vertically, in many places along nearly vertical faults. It was during this later stage that huge lakes were developed by block-faulting and local uplift; and in valleys up to 30 miles wide and 50 miles or more in length lacustrine deposits accumulated in excess of 1,000 feet thick in some places. The draining of the lakes by processes of erosion resulted in the extensive intermontane valleys of western Montana which are as characteristic of this region, although not as spectacular, as the mountains themselves.

DESCRIPTION OF FORMATIONS

Eastern and central Montana, constituting the plains area of the State, is a region more than

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*The name Lance is no longer used in Montana. In this report, the formation name "Hell Creek" will be used instead of "Lance" as in Memoir 35.

400 miles long and 275 miles wide. It is so large, and geologic conditions are so different in different localities, that statements concerning stratigraphy in one part may not apply to other parts. Consequently, for detailed descriptions of the succession and character of strata in any specific area, the reader is referred to descriptions of fields in the latter part of this report, and to references cited in the bibliography. However, general descriptions of the different formations, their lithology, distribution, thickness, and nomenclature should be helpful in an understanding of the stratigraphic geology of this region as a whole.

The strata exposed at the surface in the plains region, excepting for seven local island-like mountain areas, are all of Tertiary and Cretaceous age. Total thickness of the sedimentary rocks overlying the Precambrian metamorphic rocks ranges from about 5,000 to 14,000 feet, depending on locality. Thickness of formations differs much from place to place. Total thickness of strata of Tertiary age is generally about 1,000 feet, but it may be more; of Cretaceous age, about 3,000 feet; and of Jurassic age, 200 to 600 feet. Strata of Paleozoic age range from 3,000 to 6,000 feet in thickness. A well in the Brorson field near Sidney was drilled to 12,671 feet, but did not reach Cambrian strata.

In lithologic character Tertiary and Cretaceous strata are essentially shale and sandstone with a large predominance of shale. The Paleozoic strata are essentially limestone and dolomite, but occasional thick zones of shale are present, and a few zones of sandstone occur in some areas. Anhydrite and common salt form an important part of some formations. One confusing condition in correlation of formations is that an individual formation may be sandstone (or limestone) in one area but may grade laterally in some other part of the State into another type of rock, such as shale. The same formational name may or may not be retained for the two lithologic types. Lateral graduations from marine to terrestrial types of rocks occur, particularly in Upper Cretaceous strata. Also confusing is the wedging out and disappearance of thick formational units, resulting in several large unconformities.

The strata of the plains have been warped into great rolling folds and then truncated by relatively recent erosion. This results in different formations being exposed in different localities. Tertiary and the upper part of Cretaceous strata are not present in all parts of the plains because of removal by erosion.

The occurrence of commercial deposits of gas is largely confined to strata of Cretaceous age; but much gas, commonly, but not always, containing hydrogen sulphide, occurs in Paleozoic strata, particularly Mississippian strata. Commercial amounts of oil occur in Cretaceous, Jurassic, Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician strata. The succession of geologic formations in Montana, and their relationship to formations in other localities, are shown in Plate 1 (in pocket) and the occurrence of oil and gas in the sequence of formation in various oil and gas fields is shown on figure 5.

FORT UNION AND HELL CREEK FORMATIONS

The Fort Union and Hell Creek formations in Montana are not known to contain commercial amounts of either oil or gas; although within them, particularly in the Fort Union, occur most of Montana's enormous coal reserves (estimated 222 billion tons). These formations are of interest to the oil and gas industry in that they are at or near the surface throughout most of the eastern part of the State, and also they must be penetrated in drilling to deeper, older formations. Since these formations are youngest in the sedimentary series in Montana, they occur almost entirely in great structural basins; elsewhere, where uplift has been large, they have been removed by erosion. More of the surface of eastern Montana is directly underlain by the Fort Union formation than all other formations combined. Because of their general similarity, the Hell Creek and Fort Union may be described together in this report.

In older reports, the term Lance included the Hell Creek and Tullock members, and the term Fort Union included the Lebo and Tongue River members. Recently, the Tullock member was placed in the Fort Union formation, and the term Hell Creek formation is now used in place of the term Lance formation.

The time of deposition of these two formations had long been considered transitional between the Cretaceous and Tertiary periods. But because of the occurrence of Cretaceous dinosaurs in the Hell Creek formation, it would seem advisable to consider this formation of Cretaceous age. The Fort Union is generally considered by all to be of Tertiary age (Paleocene) because of the character of its plant and mammal remains. During the long period of uplift of the Rocky Mountains, which was accompanied by extensive erosion of the uplifted area, deposition of thick blankets of piedmont, flood plain, and river deposits took place east of the mountains. Beds of shale and sandstone in these deposits are irregular in distribution and thickness, as would be expected. Shale is dominant, color tones are from buff to tan or gray. As a whole the Hell Creek and Fort Union sediments are so similar that observers unfamiliar with them may have trouble distinguishing between them, even in the field; and it is practically impossible to distinguish between hand specimens from the two formations.

These formations are well described in the numerous coal reports of the U. S. Geological

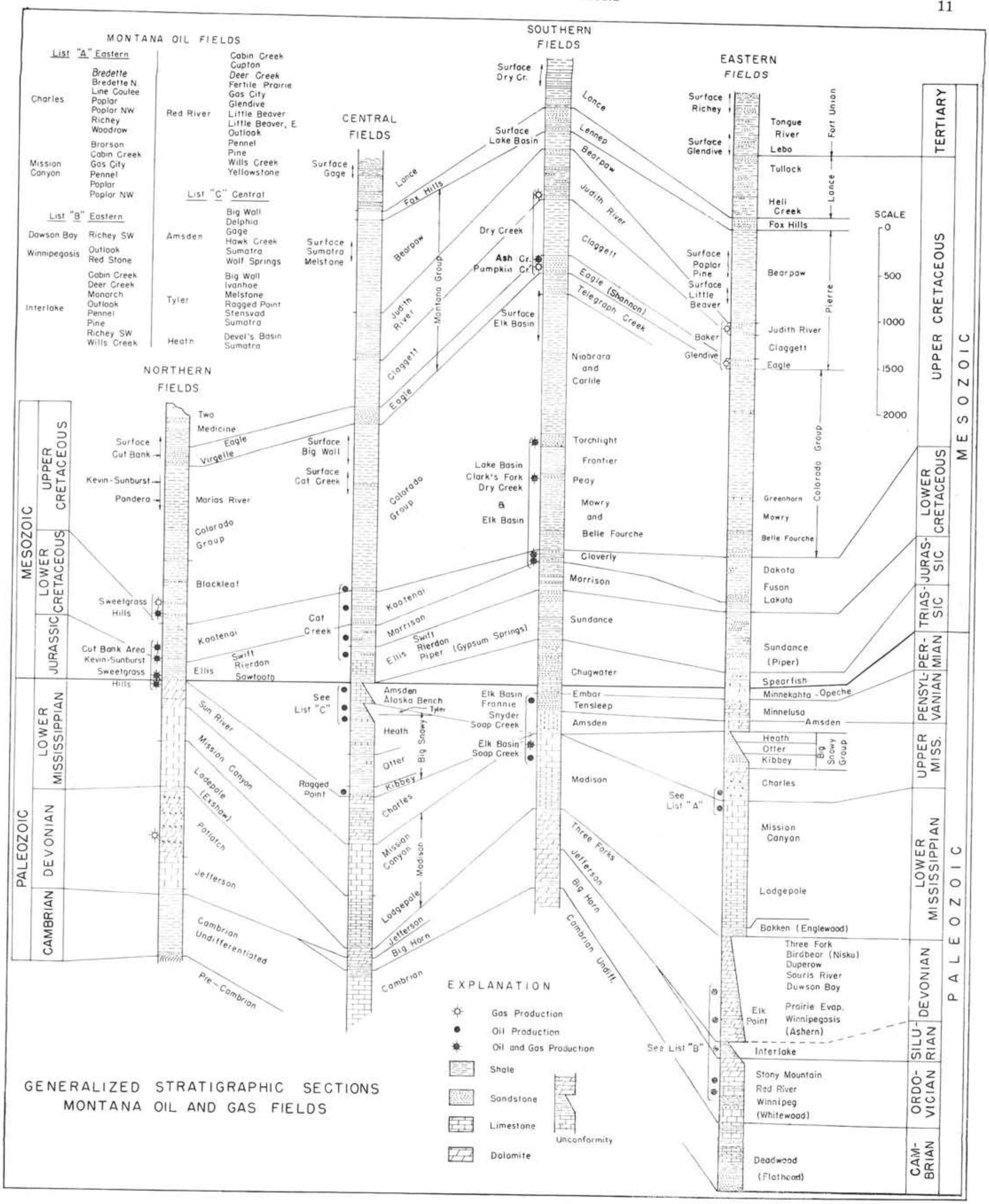

Figure 5.—Generalized stratigraphic sections, Montana oil and gas fields.

Survey dealing with parts of Montana (27 in number) and Wyoming, and those desiring detailed descriptions are referred to these reports. (See Bibliography.) The Fort Union formation has been subdivided, and subdivisions have been mapped. The Lebo shale member is a characteristic and a mappable unit about 200 to 300 feet thick separating the upper and lower sandy members, Tongue River and Tullock Creek respectivey. The Hell Creek has not been subdivided. Briefly, the Hell Creek and Fort Union may be described as a mass of somber-toned alternating beds of land-laid sandstone and shale (mainly shale) with occasional beds of coal, the total thickness of which ranges from 1,500 to perhaps 2,500 feet.

FOX HILLS SANDSTONE

Immediately below the base of the Hell Creek is a massive porous sandstone, 50 to 150 feet thick, known as the Fox Hills formation. It is persistent and easily recognizable in eastern Montana, the Dakotas, and parts of Wyoming and Alberta. Marine fossils are present within it in eastern localities. Its lithologic similarity to some of the sandstones of the Hell Creek, and its close association with the Hell Creek has caused some observers to consider it as a basal member of the Hell Creek; however, the U. S. Geological Survey considers it as a separate formation of Cretaceous age. West of Billings, a sandstone with olive-drab colorations at this horizon is known as the Lennep, and near Glacier Park the Horsethief sandstone is considered equivalent to the Fox Hills sandstone.

The Fox Hills is not known to be a reservoir for commercial amounts of oil or gas in Montana. It is an excellent artesian water horizon, as are several other sandstones in the Hell Creek and Fort Union, and it yields water to many of the flowing wells of southeastern Montana.

BEARPAW FORMATION

Throughout central and eastern Montana, stratigraphically underneath the Fox Hills sandstone, occurs the Bearpaw shale formation, a soft dark-gray gumbo-shale or clay-shale approximately 1,000 feet thick and remarkably uniform in both character and thickness. Such thin sandy zones as may occur locally are of little consequence either as horizon markers or as possible reservoirs for oil, gas, or water. Zones of large ball-like calcareous concretions and thin beds of bentonite are common within the formation. About 300 feet above the base is a persistent bentonitic zone in which the bentonite beds may becally be of commercial thickness, as near Hardin, Forsyth, and Malta. Surface structural mapping in areas of Bearpaw shale is either difficult or impossible because of lack of marker beds, although combinations of thin bentonite beds may be used locally. In places marine fossils are plentiful, and the cores of concretions may be highly fossiliferous. This shale is evidence of the last of the several large marine invasions which spread westward into central Montana in Cretaceous time. The western shore line of the Bearpaw sea was not far from the present front range of the Rockies. Upon approaching this shore line from the east, sandstone members appear, the proportion of shale to sandstone decreases, and finally the formation is scarcely recognizable as Bearpaw "shale". The formation contains much gypsum (selenite) in scattered crystals or nodules, and the gumbo soil developing by the weathering of the shale is highly alkaline. None of the shale is noticeably petroliferous. Eastward in the Dakotas the Bearpaw constitutes the upper portion of the Pierre formation.

Since no oil, gas, or water is known to occur within the Bearpaw, it would appear to be of interest to the oil and gas industry only as a formation that may have to be penetrated in drilling in certain localities.

JUDITH RIVER FORMATION

Beneath the Bearpaw shale occur 250 to 500 feet of alternating beds of sandstone and shale known as the Judith River formation. Locally, much greater thicknesses are reported. The formation is readily recognizable in outcrop and in well records throughout the central part of the state, even though the character and sequence of beds differ greatly from place to place. In fact this difference in sequence of beds is characteristic of the formation. In central Montana, exposures show a greenish to olive-drab cast due to arkosic character caused by eastward drifting of muds from the Livingston volcanics. Carbonaceous shales are common, and coal has been mined from the Judith River formation in north-central and northern Montana near Havre and south of the Little Rocky Mountains. Oyster beds, a few feet in thickness, with coal seams a short distance either above or below may be found in central and northern Montana almost as far west as the Rocky Mountain front. These beds make good horizon markers for structural studies. In central Montana the Judith River formation consists of sediments deposited near-shore on a north-south coastal plain with a sea to the east, the shore line of which shifted back and forth. Marine sediments, largely shale, accumulated in the seas at the same time that terrestrial sediments were accumulating on the coastal plain. Remains of dinasaurs occur within the Judith River formation in central Montana.

Southward in Wyoming the Judith River grades into the central part of the Mesaverde formation; northwestward it grades into the Two Medicine formation of the Glacier Park area, and into the Belly River series of Canada (pale beds and Foremost formation). All are similar in a general way. Eastward in Montana the amount and thickness of sandstone diminishes more or less gradually, and near the eastern Montana state line the massive sandstones found in central Montana do not occur. Those sandstone beds present are thin, even to a fraction of an inch, and interbedded with much shale or sandy shale. The equivalent of the Judith River formation in North and South Dakota is in the middle part of the Pierre shale.

The sandstones of the Judith River formation are an important reservoir for gas in the Cedar Creek (Baker-Glendive) field, and they have contributed most of the gas produced in that field. Gas also occurred in these strata in the Dry Creek field, and to a limited extent in the Havre-Chinook area. Commercial amounts of oil have not been found in this formation in Montana. In most of the fields in the central and northern parts of the State this formation has been removed or is deeply dissected by erosion. Elsewhere, where it is under cover, numerous test wells have penetrated it. A strong artesian water circuit is present in the formation in the central part of the state where the sandstones are massive. The water in the 75 or more flowing wells drilled along the Missouri River prior to the building of the Fort Peck dam, and water from flowing wells along the Milk River comes from this formation. It generally yields water elsewhere.

CLAGGETT FORMATION

The 500 to 600 feet of plastic shale of the Claggett formation underlying the Judith River beds tell of a marine invasion from the east which in most respects was similar to that which resulted in the laying down of the Bearpaw shale. The strata of these two formations are so similar that they are distinguished by most geologists only by field relationship. The shore line of the Clagget sea appears to have been 25 to 50 miles farther east than that of the Bearpaw sea. Well-developed sandstones begin to appear within the Claggett in west-central Montana, as at Harlowton, and become increasingly pentiful westward. The Claggett merges into the Two Medicine formation near Glacier Park, the Belly River series of Canada, and the Mesaverde formation of Wyoming. Eastward it is equivalent to strata in the lower part of the Pierre shale of the Dakotas.

Oil or gas are not known to occur in the Claggett shale in Montana.

TWO MEDICINE FORMATION

Westward from Great Falls and Shelby the Claggett and Judith River formations and the upper part of the Eagle formation thicken and grade into about 2,000 feet of alternating beds of gray, greenish-gray, and slightly red clay and clay-shale with subordinate irregular and lenticular coarse-grained gray sandstone of terrestrial origin, a shoreward or coastal plain phase of sedimentation of Late Cretaceous time. They are grouped together as the Two Medicine formation. Thin coal seams are present in the lower part. Horizon markers are poor or lacking and geologic mapping in this area is difficult due to a covering of glacial drift and terrace gravel.

No oil or gas has been discovered in the Two Medicine formation.

LIVINGSTON FORMATION

Westward from Columbus and Harlowton the Bearpaw, Judith River, and Claggett formations grade into 4,000 to 5,000 feet of alternating beds of shale, sandstone, and conglomerate derived from volcanic (andesitic) material. Colors of red, purple, and green are conspicuous, but gray is dominant. Marker beds are practically absent. This is outwash material from the great group of Late Cretaceous volcanoes which were once present in what is now the mountain area of southwestern Montana; thick Lava flows occur along with water-laid volcanic debris near Whitehall and south of Big Timber. Northward in the region between Wolf Creek and Augusta, strata and lava beds similar or identical to Livingston beds lose their andestitic (volcanic) characteristics and merge into the Two Medicine formation.

The Livingston formation is not considered a likely place for commercial amounts of oil or gas, but it is important in that it affects the depth of drilling to underlying formations.

EAGLE FORMATION

Throughout most of central Montana the Eagle formation consists of an upper and lower massive sandstone with a 50-foot shale member between, the thickness totaling from 200 to 300 feet. A commercial coal seam occurs in the shale member west of Billings and east of Bozeman. Near Billings, Winnett, and Kevin outcrops are characterized by percipitous cliffs, in places 100 feet or more in height, formed mainly by the massive lower sandstone member. In northern Montana, this lower member is known as the Virgelle sandstone. In central Montana flattened chert pebbles which have a polished jet -black exterior are imbedded in a sandy matrix at or near the top of the Eagle, and this zone may serve as a horizon marker. East of a line approximately from Hardin to Malta, the Eagle becomes shaly, and in the Porcupine dome area north of Forsyth true sandstones at this horizon are not recognized; the shales of the underlying Colorado group appear to merge into the shale of the overlying Claggett without noticeable break, although Eagle sediments are present and recognizable by diligent search. This line marks the transition zone from terrestrial sediments to the west into marine sediments to the east. Marine fossils have been found both in the shaly and sandy sediments of east-central Montana. Farther east, near the eastern state line, the Eagle consists of a sandy zone containing thin sandstones interbedded with much shale near the base of the Pierre formation.

The Eagle sandstone is an important reservoir for gas in the Bowes, Boxelder, Havre, Lake Basin, and Dry Creek fields, and much gas has been produced from it in the Baker-Glendive field. Gas occurs in the Shannon sand, equivalent to Eagle, on Pumpkin Creek, south of Miles City. Eagle equivalent in Alberta, known as the Milk River sandstone, yields large quantities of gas in several fields. Oil has not been discovered at this horizon in Montana, except in the Ash Creek field on the Montana-Wyoming state line. The Eagle sandstone is deeply buried in much of central Montana and all of eastern Montana, hence it should always be considered as a potential reservoir for gas. In many localities west of Billings and Malta, the Eagle is an excellent carrier of good potable ground water.

TELEGRAPH CREEK FORMATION

Between the Eagle sandstone and the Colorado shale in central Montana from Canada to Wyoming occur 100 to 300 feet of alternating beds of slabby sandstone and shale considered transitional between these two formations. These transitional beds, now known as the Telegraph-Creek formation, commonly were grouped in the Colorado by earlier observers, but are now considered as the basal beds of the Montana group.

No oil or gas is known to occur within this formation in Montana.

COLORADO GROUP

Beneath the Eagle sandstone (or Telegraph Creek formation where present) are the dark marine shales with occasional sandstones of the Colorado group, total thickness of which is about 2,000 feet (1,800 feet in northern Montana, 2,400 feet in southern Montana). The shales are remarkable for their uniformity in lithologic character for distances greater than 500 miles. In Wyoming and extreme southern Montana, divisions within the Colorado are somewhat easily recognizable, and it has been divided into five formations.

The upper 1,000 to 1,200 feet, consists of black shale with a little sandy shale and zones of black siderite concretions and comprises the Niobrara and Carlile formations; in Montana they are not divided.

Near the middle of the Colorado group in southern Montana and Wyoming occur two important sandstone members 10 to 80 feet thick (Torchlight above, and Peay below) separated by about 300 feet of dark shale; these 400 feet or more of strata, known as the Frontier formation, are particularly important because the sandstones are prolific reservoirs for oil and gas in many localities.

Beneath the Frontier occur about 100 to 300 feet of black shale and some interbedded sandstone which constitutes the Mowry formation. Weathered exposures of the sandstones in central Montana develop thin slabs with a distinctive silver-gray color which may be recognized from a distance. Much of the black Mowry shale, which is petroliferous, is characterized by innumerable fish scales, about the shape and size of a small finger nail. They are conspicuous on bedding planes. Recently the top of the Lower Cretaceous rocks has been raised because of fossil evidence to include the Mowry, but lithologically the Mowry and some 500 feet of underlying strata would appear to be closely related to the upper strata of the Colorado group because of lithologic character.

The lower 600 to 800 feet of the Colorado of southern Montana, once known in Wyoming as Thermopolsi shale, is also a black fissile shale and is not distinctive. About 275 feet above the base is about 20 feet of sandstone known as "Muddy sand" by drillers, and it yields oil in some of the Wyoming fields. Equivalent strata in the Black Hills region may be known as Graneros or Belle Fourche.

In central and norther Montana, divisions in the Colorado are not easily made because of the great predominance and similarity of the dark-gray and black shales, and because of the lack of easily recognizable and persistent horizon markers. The group is generally considered as a single unit, both by operators and geologists. Sandstones are present at different positions and in different localities within the shale mass, and some are mappable units for distances of 25 miles or more—for example, the Big Elk sandstone near Harlowton. These different sandstones are given local names, such as Mosby sand in the Cat Creek field, and Bowdoin sand in the Bowdoin-Saco gas field. The fish-scale zone of the Mowry is well developed and continues northward into Canada, and southward into Wyoming. Many beds of bentonite are present, and one at about the Mowry horizon is particularly well developed and persistent between Lewistown and Great Falls as well as south of Billings and in southeastern Montana. It is worked commercially in Wyoming. Large ball-like calcareous concretions up to 3 feet in diameter occur singly or in zones at different places in the shale. North and northwest of Great Falls the lower 600 to 700 feet of the Colorado, essentially dark marine shale, contains sandstone beds 20 feet or more in thickness, and this unit is known locally as the Blackleaf sandy member. Sandstone in this unit yield oil and gas in the vicinity of the Sweetgrass Hills of northern Montana. Recent studies in the Sweetgrass Arch region have caused a division of the Colorado group into an upper Marias River formation, and a lower Blackleaf formation with 4 members in each, the members being given local names. These members, recognizable throughout the Arch region, aid in structural determinations.

A basal sandstone at the bottom of the black shale series is generally present. In central Montana it is known as the First Cat Creek Sand, and it yields oil in the Cat Creek field. Lithologically it resembles sandstones in the underlying Kootenai formation.

In general, the Colorado group is a thick series of dark shales with some sandstone members laid down in perhaps the most extensive and lasting marine invasion of Cretaceous time in North America. The western shore line was probably in western Montana, but no doubt it was irregular, and it advanced and retreated in the western part of the state from time to time. The shales of the Colorado are petroliferous, and yield appreciable amounts of oil by distillation tests, some samples having been reported to yield "one to two gallons of oil to the ton." It is quite probable that the great quantities of oil and gas found in the sandstones of the Colorado group have had an origin in the black shales of this series of sediments.

Commercial amounts of oil or gas are found in the sandstone members of the Colorado shale in the Kevin-Sunburst, Sweetgrass Hills, Bowdoin-Saco, Cat Creek, Lake Basin, Hardin, Dry Creek, Clarks Fork, and Elk Basin fields. Hence this is one of the most important group of formations to the oil and gas industry.

KOOTENAI FORMATION

Widespread throughout all of Montana is a series of Lower Cretaceous land-laid or nearshore sediments, essentially sandstones and shales, outstanding because the sandstones are important reservoir rocks for both oil and gas in Canada, Montana, and Wyoming. These rocks are known as the Kootenai formation throughout most of Montana and Alberta, but in southern Montana and Wyoming approximately equivalent strata are known as the Cloverly formation, and in the Black Hills region as the Dakota group. The term Blairmore may be used in western Alberta.

Thickness in eastern and central Montana ranges from about 250 to 350 feet, but west of Great Falls and Livingston the series thickens rapidly, probably by the introduction of interfingering beds in the lower part, and thicknesses in parts of the mountain area are in excess of 1,000 feet.

The formation is characterized by the presence of red shale in most localities, and in northern and central Montana the "first reds" found in drilling were generally logged as the top of the Kootenai. The true top of the Kootenai may be a few feet higher. A sandstone above these "first reds" is placed in the Colorado group, but lithologically it would appear to belong in the Kootenai. In central Montana this sandstone is called First Cat Creek sand; in southernmost Montana, Greybull sand; and in the Black Hills region, Dakota sand. In eastern Montana a shale member (Fuson shale), generally greenish-gray, underlies this sandstone, and below it occurs a massive basal sandstone known as the Lakota sandstone. The term Lakota is also used in southern Montana. In central Montana the basal sandstone is known as the Third Cat Creek sand, and in the Kevin-Sunburst field as the Sunburst sand. In the Cut Bank field additional strata apparently are present in the lower part of the Kootenai, and the basal sandstone in this locality is known as the Cut Bank sand; it is stratigraphically lower than the Sunburst sand, but still a part of the Kootenai. In the region between Cut Bank and Lewistown the succession of beds in the middle part of the Kootenai is variable because of the irregular distribution of sandstone members. The Great Falls-Lewistown coal seam lies a few feet beneath the basal sandstone; once considered as in the Kootenai formation, it is now considered as in the top of the underlying Morrison formation.

The basal sandstone commonly becomes conglomeratic near or in the mountain area. The rounded pebbles and cobbles composed of quartzite or black and gray chert range up to 8 inches in diameter. This bespeaks of an upland to the west. Eastward the presence of black chert grains in the sandstone persists, giving the rock a speckled appearance, and resulting in the descriptive term of "salt and pepper sand" used by drillers. In the mountain area of southwestern Montana pure fresh-water limestone, up to 60 feet thick, in the upper part of the Kootenai suggests the presence of a lake rivaling Lake Superior in size. Fossil gastropods (snails) are nearly always present in this limestone, in places in great abundance.

The lower sandstones of the Kootenai yield large volumes of both oil and gas in the Cut Bank and Kevin-Sunburst fields and fields lying northward. They yield oil in the Whitlash field. An upper sandstone (Second Cat Creek sand) yields oil in the Cat Creek field, but the basal sandstone (Third Cat Creek sand) contains a strong artesian water circulation in this field, the water being suitable for drinking. Oil and gas also occur in the Lower Cretaceous strata in the Lake Basin, Dry Creek, Clark Fork, and Elk Basin fields. However, in most of central and eastern Montana the basal sandstone is a persistent and excellent horizon for fresh artesian water under much pressure, and the water from many large flowing water wells in this region comes from this horizon, even where the wells are sunk on pronounced anticlinal structure.

MORRISON FORMATION

Underlying the Kootenai formation throughout central and southern Montana occures a series of land-laid sandstones and shales with subordinate limestone comprising the Morrison formation. For the most part these sediments are dirty yellow to buff in color, but green, red, and purple shales occur. The formation is about 400 feet thick near the Wyoming line, but it becomes thinner northward. In central Montana it may be about 100 to 200 feet thick. Its identification is doubtful in parts of northern Montana, and it is not recognized in the Kevin-Sunburst field. In much of the area where these sediments are found, particularly in the central part of the state, they so resemble beds of the Kootenai that the two formations may be mapped or even logged together. The Lewistown-Great Falls coal seam recently has been considered as in the top of the Morrison rather than in the base of the Kootenai. These sediments are considered Late Jurassic in geologic age.

In central and southern Montana the sandstones of the Morrison are porous and would serve as good reservoir rocks. Certain of the deeper oil production in the Cat Creek field is from Morrison sandstone (Brindly Sand), and a Morrison sandstone in the Ivanhoe field yields oil.

ELLIS GROUP

Beneath the Morrison formation (or Kootenai if Morrison is missing) lies 200 to 600 feet of marine sediments originally known as the Ellis formation, Middle and Late Jurassic in age. Recently it has been called the Ellis group. The character of the sediments differs from place to place, but some beds may be persistent for many miles. Near Great Falls they have been divided into three units: glauconitic shales and sandstones above (Swift), limy shales and limestone (Rierdon), and then fine-grained sandstone and siltsone at the base (Sawtooth). In central Montana the general sequence is similar, except that at the base occurs gypsum-bearing red and gray shales locally known as the Piper formation, which is probably equivalent to the Gypsum Springs member of the Sundance formation of Wyoming. Gypsum is mined from this horizon near Lewistown. In eastern Montana the Piper may have a three-fold subdivision: an upper green-gray or rust-red calcareous shale; a middle oolitic limestone; and a lower rust-red shale with limestone. All members of the group are not present in all localities. Well records indicate that the Ellis is 600 feet or more in thickness in eastern Montana; whereas near the mountain front, where thicknesses vary, about 250 feet is an average thickness.

The Ellis group was laid down in an inland or epicontinental sea which extended southeastward from the Pacific ocean. The sea spread over Alberta, Montana, Wyoming, and into Colorado and Utah. An eastern shore line was probably in the Dakotas. Different names have been given to the sediments of the sea; in most of Montana they are known as the Ellis group, in Alberta as Fernie, and in Wyoming as Sundance.

In most localities the rocks of the Ellis are not particularly good reservoirs. The sandstones tend to be shaly and limy, thus reducing porosity. However, oil has been found in Ellis sandstones in the Bannatyne, Bowes, Flat Coulee, and Cat Creek fields; and the so-called "stray sands" of the Kevin-Sunburst field are in the Ellis. Gas occurs in the Sawtooth formation between Havre and Shelby. During early years of oil development in the Kevin-Sunburst field, the porous zone in the top of the Madison limestone was erroneously called "Ellis sand."

CHUGWATER AND SPEARFISH FORMATIONS

Only in southwestern, south-central, and eastern Montana are sediments of the Triassic period found. South of Billings, where they underlie the Ellis (Sundance) group, they are known as the Chugwater formation, but in the Black Hills region equivalent strata somewhat different in character are known as the Spearfish formation. In southwestern Montana, Triassic strata are divided into the Thaynes, Woodside, and Dinwoody formations, although Dinwoody may be in part Permian in geologic age. At the Wyoming line south of Billings, the Chugwater is about 450 feet thick, but it thins northward and is not definitely known to be present north of Yellowstone River.

The Chugwater beds are conspicuous because of the brilliant red colors of most of the shales and sandstones of which they are composed. This formation can be recognized from a distance by its flaming red outcrops and soils, probably 90 per cent of these strata are some shade of red. Pure granular gypsum occurs near the upper part of the formation in beds 5 to 40 feet thick, and gypsum seams and veinlets streak through the lower part of the formation. Gypsum was once mined from this formation east of Bridger. The Spearfish differs from Chugwater in that it contains impure limestone and less red coloration. Salt and gypsum are present within it south and north of Glendive, where it is essentially a brick-red non-calcareous shale with some siltstone.

Largely because of its limited distribution the Chugwater is not important to the oil and gas industry in Montana. However, some of its sandstones are unusually porous and would serve as excellent reservoir rocks. The Spearfish yields oil in Wyoming, and is widespread in occurrence in eastern Montana.

EMBAR, PHOSPHORIA, MINNEKAHTA-OPECHE FORMATIONS

South of Billings, the Embar dolomitic limestone of questionable Permian age yields oil and some gas in Wyoming, but it is believed to thin out and disappear at or a short distance north of the Montana-Wyoming state line. The northern extension of the Black Hills Permian strata, known as the Minnekahta and Opeche formations, lies deeply buried in eastern Montana. As seen in well cuttings these strata much resemble the overlying Triassic and underlying Pennsylvanian strata. The Opeche is composed of brick-red silty noncalcareous shales with some salt; the Minnekahta, occurring from Glendive into the Black Hills, is a thin carbonate-evaporite (anhydrite) unit, some shale being present. The typicale Phosphoria formation (Permian) of southwestern Montana does not extend into the plains east of the mountains.

The Phosphoria is of interest because of beds of petroliferous (kerogen) shale up to 60 feet thick, some of which may yield as much as 20 gallons of oil per ton of shale by destructive distillation. It also contains almost limitless amounts of natural rock phosphate in beds of commercial character, mined in western Montana and Idaho for many years for elemental phosphorous and fertilizer.

QUADRANT, TENSLEEP, MINNELUSA FORMATIONS

Underlying the Chugwater and Embar in southern Montana are strata of Early and Middle Pennsylvanian age known as the Tensleep formation. South of Billings they consist of massive light-colored friable sandstone 75 to 100 feet thick. Straight and steeply inclined cross-bedding and rounded uniform-sized sand grains about one millimeter or less in size suggest an eolian origin, particularly in the lower part of the formation; however, much may be beach deposits. Westward in the mountain area this sandstone has been firmly cemented and is known as the Quadrant quartzite; quartzites of the Quadrant do not extent far east of the main ranges of the Rockies. In southwestern Montana the Quadrant thickens and contains thick limestone members. Eastward in the Black Hills region Pennsylvanian strata becomes limy and contain red beds, these strata then constitute the Minnelusa formation, or else its upper part. In easternmost Montana, the Minnelusa extends as far north as the Missouri River, where it pinches out. In western Alberta and British Columbia massive Pennsylvanian quartzite, comparable to Quadrant, is known as Rocky Mountain quartzite.

In earlier reports on central Montana, the term Quadrant was erroneously applied in central Montana to a series of shaly sediments of definite upper Mississippian age, now known as the Big Snowy group. In that region the Tensleep terminates northward somewhere between Yellowstone River and Musselshell River; if present north of the Musselshell, it is only as small isolated outliers. In the Yellowstone Park region and southwestern Montana, the division between the underlying Amsden limestone and the Quadrant formation has been in dispute. It seems probable that the Amsden of that region is a transitional formation possibly crossing geologic period boundaries.

In the Big Horn structural basin of Wyoming and southern Montana the Tensleep sandstone is one of the most important oil reservoirs, and it is the main producing horizon in the Dry Creek and Elk Basin fields and in several Wyoming fields. The Tensleep yields oil in the Snyder field northeast of Hardin. Hence in southern Montana this horizon should be thoroughly tested in drilling operations. In central and northern Montana it is not present. The somewhat calcareous and shaly sandstones of the Minnelusa formation, approximately equivalent to the Tensleep, underlie eastern Montana, and they yield oil in Wyoming.

AMSDEN, ALASKA BENCH, TYLER FORMATIONS

One of the most controversial problems in Montana stratigraphy is that involving the Amsden formation and associated strata, and it is particularly important since these rocks are reservoirs for oil in several of central Montana's important oil fields. For the past twenty years different geologists have discussed, agreed, and disagreed on just what formations are present, where to draw formational boundaries, and what rock to include in each of the several units. Even geologic age of some of the rocks in this part of the geological column has been argued in spite of the presence of fossil evidence. The main difficulty seems to have been the occurrence of a suite of similar carbonate rocks transitional in time of deposition from Mississippian to Pennsylvanian periods; but the occurrence of a shale-sandstone series of red-toned beds immediately below also enters into the problem. In correlation across a region from western to central to eastern Montana and into Wyoming, a region five hundred miles across, disagreement arises.

The sequence of rocks involves esentially: (1) an upper dolomite unit containing Pennsylvanian fossils, which may grade upward into the overlying Tensleep or Quadrant formation; (2) an underlying limestone unit so closely associated with the dolomite that the two may appear to belong together, although the limestone contains Mississippian fossils; and (3) the presence of underlying reddish silty shale and sandstone, limited in horizontal extent, differing locally, and bounded by unconformities in places difficult to recognize.

In central Montana where these rocks are exposed in the Big Snowy Mountains a recent interpertation places the upper dolomites into the Pennsylvanian Amsden formation, and the underlying limestone, into the Mississippian Alaska Bench formation [a name resurrected from old overlooked literature (Freeman, 1922)]. The reddish shales and sandstones, once placed in the upper part of the Heath formation, are separated into the Tyler formation (a name likewise resurrected). This nomenclature is now in use in the central Montana oilfields. In eastern Montana these three units may be lumped together as Amsden, probably for convenience. In western Montana where the upper part of the Big Snowy sediments (Heath and Otter) are missing, the "basal Ameden reds", which may reach 70 feet in thickness, have been considered by some as possibly a part of the Kibby formation. Near the Idaho state line this series of rocks merges into the thick Brazer limestone; and in western Alberta, into the Rundle formation.

The Amsden in central Montana, as now used, is described as 0 to 50 feet of a "light-colored cherty dolomite with thin interbeds of sandstone and red shale . . . . sparsely fossilferous." Ostracods (minute fossils) absent in the Amsden formation are abundant in the Alaska Bench formation. The Alaska Bench is described as about 140 feet of "blocky limestone forming distinctive pinkish cliffs." The limestone may contain some anhydrite and may be sandy; and it contains shale partings near its base. It probably correlates with an old, little-used term, Sacajawea, for similar rocks in Wyoming. The Tyler, originally included in the top of the "old" Heath formation, is described as maroon calcareous fissile shale with streaks of grey-green shale, and erratic lenticular beds of sandstone and conglomerate some of which reach 55 feet in thickness. A non-marine aspect is prevalent in Tyler rocks (wood fragments), and it lies on marked erosional unconformity with what has been described as channel deposits in subsurface descriptions of the Sumatra oil field. Isopach maps of a lower oil-bearing sandstone in the Tyler of the Sumatra field show a meandering pattern of occurrence resembling stream meanders. Some observers consider these strata as shore-line deposits, at least in part. Although these oil-producing reservoirs, so far as have been found, are closely associated with anticlinal structure, they are erratic in occurrence and may not be present on crests of domes, the oil occurring on the flanks of the domes. Futhermore, geologic cross-sections indicate that the relief of probable buried valleys may have been considerably in excess of 100 feet. The Tyler formation is believed to be limited in extent to that area now occupied by the Big Snowy-Porcupine uplift. The sandstone members are locally designated from top downward as Tyler "A", "B", and "C" sands, although the lower two may in places grade vertically into one another.

In general, throughout much of Montana the Amsden sequence consists of 150 to 200 feet of buff- to cream-colored fine-grained cherty dolomite and limestone commonly underlain by 5 to 30 feet of purple brick-red and buff-colored sandy, silty, and calcareous shales. In the mountain areas the lower shale, upon weathering, develops red soils which commonly streak the underlying Madison limestone with red stains. In central Montana the basal red shale has decreased in amount until it is scarcely recognizable, but red and purple colorations are generally conspicuous throughout, and the "basal Amsden reds" may have merged into the Tyler formation. In eastern Montana the general aspect of the sequence is similar, but the several units are commonly grouped together as Amsden. In early reports these strata in eastern Montana may have been designated as Lower Minnelusa; the Upper Minnelusa corresponding to the eastward extension of the Tensleep formation.

Outcrops of "Amsden limestone" do not suggest that it would be a particularly favorable reservoir for oil or gas. Nevertheless, it has proved to be a good oil producer in the Big Wall, Gage, Delphia, Sumatra, Hawk Creek, and Wolf Springs oil fields of central Montana, and Soap Creek field in southern Montana, in all of which fracture porosity is important.

Development of porosity in central Montana may be related to weathering during the extensive post-Paleozoic-pre-Ellis erosion which in this locality cut deeply into the top of the Amsden. Many Amsden cores show a creviced condition with oil staining along the crevices, and much (or most?) of the oil accumulation inthis formation may result from "fracture porosity". It is possible that the limestone porosity of these central Montana fields may be somewhat comparable to the porosity developed in the Madison limestone of the Kevin-Sunburst field during the same erosion period. Such considerations may have a bearing on the location of test wells wherein this may create stratigraphic traps for oil.

Oil occurs in sandstones in the lower part of the Tyler formation in the Big Wall, Melstone, Ivanhoe, Ragged Point, Stensvad, and Sumatra fields.

BIG SNOWY GROUP

Upper Paleozoic stratigraphy of central and eastern Montana differs markedly from that of both northern and southern Montana in that in the central area up to 1,600 feet of shaly marine sediments lie between the Madison and Amsden limestones. Known as the Big Snowy group, they consist of the uppermost Heath formation, the middle Otter formation, and the basal Kibbey formation. They terminate southward between Musselshell and Yellowstone rivers apparently due to non-deposition, but northward they terminate a short distance north of Lewistown because of pre-Jurassic erosion. The problem is further complicated by striking changes in lithologic character of these sediments from a limestone facies in western Montana into clastic sediments in central and eastern Montana, and the character of clastic material changes eastward. The Big Snowy group is Late Mississippian in age.

The Heath formation, about 400 feet thick south of Lewistown, is characterized by an abundance of black fissile petroliferous (kerogen) shale, flakes of which will ignite in a match flame. Distillation tests indicate that it may contain 30 gallons or more of recoverable oil per ton of shale. Also present are massive brownish sandstones up to 20 feet thick, gray shale, and a small amount of limestone. Some of the black shale contains an abundance of conodonts (microscopic fossils), and other fossils are plentiful locally. Recently the upper part of the Heath has been separated and placed into the Tyler formation.

The Otter formation, about 400 to 500 feet thick in central Montana, is characterized by vivid green shales; but fossiliferous limestone, some of which may be oolitic, and much gray shale are also present. Locally, commercial beds of gypsum are present in the upper part of the formation.

The Kibbey formation, averaging 100 to 150 feet in thickness, is characterized by brick-red dolomitic and shaly sandstone, easily distinguishable both in outcrop and in well cuttings. The Kibbey sands differ from Heath sands in that sorting is poor, and the grains are well rounded and commonly frosted or even polished. Thick beds of gypsum (or anhydrite) occur near the top. The Kibbey is a good horizon marker. The Heath, Otter, and Kibbey continue into eastern Montana and western North Dakota.

A fractured oolitic limestone or dolomite near the top of the Heath formation (Van Duzen "sand") yielded oil in the Devils Basin field, and oil in the Ragged Point field occurs in the Kibbey sandstone.

MADISON GROUP

The Lower Mississippian Madison group of formations, consisting of the Charles formation at the top, and then the Mission Canyon and the Lodgepole formations below, comprises a carbonate series 750 to 1,500 feet thick in the plains of Montana, and the lower two units are continuous across the entire state, except where removed by late erosion. In westernmost Montana thicknesses may be double that in the plains. The relatively uniform and characteristic appearance renders the Madison easily recognizable and free from controversy. In much of Montana the similarity of these rocks has lead to a widespread and popular use of the term Madison as though it were a single formation, but in oil field terminology subdivisions are recognized. (See fig. 5).

At the base of the limestone series are a few feet of fissile jet-black shale commonly containing a conodont fauna (microscopic fossils). In Alberta it is known as Exshaw shale, and is considered uppermost Devonian because of the type of conodonts; eastward it appears to bifurcate due to dolomitic silty partings, and the unit is called Bakken formation in eastern Montana, and commonly considered lowermost Mississippian in age.

As originally described, the Charles formation, made known by subsurface studies, was considered as the lowermost formation of the Big Snowy group. More recent sudies indicate that it is more closely related to the underlying Madison group, and that it is composed of limy dolomite and evaporite deposited during the "drying-up" stages of the Madison sea. The Charles consists essentially of a series of dolomites, red shales, and anhydrite, total thickness ranging up to 1,000 feet. Several massive anhydrite beds, ranging up to 30 feet in thickness, are most characteristic. The Charles is more widespread in occurrence in central and eastern Montana than formations of the Big Snowy group, and it has been recognized in Wyoming. However, it is absent in northern Montana between Glasgow and Shelby and north of the Missouri River, probably due to pre-Jurassic erosion. West of Great Falls a dolomitic limestone at the top of the Madison group, known as the Sun River formation, is probably equivalent to the Charles formation of central Montana. In northeastern Montana the Charles contains single beds of common salt up to 100 feet in thickness, and a total thickness for all salt beds of perhaps 400 feet is reported in the East Poplar field. It is most difficult to separate Charles strata from those of the underlying Mission Canyon in drill cuttings or cores, but generally the base is placed just below the lowermost thick massive anhydrite bed.

Oil occurs in the Charles formation in the Poplar, Bredette, Line Coulee, Richey, and Woodrow fields in eastern Montana, and in the Sun River (Charles) formation in the Pondera, Reagan, North Cut Bank and Red Creek fields of the Sweetgrass Arch region. It is a potential oil-bearing formation in all of Montana.

The Mission Canyon is almost always a massive, poorly bedded, pure crystalline linestone, but chert in large nodules is commonly present, particularly in the central part of the unit. Some beds may contain more than 99 per cent calcium carbonate. Color tones of light-gray to white predominate. Thin beds of anhydrite may be present in it in eastern Montana. In the mountains, outcrops of this part of the Madison tend to form impressive cliffs with castle-like promontories.

The Lodgepole is essentially a fine-grained limestone. Although generally thin-bedded, with shale partings less than one inch thick, some beds may be a foot in thickness. Chert may be more plentiful in the Lodgepole than in the Mission Canyon, and locally much silicification is present. Insoluble residues may be 30 per cent or more. Color tones are usually dark gray with brownish tinges, but some beds are jet-black limestone. Commonly fossils are abundant through the whole series; however, fossils are scarce or lacking in many areas.

The Madison is important to the oil and gas industry, since its upper portion (both Charles and Mission Canyon) is a reservoir rock in the northern, southern, and eastern Montana oil fields, and also in Canada and Wyoming. During the earlier drilling in Montana the Madison was the "floor" to which most drilling was planned, and but few of the earlier wells passed through it. In north-central Montana the white or gray limestone beneath the darker shaly Ellis formation is comparatively easy to recognize in drilling studies, and most logs of wells which reached it record its depth accurately.

In practically all localities where oil is produced from the Charles or Mission Canyon, fractures and fracture porosity have been a vital condition affecting oil production. In the Kevin-Sunburst oil and gas field much porosity (up to 50 per cent) was developed in the upper 10 to 50 feet of the Madison (Mission Canyon) by weathering processes during the period of erosion preceding the laying down of the Jurassic Ellis formation. Silicification, dolomitization, and solution were extensive. No doubt the greatest changes took place near joint and fissure planes in the limestone surface, and cores of slightly altered limestone were left; but a widespread area of altered limestone extends through the Kevin field. Porosity in the Pondera and other fields appears to have developed in the same manner, although the producing horizon is considered Sun River (Charles). It may follow from this that where these conditions of leaching did not occur, porosity and hence oil concentrations may not be present, but this is not necessarily true. Large commercial amounts of oil have been found 100 to 200 feet beneath the top of the limestone series in porous limestone zones in some areas in northern Montana where the Charles appears on the west side of the Sweetgrass Arch. At Elk Basin large amounts of oil occurred several hundred feet within the Madison.

DEVONIAN FORMATIONS

Older classifications of Montana Devonian rocks made in southwestern Montana divided them into the Three Forks formation above and the Jefferson formation below, both of Late Devonian age. The Three Forks formation in its type area is essentially shale, about 300 feet thick, but eastward in central Montana locally it may grade into gray earthy limestone. In northern Montana about 25 feet of gray-green shale occurs at this stratigraphic position, and in northeastern Montana strata designated as Three Forks consist of about 150 feet of pale-green to rust-red dolomitic shale and shaly dolomite.

The Jefferson formation in southwestern Montana is easily recognized due to the presence in its upper part of about 450 feet of massive black granular dolomite commonly yielding a fetid odor when freshly broken. Beneath the black dolomite are about 250 feet of gray limestone, and then about 20 feet of reddish shale with limestone. In the Big Snowy Mountains of central Montana the lower limestone member is missing, and the dolomite member is believed to end about 60 miles east of these mountains, although Devonian strata appear again farther east. In the Kevin-Sunburst field in northern Montana about 20 to 30 feet of green and green-gray shale underlies the Madison, or the Exshaw black shale, and below this about 600 to 900 feet of brownish dolomite interbedded with thick beds of anhydrite. Known as the Potlatch anhydrite formation, these strata are probably about equivalent to the upper part of the Jefferson. Beneath the anhydrite zone occurs about 300 feet of brownish-gray dense limestone, argillaceous near the base.

The Devonian strata as seen in outcrops along the northern Rockies consist of (1) an upper 10 to 100 feet essentially of shale, (2) about 700 feet of dolomite and evaporite (anhydrite), (3) about 800 feet of earthy limestone, and (4) a basal unit consisting of 10 to 100 feet of reddish silty shale which may in part be an ancient soil on the pre-Devonian land surface. The coral reefs near Edmonton, which have yielded much oil, occur at about the stratigraphic position of the limestone unit.

In northeastern Montana thicknesses of the Devonian carbonate rocks range up to 1,500 feet, but thicknesses differ greatly because of unconformities above and below. The series has been divided into 6 or 7 formations, (see fig. 5), including some Middle Devonian rocks which do not occur elsewhere in Montana. The formational names in this region have been brought in from Canada where the series crops out. Locally on the Cedar Creek anticline Devonian rocks are missing due to pre-Mississippian erosion. This indicates a Paleozoic beginning of the Cedar Creek anticline.

Of interest is the occurence of a widespread erosional unconformity beneath the Montana upper Devonian strata, wherein these strata are underlain by Cambrian strata in western and northern Montana, and Ordovician strata in southern and east-central Montana. Silurian strata underlie Devonian strata in the eastern nad northeastern parts of the State. Subsurface distinction between Devonian, Silurian, and Ordovician strata has proved difficult because of lithologic similarity.

Commercial amounts of oil or gas have been found in the Devonian strata in extreme northeastern Montana in the Outlook and Redstone fields, and some oil was present in Devonian strata in the Richey field 70 miles southward. Fracture porosity appears to be important. Good "shows" of oil, amounting possibly to one barrel per day, and also gas, have been found in the lower part of the Potlatch formation in the Kevin-Sunburst field, and oil-soaked Devonian cores have been recovered elsewhere not far distant. The porous zone in which these "shows" were found is about 600 feet beneath the top of the Devonian, or 1,680 feet beneath the top of the Madison in the Kevin-Sunburst field. A strong flow of gas containing 82 percent carbon dioxide, 5 percent nitrogen, and 12 percent combustibles came from this horizon on the Sunburst dome. In northern Montana porosity appears to be favorable but permeability is low.

SILURIAN FORMATIONS

No Silurian strata have been recognized in central or western Montana, either in outcrop or in well cuttings. Silurian strata, as interpreted from both lithologic and fossil evidence, lie deeply buried in an area 100 to 150 miles west of the Montana-North Dakota state line. They pinch out before reaching the Black Hills of South Dakota. These strata are a southward extension of the Silurian strata of Canada where they are known as the Interlake formation, and this name is used in eastern Montana. The Interlake formation in Montana is described as follows: "A highly irregular erosional topographic surface separates the Silurian from the overlying Devonian. The Silurian consists primarily of creamy-tan to medium-brown dense dolomite with common pale-green waxy shale pockets and partings. The upper surface is commonly marked with a pinkish cast. Coralline and algal debris are locally present in the upper (and lower) portion".

Commercial amounts of oil occur in Silurian strata in several fields along the Cedar Creek anticline, in the Outlook field, and at Southwest Richey. The oil reservoirs appear to be much fractured, and oil may be produced dually from what is termed "Siluro-Ordovician" strata, the contention being that porosity is interconnected between the underlying Ordovician and overlying Silurian because of fracturing.

ORDOVICIAN FORMATIONS

Ordovician strata are known to be present only in the southern, east-central, and eastern parts of this State, but not in northern Montana. In southern and central Montana they consist essentially of about 300 to 400 feet of massive buff granular dolomite of the Big Horn formation of upper Ordovician age. The Big Horn dolomite terminates westward along an irregular line trending northeasterly from about Three Forks to Malta, apparently because of erosion prior to or during early Devonian time. Thus there is a zone in central Montana where the Big Horn dolomite is directly overlain by Jefferson dolomite or dolomitic limestone. In logging wells in this area the change from black dolomite limestones to buff-colored or cream-colored dolomite is generally chosen as a line of division. In eastern Montana Silurian strata overlie Ordovician strata (see figure 8).

In eastern Montana Upper Ordovician strata thicken greatly, change slightly lithologically, and some Lower Ordovician is reported present. The Upper Ordovician has been subdivided into the dolomitic Stony Mountain and Red River formations, considered equivalent to Big Horn dolomite, and the sandy Winnipeg formation, perhaps equivalent to the Lander or Harding sandstone underlying the Big Horn dolomite on the eastern side of the Big Horn Mountains. These names originated in Canada. Beneath the Winnipeg occur limy, sandy, shaly, fossiliferous beds which may be considered equivalent to the Lower Ordovician Whitewood formation of the Black Hills region.

In the upper part of the Stony Mountain formation, which greatly resembles the overlying Interlake formation of Silurian age, 10 to 15 feet of gray-green or rust-red dolomitic shale may be present; but the formation is dominantly argillaceous dolomite with some limestone, totaling about 150 feet in thickness. The underlying Red River formation, about 500 feet thick, resembles Stony Mountain in that it is dominantly dolomite with some limestone, the dolomite becoming more abundant northward as at Richey and Poplar. Anhydrite may be present throughout the Red River formation, locally in beds; but also in irregular masses; the lower part is argillaceous. The Winnipeg formation, about 175 feet thick, is essentially white or light-gray clean sandstone interbedded with dark-green to black fissile shale, the shale predominating in the Baker-Glendive area. The Whitewood, about 350 feet thick near Glendive, and generally logged in well-records as Lower Ordovician, is mainly shaly limestone interbedded with green fissile micaceous shale. It is glauconitic and fossiliferous, and may contain flat-pebble limestone conglomerate similar to that in the underlying Cambrian.

The most productive oil strata in eastern Montana lie in the upper parts of the Red River and Stony Mountain formations, consisting essentially of fractured dolomite; and most of the oil produced from seven fields along the Cedar Creek anticline comes from these strata. Oil may be taken form both Ordovician and Silurian zones some 500 feet apart in a single well, the contention being that porosity between the two zones is continuous because of fracturing. Oil also occurs in the Red River formation in the Repeat field 40 miles south of Baker, and in the Outlook field 175 miles north of Baker or 8 miles south of Canada.

CAMBRIAN FORMATIONS

The old standard classification of Cambrian strata used in western Montana for many years consisted of six formations which from top downward are the Dry Creek reddish or rusty sandy shales with some limestone, the Pilgrim massive blocky mottled dolomite, the Park fissile green shale, the Meagher mottled limestone or dolomite, the Wolsey fissile green sandy shale with some limestone, and the basal Flathead pink quartzite and coarse sandstone, all of middle and upper Cambrian age, and all lying beneath a pre-Devonian erosion surface which removed Silurian and Ordovician strata. Later, additional Cambrian strata (Snowy Range and Grove Creek) were found at or about the old Dry Creek horizon northeast of Yellowstone Park. Recent studies have about eliminated the term "Dry Creek" because of its ambiguous usage (Hanson, 1953), although the term may still be used locally. Total thickness of this series is about 2,000 feet. Eastward the dolomite units grade into limestone and then wedge or pinch out in about the middle part of the State leaving about 800 feet mainly of shale. Still farther east these strata merge into the Deadwood formation of the Black Hills, thickness of which is about 400 feet (see fig. 7). The Deadwood which extends northward under eastern Montana is composed of alternating sandstone, shale, and dolomite. The basal Flathead quartzite or sandstone is continuous from Idaho into South Dakota, but it thins eastward from about 150 feet to 25 feet; and since it was laid down by an eastward advancing sea, it "rises across time boundaries in an easterly direction . . . and at the eastern extreme the system is exclusively Upper Cambrian."

Northward in the Kevin-Sunburst field, Devonian strata are underlain by about 700 feet mainly of fractured shale, originally called Barker formation, but with some limestone and a basal quartzite. No oil or gas have been found in the Cambrian strata of Montana.

GEOLOGIC STRUCTURE OF MONTANA PLAINS

The general features of geologic structure at or near the surface of central and eastern Montana are well known, and are shown on the "Structural Contour Map of the Montana Plains" first issued by the U. S. Geological Survey in 1932, but revised and reissued in 1935, 1946, and 1955. Oil and gas field and dry holes are shown on this map. (See plate 2 in pocket). Practically all of the known anticlinal structures of consequence have been mapped in detail. No sizeable area (and probably no area at all) remains unexamined by competent geologists, and much or most of the plains has been explored by geophysical methods. Bedrock in some areas is hidden by glacial drift, terrace gravel, or alluvium, particularly in northern Montana. This makes detailed determination of geological structure difficult or impossible from surface inspection alone. Nevertheless, it is probable that no new anticlines or domes or large structures of importance will be found solely through surface studies. It would seem that future prospecting for oil and gas will be confined mainly (1) to testing different parts of known structures, either laterally or at depth; (2) to a search for stratigraphic traps, conditions for which are favorable in many places; and (3) to geophysical explorations, bringing forth information on deep-seated structural conditions.

Structurally, the state of Montana may be divided into three parts: (1) the western one-third, an intensely folded and faulted region cut by many large igneous intrusions; (2) the central one-third, a plains region consisting of nearly flat-lying sedimentary rocks interrupted by several isolated areas of mountain uplift; and (3) the eastern portion, a large structural basin throughout most of which strata lie nearly horizontal. The isolated areas of mountain uplift in central Montana, which rise island-like from nearly level plains, are of three different types: some are caused by local intrusions of igneous rock into sedimentary beds and are laccolithic in character; others were formed by out-pourings of lava onto relatively level strata; still, others are huge folds or anticlinoria 50 miles or more across in which the magnitude of uplift is in the order of 3 to 5 miles. Some of these mountain uplifts, and also the larger anticlines in the plains, may have been caused by deep-seated faulting beneath the blanket of sedimentary beds; that is, earth movements in the basal complex. Minor folds of significance lie on the flanks of some of these uplifts. They are important in oil and gas production.

THE MOUNTAIN AREA

The mountain area of western Montana, although a continuous succession of large compressed folds, great thrust faults and block faults, and widespread igneous intrusion and extrusion, is characterized by wide flat intermontane valleys containing hundreds or thousands of feet of valley-fill much or most of which is of lacustrine (lake) origin. These valleys, up to 20 miles wide and 50 miles or more long, were caused by large-scale block-faulting and crustal warping after the compressive folding of the Laramide orogeny was completed, and after most of the igneous masses had been intruded, solidified, and uncovered by erosion. The lake sediments are well stratified and partly consolidated, and subsequent deformation has tilted or folded them, so that in places dips up to 10 or 15 degrees or more can be observed. Locally, from time to time, the sediments of these valleys have been prospected by drilling for oil and gas without success.

In southwestern Montana huge synclinal structures, 20 miles or more across, made up of Paleozic and Mesozoic strata and flanked by equally large anticlinal areas on which the Precambrian basal complex is exposed, have attracted the attention of some geologists. Perhaps this is in part because the huge synclines are composite in character with minor folds within the larger structures. Dip of strata locally is nearly vertical, and in some localities strata are overturned. A deep test well was sunk northwest of Yellowstone Park on such a structure without favorable results. Another deep test well was sunk near Lima and abandoned. In general, the oil industry is not favorably impressed with this region within the mountains of western Montana as potential oil or gas territory, excepting that investigations of oil seeps and oil possibilities in the Glacier Park area are being carried on.

Since the oil and gas fields are confined to the plains east of the Rocky Mountain front, and probably always will be so confined, excepting possibly the Glacier Park region, discussions of the complicated structure in the intensely folded and faulted mountain area of western Montana, with its igneous intrusions and extrusions, will be omitted.

MAJOR UPLIFTS AND MAJOR BASINS

Eastern and central Montana can be further divided into irregular areas according to units of major geologic structure. (See plate 2 in pocket). These major units are either uplifts or downwarps; that is, structurally, great domes or anticlines and great structural basins. The surface exposures of the rock formations depend largely on structure, and also on the processes of erosion which have truncated the warped or folded strata. Of course the lithologic character of surface formations also has much influence on the physiographic character of the region, that is the presence of uplands and valleys. However, it should be noted that the land surface does not conform entirely to conditions of geologic structure; all uplifts are not topographically high, and all structural basins are not low in elevation. For example the Bull Mountain area south of Roundup is a downwarp or structural basin, and the low, flat valley-lands of the Bowdoin-Saco area are in an uplift area. Other examples may be cited. Nevertheless, commonly where amount of uplift is great, the area is high due to exposure of old and resistant rocks which, because of slow erosion, remain high. Thus, the crest of the Big Horn Mountains, composed of hard, resistant Cambrian and Precambrian formations, rises 7,000 feet above Clark Fork Valley to the west; and this valley, 30 miles or more across, is a structural basin (Big Horn Basin) with relatively soft young Tertiary sediments at the surface. Magnitude of uplift (structural relief) of these mountains is in the order of 4 miles.

Four large areas of major uplift east of the front ranges of the Rockies are outstanding in importance because they are essentially great earth folds; but other large uplifts, laccolithic in character, are nearly as important. In the first class are: (1) the Big Horn uplift, (2) the Little Belt-Big Snowy-Porcupine uplift, (3) the Sweetgrass arch, and (4) the Bowdoin dome. Popular dome is considered by some as belonging to this group. The Black Hills uplift of this character flanks Montana to the southeast. The Cedar Creek anticline, which passes through Baker and is 120 miles long, is a major fold when considered by itself. The Big Coulee-Hailstone-Broadview dome, 30 miles across and lying northwest of Billings, is a significant structural feature. The magnitude of uplift on each of these differs greatly, from less than 1 to more than 5 miles. Laccolithic types of uplift are the Judith and Moccasin Mountain group, the Little Rocky Molntains, the Sweetgrass Hills group, and in part the Bearpaw Mountains. The Highwood and Crazy Mountains, and in part the Bearpaw Mountains are essentially piles of lava which have been poured out onto relatively flat-lying strata.

The amount of uplift is commonly great, and in some cases is measurable in terms of many thousands of feet: in the Black Hills more than 25,000 feet, in the Big Horn Mountains more than 20,000 feet, in the Big Snowy Mountains more than 12,000 feet, and in the Sweetgrass Hills about 8,000 feet. It is not believed that surface elevation in the mountain areas was ever as high as the calculated amount of uplift suggests. The making of mountains is a slow process, probably in the main not much faster than the downcutting processes of erosion; and nearly as fast as the mountains were uplifted by earth forces, the forces of weathering and erosion cut them away. This resulted in deposition of sediments (high-level gravel) on the adjacent plains. In geologic age these mountain uplifts and structural basins date from the latter part of early Tertiary time.

Major structural basins, which are areas of relatively flat-lying strata between areas of uplift, are: Big Horn (Clark Fork) basin east and southeast of Red Lodge and its northwestward extension, the Crazy Mountain syncline; Powder River basin south of Miles City and its northeast extension, the Sheep Mountain syncline; Bull Mountain or Roundup syncline; Milk River basin north of Havre and Chinook; and Browning basin near Glacier Park; and of course the Williston basin of North Dakota must be included. Eastern Montana lies on the western flank of the huge Williston basin. Structural basins smaller in size are the Blood Creek syncline near the mouth of Musselshell River, and Wheatland basin south of the Big Snowy Mountains. The area known as Judith Basin is not a structural basin, but constitutes the northern slope of the Little Belt Mountain uplift, hemmed in on the north by laccolithic or volcanic mountains. These basined areas in eastern and central Montana, and the sedimentary formations underlying the surface, merge from one into another without distinct boundaries.

MINOR FOLDING

Around the borders or flanks of most of the major uplifts are many minor flexures or smaller folds (figs. 21, 22, and 23). Such minor folds are considered particularly favorable as structural traps for oil and gas accumulation as exemplified by numerous producing fields on the flanks of the Big Horn Mountains, the Black Hills uplift, and other major mountain ranges in Wyoming.

In Montana the drilling of flanking anticlines and domes has not been as successful as in Wyoming, nevertheless, several oil and gas fields have been developed on such structures. The Hardin gas field and the Snyder oil field are on a structural terrace or anticlinal nose on the northeast flank of the Big Horn Mountains; and the Soap Creek oil field lies on a small anticlinal fold close to these mountains. Paralleling the north slopes of the Beartooth Mountains near Red Lodge is a narrow fold, the Nye-Bowler lineament, about 50 miles long, characterized by several high points along its crest. The Dry Creek field is on one of these "highs". South of the Big Snowy Mountains along Musselshell River are four or five strikingly prominent domal anticlines of large size; as seen on a map they would seem ideal for oil or gas accumulation. As yet drilling has failed to develop commercial production upon them, but they have not been completely tested. It is thought by some that artesian water has flushed away such oil as may have been present in Mesozoic strata in these particular anticlinal structures. The Cat Creek, Big Wall, Sumatra, and other oil fields east of the Big Snowies are on relatively small folds which in turn lie along the somewhat flat top of the Big Snowy-Porcupine uplift. In northern Montana the Bowes oil and gas field is on a dome just north of the Bearpaw Mountains and the nearby Boxelder and Havre gas fields are on related structures. The Whitlash oil and gas field is on a broad dome lying between laccolithic mountains of the Sweetgrass Hills, and other domal structures close to these mountains have been found productive. Minor folding on the Sweetgrass arch and the Bowdoin dome is not so noticeable because of gentle dip of strata, generally less than 3 degrees, but some minor folds are present. The Reagan and Border-Red Coulee oil fields near the Canadian border are on plunging anticlines on the west side of the Sweetgrass arch, and other minor structural features are present and productive. The Kevin-Sunburst field (Sunburst dome) and the Pondera field are along the crest of the Sweetgrass arch, and include related minor folds, as well as subsurface paleogeographic features. The large Cut Bank oil and gas field results from a stratigraphic trap. Oil occurrence in eastern Montana is closely associated with anticlinal structure.

THE LITTLE BELT-BIG SNOWY-PORCUPINE UPLIFT

The structural pattern of central Montana is unique in that an elongated bench-shaped uplift, about 40 to 50 miles wide and 200 miles long, strikes eastward (S. 70° E.) from the front ranges of the Rockies. The Little Belt and Big Snowy Mountains and the Porcupine dome may be considered as high points on the uplift, but uplift is continuous. On the north, east, and south sides of the uplift, strata dip steeply, in many places in excess of 45 degrees, and locally up to perhaps 85 degrees; but across the top of the uplift the dip of strata is generally less than 5 degrees. The relatively flat top actually is irregular due to local folds extending nearly parallel to the easterly trend of the uplift. Some faulting is present. (See fig. 21).

The magnitude of uplift at its eastern end (Porcupine dome) is about 2,600 feet, and the bench-like shape of the uplift stops abruptly east of this dome in a somewhat rectangular manner. Due to soft, easily eroded strata at the surface, there is no topographic expression of the Porcupine dome, even though its structural closure is in the order of 1,250 feet. Amount of uplift in the Big Snowy Mountains is about 12,000 feet, and resistant Paleozoic strata are at the surface. Tertiary strata lie at the surface north, east, and south of the uplift as a whole, and upper Cretaceous strata lie at the surface over most of the central part of the uplift, except in the Big Snowy and Little Belt Mountains. Nearly complete sections of central Montana Mesozoic and Paleozoic strata are exposed in the Big Snowy and Little Belt Mountains, and aid in stratigraphic studies. Three major areas of laccolithic intrusion (North and South Moccasin and Judith Mountains) are present on the north side of the uplift north of Lewistown, and igneous dikes occur widely scattered throughout its length. Large sharp anticlinal folds 5 to 30 miles south of the main uplift (along Musselshell River) appear to be separate from the uplift, but they no doubt are related.

The origin of this major uplift, although problematical, may be due to faulting in the basement complex wherein the more plastic or flexible shaly rocks of the Mesozoic and Tertiary periods were bent upward along the lines of deep-seated faulting. Paleozoic strata were both folded and faulted. Interestingly, the trend of this uplift is in line with the major fault of the Coeur d'Alene mining district in Idaho 150 miles westward (Osborn fault). Also the easterly trend is nearly parallel to the Huntley fault zone 50 miles southward, and to the front of the Beartooth Mountains 100 miles southward. No structures which appear related occur northward or eastward unless possibly the easterly trend of the Bowdoin dome and Popular dome may be considered as such.

Also of interest are the reversals of earth movement in this region. In Precambrian time it was a basined area permitting the eastward tongue of Belt sediments to be deposited. (See fig. 6). It was raised somewhat in Devonian time. It was again basinal in late Mississippian time when 1,600 feet or more of Big Snowy sediments accumulated. And finally it was elevated many thousands of feet in Tertiary time. The Cedar Creek anticline appears to have gone through the same series of pulsations, although its trend is northwestward.

Much oil has been found on some of the minor folds of this uplift. Examples are Cat Creek, Big Wall, and Sumatra. However, stratigraphic traps for oil have been extremely important also. Commercial amounts of gas have not been found. This area is important to the oil industry because new oil fields may yet be discovered within it.

THE SWEETGRASS ARCH

The Sweetgrass Arch is a gentle anticlinal uplift, or up-warp, about 60 miles across, extending northward from Great Falls into Canada for a total distance of over 200 miles. The crest of the arch plunges (slopes) northward; rock formations at the surface along its top near Great Falls are about 1,500 feet deep near Shelby, and about 3,000 feet deep near Medicine Hat in Canada. The crest line bends eastward near the Canadian line. The average dip of strata is very gentle commonly as low as 50 feet per mile, or less than one degree. Colorado shale is exposed along its crest from Great Falls to Canada, and the Eagle sandstone skirts the central area on either side. The Sunburst dome with a structural closure of about 600 feet is a high place along the crest of the arch, and the Pondera structural nose distorts the trend of the crest to the west. The Sweetgrass Hills are a group of laccoliths on the eastern flank of the arch, and do not appear to be related to the arch structure. Most of the oil and gas produced in Montana so far has come from the Sweetgrass arch. It will be discussed further under description of fields.

The present Sweetgrass arch, elevated in Tertiary time, lies along the western side of an ancestral Sweetgrass arch of post-Paleozoic-pre-Jurassic age whose eastern margin lay near, or just east of the Little Rocky Mountains. Its width was about 200 miles. This ancient late Paleozoic arch vitally influenced the pattern of Paleozoic formations now lying immediately beneath the Jurassic (Ellis) strata, its influence extending even into central Montana. (See fig. 18). It was responsible for the removal or the omission of strata of several geologic periods in north central Montana. At Kevin and Havre and elsewhere Pennsylvanian, Permian, and Triassic strata are not present.

DISTURBED BELT

Lying immediately east of the main mountain front northward from Glacier Park and southward to beyond Augusta is a belt or zone of intensely crumpled and thrust-faulted Cretaceous and younger strata from 5 to 20 miles wide and 150 miles or more long. It constitutes a part of a structure basin between Browning and Augusta, the center of which may underlie the mountain front or perhaps even farther westward. This zone is significant, since within it lie the famous Turner Valley oil and gas field and other important fields in Canada. The strata were deformed by the earth forces which also caused the Lewis overthrust fault, a structure in which Precambrian strata of the Belt series have been thrust upward and over Cretaceous strata. Belt strata have been shifted eastward 15 miles or more along a slipping plane which at Glacier Park lies about 15 degrees from the horizontal as seen at the surface, Colorado shale and other strata have been overturned in asymmetrical folds, and the folds in turn are sliced parallel to their trends by thrust faults. The crests of many anticlines can be observed at the surface, but drilling has shown that thrust faults are likely to be present at depth, and the position of an anticline beneath such a thrust fault is difficult or impossible to determine without much drilling. The geology of this region is further complicated by a thick blanket of high-level gravel and some glacial drift that obscures bed-rock in most of the area. Geophysical exploration in this region has been most difficult, and results are not too reliable. It is hazardous to predict that commercial oil or gas fields lie within this area; nevertheless, it is underlain by strata which elsewhere not far distant yield quantities of both oil and gas, and only a few miles north in Canada, exceptionally large wet-gas wells have been completed.

About 30 deep wells have been sunk along a hundred miles or more of this zone in Montana. Due to faulting of strata, some wells bottomed in about the same horizon as that in which they started. Some passed through two or three fault planes. Some bottomed in Mississippian or even Devonian strata. A few good shows of oil and gas with commercial possibilities were encountered; however, as yet, no commercial production has resulted. No gas pipe-line serves the area (1959) and hence gas production is not possible.

Perhaps the most interesting of these test wells was that put down by the Union Oil Company near East Glacier, and also one put down by the Northern Natural Gas Company in Blackleaf Canyon. The Union well on the Morning Gun lease, near East Glacier, is reported to have flowed 6,000,000 cubic feet of gas and 52 barrels of oil distillate per day from the upper Madison limestone. Mechanical difficulties caused abandonment. A recent well sunk in this region is the Northern Natural Gas Company Government well (sec. 13, T. 26 N., R. 9 W.) which entered the Madison limestone three times in its total depth of 6,323 feet. In the second zone of Madison a flow of gas, reported as over 6,000,000 cubic feet per day, was found at a depth between 3,794 and 3,830 feet. The well was completed in June of 1958. Exploration is still being carried on in this region.

POWDER RIVER-SHEEP MOUNTAIN-WILLISTON BASIN

Striking northerly across eastern Montana is a great structural and depositional basin or geosyncline which extends far south into Wyoming, far east in North Dakota, and north into Canada. (See plate 2, in pocket). Although its component parts are known by individual name, such as Powder River basin, Sheep Mountain syncline, and Williston basin, it is in reality one large major unit of Great Plains geology, not only because of its major structural features, but also because of the type of strata. Paleozoic and Mesozoic strata deposited within it are somewhat similar for each formation across the region. The Cedar Creek anticline and the Poplar anticline would seem to separate the Williston basin of North Dakota from the area westward, and this separation is commonly made by the oil industry. However, from a stratigraphic point of view, such a separation should not be made. The structural features, as now observed at the surface, are later in origin than the deposition of early Tertiary strata, and hence they had little or no bearing on the deposition of Cretaceous and older strata; except that the Cedar Creek anticline and perhaps the Weldon fault are ancient structural trends of early Paleozoic age that appears to have been revived. Devonian strata may be missing locally on the Cedar Creek anticline. Subsurface studies show thickening of various deep-seated formations toward the center of the region now designated as Williston basin and definitely indicate a basin of deposition. But such thickenings as a whole bear no relationship to the anticlines of late origin. On the other hand, these anticlines and perhaps others, result in structural conditions favorable for oil and gas accumulation in the older strata; and they delineate trends of ancestral folding in Paleozoic strata.

Deep-seated structure in eastern Montana is not identical to surface structure in that (1) those structures with northwesterly trends (Cedar Creek, Poplar) may be more pronounced at depth, and may show structural closures not recognized at the surface, and (2) northeasterly structural trends occur in Paleozoic strata. The northeast trending Weldon fault zone and its northeastern projection into the Brockton-Froid fault zone may be surface manifestations of earlier Paleozoic structure. Also structural contour maps using Paleozoic formations as datum planes show at depth northeast-trending folds of 100 feet or more relief not observed at the surface (Richey area). Two or more large unconformities (pre-Jurassic, pre-Mississippian) lie one to two miles deep, and these could readily obscure Paleozoic structure. Geophysical (seismic) exploration is bringing forth much information concerning these deep-seated trends.

GEOLOGIC AGE OF DEFORMATION

The beginning of structural deformation of strata is commonly determined by the age of the youngest strata involved in the folding. At least this gives the time after which the folding must have occurred. In the Montana plains, strata of the early Tertiary (Paleocene) Fort Union formation are found bending up onto several of the uplifts. Examples are found near the Wyoming state line south of Hardin, near Red Lodge, at the northern end of the Crazy Mountain syncline, at Roundup, east of the Porcupine dome, on the flanks of the Baker-Glendive and Poplar anticlines, and in northwestern Montana near Glacier Park. The Fort Union strata are not present on the tops of the uplifts, but undoubtedly they were removed by more recent erosion. Examination of the lithologic character of the Fort Union strata from one side of an uplift to the other side leads to the conslusion that when these strata were being deposited, they were one continuous blanket throughout the region. Of course, as previously stated, the Fort Union strata are believed to be outwash material deposited on piedmont plains lying in front of the main ranges of the Rockies, and, as such they differ in lithology from place to place; nevertheless, the variations are not such that great mountain ranges like the Big Snowies and the Big Horns, or the Black Hills, are believed to have been present as barriers at the time of deposition. Hence, it follows that much or most of the observable uplift or folding in the Montana plains occurred after the deposition of the Fort Union formation.

The end of the period of deformation is not so easily determined. However, on many of the eroded surfaces are terrace or high-level gravel deposits spreading outward from the areas of uplift. Their age is indefinite, but probably middle to late Tertiary; some are thought to be Pliocene.

In general then, it is probable that most of the uplift and folding as seen at the surface of the Montana Great Plains, including the laccolithic intrusions, occurred during Eocene times.

This is a later time of earth movement than most of the intensive compressive deformation of the mountain area of western Montana which is commonly considered as Late Cretaceous (Laramide) in age. The block-faulted mountains of Western Montana are considered early to middle Tertiary because of middle Tertiary fossils present in the extensive lake deposits. Age of deformation or uplift has a bearing on stratigraphic studies and determinations in the plains area.

As stated elsewhere, a remarkable parallelism of all Paleozoic and Mesozoic strata in Montana is noticable. This indicates an absence of intense mountain making during their deposition. Periods of ancient Paleozoic uplift of the nature of warping are recognized by the absence of formations normally present in the geologic column. Examples are: (1) in western Montana where Devonian strata lie on Cambrian strata, rocks of the Silurian and Ordovician periods being absent; (2) in southern Montana where the Big Snowy group of strata are missing, and (3) in northern Montana where upper Jurassic strata lie on lower Mississippian strata, and the Pennsylvanian, Permian, and Triassic strata are missing. Many more examples may be cited. These interruptions in the continuous deposition of strata (called unconformities) are shown graphically on plate 1 by means of vertically ruled lines, and to a large extent indicate times of upward warping of parts of the earth's surface.

PRE-JURASSIC GEOLOGY IN CENTRAL MONTANA

A stratigraphic condition confusing to some geologists new in Montana is the occurrence immediately beneath the Jurassic Ellis group of formations of strata ranging in age from Early Mississippian in the northern part of the State to Triassic in the southern part of the State, and involving about eight different geologic formations. This condition is caused by a long interval of erosion during late Paleozoic and early Mesozoic time. The sequence of strata in southern Montana is further complicated by the absence of three or four formations between the Early Mississippian Madison formation and the Late Mississippian or Pennsylvanian Amsden formation (fig. 18). Recognition of these conditions is important in subsurface studies.

As previously mentioned, after the widespread deposition of the Madison group, including the evaporites of the Charles formation, the clastic Big Snowy group (Heath, Otter, and Kibbey) along with Tyler were deposited in central Montana; but the southern limit of Big Snowy deposition is probably somewhere between Yellowstoneand Musselshell Rivers. Following this deposition, the Amsden (and Alaska Bench?) limestone was laid down throughout the entire region, it being deposited on the Madison group in southern Montana, but on the Big Snowy group in central Montana. In southern Montana deposition of the Pennsylvanian Tensleep formation, the Permian Embar, and the Triassic Chugwater followed.

The erosion surface at the end of Paleozoic time, which spread from Alberta southward toward Billings, cut into the Paleozoic strata which were tilted slightly southward resulting in a general truncation of successively younger formations from north to south. The marine Jurassic Ellis formations were then spread across the beveled edges of the Paleozoic formations. The time of the beginning of the erosion is not easy to determine; it was probably progressive from north to south. The terrestrial Chugwater formation of Triassic age of Wyoming may be a depositional phase related to the erosion northward. In any case, far north in Canada, Devonian strata directly underlie Mesozoic strata. In the Kevin-Sunburst field in northern Montana the Madison limestone underlies the Ellis. The limestone was deeply eroded, and the solution, dolomitization, and silicification of the Madison surface resulted in the porosity and the oil reservoirs of that region. Big Snowy strata appear beneath the Ellis a short distance south of Great Falls, and Big Snowy and Amsden strata also appear near Lewistown in central Montana. The Pennsylvanian strata appear somewhere between Musselshell and Yellowstone Rivers, and at about Billing or a little southward Triassic strata underlie the Ellis group.

Pre-Ellis structure in the Paleozoic strata also affected the distribution or pattern of formational outcrops. Most outstanding is the ancestral Sweetgrass arch extending from Great Falls northward into Canada. However, the ancestral arch was much wider than the arch as seen today. Its eastern limb was perhaps 100 miles farther eastward, somewhere in the vicinity of the Little Rocky Mountains or even farther eastward. This huge Paleozoic arch resulted in the large sweeping semilircular curves in the pre-Ellis formational exposures. This condition likewise affected the pattern of formations beneath the Ellis in northeastern Montana, and an east-west geologic cross-section of upper Paleozoic formations from the Kevin-Sunburst field to Williston, North Dakota, is not greatly different from a north-south section made between the Kevin-Sunburst field, Billings, and Wyoming. The difference between two cross-sections such as these would be largely in thicknesses and lithologic variations, wherein the formations undergo facies changes from west to east. However, the section to Wyoming would differ in that the Big Snowy group of strata would be missing near the Wyoming line. Also, Silurian strata are present in the Williston region and not present south of Billings.

The pre-Ellis distribution of formations in Montana is shown on the accompanying map, Pre-Jurassic Paleogeologic Map of Montana and Adjacent Areas, (fig. 18). Admittedly the bounding lines of formations are approximate, and rather definitely these lines should be irregular in a pattern like the erosional outcrop patterns of gently dipping formations of today. Nevertheless, the map does show in a general way what may be expected to underlie the Ellis strata. It also follows that in the same manner as the Madison limestone in the Kevin-Sunburst field was leached and creviced by erosion, the Amsden limestone in central Montana could have been similarly affected so as to develop oil reservoirs. The Amsden yields oil in the Big Wall, Sumatra, Wolf Springs, and other fields in central Montana where it directly underlies Ellis strata.

DISTRIBUTION OF SEDIMENTARY ROCKS IN MONTANA

To aid in the understanding of general geological conditions in Montana, the accompaning suite of maps and diagrams (figs. 6 through 17) showing the distribution of the various sedimentary rocks by periods is reproduced. Much of the information comes from the interpretation of the logs of widely scattered deep wells in most places many miles apart. Hence the bounding lines on the maps are approximate, and in reality should be irregular, rather than straight in pattern. These maps are subject to revision, however, they show regional areas where strata of the individual geologic periods are to be expected. They also indicate lithologic (facies) changes from place to place, and the use of different formational names for equivalent strata in different localities.

Major breaks in the stratigraphic column are found (1) between the basal complex and the Precambrian Belt series, (2) between the Belt series and Cambrian strata, (3) between Cambrian and Devonian strata in western Montana, (4) between Ordovician and Devonian strata in central Montana, (5) between Mississippian and Jurassic strata, and (6) at the top of Paleocene strata. Many lesser interruptions in sedimentation, involving parts of nearly all geologic periods, preclude continuous or uninterrupted sequences of sediments. For example, in southern Montana the Big Snowy group is missing between Madison and Amsden strata, all Mississippian in age. In eastern Montana Devonian strata may be missing locally between Mississippian and Silurian strata. Remarkable is the nearly complete parallelism of all Paleozoic and Mesozoic strata, even in areas where strata of two or even three geologic periods are missing. Angularity in unconformity is slight and seldom evident, except in Pre-Cambrian formations and Tertiary or Recent sediments. Even in the mountain area where strata were crumpled by Laramide orogeny all Paleozoic and Mesozoic strata lie nearly parallel in the sweeping folds of the mountains. To a lesser degree this is also true of strata of the Belt series.

On the maps to which reference is made above (figs. 6 through 17) the large eastern tongue of Belt strata reaching past Lewistown gives evidence of the antiquity of a basin area extending through central Montana. Also shown are: (1) The eastward thinning of Cambrian strata. (2) The thickening of Ordovician and Silurian strata into the Williston basin, together with the western termination of each. (3) the absence of Devonian strata between Lewistown and Billings, and in southeastern Montana. (4) The distribution of three divisions of Mississippian strata, wherein the strata of each division overlap in places. (5) The distribution of Pennsylvanian, Permian, and Triassic strata and the use of different formational names for equivalent strata in different localities.

Such maps aid in the interpretation of deep well records.

OIL AND GAS OCCURRENCE

Both oil and gas in Montana are produced from sandstone and limestone (or dolomite) reservoir rocks. Structurally, both are produced from anticlinal or domal structures, but the largest deposits occur in stratigraphic traps caused by lenses of sandstones, by decrease in porosity in sandstones, or by local development of porosity in limestone (or dolomite). Depth ranges from 400 feet near Havre to 12,600 feet in the Brorson field near Sidney. In some areas only gas has been found, in some areas only oil has been found, and in other areas both oil and gas occur in the same horizon (such as a sandstone) or in different horizons in the same field. The Cut Bank field, about 30 miles long, and the largest producer of both oil and gas, is considered as having resulted from a stratigraphic trap due to decrease in porosity in sandstone on a monoclinal dip. Accumulations of oil in the Kevin-Sunburst field, 10 to 15 miles across and lying far down on the northwest flank of the Sunburst dome, (but not on its crest), results largely from development of porosity by leaching, dolomitization and silification of Madison limestone. The gas production in this field, coming from the Sunburst sandstone about 300 feet stratigraphically higher than the Madison, extends across the top of the dome, but does not follow the pattern of structural contours, due to variations in porosity of the sandstone. Oil in the Pondera field occurs in a manner similar to that in the Kevin field. The Cat Creek, Dry Creek, Elk Basin, and Bowes fields lie on sharp and much faulted anticlinal domes, the oil and gas coming mainly from persistent sandstones. The Whitlash and other fields in the Sweetgrass Hills area are anticlinal, but the main producing sandstones are lenticular, and productive areas in this region do not always conform to the structural pattern. The Baker-

Glendive and Bowdoin-Saco shallow gas fields are anticlinal and domal. Oil accumulation in Paleozoic strata in eastern Montana along the Cedar Creek anticline and in the Richey and Poplar fields appears to be controlled by anticlinal structure, but porosity variations in dolomite associated with extensive fracture systems are important in localization of commercial wells. Several anticlinal and domal structures elsewhere in Montana (along Musselshell River), which from the surface expression would appear ideal for oil and gas accumulation, have been tested without favorable results. Hence, the structural conditions are important, but they are not the controlling factor in many places.

The commercial gas fields lie in three general areas: (1) A belt about 50 miles wide and 250 miles long immediately south of the Canadian border, (2) an area west, southwest and southeast of Billings within a radius of 75 miles and adjoining Wyoming, and (3) near the eastern margin of the State. Commercial amounts of gas have not been found in the central part of the State although several important oil fields are in that area which constitutes a fourth petroliferous region in Montana.

Commercial amounts of oil and gas have been produced from 20 or more geologic formations ranging from Ordovician to Late Cretaceous in age, but of course no one field produces from all of these formations. In most fields only one or two formations are productive. The geologic occurrence is shown on the accompanying sheet showing composite stratigraphic sections in different fields (fig. 5). The producing horizons in many fields are given a local name rather than the geological formational name. Thus in the Cut Bank field the lower producing sandstone lying in or near the base of the Kootenai formation is called Cut Bank sand, and also there are the Sunburst sand or the Moulton and Darling sands stratigraphically higher in the Kootenai. In the Kevin-Sunburst field the gas-producing sandstone in the Kootenai formation is called the Sunburst sand. In the Sweetgrass Hills area a gas-producing sandstone in the Blackleaf member of the Colorado shale is called whitlash sand. Gas-bearing sandstones in the Bowdoin-Saco field occurring approximately at the position of the Frontier formation or a little higher are called Bowdoin and Phillips sands. And there are many other local names in the various fields. Hence a dual nomenclature exists; but to those operating in this region, it causes no confusion, in fact each local name carries a specific meaning. Additional information concerning names, character, and thickness of producing horizons is given in that section of this report dealing with description of fields.

Until 1951, the commercial oil fields were in a belt about 100 to 150 miles wide, paralleling and lying immediately east of the Rocky Mountain front. Deep drilling following 1950 made known the presence of oil in deep-lying Paleozoic strata (1 to 2 miles deep) in easternmost Montana, and by 1959 this region had produced 19.6 percent of the State's grand total of 304,268,000 barrels of oil in its 8 years of life. This comparison is misleading because these eastern oil fields are only 8 years old, whereas several of the central Montana fields are nearly 40 years old.

Between the four regions of known oil and gas production shown on Fig. 1 lie broad areas as yet unproductive, 50 miles or more across and up to 200 miles long, underlain by strata which in adjacent areas are highly productive of oil or gas. Large anticlinal structures are not known, excepting Porcupine dome and anticlines along Musselshell River; but many minor structures are, or should be, present. Many test wells have been drilled in these problematical areas. In view of the possibility (or probability) of stratigraphic traps, and in view of the possible presence of deep-seated structures obscured by unconformities, these areas are intriguing to the oil industry. Their future potentialities will be made known largely by additional deep drilling.

Table 3.—Production of oil and gas in Montana by districts

District	Gas in 1958 1,000 cu. ft.	Percent Gas 1958	Oil in 1958 Barrels	Percent Oil 1958	Cumulative Oil Barrels	Percent Cumulative Oil
Northern	19,515,242	63.0	4,348,256	15.5	175,030,000	57.5
Central	Nil	Nil	3,201,003	11.5	34,565,000	11.4
Southern	3,326,275	10.7	3,590,554	12.8	34,969,000	11.5
Eastern	7,386,689	23.9	16,816,836	60.2	59,625,000	19.6
Misc.	737,052	......	341	......	79,000	......
Total	30,965,253	100.0	27,956,649	100.0	304,268,000	100.0

Table 4.—Production of oil and gas in Montana by geologic periods

Formation	Gas in 1958 1,000 cu. ft.	Percent Gas 1958	Oil in 1958 Barrels	Percent Oil 1958	Cumulative Oil Barrels	Percent Cumulative Oil
Mesozoic	27,866,336	90	2,939,282	10.5	117,268,000	38.5
Perm-Penn-Miss.	3,098,917	10	13,347,152	47.7	151,332,000	49.8
Dev-Sil-Ordo.			11,669,874	41.7	35,589,000	11.7

Table 2.—Statistics of Montana Oil Fields.

From Montana Oil and Gas Conservation Commission.

Line No.	Field (or Pool)	County	Year Discovered	Production Formation	Approx. Depth (2)	No. of Oil Wells Producing 1/59 (3)	No. of Oil Wells Completed 1958 (4)	A.P.I. Gravity (5)	Net Pay Feet (7)	Porosity % (8)	Estimated Proven Acres as of 1/59 (13)	Estimated Primary Recovery % (15)	Ultimate Primary Recovery in 1000's Bbl. (16)	Cumulative Production to 1/59 in 1000's Bbl. (17)	Annual Production in 1958 in Bbls. (18)	Ultimate Primary Recovery Bbl. Acre-Ft. (21)	Line No.
1	Ash Creek	Big Horn	1952	Shannon (U. Cret.)	4,500	4	0	34	14	22	160	26	620	249	34,316	276	1
2	Bannatyne	Teton	1927	Swift (U. Jur.)	1,450	6	4	27	39	15	170	5	209	70	7,450	32	2
3	Bears Den	Liberty	1924	Kootenai (L. Cret.)	2,300	3	0	39	20	12	80	15	134	89	4,190	84	3
4	Belfry	Carbon	1958	Fuson (L. Cret.)	9,844	1	1	38	20	11.25	80	50	338	2	2,029	211	4
5	Berthelote	Toole	1929	Kootenai (L. Cret.)	2,422	2	0	36	35	—	50	....	91	23	1,488	52	5
6	Big Wall	Musselshell	1948	Tyler (U. Miss.)	3,000	14	0	31	22	17	540	42	3,880	2,654	141,427	326	6
7	Big Wall	Musselshell	1953	Amsden (L. Penn.)	2,500	14	1	19	17	16	280	27	1,017	546	80,496	214	7
8	Blackfoot	Glacier	1955	Sun River (Miss.)	3,550	11	5	25	8	14	480	30	434	180	97,781	113	8
9	Blackfoot	Glacier	1955	Kootenai (L. Cret.)	3,500	4	1 rc	30	15	15	160	25	409			170	9
10	Border	Toole	1929	Kootenai (L. Cret.)	2,400	8	0	31	22	15	300	23	1,145	1,072	7,695	173	10
11	Bowes	Blaine	1949	Sawtooth (M. Jur.)	3,250	87	0	20	22	12	4,990	25	14,097	5,023	277,263	128	11
12	Brady-Midway	Pondera	1943	Kootenai (L. Cret.)	1,450	5	0	35	5	11	200	15	72	14	806	72	12
13	Bredette	Roosevelt	1955	Charles (Miss.)	6,550	1	0	40	19	6	400	16	201	177	10,616	26	13
14	Bredette, North	Roosevelt, Daniels	1956	Charles (Miss.)	6,720	5	1	38	18	6	480	50	740	348	151,261	85	14
15	Brorson	Richland	1954	Mission Canyon (Miss.)	9,744	3	1	32	92	4	160	50	910	270	28,760	62	15
16	Bynum	Teton	1955	Madison (Miss.)	2,950	2	0	40	18	16	320	25	533	5	1,452	93	16
17	Cabin Creek (West Flank)	Fallon	1953	Siluro-Ordovician	8,300	33	4	33	94	11	2,200	30	29,766	8,995	3,570,453	144	17
18	Cabin Creek (East Flank)	Fallon	1957	Siluro-Ordovician	8,450	37	23	34	40	11.5	2,960	30	17,976			152	18
19	Cabin Creek	Fallon	1956	Mission Canyon (Miss.)	7,300	18	0	33	25	11	1,060	30	7,855	1,583	715,084	296	19
20	Cat Creek (Antelope-Mosby)	Petroleum-Garfield	1920	Kootenai (L. Cret.)	1,225	4	0	52	10	21	200	22	528	500	3,592	264	20
21	Cat Creek (West Dome)	Petroleum-Garfield	1920	Kootenai (L. Cret.)	1,100	31	0	52	51	21	920	22	16,300	15,263	52,256	348	21
22	Cat Creek	Petroleum-Garfield	1945	Morrison (U. Jur.)	1,600	6	0	52	6	22	120	32	214	187	5,075	298	22
23	Cat Creek	Petroleum-Garfield	1945	Swift (U. Jur.)	1,750	47	0	52	25	18	880	30	4,987	3,288	110,327	226	23
24	Clark's Fork	Carbon	1954	Frontier (U. Cret.)	6,730	1	0	43	28	14	40	15	89	62	3,062	80	24
25	Clark's Fork, North	Carbon	1956	Lakota (L. Cret.)	8,940	4	1	50	19	19	400	35	1,240	520	274,843	163	25
26	Clark's Fork, North	Carbon	1957	Dakota (L. Cret.)	8,750	1	0	56	11	20	80	25	125	30	25,407	142	26
27	Cupton	Fallon	1955	Red River (U. Ord.)	9,800	2	0	33	90	13	160	12	755	86	20,082	52	27
28	Cut Bank	Glacier	1932	Kootenai "Cut Bank" (L. Cre	2,950	990	12	38	15	15	48,800	18	91,943	79,702	1,668,218	125	28
29	Cut Bank	Glacier	1935	Kootenai "Lander" (L. Cret.)	2,900	28	0	35	12	18.8	1,120	25	2,714			202	29
30	Cut Bank (Darling Area)	Glacier-Toole	1939	Kootenai "Moulton" (L. Cret.)	2,550	46	1	38	28	12.5	1,350	25	5,090	2,190	126,775	135	30
31	Cut Bank (North)	Glacier	1945	Madison (Miss.)	3,000	62	0	39	10	14	3,240	25	5,596	4,445	315,177	173	31
32	Cut Bank (Caughlin)	Toole	1955	Madison (Miss.)	2,400	6	0	37	13	15	110	50	530	347	58,594	370	32
33	Cut Bank (South Darling)	Glacier	1954	Madison (Miss.)	2,800	8	1	30	12	14	260	25	539	158	36,004	173	33
34	Cut Bank (Dahlquist)	Glacier-Toole	1946	Kootenai "Cut Bank" (L. Cret.)	2,650	13	0	38	11	15	180	35	360	322	12,684	182	34
35	Deer Creek	Dawson	1952	Red River (U. Ord.)	9,850	3	0	42	112	6.7	480	24	3,600	926	97,738	67	35
36	Deer Creek	Dawson	1952	Interlake (Sil.)	9,440	3	1 rc	42	71	7	240	25	1,232	36	23,625	72	36
37	Delphia	Musselshell	1957	Amsden (L. Penn.)	6,290	5	4	35	12	6.5	440	40	650	117	56,828	123	37
38	Devil's Basin	Musselshell	1919	Heath (U. Miss.)	1,200	5	2	24	11	17	120	10	61	34	5,658	47	38
39	Dry Creek	Carbon	1930	Greybull (L. Cret.)	5,600	2	0	52	12	12	1,700	25	2,314	3,827	73,503	113	39
40	Dry Creek	Carbon	1932	Pryor (L. Cret.)	5,800	5	0	52	30	12	1,000	25	4,000			133	40
41	Elk Basin	Carbon	1915	Frontier (U. Cret.)	1,200	11	0	45	97	21	120	25	2,897	28,119	3,039,762	250	41
42	Elk Basin	Carbon	1942	Embar-Tensleep (Perm. Penn.)	4,900	29	0	29	166	10.5	1,376	25	26,117			114	42
43	Elk Basin	Carbon	1946	Madison (Miss.)	5,150	9	2	28	224	11.6	920	25	26,838			130	43
44	Elk Basin (Northwest)	Carbon	1947	Frontier (U. Cret.)	3,375	9	0	47	28	18.91	120	25	669			199	44
45	Elk Basin (Northwest)	Carbon	1947	Madison (Miss.)	6,215	2	0	35	16	19	350	25	1,535			274	45

Table 2.—Statistics of Montana Oil Fields—Continued.

Line No.	Field (or Pool)	County	Year Discovered	Production Formation	Approx. Depth (2)	No. of Oil Wells Producing 1/59 (3)	No. of Oil Wells Completed 1958 (4)	A.P.I. Gravity (5)	Net Pay Feet (7)	Porosity % (8)	Estimated Proven Acres as of 1/59 (13)	Estimated Primary Recovery % (15)	Ultimate Primary Recovery in 1000's Bbl. (16)	Cumulative Production to 1/59 in 1000's Bbl. (17)	Annual Production in 1958 in Bbls. (18)	Ultimate Primary Recovery Bbl. Acre-Ft. (21)	Line No.
46	Fertile Prairie	Fallon	1954	Red River (U. Ord.)	9,200	3	0	33	49	5.6	320	18	684	122	17,155	44	46
47	Flat Coulee	Liberty	1928	Swift (U. Jur.)	1,500	1	0	30	7	16	80	20	88	28	1,735	157	47
48	Frannie	Carbon	1928	Phosphoria-Tensleep (Perm. Penn.)	2,700	2	0	27	29	19	80	25	705	413	40,554	304	48
49	Gage	Musselshell	1943	Amsden (L. Penn.)	6,000	2	1	34	18	10	320	25	542	466	7,757	94	49
50	Gas City	Dawson	1955	Red River (U. Ord.)	8,700	12	0	38	31	11	1,120	25	4,152	1,008	279,820	119	50
51	Glendive	Dawson	1952	Stony Mtn.-Red River (U. Ord.)	8,700	12	0	38	147	6.5	1,040	24	9,610	3,825	616,226	63	51
52	Gypsy Basin	Pondera	1958	Sun River (Miss.)	3,150	3	1	....	....	....	120	....	....	2	1,922	......	52
53	Hawk Creek	Musselshell	1958	Amsden (L. Penn.)	7,100	1	1	38	11	2.3	40	50	22	1	1,245	48	53
54	Ivanhoe	Musselshell	1953	Morrison (U. Jur.)	2,800	2	0	30	10	15	80	25	121	84	5,028	151	54
55	Ivanhoe	Musselshell	1956	Tyler (U. Miss.)	4,050	11	3	33	31	15.8	280	35	2,110	925	311,933	243	55
56	Kevin-Sunburst	Toole	1922	Madison (Miss.)	1,500	1,433	18	32	6.5	20	40,205	30	72,598	63,947	902,360	278	56
57	Lake Basin	Stillwater	1925	Dakota (L. Cret.)	3,800	1	0	44	22	....	120	....	513	474	211	194	57
58	Line Coulee	Daniels	1957	Charles (Miss.)	6,410	2	1	34	6	11	160	40	170	44	39,753	177	58
59	Little Beaver	Fallon	1952	Red River (U. Ord.)	8,300	9	0	29	37	12	710	17	2,330	888	179,552	86	59
60	Little Beaver East	Fallon	1954	Red River (U. Ord.)	8,300	5	2	30	29	12.5	500	10	763	162	83,763	53	60
61	Melstone	Musselshell	1948	Tyler (U. Miss.)	4,250	9	1	34	25	12	360	30	1,615	1,093	94,776	179	61
62	Monarch	Fallon	1958	Interlake (Sil.)	8,400	1	0	32	31	11	80	25	313	7	6,701	126	62
63	Mosser	Yellowstone	1936	Kootenai (L. Cret.)	1,000	6	0	22	15.4	23.6	96	18	337	145	7,232	228	63
64	Outlook	Sheridan	1956	Siluro-Devonian	9,000	13	8	38	20	5	960	40	1,728	585	451,112	90	64
65	Outlook	Sheridan	1957	Red River (U. Ord.)	9,900	1	0	33	35	5	80	40	196	79	47,443	70	65
66	Pennel	Fallon	1955	Siluro-Ordovician	8,800	21	0	33	60	12.6	2,589	24	22,430	1,691	594,040	144	66
67	Pennel	Fallon	1957	Mission Canyon (Miss.)	7,000	1	0	12	38	3.4	80	30	153	13	4,964	50	67
68	Pine	Dawson, Wibaux, Fallon, Prairie	1952	Siluro-Ordovician	8,400	135	20	34	40	11.5	8,840	30	56,753	16,327	5,358,011	160	68
69	Pondera	Pondera, Teton	1927	Sun River (Miss.)	2,100	336	10	34	15	16	5,440	35	20,325	14,077	558,655	249	69
70	Poplar, East	Roosevelt	1952	Charles-Mission Canyon (Miss.)	5,550	108	3	40	25	11	17,909	30	102,081	20,248	4,024,865	227	70
71	Poplar, Northwest	Roosevelt	1952	Charles-Mission Canyon (Miss.)	6,200	4	0	40	16	10.3	400	30	770	191	23,787	120	71
72	Ragged Point	Musselshell	1947	Kibbey (U. Miss.)	4,400	3	0	33	28	11	140	35	645	477	30,594	164	72
73	Ragged Point	Musselshell	1956	Tyler (U. Miss.)	3,580	4	0	32	14	14.5	220	30	612	185	95,957	198	73
74	Reagan	Glacier	1947	Sun River (Miss.)	3,200	45	1	38	10	16	1,966	30	4,659	2,227	166,634	236	74
75	Red Creek	Glacier	1958	Kootenai (L. Cret.)	2,600	8	8	33	20	19.2	200	25	955	10	9,639	239	75
76	Red Creek	Glacier	1958	Sun River (Miss.)	2,750			28	18	13	280	18	578			115	76
77	Red Stone	Sheridan	1958	Winnipegosis (Dev.)	9,400	1	1	39	30	7	80	35	228	3	3,413	95	77
78	Repeat	Carter	1956	Red River (U. Ord.)	8,610	1	0	23	25	10	80	32	340	100	47,000	173	78
79	Richey	Dawson, McCone	1951	Charles (Miss.)	7,000	9	3	39	25	4	940	25	2,244	1,065	117,866	45	79
80	Richey, Southwest	McCone	1952	Interlake (Sil.)	9,200	1	1	48	21	9	300	35	730	471	46,956	116	80
81	Richey, Southwest	McCone	1952	Dawson Bay (Dev.)	9,130	1	0	48	6	9	300	35	225			125	81
82	Snyder	Big Horn	1952	Tensleep (Penn.)	4,550	4	0	21	12	20	149	30	467	221	26,560	261	82
83	Soap Creek	Big Horn	1920	Amsden (L. Penn.)	1,825	13	0	17	12	15	150	25	326	873	63,075	180	83
84	Soap Creek	Big Horn	1923	Madison (Miss.)	1,925	16	0	20	18	15	310	25	1,007			180	84
85	Stensvad	Rosebud	1958	Tyler (U. Miss.)	5,500	2	0	33	46	14	80	30	540	3	2,864	147	85
86	Sumatra	Rosebud	1949	Tyler-Heath (U. Miss.)	4,500	67	12	32	30	18.5	2,780	20	13,399	7,045	1,582,525	161	86
87	Sumatra	Rosebud	1955	Amsden (L. Penn.)	4,000	5	0	29	8	20	200	25	367	134	30,036	229	87
88	Whitlash	Liberty	1927	(L. Cret.)	1,400	35	5	38	15	21	1,040	25	4,784	1,099	91,734	307	88
89	Wills Creek	Fallon	1957	Siluro-Ordovician	8,500	9	8	32	70	12	720	25	7,340	239	225,590	146	89
90	Wolf Springs	Yellowstone	1955	Amsden (L. Penn.)	6,200	20	0	30	18	3.6	4,250	50	7,520	1,597	582,288	98	90
91	Woodrow	Dawson	1952	Charles (Miss.)	7,800	2	0	32	19	17.3	160	10	189	97	30,006	62	91
92	Yellowstone	Dawson	1953	Red River (U. Ord.)	8,800	1	0	38	24	....	80	—	57	39	1,194	10	92
93	Miscellaneous Abandoned Fields												81	79	341	......	93
	TOTALS					3,971	173				176,230		629,752	304,268	27,956,649		

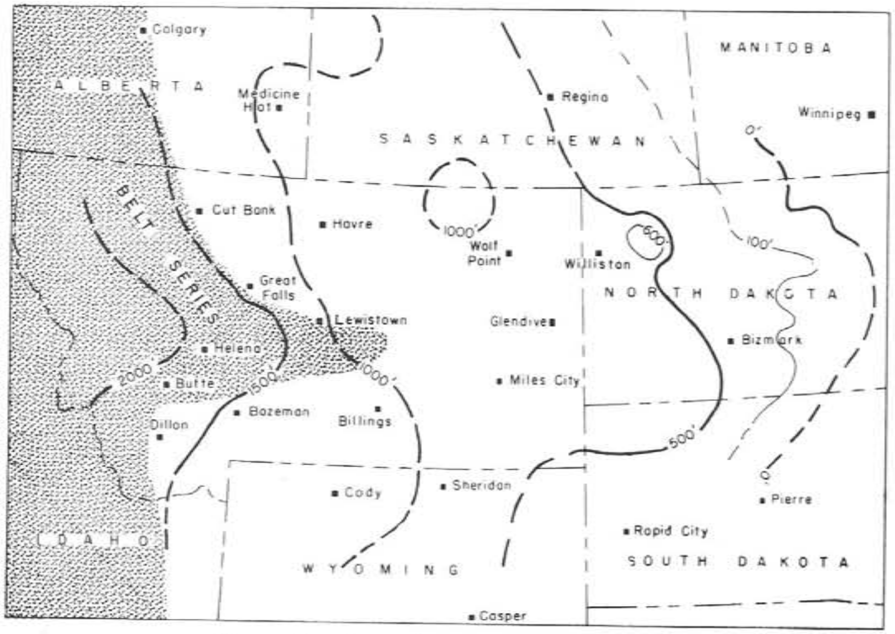

Figure 6.—Isopach map of Cambrian strata

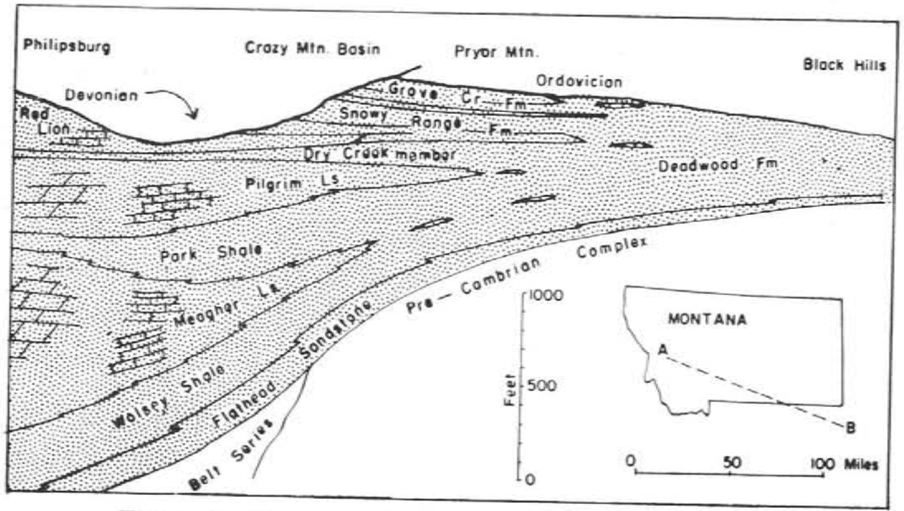

Figure 7.—Diagrammatic cross-sections of Cambrian strata. (Modified from Billings Geol. Soc., Guidebooks.)

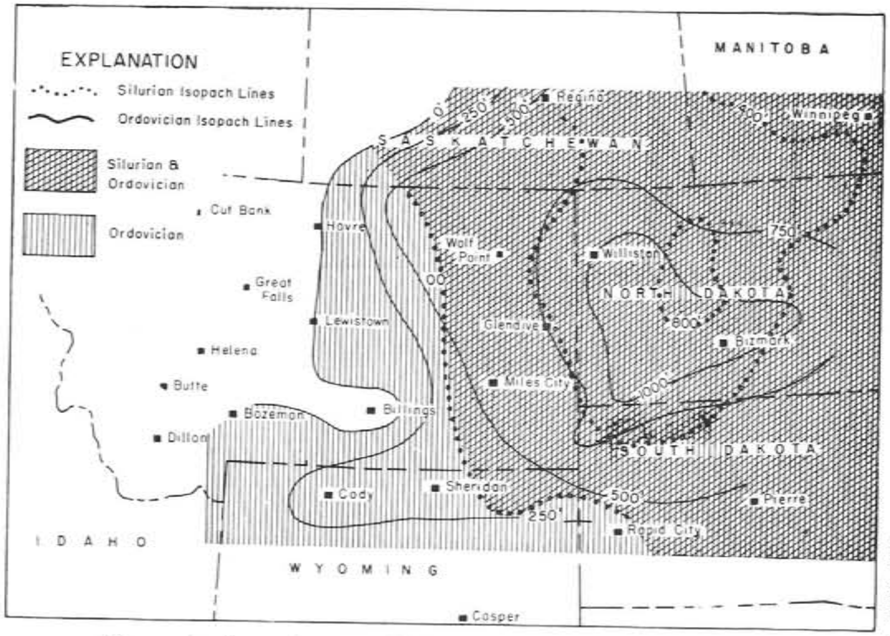

Figure 8.—Isopach map of Ordovician and Silurian strata.

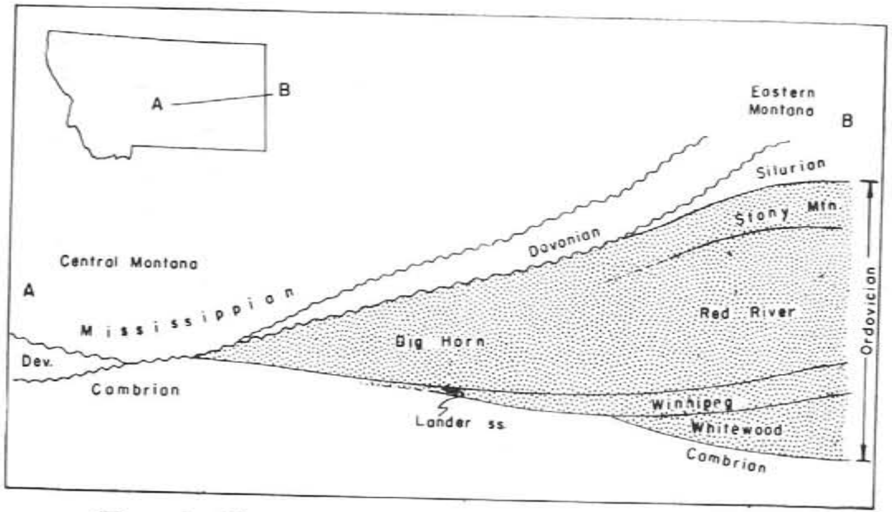

Figure 9.—Diagrammatic cross-section of Ordovician strata. (Modified from Billings Geol. Soc., Guidebooks.)

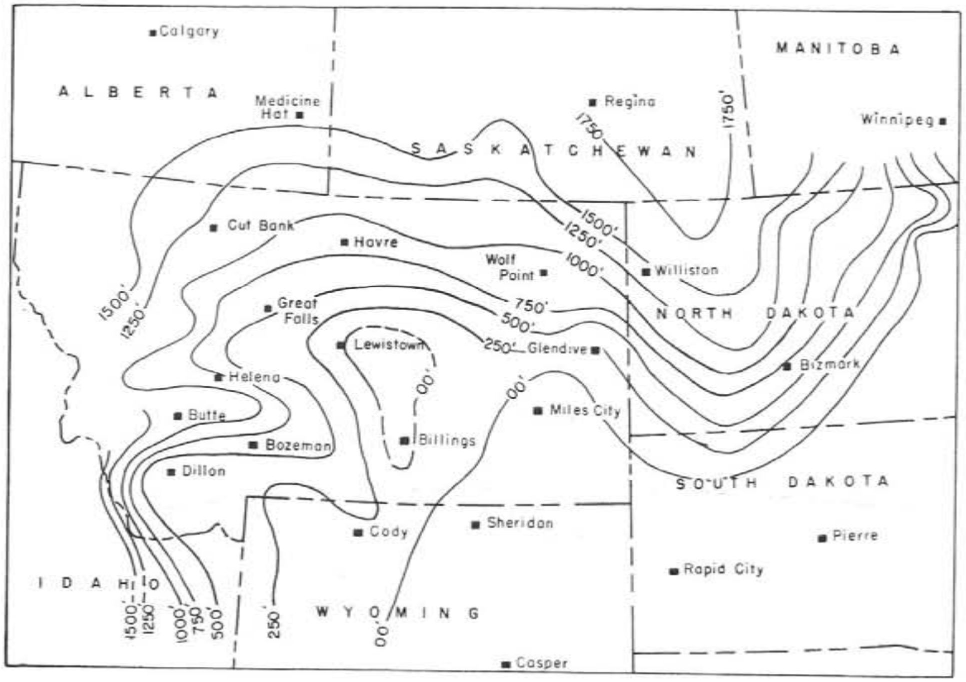

Figure 10.—Isopach map of Devonian strata. Modified after Billings Geo. Soc., Guidebooks.

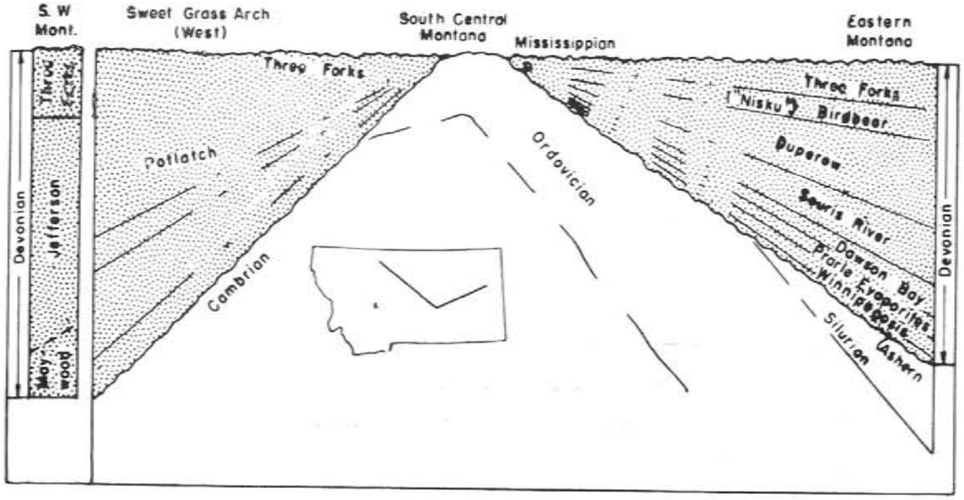

Figure 11.—Diagrammatic cross-sections of Devonian strata. Modified from Billings Geol. Soc. Guidebooks.

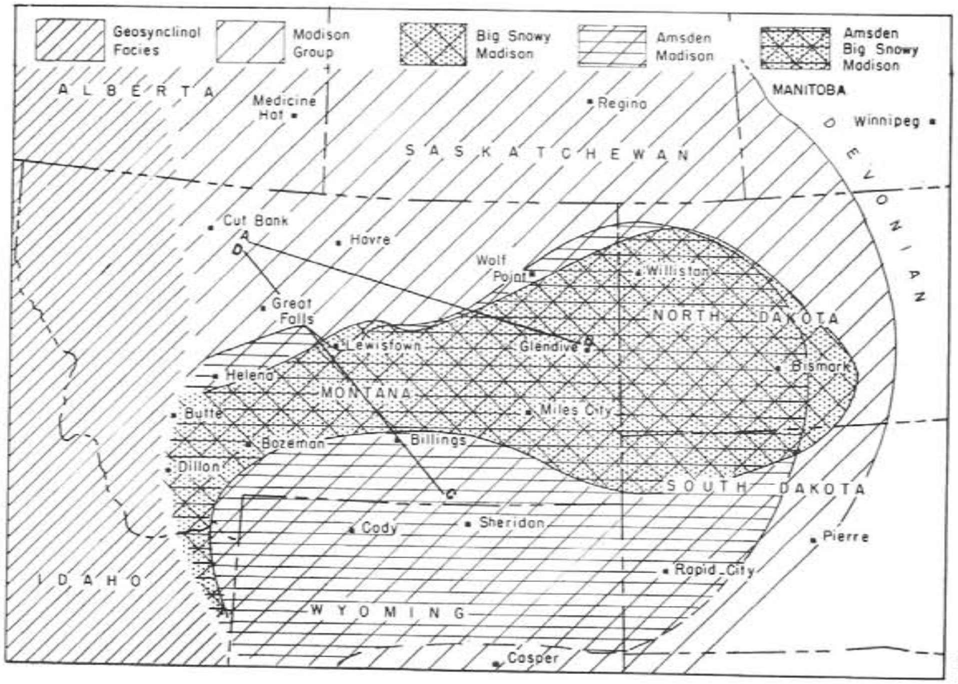

Figure 12.—Map of Mississippian formations.

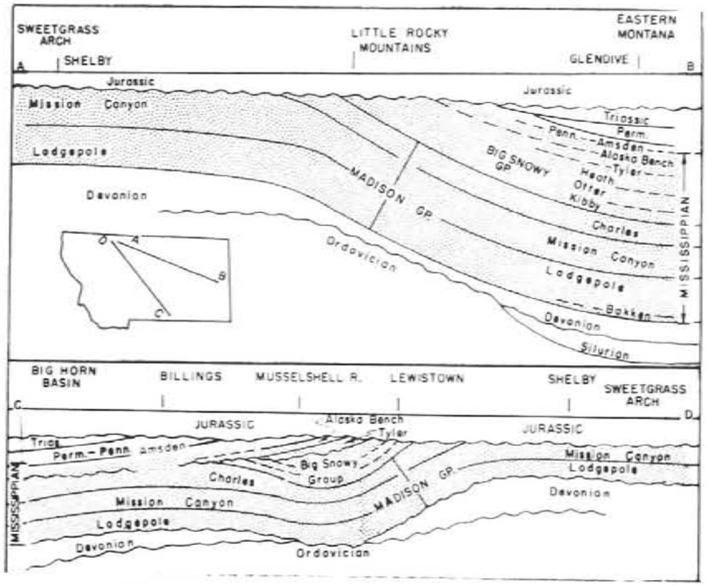

Figure 13.—Diagrammatic cross-sections of Mississippian strata. Modified from Billings Geol. Soc., Guidebooks.

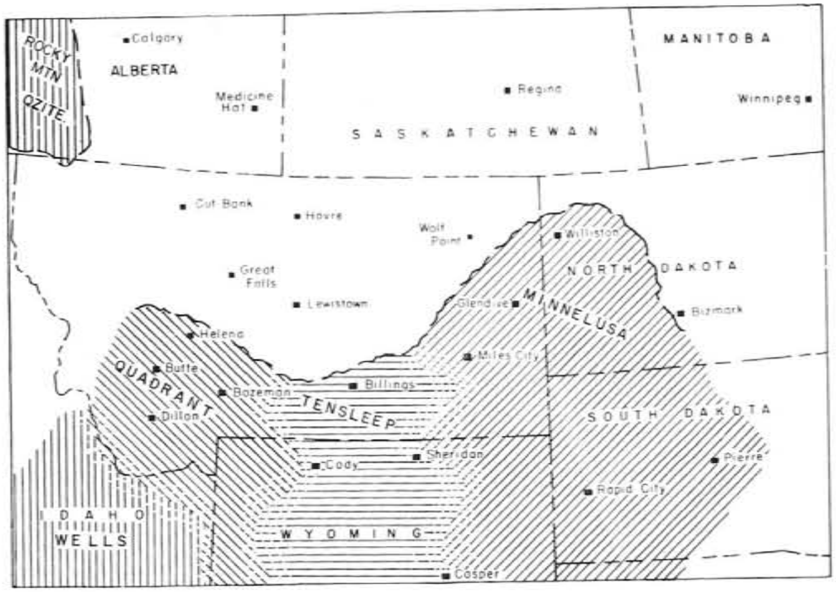

Figure 14.—Map of Pennsylvanian formations.

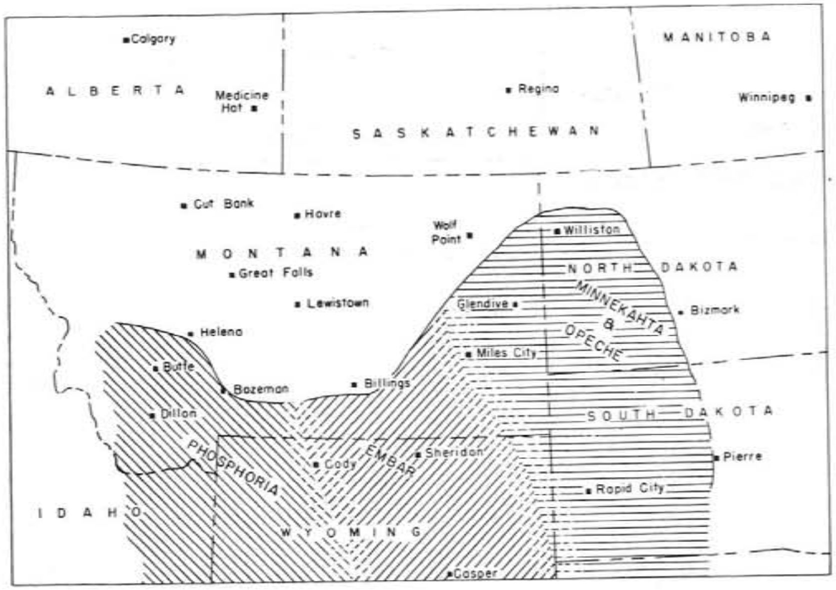

Figure 15.—Map of Permian formations.

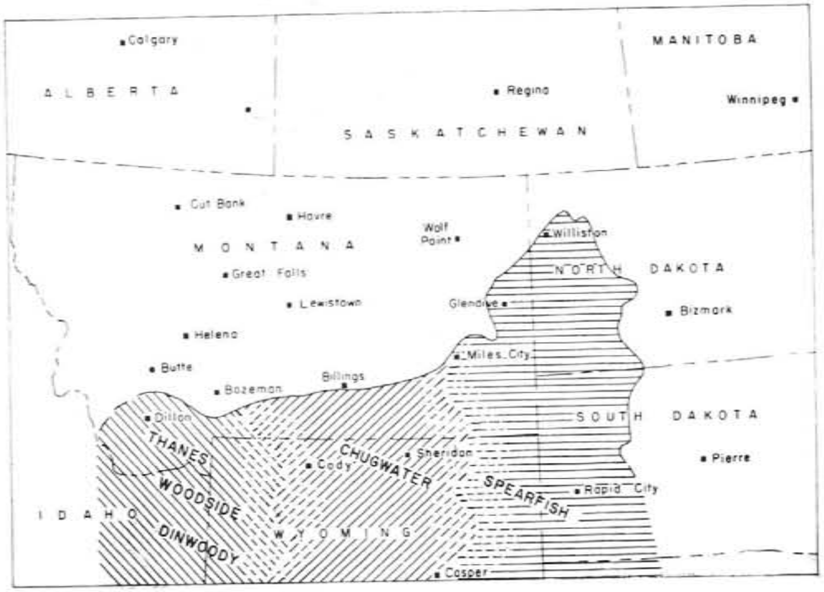

Figure 16.—Map of Triassic formations.

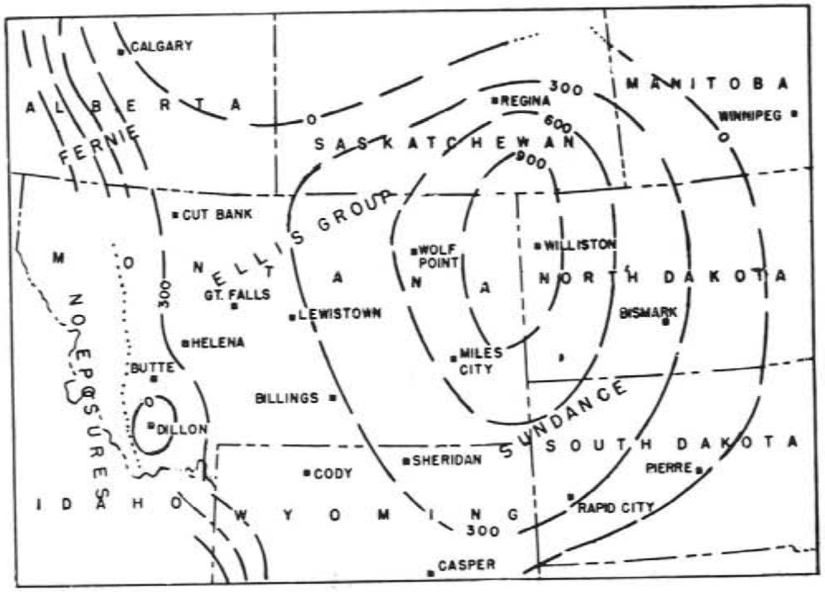

Figure 17. Isopach map of Jurassic formations.

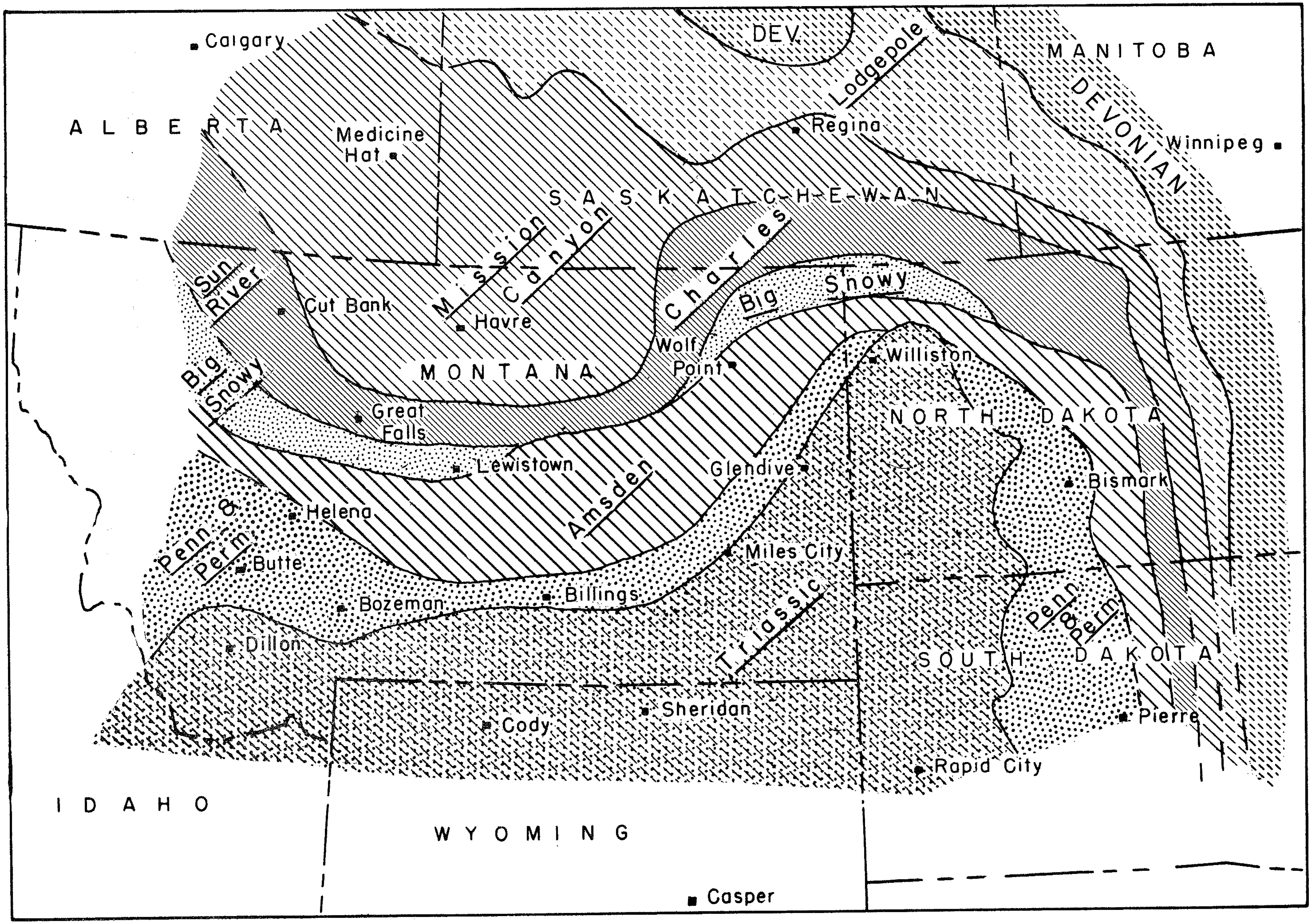

Figure 18.—Pre-Jurassic paleogeologic map of Montana and adjacent areas. (Modified after Williston Basin, 1st Int. Symposium, No. Dak. Geol. Soc. and Saskatchewan Geol. Soc., Oct. 1956.)

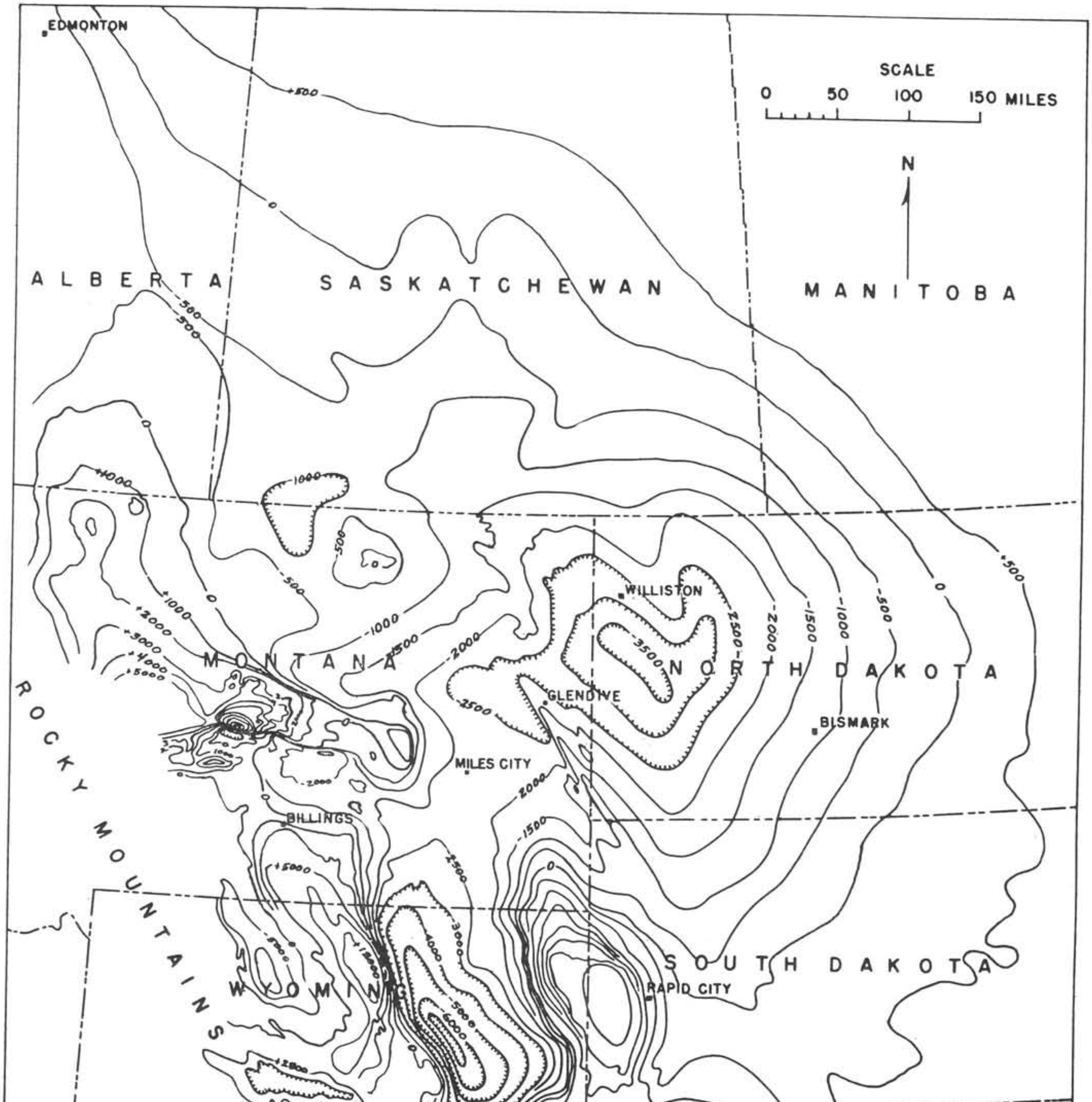

Figure 19.—Structure Contour Map of the Powder River—Sheep Mountain—Williston Basin. Contours on the base of the Colorado Shale. Datum is sea-level. Compiled by E. S. Perry.

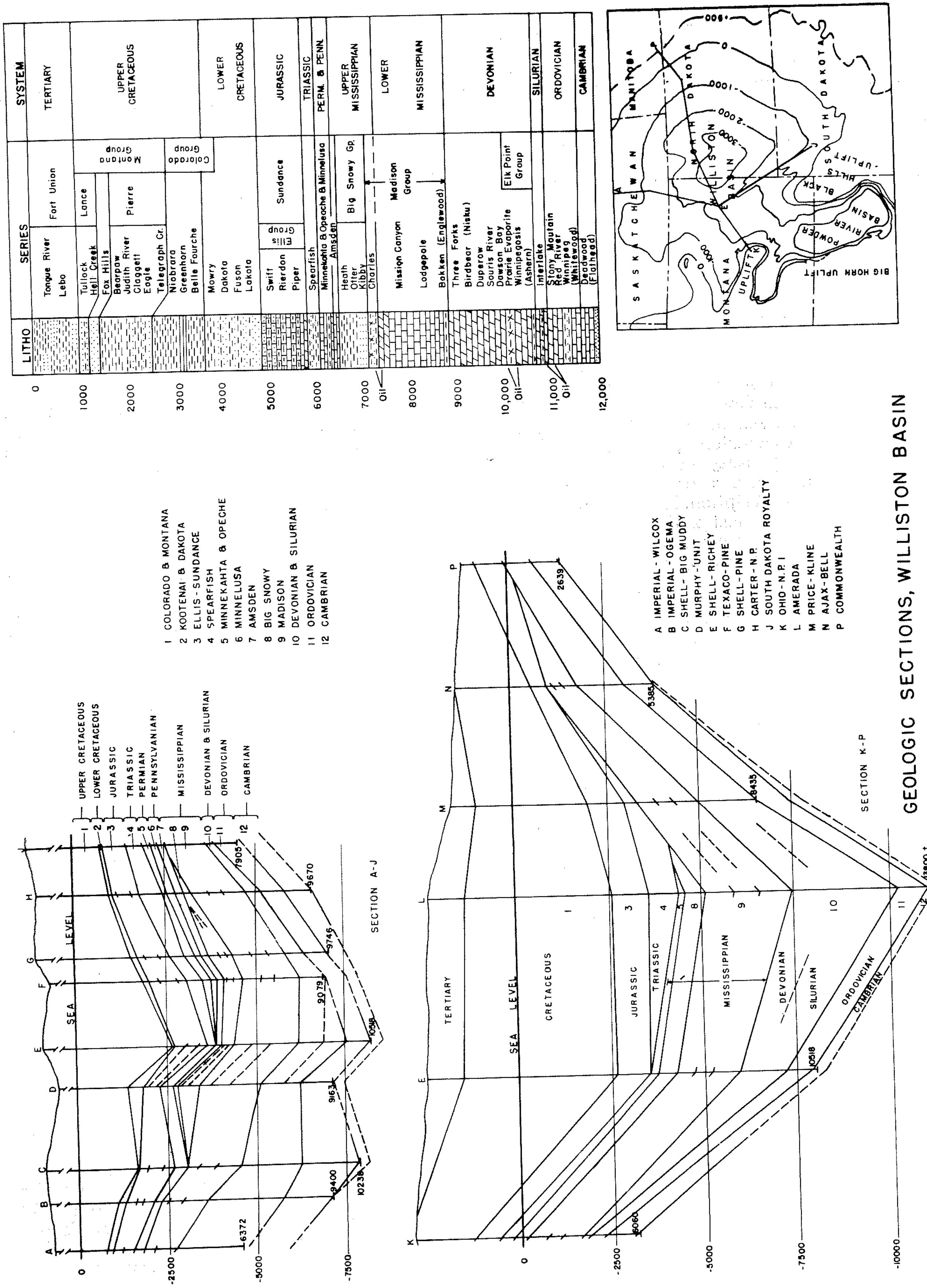

Figure 20.—Geologic cross-sections of the Williston basin.

PART 2. DESCRIPTION OF FIELDS

Montana's oil and gas fields may be grouped geographically into (1) the northern fields, (2) the central fields, (3) the southern fields, and (4) the eastern fields all lying east of the main ranges of the Rocky Mountains. (See map, fig. 1). This region constitutes the eastern three-fourths of Montana, and is 275 miles from north to south and about 400 miles from east to west. Most of the region lies in the Great Plains of northwestern United States, but locally in the central one-third of Montana, island-like mountains rise above the plains. Elevation of the plains is from 2,500 to 4,000 feet above sea level, and several rivers have eroded prominent valleys across them.

The geologic age of strata in which the commercial deposits of oil and gas occur ranges from Ordovician to Late Cretaceous. The types of oil and gas traps likewise are diverse—anticlines or domes, lenticular sandstones, lithologic change in sandstones, and porosity development in limestone or dolomite. Hence each of the fields require individual description. Relative importance and annual yield of most of the fields are shown on figures 2, 3, and 4; statistical information on fields is given in tables 1, 2, and 3.

NORTHERN FIELDS—THE SWEETGRASS ARCH

The oil and gas fields in northern Montana also may be grouped into separate areas, partly because of geographic location, but largely because of geologic conditions. These fields lie: (1) along the Sweetgrass arch, and the most important of these are the Cut Bank, Kevin-Sunburst, and Pondera fields; (2) around the Sweetgrass Hills, the Whitlash field being the most important; (3) north of the Bearpaw Mountains, the Bowes field being the most important; and (4) on the Bowdoin-Saco dome. Those fields associated with the Sweetgrass arch are the largest in Montana, and have yielded most of Montana's oil and gas.

The Sweetgrass arch is a large gentle fold or arch, geanticlinal in size, extending 150 miles northward from Great Falls into Canada. Dip of strata commonly in less than one degree, but total magnitude of uplift is in the order of 2,500 feet. Two major irregularities are present along the crest: the Sunburst dome, and the Pondera anticlinal nose. However, anticlinal or domal structure is not the controlling factor in oil and gas accumulation in all localities.

CUT BANK OIL AND GAS FIELD

The Cut Bank oil and gas field, about 30 miles long and 5 to 10 miles wide, lies north and south of the town of Cut Bank, and 40 miles east of the main ranges of the Rockies at Glacier Park. It ranks first in both size and total volume of production among Montana's fields. The Great Northern Railway and U. S. Highway No. 2 pass through Cut Bank. The surface throughout most of the field is a gently-rolling or nearly level glaciated treeless plain from 3,800 to 4,100 feet above sea level. Where large streams such as Cut Bank Creek cross the region, there are deep valleys in places confined by nearly vertical cliffs of banded strata. The climate is semi-arid (12 to 15 inches of rainfall), and temperature range from about –30° F. to about 100° F., with an annual mean temperature of about 42° F.

History.—The Cut Bank gas field was discovered in 1926 with the random drilling of the Sand Point-Berger gas well in sec. 1, T. 35 N., R. 5 W. about 15 miles west of the Kevin-Sunburst field. It yielded gas at the rate of about 8,000,000 cubic feet per day from a depth of 2,780 feet. No pipeline was available for transportation of gas at that time, and the well was plugged and abandoned. In 1929 a second well 8½ miles southwestward, the Drumheller-Yunck well, found both oil and gas in the same horizon as did the Berger well, but 250 feet lower structurally. Both oil and gas occurred in the Cut Bank sandstone at the base of the Kootenai formation (Lower Cretaceous). Intensive drilling did not begin until 1931 when 20 wells mainly 10 to 15 miles north-east of the town of Cut Bank, averaging 12,700,000 cubic feet of gas per day, were completed with but one dry hole. During this drilling campaign and before its completion, the construction of a 250-mile 20-inch welded gas pipeline with water-proof wrappings was begun by the Montana Power Company to service Butte, Anaconda, and Helena and intervening towns. The pipeline was completed in 1931 in about 2 months, a remarkable achievement when the mountainous character of much of the area serviced is considered.

Natural gas, rather than oil, was the primary consideration during the drilling campaign in 1931. However, by 1932 the naptha or gasoline content of the Cut Bank gas, and the occurrence of oil in the Drumheller-Yunck well, lead to drilling down-dip from the gas field with the result that the Cut Bank oil field immediately adjacent to the gas-producing area was discovered. But the end of 1935 development had proven a gas-producing area 18 miles long and 3 to 5 miles wide, and an oil-producing area 20 miles long and 2 to 3 miles wide. By December, 1936 there were 334 oil wells, 45 gas wells, and 49 dry or abandoned wells in the two sections of the field. By July of 1940 there were 506 oil wells, 78 gas wells, and 86 abandoned wells. The average daily oil run during June of 1940 was nearly 11,000 barrels, and the average daily gas withdrawal was slightly over 21 million cubic feet. By December, 1950, there were 1,171 oil wells and 162 gas wells, and the limits of the field appeared to be defined. The area proved for oil was about 45,000 acres, and that proved for gas about 55,000 acres. Peak oil production was reached in 1942, 1943, and 1944, and amounted to about 5½ million barrels of oil annually, or about 15,000 barrels daily.

In the summer of 1945 oil and gas were discovered in the upper part of the Madison limestone 160 to 180 feet beneath the Kootenai formation in the Carter-Brindley No. 1 well (sec. 12, T. 36 N., R. 6 W.) at a depth of about 3,090 feet. This is about three miles north of the area of oil production in the main field. Within a year about a dozen more wells scattered through an area six miles southward from the discovery well found oil and gas at or near the top of the Madison, and the southernmost of these wells also found gas in the Cut Bank sand. Thus the two sections of the field began to overlap. Wells started with a pumping capacity of about 50 barrels per day. Within two years approximately one-tenth of the oil produced in the Cut Bank field as a whole came from the Madison limestone wells, and during August of 1947 amounted to over 37,000 barrels. This productive area is known as North Cut Bank field. Structural contour maps, using the top of the Madison as a datum plane, show the presence of a gentle north-south anticline with about 50 feet of closure in places and with a fault cutting across the northeast end and side of the structure. Oil accumulation appears to be structurally controlled, but fracturing is present in the Madison limestone.

During the later stages of development of the main Cut Bank oil field (1935 to 1950), wells were being sunk 5 to 10 miles northward, resulting in the discovery of six or more smaller producing areas, more or less separated, the oil and/or gas occurring in either the top of Mississippian dolomite (Charles) or in the Kootenai sandstones. Local names were given to these fields and production statistics were kept separately. (See Tables 2 and 3). Largest are Darling (1939) and Reagan (1947), and the Border field (1929) may be included. The general geology of each is similar to that of the main Cut Bank field, excepting that local anticlinal structure is an important factor in oil accumulation. In 1955 the Coughlin and Blackfoot fields were added to this group, and in 1958 the Red Creek field. These fields are shown on plate 2, Structure Contour Map of Montana Plains.

Geology.—Strata immediately beneath the soils and glacial material throughout the Cut Bank fields are in the lower part of the Upper Cretaceous Two Medicine formation, which at Cut Bank corresponds to the Claggett and Judith River formations of central Montana. The massive lower member of the Eagle sandstone (Virgelle) underlying the Two Medicine forms a precipitious east-facing escarpment 4 to 10 miles east of the field, marking the western rim of the Kevin-Sunburst dome. Strata dip westward more or less uniformly slightly less than 100 feet per mile within the field.

Beneath the Eagle sandstone occur 100 to 130 feet of grayish to brownish, silty, fine-grained sandstone interbedded with sandy shale, transitional into the underlying Colorado shale. These beds are correlated with the Telegraph Creek formation of southern Montana. The Colorado group, about 1,750 feet thick, was recently subdivided into an upper Marias River formation and a lower Blackleaf formation, each with four named members. The "fish scale zone" of the Mowry lies in the upper part of the Blackleaf formation. Lenticular sandstones, bentonite beds, and zones of calcareous concretions lie in the upper 950 feet, which is composed essentially of uniform black shale. The lower 800 feet, once known as the Blackleaf sandy member, also consists essentially of black shale; but within it are 4 to 8 easily recognizable but not persistent sandstones, commonly glauconitic. Bentonite is more plentiful in the lower part of Colorado. About 1,250 feet beneath the top of the Colorado shale, at what is probably the base of the Mowry shale, is a persistent characteristic zone of fine whitish bentonitic sandstone containing grains and lumps of a red zeolite mineral. This horizon is popularly known as the "red speck zone", and it serves as a good horizon marker. The Blackleaf sandstones are a commercial source of gas in the Sweetgrass Hills area, but in the Cut Bank field only local small temporary flows are found in them.

The main producing horizon at Cut Bank is at or near the base of the Kootenai formation (Lower Cretaceous) which underlies the Colorado shale. Total thickness of the Kootenai at Cut Bank ranges from 500 feet on the east side of the field to 650 feet on the west side, a distance of about 10 miles. Most of the formation is an alternating and intermingled series of river-laid flood-plain, or else near-shore, deposits consisting of red, green, and gray mudstones and shales with lenticular siltstones and sandstones. The sandstones are more plentiful in the lower one-third of the formation in which lie the different oil- and gas-producing sandstone reservoirs in this field. A chert conglomerate forming part of the persistent basal member, known as Cut Bank sand, is characteristic. The Morrison formation normally underlying the Kootenai is not recognized in this field.

Beneath the Kotenai are the greenish-gray to black calcareous shales and black shaly limestones commonly known as the Ellis formation but more properly designated as the Ellis group. Its thickness ranges from 100 to 200 feet in this locality. The upper Swift formation of the Ellis group is believed to have been removed locally by pre-Kootenai erosion, and the Cut Bank sand lies on Rierdon. At the base of the Ellis is a persistent gray-white medium- or fine-grained water-bearing sandstone 10 to 20 feet thick (Sawtooth formation). An irregular erosion surface between the Ellis and Kootenai is believed to have affected the basal Kootenai sandstone or conglomerate wherein the sandstone appear to become thinner or even disappear locally above what may be topographic highs in the old Ellis erosion surface. The upper part of the Ellis tends to be glauconitic.

The Early Mississippian "Madison limestone" immediately underlies the marine Jurassic throughout northern Montana. Due to its erosion, and its truncation on the west side of the ancestral Sweetgrass arch (see previous description) the uppermost Charles (Sun River) formation is present under the Cut Bank area, its eastern margin lying midway between Shelby and Cut Bank. Hence oil production from the "top of the Madison" at North Cut Bank, Reagan, and other fields north of Cut Bank comes from the Charles formation; whereas production from the "top of the Madison" in the Kevin-Sunburst field comes from the Mission Canyon formation. This carbonate series thickens from about 1,000 feet in the Kevin-Sunburst field to about 1,100 feet at Cut Bank, and it thickens rapidly westward.

Beneath the Madison limestone is the Potlatch anhydrite formation of Devonian age, however, the 20 to 30 feet of shale commonly found at the top of this formation in the Kevin-Sunburst field is apparently absent, at elast locally. Thickness of the Potlatch is about 920 feet. Beneath the Potlatch occurs about 300 feet of light-gray dolomitic limestone and 75 feet of shaly sediments of Devonian age, then strata of Cambrian age. Deepest test well in the field (Union-Stufft No. 418) bottomed at a depth of 5,500 feet in Cambrian strata, which should be about 750 feet thick at Cut Bank.

Oil and Gas Occurrence.—The producing sandstones of the Cut Bank field, lying in the lower 150 to 200 feet of the Kootenai formation, have been divided into three zones: the upper Moulton zone, the middle Sunburst zone, and the basal Cut Bank zone, the latter of which is the most important oil and gas reservoir in the field.

The Cut Bank zone is persistent throughout the field as a sandstone unit, but it is variable in thickness and in details of lithologic character. The thickness averages about 45 feet. At its bottom lying directly on the marine Ellis shales occurs 1 to 2 feet of pyritic black chert conglomerate with rounded pebbles up to one inch in diameter in a sand matrix. Quartzite pebbles also are present. This grades upward into medium- or coarse-grained sandstone, locally conglomeratic, in which 1/5 to 4/5 of the sand grains are composed of black chert, giving the rock a gray speckled appearance ("salt and pepper" sand), or else it may be nearly black. Sorting of sand grains is poor. Lenses of chert-free quartz sand, or of pure chert sand, or of black shale, may lie interbedded with other material in the zone. Cross-bedding may be, and in some localities commonly is, conspicuous. In the upper part of the zone the sandstone becomes finer in grain size; it contains more silt and interaminations of shale, and porosity and permeability decrease. The upper portion contains less black chert than the lower, but "salt and pepper" sand may be present. A characteristic feature of the Cut Bank sand is its variability in porosity and permeability horizontally throughout the field as well as vertically. This results in small wells, or in a few places, dry holes close to large wells within the proven areas. However, porosity averages about 15 percent, and permeability about 115 millidarcys.

Two to six miles east of the gas field (up dip) the Cut Bank sand is believed by some observers to merge into a glauconitic siltstone laminated with black micaceous shale. Drillers usually log this material as "brown shale". Geologists know it as "ribbon sand" because of its banded appearance. In the Kevin-Sunburst field the ribbon sand lies beneath the "yellow shale marker" and above the marine calcareous shales of the Ellis. Some geologists prefer to consider the ribbon sand as stratigraphically older than the Cut Bank sand, and therefore not equivalent. However, its stratigraphic position, its reported interfingering with the typical Cut Bank sand southeast of the Cut Bank field, the local presence of fine black chert sand beds in its lower part, together with other evidence, point toward a correlation of the ribbon sand with the Cut Bank sand of the oil and gas field. Such a change in the lithologic character of the Cut Bank sandstone up the dip of the strata, with the accompanying decrease in porosity and permeability, is commonly considered as the cause of the localization and accumulation of oil and gas in the Cut Bank field. However, many geologists prefer to consider the Cut Bank sand as wedging or pinching out eastward. It is considered a typical stratigraphic trap.

The Sunburst zone, about 50 feet thick, is separated from the Cut Bank zone by variegated or vari-colored mudstone resembling shale, the common color tone being buff to yellow. Thickness of this separating shale ranges up to 20 feet. It is correlated with the "yellow marker" bed beneath the Sunburst sandstone in the Kevin-Sunburst field. The sandstones in the Sunburst zone, and there may be one, two, or three, are lenticular and not traceable throughout the field. They are separated by dark-gray shale. The sand itself is generally a salt and pepper sand, and variable in porosity due to intermixed silt and shale. Local lenses, as in the Lander pool, may show high porosity and permeability (18 percent and 825 millidarcys) resulting in large wells.

The Moulton zone is generally composed of mudstones and shales of various descriptions, but it may also contain thick sandstone lenses. Geologically, the Sunburst and Moulton zones should not be separated, but a subdivision is made in the field for convenience of drillers and operators. Perhaps the most important consideration is that the two zones consist of a similar series of mudstones and shales containing sandstone lenses of local distribution and variable in thickness. Commonly the lenses are much elongated in a general north-south direction.

Some of the Madison wells found oil and gas immediately at the top of the limestone, some in a porous zone 30 to 70 feet beneath the top, and some both at the top and within the limestone. Sulphurous water was found at greater depth. After treatment with 500 to 1,500 gallons of hydrochloric acid, the wells commonly started flowing oil at rates of about 75 to 700 barrels per day. Gas flows ranged up to 9,000,000 cubic feet per day, although most gas flows were much smaller. Casinghead pressures up to 730 pounds per square inch were measured.

Oil and gas in the central and southern parts of the main Cut Bank field occur on a relatively uniform homoclinal dip through a structural relief of about 600 feet, oil being present in the lower 300 feet and gas in the upper 300 feet. At the north end of the field gentle anticlinal warping of strata appears to have influenced localization of productive areas. In the 30 miles or more of length of the field, the top of the gas zone, the oil-gas contact, or the bottom of the oil zone are not marked by a particular structural contour line; that is, these zones cross contour lines. The upper (Sunburst) sands yielding oil and gas are lenses which pinch out locally. Water is found down-dip from the oil in the Cut Bank sand, but it is not found at a typical water line as in many oil fields. Wells near this water zone begin producing an oil-water mixture at time of discovery, and continue to produce about the same ratio of oil to water, suggesting interstitial water. Moreover, in the northern end of the field the so-called water line cuts across structural contours through structural relief of perhaps 500 feet. It does not appear that a water drive is in process throughout most of the field, however, some evidence points to this phenomenon at the north end of the gas-bearing area where the apparent water line crosses structural contours.

Initial yield of oil wells producing from the Cut Bank sand ranged through wide limits up to 300 barrels per day, and from the Sunburst sand up to 1,300 barrels per day. Average initial (average daily, first 10 days) for about 500 wells producing from the Cut Bank sand was 56 barrels, but in a local area (Lander pool) average initial of 11 wells producing from the Sunburst sand was 240 barrels. Initial production of gas wells ranged from about 1,000,000 to 28,000,000 cubic feet per day open flow, with an average of about 12,000,000 cubic feet.

Shut-in initial pressures of 17 gas wells averaged 705 pounds per square inch during 1931 before appreciable gas withdrawal. To this pressure about 40 pounds should be added to convert it into terms of bottom-hole pressure. Such a pressure is below that sometimes considered normal for a depth of 3,000 feet. Pressure readings were not taken on oil wells in the early period of development, but in 1939, after eight years of production, actual bottom-hole pressures of three widely spaced oil wells averaged 729 pounds. In most wells in the Cut Bank sand, oil rose about 1,600 feet in the hole, and such wells were placed on pump immediately.

Bottom-hole temperatures range from 80° to 83° F. with a temperature gradient from the surface downward to 3,000 feet of about 1° F. per 80 feet. This gradient compares with 1° F. per 100 feet to a depth of 5,000 feet as measured on the top of the Sunburst dome 25 miles eastward. Annual mean surface temperature in northern Montana is about 42° F.

The oil from the Cut Bank sand is dark brownish-green. It is of intermediate or mixed base with an A. P. I. gravity ranging from 37° to 40°. It yields about 33 percent gasoline and naptha. The amount of dissolved gas in the oil ranges from 100 to 7,000 cubic feet per barrel of oil with an average of about 890 cubic feet. Oil from the Sunburst (Lander) sand has an A. P. I. gravity of 34° to 36°. Sulphur content of both oils is about one percent.

The natural gas contains about 82 percent methane, 7 percent ethane, propane,and butane, 6 percent nitrogen, and 3.5 percent carbon dioxide. It yields about 210 gallons of gasoline per million cubic feet, and condensable gases are extracted at Cut Bank prior to piping to markets. Gas from the Madison limestone may contain hydrogen sulphide. In 1949 a plant, popularly known as a "sweetening plant", was erected north of Cut Bank to remove hydrogen sulphide from the gas coming from the Madison limestone at the North Cut Bank and Reagan fields. The sulphur was not saved because of the small capacity of the plant which treated about 10 million cubic feet of gas per day.

Edge water from the Cut Bank sand contains about 10,000 parts per million of dissolved salts of which about one-fourth is sodium chloride, and about three-fourths is sodium bicarbonate. Cut Bank sand trapped water (12,700 p.p.m.), Sunburst sand water (10,000 p.p.m.), and Moulton sand water (13,600 p.p.m.) contain 2 to 7 times as much sodium chloride as sodium bicarbonate.

During the early period of development and growth, all wells were drilled with cable-tool rigs, but at present wells are drilled with rotary equipment which ordinarily completes a 3,000-foot well in about 21 days. In most wells 7-inch casing is cemented a short distance above the producing sand.

Total production in 1958 from 990 wells in the main Cut Bank field was 1,668,218 barrels, or an average of about 5 barrels per well per day. Secondary recovery of oil by increasing reservoir pressure through injection of both gas and water has been attempted on a pilot scale. Water injection in selected wells, particularly in the southern part of the field, has shown favorable results, and may eventually be practiced on a large scale.

BORDER-RED COULEE OIL FIELD

The Border-Red Coulee oil field, about 12 miles northeast of the northern end of the Cut Bnak field, spreads across the international boundary into Canada. It lies 5 miles west of the town of Sweetgrass through which passes U. S. Highway 91 and a branch line of the Great Northern Railway. Although lying on the glaciated plain of northern Montana, the surface in nearby areas is broken by local coulees (gulches). The area of production is about one mile across. Oil was first discovered in a basal Kootenai sandstone beneath the Sunburst sand in this field; three years before the discovery of oil in this horizon in the Cut Bank field.

The first successful oil well was put down in Canada by the Vanalta Oil Company immediately north of the boundary in September of 1929. It yielded 85 barrels of oil per day from a depth of 2,470 feet. In April of 1930, the Montalta-Buckley No. 1 well (sec. 1, T. 37 N., R. 4 W.) was completed on the Montana side of the boundary as a 50-barrel oil well. Within one year 30 additional holes had been completed by several oil companies, and the limits of the field, about 500 acres in Montana and 100 acres in Alberta, had been defined.

Strata at the surface are in the upper part of the Eagle formation (Milk River sandstone of Canada), which together with the overlying Claggett and Judith River formations are commonly known as the Two Medicine formation in northwestern Montana. In drilling, wells penetrated about 160 feet of lower Eagle (Virgelle) sandstone, 130 feet of Telegraph Creek formation (transitional beds), and 1,660 feet of Colorado shale before entering the top of the Kootenai formation, 575 feet thick, at a depth of about 1,900 feet. The lower 675 feet of the Colorado group (Blackleaf formation) contains several lenticular sandstones along with much bentonite in the black marine shale. Near the base of the Colorado is a persistent water-bearing sandstone.

Beneath the Kootenai formation occurs a highly irregular thickness (50 to 200 feet) of gray calcareous marine shales and black limestones of Jurassic Ellis group of formations, the upper surface of which has been eroded. At the base of the Ellis is a persistent water-bearing sandstone (Sawtooth formation), generally less than 40 feet thick which lies directly on the eroded surface of the Madison limestone.

The Madison limestone of Early Mississippian age, penetrated only to a depth of 120 feet in the Border field, is light-gray to bluff, dense, and crystalline. Slight showings of oil were found in two wells at the top of the limestone, but most wells which reached it found surphurous water under pressure. Twenty miles southeastward the Madison limestone is about 1,000 feet thick. At the base of the Madison 20 to 30 feet of shale should be present, and then about 950 feet of the Devonian Potlatch anhydrite formation. Cambrian strata underlie Devonian strata.

The oil and gas producing sandstones lie in the lower third of the Kootenai formation. The upper two-thirds is essentially shale of various kinds, some of which is bright red; however, shaly sandstones and siltstones are present. The basal beds of the Kootenai (principal producing horizon) consist of about 60 feet of distinctive black-chert and quartz sandstone (salt and pepper sand); locally it is conglomeratic, particularly at the bottom where a two-foot bed with pebbles up to a half-inch in diameter persists throughout the area. Average depth to this conglomerate bed is 2,525 feet.The sandstone as a whole is separated by about 12 feet of greenish shale resulting in upper and lower members. They are known locally as the upper and lower Cosmos sands (equivalent to the upper and lower Cut Bank sands), but the upper member is sometimes called Vanalta sand. About 50 feet above the Cosmos sandstone zone is another persistent black and white speckled (salt and pepper) sandstone called the "gas sand." It is correlated with the Sunburst sand of the Kevin-Sunburst field, and the Sunburst or Moulton sand of the Cut Bank field. Immediately beneath it lies a variegated shale correlated with the "yellow beds" of the Kevin field. The Cosmos sandstone is said to grade eastward into the so-called ribbon sands of the Kevin field.

Average specific gravity of the oil is 31.5° A. P. I., the sulfur content is about 1.2 percent, and the gasoline content about 22 percent, which is not greatly different from other oils of the Sweetgrass arch. Total initial open flow of gas amounted to 24,000,000 cubic feet per day from several horizons, but flows were short-lived. Gas pressures at the surface were measured up to 850 pounds, the gas coming from a depth of 2,400 feet. The gas contained some naptha. Peak oil production was in 1931 when 19 wells (Canada and United States) yielded 218,068 barrels of oil.

Montana's share of production in 1950 was 13,579 barrels, and 7,695 barrels in 1958 from 8 wells.

REAGAN OIL AND GAS FIELD

The Reagan oil and gas field lies about 10 miles northwest of the north end of the Cut Bank field and 1 mile south of the Canadian boundary. It is 20 miles west of the Border-Red Coulee field. The area, 25 miles west of the railroad at the town of Sweetgrass, is reached by graded roads extending northwestward from the Cut Bank field. Surface conditions are similar to those near Cut Bank. The producing area is about 5 miles long and 1 mile wide.

The Reagan field was discovered in 1942, but intensive drilling began in 1947 when the Montana Power Company-Tribal 335 No. 1 well (sec. 10, T. 37 N., R. 7 W.) flowed oil at the rate of 50 barrels per day together with about 12,000,000 cubic feet of sulfurous gas. By the end of 1948, eight more wells had been completed, each with initial flow of 25 to over 400 barrels of oil per day after acidization. Gas accompanied the oil, and gas pressure was about 1,100 pounds per square inch. Depths ranged from 3,745 feet to 3,810 feet. The producing zone, about 20 feet of porous limestone or dolomite, occurs from 30 to 60 feet beneath the top of the Madison (Charles) limestone. Sulfurous water was found beneath the productive zone. Total production for 1950 from 18 wells was 182,334 barrels of oil. Peak production was reached in 1953 and amounted to 250,890 barrels. In 1958 about 45 wells produced 166,634 barrels of oil, or about 10 barrels of oil per well per day. The specific gravity of the oil is from 31° to 36° A. P. I. Five additional wells yielded commercial amounts of gas. Pipelines for both gas and oil were laid in 1948 to the Cut Bank field where they joined other lines.

The stratigraphy of this area is similar to that at the north end of the Cut Bank field. The field lies on a plunging anticline striking N. 15° W. locally known as the Reagan "nose", and oil accumulation appears to have resulted mainly from a structural condition, since about 50 feet of structural closure is reported. A fault 5 miles or more in length bounds the structure on its east side. Distribution of fracture porosity in the limestone may have been equally effective.

DARLING OIL FIELD

The Darling field was actually discovered in 1939 with the completion of a gas well on sec. 24, T. 37 N., R. 5 W., at that time about five miles north of the Cut Bank field. The well flowed 43,000,000 cubic feet of gas per day from the Moulton sand at a depth of 2,550 feet. In 1951 a northeast off-set well on section 13 flowed 360 barrels of oil per day from the same horizon. Subsequent drilling extended the oil producing area five miles N. 35° E. to the Canadian border. The dark-green paraffin-based oil had a gravity of 38.4° A. P. I., and contained 0.77 percent sulfur. In 1958 production from 46 wells was 126,775 barrels. Practically no water was produced with the oil.

The Moulton sand, which lies in the Sunburst zone of the Kootenai formation, occurs in this locality as a 5-mile-long straight narrow strip, about half a mile wide and 40 feet thick in the center, thinning to 0 on either side. This strip trends almost at right angles to the strike of strata, and extends 250 feet down a nearly uniform structural slope in the strata. It produced oil from end to end. Hence, oil accumulated in a lenticular stratigraphic sand trap, although the lens (about 10 times as long as wide) is inclined lengthwise. Strata at either side of the strip are described as non-porous siltstone, very fine-grained sandstone, and silty shale. A second separate and smaller sand lens, lying about one mile northeastward, also produced oil. The upper sands in the Border field four miles eastward were somewhat similar in occurrence, and trend-lines of lenses in this area are somewhat parallel. The general geology of the Darling area is similar to that in the Cut Bank field.

BLACKFOOT OIL FIELD

Midway between the Reagan and Darling fields, each 6 miles distant, and within one mile of the Canadian border, is the Blackfoot oil field. The first well was completed by the Union Oil Company in October of 1956 on the Muntzing lease in sec. 11, T. 37 N., R. 6 W. Oil was found in the Cut Bank sand at the base of the Kootenai formation, and in the top of the Madison (Sun River) dolomite at depths of about 3,275 and 3,500 feet respectively. Initial field pressures were 895 and 955 pounds per square inch. About a dozen more wells in a one-square-mile area were sunk, ten yielded oil either from the Cut Bank sand or Madison lime (Sun River dolomite). Initial flows were about 100 barrels per day from the Madison with rapid declines to about 30 barrels, and from the Cut Bank sand about 40 barrels per day with gentle declines to about 30 barrels. Both oils were black with intermediate base; 30° A. P. I. gravity in the Cut Bank, and 25° A. P. I. in the Madison. In 1958 production was 97,781 barrels from 11 wells in the Madison lime and 4 wells in the Cut Bank sand.

The general geology is similar to that of the Cut Bank field. The local structure is a gentle elongated northwest-trending anticlinal dome, cut along its eastern side by a fault, down-drop to the east. The Cut Bank sand is described as variable in thickness; and the Madison as "breciated, cherty, highly fractured, and vuggy with solution filled cavities."

KEVIN-SUNBURST (SHELBY) OIL AND GAS FIELD

The Kevin-Sunburst oil and gas field and the Shelby gas field, which are generally considered as one field, lie immediately north of the town of Shelby and extend northward for 25 miles to within 10 miles of the Canadian boundary. This surface of the field, 3,300 to 3,500 feet about sea level, is a level glaciated treeless plain without permanent streams. The Great Northern Railway and U. S. Highway No. 2 pass through Shelby, and U. S. Highway No. 91 extends from Great Falls to Shelby and northward through the field into Canada. Rainfall is from 12 to 15 inches per year. Temperatures range from a –30° F. to 100° F. and the mean annual temperature is about 42° F.

History.—Gas was noted in shallow water wells in this region as early as 1912, but the discovery oil well was completed by Gordon Campbell in March of 1922 on the western margin of the main producing area (sec. 16, T. 16 N., R. 3 W.). Oil occurred in the top of the Mississippian Madison limestone (Mission Canyon formation) at a depth of 1,770 feet. Rated as a 20-barrel well, it was not considered commercial at that time, and was abandoned. Within the next eight months 45 more wells were sunk mainly eastward within a distance of perhaps 8 miles, most of which yielded oil or gas, and some yielded oil up to 500 barrels per day. In 1923 there were 183 wells completed; in 1924, 136 wells; in 1925, 350 wells; in 1926, 390 wells; and in 1927, 380 wells. By this time the northern, eastern, and southern limits of the irregular oil and gas producing areas were fairly well defined, but large untested tracts remained within the field. Several more or less separated areas of oil production, termed pools, were developed; however, no relationship of pools to geologic structure was recognized.

In the early period of development many dry holes and small oil wells were completed within the field, and it was said that one of every three wells drilled was not commercial. The use of acid in treating limestone reservoir rocks was not known at this early time, and the use of nitroglycerin in shooting wells commonly did but little good and in some wells did damage. With the initiation of acid treatment of the wells, beginning about 1934, the yield of oil from wells was increased, and many wells, which without treatment would have been abandoned, were converted into good commercial wells. Treatment of the oil horizon with large quantities of hydrochloric (muriatic) acid became standard procedure.

Beginning about 1946 northwest extensions north of the town of Kevin were developed, and at present the Kevin-Sunburst field has been extended almost to the area of production from Madison limestone at the north end of the Cut Bank field. Many new commercial oil wells were completed each year through the 1930's and 1940's within the limits of the main producing area, and new commercial oil wells were still being completed in the 1950's. This is due largely to irregular distribution of porosity in the limestone or dolomite.

The development of the gas field north of Shelby began in August 1922 with the drilling of the Ohio-Berg well (sec. 6, T. 32 N., R. 1 W.) which yielded 7½ million cubic feet of gas per day from the Sunburst sand at a depth of 1,338 feet; and the Troy-Sweetgrass well 8 miles northward yielding 1½ million cubic feet of gas per day was also drilled in the late summer of 1923. A 3-inch gas pipeline was laid to Shelby from the Berg well in 1923. Intensive development of this gas producing area began in 1927. In 1928 a gas pipeline, in part 10-inch and in part 12-inch, was completed to Great Falls, 111 miles distant, after a total daily initial open flow of over 100 million cubic feet had been realized. Gas from the Sunburst sand throughout the field as a whole oil was also used in field operations and piped to Kevin and Sunburst.

The annual production of oil and gas for the Kevin-Sunburst field is shown graphically on figures 2 and 3. Peak production of about 1⅓ million barrels of oil per year was reached in 1926; but production declined rapidly, and by 1932 was only about one-half this amount. In 1958 a total of 1,433 wells are reported to have yielded 902,360 barrels of oil, which averages about two barrels of oil per day per well. A pilot plant for water-flooding of oil horizons to increase production was tried out locally (sec. 19, T. 35 N., R. 1 W.) in 1958, and results so far appear to be very favorable. Flooding may become regular practice.

An annual peak production of natural gas of about 3 billion cubic feet was reached in 1929 and gas production remained from about 2½ to 3 billion cubic feet per year for the next 12 years. Gas production in 1950 was a little over 2 billion cubic feet. In 1958 there were 72 wells that produced 1,003,600,000 cubic feet of gas, or an average of about 39,800 cubic feet per well per day.

Geology.—Strata exposed throughout the main part of the field are in about the middle of the Upper Cretaceous Colorado shale. The overlying Eagle sandstone is exposed in nearly vertical cliffs in an east-facing escarpment at the western side of the field, forming the western "rim" of the Sunburst dome. The outcrop of the Eagle sandstone circles the dome to the north and east, and continues southward on its eastern side 5 to 15 miles east of the field; but an escarpment is not present, exposures are scarce, and the area is almost entirely covered with glacial drift. The Colorado shale is generally considered as a unit in this field, even though its thickness is about 1,750 feet; however, the lower 700 feet contains several well-developed lenticular sandstones, and is now known as the Blackleaf formation, the upper part being known as the Marias River formation. Most of this series is black shale with accasional thin bentonite beds and zones of calcareous concretions. A persistent sandstone near the base is correlated with the First Cat Creek sandstone of central Montana and the Dakota sandstone of South Dakota.

Beneath the Colorado shale is the Kootenai formation (Lower Cretaceous) about 400 feet thick. It is composed of a mass of alternating shales of different colors together with gray sandstones and siltstones of differing textures and purity. The formation has been considered as a series of river-laid flood-plain deposits. Red shale is conspicuous in the upper portion, and the "first red" may be recorded by drillers as the top of the Kootenai, however 20 to 40 feet of gray shale may be at the top. About 300 to 350 feet beneath the top is the Sunburst sandstone horizon. The sandstone is not uniform in either thickness (average 20 feet) or lithologic character, and in places the sandstone becomes so silty or cemented with clay that its porosity and permeability are almost nil, and it may not be recognized by drillers. The Sunburst sandstone is the principal gas reservoir in the Kevin-Sunburst-Shelby field, and locally it yields much oil far down on the northern and northwestern flanks of the Sunburst dome.

Occurring just beneath the Sunburst sandstone throughout the Kevin-Sunburst field, and also throughout much of the Sweetgrass arch region, is a characteristic bed of yellow to buff shale generally recognized by drillers. This may possibly be an ancient soil, and possibly may be correlated with the land surface on which the Great Falls coal seam was developed. The Sunburst sandstone appears to be equivalent to the massive Kootenai sandstone which overlies the coal seam southeast of Great Falls and which continues eastward into central Montana where it is known as the Third Cat Creek sandstone.

The basal Kootenai sandstone (Cut Bank) main producing reservoir rock of the Cut Bank field 15 to 20 miles westward, is not present in the Kevin-Sunburst field as a porous sandstone. It is believed by many geologists (but not all) that the typical Cut Bank sandstone becomes silty and shaly eastward and merges into a laminated silty, shaly series of strata 60 to 70 feet thick known as "ribbon sand", the porosity and permeability of which are not suitable for oil or gas migration or accumulation. Many geologists believe the Cut Bank sandstone wedges out eastward.

The Ellis group of Jurassic age beneath the Kootenai is variable in thickness, but averages about 200 feet. Pre-Cretaceous erosion has cut deeply into its upper part. It is essentially greenish-gray to black calcareous marine shale and black shaly limestone, but at its base a fine-grained white porous water-bearing sandstone (Sawtooth formation) about 10 feet in thickness may be present.

The Madison limestone of Early Mississippian age lies immediately beneath the Ellis group. Its upper surface has been greatly affected by pre-Jurassic erosion which caused intense alteration of the limestone thereby resulting in the irregular but extensive oil reservoirs of the Kevin-Sunburst field. During the earlier years of development this porous zone of uppermost Madison limestone was incorrectly called "Ellis sand." Where unaltered the upper part of the Madison (Mission Canyon on the Sunburst dome) is a massive crystalline light-gray limestone, fossiliferous in places. The lower part (Lodgepole) is darker gray or black, more thinly bedded with shale laminae, and commonly more cherty. At the base is 5 to 20 feet of black petroliferous shale (Exshaw). Total thickness of the Madison in the Kevin-Sunburst field is between 1,000 and 1,100 feet, but the formation thickens westward.

Devonian strata of the Potlatch anhydrite formation, about 940 feet thick, underlies the Madison limestone. Green fossiliferous shale (Three Forks), about 15 feet thick, occurs between the Potlatch and Madison. The Potlatch is essentially brown to gray dolomite with some dark shale; anhydrite beds up to 20 feet in thickness are scattered through the formation. A porous zone in dolomite 600 to 625 feet below the top of the formation (1,700 feet beneath the top of the Madison limestone) yielded gas containing much hydrogen sulphide and up to 80 percent carbon dioxide, as well as small amounts of combustible gas and oil. The Potlatch formation is approximately equivalent to the upper part of the Jefferson formation of southwestern Montana. Beneath the Potlatch is about 300 feet of brownish-gray dense limestone correlated with the lower part of the Jefferson formation (Devonian).

Cambrian strata directly underlie Devonian strata. The upper 700 feet consists of gray and greenish shale, fine-grained and jointed, occasionally showing in well cuttings as pencil-like slivers two inches or more in length. A limestone member may be present in the upper part. The lower 25 feet of Cambrian strata is coarse quartz sandstone or quartzite correlated with the Flathead formation. Beneath this sandstone at a depth of 4,500 feet on the crest of the Sunburst dome is the schistose basal complex as determined by petrographic studies. The argillites and quartzites of the Belt series, so conspicuous at Glacier Park, have not been recognized and are believed to be absent.

The geologic structure as considered within the limits of the field is that of a nearly circular dome, known as the Sunburst dome. It is about 25 miles across and has about 800 feet of structural relief (closure) (See plate 2.) Actually this huge dome is a high place along the crest of the Sweetgrass arch. The symmetry is imperfect because the north side is flattened into a broad terrace measuring about six miles across, and lying about 150 feet lower than the crest of the dome. Gentle warping has developed a shallow syncline about 12 miles long which crosses the terrace in a northeasterly direction, dividing it in two. Several other irregularities in the form of warping are present on the flanks of the dome; and structural contours drawn with 5- or 10-foot intervals on the top of the Madison limestone may show great irregularity, possibly portraying topography developed during the period of erosion following Mississippian time. It has been suggested that topographic highs on the old erosion surface has influenced oil accumulation.

Only a part of the dome has been productive of oil and gas; and local development of porosity, rather than geologic structure, appears to have been one of the main controlling factors in both oil and gas accumulation. No oil or gas has been found in the top of the Madison limestone at the crest of the Sunburst dome, or on its east, south, or west sides. The Madison has been found productive of oil on the northern and northwestern flanks of the dome from about 100 feet structurally lower than the crest to at least 800 feet lower through a horizontal distance of 15 miles. Gas in the Sunburst sandstone is likewise erratic in distribution with reference to structure. Furthermore, in both the Madison and the Sunburst, productive areas appear to lie isolated from other productive areas not far distant, and without regard to the pattern of structural contours. Such conditions have led to statements such as "every well is a wildcat well."

Oil and Gas Occurrence.—Oil occurs mainly in the Madison limestone, but locally also in the Sunburst sandstone, and in a few localities in Jurassic strata. Gas occurs mainly in the Sunburst sandstone, but some gas is present with oil in the Madison limestone, essentially as dissolved gas. Large flows of gas containing much carbon dioxide and also much hydrogen sulphide came from Devonian strata. One or two wells penetrating Devonian strata yielded small quantities (shows) of oil, a few gallons per day.

The leached and porous limestone at or near the top of the Madison (Mission Canyon formation) is particularly noteworthy. Generally it is coarsely granular resembling brown sugar, but it may be spongy or vuggy; cavities up to half an inch in diameter lined with calcite or quartz crystals have been observed. The drillers call it "rotten lime." The material is a normal limestone which has been dolomitized, silicified, and leached; and leaching appears to have been particularly important. Porosity commonly is 30 to 40 percent in the altered rock, and some pieces 2 inches in diameter showed 60 percent porosity. In some localities silicified cup corals, bryozoa, and crinoid stems come from the oil-bearing horizon; and in other fragments of the rock; either of the dolomitized or silicified material, abundant casts of crinoid stems are present. Small fractures may cut across the rock irregularly. The porous zone is generally at the upper surface of the limestone or within 5 to 10 feet of the top, but it may be 25, 50, or even 100 feet below the top with dense light-gray unaltered Madison limestone overlying it. Both horizontal and vertical distribution of the altered porous rock are most irregular, and it was not unusual for small wells or dry holes to be drilled near or even between some of the largest wells. This condition is believed to have resulted from the intense weathering of the limestone during the pre-Jurassic erosion, the weathering probably having been accentuated along joint planes or crevices. It accounts for the irregular distribution of oil-producing areas far down on one flank of the Sunburst dome and not on its crest. With a structural relief of over 600 feet, depth to the Madison ranges from about 1,100 to 1,700 feet.

The irregularities in the Sunburst sandstone gas production are also noteworthy. Although gas occurs at this horizon 9 miles from the crest of the dome and 600 feet structurally down on both the north and south sides of the dome, as well as across its crest, the producing area does not follow structural contours, and the east and west sides of the dome are practically barren. Furthermore, within the producing areas wells ranging from less than 1 million to over 8 million cubic feet per day initial flow of gas were irregularly spaced without relationship to structure or to each other. Groups of perhaps 5 to 10 wells appeared to be related to each other as to pressure, but unrelated to adjoining groups, the pressure differential is some cases being as much as 100 pounds. Many holes with little or no gas were drilled in what may be considered the gas-producing area. The cause of this is the irregular character of the sandstone itself wherein it becomes shaly and impervious locally.

The oil from the Madison limestone is dark-green to black, of mixed base, and has a specific gravity of 27° to 34°, A. P. I. Gasoline content is about 23 percent, and sulfur content is about 1.3 percent. Oil from the Sunburst sandstone has a specific gravity of from 37° to 41° A. P. I., and a sulfur content of about 1 percent. The average initial yield throughout the field was less than 100 barrels per day, but many wells yielded over 1,000 barrels, and some are estimated to have yielded up to 5,000 barrels per day open flow initially. Oil-well pressures were seldom if ever taken, but probably were initially about 500 pounds per square inch at the casing head. A small amount of gas came with the Madison oil, usually enough to operate pumping equipment. The natural gas in the Sunburst sandstone is almost pure methane, although some gas analyses show up to 5 percent ethane. In general the Sunburst gas is considered "dry".

Water is prevalent in the Madison limestone wells regardless of location on the Sunburst dome; and next to the irregularity in size and location of producing wells, the water problem was most important. Water came to the surface intimately mixed with the oil, the proportions of oil and water ranging from almost pure oil to almost pure water. In the smaller wells, droplets of oil could be seen in the water, but wells with high pressure and large volume yielded an emulsion. Some wells yielded up to 6,000 barrels per day of oil-water fluid by pumping methods, although generally the volume was less than 1,000 barrels. No definite water horizon is known. The history of many large wells shows that at first oil with very little or no water appeared. After the lapse of perhaps a month small amounts of water became evident. As time progressed the proportion of water increased gradually until in some cases it was 99 per cent of the fluid. This suggests "water coning" and possibly improper operation of wells. Choking or limiting the flow of large wells was not practiced during the early development of the field. The Sunburst sandstone commonly yields little or no water. Some water from the Sunburst contained nearly 14,000 parts per million dissolved solids, 90 per cent sodium chloride. The great bulk of the water comes from the Madison limestone, either at the upper surface or at considerable distance within, and either structurally high or low. Composition of Madison water is similar throughout the field, dissolved material ranging ing from 3,300 to 5,000 (rarely 7,500) parts per million essentially sodium bicarbonate and chloride in a ratio of about 2 of carbonate to 1 of chloride. All Madison waters are nearly saturated with hydrogen sulphide. In detail, water from different localities differs in composition.

Ten or more wells have been drilled into Devonian strata and three of these have passed into rocks beneath. Four of these wells are within 2½ miles of the crest of the Sunburst dome, the others scattered north and south. None proved commercially successful, but several yielded sulfurous gas high in nitrogen and carbon dioxide content and low in combustible constituents, and some wells had good showings of amber-colored oil perhaps up to 1 barrel per day, the producing horizon being a porous dolomite in the lower part of the Devonian Potlatch anhydrite formation about 1,700 feet beneath the top of the Madison limestone.

PONDERA OIL FIELD

The Pondera oil field lies on a level treeless glaciated prairie about 30 miles south of the Cut Bank and Kevin-Sunburst fields and 6 miles southwest of the town of Conrad. The producing area is irregular and somewhat spotted in pattern, but it is about 6 by 8 miles in extent of which about 9 square miles are considered as productive. U. S. Highway 91 and a branch line of the Great Northern Railway pass through Conrad. Climatic conditions are similar to those at Cut Bank.

Discovered in June of 1927, development followed rapidly, and within a year 8 more wells entered the oil-bearing horizon and yielded from 50 to 200 barrels of oil per day. A pipeline from the field to the railroad at Conrad was completed in July 1928. By 1935 the field had 153 producing oil wells. Records show that 15 of these wells had initial flows of 1 to 5 million cubic feet of gas per day along with oil, but production of natural gas has been of no great importance. Acid treatment of the oil-bearing zone began in 1934 and proved very successful. Production of some wells was increased several fold, and acid treatment of wells became standard procedure.

The limits of the field were commonly thought to have been defined by 1940, but outlying test wells continued to be drilled. In 1946 and following years, particularly 1949, 1950, and later, important extensions to the producing area were discovered to the northeast, east, and southwest, and the original field was greatly enlarged. In December 1950, there were 254 producing or productible wells, and in 1958 there were 336 oil wells in the district as a whole. Local names have been given to different producing areas.

The stratigraphy of this area is similar to that of the Kevin-Sunburst field. First strata beneath the surface soils and glacial drift are in the upper one-third of the Colorado shale group, total thickness of which is about 1,800 feet. Several sandstone members lie in the lower one-third of the shales. Underlying the 1,200 to 1,400 feet of Colorado are 450 feet of differently colored, silty, sandy, and shaly sediments of the Kootenai formation with about 40 feet of Sunburst sandstone at its base. It is not productive of oil or gas. Beneath the Sunburst are 80 feet of shaly and silty sediments with yellow colorations common. These strata may possibly be correlated with the Morrison formation. They merge downward into 185 feet of fine- and medium-grained glauconitic and finely micaceous gray sandstone of the Swift formation of the Ellis group with about 20 feet of dense gray Rierdon limestone beneath .The basal subdivision of the Ellis (the Sawtooth sandstone) appears to be missing.

Underlying the Ellis is the oil-productive zone in the top of the Madison limestone (Sun River or Charles formation). Total thickness of the Madison is about 1,150 feet. Its base may be recognized by the presence of about 50 feet of dense grayish-green Devonian shale which overlies about 800 feet of dolomite and thick anhydrite beds of the Potlatch anhydrite formation. The lower part of the Devonian strata consist of 250 feet of brownish limestone and 100 feet of brown dolomite interbedded with grayish-green shale. Red colorations may be present. A porous zone yielding shows of oil and gas lies in the Potlatch about 500 feet beneath the upper Devonian shale member. The basal beds of the Devonian consist of about 110 feet of gray-brown dolomitic and shaly limestone. Cambrian strata directly underlying the Devonian consist of about 100 feet of maroon and green shale correlated with the "Dry Creek formation," 100 feet of dense buff to grayish-brown dolomite correlated with the Pilgrim formation, 550 feet of grayish-green, occasionally maroon, micaceous thin-bedded shale, and finally 20 feet of basal sandstone correlated with the Flathead formation. Precambrian granitic rocks underlie the sedimentary series.

The oil-producing zone at the top of the Madison is a granular crystalline dolomite or dolomitic limestone, the porosity apparently having been developed by leaching and alteration associated with fracture systems in the Charles member of the Madison by weathering processes during the post-Mississippian-pre-Jurassic erosion in a manner similar to that in the Kevin-Sunburst field. Thickness of the porous zone differs, but is generally about 15 feet. The porosity may be classed as vuggy and intergranular combined with fracturing, the fracturing is more plentiful in some parts of the area than others. Reservoir energy in the older central area was considered as due to expansion of dissolved gas; but water encroachment is reported in the north part of the field, and it is suggested that encroachment of bottom-hole water fed by a fracture system from an underlying porous zone, is active in places. Erratic productivity may possibly be attributed to fracture networks.

The field lies along the crest of the Sweetgrass arch; however, the axis of the arch in this locally has been shifted westward about 20 miles so that the field appears to lie high upon the nose of a north-west-plunging anticline. It could be considered a structural terrace extending westward from the main trend of the arch. Detailed structural data in the oil field shows much local irregularity in the surface of the Madison limestone, in some places amounting to differences in elevation of 50 feet or more. Faulting possibly of the graben type cuts the strata about two miles north and northeast of the productive area (Pendry fault). Oil has recently been found close to the south side of this fault zone, which on maps is shown to be about 15 miles long.

The oil has a mixed base, is about 33° A. P. I. gravity, and contains about 25 percent gasoline and 15 percent kerosene. Sulfur content is generally less than 2 percent. Initial gas pressure reported at the casing heads was about 500 pounds per square inch. In completion of wells the productive zone is generally treated with from 1,000 to 5,000 gallons of hydrochloric acid, and wells may then be placed on pump, although many early wells flowed initially 100 to 400 barrels per day. Water may be present with the oil, and some wells yield an oil-water fluid which is 50 percent water. Depth to the producing zone ranges from 1,850 to 2,100 feet.

Annual production of oil in the Pondera field is shown graphically on figure 2. Peak production of nearly one million barrels was reached in 1929, but production declined to about one-fourth this amount by 1945. Discoveries in adjacent areas after 1947 about tripled 1945 production. During 1958 production from 336 wells was 558,655 barrels, or nearly 5 barrels per well per day.

BANNATYNE OIL FIELD

The Bannatyne oil field is of interest largely because it is the southernmost known occurrence of commercial amounts of oil on the Sweetgrass arch, but also because of the occurrence of oil in Jurassic strata (Swift formation). It lies 25 miles southeast of the Pondera field and 35 miles northwest of Great Falls in sec. 8, T. 25 N., R. 1 E. Within 3 years after its discovery in 1927 by the Genou Oil Company, 41 wells had been drilled; 28 are reported to have yielded oil at rates of 3 to 100 barrels per day, and about one-half of these were considered commercial. After drilling, wells were shot with nitroglycerine. A small refinery was built at the field to treat the oil produced locally. Total production of the field is given as 55,245 barrels of oil up to 1936 when the field was abandoned, and it remained idle until 1955. The black asphaltic oil has an A. P. I. gravity of 27°. Reservoir pressure was low, gas was negligible, and pumping was necessary from the start. Gasoline content was about 18 percent, and sulfur content about 2 percent.

In 1955 and 1956 new wells were drilled, some going into Madison limestone where additional oil was found about 70 feet beneath the Swift formation; and production, averaging 16.5 barrels per day per well, was resumed. Reservoir pressure and viscosity of the oil were both low, the oil being similar in both reservoirs. "In situ combustion" was being considered in 1958.

The general geology of the field is similar to that of the Pondera and Kevin-Sunburst fields. Strata at the surface are in the middle part of the Colorado (?) shale. The Kootenai formation and Ellis group underlie the Colorado; and the upper producing horizon locally known as Emrick sand, is a sandstone in the Swift formation of the Ellis group.. It is at a depth of 1,450 feet. The productive sandstone, 70 feet thick, yielded oil only in its upper one-half. The top of the

Madison limestone is at a depth of about 1,500 feet. A deep well near the center of the field entered Devonian strata at a depth of 2,430 feet. It is reported to have entered igneous rock directly beneath Devonian strata. This indicates that an island was present in the Cambrian seas in this locality. It may be part of a deeply buried ridge, commonly designated the "Genou trend." Sulfurous water was found in the Madison limestone. The field lies on a circular dome about one mile across and with about 100 feet closure. It lies on the east slope of the Sweetgrass arch about 14 miles from, and 300 feet structurally lower than the crest; and it is the only structure of this type known to be present in this locality.

During 1958 production from 6 wells was 7,450 barrels, wells in the Swift formation yielding 3 to 5 barrels per well per day, and Madison wells yielding about 15 barrels of oil with 50 barrels of water per day. Water in the Swift contained 7,407 parts per million dissolved solids, mainly sodium chloride, and Madison water contained 2,425 parts, mainly sodium bicarbonate.

NORTHERN FIELDS—THE SWEETGRASS HILLS

GENERAL

The Sweetgrass Hills region, about 20 by 35 miles across, lies 10 to 40 miles northeast of the Kevin-Sunburst field and adjacent to the Canadian boundary in north-central Montana. This group of five small scattered laccolithic mountains, locally called "buttes", rise island-like 1,000 to 2,000 feet above a level treeless glaciated plain. Spring-fed streams rise in and near the buttes, but the water generally sinks into the glacial material on the plains where most streams are intermittent. Rainfall is from 12 to 15 inches per year, and annual mean temperature is about 42° F. Nearest railroad points are Sunburst 15 miles west of West Butte, and Chester 25 miles south of East Butte. Graveled country roads lead to the area, and graded dirt roads extend along section lines in most places.

Oil and/or gas have been found in 14 or more widely scattered localities surrounding the buttes. Most important producing areas are the Whitlash field, from which gas has been marketed since 1930, and the Keith field, which began marketing gas in 1952. Other important areas are Bear's Den, Utopia, and Flat Coulee; but commercial amounts of oil or gas have been found in still other localities, some of which are Pritchard, Bow and Arrow, Berthelote, Kicking Horse, Haystack Butte, and Grandview. The Devon gas field, actually closer to the Kevin-Sunburst field, may also be included in this general region because of similar geologic conditions. In the level plains 15 to 30 miles east of the "Hills" other commercial occurrences of gas have been discovered (Rudyard, Kremlin), and this entire region is potentially gas-bearing.

History.—First drilling in this region was in 1915 when the Montana-Canadian-Pritchard No. 1 well (sec. 4, T. 37 N., R. 2 E.) near the Canadian boundary was completed in a sandstone in the lower part of the Colorado group, and yielded about 4 million cubic feet of gas per day from a depth of 1,775 feet. The Rogers-Imperial well, 4 miles north of the border in Alberta, also was drilled in 1915; it is reported to have yielded 50 million cubic feet of gas per day from several horizons including the top of the Madison limestone. In 1918 the Montana-Canadian-E. Brown No. 1 well was drilled 4 miles west of the center of the Whitlash dome, and although a large flow of gas was encountered the well was abandoned. In 1924 the Gladys Belle-H. Brown No. 1 well, 2½ miles west of the center of the Whitlash dome was completed with an initial open flow variously reported from 15 to 31 million cubic feet of gas per day from several sandstones in the lower part of the Colorado between depths of 1,580 and 1,753 feet. This well was continued on into the Madison limestone at 2,730 feet, and although some oil was reported at 1,840 feet and 2,090 feet, the well was abandoned. Since no pipeline served this area prior to 1930 when a line was built, there was not market for the gas.

During the 1930's and 1940's many wells were drilled in the large region surrounding the Sweetgrass Hills. Shows of oil or gas were found in most of the wells, and some yielded commercial amounts of these substances, resulting in new fields. Drilling of wells continued into the 1930's.

Geology.—The Sweetgrass Hills, actually small mountains, are the result of a group of five laccolithic intrusions of igneous material forced upward through sedimentary rocks on the eastern flank of the huge Sweetgrass arch 10 to 30 miles east of its crest. Geologically they are entitrely independent of the development of the arch proper. Dikes radiate away from the "Hills" or buttes, cutting the sediments. Considerable faulting, and several irregular folds were developed in the region at the time of intrusions. Some of these folds (or domes) have influenced accumulation of oil and gas. However, oil and gas accumulation also appears to have been influenced or controlled by the presence of lenticular sandstones in sloping strata and, possibly by local variations in porosity. Erratic distribution of bodies of sandstone is particularly characteristic of the Blackleaf formation of the Colorado group.

Strata at the surface in the plains surrounding the buttes are of Late Cretaceous age. The outcrop of the Eagle sandstone circles each of the main buttes forming low foothills, and the sandstone dips gently away beneath drift-covered shales of the Claggett formation. Toward the buttes the strata bend steeply upward, resulting in successive exposures of the Colorado, Kootenai, and Ellis strata; and in the steep slopes of the larger buttes, strata of the Madison formation stand nearly verticle. Porphyritic syenite, forming the igneous cores 3 to 5 miles across, is in contact with the Madison; and older strata are missing at the surface in the buttes. Drilling in the plains near the buttes shows that Devonian and Cambrian strata underlie the Madison limestone. The succession and character of formations in the Sweetgrass Hills area are similar to that in the Kevin-Sunburst field. The main differences are that the sandstone in the lower part of the Colorado (Blackleaf formation) are more plentiful, and the lower part of the Kootenai formation may resemble the Kootenai in the Cut Bank field.

The producing horizons are the lower Colorado (Blackleaf) sandstones (comparable to the Bow Island sands of southern Alberta), the lower Kootenai sandstones, sandstones in the Ellis group (particularly the basal Sawtooth), and the top of the Madison limestone. Of course, all are not necessarily productive at each locality where oil or gas is found. Oil saturation was found in Devonian dolomite, but commercial production did not result, apparently due to lack of permeability. Gas under high pressure, and containing carbon dioxide and hydrogen sulphide may also be found in Devonian strata.

WHITLASH OIL AND GAS FIELD

Active development of the Whitlash dome, lying centrally in T. 37 N., R. 4 E., began in 1927. During this year the Western Natural Gas Company put down 8 wells yielding a combined open flow of about 33 million cubic feet per day, mainly from sandstones in the lower part of the Colorado shale. More wells were drilled in 1929. In 1930 a 10-inch 35-mile pipeline was constructed from Whitlash to Telstad where it connected with the Kevin-Sunburst-Great Falls pipeline, and in 1931 a 6-inch 7-mile pipeline was extended to the Rogers Imperial well (pipeline later abandoned). A market for gas was established, and the gas field continued to be developed. By 1935 there were 13 producing gas wells, and by 1950 there were 36 producing or producible gas wells across an area about 6 miles long and 3 miles wide. In 1958 there were 42 gas wells in the area occupied by the Whitlash dome, about 7 miles long and 3 miles wide.

Individual wells drilled into the Blackleaf (lower Colorado) sandstones yielded from 2 to 13 million cubic feet per day with initial pressure of about 300 pounds. Depth ranged from 1,400 to 1,800 feet. However, in some wells gas also occurred in Lower Cretaceous (Kootenai), Jurassic (Swift), and Mississippian (Madison) strata. All horizons did not necessarily produce in any one well. The Blackleaf sands, 100 to 200 feet apart, and known as first, second, and third Whitlash sands, are lenticular and erratic in occurrence; the Kootenai sands are more continuous, but tight and impervious in places, and the Sunburst sand may be of a channel type; the Swift shows low permeability irregularly distributed.

General stratigraphy in the Whitlash area is similar to that of the Kevin-Sunburst field 20 miles westward. The Whitlash dome, roughly circular, spreads from the Canadian border southward six miles onto the north flank of the East Butte laccolithic uplift which should be the closing side of the dome. Actual closure in this direction is in the order of 200 feet, but the proximity of the igneous intrusion may possibly have sealed off permeability to the south by metamorphism. In other directions structural closure is over 1,000 feet. Gas occurred broadly across the dome. Oil on the east side occurs about 500 feet down from the crest of the dome, but on the west side oil occurred about 1,000 feet downdip from the crest. However, as the producing sands are lenticular, structural position may not be a controlling factor. Oil occurred mainly in the Sunburst sand, but some also occurred in Blackleaf and Swift sands. Specific gravity is about 38° A. P. I. For most years from 1941 through 1958 the Whitlash field produced about 1 billion cubic feet of gas per year. In 1958, 2 wells produced 1,058,633,000 cubic feet or an average of about 70,000 cubic feet per well per day, after a field life of about 28 years. Oil production (largely from the Sunburst sand) for 1958 from 35 wells was 91,734 barrels, or a little over 7 barrels per well per day.

BEARS DEN OIL AND GAS FIELD AND KEITH GAS FIELD

The Bear's Den oil and gas field and the Keith gas field are described together because they both lie on a plunging anticline trending eastward from East Butte; however, both are shown on maps as relatively symmetrical separate circular domes, the crests lying about six miles apart. Structural closure, as shown for each is about 450 feet; although Bear's Den, within 3 miles of igneous rock on top of East Butte, may be closed on the west (the critical side) by faulting or metamorphism. Gas occurred on the western dome (Bear's Den) near its crest, and oil was found about 1,000 feet structurally lower than the crest of the dome, and 1½ miles east of the crest. Only gas has been found on the Keith dome, and only near the crest, which is structurally lower than the oil occurrence on the Bear's Den, due to eastward plunge of the structure. Two gas wells about midway between these two domes, but two miles southward, have been described as West Keith, the main east dome being designated as East Keith. It is also known as Alma dome.

The Eagle sandstone arcs around Bear's Den, and Colorado shale is exposed on the crest of the dome. The eastward plunge of the anticlinal structure carries the Eagle rapidly beneath overlying Montana group strata, which lie beneath the drift-covered plains at Keith. In the Texaco-Sorrell well (sec. 29, T. 36 N., R. 6 E., West Keith) the following depths in feet to tops of formations were reported: Colorado 645, Blackleaf 1,375, Kootenai 1,975 (Sunburst sand 2,365); Ellis 2,813, Madison 2,899, Three Forks 3,775, Potlatch 3,830, Jefferson 3,955, and Cambrian 4,915. Total depth was 4,960 feet. The well was plugged back to 2,850 feet in order to produce gas from the Ellis (Sawtooth). The sequence of strata east of the Sweetgrass Hills may be expected to correspond to that in this well,

The first well in the Bear's Den area was drilled in 1922. Other wells were drilled in the late 1920's, in the 1930's, 1940's, and 1950's. By 1935 there were 12 wells completed; 4 yielded commercial amounts of gas, 1 yielded both oil and gas, and 1 yielded oil only. Initial volumes of gas, which were reported mainly in the Blackleaf and Kootenai sandstones, ranged from 5 to 15 million cubic feet per day. Oil of 39° A. P. I. gravity, amounting to about 40 barrels per day, was reported to have been found in the Kootenai (Sunburst) sandstone. In 1958 two wells produced 31,933,000 cubic feet of gas, and 3 wells produced 4,190 barrels of oil.

The Keith Block was discovered in 1944 with the completion of the Texas-Cicon No. 1 well at West Keith (sec. 29, T. 36 N., R. 6 E.). It flowed about 3 million cubic feet of gas from the Blackleaf sands, the Sawtooth sand, and the top of the Madison. In August 1947 a well was drilled on the East Keith dome (Texas-Colbry No. 1, sec. 13, T. 36 N., R. 6 E.). After drilling to a total depth of 4,970 feet, it was plugged back to 3,048 feet and was completed producing gas from the Sawtooth formation 120 feet thick and 2,820 feet deep, and from about 110 feet of Madison limestone. Gas from the Sawtooth and Madison contains hydrogen sulfide; gas from the Blackleaf sandstones is free of sulfur. Deepest well (Montana Power Company, Sorrel-Govt. No. 1) bottomed in Cambrian strata at 5,015 feet. Initial yields of several million cubic feet per day were realized in the gas wells, the gas coming from one or all of the 3 horizons. Initial pressure at West Keith is reported as 993 pounds per square inch, and at East Keith 1,200 pounds per square inch. Reservoir energy is considered to be gas-expansion and water-drive. During 1958 the Keith block marketed 1,451,141,000 cubic feet of gas from 5 wells.

FLAT COULEE OIL FIELD

The Flat Coulee dome, about 6 miles north of East Butte, is laccolithic in character, although wells drilled on its top to depths of over 4,000 feet did not penetrate an igneous core. A large igneous dike (minette) beginning well up on the dome extends southwestward toward the Mt. Lilly (East Butte) laccolith, which is about 2 miles distant. The circular dome is about 2 miles across and has a structural closure of about 100 feet on the critical side to the southwest, and strata of the Montana group at the surface dip away from the central area at 5 to 10 degrees. Faulting is present.

The Sunburst-Disobell discovery well (sec. 10, T. 37 N., R. 5 E.) near the crest of the Flat Coulee dome, completed in 1927, is reported to have yielded about 30 barrels of 31° A. P. I. oil per day from a Jurassic sandstone (Swift) at depths of 2,611 to 2,688 feet. Flows of gas were found in 4 Blackleaf sandstones, in the Kootenai formation, in a lower Ellis sandstone, and in Madison limestone 2,850 feet deep. Total depth of well was 3,309 feet. Water occurred within the Madison limestone. Difficulty was had in completing the first well, due to collapsed casing, and it was abandoned. Oil accumulation in the Swift sands appeared to be controlled to a large extent by porosity and/or permeability variations, because the single producing well is 100 to 150 feet below the lowest closing contour. Additional wells were drilled on the structure in later years, and both oil and gas were found, the oil occurring in the lower part of the Kootenai. The Kootenai formation at Flat Coulee is reported to be somewhat similar to that at Cut Bank, wherein additional strata are present in the lower part of the &formation beneath the Sunburst sandstone. The basal sandstone of these additional strata was called Baskoo sand, a term now in little use; it is probably comparable to the Cut Bank sand of the Cut Bank field.

The Flat Coulee field produced 1,813 barrels of oil in 1950, and 759 barrels in 1951. Oil production for 1958 was 1,755 barrels from one well. Gas production for 1958 was 309,301,000 cubic feet from 4 wells or about 215,000 cubic feet per well per day.

UTOPIA GAS FIELD

The Utopia field lies in T. 33 N., R. 4 E., on a broad treeless plain 12 to 14 miles south of the Sweetgrass Hills, and about 25 miles east of the Kevin-Sunburst field. Beneath the surface soils and glacial drift are soft shales and sandstones of the lower part of the Montana group. The nearly horizontal strata have been warped into gentle flexures, the average amount of warping being in the order of 100 feet. Subsurface stratigraphy is similar to that in the Kevin-Sunburst field.

Several wells were drilled in this region in the 1920's and 1930's. Although some oil and gas were found, the wells were abandoned. Drilling operations were renewed in 1943 and continued in following years. In 1943, oil was found in the Texaco-State M-1094 well (sec. 16, T. 33 N., R. 4 W.) in the top of the Madison limestone, or else the overlying Sawtooth sandstone at a depth of 2,578 feet, and gas occurred in sandstones of overlying formations. About 20 barrels per day of 18° A. P. I. gravity oil was pumped, but difficulty was experienced with water and operations ceased. In another well one mile eastward gas was found in a Blackleaf sandstone at a depth of 925 feet, in the basal Ellis sandstone at 2,305 feet, and at the top of the Madison limestone at 2,610 feet. In the Utopia area gas flows of 1 to 4 million cubic feet per day may be found in the sandstones of the Blackleaf, the Kootenai, and the Ellis, and possibly at the top of the Madison limestone. In one well a flow of 20 million cubic feet per day was reported. The Blackleaf sandstones tend to be lenticular, and hence irregular in distribution and thickness. The Kootenai and Ellis sandstones should be persistent. One well was sunk into Cambrian strata (T. D. 4,068 feet), and shows of oil and gas are reported in Devonian strata.

A 6-inch pipeline was laid from the compressor plant at Telstad to the Utopia wells in 1949, and production began in December of that year. By 1950 there were 4 producible gas well, and production for that year was 752,429,000 cubic feet of gas. Oil production has been shut in since 1950, and the field now produces gas only. Total oil production is given as 2,879 barrels. Six gas wells in 1958 produced 619,537,000 cubic feet from basal Ellis sands, or about 286,000 cubic feet per well per day.

Six miles north of Utopia at Grandview 2 wells completed in 1930 yielded from 1 to 4 million cubic feet per day of gas from the Blackleaf sandstones at depth of about 760 feet. One well in sec. 7, T. 34 N., R. 4 E. found gas in the basal Kootenai sandstone. Drilling in this section was renewed in 1950 and following years.

DEVON GAS FIELD

The Devon gas field (west side of T. 33 N., R. 2 E.), 9 miles east of the Kevin-Sunburst field and 25 miles southwest of the Sweetgrass Hills, was discovered in 1929, and drilling continued during the 1930's. In 1941 eleven wells, each yielding from 1 to 4 million cubic feet of gas per day, were connected to the Great Falls pipeline 5 miles distant from the field, and gas was marketed. The gas which entered the pipeline came from the Blackleaf sandstones at depths of about 800 to 1,000 feet. Showings of oil were reported at the top of the Madison limestone at about 1,730 feet as well as at higher horizons, but commercial amounts of oil were not found. Strata in this area dip gently eastward off the east sides of the Sunburst dome, and gas accumulation appears to be in lenticular sandstones.

Natural gas production for the Devon field for 1950 was 208,032,000 cubic feet. Seasonal gas production for 1958 from 21 wells was 191,518,000 cubic feet, or an average of 23,000 cubic feet per well per day for the year.

OTHER OIL AND GAS FIELDS, SWEETGRASS HILLS

The Kicking Horse domal structure, 3 miles southwest of West Butte and 9 miles northeast of the Kevin-Sunburst field (northwest part of T. 36 N., R. 1 E.), was tested by drilling in 1944 and 1945. The roughly circular dome is about two miles across and has a structural relief (closure) of about 200 feet. Gas ranging from 1 to 20 million cubic feet per day was found in the lower Colorado (Blackleaf) sandstones, showings of light oil were reported from the Ellis, and a heavy tar-like oil occurred at the top of the Madison limestone. Four gas wells were considered commercial. In 1946 a 12-mile pipeline was constructed from these wells to Sunburst, but the field was abandoned in 1950 due to decrease in gas pressure. The lower Colorado (Blackleaf) sandstones, in which gas occurred, are at about 1,475 feet. The Sunburst sandstone is at 1,840 feet, and the top of the Madison limestone was reported at 2,040 feet. Natural gas production for the Kicking Horse field for 1950 was 35,534,000 cubic feet.

Five wells have been drilled on the Berthelote structure (sec. 30, T. 36 N., R. 2 E.) 6 miles south of West Butte and 10 miles northeast of the Kevin-Sunburst field. Drilling began in 1929 and was continued in 1940. Gas amounting to 1 to 5 million cubic feet per day and oil amounting to 18 barrels per day were reported. The gas occurred in a lower Colorado (Blackleaf) sandstone at about 1,440 feet, and oil and the Sunburst sandstone at 3,435 feet. No pipeline served the field but some oil was marketed by trucking.

Near Haystack Butte two wells were completed on sec. 18, T. 35 N., R. 4 E., in 1941. They yielded about 4 million cubic feet of gas per day from the lower Colorado sandstones at depths of 1,850 to 2,250 feet. The wells were closed in for lack of a pipeline.

Three gas wells were drilled on what is known as the Arch Apex structure (sec. 3 and 4, T. 36 N., R. 3 E.) in 1945 and later years. Gas reported to range from 2 to 10 million cubic feet per day open flow with a pressure of about 450 pounds came from the Blackleaf sandstones at depths of about 2,000 feet.

There is little or no doubt that additional oil and gas wells will be developed in the Sweetgrass Hills region. Due to irregularities in the potentially producible horizons, numerous wells may be necessary to outline the areas of production. This region is, however, potentially oil and gas productive.

HILL COUNTY GAS FIELD

Across the 60 miles of level glaciated plains in northern Hill County east of the Sweetgrass Hills about 75 wells have been drilled in search of oil and gas. Only gas was found, and it occurred in at least six widely spaced localities. No gas was marketed during 1958. From west to east these occurrences are known as Rudyard (T. 34 N., R. 9 E.), Gilford (T. 33 N., R. 11 E.), Fairchild (T. 37 N., R. 11 E.), Kremlin (T. 33 N., R. 12 E.), Havre (T. 32 N., R. 16 E.), and Cassady (T. 34 N., R. 17 E.). Excepting at Havre and Kremlin, no pipeline serves the area, hence there is no market for gas. Nevertheless, with the possible extension of these known gas-producing areas, or with the discovery of new areas, this region remains an important potential source of commercial amounts of gas.

The formations which have yielded gas in this region are the Eagle sandstone, lower Colorado (Blackleaf) sandstones, Kootenai sandstones, basal Ellis or Sawtooth formation, and the top of the Madison limestone. The Sawtooth formation changes gradually eastward from a sandstone, as in the Sweetgrass Hills, to a dolomitic oolite in places. Porosity persists, although amount differs locally. Strata beneath the glacial drift in practically all of this region are in the Judith River formation. The Madison limestone should lie about 3,000 feet beneath this formation.

NORTHERN FIELDS—BEARPAW MOUNTAIN REGION

The Bearpaw Mountain region is unique from a structural point of view in that scattered through a circular zone 20 to 30 miles wide on the plains surrounding the mountains occur long sharp narrow anticlinal folds (perhaps 100 or more), usually cut near their crests by steeply dipping thrust faults. Strike of the folds and faults are peripheral to the circular mountain area, and in cross-section the folds and faults appear to have been caused by nearly horizontal thrusts outward from the mountains. Length and width of folds differ much, but average length is about 10 miles, and the width from ⅛ to 2 miles. Height of folds is generally about 1,000 feet. Actually these structures probably should be considered shallow thrust faults accompanied by anticlinal folding. Between folds, which may lie 1 to 5 miles or more apart, Upper Cretaceous strata lie nearly horizontal, and apparently undisturbed. These folds and faults are not believed to extend to great depth, but are thought to die out within perhaps 1,000 to 3,000 feet in the mass of Colorado shale which underlies the area beneath surface exposures of formations of the Montana group. The Bearpaw Mountains are in part laccolithic and in part piles of lava on Cretaceous strata. Origin of this maze of interlacing folds and faults is problematical; uplift of the mountain area followed by subsidence, or else forces caused by intrusion are suggested as causes.

Numerous test wells have been sunk in this region, perhaps 30 or more not including those in productive areas. Gas has been found in several localities in the Eagle sandstone and oil was found in one locality (Bowes field) in Jurassic sandstone. However, excepting on the Bowes, Boxelder, and Havre structures on the north side of the mountains, results of drilling have been disappointing.

SHERARD STRUCTURE

South of the mountains, even as far as Winifred, small amounts of gas were found in several of the structures, but no commercial production resulted. On one known as Sherard or Birch Creek anticline (sec. 17, T. 25 N., R. 17 E.) a well drilled in 1922 is reported to have yielded gas estimated at 3,000,000 and 20,000,000 cubic feet per day flowing from depths of 1,050 and 1,750 feet respectively. The well records indicate a repetition of strata, and it is postulated that in drilling a fault was penetrated. The lower gas-bearing horizon is considered as Eagle sandstone, and the well bottomed at 2,700 feet in Colorado shale. About 15 years later other wells were drilled nearby, however, although gas was encountered, lack of a pipeline caused abandonment of the wells.

BOWES OIL AND GAS FIELD

The Bowes oil and gas field lies 6 miles south of Chinook or 20 miles southeast of Havre on the glaciated upland plain of northern Montana. It is about 10 miles northeast of the foothills of the Bearpaw Mountains. The gas producing area covers about 5 square miles, and the oil-producing area, about one mile eastward, covers about 3 square miles. The gas and the oil come from different formations.

The first well in the field was drilled in 1924 to a depth of 4,700 feet, and although some gas was found, it was abandoned because of no pipeline. The development of the gas field began in 1926 when 4 wells were drilled, and by 1935 there had been 9 wells successfully completed on the structure. Seven to 30 million cubic feet of gas per day per well flowed from the Eagle sandstone at depths from 653 to 1,078 feet, depending on structure. Initial pressures ranged from 250 to 300 pounds, the average being 260 pounds. A pipeline was laid to Chinook and Havre in 1926. The field then produced gas continuously, and the oil field remained unknown for 23 years. The gas is essentially methane.

In 1949 drilling of the Northern Ordinance-Guertzgen No. 1 well (sec. 2, T. 31 N., R. 19 E.) initiated the development of the oil-producing area, which spreads out broadly about two miles eastward. The well yielded asphaltic oil of 20° A. P. I. gravity amounting to about 200 barrels per day from the basal Ellis Sawtooth formation at a depth of about 3,400 feet or about 2,600 feet beneath the Eagle sandstone. Development proceeded rapidly, and by the end of 1951 about 20 additional wells had been drilled with initial flows ranging from 100 to 400 barrels per day. An oil pipeline was laid to the railroad at

Chinook. Peak oil production was reached in 1953 when 1,025,261 barrels of oil were produced, ranking this field fourth among Montana's oil fields at that time. By 1958 production had declined to 277,263 barrels of oil coming from 87 wells, an average of nearly 9 barrels per well per day. Peak gas production of 1,350,000,000 cubic feet was reached in 1950. In 1958 gas production was 886,086,000 cubic feet from 19 wells, an average of nearly 130,000 cubic feet per well per day.

Strata at the surface throughout most of the area are soft shales and sandstone of the Judith River formation which may contain coaly horizons and also oyster beds. Bearpaw shale is reported in down-dropped fault blocks observed at the surface, but this structure is not believed to continue in depth. Beneath the Judith River beds is the Claggett formation, about 600 feet thick, and then 150 feet of Eagle sandstone. Gas occurred in the upper 80 feet of the Eagle at a depth of 700 to 1,000 feet, depending on structural position. The colorado shale underlying the Eagle is about 2,000 feet thick, and the Kootenai formation beneath the Colorado is 300 feet thick. In some wells, shows of oil and gas were reported in the Kootenai, particularly the basal sandstone, but none proved commercial. Underlying the Kootenai is the Ellis group about 350 feet thick; and near its base is the oil-producing Sawtooth formation, about 50 feet thick in this locality.

It is described as "sandy, silty, oolitic limestone and calcareous sandstone." Beneath it accurrs 60 feet of limestone and then 70 feet of limy shale and fine-grained sandstone correlated with the Piper formation. Depth to the Sawtooth ranges between 3,300 and 3,500 feet. The Madison limestone underlying the Ellis is about 750 feet thick, which is less than in regions west, south, and east. The deepest well (Northern ordinance-Guertzgen No. 5, sec. 1, R. 31 N., R. 19 E.) penetrated the Sawtooth sand at depths between 3,310 and 3,384 feet, the top of the Madison at 3,516 feet, the top of the Devonian at 4,160 feet, and bottomed at a depth of 5,082 feet close to Cambrian strata (probably in Souris River formation). Cambrian formations underlie Devonian strata in this part of Montana.

The geologic structure is unique, and perhaps a bit confusing, because structure in deep-seated strata does not correspond with that in surface strata. Structural maps contoured on the basal Jurassic Sawtooth formation (depth about 3,300 feet) show a rather symmetrical circular dome about 3½ miles across centering on the west sides of sections 1 and 36. Closure is about 120 feet; and faulting, believed to be present at the surface, is not recognized at depth. Structural contour maps of surface structure show an irregular elongated dome, about 4 miles long and 2 miles wide, centering in sections 4 and 34, about two miles west of the crest of the deep-seated structure. The surface structure is broken by graben-type faults dropping Bearpaw shale into Judith River beds. Hence the surface structure and deep-seated structure fail to correspond either in pattern or location. The presence of unconformities between the Sawtooth formation and the surface rocks aids in explaining this discrepancy. Furthermore, these structures are not comparable to the peripheral Bearpaw Mountain thrust type previously mentioned. They must have resulted from some independent earth force.

BOXELDER AND HAVRE GAS FIELDS

The Boxelder gas field, 6 miles southeast of Havre, was made known in 1931 when a well (sec. 14, T. 32 N., R. 17 E.) drilled into the Eagle sandstone at a depth of 1,272 feet flowed 7,250,000 cubic feet of gas per day with an initial pressure of 430 pounds per square inch. A previous well had found some gas in a sandstone in the Judith River formation at a depth of 420 feet, but water was found in this sandstone in a second shallow well. In 1935 another well was drilled into the Eagle sandstone and yielded 6,500,000 cubic feet of gas per day. These wells were connected to the Bowes-Havre pipeline. By 1950, 12 wells had been completed. The gas is essentially methane.

Strata of the Judith River formation are at the surface throughout most of the area. The sequence, character, and thicknesses of formations are essentially the same as in the Bowes field 12 miles eastward. The gas wells are along the crest of an elongated faulted domal anticline, probably the same structure that passes near Havre, and which yielded gas near Havre. It is the Bearpaw Mountain type of faulted anticline.

The Havre gas field (now abandoned) was discovered in 1914, and eventually had 26 gas wells. Initial flows from early wells is reported as from 1 to 15 million cubic feet per day under pressure of 490 pounds per square inch. Gas came from the Eagle sandstone at depths of about 1,000 feet. The gas was marketed in Havre for about 10 years beginning with 1915.

Peak production of the Boxelder field was 169,068,000 cubic feet in 1954; but production in 1958 was 19,551,000 cubic feet from 2 wells, or an average of about 27,000 cubic feet per well per day.

NORTHERN FIELDS—THE BOWDOIN DOME

BOWDOIN-SACO GAS FIELD

The Bowdoin-Saco gas field in the eastern part of the northern Montana region, and one of Montana's major gas producing areas, is about 18 miles long and 9 miles wide. It lies on a broad structural arch or dome 35 miles south of Canada in the flat valley lands of Milk River and Beaver Creek at a place where the valley widens to about 20 miles. A low flat glaciated upland plain devoid of trees extends for many miles on either side of the valley. Altitudes above sea level range from 2,200 to 2,500 feet. Principal towns are Saco on the eastern edge of the field, and Malta six miles west of the field. U. S. Highway 2 and the Great Northern Railway pass through the field and these towns. The annual rainfall is about 14 inches, and the annual mean temperature is about 41° F.

The Bowdoin dome was described in 1917 and mapped in detail in 1933 by the U. S. Geological Survey. Gas was discovered in this area in 1913 on the east side of the dome in a shallow well drilled for water, and in 1916 on the west side of the dome in a deep test well. Intensive drilling to develop natural gas began in 1929 when 25 wells were sunk to depths of about 750 feet. All were reported to have yielded some gas, and a well yielding 1,000,000 cubic feet per day was considered good. Within 5 years 45 wells had been drilled; 21 were active wells at that time, 11 were shut in, and 13 were abandoned. In 1930 a 4-inch pipeline was laid to Malta and a 6-inch pipeline to Glasgow. Later a larger line was laid to Glasgow and pipelines were extended to the Fort Peck dam site and to Popular. In 1945 an 8-inch line was laid from near Wolf Point to Intake, where it connected with the Glendive-Williston gas pipeline, thereby joining with the Montana-Dakota Utilities system in eastern Montana. Peak production was in 1949 when slightly over 8 million cubic feet of gas was produced. In 1950 there were producing or producible 332 gas wells. By 1958 annual production had decreased to 2,143,347,000 cubic feet from 367 wells, or an average of about 15,500 cubic feet per well per day.

Deeper horizons near the top of the dome were tested in 1916 by the Bowdoin Oil Co. No. 1 well bottoming in Amsden limestone at 2,440 feet depth; in 1923 by the Bowdoin No. 2 well (sec. 33, T. 32 N., R. 32 E.) bottoming at 3,180 feet probably in strata at the base of the Big Snowy group; and in 1947 by the Texas-Bowdoin well (sec. 8, T. 32 N., R. 32 E.) which penetrated strata of Cambrian age and bottomed at a depth of 5,500 feet. Results of drilling beneath the gas-bearing horizon were disappointing. Large volumes of hot water (up to 108° F.) were found at several horizons beneath the Colorado shale and above the Madison limestone.

Formations beneath the Colorado shale and approximate thicknesses in feet, as interpreted from the Texas-Bowdoin well are: Kootenai, 385; Morrison, 165; Ellis, 435; Big Snowy group, 215; Charles (?), 40; Madison group, 820; Potlatch, 400; Devonian limestone unit, 620; Big Horn, 350; Cambrian, 400 plus. The top of the Kootenai was found at a depth of 1,960 feet, the Ellis at 2,510 feet, the Big Snowy group at 2,945 feet, the Madison group at 3,160 feet, the Potlatch at 3,980 feet, the Big Horn at 5,080 feet, and the Cambrian at 5,450 feet. The Heath formation appears to be missing and the Otter is about 70 feet thick.

Most of the valley lands are blanketed by thick deposits of alluvium and glacial drift, but outcrops and even steep banks of sandstone or shale are prominent, particularly near the sides of the valley and the margins of the dome. Geologic maps show conspicuously the presence of a structural dome. The outcrop of the alternating sandstones and shales of the Judith River formation, within a widespread area of Bearpaw shale, encircles the uplift; Claggett shale (580 feet thick) is at the surface over most of the central part; and erosion has penetrated nearly to the horizon of the Eagle formation. The Eagle formation in this locality consists of sandy shale and thin shaly sandstones, and is not readily recognizable. The underlying Colorado group, total thickness of which is about 1,800 feet, is considered as a single unit. The gas sands, known as Martin, Bowdoin, and Phillips, are approximately 350, 450, and 600 feet beneath the top of the Colorado shale; they may correspond to the Medicine Hat gas sands in Canada. It appears that these sands lie slightly higher, stratigraphically, than the Frontier sands of southern Montana.

The Martin or upper sandy zone did not yield commercial amounts of gas, and the Bowdoin gas zone is by far the most important producer, because of its more persistent distribution, its higher porosity and permeability, and its thickness, which ranges from 15 to 100 feet and averages 50 feet. It is described as not a typical sandstone, but a very fine-grained sandstone or siltstone, or even as a shale containing small lenses of sandstone. In some wells only shale is recorded at this horizon. Average porosity of the zone is estimated not to be more than 10 percent. Initial open flows from the Bowdoin zone ranged from 250,000 to 1,210,000 cubic feet per day, the average being about &—660,000 cubic feet. Initial reservoir pressure averaged 217 pounds. The relatively small volumes obtained from wells no doubt directly reflects the fine-grained character of the sands together with a rather low permeability, but these factors point toward long life of wells. Statistical studies of all wells shows that the field as a whole may be subdivided into component areas within which wells are related in behavior, but the different areas differ somewhat from one another suggesting that they may not be freely connected underground.

The lower or Phillips gas zone is present in only about one-sixth of the area of the productive Bowdoin zone, but lithologically it resembles the Bowdoin zone. Its thickness ranges from 20 to 80 feet averaging 35 feet, and there may be two productive horizons within the zone. Initial open flow from the Phillips zone ranged from 200,000 to 1,400,000 cubic feet per day, the average being about 725,000 cubic feet. Initial pressures were from 265 to 438 pounds, the average being about 370 pounds.

No water is present in the Bowdoin and Phillips sands within the producing area. The Martin sand contains water locally, and the Eagle sandstone horizon generally yields water. Sandstones in the Kootenai formation, Ellis groups, and Big Snowy group are water-bearers, and water is present at the top of the Madison limestone.

The Bowdoin dome is roughly circular, about 50 miles across, and has a structural relief (closure) of 700 feet or more. The top of the dome about 8 by 20 miles across, is divided into eastern (Saco) and western (Bowdoin) parts by a structural saddle with about 100 feet of relief, and minor folds extend away from the crests. Dip of strata in nearly all of the area is less than one degree, and in much of the area less than half a degree. Faulting has not been recognized in the domed area. The origin of this dome, 50 miles from other major uplifts, is problematical; some geologists have suggested that it may result of deep-seated igneous activity of a laccolithic type in the basal complex, however, no igneous dikes are known to be present in the gas producing area.

Annual production of gas from the Bowdoin-Saco area is shown graphically on Fig. 3, "Montana's Annual Production of Natural Gas." In 1958 it was 2,143,347,000 cubic feet from 367 wells.

CENTRAL FIELDS

The central Montana oil fields, twelve in number (1959) not counting subdivisions, are all closely associated with the Little Belt-Big Snowy-Porcupine uplift and lie on or close to its northern and southern sides, as well as near the middle, 20 to 50 miles east of the Big Snowy Mountains. Minor folding on the uplift appears to have been an important factor in oil occumulation, but other factors such as faulting, channel sands, porosity variation, and unconformity, differing in different fields, also have been important. It is also noteworthy that several folds in this general region, which on a map would appear to be ideal for oil or gas accumulation, have been tested without finding oil or gas in commercial quantities. Free gas in commercial quantity is not present in the oil fields in central Montana, and no commercial gas field in this region has been discovered. (The Big Coulee gas field 8 miles south of Ryegate is placed with the southern fields). Due to the truncation of upper Paleozoic formations throughout central Montana by pre-Jurassic erosion the subsurface geology differs somewhat from place to place. Furthermore, the stratigraphy in this region is characterized by the presence of the Amsden formation absent in northern Montana, and the Big Snowy group of sediments absent in northern and southern Montana.

On the accompanying generalized map, figure 21, it may be noted that these central Montana oil fields aline themselves along four anticlinal trends paralleling the Big Snowy-Porcupine trend, the oil occurring on high parts of the anticlines where local elongated domes are developed. Three of these anticlinal trends lie on the relatively flat top of the bench-shaped uplift, one lies just south of the uplift on the north flank of the Bull Mountain basin. Other similar anticlinal trends are present in this region, and wells have been sunk upon them with disappointing results. These structures strike eastward from the Big Snowy and Judith mountains, but commercial oil fields lie 30 miles or more east of the mountains far down the plunge of the anticlinal trends. Because of the structural relations of certain oil fields, they are grouped together along trend-lines in this report. However, stratigraphy of all, in a general way, is about the same, excepting the southern trend in which the Tyler and Big Snowy sediments are absent.

The producing formations in these fields are Lower Cretaceous, Jurassic, and Mississippian sandstones, and the Amsden dolomite probably of Pennsylvanian age. Testing of all of these formations involves penetration of 1,100 to 2,700 feet of strata lying beneath the Colorado shale, the thickness differing with locality. In 1958 central Montana oil fields produced 3,201,000 barrels of oil, or 11.4% of the states total production for that year.

An interesting side-light in development of central Montana's oil fields is this matter of delay between discovery of oil in different producing horizons in the same field; at Cat Creek 25 years, at Ragged Point 9 years, at Big Wall 5 years, and at Sumatra 6 years. (See Tables 2 and 3). This was largely because the commercial accumulations of oil in different formations do not always occur vertically above one another, and only by drilling off-set or out-lying wells were the additional pay zones found. In other words, stratigraphic types of accumulation are important. Along the Gage-Wolf Springs trend effective porosity appears to be intimately associated with a prevalent condition of fracturing in dolomite.

DEVIL'S BASIN OIL FIELD

The Devil's Basin oil field is 15 miles north of Roundup on U. S. Highway 87. Although it has not proven to be an important commercial oil field, it is of geologic interest because the producing horizon is within the Heath formation of Mississippian age generally considered nonproductive, and of historic interest because it was the second discovery of oil in Montana. The Elk Basin field was discovered in 1915 and the Devil's Basin field in 1919. As a result of these discoveries over 30 wells were soon drilled wide-

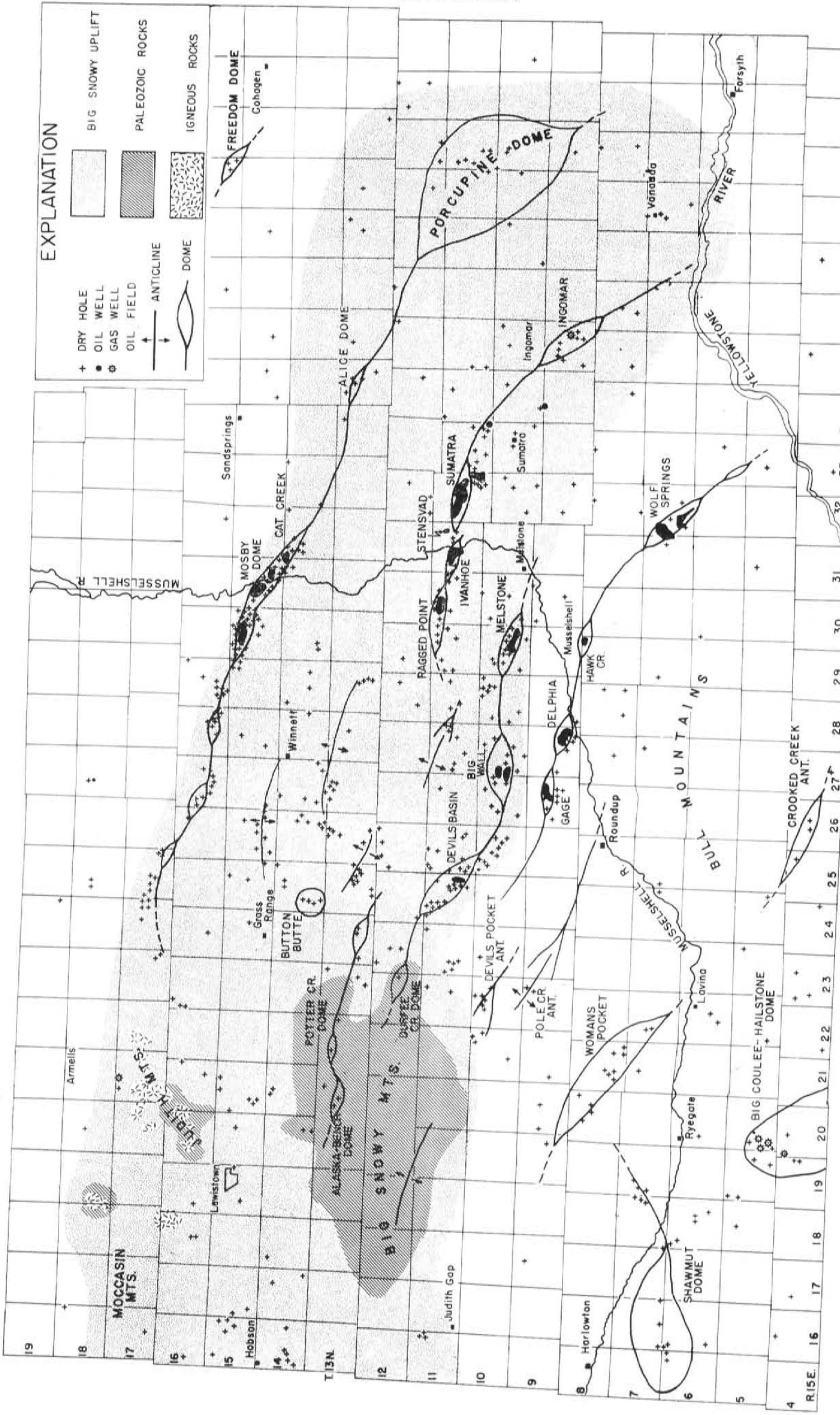

Figure 21.—Anticlinal trends and oil fields in central Montana.

spread in Montana. The Cat Creek field was discovered in 1920, and the Kevin-Sunburst field in 1922.

The field lies on the south side of the Big Snowy-Porcupine uplift on a sharp asymmetrical domal anticline which is similar to the Cat Creek anticline on the north side of the uplift. The Devil's Basin anticline is a westward continuation of the Big Wall and Melstone anticline. Structural closure at Devils Basin is about 1,000 feet. Erosion has cut through the Colorado shale, exposing the upper part of the Kootenai formation on the top of the dome. The succession of geologic formations is similar to that in the Big Wall oil field. In a deep test well (sec. 5, T. 10 N., R. 25 E.) the following depths to tops of formations were reported: First Cat Creek sand 664, Morrison 1,180, Ellis 1,390, Amsden 1,658, Tyler 1,930, Heath 2,053, Kibbey, 2,668, Charles 2,895, Mission Canyon 3,587, Bakken 4,535, Big Horn (Red River) 4,597, Cambrian 4,790, Belt 5,500, total depth 6,517. The well bottomed in argillite and quartzite believed to be Belt strata and was abandoned.

Oil in the discovery well occurred in limestone or dolomite called "Van Duzen Sand", in the upper part of the Mississippian Heath formation at a depth of about 1,100 feet. Porosity and permeability are said to result mainly from fracturing. Of 15 early wells drilled on the Devil's Basin dome, five yielded some oil, but only three were pumped. More wells were drilled later. Total cumulative production to 1959 from 5 wells during an intermitant life of the field was reported as 34,000 barrels, the production in 1958 being 5,658 barrels. The 24-degree black viscous oil contained 10 percent gasoline and 17 percent "gas-oil".

CAT CREEK OIL FIELD

The Cat Creek oil field, 20 miles east of Winnett in central Montana, was discovered in 1920, the third discovery of oil in this state. The field has had a long life, that is, a relatively slow decline. With the finding of oil in deeper horizons in 1945, interest in this field and surrounding areas was revived, and a new surge of drilling activity followed. The field may be divided into three parts lying on the west, middle, and east Mosby domes, all of which are local "highs" along the crest of the 60-mile-long asymmetrical Cat Creek anticline lying at the northern edge of the Big Snowy-Porcupine uplift. The topography throughout the field is rough, and is gullied by tributaries to Musselshell River. Cat Creek, extending about 5 miles westward from Musselshell River along the anticline, is one of these tributaries. The river has cut a narrow steep-walled valley about 425 feet below an upland plain spreading over most of this part of Montana. Steeply dipping sandstones form hog-backs along the northern flank of the anticline, but southward, where dips are gentle, the surface of the plain is relatively level. Rainfall is from 12 to 15 inches per year, and annual mean temperature is about 43° F. The oil fields are about 3,000 feet above sea level.

History.—The first oil well in the Cat Creek field was put down in 1920 by the Frantz Oil Corporation on the middle Mosby dome (sec. 21, T. 15 N., R. 30 E.) about three miles east of what later became the main producing area. Only about 10 barrels of oil per day were reported. Seven more unsuccessful wells were drilled before the Frantz Corporation completed a well in 1920 on the west Mosby dome (sec. 14, T. 15 N., R. 29 E.) which is reported to have had an initial flow of 2,500 barrels of oil per day, but which settled to about 350 barrels. Oil came from the basal Colorado First Cat Creek sandstone at a depth of about 1,200 feet, but water was found in the second Cat Creek sandstone in this well. More producing wells were drilled during the same year, some finding oil in the second Cat Creek sandstone as well as in the first. A pipeline was laid to the railroad at Winnett 16 miles distant. At first oil was shipped from Winnett to Greybull, Wyoming, for refining, but soon two refineries were built in Lewistown. By the end of 1921 over 50 producing wells had been completed, initial flows commonly being in excess of 2,000 barrels per day, and settled productions ranging up to 600 barrels daily. By July, 1926, there had been 285 wells drilled in and adjacent to the field; 190 on west Mosby dome produced oil, and of these 131 obtained oil from the First sand and 59 in the Second sand. The area of production appears to be defined. Large volumes of fresh potable artesian water were found in the Third Cat Creek sandstone at the base of the Kootenai formation 100 to 150 feet below the Second sand, and 260 to 380 feet below the First sand.

In October, 1945, the Schrock-Fifer well, drilled on the middle Mosby dome on the same section as the 1920 Frantz discovery well (sec. 21, T. 15 N., R. 30 E.), found oil 400 feet below the Second Cat Creek sand or 200 feet below the Third Cat Creek sand in a sandstone in the Morrison formation (Brindley sand). A second well drilled into the same formation started flowing at the rate of 75 barrels per day. This initiated a new campaign of drilling to deeper horizons in the entire Cat Creek field which continued for several years. Eventually oil was found in a second Morrison sandstone, and also in a sandstone in the Swift formation of the Ellis group. Initial flows ranged up to 500 barrels per day, and averaged about 200 barrels. Many old First and Second Cat Creek sand wells were deepened and found oil in the deeper horizons. The sandstones of the Morrison appear to be lenticular or at least irregular in porosity distribution. The Swift sand is continuous.

Peak production of almost six and one-half million barrels was reached in 1926. The production history and progressive decline of the field is shown in figure 3, the slight rise in production in 1946 being due to discovery of oil in deeper horizons. By 1959 the field had reached the "stripper stage", and average production from 84 wells in 1958 was 5.3 barrels per day. Of the 167,658-barrel production for 1958, about 65 percent came from the Swift formation and 31 percent from Kootenai sandstones. Experiments have been conducted by injecting water through selected wells into the oil-bearing sandstones to increase reservoir pressure, and the favorable results so far obtained should lead to widespread use of this method of secondary oil recovery.

Geology.—Strata at the surface in the producing areas are in the upper part of the Colorado shale. The overlying Eagle, Claggett, and Judith River formations crop out in narrow bands a quarter to a half a mile north of the field. The Bearpaw shale is at the surface about one mile northward, and beyond, massive sandstones of the Fox Hills formation form rugged timber-covered hills. Southward, the low escarpment of the Eagle sandstone is one to three miles distant, and the Claggett shale underlies rolling plains for several miles beyond. The outcrop of the Eagle sandstone circles the eastern end of the Cat Creek anticline about nine miles southeast of the oil fields.

The Colorado is about 1,850 feet thick. It is almost entirely dark-gray to black plastic thin-bedded to massive shale, and generally is not subdivided; however, the Mowry formation, composed of shale and shaly silver-gray sandstone and containing fish scales and bentonite, crops out conspicuously 25 miles westward. Beds of bentonite, zones of calcareous concretions, or beds of sandy shale are present throughout the Colorado; and at least two sandstones are persistent, the 40-foot First Cat Creek sand at the base, and the 5-foot Mosby sandstone 1,065 feet above the First Cat Creek sand.

The Kootenai formation, about 350 feet thick, lies beneath the Colorado shale. The upper 150 feet is essentially shale and sandy shale much of which is bright red. The "first red" is commonly considered the top of the Kootenai, but some gray shale may lie above it. The lower 200 feet also contains red shale, but it also contains important sandstone members. The uppermost of these is the Second Cat Creek sand, and the lowermost, constituting the base of the Kootenai, is the Third Cat Creek sand. The thickness of each differs from place to place, and shale partings may be present in the sandstone. Thickness of the Second sand averages forty feet, and the Third sand 75 feet. Other sandstones in the Kootenai are lenticular, impure, and irregular in occurrence.

The Morrison formation (Jurassic) beneath the Kootenai consists of 200 to 300 feet of red, green, and gray clayey shale with lenses of relatively pure sandstone. These sandstones were important in the deeper oil development of 1945 and later. The Morrison sediments, along with those of the Kootenai, are considered terrestrial in origin. The marine Jurassic Ellis group underlying the Morrison consists of 350 to 450 feet of fossiliferous sandstone with limestone and shale. It is subdivided into the Swift, Rierdon, and Piper formations. Glauconite characterizes the formations. In some localities red and gray shale with commercial beds of gypsum (Piper or Gypsum Springs formation) may occur near the base. Total thickness ranges from 400 to 500 feet.

Geologic reports dealing with parts of central Montana published prior to 1935 erroneously described a thick series of strata beneath the Ellis group and above the Madison limestone as the Quadrant formation. It is now known that these strata present in central Montana can be divided into the Amsden limestone at the top, then the Heath black shale, the Otter green shale, and the Kibbey reddish dolomitic sandstone, the last three constituting the Big Snowy group of formations. An anhydritic, dolomitic, shaly series of strata constituting the Charles formation lies beneath the Kibbey and constitutes the upper member of the Madison group. In the California Co.-Arro Oil Co.-Charles No. 4 well (sec. 21, T. 15 N., R. 30 E.) the following thicknesses of formations in feet are interpreted from well cuttings: Kootenai 325, Morrison 240, Ellis 470, Amsden 220, Heath 560, Otter 300, Kibbey 105, Charles 745, Madison (Mission Canyon and Lodgepole) 1,100, Devonian 80 (?), Ordovician 120, Cambrian 785 plus, total depth 5,705 feet. The division between the Charles and Mission Canyon formations of the Madison is difficult to determine, but is commonly made below the lowest massive anhydrite bed of which there are several in the Charles. The black granular dolomite of the Jefferson formation of Devonian age has not been positively recognized, and a cream to buff sugary dolomite beneath the Madison is thought to be the Big Horn formation of Ordovician age; fifteen feet of sandstone beneath this dolomite may be equivalent to the Winnipeg formation (Ordovician), and the underlying shales and limestones are believed to be Late Cambrian in age.

Although the oil definitely occurs on high places along the crest of the Cat Creek anticline, its concentration is confined to that part of the anticline which is cut by many cross-faults, displacements of which are reported to be up to 150 feet. Other high places along this anticline which are not faulted have failed to yield oil. It is suggested that this faulting prevented flushing of oil out of the First and Second Cat Creek sands by the strong artesian water circulation prevalent in central Montana. The thicker Third Cat Creek sand now has a strong circulation of fresh artesian water and no oil concentrations, but its thickness is greater than most of the fault displacements.

The Cat Creek anticline trends slightly north of west, and forms the northern edge of the Big Snowy-Porcupine uplift. Dip of strata on the north flank of the anticline commonly is 60 to 75 degrees, but on the south side average dip is about 2 degrees. Local "highs" along the 60-mile anticline have a structural relief (closure) of up to 600 feet, and there are 8 or more of these "highs", three of which have yielded oil. Structural contour maps show that the West Dome (main producing area) is cut by 12 or more small normal faults, and East Dome by perhaps 18 faults. (Reeves, 1927).

The oil from the several sands has a gravity of about 50° A. P. I.; it yields 58 percent gasoline, 20 percent kerosene, and has a sulfur content of about 0.25 percent. Water with oil has not been serious.

BIG WALL OIL FIELD

The Big Wall oil field, so named because of nearly vertical cliffs of Eagle sandstone nearby, lies 16 miles northeast of Roundup on the upland plain of central Montana, which locally is trenched by valleys of intermittent streams. The field is reached by graded roads which leave U. S. Highway 87 about 12 miles north of Roundup.

The anticline on which the field lies was known before 1915, and in 1922 a well (Ohio-Lemmon, sec. 24, T. 10 N., R. 26 E.) was completed on the structure. It bottomed at 3,050 feet, apparently in shales of the Big Snowy group, and was abandoned. Oil was discovered in 1948 when the Texaco-Northern Pacific well (sec. 19, T. 10 N., R. 27 E.) was drilled about one mile eastward. Oil occurred in what was then called basal Amsden at a depth of 3,098 feet. Later in 1948 another well (Texaco-Zoerb, sec. 18, T. 10 N., R. 27 E.) topped the Amsden at 2,452 feet, and from a depth of 2,811 feet began flowing about 150 barrels of oil per day, the oil coming from the Tyler formation ("A" sand). Development followed cautiously but by the end of 1950 there were 20 producing wells scattered over an area of about 1.5 square miles. Oil came from three producing horizons: the top 20 to 30 feet of the Amsden dolomite, and from the "A" and "B" sands of the Tyler formation, about 300 and 500 feet respectively beneath the top of the Amsden. Peak yearly production of 715,534 barrels was reached in 1951, but production declined rapidly to less than half this amount in 1953. Production in 1958 from 28 pumping wells was 221,923 of which 63.7 percent came from the Tyler formation. In 1958 an oil-water fluid about 50 percent water was produced for the field as a whole, the water containing 7,000 to 12,000 parts per million dissolved salts, mainly sodium chloride and sodium sulfate in ratios of 1 to 2 to about 1 to 8, the composition differing with localty and depth. Excess mineralized water which could not be turned loose on the surface was disposed largely by injection into barren sandstones.

The geologic structure of this part of Montana is interesting and unusual because it forms the southern edge of the bench-like Big Snowy-Porcupine uplift in a manner similar to that of the Cat Creek anticline 35 miles distant on the northern edge of the uplift. Along the southern edge of the uplift a long narrow asymmetrical anticline extends 50 miles eastward from the Big Snowy Mountains. On the south side of this anticline the dip of strata is up to 60 degrees, or even more; on the north side the gentle dips on top of the uplift are generally less than 5 degrees. At least 4 high places are present along the crest of the anticline resulting in elliptical domes 12 to 15 miles apart. (See map, fig. 21). From the mountains eastward these are the Duffy Creek dome, Devil's Basin dome, Big Wall dome, and Melstone dome; the last three have yielded oil. Faulting at the surface is not noticeably present, but the steep south slope of the major uplift may be the result of deep-seated faulting in the basal complex, wherein the flexible Mesozoic strata were bent along the line of the deep-seated rupture.

Strata at the surface are in the upper part of the Colorado shale series. Depths in feet to tops of critical formations are as follows: Piper limestone, 2,410; Amsden, 2,500; Alaska Bench, 2,615, Upper Tyler, 2,710; Tyler "A" sand, 2,830; and Tyler "B" sand, 3,025. Locally, at Big Wall the main anticline is divided into smaller north and south domes by an east-west syncline about 100 feet deep and one mile wide, resulting in two closely associated areas of production. At the south dome the tyler is about 500 feet thick, and oil occurs in the "B" sand erratic in distribution; whereas at the north dome the Tyler is about 300 feet thick, and oil occurs in the "A" sand. This is because of the very irregular erosional unconformity at the base of the Tyler, which is commonly considered to have filled channels on the old erosion surface. Oil occurs at the top of the Amsden on both domes. Oil from the Amsden tested 19° A. P. I. gravity and from the Tyler 29° to 30° A. P. I.

MELSTONE OIL FIELD

The Melstone oil field is 4 miles northwest of the small town of Melstone on the rolling upland plains of central Montana. At the same time that the Big Wall field was being developed in 1948, drilling was in progress on the same anticlinal fold 16 miles eastward. In the fall of 1948 the Amerada-Hougen No. 1 well (sec. 23, T. 10 N., R. 29 E.) began flowing an estimated 1,000 barrels per day of 34° A. P. I. oil from a depth of 4,195 feet or 350 feet beneath the top of the Amsden limestone. Oil occurred in two Tyler sandstones which showed erratic pinch-out distribution. By the end of 1950 there were 6 wells producing 164,398 barrels per year; a peak production of 179,088 barrels was reached in 1951. In 1958 production was 94,776 barrels from 9 wells.

The general structure and stratigraphy of the Melstone field are similar to that in the Big Wall field, excepting that a double dome is not known to be present, and the Bearpaw shale is exposed at the surface. In the discovery well the top of the Kootenai formation was found at a depth of about 2,850 feet, the top of the Morrison formation at 3,144 feet, the Ellis at 3,467 feet, and top of the Amsden at 3,850 feet. The Kibbey formation is at a depth of 4,684 feet, the Charles at 4,860 feet, the Madison at 5,460 feet, and the top of the Cambrian at 6,477 feet.

RAGGED POINT OIL FIELD

In January of 1948 the Texas Oil Company completed a well (sec. 5, T. 11 N., R. 30 E.) 35 miles northeast of Roundup or 12 miles north of Melstone, nearest railroad point, on the Ragged Point anticline. The well flowed oil of 34° A. P. I. gravity at a rate of about 200 barrels per day from a sandstone identified as Kibbey sandstone at a depth of about 4,440 feet or 1,430 feet below the top of the Amsden limestone. This area is note-worthy because it is the only area in Montana definitely producing oil from the Kibbey sandstone, which in most localities surrounding the Big Snowy Mountains yields large flows of highly mineralized artesian water. The Kibbey is one of the most persistently porous formations in central Montana. Two additional wells in this locality have yielded commercial amounts of oil from the Kibbey along the crest of the Ragged Point anticline.

In 1956, after about 8 years of production from the Kibbey sands, a well sunk on section 9, about 1 mile southeastward, found oil in an upper Tyler channel sandstone. Although the Tyler oil occurs near the crest of the anticline, actually due to local distribution of the sandstone, oil accumulation lies on the southeast flank of the structure, which accounts for the lapse in time before its discovery. During 1958, 3 wells in the Kibbey produced 30,594 barrels of oil, and 4 wells in the Tyler produced 95,957 barrels of oil. Total cumulative production to 1959 was 662,000 barrels. Reservoir energy in the Kibbey is considered water-drive, that in the Tyler, gas-expansion.

The stratigraphy of this area is similar to that at Big Wall and Sumatra and involves the same sequence of formations, however, thicknesses differ. In the Texaco-Manion well (sec. 5, T. 11 N., R. 30 E.) depths in feet to the tops of formations have been interpreted as follows: Colorado, 200; Kootenai, 1,775; Morrison, 2,220; Ellis, 2,420; Amsden, 2,950; Heath, 3,345; Otter, 3,995; Kibbey, 4,360; Charles, 4,625; Mission Canyon, 5,200; Lodgepole, 5,665. The Charles and Madison together are about 1,550 feet thick of which the upper 575 feet is probably Charles. The well bottomed at a depth of 6,312 feet, in about 170 feet of shaly limestone and dolomite, probably Cambrian in age.

The elongated Ragged Point dome, readily observed in surface exposures of Judith River and Eagle sandstones, is described as quite asymmetrical, the steep dips lying on the northern flank. The anticlinal trend, some 60 miles long, begins about 20 miles east of the Big Snowy Mountains, forming what was once known as Howard Coulee anticline; and after passing through Ragged Point, continues eastward about 20 miles through the Ivanhoe and Sumatra fields, and then bends southeastward into the Ingomar dome, figure 21. Structural closure at Ragged Point is shown as about 400 feet.

IVANHOE OIL FIELD

Seven miles east of Ragged Point, or four miles west of the Northwest Sumatra field, lies the Ivanhoe field, discovered in 1953 with the completion of the Chicago Corporation-N. P. No. 1 well (sec. 17, T. 11 N., R. 31 E.). Oil was found in fine-grained lenticular sandstone of the Morrison formation at a depth of 2,800 feet. The well, continued to 5,208 feet into Madison limestone, was then completed as a 92-barrel per day pumper in the Morrison. One more well found oil in the Morrison, but production was small. In 1956 a well sunk by R. P. Oliver on section 16, about one mile eastward flowed 235 barrels of oil per day from three sandstones in the Tyler formation, lowermost of which is at a depth of 3,970 feet. Additional producing wells were sunk. Production increased from 29,865 barrels in 1955 to 224,390 barrels in 1956; and in 1958 production was 311,933 barrels from 11 Tyler wells, and 5,028 barrels from 2 Morrison wells. Three wells were completed in 1958. Some gas produced along with oil in the Tyler was used in the field. The oil is about 32° A. P. I. gravity.

The Ivanhoe field lies on a local dome with closure of perhaps 100 feet on the east plunge of the Ragged Point anticline. Geologic maps of the surface show strata of the Judith River formation extending far eastward encircling the field, and a small area of underlying Claggett shale is exposed in the oil field. Depth to the top of the Morrison formation is about 2,705 feet, to the Swift formation 2,875 feet, to the Amsden 3,445 feet, and to the top of the Tyler 3,630 feet. Oil accumulated on the southeastern flank of the dome due to irregular sand occurrence, particularly in the Tyler.

SUMATRA OIL FIELD

Perhaps the next most important discovery among the central Montann oil fields since the

Cat Creek development is the Northwest Sumatra field lying 7 to 12 miles northwest of the small railroad station of Sumatra, the nearest town. Early "finds" of oil in this region were spread over three years and across an area from 6 miles southeast of Sumatra to 9 miles northwest of this town, the first two "finds" not resulting in large development.

In 1949 oil was found in the Texaco-N. P. "B" No. 1 well (sec. 5, T. 9 N., R. 34 E.) "near the base of the Amsden limestone or the top of the Heath formation" at a depth of 4,400 feet. After treatment with 2,000 gallons of acid, the well was completed with an initial production of 55 barrels of 32° A. P. I. gravity oil. Oil was again found about half a mile northward in a second well drilled in 1950. Later in 1950 oil was found in the Farmers Union-Sawyer well (sec. 26, T. 11 N., R. 32 E.) about 12 miles northwestward "at or near the base of the Amsden" at a depth of 4,812 feet, and the well was completed as a "222-barrel pumper." The top of the Amsden was at a depth of 4,635 feet. In July 1952 the Texaco-Grebe No. 1 well (sec. 15, T. 11 N., R. 32 E.), located after seismic studies, began flowing about 300 barrels per day of 35° A. P. I. oil reportedly from a sandstone in the "upper part of the Heath formation (now known to be Tyler) at a depth of 4,719 to 4,731 feet. This well initiated a rapid development of a producing area five miles long from east to west and one mile wide within the next three years. The east end of this area was then extended southward nearly two miles in 1957 by wells sunk by the Juniper Oil and Mining Company in secs. 24 and 25.

Production in 1955 was 1,539,829 barrels from 55 wells. In 1958 production was 1,612,561 barrels from 72 wells, or an average of about 62 barrels per well per day. Approximately 2 percent came from the Amsden. Much water is produced with the oil, but it is readily separated in "treaters." A small amount of gas, all used in the field, comes from some wells with oil.

Strata at the surface throughout all the rolling upland plain of the Sumatra area are in the Bearpaw shale formation, so similar that determination of geologic structure from surface features alone is most difficult or impossible, in part due to development of gumbo soils. Good marker beds are absent. Beneath the Bearpaw shale the following formations and approximate thicknesses in feet may be expected: Judith River, 210; Claggett, 400; Eagle, 250; Colorado shale, 2,000; Ellis, 400; Amsden dolomite, 75; Alaska Bench limestone, 80; Tyler, 400 (variable); Big Snowy group, 600; Madison group, 1,500. Beneath the Madison a small amount of Devonian and/or Ordovician strata may be present, and then Cambrian strata. The Kibbey is the oldest formation so far penetrated. Depth to the top of the Amsden in most of the field is about 4,000 feet, depending on structure. Oil occurred in a lower Ellis (Piper) limestone and Amsden dolomite; however, three sandstones in the Tyler yielded oil, designated downward as "A", "B", and "C" sands. The lower two are the most important producers in this field.

Geologic structures has been determined from well records and seismic studies. The northwest Sumatra field lies on an elongated asymmetrical domal anticline, apparently on the same trend as extends from Ragged Point to Ivanhoe, and from Sumatra to Ingomar. However, between Ivanhoe and Sumatra the axial trend is offset about one mile, the east (Sumatra) area lying to the north en echelon pattern. Closures on the elongated dome appears in 4 or 5 places along the crest, and in general are about 50 feet. Well records show abrupt lowering of strata on the north side of the anticline, in places as much as 1,000 feet within three-quarters of a mile. At first this was considered a steep north flank of the anticline; later evidence indicates the presence of faulting, at least in deeper strata. A small cross-fault is present at the west end of the field, and has affected accumulation of oil by fracturing in Amsden and Heath limestone and dolomite.

In spite of the presence of such definite domal structure at Northwest Sumatra, oil accumulation has been controlled largely by stratigraphic conditions, wherein the Tyler sandstones appear to be long meandering channel deposits, ranging in thickness from 0 up to 80 or more feet within a horizontal distance of a quarter of a mile. Hence areas of production do not always follow structural contours. This is particularly true at the southeast extension of the field, where production extends down the gently dipping south flank of the anticline into a shallow synclinal area.

As stated, the principal oil-bearing zones are the "B" and "C" sandstones of the land-laid Tyler formation, which fills valleys cut 100 or more feet into the underlying marine Heath formation during a pre-Tyler erosion period. Tyler sandstones may be conglomeratic in places. The "B" and "C" sands also are believed to join vertically in places, thereby giving the effect of a single reservoir. The "A" sandstone lies at or near the base of the upper Tyler which is essentially red and gray shale and siltstone. Considering stratigraphic oil traps, it is possible that more producing areas will be found in this part of Montana.

STENSVAD OIL FIELD

Adjoining the Northwest Sumatra field immediately to the northwest is what appears to be an extension of the Sumatra field, but which is designated as a separate oil field known as Stensvad, mainly because of geologic structure. The discovery well was completed late in 1958 by the Honolulu Oil Company on the Stensvad lease (sec. 11, T. 11 N., R. 31 E.). The large east-west fault believed to lie along the north side of the Sumatra field passes along the south side of the Stensvad field, thus placing it across the fault and in a synclinal area about 1,000 feet lower structurally than the Sumatra area. However, preliminary maps based on the few drilled wells indicate that this field lies on a small half-dome facing the fault. Erratic sand distribution has influenced localization of oil accumulation.

Stratigraphy and producing zones are the same as in the Northwest Sumatra field. In the discovery well the top of the Amsden was reached at a depth of 4,957 feet (about 4,000 in Sumatra wells), the Tyler "A" sandstone at 5,210 feet, and the Tyler "B" sandstone at 5,314 feet. The well is reported to have begun flowing from Tyler sands at a rate of 1,016 barrels of 33° A. P. I. gravity oil per day through 1½-inch choke, and 448 barrels per day through ⅜-inch choke. Some gas is produced with the oil. A northeast offset to this well also produced oil. Additional oil wells were completed in 1959.

GAGE OIL FIELD

The Gage oil field, one of the smaller producing fields in Montana, lies on an upland plain 4 miles north of the small town of Gage, or 10 miles northeast of Roundup. A map showing the anticline on which the field lies was published in 1923, but oil was not discovered until 1943. Oil occurred in brecciated and fractured Amsden dolomite at a depth of 5,960 feet in the Northern Ordnance-Morris A-1 well (sec. 15, T. 9 N., R. 26 E.) which bottomed in Madison limestone at a depth of 7,490 feet. This was the first discovery of oil in Amsden limestone in central Montana. After the discovery 15 more wells were rapidly sunk, but only 6 of these became steady producers, and in 1954 only one well was producing. The discovery well pumped about 25 barrels of 33° A. P. I. gravity oil per day after acid treatment, but a second well 1½ miles northward initially yielded 350 barrels per day from the same horizon. A peak production was reached in 1946 when 106,676 barrels of oil were produced, but production declined about 50 percent in 1947, and again in 1948. By 1957 production had dropped on 1,900 barrels. In 1958 production from 2 wells (one a new completion) was 7,757 barrels. Oil in some wells occurred lower than water in others.

Strata at the surface are at or near the top of the Tullock formation (lowermost Tertiary) and the overlying Lebo shale crops out nearby. The depth in feet to tops of formations are as follows: Bearpaw, 1,150; Judith River, 2,200; Claggett, 2,510; Eagle, 2,930; Colorado, 3,310; Kootenai, 5,235; Ellis, 5,558; Amsden, 5,964; Otter, 6,125; Kibbey, 6,365; Charles, 6,550; Mission Canyon, 7,210. The Heath formation which should occur beneath the Amsden is believed to be missing, and only 190 feet of Otter was recognized. This suggests the presence of an erosional unconformity beneath the Amsden limestone, thickness of which is 215 feet. Otherwise the succession of formations is similar to that in the Big Wall and Melstone fields, excepting that the Tyler formation is not reported present. Devonian or Ordovician strata should be present at about 8,400 feet.

The Gage dome is a small asymmetrical anticlinal fold lying 3 miles south of the steep dips which mark the southern edge of the Big Snowy-Porcupine uplift. Steeper dips are on the north side of the Gage dome. Structural closure is about 200 feet. This is the westernmost of four producing areas along the crest of a 70-mile long anticlinal trend on the north flank of the Bull Mountain structural basin. (See fig. 21). The Wolf Springs field is easternmost along this trend.

WOLF SPRINGS OIL FIELD

The Wolf Springs oil field is easternmost of the four oil fields on the Gage-Wolf Springs anticlinal trend, a structural feature which continues southeastward into the Custer anticline. (See fig. 21). Nearest railroad point is Custer 18 miles southward over graded roads. The surface, elevation about 3,450, is steeply rolling to hilly, due to broad deep valleys. The area lies on the eastern margin of the Bull Mountains which rise about 1,000 feet above the plains of eastern Montana.

The discovery well (Atlantic-Horton No. 18-1, sec. 18, T. 7 N., R. 32 E.) was completed in July of 1955, eight years after the drilling of the Carter test well about 12 miles southward on the same structural trend. After oil was found in fractured Amsden dolomite at 6,130 feet, the well was continued to 8,442 feet where it bottomed in Cambrian strata. After plugging back, the well is reported as flowing 386 barrels of 30° A. P. I. oil per day through 3/16-inch choke. Development proceeded rapidly, and production for 1956 from 15 wells was 412,949 barrels. In 1958 production from 20 wells was 582,288 barrels. More wells were being drilled in 1959.

Strata at the surface are in the lower part of the Fort Union formation which blankets the Bull Mountain area. Total thickness of Fort Union strata in this locality is between 1,000 and 2,000 feet. Massive sandstones show conspicuously at the surface, and coal is present locally. Depths in feet to tops of formations as reported in the Atlantic-Horton No. 1 well (sec. 18, T. 7 N., R. 32 E.), centrally located on the structure, are as follows: Bearpaw shale, 1,134; Judith River, 2,206; Claggett, 2,450; Eagle, 2,775; Colorado, 3,460; (Dakota sand, 5,155); Kootenai, 5,268; (Third Cat Creek sand, 5,425); Morrison, 5,477; Ellis, 5,663; (Piper, 6,055); Amsden, 6,107;

Kibbey, 6,295; Jefferson, 6,452; Big Horn, 7,915; Cambrian, 8,104; total depth, 8,400 feet. The fractured top of the Amsden dolomite was the only zone yielding significant amounts of oil, although some oil occurred in the Piper formation. The Tyler formation, such an important reservoir rock 15 to 20 miles northward, is not known to be present; either is the Tensleep sandstone recorded.

The Wolf Springs field, as stated, lies along the crest of the Gage-Wolf Springs-Custer anticlinal trend, which is characterized by several local domes along its crest line some 60 miles in extent. Two, or possibly three, such local domes at Wolf Springs lie about one to two miles apart with saddles between. Structural closure within the limits of the field is shown as in order of 100 feet, and present production occurs closely associated with the crests of domes. Water alone flowed from some wells down-structure. However, oil accumulation in the Amsden is considered intimately associated with pronounced fracturing, which in turn may be related to weathering on the surface of the Amsden developed during an erosional period between the Amsden and the overlying Piper (basal Ellis). The "pay zone" varies in thickness and depth beneath the top of the Amsden, but generally is within 40 feet. Total thickness of the Amsden ranges between 70 and perhaps 200 feet.

DELPHIA OIL FIELD

The Delphia oil field lies along the north valley slopes of the Musselshell River about three miles west of a railroad siding named Delphia, or about 12 miles east of Roundup. The discovery well (Texota-Goffena No. 1, sec. 26, T. 9 N., R. 27 E.) was completed in December of 1956, and is reported to have started flowing 554 barrels of 35° A. P. I. gravity oil per day from a fractured Amsden dolomite at a depth of 6,325 feet. Top of the Amsden is at a depth of about 6,300 feet. The first production report, dated June 1957, showed the well pumping at the rate of 278 barrels per day; in May of 1958 daily production was 94 barrels, and in November of 1958 daily production was 19 barrels. This illustrates the rapid decline experienced in this field. Gas was produced with oil at the rate of about 12,000 cubic feet per 100 barrels of oil, and associated water produced with oil was negligible. Four additional wells were completed in 1958. In that year 5 wells produced 56,828 barrels of oil.

Strata at the surface are in the Fort Union formation, and the sequence of formations is similar to that at Wolf Springs to which the reader is referred. Deepest strata tested are in the Charles formation. The field lies on a local high point or dome along the crest line of the Gage-Wolf Springs anticlinal trend. Closure is probably less than 100 feet. Production is said to be limited by a variable porosity, probably much influenced by fracturing.

HAWK CREEK OIL FIELD

The Hawk Creek oil field, discovered in November of 1958, lies 4 miles south of the railroad station of Musselshell which is 25 miles east of Roundup. It lies midway between Gage and Wolf Springs oil fields in the hilly lands on the north side of the Bull Mountains. The discovery well (Miles-Jackson-N. P.-McConnel No. 1 sec. 1, T. 8 N., R. 29 E.) produced oil from fractured dolomite near the top of the Amsden formation. During two months in 1958 production from one well was 1,245 barrels of oil. Production for May of 1959 from two wells was 526 barrels of 38° A. P. I. gravity oil.

Strata at the surface are in the Fort Union formation, and the sequence and character of formations at depth are similar to those at Wolf Springs. Depths in feet to tops of formations in the discovery well are reported as follows: Colorado, 4,160; Dakota sand, 6,138; Third Cat Creek sand, 6,442; Morrison, 6,482; Ellis, 6,695; Amsden, 7,072; total depth, 7,140 feet. The effective porosity in the Amsden, only producing formation, is described as resulting from "multiple fractures", the rock itself appearing tight or dense with low porosity and permeability.

SOUTHERN FIELDS

The Southern Montana oil and gas fields lie mainly in the Big Horn structural basin at its northern end, but also on the northern flanks of the Big Horn Mountain uplift. The Big Horn basin, extending far into Wyoming, has many oil and gas fields on domal anticlines present within it and on its flanks. The Big Horn Mountains, also extending far into Wyoming, are a major earth structure, geanticlinal in magnitude, characterized by steeply dipping strata along its margins, and relatively flat-lying strata across its crest, which is about 25 miles wide. Precambrian rocks are exposed on the crest at elevations of about 9,000 feet; Cretaceous and Tertiary strata are exposed in the valley lands on either side at elevations of 3,000 to 4,000 feet. Minor folds lie on the flanks or margins of the uplift. Actually the outer margin of the uplift at its northern end is 30 to 40 miles beyond the foothills, and this northern margin is crossed by a zone of echelon faults about 80 miles long (Lake Basin-Huntley fault zone, see plate 2.) The Broadview dome (or Big Coulee-Hailstone dome) is considered by some geologists as a northern extension of the Big Horn Mountain uplift, it being separated from the main uplift by the Lake Basin-Huntley fault zone.

Five miles north of Red Lodge the Big Horn basin is obliquely crossed by a trend of anticlinal folds about 50 miles long, known as Nye-Bowler lineament. (Wilson, 1936). It parallels the northern margin of the Beartooth Mountains about 6 miles distant, and on one of its several structural highs is the Dry Creek oil and gas field. Other highs have been tested, but commercial quantities of oil or gas have not been found, excepting as wells on the Golden dome may eventually prove commercial. The Elk Basin and Frannie fields are on separate anticlines within the basin.

The southern fields may be subdivided further into (1) those in the Big Horn basin, six in number, (2) those east of the Big Horn Mountains, four in number, and (3) those north of Yellowstone River on the north continuation of the Big Horn Mountain structure, three in number. The Big Horn basin fields produced 96 percent of the 1958 oil production of all these southern fields, and the Montana portion of Elk Basin ($\frac{3}{4}$ in Wyoming) accounted for 87 percent of the production from southern fields.

ELK BASIN OIL AND GAS FIELD

The first commercial discovery of oil in Montana was in the Elk Basin field located 60 miles south of Billings. Three-fourths of the field, which is about 8 miles long, lies in Wyoming. Oil was produced from Frontier sandstones for 27 years before deeper drilling into the Tensleep sandstone revealed more extensive oil deposits, and 4 years later oil was found in the Madison limestone at greater depth. In 1952, prior to the advent of the eastern oil fields, this field was second in productive rank in Montana. The field is also of interest because oil and gas occur on a much faulted anticlinal dome within a basinal region.

The Elk Basin structure was described as early as 1904; however, oil was not discovered until 1915. A greenish oil of 39° A. P. I. gravity came from the upper Frontier sandstone at a depth of about 1,200 feet, and from the lower Frontier sandstone at a depth of about 1,400 feet. Development followed rapidly in a productive area about 2 by 6 miles across (1 by 2 miles in Montana). Initial flow from many wells was up to 1,000 barrels per day. In 1920 three wells in Wyoming sunk into the basal Cloverly (Kootenai) sandstones at a depth of about 2,500 feet yielded gas with initial flows reported to have been 40 to 70 million cubic feet per day with a closed-in pressure of 925 pounds. Gas was not found at this horizon on the Montana side of the state line. In 1923 a $12\frac{3}{4}$-inch gas pipeline was laid to Billings, thus providing a market for gas. Casing-head gas occurred with the Frontier oil, and during the 1920's a casing-head gasoline plant was operated. In 1928 and 1929 the field was unifield, and also at this time Cloverly gas was introduced into Frontier sandstones in a effort to increase reservoir pressures, and hence oil production. This operation was only moderately successful.

In 1942 and later years several wells were completed in the Tensleep sandstone at a depth of about 5,000 feet both in Montana and Wyoming, resulting in flows of 1,000 to 3,000 barrels per day of black sulfurous oil of 27° to 30° A. P. I. gravity. Some oil also occurred in the overlying Embar formation of Permian age. Completions which followed raised annual production in the Montana part of the field from 16,000 barrels in 1942 to 2,415,000 barrels in 1948. The area of Tensleep production proved to be much more extensive than that of Frontier production because it extended farther down the dip of strata.

In 1947 wells were sunk into the Madison limestone near the top of the dome, and after heavy acid treatment began flowing at rates up to 5,000 barrels per day from a depth of about 6,200 feet. The black Madison oil of about 18° A. P. I. gravity was under the bottom-hole pres-

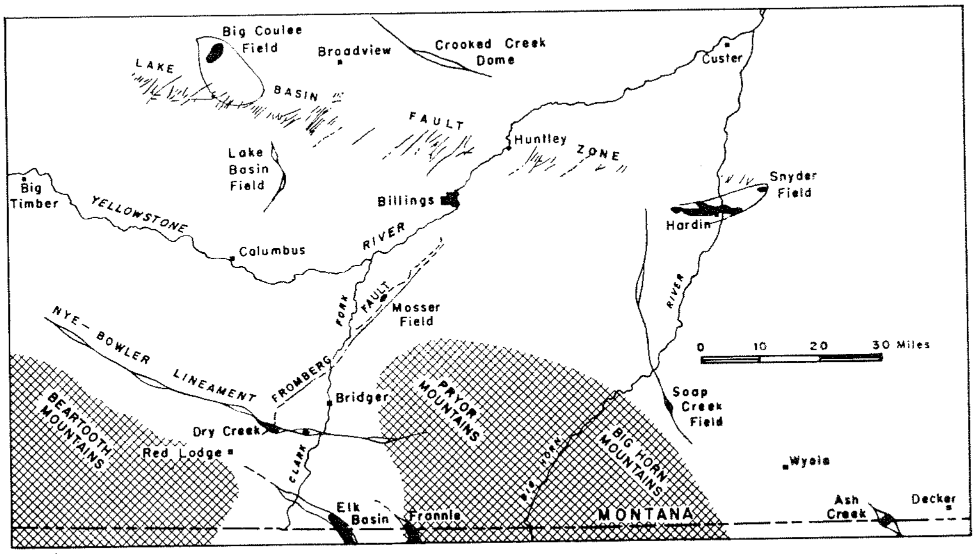

Figure 22.—Anticlinal trends and oil fields in southern Montana.

sure of over 1,700 pounds per square inch. One well drilled to a depth of over 8,400 feet entered Devonian strata, but oil was not found beneath the Madison limestone. Also in 1947 an important northwest extension to the main field was discovered and became known at Northwest Elk Basin. During 1959 there were 11 wells producing from the Frontier, 29 wells from the Embar-Tensleep, and 9 from the Madison. Total oil production from the main Elk Basin field in Montana plus Northwest Elk Basin for 1958 was 3,039,762 barrels of oil.

During the early life of the Tensleep sand development a gas cap formed at the crest of the anticline, the gas being liberated from oil because of oil withdrawals and consequent decrease in pressure. In 1949 a "gas products recovery" and "nitrogen generation" plant was completed in the Wyoming part of the field; and gasoline, liquid petroleum gases (LPG), and sulfur were recovered, and also nitrogen was generated with use of the residual fuel gas. The nitrogen was then injected into the crest of the structure, along with some methane and LPG, to maintain reservoir pressure. This operation is said to be highly successful.

At the surface in the main Elk Basin field, Colorado shale is exposed throughout the central part of the dome, and the Eagle sandstone forms striking escarpments or hogbacks rimming the central area. Intermittent streams have cut deeply into the shale creating a topographic basin, but beyond the margins of the dome is a level upland plain blanketed by upland gravel of Tertiary age. Approximate thicknesses of formations in feet in this locality are as follows: Colorado, 2,200; Kootenai (Cloverly), 200; Morrison, 200; Ellis (Sundance), 400; Chugwater, 400; Embar, 50; Tensleep, 150 to 225; Amsden, 175; and Madison, 800. Devonian, Ordovician, and Cambrian strata should underlie the Madison. The oil producing horizons are (1) shaly sandstones in the Upper Cretaceous Frontier formation, (2) clean sandstone in the Lower Cretaceous Dakota formation, (3) sandy dolomite in the Permian Embar formation, (4) clean sandstone in the Pennsylvanian Tensleep formation, and (5) fractured and vuggy limestone in the Madison formation (Mississippian). Oil occurred down to 600 feet beneath the top of the Madison, but at different depths. All formations may produce in some wells structurally favorable because all are persistent in the area. In the prolific Tensleep sandstone, which averages about 200 feet total thickness, porosity is 10 to 11 precent and permeability is about 118 millidarcies.

The Elk Basin elongated and faulted domal anticline as seen at the surface is a striking example of surface expression of this type of structure. Rugged exposures of "rim rock" circle the dome, and dip steeply away from the central area, 15° to 20° on the southwest side and 35° to 45° on the opposite side. Structural closure of the dome as shown on regional structural maps is in excess of 4,000 feet. Most of the 25 or 30 faults which strike across the long axis of the structure are believed to die out before reaching Paleozoic rocks; nevertheless, it is probable that much or most of the fracturing in the Madison limestone, so closely associated with oil accumulation in it, results from the forces that cause folding and faulting. Dip of fault planes ranges from 40 to 70 degrees, and displacement is up to 70 feet. The beginning of the development of the fold is believed by some to be in Paleocene time.

Geologic structure in Paleozoic strata is similar to surface structure, excepting for absence of known faults and perhaps steeper dips on the flanks of the fold. Structural closure at the Tensleep horizon is said to be about 2,300 feet within the limits of the field. Oil production in the Frontier sandstones (Torchlight above and Peay below) was in the upper 200 to 300 feet of the dome, but Tensleep production extended farther down the flanks of the dome, thus creating a larger producing area. In the Frontier sandstones of the main part of the field, the faulting has not materially affected production because both upthrown and downthrown blocks contain oil. In the southern part of the field, faults have affected localization of oil and gas. The high parts of some fault blocks contain mainly gas with water below, especially in the Frontier sandstones. In spite of the large number of faults in this field surface seeps of oil or gas were not observed. Apparently the 1,100 feet or more of dense Colorado shale over-lying the Frontier formation effectively sealed the faults.

Northwest Elk Basin.—In August of 1947 a well sunk by the Sinclair-Wyoming Oil Company about 2 miles northwest of the main Elk Basin field (sec. 28, T. 9 S., R. 23 E.) is reported to have flowed 4,942 barrels of oil per day from the Madison limestone between depths of 6,343 and 6,795 feet, of which 100 feet was considered "pay". Oil was also found in the upper sandstone of the Frontier formation (Torchlight, depth 3,375 feet), gas in the Dakota and Lakota, and hydrogen sulfide gas in the Tensleep sandstone. A dozen or more successful wells were completed within half a square mile, and this area then became known as Northwest Elk Basin. Nine wells produced 47° A. P. I. oil from the Peay sandstone, two produced 35° A. P. I. oil from the Madison limestone, and three Lakota gas wells were shut in at that time for want of a pipeline. In six years (to 1954) the field had produced 1,252,755 barrels of oil with 559,014 barrels of water from all horizons. In 1959 there were 9 wells producing from Frontier sandstone and 2 wells producing from the Madison.

Stratigraphy at Northwest Elk Basin is similar to that at Elk Basin, excepting that strata at the surface are uppermost Cretaceous. The structure may be considered a continuation of the main northwest-plunging Elk Basin anticline, but oil and gas accumulation has been influenced by faults which cut across the anticline. Structural closure on a local dome as reported is about 200 feet. The faults are believed to die out with depth.

DRY CREEK OIL AND GAS FIELD

The Dry Creek oil and gas field lies 16 miles north of Wyoming and 6 miles northeast of Red Lodge on a much-faulted anticlinal dome similar to that at Elk Basin but smaller. This field is in the northernmost part of the Big Horn structural basin where it narrows to about 25 miles between the Big Horn and Beartooth Mountains major uplifts, and the basin merges northward into the Crazy Mountain syncline. The surface of the Clark Fork valley in this locality is broken by east-facing escarpments and gullied by intermittent streams. Clark Fork River is 7 miles east of the field.

The Dry Creek dome was known prior to 1915, but neither oil nor gas was found until 1929. That year a well sunk by Ohio Oil Company (sec. 11, T. 7 S., R. 21 E.) yielded 2½ million cubic feet of gas per day under pressure of 960 pounds from the Eagle formation at a depth of 2,350 feet, and 6½ million cubic feet under a pressure of 1,460 pounds from the Second Forntier sandstone at a depth of 4,450 feet. In a second well, completed in 1930, oil was found in the basal sandstone of the Cloverly (Kootenai) formation at a depth of 5,500 feet in addition to gas in the upper horizons. Within 5 years, 16 wells had been put down, 10 of which were commercial in yield of oil or gas. Initial flow of oil wells was up to 2,000 barrels per day. The oil is green in color with a specific gravity of about 52° A. P. I. The field was connected with the Billings-Elk Basin gas pipeline 11 miles distant shortly after discovery. In 1934 a 10¾-inch gas pipeline was laid from the Elk Basin and Dry Creek fields northwestward to Livingston and Bozeman, and in 1950 this line was connected to the Cut Bank-Butte pipeline at Butte. Oil was marketed by a pipeline extending to the railroad near Bridger about 11 miles distant. Annual production of oil and gas at Dry Creek is shown on figures 2 and 3. Production for 1958 was 73,503 barrels of oil from Lower Cretaceous sandstones, and 1,627 million cubic feet of gas.

The strata at the surface are in the Hell Creek and Fort Union formations which so resemble each other that observers unfamiliar with the area have difficulty distinguishing them. Good marker beds are not present at the surface. Formations and their approximate thickness in feet as interpreted from the Ohio-N .P. No. 18 well (sec. 3, T. 7 S., R. 21 E.) are as follows: Hell Creek, 1,000; Lennep (Fox Hills), 170; Bearpaw, 820; Judith River, 770; Claggett, 660; Eagle, 220; Colorado group, 2,530; Cloverly (Kootenai), 260; Morrison, 270; Ellis (Sundance), 450; Chugwater, 325; Embar, 40; Tensleep, 170; Amsden, 190; and Madison, 900. Devonian, Ordovician, and Cambrian strata should underlie the Madison limestone. Depth in feet to the Eagle sandstone is 2,780; to the First Frontier sandstone, 4,355; to the Second Frontier sandstone, 4,654; to the Cloverly, 5,530; to the Tensleep, 6,876; and to the Madison, 7,140 feet. The well bottomed at 8,882 feet in Ordovician or uppermost Cambrian strata.

The Dry Creek field is on one of 12 or more domes lying along the crest of a 50-mile trend of narrow anticlinal fold known as the Nye-Bowler lineament. Several others of these domes have been tested without finding oil or gas. The Dry Creek dome, about 2 by 4 miles in dimension, and with approximately 1,000 feet of closure, is cut by 8 or more cross-faults resulting in several blocks, at least 3 of which have been productive.

THE GOLDEN DOME

The Golden dome lies about four miles east of the Dry Creek field, and is another of the several high places along the Nye-Bowler lineament of which Dry Creek is one. Structure and stratigraphy are similar. Wells at Golden dome were drilled in 1919, 1932, 1953, and 1954. The first two wells gave shows of gas, but were abandoned. The Kirk-Stow No. 1 well, completed in 1953, is reported to have yielded a pale golden-colored oil of 54° A. P. I. gravity with much gas from the Graybull sandstone, amounting to 22,920 barrels before it was shut in as a gas well. In 1954 Cities Service Oil Company after seismic exploration sank a test well into the Tensleep sandstone which was found non-productive. The well was taken over by the Kirk Oil Company, completed as a gas well in the Greybull sand, and shut in. The Frontier sandstones at Golden appear to have too low porosity and/or permeability to be suitable oil or gas reservoirs. The geologic structure at Golden actually consists of two half-domes formed by faults cutting an eastward plunging anticline. Production for 1958 was 37,596,000 cubic feet of gas from one well.

CLARKS FORK OIL AND GAS FIELDS

The Clarks Fork fields lie about 4 miles west of the Elk Basin field, or 14 miles southeast of Red Lodge, and 1 mile east of the valley of Clarks Fork of Yellowstone River. The fields lie on a much faulted northwest anticlinal trend, a northwest continuation of the Elk Basin anticline, in which each of at least 3 fault blocks 1 to 2 miles across show domal structures. Displacement on faults is shown as from 400 to 1,000 feet. Groups of wells about 2 miles apart have been drilled on each dome resulting in the 2 closely associated oil fields known as Clarks Fork and Clarks Fork North. The discovery well at Clarks Fork was the McDermitt-Government No. 1 (sec. 27, T. 9 S., R. 22 E.) completed in October of 1954 at a total depth of 8,029 feet. Oil of 43° A. P. I. gravity flowed from Frontier sandstone, depth 6,716 to 6,749, with an initial potential of 114 barrels of oil per day through a ¼-inch choke. Production water accompanied the oil. Dry holes were drilled on either side.

Two miles eastward, oil and gas were discovered late in 1944 in a well (sec. 25, T. 9 S., R. 22 E.) started by the Northern Ordnance Company and completed by the General Petroleum Corp. Oil of 45° A. P. I. gravity, found in the lower (second) Frontier sandstone at a depth of 6,446 feet, is reported to have begun flowing from the well at a rate of about 150 barrels per day. Some water was present with the oil. The well was deepened in 1951, and gas gaged at 1,100,000 cubic feet per day was found in the Dakota sandstone about 1,500 feet beneath the top of the Frontier formation. The gas yielded 66 barrels of 65° A. P. I. distillate daily. Production of oil for 1950 was 419 barrels, and for 1951 was 8,013 barrels. Production of gas began in May of 1951, and amounted to 133,016,000 cubic feet for that year. The gas entered the Bozeman-Butte pipeline. In June, 1959, a well was sunk near the General Petroleum well by the British-American Oil Producing Company, McClellan No. 1, on section 26 in the same fault block. It flowed 65 barrels of oil and 2,628,000 cubic feet of gas per day through 31/64-inch choke from the Dakota sandstone at a depth of 7,546 to 7,560 feet. Total depth was 9,446 feet, and the well bottomed in Madison limestone.

In January 1956 the British-American had completed a well in sec. 16, T. 9 S., R. 22 E., nearly two miles north of the original discovery well on a third fault block. The well flowed initially 338 barrels of 49° A. P. I. oil and 1,681,000 cubic feet of gas per day through 9/32-inch choke from the Lakota sandstone at a depth of 8,940 to 8,950 feet. Three more successful wells within half a mile followed with similar success in either the Dakota or Lakota, and this area became known as the Clark's Fork North field.

Depths to tops of formations differs much due to structure, but in the British-American-State No. 3 well (sec. 16, T. 9 S., R. 22 E.) tops in feet to selected formations are as follows: Lance, 2,630; Lennup, 3,500; Bearpaw, 3,730; Eagle, 5,255; Frontier, 7,260; Mowry, 7,750; Cloverly, 8,647; Dakota, 8,751; Lakota, 8,811. The producing horizons are sandstones in the Frontier, the Dakota sandstone, and the Lakota sandstone. The Lakota is described as lenticular ranging from 0 to 70 feet in thickness, and not covering all of the North dome. Porosity and permeability are variable in the Frontier and Dakota sandstones, but are generally low. Fracturing is said to be present in all sandstones, apparently increasing permeability.

Oil production in 1958 from Clark's Fork (south) from 1 well in the Frontier formation was 3,062 barrels, and from Clark's Fork North from 4 wells in the Lakota sandstone was 274,843 barrels. Gas production in 1958 from Clark's Fork North from 4 wells in the Dakota and Lakota was 360,744,000 cubic feet. Gas enters the Montana Power Company pipeline extending to Butte.

Belfry Field.—About 6 miles south of the small town of Belfry, the Carter Oil Company completed a well (Carter-Gov.-Wheatly; sec. 7, T. 9 S., R. 22 E.) with initial flow of 1,121,000 cubic feet of gas and 196 barrels of "oil condensate" through 13/64-inch choke. The producing horizon is described as the "first Fuson stray sand" at a depth of 9,844 feet. The Fuson is commonly considered the middle member of the Cloverly formation and is normally a greenish-grey shale. It is probable that fracturing is an important factor in oil accumulation. Faulting is present, and it would appear that this locality, known as the Belfry field, together with Clark's Fork fields, is on a northwest continuation of the large Elk Basin anticline. Production for 1958 is given as 2,029 barrels of 38° A. P. I. oil from 1 well.

FRANNIE OIL FIELD

The Frannie oil field, lying almost entirely in Wyoming adjacent to the Montana state line, is 10 miles east of the Elk Basin field; it also is on a northwest trending asymmetrical anticline. In 1958 there were 129 producing wells in Wyoming and only 2 in Montana. Oil was discovered in 1928 when a well drilled into the Tensleep sandstone at a depth of 2,585 feet flowed at a rate of 125 barrels per day. Later, the well was sunk to a depth of 2,612 feet, and when completed pumped 260 barrels daily. In 1929, wells deepened into the Madison limestone at 2,925 to 3,013 feet in the south end of the field initially yielded oil up to about 2,400 barrels daily. This was the first discovery of oil in the Madison limestone in Wyoming.

In 1940 a well drilled on the Montana side of the state line yielded 124 barrels of oil daily from a depth of 3,562 feet, the oil occurring in the Tensleep sandstone. During 1958 the two Montana wells produced 40,554 barrels of 27° A. P. I. gravity oil.

Strata at the surface are in the upper part of the Colorado shale. Thicknesses of formations in feet penetrated by drilling are as follows: Frontier, 350; Mowry, 410; Thermopolis, 370; Cloverly, 250; Morrison, 270; Sundance, 380; Chugwater, 505; Embar, 65; Tensleep, 100.

MOSSER OIL AND GAS FIELD

The Fromberg fault, known since 1920 or before, starts about six miles south of Billings and extends southwestward for 25 miles to the Dry Creek field. The fault is described as a graben type, wherein the down-dropped block is about one mile wide and composed of segments of Upper Cretaceous strata which also are exposed on either side of the faulted zone. Maximum down-drop is reported to be about 250 feet. The fault lies peripheral to the Big Horn (Pryor) Mountain uplift on its northwestern flank. Doming of strata, known at the Mosser dome, (sec. 26, T. 3 S., R. 24 E.), is shown on the basin side of the fault, and structural closure may amount to 600 feet.

Drilling along the trend of this fault began in the early 1920's, and continued intermittently for 30 years, during which time about 30 wells were sunk. Gas was reported in 2 wells, and oil in 8 wells, but none became large producers. In 1936 and 1937 there were 5,588 barrels of oil marketed; after the drilling of 4 successful wells by the Amick Drilling Company; but the field then remained idle until 1947 when 3,961 barrels of oil were marketed. Water encroachment was rapid; however, production continued each year since that time, the amount ranging from about 1,000 to 15,000 barrels annually. Total oil production for 1958 from 6 wells was 7,232 barrels, making a grand cumulative total of 144,964 barrels. The producing horizon is a sandstone in the upper part of the Kootenai (Cloverly) formation, locally known as "Mosser sand", at a depth of about 1,000 feet. A deep test well sunk to a depth of 2,568 feet into Madison limestone failed to make known additional oil accumulation. The oil has 22° A. P. I. gravity.

SOAP CREEK OIL FIELD

The Soap Creek oil field, among the first fields discovered in Montana, lies 30 miles southwest of Hardin in the northeastern foothills of the Big Horn Mountains. Nearest railroad station is Lodge Grass, 20 miles eastward. Hindering development were lack of pipeline, poor roads, and low quality of oil, resulting in intermittent operations during its nearly 40 years of life. The discovery well, sunk by Western States Oil and Land Company on Tribal land (sec. 26, T. 6 S., R. 32 E.) was completed in February of 1921 with an initial flow estimated at 200 barrels of oil per day; the oil had 17° A. P. I. gravity and 3.9 percent sulfur. The producing horizon, near the top of the Amsden formation, is described as a highly fractured dolomite. Good shows of oil were also reported in the Tensleep and Madison formations. Eleven more wells were sunk within the next 2 years, 5 of which produced oil, some flowing, some pumping, mainly from the Amsden; but some oil came from the Madison, which produced lightly. The field was then shut in during 1923 after 43,815 barrels of oil has been marketed to that used for field purposes, and the field remained idle until 1933..

During 1933 production was resumed, and another well was drilled in 1934 into the Amsden pay zone. Between 1933 and 1938 a total of 83,680 barrels of oil were produced, but the field was again shut in during 1938, and remained idle until 1947. In 1948 the Inland Empire Oil Company sank a 4,470-foot well bottoming in Cambrian strata. Additional productive horizons were found in fractured Madison limestone, some old wells were reconditioned, and the field has produced oil continuously beginning with 1947. Water invaded the field early in its development, and some wells were abandoned because of excess water. The ratio of oil to water in the Amsden pay zone in 1954 was estimated as 1 to 10. With the drilling of five additional Madison wells since 1952, annual production reached a peak in 1956 amounting to 216,603 barrels, about half of the entire cumulative production up to this time. In 1958 production from 13 wells in the Amsden and 16 wells in the Madison was 63,075 barrels of 17° to 20° A. P. I. gravity oil containing up to 3.9 percent sulfur and practically no solution gas.

The surface at the crest of the dome is directly underlain by shales and impure sandstones of the Morrison formation, and the outcrop of the basal Cloverly sandstone circles the central area. Shales of the Colorado group lie around the margin of the dome. Formations penetrated in drilling and approximate thicknesses in feet are: Cloverly, 335; Morrison, 390; Sundance (Ellis), 580; Chugwater (Spearfish), 520; Tensleep, 110; Amsden, 140; Madison, 870; Devonian, 150; Ordovician, 320; and Cambrian, 1,020. Oil occurred in the Tensleep, Amsden and Madison, but only the last two have produced commercially. Fracturing has been an important factor in oil accumulation. The Soap Creek dome is on a long narrow anticlinal fold 2 to 4 miles northeast of, and parallel to, the front line of the Big Horn uplift. The anticline extends for about 18 miles; but the Soap Creek dome is about 8 miles long and 3 miles wide, and the producing area occupies less than 1 square mile on the crest. Total closure is 500 feet. The dome is strongly asymmetrical, the steep dips being on the eastern flank away from the mountains. It is suspected that faulting in deep-eated strata is present at depth beneath the steep dips on the east side of the anticline.

HARDIN GAS FIELD AND SNYDER OIL FIELD

The Hardin gas field and the Marcus Snyder oil field are described together because they lie about 5 miles apart on a prominent anticlinal trend (or nose) extending 40 miles northeastward from the Big Horn Mountain uplift. At Hardin the trend flattens into a structural terrace perhaps 5 miles across, but at the Snyder field the plunging anticline ends abruptly in relatively steep dips, after forming a local dome with about 100 feet closure. The Snyder area also marks the eastward termination of the Huntley-Lake Basin fault zone of perhaps 100 echelon northeast trending faults, the fault zone intersecting the anticline at the Snyder field. Several faults are reported present in the field.

The Hardin gas field is of minor importance as a gas producer, but it has supplied natural gas to Hardin (population 1,886 in 1950) for 23 years. The field lies on a low gravel-covered river terrace immediately west of Big Horn River, west and north of Hardin. Gas was found as early as 1913, but active development started in 1928 when a group of Hardin businessmen formed the Big Horn Oil and Gas Company and drilled 27 wells within 1¼ miles of the townsite. In 1929 gas was marketed in Hardin, and since then (in 1951) the field has been connected with the Worland-Baker gas pipeline, in part for the purpose of underground gas storage. The gas occurred in irregular sandstones probably in the Frontier formation of the Colorado group at depths of about 725 feet. The shaly fine-grained sand, about 15 feet thick, may pinch out or loose its porosity mountainward. Initial flows of individual wells ranged from 30 to 160 thousand cubic feet per day, and initial closed-in pressure was about 137 pounds per square inch. The gas is essentially methane. Deep tests into Madison limestone have failed to reveal oil or additional gas in this field. During 1958 gas production from 48 wells was given as 50,502,000 cubic feet; however, this figure may be modified by storage gas from Wyoming.

The Snyder oil field was discovered in October of 1952 by the drilling of the George Greer-Kendrick No. 2 well (sec. 6, T. 1 S., R. 35 E.) after seismic exploration. Sulfurous oil of 21° A. P. I. gravity was found in the Tensleep sandstone at a depth of 4,600 feet, the initial pumping potential being 150 barrels per day. Two additional oil wells and two dry holes subsequently were put down. Production in 1958 from four wells was 26,560 barrels of oil from the Tensleep sandstone, porosity of which is given as 20 percent and permeability as 120 millidarcies.

Strata beneath the soils and river terrace gravel in the lowlands of Little Powder River valley at Hardin are shales in the upper part of the Colorado group (lower Niobrara). At the surface in the Snyder field are strata of the lower part of the Judith River formation (Parkman sandstone). Deep drilling 477 feet into Ordovician strata (top at 6,335 feet) failed to reveal additional accumulations of oil or gas.

ASH GREEK OIL FIELD

The Ash Creek oil field, somewhat like the Elk Basin and Frannie fields, lies mainly in Wyoming; of 28 producing wells only 4 are in Montana. The field lies in rugged or hilly lands about 10 miles west of Tongue River on the western flank of the Powder River Basin, or about 30 miles east of the Big Horn Mountains. The discovery well, drilled in Wyoming in 1952 after seismic studies, produced from the so-called "Ash Creek sand", which is correlated with the Shannon sandstone approximately equivalent to the Eagle sandstone, from a depth of 4,714 feet. The oil of 33° A. P. I. gravity is sulfur free, and has a gas-oil ratio of 18 cubic feet of gas per barrel of oil. The sandstone 15 to 30 feet thick has an average porosity of 20 percent and a permeability of 150 millidarcies. The geologic structure is that of a faulted south-plunging anticline resulting in a half-dome, structural closure of which is about 400 feet. Strata at the surface are well up in the Fort Union formation. Montana production for 1958 from 4 wells was 34,316 barrels.

LAKE BASIN OIL AND GAS FIELD

The Lake Basin (or Big Lake) oil and gas field in south-central Montana is about 25 miles due west of Billings on the gently rolling upland plain characteristic of most of central Montana. Although no gas has been produced since 1931, and oil production is small, the field is of interest because it lies in a large region between Yellowstone and Musselshell rivers in which structural and stratigraphic conditions appear favorable for oil and gas occurrence, but in which rather extensive prospecting has been disappointing. This region was mapped by the U. S. Geological Survey in detail in 1916, particularly the unusual 80-mile long zone of echelon faults (Lake Basin-Huntley fault zone), lying 10 miles north of the field; but this early mapping did not show structural closure in the structural dome which later became productive. Later mapping showed presence of closure. The area lies in a broad saddle, or low, between the Pryor (Big Horn) Mountain uplift and Big Coulee-Hailstone dome; or it may also be considered as on the eastern flank of the Crazy Mountain syncline.

Gas had been discovered in this area as early as 1922 in the Eagle sandstone in wells drilled on the southwest flank of the dome. One year later the Barnsdall-Foster-Biron No. 2 well drilled along the axis of the anticline three miles north of the crest found gas in the Eagle and Frontier sandstones, and oil in the Dakota sandstone, but the well was abandoned because of mechanical difficulty. The discovery well is generally considered the Midwest Refining Sompany No. 1 Hepp well on the crest of the dome (sec. 26, T. 1 N., R. 21 E.) which was first reported to have flowed 1,000 or more barrels of oil per day, but which on completion in October of 1924 yielded somewhere in the order of 100 barrels per day. Gas flowed from the Eagle sandstone at a depth of between 1,050 and 1,300 feet, and from the Frontier sandstone at 3,000 to 3,220 feet. Oil occurred in the Dakota sandstone at a depth of 3,800 to 3,940 feet. Within the next three years 22 wells had been drilled; 6 yielded oil from the Dakota sandstone, and 12 yielded gas from the Eagle and Frontier sandstones. Closed-in initial gas pressure in the Eagle was about 300 pounds, and in the Frontier about 1,000 pounds. The maximum initial yield of gas is reported as 42 million cubic feet per day from the Frontier sandstone, but the average of all gas wells was between 5 million and 10 million cubic feet. The initial yield of oil wells was about 30 barrels per day. The oil is 48° A. P. I. gravity, green in color, of paraffin base, and yields 40 percent gasoline.

Between 1926 and 1931 natural gas was consumed at the field in a carbon-black plant which produced a total of about 5 million pounds of carbon-black. Since 1931 the gas wells have been closed in, and by 1935 pressures in the Eagle had built back to 160 pounds and in the Frontier to 500 pounds. No gas pipelines serve the field and the oil is marketed at the railroad at Coombs about 6 miles distant. Some oil has been marketed each year from 1925 to 1959; peak production was reached in 1926 amounting to 49,522 barrels from 7 wells, but by 1944 annual production had dropped to 10,890 barrels with a cumulative production of 438,223 barrels. During the 1950's annual production was between 1,000 and 2,000 barrels, excepting 1958 when 1 well produced 211 barrels. Before the end of this year the one well was closed in, thus ending a production history of 34 years.

Six miles north of the main Lake Basin field on the same anticlinal trend, a well (Holland-American-Castle No. 1; sec. 22, T. 2 N., R. 21 E.) completed in January of 1958 on a local high along the anticlinal axis, yielded a commercial amount of gas from the Eagle and Frontier sandstones. Since no pipeline served the area, the well was shut in; however, this area became known as North Lake Basin. Six or more wells had previously been sunk in this general area without success. One was the Superior-Copulos well which bottomed in Precambrian rocks at a depth of 7,929 feet.

Beneath the soil covered surface of the Lake Basin field are strata of the Bearpaw shale formation; but 3 miles westward the overlying Lennep (Fox Hills) sandstone (andesitic in character) is well exposed, and 3 miles eastward are exposures of the underlying Judith River formation. Total thickness of the Bear-paw is about 800 feet. The Judith River and Claggett formations each are about 500 feet thick, the Eagle sandstone is about 200 feet thick, and the Colorado group as a whole is about 2,200 feet thick. The Frontier formation is about 1,100 feet beneath the top of the Colorado, or at a depth of about 3,000 feet. Depths in feet to tops of selected underlying formations are as follows: Dakota, 3,800; Ellis, 4,395; Tensleep, 4,740; Madison, 5,090; Devonian, 6,290; Ordovician, 6,680; Cambrian, 6,920; Precambrian, 8,000.

The geologic structure at Lake Basin is a gentle anticlinal fold about 5 miles long and 1 mile wide with a closure of about 120 feet. It is not as strong or well-defined a fold as others in this general region which have been tested without finding oil or gas, and it is not known to be disrupted by faulting. Such an occurrence of oil and gas about half way between the central and southernmost Montana fields, gives promise of other productive fields in this region 75 miles across in which several other anticlinal and domal folds are present.

BIG COULEE GAS FIELD

The Big Coulee-Hailstone dome in south-central Montana is one of the larger structural features in the Montana Plains, comparing in shape and size with the Bowdoin and Porcupine domes. Nearly circular in pattern, with slight northwest elongation, and about 30 miles across, it appears to be a northwest continuation of the Big Horn Mountain uplift extending 50 miles into the plains beyond the mountains themselves. (See fig. 21). The dome is crossed on its southern margin by the unique Lake Basin-Huntley echelon fault zone about 80 miles long and characterized by perhaps 100 short northeast trending faults. Although available maps show the top of the dome practically level, no doubt minor irregularities are present. Some 40 wells, many relatively shallow, have been drilled within the limits of the domed area; particularly on two small structures (Sixshooter and Broadview domes). Shows of oil and gas have been found, but until 1948, no commercial production resulted.

In November of 1948 the Texas-N. P. D.-1 well 8 miles south of Ryegate (sec. 31, T. 5 N., R. 20 E.) yielded a large flow of gas from the Lakota sandstone 1,950 feet deep, and from a Morrison sandstone 2,100 feet deep. The well was closed in. Again in September of 1954 the Northern Natural Gas Producing Company completed a well on the same section which flowed 5,512,000 cubic feet of gas per day from the Lakota and Morrison with initial pressure of 1,100 pounds per square inch at depths between 1,950 and 1,990 feet. More productive weels were drilled proving a productive area about 5 miles long and 1 to 2 miles wide. Local doming of strata with about 200 feet closure is shown on maps contoured on the Lakota sandstone. Marketing of gas began in 1956 when the Montana Power Company laid a pipeline to Harlowtown, Lewistown and intervening towns. The field was unitized in 1956. Gas production during 1958 from 6 wells was 659,287,000 cubic feet. The gas is free of hydrogen sulfide, contains 91 percent methane and 9 percent nitrogen, and has a heat value of about 9,000 B.T.U.

Strata at the surface in the gas field are in the upper part of the Colorado shale. The Eagle sandstone encircles the field 2 to 4 miles distant.

Strata at depth are similar to those in the Lake Basin field 25 miles southward. The Lakota sandstone is described as medium-grained conglomeratic sandstone 10 to 70 feet thick, with abundant black chert grains. Average porosity is 12 percent and average permeability is 81 millidarcies.

EASTERN MONTANA GAS FIELDS

Eastern Montana has produced large quantities of natural gas from the Cedar Creek (Baker-Glendive) anticlinal field for 45 years, and has supplied the needs of the region within a radius of about 100 miles. Then the 1951-1952 discoveries

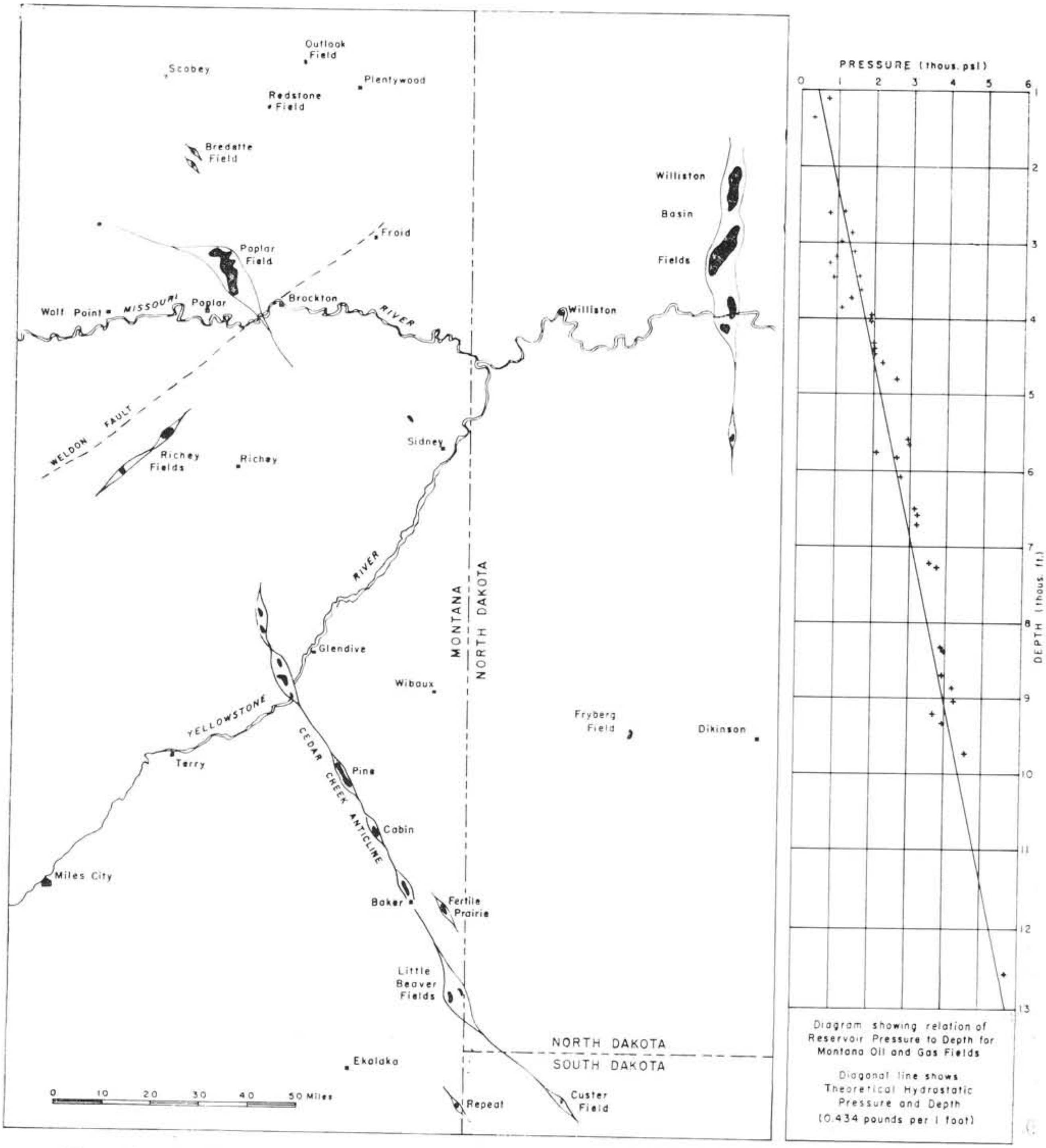

Diagram showing relation of Reservoir Pressure to Depth for Montana Oil and Gas Fields

Diagonal line shows Theoretical Hydrostatic Pressure and Depth (0.434 pounds per 1 foot)

Figure 23.—Anticlinal trends and oil fields in eastern Montana, and pressure-depth relations in oil fields.

of large deep-seated oil deposits in five widely-spaced localities in eastern Montana resulted in leasing and development activities rivaling some of the largest in other oil-producing states. About 10 million acres of land are said to have been leased for oil and gas during this period.

The area of gas production is a narrow strip of land about 80 miles long lying on the observed crest of the Cedar Creek anticline. The early oil discoveries lie along this anticline (1) near the south end (Little Beaver dome), (2) near the middle (Cabin Creek and Pine Units), and (3) near the north end (Glendive field); also early discoveries were made (4) northwestward near Richey in a region where the surface strata are nearly flat lying, and (5) farther north on the Poplar anticline. The distances are 48 miles from the Little Beaver dome to the Pine Unit, 27 miles from the Pine Unit to Glendive wells, 55 miles from the Glendive wells to the Richey wells, and 30 miles from the Richey wells to the Poplar wells, an over-all distance of 160 miles. (See Plate 2). Oil occurred on scattered deep-seated "highs" along the Cedar Creek anticline. Geophysical exploration was necessary to determine the location of such "highs" not only on the Cedar Creek anticline, but also at Richey and Poplar. Richey lies on a deep-seated anticlinal dome trending northeastward, almost at right angles to the Cedar Creek anticlinal trend, and it does not show at the surface. Depth to oil producing formations in eastern Montana is from 1 to 2 miles.

Following these first main discoveries, many scattered wells were sunk in this vast region of eastern Montana, about 100 by 330 miles in extent (over 20 million acres), resulting in the discovery of a dozen or more productive areas of varying degrees of importance (See Table 2 and 3). By 1958 these eastern Montana oil fields were producing 60 percent of Montana's annual total of about 28 million barrels.

Of particular interest in so large a region are many areas, some as much as 1,000 square miles, in which no test well has been sunk. Since the deep-seated structures, and hence potential localities of oil production, require geophysical methods for determination (deep-seated structure may differ from surface structure, as at Richey), exploration by drilling of wells is likely to proceed slowly and over a long period of time.

The history and geological conditions pertaining to the natural gas field, and to the oil occurrences are so different that each should be described separately, even though some of the oil-bearing areas are on the same anticline that has influenced gas accumulation. However, general statements about the region as a whole can be made.

Eastern Montana lies in the northern part of the Great Plains of western United States. The surface is nearly level or gently rolling, except where large rivers and their tributaries have cut valleys into the upland plain. Commonly, the valley slopes are gullied causing the development of rugged badlands, and as the railroads and main hikhways follow the river valleys, badland topography is a large part of the visible landscape seen by travelers. Altitude of the upland plain is from 2,500 to 3,000 feet, and of Yellowstone River valley at Glendive 2,070 feet. Average annual rainfall is about 15 inches, and annual mean temperature is from 40° to 43° F. Raising of grain, cattle, and sheep is the chief industry, but coal is plentiful and widespread.

Soft shales and sandstones lying directly beneath the surface in most of this region are in the lower Tertiary Fort Union formation. The Upper Cretaceous Bearpaw shale and the Hell Creek (Lance) formation are exposed on the crests and flanks of the Cedar Creek and Poplar anticlines; and near the Wyoming state line the Colorado shale and younger formations are exposed on the northern flank of the Black Hills uplift.

Strata as seen at the surface generally lie so nearly horizontal that instruments are needed to determine dip, excepting that on the west side of the Cedar Creek anticline dips range from 15° to 20°. Structure of deeply seated strata is known to be somewhat different from that of strata at the surface. Location of wells to be sunk less than 1,000 feet has generally been made from studies of near surface structure, but wells to be sunk a mile or more deep are in most places located after geophysical exploration, mainly seismic.

The succession or sequence of geologic formations of post-Precambrian age along the Montana-North Dakota state line is perhaps the most complete for all of Montana; strata in every geologic period from Precambrian to Recent are present. Total thickness of this sequence is between 10,000 and 12,000 feet. Of course, all parts of all periods are not represented, because several unconformities (or disconformities) are present. But deposition of Paleozoic, Mesozoic, and Cenozoic sediments was more persistent and continuous than elsewhere in Montana, and erosion producing unconformities did not cut so deeply as it did farther westward. For detailed descriptions of formations the reader is referred to an earlier part of this report, and to the geologic sections shown on figure 5.

CEDAR CREEK (BAKER-GLENDIVE) GAS FIELD

The Baker-Glendive gas field or Cedar Creek gas field as it is called by the United States Geological Survey, lies along the eastern border of Montana 150 miles east of the commercial oil and gas fields of central and southern Montana. It has been one of the most important gas fields in Montana because of its large areal extent, (about 60 miles long), the large amount of gas produced, and its location far from other sources of supply. Although over 45 years old, the field still produces much gas. Its early discovery resulted from the east with which the anticlinal fold on which it lies may be observed at the surface, and the shallow depth of the gas.

History.—Gas was discovered at the extreme northern end of the anticline (Gas City dome) in 1912, and in 1915 was marketed in Glendive 9 miles distant. This local area was abandoned in 1926 when most of the wells began to yield salt water. Gas also was discovered near Baker in 1915. From 1915 to 1926 completions of gas wells on the Baker and Cabin Creeks domes of the Cedar Creek anticline ranged from 1 to 10 per year. The Cabin Creek dome, 15 miles northwest of Baker, became most important because of the large volume of gas coming from individual wells and the area as a whole. From 1926 to 1931 (inclusive) 141 gas wells were completed in the Baker-Glendive field. By this time the limits of the gas-producing area were defined. Carbon black was manufactured in a plant at Baker between 1918 and 1930 by the channel process; daily capacity of the plant was 4,000 pounds. In 1950 there were reported 230 producing or producible gas wells, including intake wells. Beginning in 1946 gas from other distant fields was stored underground, and in 1946 there were 186 million cubic feet of gas injected.

Most of the pipelines from the field were constructed between 1928 and 1931. Gas was supplied to Miles City, Terry, and Glendive in Montana; Belle Fourche, Deadwood, Lead, and Rapid City in South Dakota; and Marmarth, Bowman, Bismarck, and Williston in North Dakota. In 1946 a pipeline was laid from near Wolf Point to Intake thereby connecting the Bowdoin-Saco gas field with the Williston pipeline, and hence with the entire eastern Montana system of the Montana-Dakota Utilities Company. This made possible transportation of Bowdoin gas into the Baker field where it could be stored underground during summer preparatory for use during periods of heavy winter consumption. In 1950 and 1951 a 340-mile 12¾-inch gas pipeline was laid from the Worland gas field in Wyoming to Baker, and gas transported into Montana through this pipeline greatly increased the dwindling supply being produced from the Baker-Glendive field. The Wyoming gas was stored underground during summer months near Baker. From 150 to 200 million cubic feet of gas from Wyoming and Bowdoin are injected annually. The gas field has been unitized into several blocks.

Geology.—The geologic map, as well as the structural contour map, of the 125-mile long Cedar Creek anticline is striking (see plate 2). Along the crest of the structure in a long narrow strip 2 to 10 miles wide, are exposures of Bearpaw (Pierre) shale. The outcrop area of this formation is enclosed by a band of Fox Hills sandstone, beyond which are exposed strata of the Hell Creek (Lance) formation and then of the Fort Union formation in which coal beds can be followed. A key-bed used in surface structural mapping is a zone of phosphatic concretions at the top of the Bearpaw shale, but the zone is easily overlooked unless one is searching for it. Good key-beds are not found in records of the gas wells, most of which were less than 1,000 feet deep. Strata at depth will be discussed in following pages dealing with oil occurrences.

The anticline trends S. 30° E. from near Glendive; 75 miles of the anticline lies in Montana, 25 miles in North Dakota, and it continues into South Dakota. Its width ranges from about 9 miles north of Baker to 14 miles south of Baker (Little Beaver dome). The structure is asymmetrical, strata dip 5° to 30° on the west side and 1° to 8° on the east side. Cross-sections of the fold show up to 800 feet of structural relief on the Little Beaver dome south of Baker, but north of Baker structural relief across the anticline is about 400 feet. The anticline plunges northward 1,200 feet in 80 miles. Locally along the crest of the anticline are areas structurally higher than other areas, resulting in several elliptical domes in which gas was concentrated. Structural closure of domes is from 40 to 100 feet. From north to south these domes have been named Gas City, Thirteen, Ash Creek, Cabin Creek, Baker, Lookout Butte or Hidden Water, and Little Beaver. Maps of subsurface structure at depths of a mile or more indicate that the axial plane is vertical and that the fold is cut on its western side by a major fault at least 80 miles long, and with displacement up to 1,000 feet. Faulting does not show at the surface.

Occurrence and Production of Gas.—The gas producing zones of the field lie within strata which correspond in geologic age to the Judith River and Eagle formations of central Montana, and these names are used in the field. However, the character of strata at these two geologic horizons is very different from that in central Montana. Massive persistent sandstones are not present as is the case near Billings and Lewistown. Some well cores of gas-bearing "sandstone" show alternating sandy and shaly layers which may be a quarter to a half inch thick. Other cores show shaly sandstone which when placed in water slacks to a sandy mud. It appears that in some wells fairly pure sandstone was encountered, but probably much clay-shale was interbedded with such sandstone. No single definite sandstone member can be followed in records of wells throughout the field, although locally a sandy zone may be traced from well to well. Depths to gas-bearing zones are from 600 to 1,500 feet.

Thickness of the upper gas-bearing zone (Judith River) in the northern part of the field ranges from 20 to perhaps 200 feet, the average being about 60 feet. Also gas may be reported at two or more depths within a 200-foot zone. Thickness of the Eagle productive zone is less than that of the Judith River. Little or no gas occurs at the Eagle horizon north of Baker.

South of Baker 2 gas-bearing zones, about 600 feet apart, correspond to the Judith River and Eagle horizons. Most of the gas in this area occurred in the upper or Judith River zone, but it does not have the porosity in the southern part of the field that it does in the northern part. Likewise, the Eagle nowhere shows effective porosity such as is possessed by the Judith River zone. A common history for gas wells in the Baker-Glendive field is that upon first entering a gas-bearing zone, a well starts flowing a small amount of gas, but with deeper drilling the volume of flow progressively increases until the productive zone is penetrated. Porosity probably averages 10 to 15 percent for the sandy zones. The gas is nearly pure methane.

Volume of initial open flow of wells ranged from 100,000 to 28,000,000 cubic feet per day. Within a given area flow of wells was generally similar, but different areas differed much. Wells on the Gas City and Ash Creek domes flowed 1 million to 3 million cubic feet per day. On the Cabin Creek dome 32 of 75 wells yielding gas had an initial flow of more than 10 million cubic feet, the maximum was 28 million cubic feet, and the average was 17 million cubic feet. South of Baker flow of a few wells reached 3 million cubic feet per day, and the majority had initial open flows of less than 1 million cubic feet. In 1931 when development of the field was nearly completed, combined open-flow of all wells in the field as recorded by the State Oil and Gas Inspector added up to 850 million cubic feet per day, but this figure is misleading because total open flow at no one time equalled this amount, the figure being based on initial open flows.

Initial pressures as measured at the casing head averaged 220 pounds per square inch for those wells producing from the Judith River formation at depths of 750 to 900 feet. Initial pressures in wells producing from the Eagle formation at depths from 1,250 to 1,450 feet average 420 pounds. During the early life of the field gas pressures were adequate to force gas through pipelines to markets, but by 1935 pressure had decreased so that compressors had to be installed to force gas to distant markets; at present gas pressures are less than 100 pounds. However, with importation of gas from other districts, and with its storage underground, local pressures are being increased.

Natural gas produced from the Baker-Glendive field, including a few wells in North Dakota, is reported at 3,903,584,000 cubic feet for 1950, and 2,822,771,000 cubic feet for 1951. Production for 1958 from 232 wells is given as 5,387,597,000 cubic feet. These figures are somewhat misleading because they include some gas injected from other fields and later withdrawn.

PLEVNA AND PUMPKIN CREEK GAS FIELDS

The Plevna anticline (also known as 101 Ranch) lies 5 to 6 miles west of the Cedar Creek anticline and parallel to it. In 1945 a well drilled on its southern end, where it appears to merge with the Cedar Creek structure, yielded gas reported to flow at a rate of 300,000 cubic feet per day from the Judith River formation at a depth of about 1,000 feet. Initial pressure is given as 200 pounds per square inch. The discovery well (F. H. Becker No. 1, sec. 28, T. 5 N., R. 60 E.) was completed in January of 1946. It bottomed at 1,053 feet in the Judith River formation, and flowed 300,000 cubic feet of gas per day with initial pressure of 210 pounds per square inch. Bottom hole temperature was 80° F. Additional wells in following years proved an area about 6 miles long and 1 mile wide trending northwesterly. Peak production was in 1951 when 315 million cubic feet of gas was produced. In 1958 production from 29 wells was 216 million cubic feet. The gas enters the Montana-Dakota Utilities pipeline system.

Still another producing area in eastern Montana is on Pumpkin Creek (east side of T. 1 S., R. 49 E.) about 75 miles southwest of the Cedar Creek gas field. The discovery well (G. J. Greer-Allen No. 1; sec. 24, T. 1 S., R. 49 E.) is reported to have flowed 15.5 million cubic feet of gas per day with a pressure of 779 pounds per square inch. The gas occurred in the Shannon (upper Eagle) sandstone at a depth of about 3,000 feet. Strata at the surface are in the Tongue River member of the Fort Union formation. Seven more wells in an area about 6 miles long were sunk subsequently and initially yielded 1 to 8 million cubic feet per day. Since no pipeline serves the field, all wells were shut in during 1958. The Shannon sandstone in this area is described as "a series of offshore bars of varying age and stratigraphic position". Local structure is that of a terrace.

The Bowdoin-Saco gas field is considered by some to lie in eastern Montana; actually it is 150 miles west of Montana's eastern boundary, and midway between the eastern and western fields. Because of its general geology, the writer has described it under Northern Fields.

Gas is produced with oil from deep-seated strata (Siluro-Ordovician) in the Cabin Creek and Pine oil fields. In 1958 this gas, entering the Montana-Dakota Utilities pipeline system, amounted to 1,782,501,000 cubic feet. A small amount of hydrogen sulfide is removed from the gas prior to entrance into main pipeline.

EASTERN MONTANA OIL FIELDS

The general stratigraphy of all eastern Montana oil fields is quite similar excepting that thicknesses of formations differ and deep-seated unconformities have caused absence of certain strata in some areas (See plate 1). It differs from that of the more western oil fields of Montana in that additional formations are present, and the names of equivalent formations commonly are different. For example, the Ordovician Red River formation of eastern Montana is equivalent to the Big Horn formation south of Billings, 200 miles westward.

Furthermore, descriptions of the 10 named oil fields along the Cedar Creek anticline are about the same, excepting for stratigraphic position of producing zones, and minor structural features. It is convenient to described these 10 or more associated fields together. The Richey oil fields require separate description because of different structural conditions, and the Poplar fields form a unit by themselves. Other than these, there were 8 oil producing localities in 1958 given special names, lying widely scattered along 230 miles of the eastern state line, and within 50 miles of it. Again for convenience these are grouped together.

The stratigraphic nomenclature of eastern Montana is that commonly used in the Williston Basin of North Dakota, and many of the names have been brought in from Canada where the formations have been studied in outcrop. This is particularly true of Devonian, Silurian, and Ordovician strata, much of which has no counterpart in central Montana. For those unfamiliar with the different formational names, the Stratigraphic Correlation Chart (pl. 1), or generalized geologic sections of Montana oil fields (fig. 5) should prove helpful. Of importance in oil field stratigraphy is the presence of unconformities above and below Devonian strata, thereby causing variation in thickness, or omission, of certain units. That above the Devonian is most widespread.

OIL ALONG THE CEDAR CREEK ANTICLINE

The geology of the Cedar Creek anticline, first described in 1910, has been covered on preceeding pages in this report. The presence of oil on the anticline had long been suspected. However, oil was not discovered until 1936, and was not produced commercially until 1952, at which time three widely spaced commercial discoveries were made on the structure. Early history is as follows: In 1918 a well near Yellowstone River was sunk to a depth of 4,104 feet. It ended in Kootenai strata. In 1924 a well on Little Beaver dome 75 miles southeast of Yellowstone River was sunk to a depth of 4,187 feet. It also stopped at or just below the base of the Kootenai. In 1937 a well, 7,264 feet deep was drilled about six miles northwest of Baker near the central part of the anticline. Salt water was found in the deeper strata. All these wells were abandoned.

Intensive deep drilling began on the Little Beaver dome in 1936 and continued intermittently through following years. In this year the Montana-Dakota Utilities-Northern Pacific well No. 1 (sec. 17, T. 4 N., R. 62 E.) was sunk to a depth of 8,186 feet on East Little Beaver dome. Oil of about 30° A. P. I. gravity, amounting to 39 barrels per day was reported from depths between 6,747 and 8,186 feet, but the well was finally mudded, with pipe in the hole and left standing. A one-mile offset drilled during the same year on section 8 was reported to have yielded considerable oil from depths between 6,746 and 6,765 feet. In 1941 the Carter-N. P. No. 1 well on West Little Beaver dome, 2 miles southwest of the M.D.U. well (sec. 19, T. 4 N., R. 62 E.), was sunk through Cambrian strata and 23 feet into Precambrian schist (amphibolite), bottoming at 9,678 feet. Oil of about 29° A. P. I. gravtiy, reported to have amounted to over 100 barrels per day initially, together with water, occurred between 8,300 and 8,630 feet; but the well was plugged and abandoned apparently because of difficulty with water. In 1949 the Husky-Rangely-N. P. well No. 1 on east dome (sec. 19, T. 4 N., R. 62 E.) was sunk to a total depth of 6,834 feet. Oil amounting to 30 barrels per day was reported between 6,810 and 6,834 feet depth, but operations ceased in 1950. In 1952 the Shell-N. P. well No. 1 on the west Little Beaver dome (sec. 3, T. 4 N., R. 61 E.) was completed to a total depth of 8,553 feet, bottoming in Ordovician strata. Oil occurred in zones between 8,355 and 8,474 feet in Ordovician strata, but the well was abandoned. During the early explorary state of development over 32,000 barrels of oil were raised to the surface; 17,587 barrels in 1937 and 1938; 9,699 barrels in 1941; and 5,226 barrels in 1949 and 1950, from the several wells which were tested.

Between 1952 and 1960 about 300 successful oil wells were sunk on the Cedar Creek anticline, and all of eastern Montana about 450 successful wells were sunk. This activity resulted in eastern Montana producing about 60 percent of Montana's 28 million barrels of oil in 1958.

Of interest is the character of the oil coming from the Siluro-Ordovician dolomites along the Cedar Creek anticline, wherein the A. P. I. specific gravity decreases progressively northward from 29° at Little Beaver, to 33° at Pennel, to 34° at Pine, to 38° at Glendive, to 42° at Deer Creek, and oil from the same horizon at Southwest Richey north of the Cedar Creek anticline is 48°. Over-all distance from Little Beaver to

Richey is about 120 miles. Sulfur content ranges from 0.3 to 0.5 percent. The oil is black and largely of asphaltic base. Depth ranges from about 8,350 feet at the south end to about 9,500 feet at the north end. Reservoir temperatures are in the order of 200° F. Many geologists believe that the oil had accumulated in the reservoirs prior to the end of Paleozoic time along a paleozoic "Cedar Creek" anticline vertically beneath the structure observed at the surface. The writer suspects that the variation in gravity of the oil may possibly be related to variations in original type of source material. Specific gravity of Madison oils from this region ranges from 32° to 39° A. P. I.

All oils are associated with water containing variable quantities of dissolved salts, in some localities at or near saturation with sodium chloride. The water problem is serious because the water is costly to raise to the surface, it must be separated from the oil, and because of the cost of disposal by injecting back into the ground either into barren formations or into the oil-bearing zone in selected wells. Highly mineralized water produced cannot be released on the surface. Most of the water from Mississippian production zones is brackish and considered meteoric. In certain localities, e.g., Gas City and northern part of Pine field, brackish to moderately saline water is produced from Siluro-Ordovician zones. However, a large part of the highly saline water from these deeper pays may be considered connate, and it occurs at different depths, either lower or higher than oil, and apparently in some places from the same horizon. The Siluro-Ordovician oil reservoir rock is a porous dolomite in which the amount of porosity differs from place to place, and from depth to depth. Fracturing is generally present, and at some localities is considered an important factor in oil concentration. Such terms as "fracture porosity" are in common use. Early procedure in drilling was to penetrate all the oil-bearing strata, and produce from perforations in the casing at several depths in the oil-bearing zone. Large volumes of water commonly accompanied the oil. Recent completions have confined casing performations to thin zones considered as most prolific in yield of oil, with the result that the volume of water produced has been much diminished. This may be explained by a variation in the size of pores (openings) in the dolomite. Water is held in small openings or pores with greater force than oil due to capillarity; the oil occurring in that part of the dolomite where the size of the openings is comparatively large. The amount of porosity in each may be approximately the same. Hence bodies of water could be trapped in masses of finely porous dolomite along side of concentrations of oil, or even about oil concentrations.

LITTLE BEAVER DOME

In detail the Cedar Creek anticline widens at Little Beaver, and shows two anticlinal axes two miles apart, separated by a syncline. The major deep-easted Cedar Creek fault zone cuts the west side of the west anticline. Several domal closures of about 100 feet lie along the crests of each of these minor anticlines, and early drilling was on highs of both anticlines. Early history of these fields is described on a preceding page. Later drilling proved the western structure more productive, and in 1958 it produced 179,552 barrels of oil from 9 wells, whereas on East Little Beaver 5 wells produced 83,763 barrels in that year, both areas producing from Ordovician strata. Two additional wells were completed on East Little Beaver in 1958.

Regional maps of this region indicate that there are still other anticlinal structures paralleling the Cedar Creek trend, the Plevna anticline being one. It is probable that the Fertile Prairie oil field lies on a subsidiary anticline to the east, and that the Repeat oil field lies on such a structure to the west of the main Cedar Creek anticlinal trend.

PINE OIL FIELD

During December of 1951 the Shell Oil Company completed a well (Pine Unit No. 1, sec. 30, T. 12 N., R. 57 E.) on the Cedar Creek anticline, 31 miles northwest of Baker or 25 miles south of Glendive, which initially tested 250 barrels of oil per day. Large amounts of acid were used. In January 1952 the well pumped 467 barrels of 33° A. P. I. oil and 148 barrels of water per day. The oil came from dolomitic strata of Ordovician (Stony Mountain) age mainly from a depth of 8,910 to 8,970 feet, but oil was obtained by swabbing tests downward to a depth of 9,115 feet. Offset wells were located at once. Development proceeded cautiously, but by 1958 an area about 8 miles long and up to 2 miles wide had been proven productive. In 1958 production from 135 wells was 5,358,011 barrels, making Pine Unit the largest producing field in the state. Average daily production was 110 barrels of oil per well.

At Pine, black oil of about 34° A. P. I. gravity and with 0.44 percent sulfur, was produced from the Silurian Interlake dolomite at 8,500 feet and the Ordovician Stony Mountain and Red River dolomites at depths of 8,800 to 9,000 feet, commonly through dual perforations in casing in a single well. Bottom hole pressure at a depth of 8,969 feet (6,250 feet below sea level) was 4,105 pounds per square inch, and temperature was 196° F. The oil-water fluid brought to the surface averaged about 30 percent water which contained up to 120,000 parts per million dissolved salts, mainly sodium chloride. The water is considered connate, and it probably interstitial with oil. It is disposed of by injecting back into the ground, either in barren formations or into the producing formation through edge wells. No gas cap is present, but much gas was produced with oil, and in 1958 amounted to 993,045,000 cubic feet. After removal of a small amount of hydrogen sulfide, the gas entered the Montana-Dakota Utilities pipeline system.

Strata at the surface at Pine are in the upper part of the Bearpaw formation. The sequence of formations penetrated, and depth in feet to formational tops near the east side of the field, are as follows: Judith River, 865; Claggett, 1,118; Eagle, 1,515; Colorado group, 1,680; Kootenai (Dakota), 4,068; Morrison, 4,260; Sundance (Ellis), 4,330; Spearfish, 5,326; Minnekahta and Opeche, 5,792; Amsden, 6,218; Big Snowy group (Otter), 6,680; Charles, 6,948; Mission Canyon, 7,394; Devonian, 8,495; Silurian, 8,512; Ordovician (Stony Mountain), 8,866; and Cambrian, 9,642. Beds of solid salt were found at 5,470 to 5,490 feet depth in a series of Triassic red-bed and evaporite strata, and also in the Charles formation. The limy strata beneath the top of the Devonian are similar and difficult to interpret as to geologic age from cores and cuttings alone, and electric well logs are always used in conjunction with well samples.

The location of the Shell Pine Unit is along the crest of the Cedar Creek anticline as observed at the surface. However, the field was located after extensive geophysical (seismic) exploration which indicated that the anticlinal axial plane is nearly vertical, and that structural closure in the order of 100 feet in Ordovician strata is present in the deep-lying strata, with the major fault zone lying immediately westward .The local structure is that of an asymmetrical domal anticline 12 miles long and about 2 miles wide. This information was verified later by drilling. The area was unitized early.

GLENDIVE OIL FIELD

Also in late 1951 the Glendive field on the northern end of the Cedar Creek anticline 9 miles southwest of Glendive was discovered when the Texas-N. P. well No. NCT-1 (sec. 35, T. 15 N., R. 54 E.) flowed 201 barrels of oil and 45 barrels of water per day through a 20/64-inch choke from the Red River dolomite at a depth of about 8,900 feet without the use of acid. Five months later a northwest offset well (Shell-No. 34-26-G, sec. 26, T. 15 N., R. 54 E.) is reported to have flowed 214 barrels of oil per day and 33 barrels of water after treatment with 5,000 gallons of acid. Initial potential for the Texas well is rated at 254 barrels per day, and for the Shell well 360 barrels per day. This discovery of a new oil producing area 21 miles northwest of the Shell Pine Unit discovery and 55 miles southeast of the 1951-Shell discovery near Richey, added new zeal to the high pitch of exploration and development already rampant in eastern Montana. By 1958 an area 2 miles long and 1 mile wide had been proven productive at Glendive, and in that year 12 wells yielded 616,226 barrels of oil, or an average of about 140 barrels per well per day.

The wells in the Glendive field started close to the top of the Hell Creek (Lance) formation which underlies the low hills of Yellowstone River valley 3 miles north of the river. The sequence of geologic formations is similar to that at Richey and at the Shell Pine Unit although thicknesses may differ somewhat. Depth to the Kootenai (Dakota) formation as reported is about 4,100 feet; to the top of the Charles formation, about 6,800 feet; and to the top of the Devonian, about 8,550 feet. The main producing horizons are in the Ordovician Stony Mountain and Red River dolomites at depths of about 8,800 and 8,900 feet. Porosity of about 6 percent is intimately associated with fracturing in the dolomite. The structure on top of the Red River formation is that of an elongated half-dome which faces, and is cut on its west side by, the major fault zone paralleling the Cedar Creek anticline. Structural closure is about 200 feet.

In an area known as Sand Creek about 2 miles due north of the Glendive field 2 wells drilled into Ordovician strata yielded oil. As seen on maps they were about 1 mile east of the crest of the Cedar Creek anticline. Completed in 1952 to 1954, they were abandoned in 1956 after a total production of 3,839 barrels of oil. The discovery well (Texas-N. P., NCT-6, No. 1, sec. 11, T. 15 N., R. 54 E.) completed in October of 1952, bottomed at 10,076 feet in Cambrian strata. The well initially produced 66 barrels of oil and 114 barrels of water per day from perforations in casing at 8,992 to 9,025 feet in strata considered the Interlake formation of Silurian age. Fracturing was present. The oil was 38° A. P. I. gravity and gas came with the oil at a ratio of 264 cubic feet per barrel of oil. Cause of abandonment was the increase in the amount of water raised in the oil-water fluid.

CABIN CREEK OIL FIELD

The Cabin Creek oil field was discovered in May of 1953 by the drilling of the Shell 22-23 well (sec. 33, T. 10 N., R. 58 E.) along the crest of the Cedar Creek anticline 15 miles southeast of Pine or 17 miles northwest of Baker. Oil was found in the Siluro-Ordovician dolomites at several depths through about 800 feet of strata, but principally at about 9,000 feet in the Red River formation. In 1956 oil also was found in the Mississippian Mission Canyon limestone at about 7,000 feet, and in 1958 one-fifth of this field's oil production came from these strata.

The Ordovician oil at Cabin is 33° A. P. I. gravity with 0.56 percent sulfur and is black in color. Mississippian oil is similar. Some water was present with the oil, the amount seeming to vary in different places, dependent on poresize distribution. Porosity ranges from 5 to 25 percent, an average being 8 to 10 percent. Fracturing is present. Original bottom-hole pressure was 4,003 pounds per square inch in the deeper levels, and reservoir temperature was 205° F. Some gas (30 percent methane, 20 percent ethane, 18 percent propane, 19 percent heavier hydrocarbons, and 12 percent nitrogen) was produced with the oil at a ratio of 331 cubic feet of gas per barrel of oil. In 1958, 790 million cubic feet of such gas was marketed after removal of a small amount of sulfur occurring as hydrogen sulfide.

Structural contour maps of the Cabin Creek field, contoured on top of the Ordovician Red River formation (main productive horizon) show a subsidiary fault paralleling the major Cedar Creek fault zone, and about ¾ to 1 mile east of it. An elongated domal anticline lying as an up-raised block between the two faults was found productive along a northwesterly trend for about 6 miles. Other deep-seated faults of less importance are thought to be present.

In 1958 the Cabin Creek field produced 3,570,453 barrels of oil from 70 wells in Siluro-Ordovician strata, and 715,084 barrels from 18 wells in Mississippian Mission Canyon strata. In 1958 there were 27 new oil wells completed at Cabin Creek on a new development on the east side of the field, known as East Flank. The so-called Wills Creek oil field is a small non-unitized part of the Cabin Creek field, most of the field being operated under unit control.

DEER CREEK OIL FIELD

The Deer Creek oil field, another of the 1952 discoveries, lies at the extreme northern end of the string of Cedar Creek anticline fields, and 15 miles north of the Glendive field. The discovery well (Texas-N. P. No. 1"G", NTC-4, sec. 23, T. 17 N., R. 53 E.) is reported to have flowed 191 barrels of oil and 129 barrels of water per day from both the Silurian Interlake and Ordovician Red River fractured dolomites at depths of about 9,440 and 9,910 to 10,100 feet respectively. Initial reservoir pressure was 4,500 p.s.i. The gravity of the oil of about 41° A. P. I. in the Red River and 43° A. P. I. in the Interlake are the highest of all Cedar Creek trend fields, which progressively increases northward from 29° at Little Beaver. Much water is produced with the oil, the ratio in Silurian strata being about 1 to 1. Associated gas was too small to measure. The annual decline of beginning wells is reported at 35 percent. Six producing wells were completed over an area of about 1 square mile; and in 1958 three wells produced 23,625 barrels of oil from the Siluro-Ordovician reservoirs collectively, or approximately 22 barrels per well per day..

Strata at the surface at Deer Creek are in the lower part of the Fort Union formation. The Dakota sandstone is at a depth of 4,610 feet, the top of the Devonian at 8,870 feet, the top of the Silurian at 9,410 feet, and the Ordovician (Stony Mountain) at 9,760 feet. The Red River, principal producing horizon, is 9,900 feet deep. Geologic structure on top of the Red River formation is that of a nearly circular dome with about 200 feet closure, the dome being cut on its western side by faulting, apparently a northward continuation of the major Cedar Creek fault zone. This is the northernmost point of recognition of the fault.

WOODROW OIL FIELD

The Woodrow oil field, lying about 2 miles south of the Deer Creek field, had only 2 wells, spaced 1 mile apart, producing in 1958, and each well producing from a different formation. In 1958 total production was 30,006 barrels of 32° A. P. I. oil from the Madison. The Texas-Elpel No. 1 well (sec. 6, T. 16 N., R. 54 E.) bottomed in November of 1953 at a total depth of 10,370 feet in Red River strata of Ordovician age. Oil was found in the Charles and Interlake formations as well as in the Red River formation. Initially, the well pumped 73 barrels of 42° A. P. I. gravity oil per day, the oil-water fluid being pumped containing about three-fourths water. In November of 1956 the Texas-N. P. "G" well NCT-8 (sec. 7, T. 16 N., R. 54 E.) bottomed in Madison limestone at a total depth of 8,124 feet. The well was completed with perforations in casing between 7,840 and 7,914 feet in the Charles formation. Initially the well pumped 96 barrels of 32° A. P. I. gravity oil per day with about 10 percent water in the oil-water fluid. Gas coming with oil was negligible. Excess water was injected into the Dakota formation. The showing of oil in the Interlake was adequate to suggest commercial production. Porosity throughout all the dolomites in both upper and lower oil-bearing zones is widely variable and associated with fracturing. Strata at the surface as well as at depth at Woodrow are similar to Deer Creek. The structure is described as a "relatively flat" dome along the Cedar Creek anticline.

YELLOWSTONE AND GAS CITY OIL FIELDS

Three additional discoveries along the Cedar Creek anticline were made in 1955, Yellowstone and Gas City at the northern end near Yellowstone River, and Pennel 45 miles southeastward near Baker. The first two form a structurally related unit. During 1958 Pennel had 22 wells producing 599,004 barrels of oil, Gas City had 12 wells producing 279,820 barrels, and Yellowstone with 1 well produced 1,194 barrels of oil.

The strata at the surface of both Gas City and Yellowstone are in the Bearpaw shale formation. Stratigraphy at depth is unusual in that erosion at the end of Devonian time locally removed Devonian strata and some Silurian strata so that the Mississippian strata lie directly on eroded Silurian rocks. Depth to the Ordovician

Red River formation is about 9,080 feet. The deep-seated geologic structure of these two fields is shown as an 8-mile compound domal anticline ending to the north in the Glendive oil field dome. The structure is separated from the main Cedar Creek fault zone by a subsidiary fault, leaving the main fault at Yellowstone, and diverging southeastward about 20 degrees from the main fault for four or more miles. Between the two faults is a down-dropped (graben) block which in itself is anticlinal. The commercial wells lie on the eastern side of the subsidiary fault, although wells in the graben yielded some oil. Wells in the Red River formation had an initial potential flowing of about 200 barrels per day with 5 to 10 barrels of water. Associated gas produced with oil was small in amount.

PENNEL OIL FIELD

The Pennel oil field lies along the crest of the Cedar Creek anticline on a local anticlinal dome 5 miles long and ¾ mile wide. Separate closures appear at the north and south ends, and amount to 100 to 200 feet. A minor or subsidiary fault of about 75 feet displacement and 3 miles long cuts slightly diagonal northward across the dome, the major Cedar Creek fault zone lying to the west. The discovery well (Shell-State No. 22X-36; sec. 36, T. 8 N., R. 59 E.), completed in September of 1955, bottomed at 9,242 feet in Lower Ordovician strata. Oil was found in the Mission Canyon formation at 7,280 feet, and in Silurian and Ordovician strata at several places between 8,100 and 8,700 feet. Initial potential was 205 barrels of oil with 39 barrels of water per day, the well producing from Siluro- Ordovician strata. Devonian strata at Pennel are less than 50 feet thick due to pre-Mississippian erosion. In 1958 only 1 well of 22 commercial oil wells was producing from the Mississippian Mission Canyon formation. No gas cap was present in either reservoir, but gas accompanied oil production at a ratio of 205 cubic feet of gas per barrel of oil. No gas from this oil field was marketed in 1958.

Water from the Red River formation at Pennel contained about 62,000 parts per million dissolved salts. 90 percent sodium chloride. The excess mineralized water is injected back into the ground, either in shallower barren formations of into the producing formations through edge wells. Porosity in all oil-bearing zones, average perhaps 11 percent, is believed to be closely associated with fracturing which is prevalent throughout.

RICHEY OIL FIELDS

First commercial discovery of oil in eastern Montana was on the rolling uplands 12 miles northwest of the small town of Richey in July of 1951 when the Shell-N. P. 11-9 No. 1 well (sec. 19, T. 23 N., R. 50 E.) began flowing at a rate of several hundreds of barrels of oil per day. Oil of 39° A. P. I. gravity came from a fractured and porous zone in the Charles formation at a depth between 7,100 and 7,250 feet. Following this discovery the well was sunk to a total depth of 10,518 feet to test Devonian, Silurian, and Ordovician strata. The well bottomed near Cambrian strata. The well was then plugged back to 7,370 feet, and placed on production, the initial flow without acid treatment being reported as at the rate of 1,656 barrels of oil per day with 408 barrels of water. Settled production was about 170 barrels per day through 32/64-inch choke. Following discovery 6 more wells were started in the vicinity. In 1956 eight wells were producing from the Madison; and in 1958, nine wells produced 117,866 barrels of 39° A. P. I. gravity oil, or about 37 barrels per well per day. The oil contained 0.6 percent sulfur. The water contained from 120,000 to 300,000 parts per million dissolved salts essentially sodium chloride and came from different places in the Madison. Beds of solid salt totaling 50 or more feet in thickness occur in the Charles formation—top member of the Madison. The highly mineralized water, which could not be turned loose on the surface because of danger to live stock and damage to land, was injected back into the ground, much of it going into the Dakota formation.

At the same time the Richy descovery well was being drilled, another well (Shell-N. P. well No. 22-25; sec. 25, T. 22 N., R. 48 E.) was being sunk 3 miles southwestward into Ordovician strata, and oil was found. It was not completed until 1952. This area, near Duck Creek, then became known as Southwest Richey; it is 21 miles due west of the town of Richey. Several more widely spaced wells were drilled in following years, most without success; however, an 80-acre offset well to the discovery, sunk to a depth of 11,075 feet and into Precambrian rocks, found oil in Devonian (Dawson Bay), Silurian (Interlake), and Ordovician (Red River) strata. It was completed flowing 297 barrels of oil and 28 barrels of water per day after acidization between depths of 9,250 and 9,834 feet. Much gas (660 cubic feet per barrel of oil) came with the oil. It was composed of about one-half methane, the remainder being higher hydrocarbons, and analyzed 1,538 B.T.U. The producing horizons are a fractured dolomite in which porosity and permeability are variable in depth, locality, and amount. During 1959 additional wells were being completed with much success.

Strata at the surface at both Richey fields are well up in the Fort Union formation. In the Shell-N. P. well 11-19 on section 19 depths in feet to tops of formations are as follows: Judith River, 2,157; Clagget, 2,370; Eagle, 2,540; Telegraph Creek, 2,650; Mowry, 4,340; 1st Cat Creek, 4,734; 3rd Cat Creek, 5,074; Morrison, 5,120; Ellis group, 5,175; Spearfish, 6,044; Amsden, 6,080; Big Snowy group, 6,275; Charles "A", 6,695; Mission

Canyon, 7,304; Three Forks, 8,490; Interlake, 9,325; Stony Mountain, 9,775; Winnepeg, 10,232; Cambrian, 10,434. Total depth is 10,518 feet, which is 8,015 feet below sea level.

Maps of geologic structure at the surface show nearly horizontal strata with only slight irregularity. The geologic structure contoured on deep-seated strata of both fields show elongated anticlinal domes with 50 to 100 feet closure. Actually, these are probably two high places on the same anticlinal trend. On maps, the Richey field falls on the northward projected line of the Cedar Creek anticline, but Richey is not a part of that structure. The unusual feature about the Richey anticline is that it trends about N. 40° E. which is nearly at a right angle to the Cedar Creek trend. Northwest of the Richey fields about 8 miles, is the northeast trending Weldon fault which if projected strikes into the Brockton-Froid fault zone. These features, as well as others, indicate that there is a definite northeast trend to geologic structure in Paleozoci rocks in this area. The fracturing which seems to have affected porosity so much in the Paleozoic dolomites is probably related to these deep-seated structural trends.

POPLAR OIL FIELDS

The Poplar oil field, discovered in 1952, is among the three first discoveries made in that year in eastern Montana, and after Pine Unit on the Cedar Creek anticline, it has proven to be the second largest producer for all Montana, Pine being first. Poplar reached a peak production in 1957 of about 4½ million barrels of oil from 100 wells. Differing from the Cedar Creek fields which produced oil mainly from Ordovician strata at depths of 8,000 to 9,000 feet, the Poplar oil production comes from the Mississippian Charles formation at depths of 5,000 to 6,000 feet. In 1958 oil production from 112 wells at Poplar was 4,048,652 barrels. The greenish-brown oil, said to have a paraffin base, has 40° A. P. I. gravity and contains 0.37 percent sulfur.

The discovery well (Murphy Corporation-East Poplar Unit No. 1 well; sec. 2, T. 28 N., R. 51 E.) was completed in March of 1952. Although oil was found in the Charles formation, the well was continued downward into the Winnipeg formation of Ordovician age, bottoming at 9,163 feet. After plugging back, the well was completed in the Charles and initially flowed 715 barrels of oil per day through 10/64-inch choke. In May of 1952, the Ajax Oil Company completed a flowing well (Ajax-McGowan No. 1; sec. 10, T. 29 N., R. 50 E.) seven miles northwest of the Murphy discovery, and because of the intervening distance, this local area became known as Northwest Poplar, thus distinguishing it from East Poplar. In September of 1952 Murphy Unit No. 10 was completed flowing 402 barrels of oil per day 3 miles northwest of the discovery well. Again in April of 1953 the Empire State Oil Company brought in a well on section 8, 4½ miles north of the first discovery, which reportedly flowed an estimated 6,000 barrels of oil initially. These widely spaced wells were originally considered as "wild cats" (wells in unproven areas); eventually after drilling of the many producing wells in intervening areas, they became a part of the one continuous oil field about 10 miles long in a northwesterly direction and up to 4 miles wide, covering about 25 square miles. About 97 percent of the field is operated under Federal Unit Agreement by Murphy Corporation. Well spacing is commonly 1 well per 160 acres, except locally where offsetting may require 40-acre spacing.

The surface of most of this region is a glaciated plain blanketed by drift and high-level gravel of Tertiary age. Poplar River flows through the center of the field at an elevation of about 2,100 feet, and the upland plain is about 200 feet higher. Strata at the surface are in the upper part of the Bearpaw shale formation. The Fox Hills sandstone lies in an irregular 2-mile band adjacent to the field on its north side, and Hell Creek and Fort Union strata lie beyond.

As stated, commercial production comes from the Charles formation of Mississippian age, the oil occurred in zones designated as "A", "B", and "C". These zones are layers of more porous strata (dolomite), thickness of which ranges from 25 to 50 feet; they lie about 90,260, and 410 feet beneath the top of the Charles, total thickness of which is over 500 feet. Although the zones are recognized throughout the field (and perhaps throughout this region) different wells may produce from different zones, due to porosity variations and a local absence of effective porosity. It has been suggested that the several zones have communication with one another by means of nearly vertical fractures which are prevalent in the area. The porosity of the dolomite is believed to closely relate to the amount of fracturing. Observed porosity and permeability in solid cores is commonly very low.

Much water accompanying the oil at time of production has been serious, not only because of its presence, but also because of disposal problems, as the water cannot be turned loose on the surface due to its high mineral content. The amount of water produced with oil (probably traveling through fractures) is reported to range from 25 percent to 70 percent of the oil-water fluid, and may amount to 10,000 to 20,000 barrels per day. It is being disposed by injecting into either barren strata above the oil zones (Dakota formation), or else back into the oil zones from which it came, in carefully selected wells. It is reported that injection into the oil-bearing zones has resulted in delay of pressure decline, or actual increase in pressure, thereby increasing oil production. The water, after separation from oil is described as clear and colorless, although it contains from 130,000 to perhaps 300,000 parts per million dissolved salts, 95 percent sodium chloride. Reservoir temperature is about 180° F. Much solid salt occurs in the Charles formation in beds which total several hundred feet in thickness.

The geologic structure of the Poplar anticline at the surface, as shown on the U. S. Geological Survey Structure Contour Map (see plate 2), is that of a broad dome 30 miles long and 25 miles wide centering about 6 miles north of the town of Poplar; the oil field lies on its northeatsern flank. Structural closure is about 300 feet. Geologic structure contoured on a marker in the Charles formation ("B" zone) at a depth of about 5,600 feet shows that the productive area also lies on a dome, but is limited to an area of 5 by 8 miles; the subsidiary dome in turn lies on the northeast side of the structure shown at the surface. Structural closure at depth as shown on maps is approximately 100 feet, but in a much smaller area. Information is not at hand to say if other deep-seated structural domes are present on the Poplar dome, but this seems probable. No faulting of consequence has been noted.

BREDETTE, LINE COULEE, AND RED STONE OIL FIELDS

For 50 miles north of the Missouri River (and the Poplar oil field) is nearly level treeless glaciated plain, characteristic of northeastern Montana, and best known for the grain and cattle it produces. Sluggish streams flow through shallow valleys. The soft shales and sandstones at the surface lie nearly horizontal, and a lack of outstanding geologic structure has for many years turned oil prospecting away from this region. With the oil discoveries near Williston and Poplar, and after geophysical surveys, several widely spaced wells were sunk in this region. After 1954, oil was discovered in at least three new localities: Bredette, 30 miles north of the town of Poplar; Outlook, 25 miles northeast of Bredette; and Red Stone lying midway between these two. Line Coulee close to Bredette, and Wolf Creek 25 miles northwest of the Poplar field may also be added to this group. In December 1959, one well at Line Coulee produced 730 barrels of oil.

Near the small rural village of Bredette, the California Company completed the Elizabeth Grimm well (sec. 13, T. 32 N., R. 49 E.) in May of 1955 with an initial potential flow of 140 barrels of oil and 31 barrels of water per day through ⅛-inch choke, the oil coming from the Mississippian Charles formation (lower or "C" zone) at a depth of 6,540 feet. Gravity of the dark-green oil was 40° A. P. I., and it contained approximately 0.5 percent sulfur. Within 5 months after completion of the discovery well 7 more wells were sunk within 1½ miles northwestward, 4 of which were considered non-commercial. In May of 1956 the California-Paulson No. 1 well (sec. 34, T. 33 N., R. 49 E.), three miles north of the Grimm discovery well, came in flowing 114 barrels of oil through 7/64-inch choke from a depth of 6,720 feet, also in the Charles "C" zone seven offsetting wells were sunk, and this locality became known as North Bredette. The history of wells in this general area is that a well starts flowing 100 percent oil, but within a few days water appears, gradually increasing in volume until within one or two months close to 100 percent water may be produced. With increase of water production, wells stop flowing and must be pumped. The water contained up to 45,000 parts per million dissolved salt. Experience so far indicates short life to wells. In 1958 production from Bredette (south) was 10,616 barrels from 1 well, or about 30 barrels per day. North Bredette produced 151,261 barrels from 5 wells in 1958, or an average of about 84 barrels per well per day. Total cumulative oil produced from both fields since discovery to January of 1959 was 525,000 barrels. Sixteen wells were drilled.

Rocks at the surface are in the lowermost part of the Fort Union formation. Depths in feet to tops of selected formations are as follows: Judith River, 1,690; Eagle, 2,150; Dakota, 4,200; Spearfish, 5,566; Kibbey, 5,762; Charles, 6,012; Mission Canyon, 6,470; Devonian, 7,755; Silurian, 9,225; Ordovician (Stony Mountain), 9,595. Oil occurs in the "C" zone (or "McGowan" zone) which is in the lower part of the Charles formation. The producing zone is essentially dolomite or dolomitic limestone which without fractures shows porosity and permeability too low to be an effective reservoir rock (average porosity 3.5 percent, average permeability 1.9 millidarcies). However, a fracture system, perhaps a network of fractures, appears to be present along the anticlinal axes, and hence responsible for oil accumulation. Such a condition explains the short life of some wells, and the "spotted" distribution of productive areas.

The geologic structure at the surface throughout this northeastern part of Montana shows little variation from the uniform easterly slope, but seismic studies are said to have shown gentle anticlinal structures with northwest trends and small closures at depth.

The name Line Coulee was given to an area with 2 wells lying about 3 miles north of the 2 Bredette fields. As seen on a map, these 3 local areas within 9 miles of each other would seem to be 1 field, alined north to south with 1 to 2 miles of intervening unproven areas. The discovery well is the Pan American-Godden No. 1 (sec. 5, T. 33 N., R. 49 E.) which when completed in October 1957, initially flowed 58 barrels of oil and about an equal amount of water from the "C" zone (McGowan zone) of the Mississippian Charles formation at a depth of 6,410 feet. This well had been sunk to a total depth of 9,556 feet into Ordovician strata and then plugged back to 6,464 feet. The second well, completed 1 year later by the Juniper Oil and Mining Company on section 9 a quarter mile southeastward, is reported to have flowed 120 barrels of oil with 80 barrels of water per day. Gas accompanied the oil at a rate of 365 cubic feet of gas per barrel of oil. Production for 1958 from 2 wells was 39,753 barrels.

Strata at the surface at Line Coulee are in the lower part of the Fort Union or top of the Hell Creek formation. Depths in feet to tops of selected formations are as follows: Judith River, 1,692; Eagle, 2,145; Dakota, 4,194; Spearfish, 5,556; Kibbey, 5,762; Charles, 6,012; (McGowan "C", 6,479); Devonian, 7,565; Silurian (Interlake) 8,775; Ordovician (Red River), 9,250. The oil in the Charles is described as occurring in "closely-spaced subparallel nearly-vertical fractures . . . sufficiently abundant to contribute materially to reservoir space." Information on geologic structure is not at hand. The oil is described as brownish-black, of 35° A. P. I. gravity, with 0.55 percent sulfur. An analysis shows 28.6 percent gasoline, 12.8 percent kerosene, and 57.7 percent reduced crude. The water produced with the oil contained 37,848 parts per million dissolved salts, over 95 percent sodium chloride.

The name Red Stone has been given to an area lying about midway between Bredette and Outlook. Only one well (Hunt-Hagen No. 1; sec. 7,T. 34 N., R. 52 E.) has been sunk. The well originally drilled in 1952 was abandoned at that time as uncommercial, but was re-opened in November of 1958 to produce oil with some gas from the Winnipegosis formation of Devonian age at a depth of 9,400 feet. It is said to have initially flowed 115 barrels of oil with 18 barrels of water in 11 hours through a ¾-inch choke. Total depth of the well is 10,105 feet. It bottomed in the Ordovician Winnipeg formation. The top of the Devonian is reported at 7,788 feet, the top of the Silurian at 9,226 feet, and the top of the Ordovician Red River formation at 9,776 feet. Production for the 2 months in 1958 from 1 well was 3,413 barrels.

OUTLOOK OIL FIELD

The Outlook oil field, 30 miles north of the Poplar field and 10 miles from the Canadian border, was discovered in December of 1956 by the drilling of the Amerada Oil Company-Tange No. 1 well (sec. 20, T. 36 N., R. 53 E.). This and following nearby wells found oil in Devonian, Silurian, and Ordovician strata at depths of 8,900 to 9,900 feet, not all wells producing from the same formation. After completion of the Tange well, which found oil in the Silurian Interlake formation at a depth of 9,050 feet, the Loucks well (sec. 35) four miles southwestward found oil in the middle of the Ordovician Red River formation at a depth of 9,900 feet. Five wells were completed in 1957, and 8 in 1958. The production from 13 Devonian-Silurian wells in 1958 was 451,112 barrels, and from 1 Ordovician well was 47,443 barrels.

Strata at the surface at Outlook are well up in the Fort Union formation, and formations at depth are similar to those at Bredette. The top of the Eagle sandstone should be about 2,800 feet deep, the Dakota sandstone 4,700 feet deep, and the Charles formation 6,400 feet deep. In the Loucks well the top of the Devonian is 7,955 feet deep, the Silurian 9,300 feet, and the Ordovician 9,600 feet. The Devonian rocks in this region have an over-all thickness of about 1,400 feet, and have been subdivided into 8 formations. Much of the oil at Outlook comes from the Dawson Bay formation about midway in the series, but a vertical fracture zone is believed to cut through the lower part of the Devonian and into the underlying Silurian Interlake formation. The oil-bearing strata at all the different depths are a much-fractured and vuggy dolomite. It is believed that the fracturing has been a vital factor in oil accumulation; however, gentle anticlinal structure is reported present. Some observers have suggested vertical inter-communication between these deep-seated formations by reason of the nearly vertical fractures.

Maps of the geologic structure at depth at Outlook show 2 parallel east-plunging gentle anticlinal folds, with little or no closure, trending northwesterly.

BRORSON OIL FIELD

Some 50 miles east of the other eastern Montana oil fields, and 9 miles from the state boundary line near Sidney, are a group of 3 oil wells known as the Brorson field. Again 50 miles south of this area and 5 miles from the state line a well near Wibaux gave promise of commercial production. At Brorson the discovery well was put down jointly by the Sun Oil Company and the Phillips Petroleum Corporation on the Carl Dynneson lease in sec. 32, T. 24 N., R. 58 E., and completed in August of 1953. The well was driven to a total depth of 12,671 feet, and bottomed in the Ordovician Red River formation where oil was found. An initial potential is given as flowing 745 barrels of oil with 21 barrels of water per day through 20/64-inch choke from perforations in casing at 12,585 to 12,605 feet. After production of about 100,000 barrels of oil from Ordovician strata (Red River), the casing collapsed, and the Ordovician was temporarily abandoned as uneconomical. Reservoir pressure is given at 5,785 p.s.i. The "pay horizon" is described as being fractured and vuggy; solid cores show 6 percent porosity.

Oil has also been found in the upper part of the Madison group between 9,100 and 9,300 feet, and 2 new off-set wells were completed producing from this formation. One of these wells had been drilled into the Ordovician and plugged back. Production from 3 wells in the Madison for 1958 was 28,760 barrels, making a grand total of 270,000 barrels field cumulative. Gravity of the Red River oil is 48° A. P. I. with 0.12 percent sulfur; that in the Madison is 30° A. P. I.

Strata at the surface are well up in the Fort Union formation, and formations at depth are similar to those described under the Wibaux well below. Solution gas was about 1,000 cubic feet per barrel of oil produced, and mineralized water amounted to about 1 barrel per 20 barrels of oil. Initial bottom-hole pressure was about 5,700 p.s.i.

WIBAUX WELL

The deep well at Wibaux (sec. 29, T. 14 N., R. 60 E.) sunk by the Lion Oil Company in 1954 on the Knight lease bottomed at a total depth of 11,153 feet in the Ordovician Red River formation of Ordovician age. Oil was found in fractured Red River dolomite, and after injection of a large amount of acid, the well started flowing oil at the rate of 118 barrels per day. Water soon appeared and the well was put on pump. Water increased, and the well was finally abandoned in May 1957, after having produced a total of 21,513 barrels of 32° A. P. I. gravity oil. Very little gas occurred with the oil.

Strata at the surface at both Brorson and Wibaux are well up in the Fort Union formation, and formations are similar at depth. The depths in feet to tops of selected formations at Wibaux are as follows: Dakota sandstone, 5,197; Spearfish, 6,495; Amsden, 7,410; Kibbey, 8,100; Charles, 8,292; Mission Canyon, 8,697; Devonian, 9,825; Silurian, 10,377; Ordovician Stony Mountain, 10,855; Red River, 10,910. Slight anticlinal folding is shown in this region at the surface, but the deep wells were located after seismic exploration. Both the Madison limestone and the Red River dolomite reservoirs are described as tight and with very low porosity and permeability. As in others of these eastern Montana fields, the accumulation of oil appears to have been strongly influenced, if not controlled, by fracturing.

FERTILE PRAIRIE AND REPEAT OIL FIELDS

Lying toward the south end of the Cedar Creek anticline, but on either side, are the Fertile Prairie oil field, six miles east of Baker and the crest of the major anticline; and the Repeat oil field, about 35 miles south of Baker and 12 miles west of the crest of the Cedar Creek anticline. Both are near the state line.

The discovery well at Fertile Prairie (Mon-O-Co.-Ferguson-Golden No. 1; sec. 18, T. 7 N., R. 61 E.) was driven to a total depth of 9,286 feet into the Ordovician Winnipeg formation in November of 1954. Oil was produced from perforations in casing at about 9,250 feet in the Red River formation. After injection of 2,500 gallons of acid, the well pumped 132 barrels of oil per day. Bottom-hole pressure was 3,520 p.s.i. Water coming with the oil, which eventually proved serious, analysed 76,400 parts per million dissolved salts 96 percent sodium chloride. The brownish-black oil is of 33.4° A. P. I. gravity and contains 0.42 percent sulfur. A peak annual production of 44,040 barrels was reached in 1955, the second year of production. In 1958 production from 3 wells at Fertile Prairie was 17,155 barrels of oil. Cumulative production to January of 1959 was 122,231 barrels.

Sandstones and shales of the Hell Creek formation lie at the surface at Fertile Prairie. The succession of formations at depth is similar to that along the Cedar Creek anticline; excepting that depths differ, and thicknesses may be slightly different.

The one well Repeat oil field is farthest south of all the eastern Montana oil fields. The discovery well, completed in March of 1956, was put down by the Ohio Oil Company on a Government lease in sec. 6, T. 1 S. R. 62 E. to a depth of 9,362 feet, the well ending in the Winnipeg formation (Ordovician). Oil in the Red River formation began flowing from a depth of 8,610 feet at a rate of 186 barrels per day with very little water or gas through 10/64-inch choke. Water had been found in the Red River at 8,434 feet depth. Water in the Red River analyzed 18,614 parts per million dissolved salt, and that in the Winnipeg 23,661 parts. Porosity in the Ordovician is described as vuggy, brecciated, and associated with fractures. Temperature at 8,434 feet was 182° F.

Strata at the surface at Repeat are in the Fort Union formation. Depths in feet to tops of selected formations are as follows: Eagle, 1,975; Greenhorn, 3,600; Dakota, 4,630; Morrison, 4,890; Ellis, 5,220; Spearfish, 5,800; Minnekahta, 6,128; Minnelusa, 6,225; Big Snowy, 6,560; Charles, 6,690; Devonian, 8,000; Silurian, 8,240; Ordovician (Stony Mountain), 8,495; Ordovician (Winnipeg), 9,055; total depth, 9,362. Geologic structure is that of a minor anticline paralleling the Cedar Creek anticline on its western side.

Production for Repeat for 1958 from 1 well was 47,000 barrels. Cumulative production to 1959 is 99,625 barrels of oil.

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent area: U. S. Geol. Survey Prof. Paper 174.

Andrichuk, J. M., 1951, Regional stratigraphic analysis of Devonian system in Wyoming, Montana, southern Saskatchewan, and Alberta: Bull. Amer. Assoc. Pet. Geol., v. 35, p. 2368-2408.

Bartram, J. C., 1929, Elk Basin oil and gas field. Structure of typical American oil fields (a symposium): Amer. Assoc. Pet. Geol.

Blackstone, D. L., Jr., 1940, Structure of the Pryor Mountains: Jour. of Geol., v. 48, p. 590-618.

Blixt, J. E., 1941, Cut Bank oil and gas field, Glacier County, Montana, in Leversen, A. I., ed., Stratigraphic type of oil fields: Amer. Assoc, Pet. Geol., p. 327-381.

Bowen, C. F., 1915a, Possibilities of oil on the Porcupine dome, Montana: U. S. Geol. Survey Bull. 621-F.

———, 1915b, Stratigraphy of the Montana group with special reference to the position and age of the Judith River formation in north-central Montana: U. S. Geol. Survey Prof. Paper 90-I.

———, 1918, Anticlines in a part of Musselshell Valley, Montana: U. S. Geol. Survey Bull. 691-F.

———, 1921, Gradations from continental to marine conditions of deposition in central Montana during Eagle and Judith River epochs: U. S. Geol. Survey Prof. Paper 125-B, p. 11-12.

Clapp, C. H., Bevan, Arthur, and Lambert, G. S., 1921, Geology and oil and gas prospects of central and eastern Montana: Mont. Bur. Mines and Geol. Bull. 4.

Cobban, W. A., 1945, Marine Jurrassic formations of the Sweetgrass Arch, Montana: Bull. Amer. Assoc. Pet. Geol., v. 29, p. 1262-1303.

———, Erdmann, C. E., Lemke, R. W., and Maughan, E. K., 1959, Revisions of the Colorado group on Sweetgrass Arch, Montana: Bull. Amer. Assoc. Pet. Geol., v. 43, p. 2786-2796.

Collier, A. J., 1929, The Kevin-Sunburst oil field and other possibilities of oil and gas in the Sweetgrass Arch, Montana: U. S. Geol. Survey Bull. 821-D.

———, and Cathcart, S. H., 1923, Possibilities of finding oil in laccolithic domes south of the Little Rocky Mountains, Montana: U. S. Geol. Survey Bull. 736-J.

Dobbin, C. E., and Erdmann, C. E., 1934, Geologic occurrence of oil and gas in Montana: Problems of Petroleum Geology: (Sidney Powers memorial volume): Amer. Assoc. Pet. Geol., p. 708-709.

Erdmann, C. E., 1940, Principles of oil accumulation in the Cut Bank district, Montana: Oil and Gas Jour., v. 38, p. 55.

———, and Schwabrow, J. R., 1941, Border-Red Coulee oil field, Montana, in Levorsen, A. I., ed., Stratigraphic type of oil fields: Amer. Assoc. Pet. Geol., p. 267-326.

Ellis, A. J., and Meinzer, O. E., 1924, Ground water in Musselshell and Golden Valley Counties, Montana: U. S. Geol. Survey Water Supply Paper 518.

Freeman, O. W., 1922, Oil in the Quadrant formation in Montana: Engr. and Mining Jour., v. 113, p. 825-827.

Gardner, L. S., Hendricks, T. A., Hadley, H. D. Rogers, C. P., Jr., and Sloss, L. L., 1946, Stratigraphic sections of upper Paleozoic and Mesozoic rocks, south-central Montana. Fauna of Amsden and Heath formations: Mont. Bur. Mines and Geol. Mem. 24.

Hall, G. M., and Howard, C. S., 1929, Ground water in Yellowstone and Treasure Counties, Montana: U. S. Geol. Survey Water Supply Paper 599.

Hancock, E. T., 1918, Geology and oil and pas prospects of the Lake Basin field, Montana: U. S. Geol. Survey Bull. 691-D.

———, 1920, Geology and oil and gas prospects of the Huntley field, Montana: U. S. Geol. Survey Bull. 711-G.

Heald, K. C., 1927, Geology of the Ingomar anticline, Treasure and Rosebud Counties Montana: U. S. Geol. Survey Bull. 786-A.

Knappen, R. S., and Moulton, G. F., 1930, Geology and mineral resources of parts of Carbon, Big Horn, Yellowstone, and Stillwater Counties, Montana: U. S. Geol. Survey Bull. 822-A.

Laird, W. M., 1941, Selected deep well records: No. Dak. Geol. Survey Bull. 12.

———, 1944, Stratigraphy and structure of North Dakota: Reprint, No. Dak. Geol. Survey Bull. 18.

Lee, W. T., 1927, Correlation of geologic formation in Colorado, Wyoming, and Montana: U. S. Geol. Survey Prof. Paper 149.

Minerals Yearbook, Annual reports on natural gas and petroleum: U. S. Bur. Mines.

Montana Oil Journal, Weekly publication. (Chronological record of oil and gas activities in Montana.)

Montana Oil and Gas Conservation Commission; Statistical reports on oil production. Monthly and annual.

Neeley, Joseph, 1937, Stratigraphy of Sundance formation and related Jurassic rocks in Wyoming, and their petroleum aspects: Bull. Amer. Assoc. Pet. Geol. v. 21, p. 715-770.

Nevin, C. M., and Laird, W. M., 1946, The Keene dome, northwest North Dakota; I. The Keene dome, II. Subsurface stratigraphy: No. Dak. Geol. Survey Bull. 21.

Perry, E. S., 1929, The Kevin-Sunburst and other oil and gas fields of the Sweetgrass Arch, Montana: Mont. Bur. Mines and Geol. Mem. 1.

———, 1937, Natural gas in Montana: Mont. Bur. Mines and Geol. Mem. 3.

———, and Sloss, L. L., 1943, Big Snowy group: Lithology and correlation in northern Great Plains: Bull. Amer. Assoc. Pet. Geol., v. 27, p. 1287-1304.

Pierce, W. G., and Hunt, C. B., 1936, Geology and mineral resources of north-central Chouteau, western Hill, and eastern Liberty Counties, Montana: U. S. Geol. Survey Bull. 847-F.

Reeves, Frank, 1924, Geology and possible oil and gas resources of the faulted area south of the Bearpaw Mountains, Montana: U. S. Geol. Survey Bull. 751-C.

———, 1927, Geology of the Cat Creek and Devil's Basin oil fields and adjacent areas, Montana: U. S. Geol. Survey Bull. 786-B.

———, 1929, Thrust faulting and oil possibilities in the plains adjacent to the Highwood Mountains, Montana: U. S. Geol. Survey Bull. 806-E, p. 155-195.

———, 1931, Geology of the Big Snowy Mountains, Montana: U. S. Geol. Survey Prof. Paper 165, p. 135-149.

Renick, B. C., 1929, Geology and ground-water resources of central and southern Rosebud County, Montana: U. S. Geol. Survey Water Supply Paper 600.

Scott, H. W., 1935, Some carboniferous stratigraphy in Montana and northwestern Wyoming: Jour. of Geol., v. 43, p. 1011-1032.

Seager, O. A., 1942, Stratigraphy of North Dakota: Am. Assoc. Pet. Geol., v. 26, p. 1414-1423.

Stebinger, Eugene, 1915, The Montana group of northwest Montana: U. S. Geol. Survey Prof. Paper 90-I.

———, 1917, Oil and gas geology of the Birch Creek-Sun River area, northwestern Montana: U. S. Geol. Survey Bull. 691-E, p. 149-184.

Sloss, L. L., 1950, Paleozoic sedimentation in the Montana area: Bull. Amer. Assoc. Pet. Geol., v. 34, p. 423-451.

———, and Hamblin, R. H., 1942, Stratigraphy and insoluble residues of the Madison group (Mississippian), of Montana: Bull. Amer. Assoc. Pet. Geol., v. 26, p. 305-335.

———, and Laird, W. M., 1947, Devonian system in central and northwestern Montana: Bull. Amer. Assoc. Pet. Geol., v. 31, p. 1404-1430.

Thom, W. T., Jr., 1923, The relation of deep-seated faults of surface structural features of central Montana: Bull. Amer. Assoc. Pet. Geol., v 7, p. 1-13.

———, Hall, G. M., Wegmann, C. H., and Moulton, G. F., 1935, Geology of Big Horn County and the Crow Indian Reservation, Montana: U. S. Geol. Survey Bull. 856.

U. S. Geological Survey, 1906 to 1948, Bulletins describing Montana coal fields, Bull. 285-F; 316; 341-A; 356; 381; 431-B; 471-D, E; 531-F; 541-H, K; 621-K, P; 641-G, H; 647; 749; 751-E, F; 806-B; 812-A; 822-A; 831-B; 847-B, C; 856; 905; 906-C.

Waldron, C. R., 1942, Bibliography of the geology and mineral resources of Montana: Mont. Bur. Mines and Geol. Mem. 21.

Williston Basin, First International symposium: No. Dak. Geol. Soc. and Saskatchewan Geol. Soc., October, 1956.

———, Second International symposium: Saskatchewan Geol. Soc. and No. Dak. Geol. Soc., April, 1958.

Wilson, C. W., Jr., 1936, Geology of the Nye-Bowler lineament, Stillwater and Carbon Counties, Montana: Amer. Assoc. Pet. Geol., v. 20, p. 1161-1188.

MAPS AND CHARTS

Bear's Den, Flat Coulee, and Whitlash districts, north-central Montana, Preliminary structural contour map: Erdmann, C. E., U. S. Geol. Survey (special map) 1930.

Bowdoin dome, Montana, Structural contour map of the central part: Erdmann, C. E., and Schwabrow, J. R., U. S. Geol. Survey (special map) 1933.

Cedar Creek anticline, Montana, Geologic and structure contour map; Erdmann, C. E., and Larson, R. M., U. S. Geol. Survey (special map) 1934.

Cutbank-West Kevin-Border district, Perliminary structure contour map: Erdmann, C. E., Beer, William, and Nordquist, J. N., U. S. Geol. Survey, 1939. Revised 1946.

Devonian stratigraphy of central and northwestern Montana: Sloss, L. L., and Laird, William, U. S. Geol. Survey, Oil and Gas Investigations, Prelim. Chart No. 25, 1946.

Dry hole map of Montana, Petroleum Information, (annual) Billings, Montana; Denver, Colorado.

Elk Basin oil and gas field and vicinity, Park County, Wyoming, and Carbon County, Montana, Geologic and structural contour map: Dobbin, C. E., Kramer, W. B., Miller, J. C., and French, H. (special map) 1945.

Oil and gas fields with wildcat wells, Montana: Bransford, J. C., Mont. Oil Jour., Great Falls, Montana.

Geologic Map of Montana: Ross, C. P., Andrews, D. A., Whitkind, I. I., in cooperation with the Mont. Bur. Mines and Geol., U. S. Geol. Survey, 1955.

Little Rocky Mountains, Montana, Plains adjacent to: Knechtel, M. M., U. S. Geol. Survey, Oil and Gas Investigations, Prelim. Map No. 4, 1944.

Lothair area, Liberty County, Montana, Geology: Erdmann, C. E., U. S. Geol. Survey, Oil and Gas Investigations, Prelim. Map No. 87, 1948.

Mesozoic and Paleozoic rocks on south-central Montana, Maps showing thickness and general distribution: Rogers, C. P., Gardner, L. S., and Hadley, H. D., U. S. Geol. Survey, Oil and Gas Investigations, Prelim. Map No. 43, 1945.

Mesozoic and Paleozoic rocks that underlie the basin areas in south-central Montana, Graphic sections: Hadley, H. D., Gardner, L. S., and Rogers, C. P., Jr. U. S. Geol. Survey, Oil and Gas Investigations, Prelim. Chart No. 19, 1945.

Mississippian and Devonian stratigraphy of northwestern Montana: Sloss, L. L., and Laird, William, U. S. Geol. Survey, Oil and Gas Investigations, Prelim. Chart No. 15, 1945.

Montana plains, Structure contour map: Dobbin, C. E., and Erdmann, C. E., U. S. Geol. Survey, 1942, Map OM 178A and 178B, 1955. (OM 178B is pl. 2 of this report.)

Paleozoic rocks in the mountains of south-central Montana, Columnar sections: Gardner, L. S., Hendricks, H. D., and Rogers, C. P., Jr., U. S. Geol. Survey, Oil and Gas Investigations, Prelim. Chart No. 18, 1945.

Pondera oil field, Pondera and Teton Counties, Montana: Erdmann, C. E., and Holmes, U. S. Geol. Survey (special map) 1952.

Powder River Basin, Wyoming and Montana, Structural contour map: Pierce, W. G., and Girard, Roselle, U. S. Geol. Survey, Prelim. Map No. 33, 1945.

Structure contour map of the base of the Mississippian rocks in the Williston Basin and adjoining areas of Montana and Wyoming: U. S. Geol. Survey, Oil and Gas Investiagtions, Map OM 165, 1954.

Subsurface stratigraphy of the Heath and Amsden formations in central Montana: Nieschmidt, C. L., U. S. Geol. Survey, Oil and Gas Investigations, Chart OC 50, 1953.

Tectonic map of the United States (showing structural contours of the Great Plains): Amer. Assoc. Pet. Geol., 1944.

Other Sources of Information

Statistical information on oil and gas field production is compiled by the Montana Oil and Gas Conservation Commission, head office at Helena. This Commission also has offices at Shelby, Glendive, and Billings, and at the Billings office is a depository for well records, cuttings, and cores. Offices of the United State Geological Survey are at Billings and Great Falls. Detailed information on oil and gas field activities and "wildcat" drilling since their beginning in this State has been given in the weekly issues of the Montana Oil Journal which has offices in Great Falls and Billings. This Journal has for sale many maps of the different fields. The Library at the Montana School of Mines at Butte has on file back issues of most of the technical journals, the publications of the United States and Canadian Geological Surveys, and the publications of the different states and Canadian provinces. The annual reports of the Billings Geological Society at Billings give many excellent descriptions of geology and oil fields, and contain much statistical information, and the Symposium issued in 1958 contains statistical information and structural contour maps for nearly all Montana oil fields.