STATE OF MONTANA
Tim Babcock, *Governor*

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

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MINERAL AND WATER RESOURCES OF MONTANA

Report compiled by
UNITED STATES GEOLOGICAL SURVEY
and
MONTANA BUREAU OF MINES AND GEOLOGY

for

United States Senate Committee on Interior and Insular Affairs,
at request of
Senator Lee Metcalf

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COMMITTEE PRINT

MINERAL AND WATER RESOURCES OF MONTANA

REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

MONTANA BUREAU OF MINES
AND GEOLOGY

PREPARED AT THE REQUEST OF

SENATOR LEE METCALF
of Montana

OF THE

COMMITTEE ON INTERIOR AND
INSULAR AFFAIRS
UNITED STATES SENATE

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MEMORANDUM FROM THE CHAIRMAN

To Members of the Senate Committee on Interior and Insular Affairs:

I am transmitting for your information a report entitled "Mineral and Water Resources of Montana," prepared by the U.S. Geological Survey at the request of our colleague, Senator Lee Metcalf.

This detailed survey will be particularly helpful to government and business leaders in Montana. It will also be valuable to the Congress and members of this committee as we consider legislation regarding mineral and water development.

HENRY M. JACKSON, *Chairman.*

FOREWORD

This report was prepared at my request by the U.S. Geological Survey, in cooperation with the Montana Bureau of Mines and Geology.

The objective—which was fully met—was to make significant data on Montana's abundant mineral and water resources readily available to interested citizens and government, civic and industrial leaders.

In 1958 the Forest Service prepared a somewhat similar report, "Full Use and Development of Montana's Timber Resources" (S. Doc. 9, 86th Cong., 1st sess.), at the request of the Montana congressional delegation. That report has proved invaluable to many persons as a reference and as a guide to further development.

This excellent study on "Mineral and Water Resources of Montana" is a worthy companion to "Full Use and Development of Montana's Timber Resources," and provides data from which further development of Montana resources can proceed.

I wish to thank the personnel of the U.S. Geological Survey and the Montana Bureau of Mines and Geology who contributed to this report.

LEE METCALF.

MINERAL AND WATER RESOURCES OF MONTANA

REPORT

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UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH

MONTANA BUREAU OF MINES
AND GEOLOGY

PREPARED AT THE REQUEST OF

SENATOR LEE METCALF

LETTER OF SUBMITTAL

Department of the Interior,
Geological Survey,
Office of the Director,
Washington, D.C., February 15, 1963.

Hon. Lee Metcalf,
U.S. Senate, Washington, D.C.

Dear Senator Metcalf: I am pleased to transmit herewith a summary report on the mineral and water resources of Montana which has been prepared by the Geological Survey in collaboration with the Montana Bureau of Mines and Geology. It has been prepared in response to your request of August 23 and discussed further in your letter of November 16, 1962.

The report covers all mineral commodities known to exist in significant amounts in Montana, although the discussion of each commodity is necessarily brief. Surface and ground water supplies of the major river basins are described in somewhat greater detail and generalized information is presented on the chemical quality of water. A number of maps and diagrams in black and white are used to supplement the narrative discussion of the occurrence and distribution of many of the commodities and the availability of water supplies.

It is hoped the data provided by the report will be adequate to supply the needed information.

Sincerely yours,

Thomas B. Nolan, *Director.*

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INTRODUCTION

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

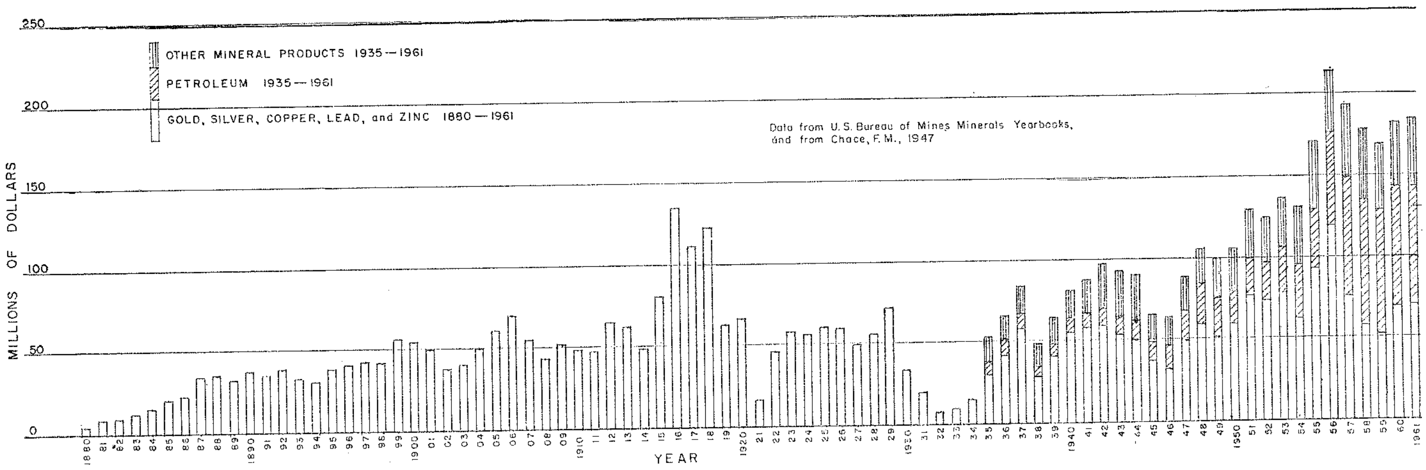
This report describes in summary form the mineral and water resources of Montana, their uses in industry, the economic factors that affect their exploration, their distribution throughout the State, and the manner in which they occur. Production figures are given where available, and the relative importance of the State as a source of each commodity is discussed. All mineral commodities known to exist in Montana in significant amounts are considered whether they are being successfully exploited at present or not. The geology of the State is summarized in an introductory chapter and the relation between the regional geology and the distribution and character of the State's resources is considered briefly.

The report has been compiled by members of the staff of the U.S. Geological Survey and the staff of the Montana Bureau of Mines and Geology. It is based essentially on the publications on the geology and resources of Montana, supplemented by material in the files of the U.S. Geological Survey and the Montana Bureau of Mines and Geology and the personal observations of the more than 17 individuals who have contributed to the various chapters of the report.

Treatment of each commodity is necessarily brief. It is hoped, however, that this report will provide a ready reference to those interested in the mineral and water resources of Montana. Comprehensive bibliographies are attached to each major section of the report for the convenience of those who wish to investigate the original sources, and throughout the text specific references are made to these sources.

Thanks are due to Dr. Edwin G. Koch, director of the Montana Bureau of Mines and Geology, who provided for the cooperation of his staff in the preparation of the report, and to members of the Montana bureau who contributed numerous chapters to the report. Special thanks are due Mr. Uuno Sahinen, chief geologist of the Montana bureau, for his valuable suggestions and assistance.

We are also indebted to Mr. G. W. Yoder, chairman of the Oil and Gas Commission of the State of Montana, for permission to reproduce figure 6 and table 1 of this report, both of which have been taken from publications of the commission.



Data from U.S. Bureau of Mines Minerals Yearbooks, and from Chace, F.M., 1947

FIGURE 1.—Dollar value of Montana mineral production.

THE MINERAL INDUSTRY IN MONTANA

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Montana is known as the Treasure State because of the richness and variety of its mineral resources, and the State's economy from its beginning has been closely tied to its mineral wealth. It was the discovery of gold that in the 1860's brought the first permanent settlers to what is now the State of Montana, and it was the copper mines of Butte that in the early 1880's brought the railroads to Montana, thus facilitating the settlement of the country. The population centers that grew around the mines and smelters provided local markets for the products of the rancher and farmer who soon followed the miner. Montana mineral production has made important contributions to both the local and the national economy, Butte alone having added over $2 billion of new wealth to the Nation—one of the very few metal mining districts in the world that has produced this much. Montana's gold production is estimated at 17,600,000 ounces or over $616 million at the present price of gold, much of it having been produced in the years following the Civil War when gold was urgently needed to strengthen the currency and to bolster the economy. Strategic and critical metals and minerals from the State's mines have contributed significantly to the national security at times when these were urgently needed. The value of the annual output of the minerals and metals that Montana has produced is shown graphically in figure 1 on opposite page.

Although Montana's beginnings are rooted in the mineral industries, as the State's population increased the value of agricultural products became greater than the value of its mineral products. In 1961, the cash receipts from farm marketing amounted to $374.6 million; the value of all mineral products during the same year was $183.4 million according to the U.S. Bureau of Mines Minerals Yearbook. Although now second to agriculture, the mineral industry nevertheless is of vital importance to the economy of the State.

Despite extreme fluctuations such as occurred from 1916 to 1919, or in the depression years of the 1930's, the value of Montana's mineral production has shown a fairly consistent upward trend (fig. 1). This trend is to some degree misleading, because it shows the value of mineral products produced, not the amount, and higher prices in recent years for some commodities tend to distort the curve. For instance the tons of copper produced in 1961 is no greater than the annual production in years immediately preceding World War I, although its dollar value is considerably greater. Nevertheless, the graph serves as a guide to the development of the mineral industry in Montana. For example, it brings out clearly the rapid growth since 1935 of the petroleum industry relative to the other mineral industries.

According to statistics from the Montana State Employment Service (as given in the U.S. Bureau of Mines Minerals Yearbooks) in 1961 the total employment in mining within the State, including production of petroleum and natural gas, was 6,900 of which 4,200 persons were employed in metal mining, 700 in mining nonmetals (including coal) and 2,000 in the production of petroleum and natural gas. An additional 4,500 persons were employed in plants processing primary metals and in petroleum refineries. Total employment in 1961 directly connected with mineral industries was 11,400. This contrasts with 1953 when 11,600 were employed in mining: 8,200 in metal mines, 1,000 in nonmetal mines and 2,400 in producing petroleum and natural gas. An additional 4,800 were employed in processing mineral products, making a total of 16,400 employed in the mineral industries. Thus, although the value of mineral production was considerably greater in 1961 than it was in 1953, this production was obtained with a greatly decreased labor force—in the case of metal mining with only a little over half the number employed in 1953. This trend, which is industrywide and not confined to Montana alone, is represented graphically in figure 2. It presents a serious problem to States such as Montana whose economy is so dependent on the mineral industry, and warrants some discussion.

Many factors have tended to bring this about. In contrast to the situation, a few years ago, when there was a scarcity of many mineral commodities, exploration has been successful in finding new deposits of copper, lead, zinc, and other metals, both in the United States and in foreign countries. The result is that for some metals, world productive capacity has caught up with, and in some instances surpassed, consumptive demands, at least temporarily. Coupled with this, some metals are faced with competition from other metals or from such materials as plastics, which, for some uses, can replace them. All this has tended to hold prices of metals and mineral commodities to relatively low levels when compared with other commodities. At the same time, increased labor and materials costs, declining ore grades, deeper mining, and related factors have resulted in higher operating costs. Mine operators have been forced to increase the efficiency of their operations in order to survive. The tendency has been to concentrate operations into fewer, more effective operating units with a significant decrease in the number of active mines. This trend is not new; it has been going on for a long time as can be seen from inspection of the upper curve of figure 2—the number of mines operating in Montana since 1900—and is paralleled by similar trends in other industries, such as agriculture. An interesting feature of the curve is the sharp reversal that occurred between 1931 and 1943. This resulted from two things—the depression years of the 1930's when many jobless miners tried to scratch a living by prospecting and mining on their own, and the rise in the price of gold, which encouraged the attempt to operate small placer and lode mines. After 1943, the downward trend continued without interruption.

Montana's mineral industry is founded on the resources hidden beneath her mountains and plains, but the minerals produced are consumed almost entirely outside the State. Thus the prosperity of the mineral industry within the State is dependent on the national economy and on demands by industry for mineral products. The past few years have been difficult ones, particularly for the small operator. This situation is not likely to change greatly in the next few years. Nevertheless, there are some hopeful signs. The output of Montana's mineral products has shown a healthy upward trend

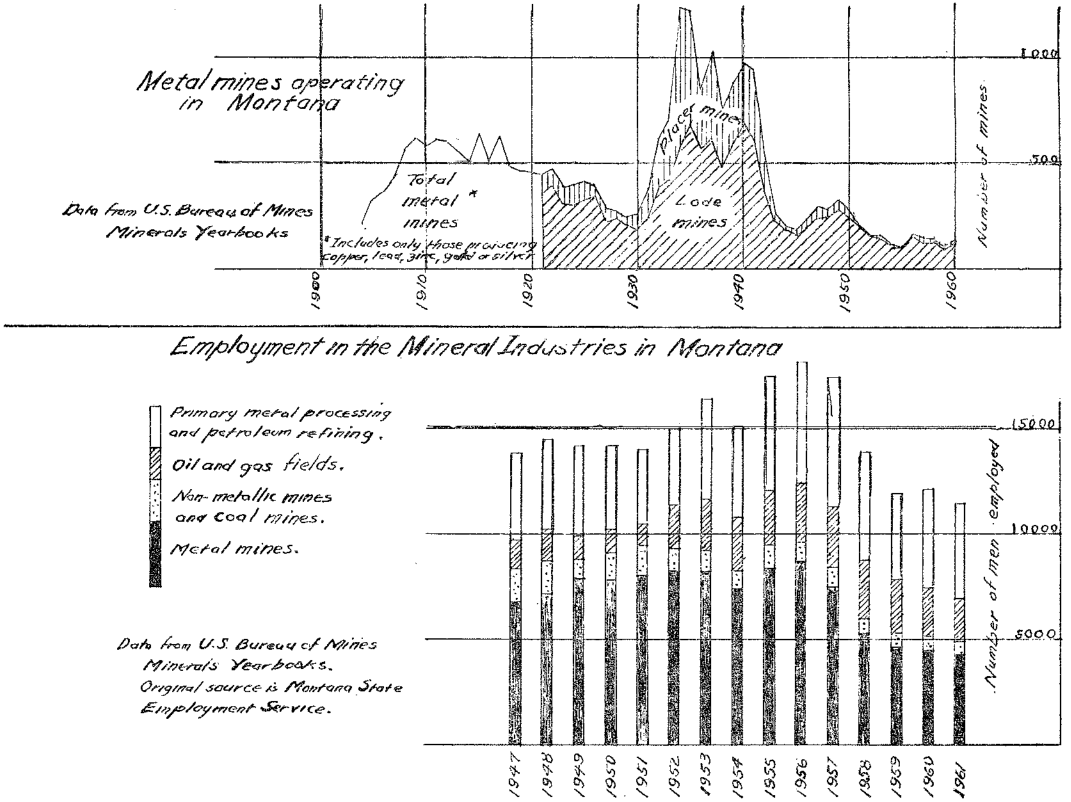


FIGURE 2.—Metal mines operating in Montana, and employment in the mineral industries in Montana.

in the past few years (fig. 1), ore reserves at Butte are said to be at an alltime high, and there appears to be some indication of increasing activity in mineral exploration within the State. Consequently, the immediate future can be viewed with at least moderate optimism. In the longer range view, prospects seem brighter. With increasing populations and improved standards of living, both at home and abroad, the metals and minerals that Montana can produce are likely to be urgently needed.

GEOLOGY

(By U. M. Sahinen, Montana Bureau of Mines and Geology, and C. E. Erdmann, A. E. Weissenborn, and P. L. Weis, U.S. Geological Survey)

INTRODUCTION

Montana is separable physiographically into three distinct, roughly parallel, northwestward-trending regions. Each comprises about one-third of the State, and the distinctive character of each is strongly influenced by the stratigraphy and structure of the underlying rocks. The distribution of these rocks is shown in figure 3 [1] (Perry, 1962). This has been generalized from a map that has been published by the U.S. Geological Survey in cooperation with the Montana Bureau of Mines and Geology (1955).

TOPOGRAPHY

The western third of Montana forms the eastern part of the Northern Rocky Mountains (Fenneman, 1931, pl. I, province 19; ch. V, pp. 183–224). This province is characterized by deeply dissected mountain uplands, separated by intermontane basins. These mountains have been carved by erosion from rocks that have been uplifted and in many places faulted and folded. Alden (1953) has recently described their surface features and glacial sculpturing. The southern half of this western mountain region has been invaded extensively by granitoid igneous rocks, the two principal bodies being the Idaho batholith south of Missoula and the Boulder batholith between Helena and Butte (Billingsley, 1916) (fig. 4).[1] Volcanic activity in this region has resulted in lava flows, and beds of agglomerate and tuff, as well as small intrusive bodies.

The eastern border of the Northern Rocky Mountains is marked by a 10- to 30-mile-wide strip, known as the Disturbed Belt (fig. 5),[1] that is distinguished by severe deformation in consequence of overthrust faulting. The topographic transition from the bold Rocky Mountain Front to the Great Plains Province, or Missouri Plateau (Fenneman, 1931, pl. I, provinces 13a, 13b; pp. 61–66), takes place over a short distance across the Disturbed Belt.

Most of the processes that contributed to the formation of the majestic western ranges also have been active in the Great Plains province of Montana, the principal differences being that the major components of diastrophism have been mostly vertical rather than tangential and were somewhat later in time. The result is a series of isolated mountain ranges that break the monotony of the seemingly endless plains. Some are formed as a result of block faulting; others by the intrusion of igneous stocks or laccolithic masses; still others are the remnants of volcanic piles. Some are simply broad welts without much topographic relief, but all are separated by gently inclined beds.

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[1] **NOTE.—Figure indicated appears as a folded map at the rear of this document.**

The eastern third of the State is devoid of mountains and, except along the west flank of the Cedar Creek anticline south of Glendive, the strata are nearly flat-lying (fig. 5). The surface features of the middle and eastern parts of Montana have been described in detail by Alden (1932).

STRATIGRAPHY

PRECAMBRIAN ROCKS

The Precambrian rocks of Montana may be divided into two units, an older pre-Belt unit of metamorphic and intrusive rocks and a thick overlying unit of sedimentary rocks known as the Belt series.

PRE-BELT METAMORPHIC AND INTRUSIVE ROCKS

The rocks of this unit are exceedingly old and constitute the so-called basement complex. Their principal areas of exposure in Montana are in the southern part of the State between Dillon and Livingston and between Livingston and Red Lodge. Other exposures of smaller extent occur in the Little Belt Mountains around Neihart and in the core of the Little Rocky Mountains south of Harlem. As shown by scattered drill holes, this ancient terrane also underlies much of the Plains area at depth.

Several groups of these highly metamorphosed rocks are known, the best exposed being the Pony and Cherry Creek groups and the Stillwater complex. The first two consist of marine sediments which were complexly folded, metamorphosed, and intruded by diabasic, gabbroic, and granitic igneous rocks before the deposition of the sedimentary rocks of the overlying Belt series (Tansley, et al., 1933; Heinrich and Rabbitt, 1960; Reid, 1957). The Stillwater complex of ultrabasic igneous rocks is exposed over a wide area in Park, Stillwater, and Sweet Grass Counties. Radioactive age measurements on three pre-Beltian rocks indicated ages of 1,690 million and 2,540 million years for these rocks (Hayden and Wehrenberg, 1959, pp. 1778–79).

Much of northwest Montana is occupied by rocks of the Belt series (Ross, 1959; Ross, in press), a sedimentary sequence of shallow-water marine origin 35,000 to 50,000 feet thick, that rests with great unconformity on the crystalline rocks below, and is in turn overlain by beds of Middle Cambrian age. Deposition took place in a broad, slowly sinking structural trough whose eastern margin in Montana extended roughly southeast from Glacier Park to the Big Snowy Mountains in the central part of the State, and from there southwest through Three Forks, Whitehall, the Highland Mountains, and Armstead.

Regional low-grade metamorphism has altered the original sedimentary rocks—sandstone, silty shale, and carbonates—to quartzite, argillite, and impure dolomite. They are divided stratigraphically into four units which are, from oldest to youngest: the pre-Ravalli rocks, the Ravalli, the Piegan, and the Missoula groups (Ross, 1959, p. 17). Sills, dikes, and lava flows of Precambrian Age are present locally. On the basis of radioactivity measurements of two specimens of pitch-blende from the Sunshine Mine, Coeur d'Alene district, Idaho, which is in strata correlative with the Ravalli group of Montana, Eckelmann and Kulp (1957, pp. 1129, 1130) concluded that the uranium mineralization occurred about 1,190 million years ago. The rocks that enclose the uranium minerals must therefore be still older (Wallace and others, 1960, p. 25).

PALEOZOIC ROCKS

Strata of Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian age comprise the Paleozoic era, which in Montana had an original thickness of approximately 10,000 feet. Rocks of this era, which is estimated to have had a duration of about 335 million years, have been deposited extensively over Montana (Sloss, 1950, pp. 423–451). Today, except for small isolated remnants, Paleozoic rocks have been completely removed by erosion west of longitude 113°40′, or the meridian through a point about 16 miles east of Missoula. East of this line Paleozoic rocks are exposed in upturned belts along the Rocky Mountain front, surround the cores of the larger mountain masses of southwest Montana as well as some of those out on the Plains, and generally are in the subsurface wherever younger rocks are present.

This distribution has been outlined on a series of preliminary paleogeographic maps by Perry (1962, pp. 23–27); and the stratigraphic nomenclature of the various series, groups, and formations is given in further detail for nine separate areas in a chart which is included here through the courtesy of the Montana Oil and Gas Commission (fig. 6).[1] The stratigraphic names of the various formations in this chart may not in every case follow the customary usage of the U.S. Geological Survey. Practically all Paleozoic units shown are of marine origin. Dolomite and limestone are the preponderant rock types, although shale, siltstone, sandstone, and evaporites (gypsum, anhydrite, and salt) also are present. The vertical shading in the chart represents strata that are absent either because of nondeposition or because of subsequent uplift and erosion. Such breaks represent unconformities of various kinds, some of which are regional in extent. These unconformities are in places of economic significance because of the influence they may have had on the migration and accumulation of petroleum and natural gas.

MESOZOIC ROCKS

Sedimentary formations of Mesozoic age with an aggregate thickness of about 5,000 feet crop out over about 55 percent of the area of Montana, chiefly in the central and eastern part of the State, where they have been brought to the surface on the northern end of the Black Hills uplift and the elongate Cedar Creek anticline. In western Montana limited exposures occur in belts adjacent to Paleozoic rocks in scattered mountainous areas. Deposition was continuous during most of the Jurassic and Cretaceous Periods, but in some areas much or even all of the Triassic strata is missing, the absence of these beds marking a great unconformity that separates the Mesozoic from the Paleozoic system over much of Montana (fig. 6).

The Mesozoic era, which had a duration of about 155 million years, is characterized by the deposition of both continental (terrestrial) and marine rocks. The Upper Cretaceous rocks in particular consist of a sequence of thick alternating wedges of marine and continental strata.

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Shale is the most abundant Mesozoic rock of marine origin, with sandstone next. Marine limestone is conspicuous in the Jurassic system. The terrestrial strata are chiefly mudstone, siltstone, and sandstone, with minor fresh-water limestone.

The Mesozoic era culminated in a period of major mountain building, accompanied by volcanism, that persisted into the early part of the Tertiary period, the entire interval constituting the rather ill-defined Laramide Revolution. A thick sequence of tuffs and andesitic flows interbedded with continental sediments was laid down in the Boulder batholith area, in the Livingston area, and elsewhere. The granitic intrusives such as the Idaho batholith in Idaho and western Ravalli County, Mont., and the Boulder batholith and Tobacco Root batholith in central-western Montana, and others were emplaced during this period of diastrophism. Most of the metalliferous ore deposits of the State are associated with these granitic intrusive rocks and were formed approximately at the same time.

CENOZOIC ROCKS

Tertiary system.—Throughout the Cenozoic, which is estimated to have had a duration of 60 or 65 millions, streams and rivers were reinvigorated by the Late Cretaceous-early Tertiary orogeny of the Northern Rocky Mountains. Vertical uplifts or tilting that may still be in progress swept great floods of rock waste over the Eastern Plains region of Montana and into deep structural basins and valleys within the mountains in the western part of the State. The original aggregate thickness of this continental detritus is difficult to estimate because of more or less continuous erosion and redeposition. Along the mountain front, however, and in some intermontane valleys, the order of thickness may have been as much as 4,000 to 6,000 feet, thinning to 3,500 to 4,000 feet in eastern Montana. Now more or less consolidated, these sediments comprise the Tertiary system which is subdivided into the Paleocene, Eocene, Oligocene, Miocene, and Pliocene epochs. At no one place in Montana, however, was deposition continuous. Except for a few formational units of early Paleocene age which have been inserted to mark the top of the Mesozoic, the Tertiary system has been omitted from the correlation chart (fig. 6) for thus far no indigenous oil or gas has been found in rocks of that age in Montana.

Rocks of Paleocene age are distributed widely over the eastern Montana Plains (fig. 3) where they comprise the Fort Union formation which, in ascending order, consists of the Tullock, Lebo, and Tongue River members. The Wasatch formation of Eocene age consists of soft, variegated mudstone with minor beds of stream conglomerate, but has been almost completely stripped off by erosion. Its former extent, however, is indicated by remnants preserved in small down-faulted blocks in the vicinity of the Bearpaw Mountains. These remnants have been of immense assistance in the geologic dating of the volcanic rocks of that detached uplift.

Rocks of Oligocene and Miocene age are rare on the Eastern Plains, occurring only as small, thin outliers on the highest major stream divides, or as caps on isolated buttes. On the other hand, in western Montana thick sections of Oligocene and Miocene rocks, commonly referred to as "lakebeds," are well preserved in the fill of the intermontane valleys. Each is more or less a distinct unit, depending upon local environment. The valley sediments of western Montana, therefore, are highly variable sequences that involve mudstone, siltstone, and claystone, much of which may be tuffaceous, yet also contain thin interbeds of bentonite or crystal tuff, and more rarely, layers of diatomaceous earth. Other rock types prevalent are units of fissile bituminous shale, thin seams of impure coal, thick accumulations of stream conglomerate, and fine- to coarse-textured fanglomerate. Rocks of Paleocene age seem to be absent, and beds of proved Eocene age are uncommon. The youngest Tertiary formation on the Eastern Plains is the Flaxville formation, which probably is of Miocene or Pliocene age, but which may range from late Miocene into earliest Pleistocene. Most of the deposits are remnants of thin sheets of quartzite stream gravel derived from the Belt series that rest on high-level erosion surfaces or pediments. In the vicinity of the mountain ranges on the Plains, however, the Flaxville formation consists largely of local material from the uplift.

QUATERNARY SYSTEM

Pleistocene series.—At least twice during the Pleistocene epoch, which is considered to have had a duration of about 1 million years, the northern part of the Missouri Plateau (Fenneman, 1931, pl. I, province 13a) has been the terminal area of continental ice sheets. Earlier ice sheets may also have extended into extreme northeastern Montana. Western Montana likewise has undergone extensive glaciation both from continental and from Alpine glaciers. Glacial deposits abound where the country formerly was covered by ice, and they vary in origin from simple boulder-clay or till in the ground moraine, which is most prevalent, through terminal moraines, kames, and eskers formed by melt water at ice contacts, to fluvioglacial outwash aprons and glacial lakebed clay and silt. The spectacular alpine scenery of western Montana is the result of glaciation, and the stream pattern, waterpower potential, and suitability of the land for agriculture—all have been profoundly affected by glacial activity.

RECENT SERIES

Alluvium.—Alluvium consists of mud, sand, silt, gravel, reworked soil, or other detrital deposition by running water during Recent geologic time. Extensive accumulations make the flood plains along streams, where further concentration and sorting have formed low-level deposits of gravel and sand.

STRUCTURE

Geologic structures in Montana can be considered in the same threefold areal subdivisions as were topography and stratigraphy.

In eastern Montana structures, like topography, are subdued. Layered rocks in the plains area are flat-lying or dip gently as a result of broad, gentle flexures that form simple structures of large size. Major features, such as the Williston Basin and the Cedar Creek anticline (fig. 5) have a total structural relief of only a few hundred feet, yet extend for many tens of miles across the countryside. Many such structures are so broad and gentle that they can only be recognized by careful geologic mapping over large areas. Faults are few, and most are of relatively minor displacement. For hundreds of millions of years, no violent structural deformations occurred in the Montana Plains.

Central Montana has structures that are closely correlative with its topography. The area is predominantly one of gently dipping rocks, which underlie the plains. In a number of places, however, the rocks are domed steeply over isolated mountain ranges of considerable size. Topographic and structural relief in these ranges are both measured in thousands of feet. Some of the ranges, as the Big Snowy Range, formed by vertical uplift alone, and are surrounded by steeply tilted, but otherwise comparatively undeformed rocks. Elsewhere, as in the Bearpaw and Pryor Mountains, faulting has complicated the structural picture. Some of the ranges were domed by igneous activity: the Little Rocky and Crazy Mountains are examples of mountains with laccolithic cores. In those, a variety of complex structures exist, in response to both overall folding and local disruption of the preexisting rocks by the intrusives. Faults are more numerous and of greater displacement in the plains of central Montana than they are farther east; they, like the folds, represent a transition zone between the east and west.

The Disturbed Belt marks the eastern edge of the complex and intensely deformed western third of the State. The belt itself is a complicated system of thrust faults, in places with compound thrust plates piled on top of one another. Elsewhere, as on the Lewis overthrust at the east edge of Glacier National Park, it is a single thrust sheet with at least 40 miles of horizontal displacement (Ross, 1959, p. 102). West of the Disturbed Belt are a system of linear mountain ranges and large intervening structural basins that show a great variety of structural features. Folds range from broad and open to steep, overturned, and to complex multiple systems formed through successive periods of movement in different directions. They range in size from great arches many miles across to intricate contortions on a microscopic scale. Faults are equally abundant and varied. Thrusts, normal faults, reverse faults, and strike-slip faults are known, and like the folds, they show a wide range in size and displacement. Some of the range front faults in southwestern Montana show evidence of comparatively recent movement, and the 1959 earthquake in Madison Valley indicates continued structural activity in at least part of the area through the present.

Unlike individual structures in central and eastern Montana, some of the structures in western Montana are segments of features that are continental or subcontinental in scope. The Disturbed Belt is a part of a structural system that marks the front of the Rocky Mountains for hundreds of miles north into Canada. The Lewis and Clark overthrust line cuts across parts of three States, and has been traced west into eastern Washington. One segment of the line is represented by the Osburn Fault, which in western Montana has a horizontal displacement of at least 12 miles (Wallace and others, 1960).

Igneous activity has had a marked effect on the structures of the area. Intrusives range in size from the Idaho batholith, one of the largest in North America, to small dikes, sills, plugs, and related intrusive bodies, some only a few inches in length. Associated structures are equally varied. They include profound deformation of surrounding rocks in places, and in some instances large masses of igneous rocks appear to have acted as buttresses that resisted deformation caused by later rock movements.

The nature of the structures of Montana, their variety and distribution, have an important bearing on the fuel and mineral resources of the State. Complex structures in areas that also contain igneous rocks are a favorable environment for mineralization, particularly for metallic minerals. Areas containing thick deposits of Paleozoic and Mesozoic sedimentary rocks that have been gently folded and domed are favorable for the discovery of oil and gas. Thus structure, like stratigraphy, must be understood in order to properly understand the distribution of natural resources in Montana.

Economic Geology

The three parts into which Montana can be divided differ markedly in the mineral resources which are found therein. These differences are directly related to differences in the geology and structure of the underlying rocks which have been discussed in the preceding pages.

The metalliferous ore deposits of the State—and especially those of gold, silver, copper, lead, zinc, and tungsten—in most cases are closely associated with igneous intrusive rocks of intermediate to acidic composition, particularly those that were intruded in late Mesozoic or early Tertiary time. The ore deposits are found both in the intrusive and the invaded rocks, and most are related to fractures or other types of deformation. The host rocks may be of any age from Precambrian to Tertiary and may be of either sedimentary, igneous, or metamorphic origin. The sedimentary or volcanic rocks that were formed after the intrusive rocks were emplaced and that in places cover them contain few workable deposits.

Intrusive granitic bodies of late Cretaceous-early Tertiary age such as the Idaho batholith, the Boulder batholith, and the Tobacco Root batholith are prevalent in the mountainous western third of the State (fig. 4). The concentration of metalliferous ore deposits in western Montana in and around these bodies and smaller satellite stocks is very striking (see maps in chapters on "Gold"; "Silver, Zinc, and Lead"; and "Tungsten") and accounts for the great mineral productivity of this part of the State.

In southwestern Montana deposits of talc, corundum, iron ore, graphite, sillimanite, and kyanite are found in Precambrian rocks of the Cherry Creek Group, and large deposits of chromite are found in the Precambrian Stillwater Complex in Stillwater and Sweet Grass Counties. In the western third of Montana sedimentary rocks of Paleozoic and Mesozoic age are actual or potential sources of phosphate rock, limestone, silica, crushed and dimension stone, clays, and other industrial minerals. Some bentonite has been mined from highly altered beds of volcanic ash in Tertiary sediments in intermontane basins. Oil and gas have not been found to date in this part of the State.

In central Montana metalliferous ore deposits have been mined in the Little Rocky Mountains, the North Moccasin Mountains, the Judith Mountains, the Little Belt Mountains, and other isolated ranges. As in western Montana, the deposits almost invariably are closely associated with granitic intrusive rocks of late Cretaceous or early Tertiary age.

Central Montana, however, is better known for the production of petroleum and natural gas. Such structures as the Cat Creek anticline, the Kevin-Sunburst dome, the Sweet Grass arch, and many others have been highly productive. In central Montana, Mesozoic sandstones are important reservoir rocks for the accumulation of petroleum and natural gas. Some Paleozoic formations have also been productive. Some Cretaceous sandstone, for example the third Cat Creek sand at the base of the Kootenai formation, the Virgelle sandstone member of the Eagle sandstone, and the Fox Hill sandstone, are valuable ground water aquifers—an important asset in a semiarid region. The Kootenai formation also in places provides clay suitable for brick and tile. Coal deposits underlie much of central Montana, most of the coal in the area being either in beds of Jurassic or late Cretaceous age.

No metalliferous ore deposits are present in the eastern third of the State, but this area contains over 90 percent of Montana's extensive coal reserves. The coal is in the Fort Union formation of Paleocene age and is especially widespread in the uppermost or Tongue River member. The eastern region also produces petroleum, principally from the west end of the highly productive Williston Basin and from the Cedar Creek anticline. In this area most of the petroleum production is from Paleozoic rocks, although some gas is derived from Cretaceous formations. Bentonite is mined from beds of Cretaceous age in Carter County.

In summary, in western Montana igneous, sedimentary, and metamorphic rocks are present, and geologic structures are complex. The region is dominantly a metalliferous province but has large resources of many nonmetallic minerals. In central Montana, igneous and metamorphic rocks are much less abundant. Geologic structures are simple to complex. The resources of the area are chiefly petroleum, natural gas, coal, and some metals. The variety of nonmetallic resources is less than in western Montana. Eastern Montana is a sedimentary terrane. Geologic structures are simple and subdued. Mineral resources are chiefly petroleum, coal, and natural gas. Nonmetallic resources are chiefly clay, bentonite, and sand and gravel.

The above is a highly generalized and very incomplete description of Montana's resources of minerals and fuels, but it shows how different these resources are from one part of the State to another and how closely they are related to the geology and structure of the underlying rocks. A more detailed summary of the resources on a commodity-by-commodity basis is presented in the ensuing chapters.

SELECTED REFERENCES

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174, 133 p.

——— 1953, Physiography and glacial geology of western Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 231, 200 p.

Billingsley, Paul, 1916, The Boulder batholith of Montana: Am. Inst. Mining Engineers Trans., v. 51, pp. 31–56.

Chace, F. M., 1947, Metallic mineral deposits of Montana: U.S. Geol. Survey Missouri Basin Studies Map 16.

Eckelmann, W. R., and Kulp, J. L., 1957, Uranium-lead method of age determination, pt. 2: North American Localities: Geol. Soc. America Bull., v. 68, no. 9, September 1957, pp. 1117–1140.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co., Inc., 534 p.

Hayden, R. J., and Wehrenberg, J. P., 1959, Potassium-argon dating in western Montana (abs.): Geol. Soc. America Bull., v. 70, no. 12, pt. 2, December 1959, pp. 1778–1779.

Heinrich, E. W., and Rabbitt, J. C., 1960, Pre-Beltian geology of the Cherry Creek and Ruby Mountains areas, southwestern Montana: Montana Bur. Mines and Geology Mem. 38, 40 p.

Merewether, E. A., 1960, Geologic map of the igneous and metamorphic rocks of Montana showing locations of uranium deposits: U.S. Geol. Survey Misc. Geol. Inv. Map I–311.

Perry, E. S., 1962, Montana in the geologic past: Montana Bur. Mines and Geology Bull. 26, 78 p.

Ross, C. P., The classification and character of the Belt Series in northwest Montana: U.S. Geol. Survey Prof. Paper 346 (in press).

——— 1959, Geology of Glacier National Park and the Flathead region, northwestern Montana: U.S. Geol. Survey Prof. Paper 296, 125 p.

Ross, C. P., Andrews, D. A., and Witkind, I. J., 1955, Geologic map of Montana, scale 1:500,000, 2 sheets: U.S. Geol. Survey.

Sloss, L. L., 1950, Paleozoic sedimentation in Montana area: Am. Inst. Petroleum Geologists Bull., v. 34, no. 3, March 1950, pp. 423–451.

Reid, R. R., 1957, Bedrock geology of the north end of the Tobacco Root Mountains, Madison County, Montana: Montana Bur. Mines and Geology Mem. 36, 25 p.

Tansley, Wilfred, Schafer, P. A., and Hart, L. H., 1933, A geological reconnaissance of the Tobacco Root Mountains, Madison County, Mont.: Montana Bur. Mines and Geology Mem. 9, 57 p.

Wallace, R. E., Griggs, A. B., Campbell, A. B., and Hobbs, S. W., 1960, Tectonic setting of the Coeur d' Alene district, Idaho: U.S. Geol. Survey Prof. Paper 400-B, pp. 25–27.

MINERAL FUEL RESOURCES

INTRODUCTION

(By C. E. Erdmann, U.S. Geological Survey, Great Falls, Mont.)

Mineral fuels consist of petroleum, natural gas, oil shale, and coal, and will be considered briefly in that order in this chapter. In recent years, mineral fuels, taken as a group, have accounted for over 40 percent of the value of all minerals produced in Montana. So that this may appear in proper perspective, the money value of the basic components of the raw-material economy of the State for 1961 are outlined below:

Agriculture:	
Crops	$185, 281, 000
Livestock (ranching)	222, 065, 000
Government payments	15, 640, 000
Total	422, 986, 000
Minerals:	
Petroleum	74, 795, 000
Natural gas	2, 509, 000
Coal	1, 207, 000
Total	78, 511, 000
All other minerals	104, 843, 000
Total minerals	183, 354, 000
Lumber:	
Unfinished logs	37, 000, 000
Stumpage	7, 000, 000
Total	44, 000, 000
Grand total value of raw materials	650, 340, 000

NOTE.—Information on agriculture has been supplied by the Bureau of Business and Economic Research, Montana State University, Missoula; mineral data is from "The Mineral Industry of Montana for 1960," U.S. Bureau of Mines; and information on lumber is from the U.S. Forest Service through the Montana State Planning Board, Helena.

All minerals, therefore, make about 28 percent of the total value of the raw materials, and mineral fuels alone about 12 percent.

Further analysis of the mineral contribution reveals that petroleum supplies about 40.8 percent of the total value of the mineral products; natural gas, 1.4 percent; and coal 0.7 percent for a total of about 42.8 percent of the State's mineral income. Restated in terms of energy consumption, excluding water power, during 1957 petroleum contributed 59.2 percent; natural gas, 35.7 percent; and coal, 5.1 percent (Independent Petroleum Association of America, 1959, p. 88).

OUTLINE HISTORY OF OIL AND GAS DEVELOPMENT

(By Charles E. Erdmann, U.S. Geological Survey, Great Falls, Mont.)

INTRODUCTION

The classical pattern of petroleum exploration in virgin territory is for the first tests to be made in the vicinity of natural surface indications of oil and gas, if any have been found. Unusual combinations of geologic conditions are required for the development of these surface features, and their occurrence is transient and infrequent. Their value, however, is that they provide tangible evidence of the local presence of hydrocarbons, thereby raising hopes that commercial accumulations may be found underground. The analogy with surface discovery of inorganic minerals is obvious: both require bold and enterprising spirits if the usually costly and difficult adventure of development is to be undertaken. Because they are few in number, they are soon exploited, and this first stage of exploration is of short duration; but the often amateurish effort frequently clothes it with many colorful and dramatic incidents. If no significant discoveries result, and they seldom do, drilling on easily recognized geologic features such as anticlines and domes may follow with more or less delay. If drilling depths are shallow, as they are in some of the older fields in Montana, this second stage may mark the heyday of the small independent operator.

By the time the obvious surface structures have been recognized and evaluated, a more mature third stage has appeared in which search for subsurface structures and porous beds and stratigraphic traps is carried on by the sophisticated techniques of geophysical prospecting and study of formation samples or subsurface stratigraphy. Other later stages may involve deeper drilling, secondary recovery techniques and, finally, abandonment. Initially, each stage may appear in order. No firm line between them exists, however, for if the petroleum industry is to prosper, new discoveries must succeed abandonments. Review of the history of oil and gas development in Montana indicates close adherence to this pattern, which will be the outline for this chapter.

EXPLORATIONS ON SURFACE INDICATIONS, 1889–1910

The exact number of oil and gas seepages in Montana is not known with certainty, but probably there are not more than 15 or 20, and some of them have become inactive since they were discovered. Several of them have been known for many years, and were responsible for the pioneer oil excitement. The first of record was noticed August 10, 1864, by members of an immigrant train crossing the northeast flank of the Pryor Mountains on the Bozeman Trail, as a scum of heavy oil on a stagnant pool of water. In this instance the immediate practical application was for axle grease for the wagons. No drilling development followed, and even the report was not made for many years. Furthermore, no rediscovery seems to have been reported. The exact location, therefore, is not known, other than it was northwest of Beauvais Creek toward the East Fork of Pryor Creek Divide. A likely possibility, however, is that it was on some intermittent upper tributary of Woody Creek in T. 4 S., R. 28 E., Big Horn County, near where that drainage was crossed by the Bozeman Trail.

Roscoe seep.—The first oil seep to be drilled in Montana was the occurrence of heavy black oil or asphalt near the southeast corner NE¼SE¼ sec. 32, T. 6 S., R. 18 E., Carbon County, about 5½ miles south of the old Roscoe post office. Date of discovery and name of the original locator are not known. In the late 1880's, however, the area was acquired by Thomas Cruse, who had found the famous Drumlummon lode near Marysville in 1876. The location of the first test, Thomas Cruse well No. 1, was about 650 feet northwest of the seep, and was completed and abandoned in 1889 as a dry hole in the Judith River formation at a total depth of 1,100 feet. Insofar as known, this was the first organized attempt to discover oil by drilling in Montana. Undeterred by failure, Cruse continued operations in the vicinity of the seep during 1890 and drilled eight more dry holes that ranged in depth from 600 to 800 feet before giving up; and even then he retained ownership of the tract. Others continued to be intrigued by the possibilities, and additional tests were made in 1909, 1931, and even as late as 1947, but without success.

Kintla Lake area.—Impressive amounts of pale-yellow, high-gravity (44° A.P.I.) oil issue from surficial deposits at the Sage Creek seeps in southeastern British Columbia, about 8 miles north of the international boundary at the northwest corner of Glacier National Park. The controlling structural feature appears to be a normal fault of great magnitude that can be projected into Montana where it is called the Roosevelt Fault. In 1892 active seepages of oil and gas were discovered in Montana near the northeast end of Lower Kintla Lake, not far east of where the lake crosses the trace of the fault. An organization called the Butte Oil Co. posted a location notice on August 10, 1900. Drilling began late in October 1901, the well location being NW¼NW¼NW¼ sec. 18, T. 37 N., R. 20 W., Flathead County. Late in 1902 work was suspended temporarily, with the hole at a depth of 1,450 feet in very hard "black limestone and iron," probably one of the units of the Belt Series. A significant incident was the discovery of gas at a depth of 720 feet, which is said to have burned with a 4-foot flame. As will appear later, however, this was not the first discovery of gas in Montana by drilling.

In late June 1902 the Kintla Lake Oil Co. of Kalispell commenced operations at their No. 1 well, approximately in the center of NE¼ sec. 12, T. 36 N., R. 22 W.; and in 1903 a second test is said to have been located toward the center of the section. Both are situated on Tertiary "lake beds" on the left bank of the North Fork of Flathead River. The No. 1 well was drilled to 1,290 feet at least, and the No. 2 to about 1,000 feet. Traces of oil and gas were reported from each, but both were abandoned as dry holes. The circumstances that led to these tests are not known, but they may have been drilled on seeps in the "lake beds" that emerged along faults cutting deep-seated Mesozoic formations.

Another old venture, for which there is good authority but no log or operational information, is the Southwest Kootenai Land Oil Co. test on Kintla Creek about 3 miles above Upper Kintla Lake. This locality is approximately in the north center of sec. 8, T. 37 N., R. 19 W., Flathead County, in a deep glaciated valley about 1.5 miles west of the Continental Divide. Drilling is reported to have commenced March 8, 1906, and continued to a depth of at least 600 feet. The bedrock formation at the surface is the Siyeh limestone of the Belt series, which is not known to contain indigenous hydrocarbons. In all probability, therefore, the location was made on the basis of seeps or irridescent films of oil whose origin is more or less identical with those on Cameron Brook at Oil City, Alberta, a short distance northeast across the divide, where petroleum exploration had been going on since 1901.

Swiftcurrent Creek.—Sustained efforts to develop oil by drilling on or near obscure surface indications of petroleum and natural gas in Swiftcurrent Creek Valley throughout the 9-year period before the district became incorporated into Glacier National Park in 1910 resulted in seven tests that give it the nominal distinction of being the first oil and gas field in Montana and the only locality in the State where drilling on seepages proved successful. Credit for the recognition of these showings appears to be divided between two men: Frank M. Stevenson identified certain exposures of Upper Cretaceous marine shale as "oil shale" in the summer of 1901; and Samuel D. Somes, prospecting near where Sherburne Dam is located, observed small pools of oil in irregularities on freshly broken shale and limestone on the floor of his adit in late February or early March 1902.

Within a short time, 52 oil claims were located under the placer mining law. Companies were organized and consolidated as claims were exchanged for shares, the ultimate operator being the Swift Current Oil, Land & Power Co. The first derrick was erected in November 1902, approximately at the center of SW¼NE¼ sec. 4, T. 36 N., R. 15 W., unsurveyed, on the Lakeside placer claim which had been located by Stevenson. Drilling began in 1903, when the hole was taken to a depth of 430 feet, with a showing of oil; but was abandoned because of inability to shut off water. The rig was then skidded 30 feet west, and work begun on location 1–A, which was completed as an oil well at a total depth of about 550 feet during the summer of 1905. Oil from this well was displayed at the State fair at Helena in the fall of 1905, where the company was awarded a diploma for "the first producing oil well in the State of Montana." Operations were terminated through lack of finances in 1907, and the properties turned over to Stevenson. In the meantime, however, one other oil well, with an initial capacity of about 20 barrels per day, by bailing, and 2 dry holes had been completed.

M. D. Cassidy, locator of a neighboring claim to the east, became aroused by this activity and organized the Cassidy-Swiftcurrent Oil Co., date of incorporation being July 15, 1905. Approximate location of the first test by this company, which may have been near a gas seep recognized by Cassidy, was in the extreme northeast corner of NW¼NW¼NE¼ sec. 3, T. 35 N., R. 15 W., unsurveyed, near the center of St. Louis Placer No. 1. Drilling began in 1907, and continued at intervals into 1909 to a total depth of about 2,800 feet, where the tools were lost. Natural gas was reported from depths of 430, 1,900, and 2,800 feet, the initial shut-in pressure being about 250 p.s.i. No measurement of volume seems to have been taken, but, upon being ignited, the gas flow from a 1-inch pipe is said to have burned to a height between 15 and 20 feet. Cassidy piped the gas into his house, where it was used for heating and lighting until 1914 when the flow ceased, due to caving in the hole. The Cassidy-Swiftcurrent well No. 1, therefore, has the distinction of being the first producing gas well in Montana, even though it had only one customer.

Boulder Creek.—Following Somes' discovery of oil in his adit on Swiftcurrent Creek in 1902, other prospects in the dark Upper Cretaceous shale (Marias River formation) were examined for traces of oil. Favorable indications were reported in an abandoned working on Boulder Creek, probably somewhere near the center NW¼ sec. 27, T. 35 N., R. 15 W., unsurveyed, Glacier (formerly Teton) County. Recognition of this seep may have contributed to the organization of the Swift Current-Boulder Oil Co., which soon acquired substantial acreage south of Swiftcurrent Creek. Drilling commenced in July 1904, the approximate site being south of the center SE¼SE¼, sec. 11, T. 35 N., R. 15 W., on the left bank of Boulder Creek. A show of gas was reported in shale at a depth of about 1,750 feet, and a show of oil "of a superior quality" was found in the top of a sandstone at a depth of 2,010 feet on July 8, 1905. Operations were abandoned at this depth in the spring of 1906.

No seepage has been reported from this locality, and the reasoning that led to its selection is unknown. It may be surmised, however, that observation of oil seeping from freshly broken shale in various prospects, which had been driven in search of copper, originated the conjecture that any shale section might yield oil in commercial amounts, particularly in the subsurface. This, of course, is not generally true. The shale seeps are restricted to certain comparatively thin units of bituminous rock (as in the Cone calcareous member of the Marias River shale) that have been subjected to severe dynamic stress through being overridden by the plate of the Lewis overthrust fault, or related diastrophism in the Disturbed Belt. The associated pressure and frictional heat resulted in local destructive distillation to produce small quantities of liquid petroleum. Nevertheless, faith in the idea seems to have been responsible for several other test wells along the mountain front, whose locations are otherwise difficult to account for. Among them are those at Lubec, Midvale, Two Medicine Valley, St. Mary Valley, and Belly River Valley, all of which were dry holes.

This persistent run of failure naturally resulted in loss of interest, and by the close of 1907 such random drilling had come to an end. The Congress passed the act establishing Glacier National Park on May 11, 1910, thereby precluding new ventures. In the meantime, the Lakeside and New Era placer claims in the Swiftcurrent District had been patented, and the patent for the St. Louis No. 1 was pending but held in abeyance as Sherburne Lake project of the Bureau of Reclamation approached realization. More or less ineffectual efforts to recondition the two small oil wells and the gas well persisted for several years, but terminated in the summer of 1919 when the locations were flooded by water rising behind the Sherburne Lake Dam.

No other drilling on surface indications has been recorded in Montana.

EXPLORATION OF SURFACE STRUCTURES, 1890–1950

Many anticlines and domes are expressed in rocks at the surface on the Montana Plains. The precise number is unknown, but more than 475 areas, fields, and structures have been named. Approximately 185 fields and structures have been named on the latest edition of the "Structure Contour Map of the Montana Plains" (U.S. Geological

Survey, 1955); but only about 100 areas have been proved to contain oil or gas in commercial quantities, and not all are anticlines. The producing fields are shown on figure 7,[1] and their names are keyed by number to the list in table 1. This chart, it should be noted, is not a complete list of Montana oilfields, nor does it include the major gas fields. Some repetition of names results from listing more than one pool or producing formation on the same feature, as at Cat Creek. Actually, about 20 fields produce from more than 1 formation. On the other hand, Cedar Creek anticline is not named, although 11 of the 20 pools or fields on that anticline are listed. If fields that produce both gas and oil from different formations were listed the number would be increased by 15, or from 89 to 104.

The surface structures exhibit wide variation in size, shape, and amount of structural relief. Bowdoin dome in Phillips and Valley Counties, and Kevin-Sunburst dome in northern Toole County occupy hundreds of square miles, and are so broad and have such comparatively low relief that the domical structures cannot be visualized on the ground. The Cedar Creek anticline in the southeastern part of the State is more than 100 miles in length, but the narrow Pierre shale inlier along the crest is only a few miles in width. Flat Coulee dome north of the Sweetgrass Hills, on the other hand, is contained within a single square mile. Elk Basin anticline, which straddles the Montana-Wyoming boundary, or Milk River anticline in the Disturbed Belt on the Blackfeet Indian Reservation, are nearly perfect folds in which both flanks can be observed from a single viewpoint.

Not too many years had elapsed since the pronouncement of the anticlinal theory of oil and gas accumulation and, in the absence of an oil seep, a sharp or closely folded anticline seemed the next best feature on which to drill. Recognition of a completely exposed fold in rock requires so little imagination or interpretative skill that when they were observed they were reported, often by sheepherders, and the more evident small folds were described as "sheepherder structures." Insofar as known, the first test in Montana to be located on an anticline, presumably in accordance with the anticlinal or structural theory, was the R. O. Morse well No. 1, NE¼ sec. 4, T. 6 S., R. 18 E., Carbon County, on the northeast flank of Roscoe dome, a "sheepherder structure" toward the west end of the Nye-Bowler lineament. It may be, however, that Morse had been attracted to the area by Cruse's exploration around the Roscoe seep a few miles south, which was then in progress. Drilling equipment in 1890 was very inadequate for a complete test of the structure and the operation was abandoned as a dry hole in the upper part of the Colorado Group at a total depth of 1,100 feet. Subsequent drilling has proved the structure to be dry into the upper part of the Cambrian series at a total depth of 5,923 feet. Chance plays an important part in exploration for oil and gas, and the first discovery of natural gas by drilling on the Montana Plains came unexpectedly in 1893 a few miles southwest of Havre at Fort Assiniboine in a water well in the upper sandstone unit of the Eagle sandstone. Although not of commercial volume, the find directed attention to the possibility of gas development out on the plains, but this did not follow for nearly 20 years.

The principal technique for the recognition and discovery of geologic structure at the surface is systematic areal and structural mapping.

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

STATE OF MONTANA—SUMMARY OF PRODUCING OIL FIELDS

LINE NO.	FIELD (OR POOL)	COUNTY	YEAR DISCOVERED	PRODUCTION FORMATION	APPROX. DEPTH	A.P.I. GRAVITY	VOLUME FACTOR	AVG. NET PAY FT.	AVG. POROSITY %	AVG. CONNATE WATER %	ORIGINAL OIL IN PLACE BBLS/ACRE	PRODUCTIVE AREA 1-1-62 ACRES	ORIGINAL OIL IN PLACE 1000 BBLS.	ESTIMATED RECOVERY FACTOR &		ORIGINAL PRIMARY RESERVES 1000 BBLS.	ORIGINAL SECONDARY RESERVES 1000 BBLS.	TOTAL ORIGINAL RESERVES 1000 BBLS.	CUMULATIVE PRODUCTION 1-1-62 1000 BBLS.	REMAINING RESERVES 1-1-62 1000 BBLS.	1961 PRODUCTION		ORIGINAL RECOVERABLE RESERVES		LINE NO.
														PRIMARY	SECONDARY						TOTAL BBLS.	AVG. DAILY BOPD.	BBLS./ ACRE	BBLS. ACRE/FT.	
1	Ash Creek	Big Horn	1952	Shannon (U. Cret.)	4500	34	1.05	14	22	35	14,855	160	2,377	26	--	618	--	618	339	279	28,163	77	3,865	276	1
2	Bannatyne	Teton	1927	Swift (U. Jr.)	1450	27	1.05	39	15	43	24,635	170	4,188	5	--	209	--	209	132	77	17,948	49	1,230	32	2
3	Bears Den	Liberty	1924	Sunburst (L. Cret.)	2300	39	1.08	20	12	35	11,205	200	2,241	15	--	336	--	336	150	186	46,411	127	1,680	84	3
4	Belfry	Carbon	1958	Fuson (L. Cret.)	9844	38	1.60	20	11.25	17	9,049	160	1,448	10	--	145	--	145	72	73	15,375	42	906	46	4
5	Benrud	Roosevelt	1961	Nisku (Dev.)	7650	43	1.41	22	16	30	13,550	160	2,168	17	--	369	--	369	4	365	4,277	300	2,304	105	5
6	Big Wall	Musselshell	1948	Tyler (U. Miss.)	3000	31	1.02	22	17	40	17,066	1,140	19,455	30	--	5,837	--	6,869	4,069	2,800	400,075	1,098	5,120	233	6
7	Big Wall	Musselshell	1953	Amsden (L. Penn.)	2500	19	1.01	17	16	35	13,647	280	3,821	27	--	1,032	--						3,685	217	7
8	Blackfoot	Glacier	1955	Madison (Miss.)	3550	25	1.15	8	14	40	4,533	480	2,176	20	--	435	--	844	516	328	101,257	277	906	113	8
9	Blackfoot	Glacier	1955	Cut Bank (L. Cret.)	3500	30	1.11	15	15	35	10,221	160	1,635	25	--	409	--						2,556	170	9
10	Border	Toole	1929	Cut Bank (L. Cret.)	2400	31	1.08	22	15	30	16,593	340	5,641	23	--	1,297	--	1,297	1,097	200	9,975	27	3,816	173	10
11	Bowes	Blaine	1949	Sawtooth (M. Jur.)	3250	19	1.02	37	11.7	31	22,719	5,282	120,000	5.75	9.92	6,900	5,000	11,900	5,877	6,023	240,899	660	1,306	35	11
12	Bredette-North	Roosevelt, Daniels	1956	Charles (Miss.)	6720	38	1.24	24	6	53	4,234	640	2,710	20	--	542	--	542	475	67	11,157	31	847	35	12
13	Brorson	Richland	1954	Mission Canyon (Miss.)	9750	32	1.50	92	4	40	11,419	320	3,654	15	--	548	--	548	376	172	25,634	70	1,712	19	13
14	Cabin Creek	Fallon	1953	Siluro-Ordovician	8400	33	1.20	50	13	30	29,415	6,660	195,904	18	28	35,263	19,000	59,636	23,595	36,041	4,197,696	11,500	5,294	106	14
15	Cabin Creek	Fallon	1956	Mission Canyon (Miss.)	7300	33	1.13	25	11	30	13,215	2,259	29,852	18	--	5,373	--						2,378	95	15
16	Cat Creek (Antelope-Mosby)	Petroleum, Garfield	1920	Kootenai (L. Cret.)	1225	52	1.10	10	21	19	11,997	200	2,399	22	--	528	--	25,656	19,809	5,847	239,050	654	2,640	264	16
17	Cat Creek (West Dome)	Petroleum, Garfield	1920	Kootenai (L. Cret.)	1100	52	1.10	51	21	19	61,186	920	56,291	30	35	16,887	3,000						18,351	360	17
18	Cat Creek	Petroleum, Garfield	1945	Morrison (U. Jur.)	1600	52	1.10	6	22	40	5,586	120	670	32	--	214	--						1,783	297	18
19	Cat Creek	Petroleum, Garfield	1945	Swift (U. Jur.)	1750	52	1.10	25	18	40	19,043	880	16,758	30	--	5,027	--						5,713	229	19
20	Clarks Fork-North	Carbon	1956	Lakota (L. Cret.)	8940	50	1.92	19	19	39	8,896	400	3,558	35	--	1,245	--	1,245	991	254	22,967	63	3,112	165	20
21	Cupton	Fallon	1955	Red River (U. Ord.)	9800	33	1.50	33	13	35	14,421	160	2,307	7	--	161	--	161	124	37	12,674	35	1,000	30	21
22	Cut Bank	Glacier, Toole	1932	Kootenai (L. Cret.)	2900	38	1.15	16	15	35	10,542	54,250	571,903	19	23	108,661	26,500	142,645	93,322	49,323	2,035,633	5,577	2,003	125	22
23	Cut Bank	Glacier, Toole	1945	Madison (Miss.)	3000	39	1.10	10	14	30	6,912	4,010	27,717	27	--	7,484	--						1,866	187	23
24	Deer Creek	Dawson	1952	Red River (U. Ord.)	9850	42	1.21	112	6.7	35	31,270	480	15,010	8	--	1,201	--	1,973	1,578	395	211,979	581	2,502	22	24
25	Deer Creek	Dawson	1952	Interlake (Sil.)	9440	42	1.22	71	7	35	20,543	400	8,217	9.4	--	772	--						1,930	27	25
26	Delphia	Musselshell	1957	Amsden (L. Penn.)	6290	35	1.15	12	6.5	30	3,683	440	1,621	20	--	324	--	324	221	103	12,946	34	736	61	26
27	Dry Creek	Carbon	1930	Greybull (L. Cret.)	5600	52	1.60	12	12	22	5,445	1,700	9,257	20	--	1,851	--	5,342	3,937	1,405	24,049	66	1,089	91	27
28	Dry Creek	Carbon	1932	Pryor (L. Cret.)	5800	52	1.20	30	12	25	17,455	1,000	17,455	20	--	3,491	--						3,491	116	28
29	Dwyer	Sheridan	1960	Mission Canyon (Miss.)	8000	33	1.12	30	11.8	55	11,033	2,560	28,244	15	--	4,236	--	4,236	536	3,700	443,682	1,216	1,654	55	29
30	Elk Basin	Carbon	1915	Frontier (U. Cret.)	1200	45	1.16	30	21	20	33,702	120	4,044	--	54	--	2,184	107,359	35,976	71,383	2,645,611	7,248	--	--	30
31	Elk Basin	Carbon	1942	Embar-Tensleep (Perm.-Penn.)	5000	29	1.16	124	10.5	10	78,596	1,376	108,144	--	57	--	61,642						--	--	31
32	Elk Basin	Carbon	1946	Madison (Miss.)	5300	28	1.12	224	12	9	168,975	920	155,474	21.5	28	33,427	10,106						36,333	162	32
33	Elk Basin-Northwest	Carbon	1947	Frontier (U. Cret.)	3375	47	1.29	28	19	30	22,448	120	2,694	25	38	680	340	1,020	692	328	22,576	62	5,616	200	33
34	Elk Basin-Northwest	Carbon	1947	Madison (Miss.)	6215	35	1.08	124	11.6	20	83,036	382	31,720	19	--	6,027	--	6,027	880	5,147	21,865	60	15,777	70	34
35	Flat Coulee	Liberty	1933	Swift (U. Jur.)	2900	39	1.10	22	22	40	20,500	80	1,640	15	--	246	--	246	36	210	4,568	13	3,080	140	35
36	Frannie	Carbon	1928	Tensleep (Penn.)	2700	27	1.02	29	19	16	35,272	80	2,822	25	--	706	--	706	485	221	22,949	63	8,830	305	36
37	Gage	Musselshell	1943	Amsden (L. Penn.)	6000	34	1.07	18	10	48	6,786	320	2,172	25	--	543	--	543	512	31	8,703	24	1,696	94	37
38	Gas City	Dawson	1955	Red River (U. Ord.)	8700	38	1.28	25	9	35	8,836	2,105	18,599	18	--	3,348	--	3,348	1,854	1,494	442,645	1,212	1,590	64	38
39	Glendive	Dawson	1952	Stony Mtn.-Red River (U. Ord.)	8700	38	1.25	147	6.5	35	38,544	1,040	40,086	20	--	8,017	--	8,017	5,305	2,712	519,126	1,422	7,708	52	39
40	Graben Coulee	Glacier	1961	Sunburst (L. Cret.)	2775	34	1.10	12	16	35	8,784	40	351	15	--	53	--	53	--	53	--	--	1,320	110	40
41	Gypsy Basin	Pondera	1958	Madison (Miss.)	3150	--	--	--	--	--	--	160	300	25	--	75	--	75	29	46	10,275	28	469	--	41
42	Hibbard	Rosebud	1960	Amsden (L. Penn.)	4810	31	1.05	12	15	35	8,644	40	346	30	--	104	--	104	83	21	35,970	99	3,005	250	42
43	Ivanhoe	Musselshell	1960	Amsden (L. Penn.)	3600	32	1.08	9	17	40	6,594	110	725	35	--	254	--	254	2,051	1,365	470,333	1,288	2,309	265	43
44	Ivanhoe	Musselshell	1953	Morrison (U. Jur.)	2800	30	1.08	10	15	35	7,004	80	560	18	--	100	--	100					1,250	125	44
45	Ivanhoe	Musselshell	1956	Tyler (U. Miss.)	4050	33	1.08	29	15	20	24,997	490	12,248	25	--	3,062	--	3,062					6,249	215	45
46	Keg Coulee	Musselshell	1960	Tyler (U. Miss.)	4550	32	1.15	30	15	25	23,071	920	21,225	20	--	4,245	--	4,245	932	3,313	698,882	1,914	4,614	154	46
47	Kevin-Sunburst	Toole	1922	Madison (Miss.)	1500	32	1.08	6.5	20	35	6,053	40,205	243,361	30	--	73,008	--	73,008	66,189	6,819	666,303	1,825	1,816	280	47
48	Laurel	Yellowstone	1961	Dakota (L. Cret.)	850	54	1.10	8	10	30	3,352	10	40	15	--	6	--	6	--	6	--	--	592	74	48
49	Little Beaver	Fallon	1952	Red River (U. Ord.)	8300	29	1.16	37	12	35	19,299	2,220	42,843	15	--	6,426	--	6,426	1,774	4,652	447,645	1,226	2,895	78	49
50	Little Beaver-East	Fallon	1954	Red River (U. Ord.)	8300	30	1.20	29	12.5	35	15,233	1,020	15,537	15	--	2,485	--	2,485	868	1,617	336,410	922	2,436	84	50
51	Lookout Butte	Fallon	1961	Siluro-Ordovician	8500	33	1.25	45	15	50	20,925	160	3,348	15	--	504	--	504	--	504	--	--	3,150	70	51
52	Melstone	Musselshell	1948	Tyler (U. Miss.)	4250	34	1.09	25	12	30	14,945	360	5,380	25	--	1,291	--	1,291	1,241	50	45,631	125	3,586	143	52
53	Monarch	Fallon	1958	Siluro-Ordovician	8400	32	1.10	31	7	35	9,946	2,240	22,279	15	--	3,342	--	3,564	884	2,680	372,047	1,020	1,492	48	53
54	Monarch	Fallon	1961	Mission Canyon (Miss.)	6710	34	1.05	17	19	60	9,238	160	1,478	15	--	222	--						1,387	82	54
55	Mosser	Yellowstone	1936	Dakota (L. Cret.)	1000	22	1.01	15.4	23.6	30	19,540	96	1,876	18	--	338	--	338	163	175	5,046	14	3,521	229	55
56	Outlook	Sheridan	1956	Siluro-Devonian	9000	38	1.12	20	8	30	7,758	1,760	13,652	25	--	3,413	--	3,571	2,542	1,029	589,295	1,614	1,939	97	56
57	Outlook	Sheridan	1957	Red River (U. Ord.)	9900	33	1.21	35	8	45	9,875	80	790	20	--	158	--						1,975	56	57
58	Pennel	Fallon	1955	Siluro-Ordovician	8800	33	1.14	40	11	35	19,548	4,640	90,702	10	--	9,070	--	10,443	3,688	6,755	871,688	2,388	1,954	49	58
59	Pennel	Fallon	1957	Mission Canyon (Miss.)	7000	31	1.10	38	3.4	30	6,378	720	4,592	15	--	688	--						963	25	59
60	Pennel	Fallon	1960	Lodgepole (Miss.)	7500	36	1.13	30	8	35	10,709	320	3,426	20	--	685	--						2,141	71	60
61	Pine	Dawson, Wibaux, Fallon, Prairie	1952	Siluro-Ordovician	8400	34	1.17	32	11.5	30	17,078	14,568	248,792	20	26	49,758	14,800	64,558	31,483	33,075	5,212,260	14,280	3,415	107	61
62	Pondera	Pondera, Teton	1927	Madison (Miss.)	2100	34	1.20	15	16	31	10,706	5,560	59,525	35	--	20,834	--	20,834	15,597	5,237	494,429	1,355	3,747	250	62
63	Pondera Coulee	Teton	1961	Madison (Miss.)	2000	34	1.10	15	15	30	11,100	40	444	20	--	89	--	89	3	86	3,043	8	2,220	148	63
64	Poplar	Roosevelt	1952	Charles-Mission Canyon (Miss.)	5550	40	1.10	25	11	30	13,576	17,909	243,133	30	--	72,940	--	72,940	29,570	43,370	2,365,321	6,480	4,073	163	64
65	Poplar-Northwest	Roosevelt	1952	Charles-Mission Canyon (Miss.)	6260	40	1.10	16	10.3	45	6,393	400	2,557	15	--	384	--	384	262	122	21,316	58	960	60	65
66	Ragged Point	Musselshell	1947	Kibbey (U. Miss.)	4400	33	1.09	28	11	40	13,152	140	1,841	27	--	497	--	1,558	1,104	454	138,134	378	3,550	128	66
67	Ragged Point	Musselshell	1956	Tyler (U. Miss.)	3580	32	1.10	14	14.5	35	9,307	380	3,537	30	--	1,061	--						2,785	199	67
68	Reagan	Glacier	1947	Madison (Miss.)	3700	38	1.10	11	12	30	6,517	3,050	19,877	30	33	5,963	600	6,563	2,745	3,818	152,764	419	1,950	178	68
69	Red Creek	Glacier	1958	Cut Bank (L. Cret.)	2600	33	1.17	20	19.2	25	19,094	840	16,041	25	--	4,010	--	5,923	873	5,050	333,636	914	4,780	242	69
70	Red Creek	Glacier	1958	Madison (Miss.)	2750	28	1.10	18	13	30	11,553	920	10,628	18	--	1,913	--						2,080	115	70
71	Redstone	Sheridan	1958	Winnipegosis (Dev.)	9400	39	1.10	10	7	45	2,715	80	217	20	--	53	--	53	29	24	12,565	35	662	66	71
72	Repeat	Carter	1956	Red River (U. Ord.)	8610	23	1.02	25	10	30	13,258	160	2,122	16	--	340	--	340	196	144	26,472	73	4,250	85	72
73	Richey	Dawson, McCone	1951	Charles (Miss.)	7000	39	1.20	25	8	30	9,028	940	8,486	23	--	1,952	--	1,952	1,580	372	126,654	347	2,080	83	73
74	Richey-Southwest	McCone	1952	Interlake (Sil.)	9200	48	1.37	21	9	35	6,955	300	2,087	35	--	730	--	955	656	299	57,175	157	2,435	116	74
75	Richey-Southwest	McCone	1952	Dawson Bay (Dev.)	9130	48	1.37	6	9	30	2,140	300	642	35	--	225	--						750	125	75
76	Sand Creek	Dawson	1959	Interlake (Sil.)	8950	39	1.30	20	10	40	7,160	680	4,869	20	--	974	--	1,167	667	500	178,901	490	1,432	72	76
77	Sand Creek	Dawson	1959	Red River (U. Ord.)	9400	39	1.30	15	10	40	5,370	240	1,289	15	--	193	--						804	54	77
78	Seven Mile	Dawson	1961	Siluro-Ordovician	9632	42	1.25	30	12	40	13,380	160	2,141	15	--	321	--	321	16	305	15,816	225	2,006	67	78
79	Sidney	Richland	1958	Mission Canyon (Miss.)	9000	32	1.50	30	4	40	3,724	320	1,191	20	--	238	--	238	61	177	22,144	61	744	25	79
80	Snyder	Big Horn	1952	Tensleep (Penn.)	4550	21	1.16	12	20	35	10,431	149	1,554	20	--	311	--	311	285	26	19,139	52	2,085	174	80
81	Soap Creek	Big Horn	1920	Tensleep-Amsden-Madison	1900	20	1.05	20	15	35	14,488	410	5,940	22	--	1,307	--	1,307	1,071	236	67,498	185	3,185	159	81
82	Stensvad	Musselshell, Rosebud	1958	Tyler (U. Miss.)	5500	33	1.17	26.25	14	20	19,465	1,382	26,900	25	--	6,725	--	6,725	4,596	2,129	1,549,353	4,245	4,860	185	82
83	Sumatra	Rosebud	1949	Tyler (U. Miss.)	4500	32	1.16	30	18.5	35	24,123	3,720	89,737	25	--	22,434	--	22,801	13,800	9,001	2,462,839	6,748	6,030	201	83
84	Sumatra	Rosebud	1955	Amsden (L. Penn.)	4000	29	1.10	8	20	35	7,335	200	1,467	25	--	367	--						1,835	229	84
85	Tule Creek	Roosevelt	1960	Nisku (Dev.)	7700	46	1.41	25	15	30	14,541	1,120	16,286	25	--	4,072	--	4,072	512	3,560	480,298	1,315	3,635	145	85
86	Whitlash	Liberty	1927	(L. Cret.)	1400	38	1.13	15	16	20	13,180	1,130	14,893	15	--	2,234	--	2,234	1,266	968	92,099	252	1,980	132	86
87	Wills Creek	Fallon	1957	Siluro-Ordovician	8500	32	1.20	70	12	25	40,730	960	39,100	20	--	7,820	--	7,820	1,407	6,413	403,769	1,106	8,150	116	87
88	Wolf Springs	Yellowstone	1955	Amsden (L. Penn.)	6200	30	1.07	10.5	5.75	23	3,356	4,330	14,531	22	--	3,197	--	3,197	2,797	400	304,933	835	738	70	88
89	Woodrow	Dawson	1952	Charles (Miss.)	7800	32	1.45	19	17.3	35	11,433	160	1,829	10	--	183	--	183	161	22	21,331	58	1,143	60	89
	TOTALS												2,852,787			585,043	143,172	728,215	394,141	334,074	30,901,304	84,660			

Courtesy of Montana Oil and Gas Conservation Commission, An. Rev., Vol. 6, 1961.

TABLE 1.—State of Montana—Summary of producing oil fields.

94765 O - 63 (Face p. 28)

More than 20 oil and gas fields have been found directly by this method, which is still very useful even though most of the conspicuous surface structures have been found. Many of the features that localized these pools were found and first described by the U.S. Geological Survey as its program of mineral classification developed following the withdrawal of the public lands for that purpose in 1906, notably the Cedar Creek anticline, Poplar dome, and the Sweetgrass arch.

The structures found by surface methods on which oil and gas have been discovered are listed here in order of that discovery, the year in parentheses following the name of the field; usually, however, the presence of structure had been known for some time: Gas City dome, Cedar Creek anticline (1913); Havre gas field (1914), abandoned; Elk Basin (1915); Boxelder gas field (1916); Bowdoin gas field (1917); Devils Basin (1919); Cat Creek (1920); Soap Creek (1921); Kevin-Sunburst (1922); Sherard (Birch Creek) gas field, 1923, shut in; Bears Den (1924); Lake Basin (1924); Bowes gas field (1926); Bannatyne (1927); Flat Coulee (1928); Frannie (1928); Dry Creek (1929); Mosser (1937); Gage (1943); Kicking Horse gas field (1943), abandoned; Plevna (1946); Ragged Point (1948); Golden dome (1953); Ivanhoe (1953).

Several of these discoveries proved the presence of commercial volumes of oil and gas, hitherto something that had been lacking, over wide areas on the plains; and the impact of others, especially in rocks of Paleozoic age, did much to sustain the hope when interest was low that many more were to come.

The first commercial flow of natural gas in eastern Montana was found in Gas City dome at the north end of the Cedar Creek anticline in 1913. Drilling was initiated by the Mid-West Oil Co., in November 1912, at their No. 1 well, W½NE¼NE¼ sec. 20, T. 14 N., R. 55 E., Dawson County; but with change of ownership the hole was completed by the Eastern Montana Oil & Gas Co., which developed the field. Drilling continued to a total depth of 2,710 feet, which was reached in April 1914. In the meantime a flow of 500,000 cubic feet of gas per day with a shut-in pressure of 220 pounds per square inch, and some water had been found between depths of 730 and 745 feet in a sand assigned arbitrarily to the Judith River formation of late Cretaceous age. Beginning in 1915 gas for domestic use was supplied to the city of Glendive 10 miles north on Yellowstone River. Peak of production was reached in the fall of 1917, when the combined flow of eight wells amounted to about 10,600,000 cubic feet of gas per month. The field was abandoned in 1925; but other gas production followed along the anticline to the south.

The year 1915 also was notable for the discovery of oil in the Elk Basin anticline in Carbon County, Mont., and Park County, Wyo., a structure which had first been noticed some 10 years previously by the U.S. Geological Survey. The discovery well, which produced from the Torchlight sand in the Frontier formation of Late Cretaceous age at depths of 1,335 to 1,402 feet, was in Wyoming; and about 87 percent of the productive acreage fell in that State. The remaining northern portion of about 120 acres became Montana's first producing oilfield. The beginning, therefore, was rather small. Four oil wells were drilled in 1915, but were not brought into production until shipping facilities became available the following summer. Two more oil wells and one dry hole were drilled in 1916, and production for the last 6 months of the year totaled 44,917 barrels, with a value of $44,019.

Excellent examples of the possible rewards of deeper drilling are furnished by the development of the Elk Basin field. Natural gas was found in the Cloverly formation of Early Cretaceous age, about 1,150 feet below the Torchlight, in 1922, but is now largely exhausted. The major discovery, however, did not come until December 1942 when oil was found in the Tensleep sandstone of Pennsylvanian age at a depth of about 4,500 feet. This reservoir proved to have about 215 feet of saturation, the thickest producing section of any field in the State. About 1,375 acres, or 27.5 percent, of this Tensleep pool are in Montana. Finally, in 1946 oil was found in the underlying Madison limestone of Mississippian age.

The immediate effect of the original Elk Basin discovery was to direct attention to the Montana extension of the Bighorn Basin and the country to the north where interest still centered on sharp-dip structures; but prospecting from 1916 until late in 1919 resulted only in dry holes. One of the more prophetic of these efforts was the first test on the large Woman's Pocket anticline, which was spudded May 6, 1916, by the Foster Oil Co., in C SW¼NE¼ sec. 15, T. 8 N., R. 20 E., Golden Valley County, and completed in June 1918 by the Tri City Oil Co., at a total depth of 2,215 feet. The trace of oil from 1,550 to 1,565 feet, and two other minor shows at greater depth, were the first evidence in Montana of the occurrence of petroleum in the Kootenai formation of Early Cretaceous age, and provided the incentive for further exploration of that unit. Although still far short of commercial production, more tangible encouragement soon came from the Devil's Basin anticline to the northeast where the Van Duzen Oil Co. well No. 1 spudded in the Kootenai formation in NE¼SW¼NW¼ sec. 24, T. 11 N., R. 24 E., Musselshell County, on August 10, 1919. Drilling continued to a total depth of 2,031 feet on November 6, 1919. In the meantime, 10 or 12 barrels of oil had been found in a 6-foot limestone at a depth of 1,167 feet in what was then called the Quadrant Formation. Later stratigraphic work has shown the producing horizon to be in the Heath Formation of the Big Snowy Group, which is late Mississippian in age. The trend of exploration continued toward the northeast, and the next structure to be drilled was Mosby dome on the elongate Cat Creek anticline. Here the Franz Oil Corp. well No. 1 (now Continental Oil Co., Charles 1–A) was started December 18, 1919, and was completed at a total depth of 1,034 feet as a 30-barrel oil well on February 20, 1920. Production was obtained from the second Cat Creek sand of the Kootenai formation between the depths of 998 to 1,014 feet. This famous discovery well, which in itself never produced more than 700 barrels of oil, resulted in the development of the Cat Creek field, the first important field in the State and, for its size, still one of the most productive and most profitable that has been found. Exploitation was rapid. A peak production of 2,080,826 barrels per year was reached at the close of 1923; and cumulative production to the close of 1961 has amounted to nearly 20 million barrels of oil.

The discovery of the Cat Creek field definitely carried the struggling Montana petroleum industry beyond the nascent stage; but national significance was not achieved until the oil discovery on the Kevin-

Sunburst dome in Toole County 2 years later. Actually, there were two oil discoveries; and the short interval between them compounded the excitement they raised. Oil was found first on April 14, 1922, when the Gordon Campbell, Kevin Syndicate-A. Goeddertz well No. 1, NE¼NE¼NE¼ sec. 16, T. 35 N., R. 3 W., was completed as a 20-barrel producer between depths of 1,770 to 1,790 feet in the basal sandstone unit of the Sawtooth formation of Middle Jurassic age and the eroded, weathered upper surface of the Mission Canyon formation of the Madison group of Mississippian age, which are separated by an unconformity. In the second, oil was found June 5, 1922, when the Ohio-Sunburst Oil Cos.'-R. Davey well No. 1, SE¼SE¼SW¼ sec. 24, T. 36 N., R. 2 W., was completed as a 150-barrel producer between depths of 1,535 to 1,564 feet in a sand at the base of the Kootenai formation, which later was named the Sunburst sand. These discoveries, together with the great size of the dome, first production from rocks of Paleozoic age in the Rocky Mountain region, shallow drilling, and demonstrated production from a low-dip structure, attracted immediate attention from major oil companies and numerous small operators. The result was remarkable and, by the close of 1922, out of a total of 42 completed tests the field could show 22 producing oil wells, 4 wells producing both oil and gas, 3 Sunburst sand gas wells, 3 dry holes with shows of oil and gas, and 8 dry holes, with 11 tests drilling. Peak oil production of 6,457,217 barrels of oil was reached rapidly in 1926, since when it has been declining; and cumulative production to the close of 1961 has amounted to 66,189,439 barrels, which is not far from its estimated ultimate production of 70 million barrels of oil. Peak production of natural gas of 4,950 million cubic feet was reached in 1928, with cumulative production of about 78 billion cubic feet through 1961. With the development of the Kevin-Sunburst field the petroleum industry became firmly established.

Partial indications of structure at perhaps as many more fields or pools as were found by areal or structural geology also were found by surface mapping but development did not follow until the geologic structure of the concealed part or the deeper structure had been worked out by geophysical methods; usually detailed seismograph surveys. In some districts, for example, the Poplar or Cedar Creek anticline, the interval between recognition of surface structure and the seismic surveys that led to deep drilling has been as long as 30 to 45 years. Much of this delay occurred before the development of prospecting with the reflection seismograph, and these poorly exposed structures were natural testing grounds. Among the fields that have been found by this combination of methods are the following, and the list may not be complete: West Utopia (1943); North Reagan (1947); Big Wall (1948); Bowes, oil (1949); Glendive, Cedar Creek anticline (1951); Ash Creek (1952); Little Beaver, Cedar Creek anticline (1952, 1954); Marcus Snyder (1952); Poplar, East (1952); Cabin Creek, oil, Cedar Creek anticline (1953, 1956); Ash Creek, South (1954); Big Coulee (1954); Clarks Fork (1954); Little Beaver, East, Cedar Creek anticline (1954); Gas City, oil, Cedar Creek anticline (1955); Pennel, Cedar Creek anticline (1955); Pine, Cedar Creek anticline (1955); Clarks Fork, North (1956); Belfry (1958); Monarch, Cedar Creek anticline (1958). Beginning with the discovery in 1951 of oil in rocks of Ordovician age in the Glendive field at the north end of Cedar Creek anticline, the impact of this combination method on rate of discovery and oil production in eastern Montana (Williston Basin) was literally explosive, about 20 deep pools being found on Cedar Creek anticline alone. According to the records of the Montana Oil and Gas Conservation Commission, oil production in eastern Montana jumped from nothing to 56.4 percent of the total for the State for 1961, or by more than 17 million barrels (see figure 8).

SUBSURFACE EXPLORATION, 1940–60

Subsurface stratigraphy.—By the close of 1961 approximately 12,840 wells had been drilled for oil and gas in Montana. Of this number about 10,500 are field wells; for example, at that time the total number of wells in the Kevin-Sunburst field was 4,019. The remaining 2,342 tests were "wildcats," or wells drilled in search of oil and gas in unproved areas. Most of the wildcat wells were dry, those that made discoveries being included with the field wells drilled around them. All of these tests, especially the widely scattered wildcat tests, have contributed more or less information to subsurface stratigraphy such as what formations are present, the rate and direction in which they thicken or thin, lithologic changes, presence of unconformities, and data on porosity and permeability. These are the basic data for petroleum exploration. Subsurface stratigraphy seldom has been used alone in Montana, but the tendency to do so is increasing. At least seven discoveries have been credited to it during the past 10 years, and as the data increase in amount and quality so will its capability for discovery. Fields whose discovery has resulted primarily from applications of subsurface stratigraphy include the following (with year of discovery): Reagan (1941); Cut Bank, north (1945); Pondera Coulee (1951); Grandview (1952); Brady, west (1958); Stensvad (1958); Cut Bank, southwest (1959); Pondera Coulee, west (1959); Keg Coulee (1960). Discovery of the Pumpkin Creek field in 1954 is credited to both surface and subsurface mapping.

Geophysical methods.—Fields whose discovery is credited to detailed seismograph surveys, with little or no assistance from other methods, are as follows: Reagan, north (1942); Sumatra (1949); Richey (1951); Deer Creek, Cedar Creek anticline (1952); Richey, southwest (1952); Wolf Creek (1952); Brorson (1954); Fertile Prairie, east flank Cedar Creek anticline (1954); Bredette (1955); Cupton, east flank Cedar Creek anticline (1955); Wolf Springs (1955); Bredette, north (1956); Outlook (1956); Delphia (1957); Line Coulee (1957); Outlook, south (1957); Blackleaf (1958); Redstone (1958); Dwyer (1959); Tule Creek (1960). The Wolf Springs field (1955) was found by a combination of gravity and seismic methods. The increasing use of the seismic method in the last decade will be noted, and this trend is expected to continue.

Subsurface and seismic.—Fields whose discovery is credited to a combination of subsurface and seismic methods are few: Blackfoot (1955); Red Creek (1958); Gold Butte (1959); Middle Butte (1959); Sand Creek, north end Cedar Creek anticline (1959). However, their number is expected to increase as subsurface data from northeast Montana become more abundant.

RANDOM DRILLING

Random drilling is not a disciplined or technical method of oil finding. Usually the values involved are subjective, and may include simple faith, curiosity, an intuitive impression, or a hunch that a certain tract will be underlaid by oil; that the trend of discovery will be in a certain direction; a layman's misinterpretation of geologic data; or flagrant wildcat promotion. On the other hand, it may be eminently practical, such as an opportunity to test a large block of acreage for the cost of a single well. Whatever the reasons, and no matter how great the odds may be, random drilling sometimes results in discoveries that would not have been made by conventional thinking. Where drilling depths are shallow and costs relatively low this type of exploration will continue but its use is becoming more and more infrequent. Among the discoveries that have been made by random drilling are the following fields: Hardin (1913); Whitlash (1918); Berthelote (1926); Cut Bank, gasfield (1926); Devon (1926); Pondera (1927); Border-Red Coulee (1929); Brady (1943); Gypsy Basin (1958).

More systematic categories of drilling exploration include successively deeper drilling, such as that which led to the Tensleep discovery (1942) and the Madison discovery (1946) at Elk Basin. Now, however, unless oil is found at shallow depth, the major operators tend to make complete tests of the available stratigraphic section with the first exploratory well. As a method, therefore, deeper drilling is largely restricted to the older fields whose original discoveries were shallow. Stepout drilling, or simply following the trend of oil occurrence, is credited with the discovery of the Darling pool in the north part of the Cut Bank district in 1939, and the Melstone field in the central part of the State in 1948. Lastly, fields or pools have been discovered by revaluation and testing of apparently noncommercial tests, as happened in the very prolific Lander pool (1935), in the Cut Bank field, and in the Redstone field in the northeast part of the State in 1958.

PETROLEUM

(By Charles E. Erdmann, U.S. Geological Survey, Great Falls, Mont.)

The petroleum resources of Montana occur east of the Continental Divide beneath the Great Plains. This region, outlined on figure 7, page 47, is essentially the area of the "Structure Contour Map of the Montana Plains" of the U.S. Geological Survey (1955). That map covers 112,060 square miles, or about 76 percent of the State, yet does not include some 9,900 square miles of mountainous country also east of the Continental Divide southwest of Bozeman and south of Butte. The area of Montana east of the Continental Divide, therefore, is about 121,960 square miles, or nearly 83 percent of the total area of the State.

Not all of this vast country is suitable for the occurrence of hydrocarbons. Approximately 3,100 square miles are underlaid by pre-Belt crystalline and metamorphic rocks, including 60 square miles of the Stillwater igneous complex, which, along with younger igneous rocks, have never contained any oil or natural hydrocarbon gases. Another

3,300 square miles are occupied by the sedimentary rocks of the Belt series of Precambrian age, which include about 6 square miles of Purcell lava sills. Thin films of carbon in haphazard arrangement on the bedding surfaces of some of those ancient sediments have been interpreted quite properly as evidence of Precambrian life; but no inference that these rocks once contained oil and gas has ever been made, and the Belt terrane is generally regarded as nonproductive. Where the Belt rocks are involved in the Lewis overthrust fault on the east side of Glacier National Park they are underlaid by Upper Cretaceous strata that have yielded shows of oil and gas, as has been pointed out, but since this locality is now proscribed from prospecting by park regulations it is included with the Belt series as nonproductive territory. East of the Continental Divide, therefore, the total area of the Precambrian outcrop is about 6,400 square miles. Extensive areas of Cretaceous and Tertiary igneous rocks also are present. The Cretaceous igneous terrane totals about, 1,560 square miles, and can be separated roughly into 1,180 square miles of extrusive rocks, including the agglomerate member of the Livingston formation, 176 square miles of intermediate (andesitic) intrusives, and about 83 square miles of diorite and gabbro. Tertiary igneous rocks are even more abundant, totaling about 4,120 square miles. Extrusive volcanics cover 2,310 square miles, considerable areas being in the Bearpaw and Highwood Mountains out on the Plains; the Boulder batholith and broadly related stocks appear over 1,300 square miles, and the aggregate area of the smaller intrusives is about 500 square miles. It is also necessary to exclude about 1,080 square miles of Cambrian sedimentary rocks and about 530 square miles of Devonian rocks on the grounds that where these older Paleozoic strata are at the surface any hydrocarbons they may once have contained have been dissipated, and all the younger overlying beds that may once have contained oil or gas have been removed by erosion. The total area east of the Continental Divide in which prospects for oil or gas are negative is thus about 13,930 square miles.

Simple subtraction, therefore, gives about 108,000 square miles east of the Continental Divide as the region in which the stratigraphic column is generally favorable and of sufficient thickness to offer some prospect for the discovery of oil and gas. Two small districts west of the divide, 180 square miles in the valley of the North Fork of the Flathead River, and 140 square miles southwest of Marias Pass also fall in this category. By no means should they be ignored indefinitely; but they are omitted now because together they are equivalent to only about 0.3 percent of the prospective area east of the divide, which is the country that contains Montana's petroleum resources. Very little of it, however, is actually producing or has produced oil or gas, and the crux of the petroleum resource problem is the whereabouts of whatever undiscovered pools there may be. Addition of the productive areas given in table 1 gives the total area producing oil on January 1, 1962, as about 228,650 acres, or 357 square miles, which is only 0.33 percent of the favorable part of the Plains region. Estimates of the aggregate area producing natural gas come only to about 456,990 acres (710 square miles), or 0.66 percent of the Plains region. The total acreage producing oil and gas thus has a productivity index, if it may be called that, of about 1 percent.

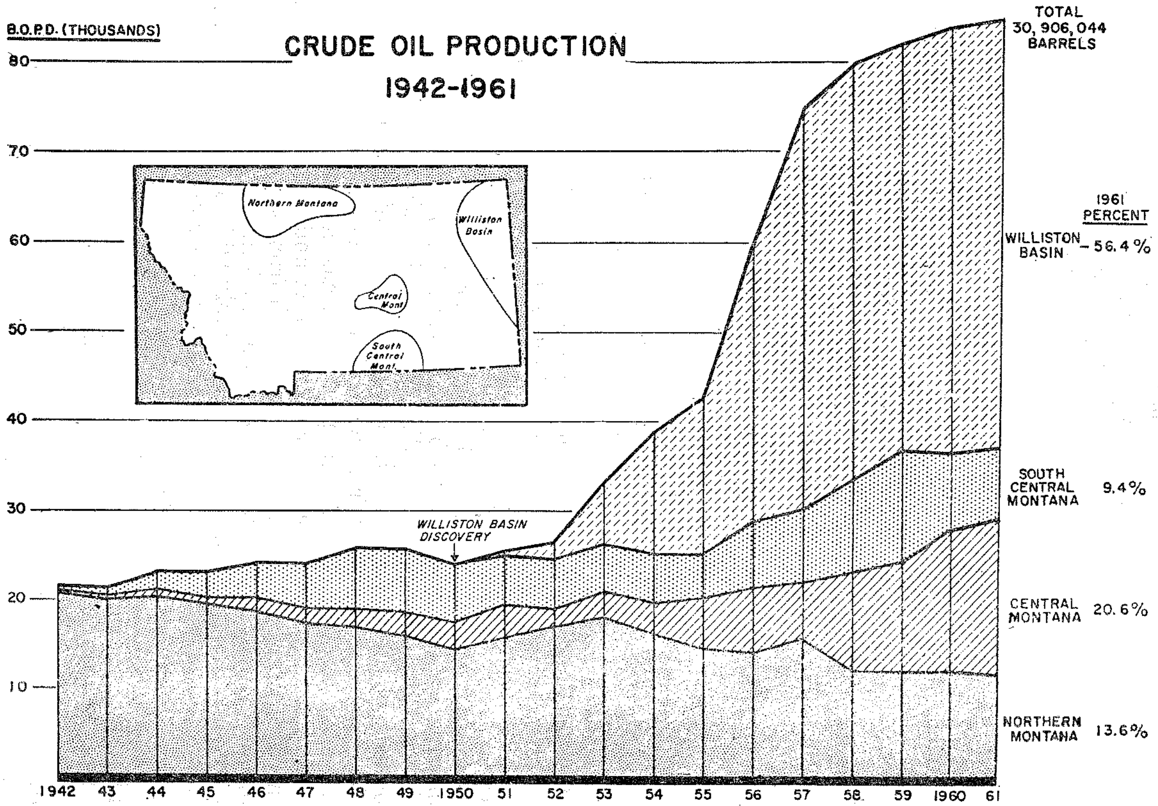
For purposes of this summary it will be convenient to consider the petroleum resources of Montana briefly from the standpoint of past discoveries, which may be subdivided further into cumulative production—which is now history, and proved reserves—or present reality, and the ultimate potential reserve or the amount of oil and gas that remains to be found and produced in the future. Many of the basic data for an appraisal of past discoveries are given in table 1. The data particularly show the very small number of major fields, the large number of small fields, the large number of fields that produce from only one horizon, and the comparative thinness of the pay zones. This is a record of past experience, however, and should not be assumed to indicate future performance, even though it may be suggestive.

Petroleum occurs in Montana in 21 geologic formations which range stratigraphically from the Red River formation of Late Ordovician age upward to the Shannon sandstone member of the Cody shale of Late Cretaceous age. The extensive range of this occurrence is brought out in the generalized stratigraphic correlation chart (fig. 6) in which the producing zones are indicated by standard oil well symbols (small black circles) together with the name of the field or fields at that horizon. The same information also is included in table 1, but the stratigraphic position and frequency of occurrence are not evident in that tabulation.

Cumulative oil production dating from the first commercial wells at Elk Basin in 1916 to the close of December 31, 1960, was about 364,400,000 barrels and had an aggregate value of about $734,200,000 (Montana Oil and Gas Conservation Commission, "Statement of Crude Oil Production, 1960"). In 1960 Montana ranked 12th in petroleum production by States, producing about 30,240,000 barrels of oil, or 1.18 percent of the U.S. total, and, at the close of that year, the State ranked 13th in proved reserves with about 267,690,000 barrels, or approximately 0.84 percent of the national total (American Petroleum Institute, 1961, p. 35). The reserve estimate for 1961 was somewhat greater, 334 million barrels (table 1), indicating extension of known fields and new field discoveries during that year. At the 1960 rate of production, which is shown graphically in figure 8, subdivided into the provinces from which it came, reserves of this magnitude would be 10 or 11 years' supply, which has been the approximate status of the national reserve for some years; and it will also be augmented substantially as time goes on by oil from secondary recovery projects of which 15 or more are now in operation. The proved petroleum reserve in Montana, therefore, probably will continue to remain at about this level for a number of years, and there need be no concern about the immediate future.

It is evident, however, that production from the older northern fields, which for more than 20 years supported the petroleum industry in the State, is falling off rapidly and unless a new major discovery is made, at the rate of decline indicated in figure 8, in 20 years the province virtually may cease to produce. This, of course, is the ultimate fate of all extractive industries, and the reason it is so necessary that new discoveries continue to be made. But, in view of the thorough exploration, it is questionable if sufficient area remains on the Sweetgrass arch in which another extensive field could occur. In the meantime the loss has been more than made up by the marked increase in production from central and south-central Montana, where the fields are numerous but small. On the other hand, the probable life

FIGURE 8



Courtesy of Montana Oil and Gas Conservation Commission, An. Rev., Vol. 6, 1961.

expectancy of the great new fields in the eastern part of the State may be as long as 20 to 30 years, and during that period many extensions and new discoveries doubtless will be made.

Estimation of the ultimate potential petroleum reserve is a very difficult matter, and no completely satisfactory method has ever been devised. According to Weeks (1958, p. 433), "The only determinants that have any general application, and which can be classified as basic today are (1) geology, and (2) experience on the broadest possible scale in what geology means in terms of oil occurrence." Some of these factors are involved in the productivity index referred to above, which is an approximate measure of probability of occurrence, and will now be considered at greater length. The real or ultimate value of this index is uncertain and can only be determined by the results of future exploration. Obviously, it does not suggest that 1 percent of any specific tract of land will yield both oil and gas; the larger the area to which it is applied and the more favorable structures that area contains, the more accurate it is likely to be. Nor does it mean that gas is more apt to be found than oil, much of the natural gas in Montana is not associated with petroleum; and it offers no clue to where a discovery will be made. Even the value of the index is subject to change and should improve (increase) with future discovery, an increment of 0.18 for oil having occurred since 1951 in consequence of the discoveries in eastern Montana. If this oil increment should continue to increase to the 1.7 percent (Pratt, 1944, pp. 67, 68) which has been reported for some of the more thoroughly explored States, the future for petroleum in Montana would indeed be bright.

Either the productivity of the sedimentary rocks in the Plains region of Montana is less than equivalent sedimentary sections in other parts of the United States that produce oil, as is suggested by the comparatively low success ratio for new field wildcats, or exploration is inadequate, which is suggested by the obviously low density of exploratory tests. Some data favor the latter interpretation, and certainly many cubic miles of rock remain undrilled. In line with this is the fact that the most thoroughly explored structural province in Montana—the Sweetgrass arch—through 1961 produced 45.6 percent of the cumulative production of the State, or about 180,732,000 barrels of crude oil. Further confirmation of the more or less direct relationship between exploration and production is now available from the country east of R. 46 E., broadly the western part of the Williston Basin province, where deep systematic drilling to Palezoic terranes has been underway only since 1950. During the first 4 years production raised so sharply (fig. 8) that it almost equaled that from the Sweetgrass arch, and exceeded it in 1955. By the close of 1961 cumulative production for eastern Montana amounted to 108,178,000 barrels, or about 27.4 percent of the total cumulative production of the State at that date, and if the current annual rate can be sustained or increased the cumulative record for the Sweetgrass arch will be exceeded in 4 or 5 years.

It should be borne in mind, however, that most of this exploration in the Williston Basin province, both in Montana and North Dakota, has been on well-defined surface structures that had been known for many years. Now that their development is established, new field discoveries must be searched for with seismic and subsurface techniques on much more obscure features and the rate of discovery may be expected to level off or even decrease. This endeavor has already begun. Brorson, Dwyer, Redstone, and Sidney, to mention only a few, are examples of fields not on obvious surface structures that have been found by seismic surveys. The comparatively recent Dwyer field, however, which has already produced about 1 million barrels of oil, seems in some way to have been localized by a major transcurrent fault. An intersection of another element of this trend, which is northeast, with the complementary Cedar Creek axis is illustrated in the Richey field. Lineaments similar to these and the many irregularities of stratigraphy, porosity, and other inherent variables that they afford, should provide many different kinds of traps for oil and gas in eastern Montana. That province, therefore, is considered to have the most favorable prospects for future discoveries of petroleum in Montana, and to contain the greater part of the ultimate potential reserve. Any estimate in specific units of production, however, would be hazardous and very subjective.

Reference has been made to the impending expenditure of the ultimate potential of the Sweetgrass arch. Ultimate potentials for central and south-central Montana, which together during 1961 contributed about 30 percent of the total production of the State, are not regarded as impressive and it seems probable that they may not equal the original recoverable reserves of the known fields. Reasons for this opinion are based on many factors that include the comparatively small area involved, its rather complete structural compartmentation, relatively high density of dry holes and the number of structures proved to be dry, time of migration and accumulation, possibility of hydrostatic flushing, productive age of known fields, absence of some of the Paleozoic formations that produce in eastern Montana, and the failure of others that are present to produce.

Some parts of the Plains region that have received little or no drilling also may have latent potentials for oil and gas. Among the larger of such areas are: the north end of the Powder River basin; the upper or outer flanks of the Crazy Mountain basin; the lower flanks of the Bearpaw arch, which are concealed by volcanics; and, on more than a statistical basis, the Disturbed Belt, whose exploration illustrates how elusive and discouraging realization of a prospect may be.

The narrow, structurally complex Disturbed Belt has an area of about 2,000 square miles in Montana, where it separates the mountains from the Plains (Sweetgrass arch), extending from the Missouri River northwest to the International Boundary, and continues on into Alberta, Canada, where it is known as the Foothills Belt. Surface indications of petroleum have been known from it since 1902. Most of the 30 tests made before 1940 were too shallow to be conclusive or even informative and all were abandoned as dry holes without shows of oil or gas except for the few on Swift Current Creek and the test on the Boulder Creek. More competent and determined exploration beginning in 1946, since when approximately the same number of tests have been made, all of them deep and to objectives known to contain oil and gas on the plains, also has been without material return. This effort has been all the more frustrating because the extension of the Belt into southern Alberta includes among other fields: Turner Valley, which to the close of 1956 had produced about 124 million barrels of high-grade (39° A.P.I.) paraffin base oil and about 1,760 million cubic feet of gas; Pincher Creek, with its literally enormous gas-condensate reserve; the more recent Waterton gas field; and, since 1960 a gas well discovery within 6 miles of the boundary. The consequences of finding an extension of this productivity in Montana would be momentous, and might add greatly to the oil and gas reserve. Exploration in the Disturbed Belt may therefore be expected to persist until a significant find has been made or accumulated geologic data indicate the probability that commercial prospects are not present. In this connection, however, it should be remembered that before success was obtained in the Alberta Foothills the exploration phase of some of its great fields was long, difficult, and expensive.

NATURAL GAS

(By Charles E. Erdmann, U.S. Geological Survey, Great Falls, Mont.)

Natural gas has been found in Montana in 40 or more fields, some of them one- or two-well pools, and perhaps 150 wildcat tests have been abandoned as dry holes with shows of gas and oil or shows of gas alone. This rather large number of occurrences, many of which will be mentioned by name later, has given rise to the belief that natural gas is abundant in Montana. Weeks (1958, p. 46) has remarked that "experience in this country (i.e., the United States) has shown that about 5,000 cubic feet of natural gas have been discovered for each barrel of liquid petroleum." At the close of 1962, in terms of this ratio, the cumulative oil production and proved petroleum reserve of Montana, respectively, should have been associated with 2.1 and 1.7 trillion cubic feet of natural gas, for a total of 3.8 trillion cubic feet, without consideration of the amount that may be contributed in the future by the development of the ultimate potential oil reserve. Although not particularly impressive as a reserve figure for so vast a country as the Plains region, 3.8 trillion cubic feet of gas provides a convenient frame of reference against which the natural gas resources of Montana may be viewed.

Information on natural gas in Montana is not so complete or systematic as the data for petroleum. Much of this shortcoming results from the early exclusive emphasis on petroleum exploration, from which gas was an incidental, unwanted byproduct with little or no market that seldom brought a price of more than 3 cents per thousand cubic feet at the casing head, if it could be sold at all. Such circumstances offered operators no encouragement to prospect for gas; and to some extent this tradition of low field prices for natural gas still prevails even though the value of the commodity is now much greater. Hence, other than the pioneer commercial gas development on Gas City Dome at the north end of Cedar Creek anticline in 1915, and at Havre in 1916, little interest was shown for 8 or 10 years. With increasing evidence of marketable reserves, however, some short lines were laid from several fields to nearby towns as that from the Kevin-Sunburst gas area to Shelby in 1923, and from Bowes field to Chinook and Havre in 1926. The first long line was built from the Kevin-Sunburst field to the city of Great Falls in 1928; and the large-diameter line from the Cut Bank district to the copper smelter at Anaconda followed in 1931. Descriptions of gas development at this stage have been given by Bartram and Erdmann (1935) and by Perry (1937).

In 1953 the American Gas Association estimated the proved recoverable natural gas reserve for the United States at about 211.5 trillion cubic feet. During that same year Casper (1953 p. 209) provided a somewhat more conservative estimate of the national reserve as about 197 trillion cubic feet at 60° F., and 14.65 pounds per square inch absolute. Only 800 billion cubic feet, or about 0.41 percent of Casper's total, were credited to Montana, with no breakdown by individual fields. This estimate has just been proved low, for at the close of 1961 it was exceeded by measured cumulative production totaling about 880 billion cubic feet which, of course, is less than the amount of gas actually withdrawn. Inclusion of the proved reserve of about 325 billion cubic feet, exclusive of the ultimate gas potential, brings the total original reserve estimate for Montana to about 1.2 trillion cubic feet, or about 2.6 trillion cubic feet less than the amount indicated on the basis of the national ratio between oil and gas production.

Reflecting new discoveries and field extensions during the past decade, current estimates of the national gas reserve are of the order of 267.7 trillion cubic feet. An approach to the probable Montana fraction of this figure from the viewpoint of Casper's ratio, which may still be valid even though the estimates on which it was determined seem to be low, gives about 1.1 trillion cubic feet, which is remarkably near the original reserve estimate of 1.2 trillion cubic feet based on cumulative production and proved reserves. Probably this is a fortuitous circumstance, for they are not strictly comparable because about 73 percent of the original reserve estimate consists of gas that has been produced and, therefore, not in the reserve. However, if that volume of gas, about 0.9 trillion cubic feet, is added to the 1.1 trillion cubic feet derived by taking 0.41 percent of the current national reserve the resulting sum is 2 trillion feet. This is about as large an ultimate recovery as can be rationalized from the incomplete data available, but it is still only about half of the 3.8 trillion cubic feet estimate that might be anticipated from national experience. This critical condition has been appreciated in the local natural gas industry for some time, and potential shortages fortunately have been averted by imports from both Wyoming and some of the fields with large reserves in southern Alberta. However, before considering these imports in greater detail, reference should be made to the geologic and geographic occurrence of natural gas in Montana.

Commercial volumes are present in 16 or 18 geologic formations which range from Late Ordovician to Late Cretaceous in age—essentially the same as that for petroleum. Most of the formations yielding large amounts are indicated in the Generalized Stratigraphic Correlation Chart (fig. 6) by standard gas well symbols (small open circles with short perpendiculars on the circumference) together with the name of the field producing from that horizon (table 2).

TABLE 2.—*Stratigraphic occurrence of natural gas in Montana*

System or series	Group	Formation	Member or sand
Upper Cretaceous	Montana	Judith River	
		Eagle sandstone	Upper part
Lower Cretaceous	Colorado		Bowdoin Phillips
		Frontier	
		Blackleaf	Bootlegger member (Bow Island) Taft Hill Glauconitic member Flood member
		Kootenai	Sunburst Third Cat Creek Lakota Cut Bank
Upper Jurassic		Morrison	
	Ellis	Swift	
		Sawtooth	Middle Basal sandstone
Upper Permian		Embar (of former usage)	
Pennsylvanian		Tensleep sandstone	
Upper and Lower Mississippian	Madison	Castle Reef dolomite	Sun River member
		Mission Canyon limestone	
Lower Mississippian		Lodgepole limestone	
Upper Devonian		Potlatch anhydrite	
Middle Silurian		Interlake (of Canada)	
Upper Ordovician	Bighorn	Red River	
		Stony Mountain	

In general, the gas from the Upper Cretaceous sands is a "dry," sweet (no hydrogen sulfide) gas high in methane (CH_4) or "marsh gas," with little or no ethane (C_2H_6). Often a few percent of nitrogen (N_2) and sometimes carbon dioxide (CO_2) are present as impurities. Gross B.t.u. content may average about 970 B.t.u. These gases do not seem to be associated with petroleum and, in some units such as the upper part of the Eagle sandstone, appear to have been derived by decomposition of carbonaceous debris. The gas from rocks of Early Cretaceous and Late Jurassic age is "wet" sweet solution gas from oil. While predominantly methane, these gases contain ethane (sometimes as much as 13 percent), propane (C_3H_8) and butane (C_4H_{10}), with percentages of nitrogen and carbon dioxide somewhat larger than in the Upper Cretaceous gas. Heat values usually run over 1,000 B.t.u. Gas from the Cut Bank sand falls in this group, and where of average composition may contain about 215 gallons of gasoline per million cubic feet, which is removed before the gas is distributed for industrial or domestic use. The gas from the older (Paleozoic) formation usually is characterized by the presence of hydrogen sulfide, which may vary from a trace to concentrations of more than 16 percent as in the Embar-Tensleep reservoir at Elk Basin, which is mentioned briefly in the chapter on Sulfur. Most of the gas in rocks of Paleozoic age is exsolution gas from petroleum. Good examples of its occurrence may be found in the Sun River member of the Castle Reef dolomite in the Reagan field, and in the Interlake, Red River, and Stony Mountain formations on Cedar Creek anticline. Gases rich in carbon dioxide and nitrogen have been found in some Devonian and Cambrian units on the Sweetgrass arch, from where they have been described by Dobbin (1935, p. 1057, 1065), and along the wedge-edge of the Ordovician system to the northeast. Small percentages of helium have been reported from the nitrogen fraction of some of these gases, but there is no evidence that the volume of the nitrogen reserve is large enough to warrant processing for helium. In contrast to these occurrences, the richest helium gas in Montana, 3.91 percent associated with 81.6 percent nitrogen (Anderson and Hinson, 1951, p. 74, 75. Index No. 678) was found in the base of the Swift Formation on the Kootenai Dome of the Car Creek anticline by the J. C. Neudigate Oil Co., Root well No. 1, sec. 28, T. 16N., R. 26E., Petroleum County. The volume of gas was small and was soon drowned out by water which caused the hole to be abandoned. This occurrence is believed to be related to deep-seated faulting associated with the development of the structure, as no helium has been reported from later penetrations of the Swift formation on other parts of the anticline.

Both gas and oil are produced in Montana in 15 fields. Gas occurs alone in 29 or 30; but 6 small pools have been exhausted, 11 are of minor importance, and only 12 actually produce gas alone. The fields that produce both gas and oil, but which do not have large separate gas areas are shown simply as oilfields on figure 7. Oil and gas fields of Montana, the index numbers in circles (also in parentheses after the names that follow) correspond to those listed in table 1. These fields are: Bears Den (3), Belfry (4), Bowes (11), Clark's Fork, north (20), Dry Creek (27, 28), Elk Basin (30 to 34), Flat Coulee (35), Gypsy Basin (41), Lake Basin (not producing), Reagan (68), Red Creek (69), Whitlash (86). A new gas well with a reported initial open-flow capacity of about 52 million cubic feet per day from the upper part of the Madison group (Sun River formation) was found during October 1962 at Gypsy Basin, improving the potential of that district. Bowes and Whitlash of this group may be considered as local major gasfields, each having production capability of a little more than 1 billion cubic feet of gas per year, but their reserves are considerably depleted and this rate may be expected to decline in the near future. Recently, however, a west extension to the Whitlash Field gaged 58 million cubic feet, improving the outlook there but the area of the extension probably will be small. In some of the other fields where the gas and oil are in the same reservoir, for example, Red Creek, the gas wells have been shut in to maintain pressure for production of oil.

The exhausted and minor gasfields either are not numbered on the map, or are not shown. The old field at Havre ceased production in 1925, and unsuccessful efforts were made to revive it between 1946 and 1950. Other small exhausted fields are Bow and Arrow, Haystack Butte, Kicking Horse, and Marias River (Nadeau). The field at Box Elder ceased producing in 1959, and is now being used for underground gas storage. The Brown's Coulee, Cassidy, Kremlin, Sherard, Signal Butte, and Winifred districts, which hardly merit the distinction of being called fields, are either abandoned or shut in. All are in the folded and faulted country surrounding the Bearpaw Mountains where they mark small accumulations of methane in the upper sandstone unit of the Eagle Sandstone or in the Judith River formation. At Sherard and Winifred it can be shown that the gas does not occur in the anticlinal (allocthonous) structure but in porosity traps in the upper sandstone bed of the Eagle in place in the underlying autochthon where local structural relief is considerably less. With the exception of Bowes field, therefore, the potential of these districts for Upper Cretaceous gas should be discounted substantially.

In the northern part of the State several small fields that have been shut in without having produced, except possibly for local use are Armells, Blackleaf, Gildford, North Gold Butte, and Rudyard. The little field at South Gold Butte has only recently received a pipeline connection. Small shutin fields in the southern part of the State include Liscom Creek, McKay Dome, Mosser Dome, Pumpkin Creek, Rapelje, and Sixshooter. Lack of pipeline outlet at these localities suggests either low productive potential or no local market.

Fields that produce gas only, or have gas areas large enough to be shown separately, are indicated on the map, figure 7, by numbers in open squares which are keyed to the following list (table 3):

TABLE 3.—*Summary of producing gas fields* [1]

Map No. and Name	Producing formation	1961 production, Mcf
1 Apex	Blackleaf	340,352
2 Big Coulee	Lakota-Morrison	890,509
3 Bowdoin	Colorado—Bowdoin-Phillips	4,013,919
4 Cedar Creek	Judith River-Eagle	5,492,270
	Siluro-Ordovician	1,919,801
5 Cut Bank	Kootenai; Sun River	12,275,935
6 Devon	Blackleaf	55,494
7 Fred and George Creek	do	No Record
8 Golden Dome	Eagle	12,876
9 Grandview	Marias River shale-cone	146,776
10 Hardin	Frontier	55,776
11 Keith Block	Sawtooth-Madison	2,126,038
12 Kevin-Sunburst	Kootenai-Sunburst	1,074,342
13 Plevna	Judith River	168,546
14 Utopia	Sawtooth	528,314
Total		29,100,948

[1] Production data in part from Montana Oil and Gas Conservation Commission, Annual Review for 1961, p. 3.

This list includes the more important gas fields in the State, except for Bowes and Whitlash which are shown on the map as oil fields. Gas production from the fields that produce both oil and gas amounted to 5,418,394 Mcf in 1961 to bring the total amount withdrawn in the State to 34,519,342 Mcf. Seven fields: Bowdoin, Bowes, Cedar Creek, Cut Bank, Keith, Kevin-Sunburst, and Whitlash, produced about 85.5 percent of the gas. At the present overall rate of withdrawal their proved reserves may soon be depleted, perhaps within 8 or 10 years, and some of the smaller older fields before then.

This possibility, of course, had been recognized in Montana's natural gas industry for some time, and first became critical during World War II when large amounts of gas were required for defense production operations of the Anaconda Copper Mining Co. Beginning in 1952, the reserves depleted by defense mineral production were to some extent replenished by the grant of a license from the Canadian Government and the Federal Power Commission to the

Montana Power Co. to import 43.8 billion cubic feet of gas over a period of 5 years, which has since been extended, from the Lake Pakowki—Manyberries area in southern Alberta. Gas imports from this area in 1961 amounted to about 15.7 billion cubic feet. Further relief also came in 1961 through a contract between the Montana Power Co. and the Alberta and Southern Gas Co. to import 11 billion cubic feet of gas annually on a "take it or pay for it" basis from the large reserves in southwestern Alberta. Any excess or unused gas will be placed in temporary underground storage in the Cobb field in the north part of the Cut Bank district. Through this arrangement it is expected that the annual import from the Lake Pakowki area may be reduced to about 5 billion cubic feet.

Natural gas also is imported into Montana from Wyoming by the Montana Power Co., and from both Wyoming and North Dakota by the Montana-Dakota Utilities Co. In 1961 the Montana Power Co. import consisted of about 4.9 billion cubic feet from the Heart Mountain field, Wyoming, which was brought to Billings for operation of their gas-steam plant at that place; and about 3.7 billion cubic feet purchased from the Montana-Dakota Utilities Co., at Warren, Mont., where it had been brought from Worland, Wyo. The total gas import of the Montana Power Co. in 1961 was thus of the order of 24.3 billion cubic feet. Excess gas in the Montana Power Co. System in the southern part of the State is stored underground in their Madison River gas bubble in T. 1 N., R. 2 E., west of Bozeman. Imports of gas into Montana by the Montana-Dakota Utilities Co. during 1961 consisted of about 20.7 billion cubic feet from Wyoming, and 5.7 billion cubic feet from North Dakota. The company also stores considerable volumes of gas in Cedar Creek anticline in some depleted parts of the Judith River formation as follows:

	Million cubic feet
From Wyoming	3, 500
From North Dakota	1, 665
From Montana	92

Exports to South Dakota (including Colony, Wyo.) amounted to about 9 billion cubic feet, and about 5 billion cubic feet were returned to North Dakota. However, virtually all of the exported gas is of Wyoming and North Dakota origin. The net gain to Montana was thus about 12.4 billion cubic feet. On balance, therefore, total imports of natural gas into Montana during 1961 came to about 36.7 billion cubic feet, or 2.2 billion cubic feet more than was produced within the State. Total gas consumption in Montana during 1961 was therefore of the order of 71.2 billion cubic feet.

Through commendable foresight of the public service companies it is evident that Montana will suffer no shortage of natural gas within the foreseeable future. However, the prospect of developing additional supplies of gas within Montana at the present time is not promising, and probably will not improve until higher field prices stimulate sufficient drilling exploration to locate some of the ultimate potential reserve. This problem is analogous to and part of the petroleum resource problem; and because of the association of gas with oil in the older rocks quite probably there will be a joint solution. Whether that will mean discovery of a high-pressure gas-condensate field in Paleozoic rocks in the Disturbed Belt with trillions of cubic feet of gas in reserve, which is really what is needed, or large fields out on the Plains remains for future determination.

OIL SHALE

(By C. B. Bentley, U.S. Geological Survey, Great Falls, Mont.)

Oil shales are organic shales which contain kerogen, a mineraloid consisting of a complex of macerated organic debris and forming the hydrocarbon content of oil shale (Levorsen, 1954, p. 656). Kerogen consists chiefly of algae, pollen, spores, and spore coats, and may contain the remains of insects. Chemically it is a mixture of large molecules containing hydrogen, carbon, oxygen, nitrogen, and sulfur. Oil shale, as defined by Winchester (1923, p. 14), refers to any shale that contains material (kerogen) which yields oil by distillation and is distinguished from shale that contains free oil which can be extracted with a solvent or by mechanical means. The organic debris from which kerogen originates may accumulate either in a marine or a nonmarine environment. Both types of accumulation are represented by the deposits in Montana.

Oil shale of marine origin occurs as thin beds and laminae in the Phosphoria formation of Permian age in many of the mountain ranges in southwestern Montana (Bowen, 1918, p. 319; McKelvey and others, 1959, p. 29) (fig. 9,[1] locality No. 1). Yields vary from less than 10 to 21 gallons of oil per ton of shale (Condit, 1920, pp. 24–26). Other occurrences have been noted by R. N. Miller (1953, "Oil Shales in Montana," unpublished thesis, Montana School of Mines, pp. 17, 26–28, 59–78) in the Lodgepole and Heath formations of Mississippian age in the Big Snowy Mountains south of Lewistown (Nos. 2, 3), and in the Heath formation from depths of 5,065–5,094 feet and 5,259–5,279 feet in the Farmers Union Oil Co. Nason No. 1 well (No. 4). Condit (1920, pp. 17–18) collected several samples from the Heath formation in T. 14 N., Rs. 1 and 2 E. (No. 5). Stebinger (1919, pp. 157–164) noted oil shale in the Blackleaf and Marias River formations of Cretaceous age along the mountain front west of Choteau (No. 6). Condit (1920, pp. 18–19) reported an occurrence of oil shale in the Three Forks formation of Late Devonian age in the Jefferson River Valley (No. 7), but the only samples which yielded more than slight quantities of oil were predominantly coal.

Oil shale of nonmarine origin occurs as beds of light brown shale alternating with beds of sandstone, shale, and lignite in tertiary lakebeds up to 1,000 feet thick in intermontane basins west and southwest of Dillon (Pardee, 1913, pp. 230–235). Richer looking layers as much as 5 feet thick were reported by Condit (1920, pp. 27–28) to yield about 24 gallons of oil per ton. Unweathered beds below the surface may yield even larger quantities. The principal belt of oil shale-bearing lakebeds extends for about 28 miles from a point near Bannack in T. 8 S., R. 11 W., south to Horse Prairie, near Grant, in T. 9 S., R. 12 W., thence up Medicine Lodge Creek (No. 8). The other occurrence is in Muddy Creek Basin in Tps. 12, 13, and 14 S., Rs. 10 and 11 W. (No. 9). The basin is about 12 miles long and 3 miles wide.

Oil shale has also been reported in Tertiary beds in the valley of the Middle Fork of the Flathead River and in the Flathead Valley above the mouth of the Middle Fork (C. E. Erdmann, personal communication) (No. 10). The oil shale resembles in appearance some of the oil shale of the Green River formation of Colorado and Wyoming.

None of the oil shale in Montana is as rich or as extensive as that in Colorado, Utah, and Wyoming. The oil shale in the Phosphoria formation and in the Tertiary lakebeds near Dillon may become com-

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[1] NOTE.—Figure indicated appears as a folded map at the

mercial in the future, but for the present it possesses at best a latent resource potential. The oil shale reported to occur in the Three Forks, Lodgepole, Heath, Blackleaf, and Marias River formations, with the exception of a few thin beds, is only slightly petroliferous. Not enough information about the oil shale in the Flathead Valley is known to determine its resource potential.

No development has been undertaken, and available data do not permit tonnage estimates. The petroliferous portion of the Phosphoria formation is present over at least 600 square miles at the surface or in the subsurface of southwestern Montana. The Tertiary lakebeds in which oil shale is known to occur occupy about 280 square miles.

COAL

(By Paul Averitt, U.S. Geological Survey, Denver, Colo.)

Montana contains about 13 percent of the coal reserves of the United States and ranks second among the States in the total quantity originally present in the ground. Of the 222 billion tons of original reserves currently estimated for the State, 2 billion tons is bituminous coal, 132 billion tons is subbituminous coal, and 88 billion tons is lignite (table 4). The estimate includes reserves to a maximum depth of 2,000 feet below the surface, but 75 percent of the total is less than 1,000 feet below the surface.

TABLE 4.—*Estimated original coal reserves in Montana*

(In millions of short tons)

County	Bituminous coal	Subbituminous coal	Lignite	Total	Percent of total original reserves
Big Horn		43,500.65		43,500.65	19.6
Blaine		39.73		39.73	(1)
Broadwater	5.66			5.66	(1)
Carbon	1,247.22			1,247.22	.6
Carter			[2] 463.47	[2] 463.47	.2
Cascade	435.12			435.12	.2
Chouteau		1.48		1.48	(1)
Custer		2,678.86	[2] 2,198.85	[2] 4,877.71	2.2
Daniels			3,964.72	3,964.72	1.8
Dawson			[2] 11,110.49	[2] 11,110.49	5.0
Fallon			[2] 2,544.08	[2] 2,544.08	1.1
Fergus	341.40	1.54		342.94	.2
Garfield		612.74	(2)	[2] 612.74	.3
Glacier	33.36			33.36	(1)
Granite			23.00	23.00	(1)
Hill		76.55		76.55	(1)
Judith Basin	243.93			243.93	.1
McCone			24,871.57	24,871.57	11.2
Meagher	.53			.53	(1)
Missoula			19.70	19.70	(1)
Musselshell		3,471.49		3,471,49	1.6
Park	20.83	12.40		33.23	(1)
Phillips		3.50		3.50	(1)
Pondera	21.89			21.89	(1)
Powder River		40,984.48	2,433.69	43,418.17	19.5
Prairie			[2] 1,581.27	[2] 1,581.27	.7
Richland			[2] 21,085.62	[2] 21,085.62	9.4
Roosevelt			[2] 4,164.23	[2] 4,164.23	1.9
Rosebud		38,873.78	[2] 10.10	[2] 38,883.88	17.5
Sheridan			[2] 5,763.82	[2] 5,763.82	2.6
Stillwater	12.67			12.67	(1)
Treasure		1,303.66		1,303.66	.6
Valley			257.93	257.93	.1
Wibaux			[2] 7,040.73	[2] 7,040.73	3.2
Yellowstone		590.20		590.20	.3
Total	2,362.61	132,151.06	[2] 87,533.27	[2] 222,046.94	99.9

[1] Less than 0.1 percent.

[2] Incomplete.

The Montana coal fields cover 51,000 square miles, or about 35 percent of the total area of the State (fig. 10).[1] Reserves are present in 35 out of 56 counties, but are concentrated in the eastern part of the State. Big Horn, Powder River, and Rosebud Counties alone account for more than half of the total in the State. Parts of the coal-bearing area totaling nearly 5,000 square miles and representing about 10 percent of the area of coal-bearing rocks have been omitted from consideration in preparing the reserve estimates because of the lack of detailed information. The areas omitted are concentrated for the most part in the northeastern corner of the State where the coal-bearing rocks are concealed by glacial drift. In many of the areas included in the estimates, beds remote from outcrops or at depth were also omitted. As mapping and exploration are continued in Montana it is certain the additional coal will be discovered and that the total estimated tonnage will be increased accordingly.

The Montana coal fields can be divided into two major regions, the Fort Union, or eastern region, and the north-central region; and into many subordinate fields and areas as shown on figure 10. The more important of these are discussed briefly in the following paragraphs:

FORT UNION REGION

The Fort Union region includes most of the eastern third of Montana and is underlain by rocks of the Fort Union formation of Paleocene age. It contains more than 90 percent of the coal reserves of the State. Coal is present in each of the three members of the formation, and is especially widespread in the uppermost Tongue River member. Individual coalbeds are discontinuous, and they vary greatly in thickness so that correlations between beds in different areas are difficult to establish. In general, however, the coalbeds increase in number and thickness to the west and south. In the western and southern part of the region, for example, as many as 20 beds are present, some of which are as much as 40 feet thick.

Most of the present and past mining in the region has been concentrated in Custer, Powder River, Richland, Rosebud, and Sheridan Counties. Because the coal is flat lying and locally near the surface, most of the mining is by stripping methods. Two large strip mines in Richland County account for most of the present production in the region. Much of the lignite produced in Richland County is consumed in the steam-electric generating plant of the Montana-Dakota Utilities Co. located at Sidney. During 1962 the Montana Power Co. acquired the coal property of the Northwest Improvement Co. (Northern Pacific Ry.) at Colstrip, in Rosebud County, about 25 miles south of Forsyth. At this locality the 28- to 30-foot Rosebud bed is underlaid at an interval of 6 to 8 feet by the 7- to 10-foot McKay bed. Drilling exploration of these beds has been carried out in anticipation of resuming mining coal for a new steam-electric plant now in the planning stage.

The rank of the coal in the region increases progressively westward from lignite at the North Dakota line to subbituminous C west of Miles City and to subbituminous B farther west in southern Rosebud and eastern Big Horn Counties. A line on the accompanying map (fig. 10) shows the approximate boundary between lignite and sub-

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

bituminous coal. The change is very gradual, however, and the difference between coal on opposite sides of the line is negligible.

BULL MOUNTAIN FIELD

The Bull Mountain field is mainly in Musselshell and Yellowstone Counties. The coal is concentrated in the Tongue River member of the Fort Union formation, but thin and impure beds occur in the underlying Lebo and Tulloch members. The main, central part of the field is a broad, shallow, west-trending synclinal basin in which the dips are nearly horizontal. At the west end of the basin, however, the coal-bearing rocks extend to the west and northwest in two sharply accentuated anticlines in which the dips steepen to a maximum of 36°.

Most of the mining in the field is in Musselshell County, where underground methods are generally employed. In 1961 there were seven operating mines in the county, which accounted for about 80 percent of bituminous and subbituminous coal production in the State. Mining is concentrated in the Roundup and Carpenter Creek beds, which are about 50 feet apart stratigraphically. The Roundup bed, which is 4 to 6 feet thick near Roundup, is mined in the northern and northwestern part of the field. The Carpenter Creek bed is mined in the northeast part of the field, where it is 4 to 8 feet thick. The coal is of subbituminous A and B ranks.

NORTH-CENTRAL REGION

The north-central region (fig. 10) comprises four areas which differ in one or more aspects because of structure, age of coal-bearing rock, or rank of coal. These four areas are described below under separate headings as follows: Great Falls field, Lewistown field, area surrounding the Bearpaw Mountains, and the Blackfeet-Valier area:

Great Falls field.—The Great Falls field is in Cascade and Judith Basin Counties. It extends in a generally eastward direction for a distance of 60 miles from a point 25 miles southwest of Great Falls to a point southeast of Stanford. The coal-bearing rocks in the field dip gently northward away from the north flank of the Little Belt Mountains. The coal occurs at a single stratigraphic horizon in the upper part of the Morrison formation of Late Jurassic age and is geologically the oldest coal in the State. Because of downwarp and erosion in post-Jurassic time the coal horizon is discontinuous, but is preserved in three basins, which define three producing districts. These are known, from west to east, as the Sand Coulee, Otter Creek, and Sage Creek districts.

In the Sand Coulee district, which is the most important of the three, the coal bed is 4.6 feet thick at Belt, 8.0 feet at Sand Coulee, 7.5 feet at Smith River, and averages about 4 feet at Hound Creek. In the Otter Creek district the coal is 3 to 6 feet thick and is separated into two benches by a bone parting. In the Sage Creek district south of Stanford the coal commonly occurs in three benches, which in total contain 2.5 to 7.0 feet of coal. The lower bench is typically 2 feet thick and contains the best coal.

The coal in the Great Falls field is of high volatile B and C bituminous ranks and is moderately high in heat value. In the Sand Coulee district, certain benches, some as thin as 7 to 9 inches, have coking properties and have been used in the manufacture of coke. The Anaconda Mining Co. formerly operated a battery of beehive coke ovens at Belt, but these were abandoned many years ago, in part because of the difficulty and expense of separating coking from noncoking coal by handpicking, and in part because of the decline in use of the blast furnace in nonferrous smelting.

Lewistown field.—The Lewistown field is in Judith Basin and Fergus Counties, centering around Lewistown, and is an eastward extension of the Great Falls field. As in the Great Falls field, the coal occurs in several different basins at or near a single stratigraphic horizon in the Morrison formation. Where mined, the coalbeds range in thickness from 2.5 to 8.0 feet and commonly occur in two or more benches separated by bone partings.

Area surrounding the Bearpow Mountains.—North of the Great Falls and Lewistown fields, in Hill, Toole, Liberty, Chouteau, Fergus, and Blaine Counties, is an area of 10,500 square miles underlain by flat-lying coal-bearing rocks. These rocks are largely concealed by a cover of glacial drift. The coal in this area occurs primarily in the Judith River formation and to a minor extent in the Eagle sandstone, both of late Cretaceous age. At one locality coal is mined from a bed in the Fort Union formation of Paleocene age.

Most of the coal in the Judith River formation occurs in two thin discontinuous beds in the upper 75 feet of the formation. In the Milk River field in Blaine and Hill Counties these beds are being mined for local use near Chinook and formerly were mined north of Havre. At these localities the coal ranges in thickness from 2.5 to 6.7 feet, but is impure and contains bone partings.

The coal in the Eagle sandstone occurs as thin lentils in the basal part of a 75-foot unit of carbonaceous shale, but is too thin and too low grade to be minable, except locally. Insofar as known, none has been mined since about 1925.

A bed of coal in the Fort Union Formation is mined at the Rocky Boy mine in sec. 31, T. 29 N., R. 15 E. to supply local demand at the Rocky Boy Indian Reservation.

The coal in the area surrounding the Bearpaw Mountains is typically of subbituminous A and B ranks, but in northwest Liberty and northeast Toole Counties is of high volatile B bituminous rank as a consequence of proximity to the Sweetgrass Hills intrusive uplift.

Blackfeet-Valier area.—The Blackfeet-Valier area extends in a narrow belt from the Canadian border south through Glacier, Pondera, and Teton Counties to a point about 30 miles south of Choteau. The coal in this belt occurs at three or four stratigraphic horizons in the Two Medicine formation, and at two horizons in the St. Mary River formation, both of late Cretaceous age, but the beds are generally thin and discontinuous. All the coal is of high volatile B and C bituminous ranks.

In the Valier field in Pondera County coal in the lower part of the Two Medicine formation is 20 to 24 inches thick, including a 2-inch clay parting, and the beds are gently dipping. This area has been dormant since the early 1930's.

In the Blackfeet Indian Reservation in Glacier County coal has been mined in the past from beds in both the Two Medicine and St. Mary River formations. The coal in this area is locally as much as 3.5 feet thick, but the beds are steeply dipping and are broken by faults.

BRIDGER AND SILVERTIP FIELDS

The Bridger and Silvertip fields are part of a northern extension of the Bighorn Basin of Wyoming into eastern Carbon County, Mont. The coal in these fields is of high volatile C bituminous rank. Coal beds occur at three stratigraphic horizons in the Eagle Sandstone of Late Cretaceous age. The beds are discontinuous, and coal of usable thickness is present at only one horizon in any one locality. Mining has been carried on near Joliet and Fromberg, and also at Bridger.

RED LODGE FIELD

The Red Lodge field is also in Carbon County about 20 miles west of the Bridger and Silvertip fields. The coal in the Red Lodge field is also of high volatile C bituminous rank. Eight beds in the Fort Union formation have been mined in the vicinity of Red Lodge and Bear Creek.

ELECTRIC FIELD

The Electric field covers an area of less than 20 square miles in central Park County. The field is part of a folded and downfaulted block in which coal-bearing rocks of Late Cretaceous age have been preserved. Over most of the area of the field the coal-bearing rocks are deeply buried but they are exposed locally in two small synclines covering an area of about 3 square miles. Where exposed the coal-bearing sequence is about 300 feet thick and includes three coal beds, each ranging in thickness from 3 to 5 feet, including partings. The uppermost bed, the only one mined, is of high volatile A bituminous rank. In the past coal from this bed was used to manufacture coke for smelters at Anaconda and at Butte. The use of this coke was discontinued because the operators were unable to meet smelter specifications for a coke containing less than 18 percent ash, but otherwise the coke was reported to be of good quality.

LIVINGSTON-TRAIL CREEK FIELD

The Livingston-Trail Creek field extends in a narrow strip across three townships in Gallatin and Park Counties. The coal-bearing rocks in this field are probably stratigraphically equivalent to rocks in the Electric field, 30 miles to the east, and are strongly folded, faulted, and locally overturned. The coal-bearing sequence contains several coalbeds, each ranging in thickness from 2 to 5 feet, including partings. The coal ranges in rank from high volatile C to A bituminous, depending in part on the amount of deformation. Prior to 1908 coal near Cokedale was mined and used for the manufacture of coke; at one time 100 beehive ovens were in operation.

As noted in previous paragraphs, three areas in Montana—the Great Falls, Livingston-Trail Creek, and Electric field—yield coal with coking properties. In the past coal from each of these fields was used to manufacture coke, but the product was inferior to or more expensive than coke manufactured elsewhere and the operations were abandoned.

The cumulative recorded production of coal in Montana from the date of earliest record to January 1, 1962, totals 171 million tons, and actual production has probably been somewhat larger. In common with most other Rocky Mountain States, annual production in Montana has declined drastically in recent years. Between 1944 and 1958, for example, production declined from a maximum of 4,844,000 tons to a minum of 305,000 tons (fig. 11). Since 1958, production has increased slightly but in 1961 the production was only 371,000 tons. The decline in production is attributed to the replacement of steam by diesel-driven locomotives, to the increased use of oil and natural gas for the generation of electric power, to the increased use of hydroelectric power, and to the increased use of natural gas and liquefied petroleum gases for residential and commercial heating.

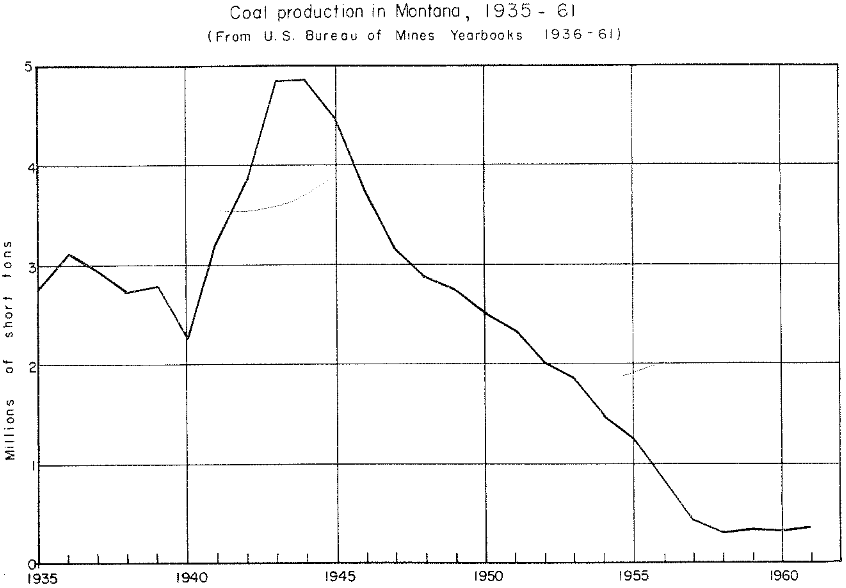

FIGURE 11.—Coal production in Montana, 1935–61.

SELECTED REFERENCES

PETROLEUM AND NATURAL GAS

Am. Petroleum Inst., 1961, Petroleum facts and figures: New York City, 296 p.

Anderson, C. C., and Hinson, H. H., 1951, Helium-bearing natural gases of the United States. Analyses and analytical methods: U.S. Bur. Mines Bull. 486, 141 p.

Bartram, J. G., and Erdmann, C. E., 1935, Natural gas in Montana, in Geology of natural gas: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 245–276.

Billings Geol. Soc., 1958, Montana oil and gas fields symposium: Billings, Mont., 247 p. with 55 p. supp. in 1961.

Casper, John C., 1953, Oil and Gas Jour.: Tulsa, Okla., Oil and Gas Jour., Jan. 26, 1953, p. 209.

Dobbin, C. E., 1935, Geology of natural gases rich in helium, nitrogen, carbon dioxide, and hydrogen sulphide in Geology of natural gas: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 1053–1072.

Dobbin, C. E., and Erdmann, C. E., 1934, Geologic occurrence of oil and gas in Montana, in Problems of petroleum geology: Tulsa, Okla., Am. Assoc. Petroleum Geologists, August 1934, p. 695–718.

——— 1955, Structure contour map of the Montana plains: U.S. Geol. Survey Oil and Gas Inv. Map OM–178–A.

Indep. Petroleum Assoc. of America, 1959, The oil-producing industry in Montana, p. 47–48, and The importance of oil and gas to consumers in your State in 1957, p. 88, in The oil producing industry in your State: Tulsa, Okla., and Washington, D.C., Spec. Ed., 96 p.

Oil and Gas Conserv. Comm. of the State of Montana, 1961, Annual review relating to oil and gas, v. 6: Helena, Mont., 42 p.

Perry, E. S., 1937, Natural gas in Montana: Montana Bur. Mines and Geology Mem. 3, 96 p.

———1960, Oil and gas in Montana: Montana Bur. Mines and Geology Bull. 15, 86 p.

Pratt, W. E., 1942, Oil in the earth: Lawrence, Kans., Univ. Kans. Press, 105 p.

Weeks, L. G., 1958, Fuel reserves of the future: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 2, p. 431–441.

OIL SHALE

Bowen, C. F., 1918, Phosphatic oil shales near Dell and Dillon, Beaverhead County, Montana: U.S. Geol. Survey Bull. 661–I, p. 315–328.

Condit, D. D., 1920, Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah: U.S. Geol. Survey Bull. 711–B, p. 15–40.

Levorsen, A. I., 1954, Geology of petroleum: San Francisco, W. H. Freeman & Co., 703 p.

McKelvey, V. E., and others, 1959, The Phosphoria, Park City, and Shedhorn Formations in the western phosphate field: U.S. Geol. Survey Prof. Paper 313–A, p. 1–47.

Pardee, J. T., 1913, Coal in the Tertiary lakebeds of southwestern Montana: U.S. Geol. Survey Bull. 531–G, p. 229–244.

Reeves, Frank, 1931, Geology of the Big Snowy Mountains, Montana: U.S. Geol. Survey Prof. Paper 165–D, p. 135–149.

Stebinger, Eugene, 1919, Oil and gas geology of the Birch Creek-Sun River area, northwestern Montana: U.S. Geol. Survey Bull. 691–E, p. 149–184.

Winchester, D. E., 1923, Oil shale of the Rocky Mountain region: U.S. Geol. Survey Bull. 729, 204 p.

———, 1928, The oil possibilities of the oil shales of the United States, Report 2 of the Federal Oil Conservation Board to the President of the United States.

COAL

Averitt, Paul, 1961, Coal reserves of the United States—A progress report, January 1, 1960: U.S. Geol. Survey Bull. 1136, 116 p.

Berryhill, L. R., and Averitt, Paul, 1951, Coking-coal deposits of the western United States: U.S. Geol. Survey Circ. 90, 19 p.

Combo, J. X., Brown, D. M., Pulver, H. F., and Taylor, D. A., 1949, Coal resources of Montana: U.S. Geol. Survey Circ. 53, 28 p.

Combo, J. X., Holmes, C. N., and Christner, H. R., 1950, Map showing coal resources of Montana: U.S. Geol. Survey Coal Inv. Map C–2.

Denson, N. M., 1959, Uranium in coal in the western United States: U.S. Geol. Survey Bull. 1055, 315 p.

Fulkerson, F. B., Kauffman, A. J., Jr., and Knostman, R. W., 1962, The mineral industry of Montana: U.S. Bur. Mines Minerals Yearbook 1961, v. 3, p. 615–640.

Kepferle, R. C., 1954, Selected deposits of strippable coal in central Rosebud County, Montana: U.S. Geol. Survey Bull. 995–I, p. 333–381.

Warren, W. C., 1959, Reconnaissance geology of the Birney-Broadus coal field, Rosebud and Powder River Counties, Montana: U.S. Geol. Suvey Bull. 1072–J, p. 561–585.

METALLIC AND INDUSTRIAL MINERAL RESOURCES

INTRODUCTION

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

The early development of the mineral resources of Montana was almost entirely directed toward the metallic minerals. As in so many parts of the West, gold was the initial goal of the early miners and prospectors. Exploitation of other metallic deposits soon followed, but it was not until a larger and more diversified population arrived that other mineral resources drew attention. By the early 1900's, Montana had a significant population engaged in ranching, lumbering, and commerce, and the need for some of the less glamorous mineral commodities began to be felt. Cement, stone, sand and gravel were used in increasing quantities for roads and building construction. The rapid changes and advances in technology created demands for many mineral products formerly considered of little or no value. Vermiculite is an outstanding example; it was not until the initiative and vision of a few people developed some of the many present-day uses for vermiculite that it was considered a mineral commodity at all. There are many other similar examples. The net result of Montana's growing population and industrial variety is the long list of mineral commodities now produced in the State. Although the metallic minerals are as important as ever, and although Montana remains a leading producer of them, the importance of nonmetallic minerals continues to grow. As will be seen in the text that follows, not only the quantity, but the variety, of Montana mineral production is great.

ANTIMONY, ARSENIC, BISMUTH, CADMIUM, GERMANIUM

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

These elements, chiefly recovered as byproducts, are present in different ores and in varying degrees of abundance; all except arsenic are in relatively short supply.

Antimony and bismuth are soft, silver-gray metals with low melting points. Both are rare in the United States. Antimony is recovered as a byproduct from silver refining (almost all U.S. production comes from the Sunshine mine in Idaho), and bismuth is a byproduct from certain lead ores, including those from Butte. The Anaconda Co. produces the only bismuth recovered from Montana ores. Antimony ores (stibnite) are mined in some parts of the world but, although no economic deposits are presently known in the United States, some deposits in Sanders County once produced a little more than 200 tons of ore.

Both metals are used in alloys such as type metal, babbitt metal, ammunition, battery lead alloys (antimony), aluminum alloys, malleable iron and steel, pharmaceuticals, and laboratory chemicals (bismuth). Antimony oxide is used in the plastics industry. Most of the U.S. supply of both metals is imported.

Butte produces almost the entire domestic supply of arsenic, and could increase its production by many times if required (John R. Cooper, U.S. Geological Survey, written communication, 1960). The arsenic is contained mostly in the mineral enargite, an important copper ore mineral at Butte, and is recovered from the smelter at Anaconda principally to prevent contamination of the surrounding area with poisonous arsenical fumes.

Chief use of arsenic is as the oxide As_2O_3 (white arsenic of commerce) and calcium arsenate, for insecticides, pesticides, and cattle and sheep dips. Arsenic compounds are also used in wood preservatives, dyestuffs, weed killers, glass manufacture, fireproofing, and hide-tanning compounds.

Present supply far exceeds demand, and prospecting for mineral deposits to produce arsenic for the market at present does not offer much promise.

Cadmium is a soft, silver-white metal that is markedly rust resistant. Chief uses for cadmium are in electroplating automobile and aircraft engine parts, radio and television parts, nuts and bolts, and as an alloy in bearing metals, low fusion-point metals, photography, paint pigments, and dyes.

Cadmium is recovered almost exclusively as a byproduct from zinc smelting. The Anaconda Co. recovers it from Butte ores, and in 1960 was the only producer in Montana. Current U.S. needs are adequately supplied from this and other domestic zinc producers.

Germanium is an extremely rare element. When pure it is a white, brittle, crystalline metal. It is recovered principally from certain zinc ores (Fisher, 1960, pp. 1252–1253). Chief uses are for transistors, diodes, and rectifiers in the electronics industry. It is also used sparingly as a color modifier in fluorescent lights. Germanium is known to occur with enargite and some sphalerites (Fleischer, 1961), but no production has been reported from Montana.

ASBESTOS

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Asbestos is the term given a group of silicate minerals with fibrous habit, which can be separated into very thin, more-or-less flexible fibers. Asbestos minerals are of two types: chrysotile, which forms from serpentine, yields highly flexible, tough fibers, which, if long enough, can be spun and woven; and amphibole asbestos, which produces brittle fibers that cannot be woven but can be mixed with binders such as cement, plaster of paris, or resins to make useful products (Jenkins, 1960, p. 49).

Chief uses for asbestos are as thermal and electrical insulation. Fireproof clothes, gloves, and curtains are made from chrysotile as are clutch facings, brake linings, and gaskets for the automotive industry. Amphibole asbestos is used in fireboard, shingles, furnace coverings, and similar uses not requiring flexibility.

Asbestos has been reported at four places in Montana (fig. 12)[1] (Chidester and Shride, 1962). Chrysotile occurs at Cliff Lake,

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Madison County, and at the Anderson deposit southwest of Armstead, Beaverhead County (Perry, 1948, p. 35). Several attempts have been made to produce asbestos from the Cliff Lake deposit but, as of 1959, none were successful. Activity at the Anderson deposit has been confined to prospecting (Sahinen and Crowley, 1959, p. 4–5).

Although no other deposits of chrysotile asbestos are known in Montana, metamorphosed dolomites in the Precambrian rocks of southwestern Montana consititute a favorable environment for their occurrence, and the potential exists for discovery of minable deposits.

Amphibole asbestos was mined at the Karst deposit, 35 miles south of Bozeman. The deposit was operated by Interstate Products Co., Bozeman. Production prior to 1959 was approximately 1,800 tons; the mine is now inactive and remaining reserves appear small.

Large quantities of amphibole asbestos (tremolite) are present at the Rainy Creek vermiculite deposit near Libby. No attempts have been made to market the material as yet, but commercial exploitation may be possible.

BARITE

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Barite is a white, heavy (specific gravity about 4.5), relatively soft crystalline mineral with the composition $BaSO_4$. It occurs in veins and replacement deposits, either alone, with quartz, calcite and similar minerals, or commonly as a gangue mineral in metallic sulfide deposits (Brobst, 1958, p. 83). Commercial deposits generally contain few impurities. Market price for crude barite in 1961 was $18 per ton.

A major use for barite is in drilling muds, for which it is normally ground to minus 325 mesh and mixed with bentonite to keep it in suspension. The resulting muds are used in oil well drilling, where their high specific gravity assists in controlling oil and gas pressures.

A second important use is in lithopone, a mixture of barite and zinc sulfate used as a white pigment in paint. Other uses are in glass manufacture; filler in paper, asbestos products, linoleum, textiles, and rubber goods; and for a variety of products in the chemical and drug industries. Annual domestic consumption of barite and its derivative materials ranges from about 1½ to 2 million tons, of which about one-third is imported (Brobst, 1960, p. 59).

There are three productive deposits in Montana; two are near Greenough, about 25 miles east of Missoula. One of these, the Elk Creek deposit (fig. 13,[1] locality No. 1) was discovered in 1950, and mining began shortly thereafter (DeMunck and Ackerman, 1958, p. 12). The other, the Coloma vein (No. 2), about 2 miles to the south, was discovered in 1955, and mining began in 1956. The barite has been used mostly for drilling mud. The deposits are fracture fillings of relatively pure crystalline barite; principal impurity is a mixture of wall rock (principally Belt series) that has been faulted into the vein.

Some shipments have been made from the Kennelty deposit, about 35 miles southeast of Libby, Lincoln County (No. 3), where barite occurs in a massive vein cutting Belt argillites. Similar barite veins are known elsewhere in western Montana, and several may be large

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

enough to justify exploitation. Among them are a deposit about 4 miles south of Missoula (No. 4); the Copper Mountain veins near Troy, Lincoln County (No. 5); the Whaley deposit northeast of Florence, Missoula County (No. 6); the Shook vein, between Woods Creek and Deer Creek south of Darby, Ravalli County (No. 7); and the Fletcher deposit north of York, Lewis and Clark County (No. 8) (DeMunck and Ackerman, 1958, p. 17–26). A number of other deposits are known; some are probably sufficiently large and high grade to constitute potentially productive deposits, provided a market can be found for the product.

BENTONITE

(By U. M. Sahinen, Montana Bureau of Mines and Geology, Butte, Mont.)

Bentonite is the commercial name given to a type of clay consisting essentially of the mineral montmorillonite. Bentonite exhibits certain unusual physical properties that lead to its utilization in industry. When wet, it swells greatly, and thus finds use as a watertight seal in irrigation ditches, soils, dam foundations, and drill holes. When mixed with water and allowed to stand it forms a gel which becomes liquid again upon agitation. This property, known as thixotropy, leads to its use in drilling muds to keep heavy minerals in suspension. Bentonite is also used as a bonding agent in foundry sands, as a filler and carrier in insecticides and fungicides, and as a filler in paper. A variety found in southeastern United States swells less than western bentonite, and is used as an adsorbent and decolorizer. Some Montana bentonite has been used as a binding agent in pelletizing iron ore.

Bentonite is formed by devitrification of volcanic glass. Tuff beds of Cretaceous and Tertiary age are widespread in Montana, Wyoming, the Dakotas, and elsewhere in western United States. Many, particularly in Cretaceous rocks, have been altered to bentonite, and some of the larger and more accessible deposits are mined. The main use is for foundry sands and in drilling muds; therefore, most of the bentonite produced has come from deposits near oilfields or iron and steel centers.

Bentonite occurs in many parts of Montana (fig. 14).[1] In the southwestern part of the State it occurs as beds of highly altered volcanic ash interbedded with soft clay-shale, sand, and gravel in the Tertiary sediments of the intermontane valleys. The bentonite beds vary in thickness from a few inches to beds measurable in tens of feet; quality also is variable. The clay has been mined on a small scale near Gregson and near Melrose, both in Silver Bow County, but the deposits, as a whole, have not been surveyed, and estimates of reserves cannot be made. Some of the bentonitic clays and soils of the larger valleys of southwestern Montana have been tested and found suitable for compacted irrigation canal-lining (Green and Agey, 1960, Everett and Agey, 1960 and 1961).

In central Montana, bentonite of good quality is found at several places, but the best known are the deposits in the Hardin area described by Knechtel and Patterson (1956) where some 24 beds ranging from 3 to 45 feet thick are interbedded in a shaly sequence 4,800 feet thick. Regarding these deposits Knechtel and Patterson (1956, p. 48–49) state:

> * * * beds of minable thickness lying in belts more than 50 feet wide under less than 30 feet of overburden are estimated to contain about 110 million short

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

> tons of bentonite * * *. Apparently, all the beds contain some bentonite that is suitable for use as foundry clay. * * * Some of the bentonite of this district also could be used as an ingredient of drilling mud, but most of it is not comparable in quality to the best grades of drilling clay mined in the Black Hills district. * * *

A small bentonite-processing plant has been operated by the Wyotana Mining Co. at Aberdeen siding, 6 miles south of Wyola, but the clay came from the Wyoming side of the State line. Bentonite, from a deposit near Geraldine, in Chouteau County, in central Montana has been used for lining irrigation ditches.

Bentonite of good quality has been produced from Carter County in the Montana section of the Black Hills district in southeastern Montana. Here nine beds of bentonite with average thicknesses ranging from 1 to 5 feet occur in about 3,000 feet of shaly sediments of Cretaceous age. The quality ranges from very poor to excellent. Only one bed, the Clay Spur bed in the Mowry Shale, has been mined, but material from this bed ranks from good to excellent in quality. Bentonite from the Black Hills district is usable as an ingredient in drilling muds, for preparation of metallurgical molding sand of superior strength, and for bonding material in pelletizing taconite iron ore of the Lake Superior district (Knechtel and Patterson, 1962, p. 1).

CHROMIUM

(By Everett D. Jackson, U.S. Geological Survey, Washington, D.C.)

Chrome ore has been one of the critical commodities of the United States for many years. At present, no domestic chrome deposit can compete with foreign ore, either by reason of low grade, small size, or remote location. However, over 80 percent of the potential chromite resources of the Nation are in Montana. In the past, these deposits have been mined under contracts with the U.S. Government, but in the future they may become economic in their own right. They are, therefore, important in any resource evaluation of the State.

Consumption of chrome ore in the United States averages about 1.3 million short tons per year, for three principal uses: (1) metallurgical, (2) refractory, and (3) chemical. Metallurgical use constitutes about 55 percent of the total; chromium is added to improve the strength and corrosion resistance of steel, and in the production of other ferroalloys and chromium metal. Refractory use consumes about 30 percent of the total chrome ore in the manufacture of bricks for lining open hearth steel and other high-temperature furnaces. Chemical use amounts to about 15 percent of the total for the manufacture of sodium dichromate for tanning, pigments, and electroplating. Historically, the metallurgical, refractory, and chemical industries have specified different types of chrome ore for these uses.

The mineral chromite is the only commercial source of chromium. However, pure chromite contains four major metallic constituents—chromium, aluminium, magnesium, and iron—and its composition varies widely. For example, the chromic oxide (Cr_2O_3) content of natural pure chromite ranges from more than 60 weight percent to less than 30 and its Cr:Fe ratio ranges from more than 4:1 to less than 1:1. In addition to chromite, commercial chrome ores contain small amounts of gangue minerals of which silica (SiO_2) is an important constituent. The "standard" specifications for metallurgical-grade chrome ore call for 48 percent Cr_2O_3, a Cr:Fe ratio of 3:1 and an SiO_2 content of less than 5 percent. Refractory-grade ores should have Cr_2O_3 plus Al_2O_3 in amounts greater than 57 percent and Fe and SiO_2 must be low. Specifications for chemical-grade ore are more variable, but in general it should be high in Cr_2O_3 and low in Al_2O_3 and SiO_2. These specifications interest metallurgical and chemical users only insofar as they affect the cost of extracting chromium, and are subject to change with economic factors. Thus, in 1961, about 15 percent of the chrome ore used in the metallurgical industry was chemical-grade (Prokopovitch and Heidrich, 1962, p. 432). Users of refractory-grade chrome ores, however, are concerned with the physical properties of the chromite itself, and until recently high-iron chromites were unsuitable for chromite refractories. However, successful service trials of refractories made from chemical-grade chromite have recently been reported (Heiligman, Mikami, and Samuel, 1961).

Chromite deposits may be classified into three principal types (1) stratiform, (2) podiform, and (3) placer. Stratiform chromite deposits occur in the lower parts of great tabular gabbroic intrusions as uniform layers that commonly can be traced for miles. Podiform chromite deposits occur as irregular lenses in dunite or troctolite of alpine mafic intrusions. Placer chromite deposits are derived from weathering of peridotite and chromite deposits, and occur either as black sand, or as chromiferous lateritic iron ore. Most stratiform chromite deposits are chemical grade, whereas podiform chromite deposits are typically either metallurgical- or refractory-grade (Thayer, 1946; 1960).

The total measured, indicated, and inferred reserves of chrome ore in the United States were estimated to be equivalent to about 3.5 million long tons of Cr_2O_3 in the ground as of 1956; of this total more than 80 percent was estimated to be in Montana.[1] Although both stratiform and podiform deposits occur in the State, nearly all of the reserves are contained in the great stratiform intrusion known as the Stillwater Complex, in Stillwater and Sweetgrass Counties.

The chromite deposits of the Stillwater Complex occur in a belt or ribbon across the northern front of the Beartooth Range in south-central Montana. The belt is about a mile wide and 30 miles long, is gently arcuate in shape, and trends from east-west to northwest-southwest.

The deposits are stratiform in type and chemical in grade. The chromite is concentrated in layers that are parallel to those of the enclosing rocks, which are olivine- and pyroxene-rich harzburgites and bronzitites. Chromite-rich layers, however, occur only within the olivine-rich layers. About 13 zones of chromite enrichment, called chromitite zones, are known, and these vary in thickness from less than an inch to more than 12 feet. Although the chromitite zones vary in thickness from layer to layer, and along the strike, they are remarkably continuous. Several of them can be traced laterally for more than 15 miles. Dips of the chromitite zones—and of the harzburgites and bronzitites that enclose them—are steep, ranging mostly from vertical to about 50°. The deposits extend downward to great depths, except where terminated by major faults.

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[1] Estimate by T. P. Thayer and E. D. Jackson, Department of the Interior Information Service, press release, June 5, 1957.

The pure chromite varies considerably in composition: the Cr_2O_3 content ranges between 36 and 49 percent, and the Cr:Fe ratio ranges between 0.8:1 and 2.3:1. Average values are about 43 percent Cr_2O_3 and 1.5:1 Cr:Fe. These compositions were obtained on laboratory purified material; commercial concentrates made from these chromites would contain somewhat less Cr_2O_3. The composition of the chromite in the chromitite zones tends to change in a regular way—between different zones, along the same zone, and from bottom to top of the same zone (Jackson, Dinnin, and Bastron, 1960; Jackson, in press).

Interest in the chromite deposits of the Stillwater Complex was first stimulated by the war demand of 1917 and 1918 (Westgate, 1921). Several properties were developed, but no ore was shipped. Development continued sporadically during the 1920's and 1930's and a number of claims in the eastern part of the area were patented in 1933. Schafer (1937, p. 7–20) summarized the knowledge of ore deposits at that time. In the period 1939–45 the U.S. Geological Survey, in cooperation with the U.S. Bureau of Mines, began a detailed study of the geology and grade of the chromite deposits of the Stillwater Complex. Results of this work, including geologic maps and drill hole data, have been published by Peoples and Howland (1940); Wimmler (1948); Howland, Garrels and Jones (1949); Jackson, Howland, Peoples, and Jones (1954); Peoples, Howland, Jones, and Flint (1954); and Howland (1955).

In June 1941, the Anaconda Copper Mining Co., as agent of the Defense Plant Corporation of the U.S. Government started underground development for chromite in three favorable areas in the Stillwater Complex: (1) The Benbow area near the head of Little Rocky Creek; (2) the Mouat or Mountain View area just west of the Stillwater River; and (3) the Gish area on the Boulder River. Large camps and mills were constructed in the Benbow and Mouat areas, and a camp was built at the Gish property. At Benbow, the Anaconda Copper Mining Co. mined 200,625 long tons of ore and milled 166,400 long tons to produce 64,791 long tons of concentrates averaging 41.5 percent Cr_2O_3 and 1.61:1 Cr:Fe. At Mouat, they mined 163,571 long-tons and milled 69,371 long tons to produce 26,373 long tons of concentrates averaging 38.8 percent Cr_2O_3 and 1.44:1 Cr:Fe. Some ore was broken at the Gish mine, but none was milled. All operations were stopped by Government order in September 1943, when higher grade foreign chrome ore again became available.

In 1952 the American Chrome Co. entered into a contract with the U.S. Government to produce 900,000 short tons of Stillwater chromite concentrates averaging 38.5 percent Cr_2O_3. The Mouat mine was reopened in 1953, the mill was rebuilt, and the concentrates were delivered to the Government stockpile at Nye, Mont. In 1958 American Chrome Co. installed a pilot plant to investigate production of charge-grade ferrochromium by electrical reduction. The Government contract was completed in 1961, and the mine was closed the following year.

Estimated chromite reserves of the Stillwater complex as of 1962, corrected from Thayer and Jackson's earlier estimates,[2] are equivalent to 2,520,000 long tons of Cr_2O_3 content in the ground.

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[2] Department of the Interior Information Service press release, June 5, 1957.

Podiform chromite deposits occur in two areas of Montana: near Red Lodge in Carbon County, and near Sheridan in Madison County. Both areas contain a number of small deposits, and both are unusual in that they contain predominantly chemical-grade chromite.

The Red Lodge district is a 45-mile-square area near the southeastern end of the Beartooth Range just north of the Montana-Wyoming boundary. In contrast to the stratiform deposits of the Stillwater complex, the Red Lodge chromite deposits consist of irregular pods and lenses in remnants of sill-like masses of serpentine. The serpentine, an alteration product of original olivine and pyroxene rocks, occurs as roof pendants in gneissoid Precambrian granite. Chromite deposits range in size from bodies a few feet square to a lens averaging 40 feet wide by 150 feet long; they contain from a few pounds to as much as 35,000 tons of chromite. The size of the deposits is not related to the size of the enclosing serpentine bodies, and neither chromite nor serpentine extends to any great depth. The pure chromite mineral varies considerably in composition; Cr_2O_3 contents range from 36 to 52 percent, and Cr:Fe ratios range between 0.7:1 and 2.1:1.

Chromite was first discovered in the Red Lodge area in 1916; in 1933 Montana Chrome, Inc., was organized to develop the deposits (Schafer 1937, pp. 21–34). In the period 1941–43 the U.S. Geological Survey, in cooperation with the U.S. Bureau of Mines, mapped and evaluated the chromite deposits (James, 1946; Herdlick, 1948). In 1941 the U.S. Vanadium Corp., as agent for the Government, began development work in the area and built a mill in Red Lodge. U.S. Vanadium Corp. mined a total of 67,943 long tons of ore, from which were obtained 21,958 long tons of lump ore averaging about 32 percent Cr_2O_3, and 11,689 long tons of concentrates averaging about 40 percent Cr_2O_3. Operations ceased in 1943. Estimated chromite reserves based on data by James (1946, p. 178) are equivalent to about 4,600 long tons of Cr_2O_3 content in the ground.

The Sheridan deposits occur in an area in the northern part of Madison County bounded by the towns of Sheridan, Silver Star, and Pony. The deposits are irregular pods and lenses in sill-like masses of altered ultramafic rocks, and are very similar to those of the Red Lodge area. The largest chromite deposit reported was between 5 to 25 feet wide and 250 to 300 feet long. The chromite of the Sheridan deposits is somewhat lower in grade than those of the Red Lodge area; reported Cr_2O_3 content of clean chromite ranges from 38 to 45 percent, and Cr:Fe ratios range between 0.8:1 and 1.3:1.

Chromite in the area was first described by Jones (1931), and later by James (1943). The Silver Star deposit was developed by the Silver Star Chrome Corp. in the period 1941–44, and several thousand tons of crude lump and concentrates were produced. Small amounts of chromite were also mined from nearby properties. All operations stopped in 1944, and remaining chromite reserves are equivalent to about 1,000 long tons of Cr_2O_3 in the ground.

CLAYS

(By U. M. Sahinen, Montana Bureau of Mines and Geology)

Clays have been a subject of interest and commercial significance in Montana for many years. Since World War II, with the growth of industry in the State, increasing interest has been shown in clays for ceramic use and as raw material for the manufacture of expanded shale lightweight concrete aggregate; and since the establishment of the Anaconda aluminum plant at Columbia Falls in 1955, interest in Montana clays as possible sources of alumina for the manufacture of metallic aluminum has rapidly increased.

The term "clay" is applied to a large variety of minerals, but the common concept is that of an earthy material which is plastic when wet; while in the plastic state it can be molded into many shapes and subsequently fired (baked) in kilns to a highly indurated product in an infinite number of forms ranging from common bricks to the most intricately designed pottery.

Clays can be classified into three broad categories based on composition and crystal structure: the kaolin group, composed essentially of hydrous aluminum silicates, that include the highest grade ceramic clays and most fire clays; the illite group, composed of complex micaceous silicates; and the bentonite group, composed essentially of montmorillonite. The bentonite group is described separately in another section of this report.

Since 1894 Montana has produced 1,017,389 tons of clay valued at $1,730,428. This includes miscellaneous clays used for heavy construction and fire clay (kaolin type mostly). The value per ton of fire clay in Montana is about four times that of other clays, excluding bentonite. Production of clay as a source of expanded shale lightweight aggregate was begun in 1959 by the Montana Lightweight Aggregate Co. in Billings. The Treasurelite lightweight aggregate plant at Great Falls began operations in 1960.

The uses of clay are innumerable and depend on quality. High quality white-firing dickite (kaolin) clay occurs in the South Moccasin Mountains (Dougan, 1947) but is not mined for lack of sufficient markets within economic freight-rate distances for the high-grade ceramic products that could be made from it. It is a high quality whiteware clay. Similar material, but in thin beds of doubtful economic importance, occurs on the south side of the Little Rocky Mountains.

Figure 15[1] shows the locations of clay pits and clay products plants in Montana. High-grade kaolin-type fire clay is mined at Armington, Mont. (fig. 15, locality No. 1), where it is associated with a workable coal bed. Siliceous fire clay is mined at a pit on Lost Creek just north of Anaconda (No. 2). A red kaolin clay has been mined from a deposit on Dyce Creek (No. 3), west of Dillon, for use as refractory patching in an electric furnace. Armington and Lost Creek fire clays are used as refractories in the Anaconda Co.'s smelters.

Common brick clay and clay suitable for the manufacture of tile and similar grade ceramic products has been mined from pits at Butte (No. 4), Deer Lodge (No. 5), Missoula (No. 6), Thompson Falls (No. 7), Whitehall (No. 8), Blossburg (No. 9), Great Falls (No. 10), Havre (No. 11), Lewistown (No. 12), Billings (No. 13), and Fromberg (No. 14). At present, brick plants are in operation at Helena, Great Falls, Lewistown, and Billings. A plant at Havre is presently inactive.

The newest use of clay in Montana is in the manufacture of lightweight aggregate for concrete. For this use a clay is needed that will expand to a firm cellular product when heated suddenly to the temperature of incipient fusion. For economic practice this temperature

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

should not exceed 2,200° F. Many of Montana's bentonite clays and shales, which are useless for the manufacture of ceramic products, are admirably suited for this purpose. At present, the Treasurelite Co. of Great Falls utilizes bentonitic clay from the Blackleaf formation of early Cretaceous age. In the Billings area, the bentonitic Claggett shale of Late Cretaceous age is expandable. At Three Forks the Builder's Products Co. will soon be expanding shale for lightweight aggregate from a pit in Colorado shale of Cretaceous age, a few miles north of Logan (fig. 15, No. 15). Expandable clay shales have also been found near most of the principal towns and cities of Montana. In 1960 nearly 40,000 tons of clay were used for expansion into lightweight aggregate—and the industry is due to expand.

The Montana Bureau of Mines and Geology is conducting a survey of Montana's clay resources, and a great many deposits have been sampled. The sampling sites and the analyses of these samples have been published in progress reports of the Montana Bureau of Mines and Geology (Sahinen and others, 1958, 1960, 1962).

Although some high-alumina clays have been found in Montana, no published data is available on their usefulness as a source of alumina for the manufacture of metallic aluminum.

COPPER

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Copper is one of the metals vital to the needs of an industrial economy. Prior to 1927 the United States supplied more than 50 percent of the world's production of copper. In 1961 domestic mine production of 1,165,155 tons of copper was the highest of record (U.S. Bureau of Mines Minerals Yearbook 1961, vol. 1, p. 497) but this was only 23 percent of world production. Since about 1938 consumption has exceeded domestic production, and the United States became dependent on foreign sources to make up the deficit. However, in 1960 and 1961, domestic production and consumption were nearly in balance.

Montana has long been one of the three important copper-producing States. In 1961 it produced 104,000 short tons of copper, or approximately 8 percent of that produced from domestic ores. Of about 47,176,425 short tons of copper produced from domestic ores from earliest records through 1961, Montana has produced 7,683,960 short tons or approximately 16.2 percent. This is a little less than half the total production of Arizona (17,782,444 short tons), and a little less than that of Utah (8,392,059 short tons) (U.S. Bureau of Mines Minerals Yearbook 1961, vol. 1, p. 499).

In contrast to Arizona where copper is, or has been, produced from at least a dozen major mining districts, more than 99 percent of the entire Montana production has come from a single area, the Summit Valley district—better known as the Butte district. Essentially all of the copper of the Butte district—and most of the zinc, lead, manganese, and silver—has been produced from an area 2½ miles wide and 5 miles long (Hart, 1935, p. 289). The copper deposits form a series of steeply dipping veins in a fissure system of great complexity, cutting quartz monzonite as well as dikes of aplite and quartz porphyry. The ore, found mainly as replacements along fissures, contains pyrite, chalcocite, enargite, tennantite, bornite, sphalerite, chalcopyrite, and covellite in a scant gangue of quartz (Lindgren, 1933, p. 615–616). A primary zoning of the ore has been recognized with a central copper zone, an intermediate zone with copper and zinc, and a peripheral zone with zinc, lead, and manganese. Silver enrichment is common in the peripheral zone (Sales, 1914, p. 58; Hart, 1935, p. 297).

In the eastern part of the Butte district, the veins tend to become discontinuous, lose their identity, and break up into a series of narrow, closely spaced transverse fractures, known locally as horsetail structure. Ore has been mined from the "horsetail" area for many years, but with the successful introduction in the Butte district a few years ago of lower cost block-caving and open pit methods of mining, the "horsetail" area has become of increased economic significance.

Copper is found in many localities outside the Butte district. The more important of these are the Hellgate and Radersburg districts in Broadwater County; the Basin, Boulder, and Wickes districts in Jefferson County; the Hecla and Utopia districts in Beaverhead County; the Heddleston district in Lewis and Clark County; the Neihart district in Cascade County; the Philipsburg district in Granite County; and the New World district in Carbon County (fig. 16). With the exception of the ankerite-quartz-chalcopyrite deposits of the Hellgate district (Pardee and Schrader, 1933, pp. 165–166) and the contact metamorphic deposits of the Utopia district (Winchell, 1914, pp. 63–64; Myers, 1952, p. 36) nearly all of the copper was mined from deposits chiefly valuable for other metals. Total production of copper from these districts is probably of the order of 150 million pounds, but this represents only about 1 percent of the total production of the State. Numerous other occurrences of copper are known in the State but few of these have produced more than a few tons of ore. Their locations are indicated on figure 16.[1]

Copper ore was known in Butte as early as 1865 but early attempts to smelt the ore were unsuccessful. Copper mining did not begin in earnest until 1882, when the construction of a successful smelter and the coming of a railroad made copper mining at Butte feasible (Weed, 1912, pp. 18–19). Developmentwas rapid, and by 1896 yearly copper production from Butte reached 100,000 tons (fig. 17) and consistently exceeded this figure until the 1930's with the exception of a short period following World War I. Since the depression years, the value of Montana's copper production has followed an upward trend, and in 1961 totaled $62,400,000, a figure exceeded only in 1956 and by the World War I peak of 1916–18. However, since 1944, only in 1961 has the annual tonnage of copper—as contrasted with the dollar value of the production—exceeded the 100,000-ton figure which was so consistently maintained from 1896 through 1918.

Although it is by no means inconceivable that significant copper discoveries may be made in Montana outside of the Butte area, copper mining in Montana for the foreseeable future is tied to the Butte district. Despite its 80 years of continuous production, the outlook for Butte seems brighter than it has in recent years. Development of low-cost methods of extraction through block caving through the Kelly shaft, and open-pit mining at the Berkeley pit, have added large tonnage of low-grade ore to the reserves. Recent development of the Butte veins in depth is reported to have resulted in a significant addi-

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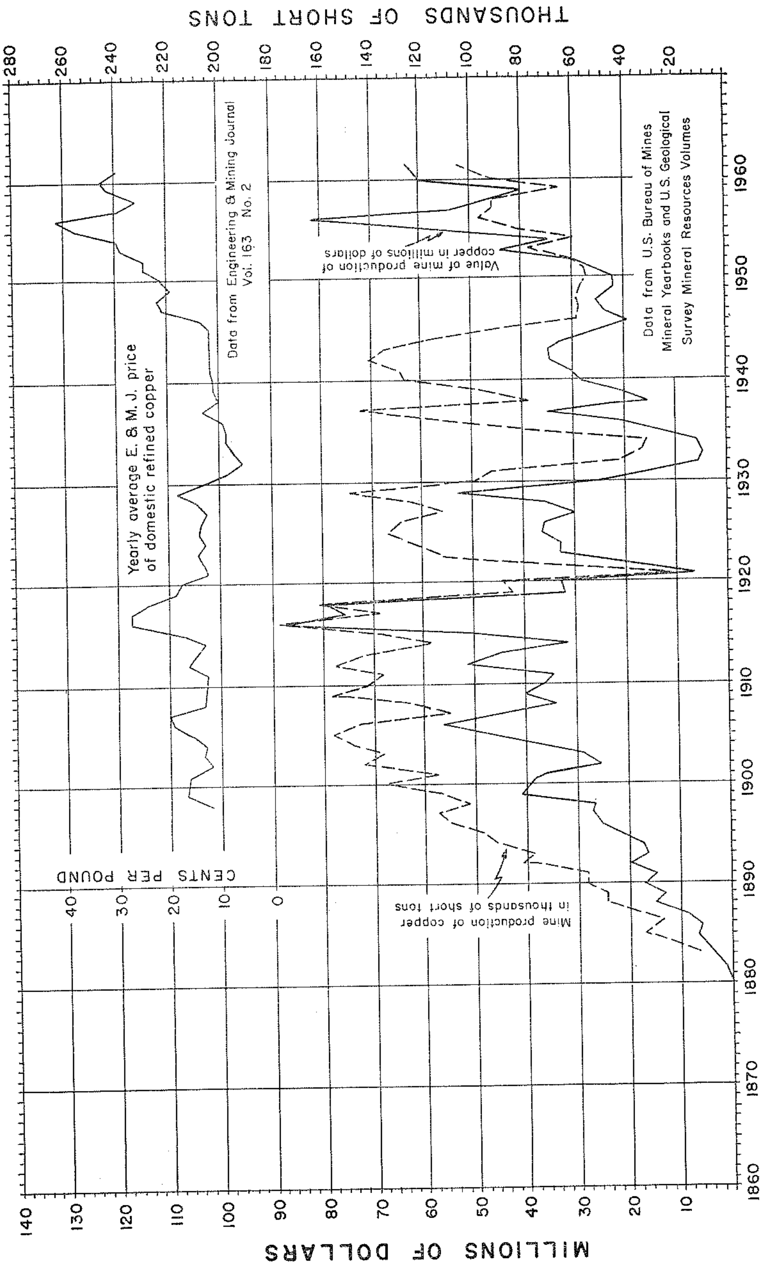
[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

FIGURE 17

MONTANA COPPER PRODUCTION



tion to the reserves of high-grade ore. E. P. Shea, chief geologist, Montana Division, Anaconda Co., stated [2] recently that Butte ore reserves are at an all-time high. It seems, therefore, that if market conditions permit, Butte can continue to produce copper at an annual rate of 100,000 tons for an indefinite period.

FLUORSPAR

(By R. D. Geach, Montana Bureau of Mines and Geology, Butte, Mont.)

Fluorspar is the commercial term for the mineral fluorite (CaF_2). It displays a wide array of colors, ranging from colorless, yellow, green, and blue, to purple. Fluorite is harder than calcite and softer than quartz, but heavier than either one. Use is made of this latter property as both calcite and quartz are commonly intermixed with fluorite in nature, and an upgraded fluorspar product can sometimes be made by using mineral dressing techniques based on specific gravity.

Major use of fluorspar is in the iron and steel and aluminum industries. In the aluminum industry, high-grade fluorspar is used to produce hydrofluoric acid, a primary ingredient in the manufacture of synthetic cryolite and aluminum fluoride for electrolytic reduction of alumina. The iron and steel industry utilizes fluorspar principally in the basic open-hearth steel process, where it reduces the viscosity of the slag and assists materially in dissolving lumps of lime which may have resisted fusion. Amounts as high as 10 pounds per ton of steel may be used; and in 1961, out of a total fluorspar consumption by industry of 681,833 tons, 155,938 tons were used for this purpose (Kuster and Schreck, 1962, p. 571).

Ceramic consumption (35,589 tons in 1961) of fluorspar is less than that consumed in the aluminum and the iron and steel industries, but nevertheless its use is vital in the production of enamels for coating steel and cast iron, and in the manufacture of opal and flint container glass.

Hydrofluoric acid, derived from fluorspar, is a starting material for a diversity of chemical compounds. Refrigerants, fluo-carbon elastomers, plastics, and drugs are but a few items requiring hydrofluoric acid for their manufacture. The catalytic action of hydrofluoric acid is used in the manufacture of high-octane aviation fuel.

Fluorspar is marketed under three grades, acid, ceramic, and metallurgical. Acid-grade fluorspar is the source material for production of hydrofluoric acid (1961 production, 412,155 tons) and must contain at least 97 percent CaF_2 with specific limitations on quartz, calcite, and sulfur content. Specifications for ceramic-grade fluorspar, however, are not as high, and depend somewhat on qualifications set forth by the buyer; in general, acceptable raw material must contain at least 95 percent CaF_2, and the amount of quartz, calcite, and iron oxide is limited. Metallurgical-grade fluorspar (1961 production, 228,181 tons) must contain at least 60 percent effective CaF_2—effective CaF_2 is that percentage of CaF_2 remaining after subtraction of 2.5 percent CaF_2 for each percent of SiO_2 in the raw material.

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[2] The Glittering Hill 80 years later, geology; paper given at the Seventh Annual Rocky Mountain Minerals Conference, Butte, Mont., September 1962.

Fluorspar occurrences in Montana are many and varied. Sahinen (1962, p. 5) has grouped the deposits into the following three geologic provinces:

1. Deposits related to the Idaho batholith.
2. Deposits related to the Boulder batholith.
3. Deposits related to the Potassic province of central Montana.

Each will be considered separately in following paragraphs. The discussion is largely drawn from Sahinen's report (1962).

The fluorspar deposits related to the Idaho batholith are, and have been, the primary producers of commercial ore in Montana. Most deposits are in the Belt series of Precambrian age, or their metamorphosed equivalents, and are within the contact zone of the Idaho batholith. They are similar mineralogically in that they all contain masses of quartz and calcite as well as fluorite.

The Crystal Mountain deposit in Ravalli County is the State's largest individual producer, having been brought into production in 1952 (fig. 18).[1] The host rock is granite and fine-grained gneiss; the trend of the ore bodies is east-west. The fluorite ranges in color from white or pale green to deep purple. Gangue minerals are altered feldspar, sericite, quartz, and biotite. Massive quartz overlies the west outcrop. Reserves are not known, but the ore is reported to contain more than 96 percent CaF_2. Presently (1962), the deposit is mined by the Roberts Co. of California. Their product is used for metallurgical purposes.

The Snowbird property in southwestern Mineral County and the Spar property in the central part of the same county are in some respects similar types of occurrences. However, they contrast with the Crystal Mountain deposit in that they are nowhere in contact with igneous rock. Massive quartz and calcite are present in large amounts. Both deposits were productive in the late forties to 1950, and though they are considered exhausted, it is conceivable that similar fluorspar deposits might be disclosed through exploration and development work.

The more promising fluorspar deposits related to the Boulder batholith occur near the boundary of the granitic and surrounding rocks. Examples are the Albion mine in eastern Granite County, the Silver Bow deposit in Silver Bow County, the Bald Butte and Boeing prospects in Lewis and Clark County, and the Boulder Mountain and Normany prospects in Broadwater County. Others are the Jetty and Weathervane prospects in Deer Lodge County. No commercial ore bodies of fluorspar are known in any of these properties. However, fluorite appears to be associated with the metalliferous veins, and minable fluorspar bodies may yet be found.

The Potassic Province is an area in central Montana characterized by alkali intrusives, particularly syenitic rocks. It includes the Belt, Highwood, Bearpaw, Little Rockies, North and South Moccasin, and Judith Mountains, and the Sweetgrass Hills. In this province fluorite occurs in veins and disseminations within the syenite, and as veins and replacement deposits in the surrounding limestones. The more promising seem to be those localized in zones in Madison Limestone of Mississippian age. The best known are those in the Sweetgrass Hills in Liberty County, particularly those in the Tootsie Creek area (Ross, 1950, p. 195).

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Other fluorspar occurrences within the Potassic Province are in the South Mocassin Mountains, the Judith Mountains, and the Little Rocky Mountains. Here its general occurrence is as a gangue mineral in gold and lead-silver veins, narrow stringers in or near fault zones, disseminations and replacements in the Madison limestone, and fine seams or disseminations in rocks of syenitic composition. Even the best deposits probably are too small to be considered of commercial significance.

An important potential source of fluorine, though not of the mineral fluorite, is also present in Montana. The Phosphoria formation of Permian age contains a large reserve of phosphate in the State, and is being mined at many places (see chapter on phosphate). The phosphate occurs as the mineral carbonate-fluorapatite, which contains approximately 1 percent fluorine for each 10 percent P_2O_5 (Altschuler, Clarke, and Young, 1958, p. 49). No phosphate processing plant in Montana is currently recovering fluorine, but under certain conditions it is technically feasible to do so. The tonnage of rock treated is great enough to make Montana phosphate rock an important potential source of fluorine.

GEMS AND GEM MATERIALS

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Gems and gem materials are naturally occurring substances that combine the properties of beauty, rarity, and durability in sufficient degree to make them prized for personal adornment.

A wide variety of minerals have been used as gems. Many of them are found in placers, where their durability and weight permit their concentration. A few are recovered from lode deposits.

Prices of gemstones depend on their scarcity, their beauty, and their popularity. Prices range from thousands of dollars per carat for best-quality rubies, sapphires, and emeralds to a few cents per carat for some of the varieties of quartz (Jahns, 1960, p. 435). Certain gem material is also used in industry. Diamond and corundum, because of their great hardness, are used in dies, bearings, abrasives, and as cutting agents. Garnet is a widely used abrasive. Quartz, calcite, and fluorite are used as piezoelectric elements in strain gages.

Montana contains several deposits and occurrences of gemstones (fig. 19).[1] The most valuable are the sapphires, which have been found in several places. In fact, the Montana sapphire deposits comprise the most valuable gemstone deposits in the United States. Sapphire is the term given to the colorless, yellow, or blue varieties of the mineral corundum (Al_2O_3). The red variety is called ruby. Although corundum found in Montana has a variety of colors, very few rubies have been found. However, the highly prized "cornflower blue" sapphire occurs in several places, and is especially characteristic of the well-known deposits at Yogo Gulch, Judith Basin County (Clabaugh, 1952, p. 21–22).

The importance of Montana sapphire deposits is indicated by past production figures; \$3 to \$5 million worth of stones have been produced. Material from Yogo Gulch alone, prior to 1929, was worth about \$2½ million in the rough; cut stones from that deposit have a present value

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

of more than $25 million (Clabaugh, 1952, p. 2) (fig. 19, locality No. 1). Production from this deposit has been intermittent since 1929, but some 20,000 carats were recovered in 1958 (Sinkankas, 1959, p. 60). About 20 percent of this material was of gem quality.

Yogo Gulch sapphires occur in a nearly vertical pyroxene-biotite dike that intrudes Madison limestone. The dike is almost 5 miles long and is from 8 to 20 feet in width. Sapphires are distributed uniformly throughout the dike, and the average yield has been estimated to range from 20 to 50 carats per ton of rock (Clabaugh, 1952, pp. 11–18). Sapphires were first found in gold placers in Yogo Gulch some time after 1878, but the dike was not recognized as the source of the gems until later. The deposit has been extensively worked, both at the surface and at depth by underground methods, since the 1880's. The dike is altered to a soft, easily worked material in its upper part, and thus far all production has come from this material. Remaining reserves of altered material are about twice as great as the amount already mined; reserves below the present workings are undoubtedly many times larger (Clabaugh, 1952, p. 34).

The first Montana sapphires were found in gravels along the Missouri River northeast of Helena. These placer deposits are chiefly in gravel beds or terraces as much as 200 feet above river level. Sapphires were found at Magpie Gulch (No. 2), about 15 miles due east of Helena, and at American Bar (No. 3). Early attempts to mine the gravels were not encouraging, and operations were mostly small and sporadic until about 1940, when construction of dams and submergence of some of the deposits made large-scale gold dredging possible. Sapphires have since been recovered as a byproduct of gold dredging, but most of these stones have been sold for industrial purposes.

The Rock Creek sapphire deposits on the north side of the West Fork of Rock Creek, about 16 miles southwest of Philipsburg, Granite County (No. 4), are in gravels. Fragments of igneous rock similar to the sapphire-bearing dike near Canyon Ferry have been found, but neither the dike nor the gems have been found in place. Sapphires from this locality generally show a wide range of deep colors.

The upper 4 miles of the South Fork of Dry Cottonwood Creek, Deer Lodge County (No. 5), have been worked for sapphires, but the source rock has not been identified; recovery has apparently been entirely from alluvium and residuum. Most of the stones are of poor quality, and only a few thousand carats is believed to have been produced (Clabaugh, 1952, p. 54).

Sapphires have been reported from other localities in Montana, but the deposits listed above appear to exceed all others in productivity and reserves. It is of interest to note that all of the gem-quality sapphires in Montana have come from such rocks. Deposits of corundum are also known in metamorphic rocks in Gallatin and Madison Counties, but no gemstones occur in these deposits (Clabaugh, 1942, p. 58) (Nos. 6 and 7). In terms of dollar value, the sapphire production of Montana far exceeds that of other gemstones.

A number of other gem materials are known to occur in Montana, and some may be better known than the sapphires. Moss agate, a translucent gray variety of chalcedony with black or brown dendritic inclusions, is a well-known semiprecious stone in Montana. Large quantities of this material are found in gravels along the Yellowstone River between Billings and Glendive. No commercial workings are known; collectors and gemcutters pick the rough stones from gravel bars along the river. The polished slabs cut from them are distinctive and are widely distributed in gift, souvenir, and rock shops. The quantity of moss agate collected each year in Montana is unknown but it is undoubtedly large enough to be of considerable value.

The Pohndorf amethyst mine, about 2 miles northeast of the Toll Mountain picnic grounds in southwestern Jefferson County (No. 8), was worked for many years. Clear, smoky, and amethystine quartz were recovered from cavities in pegmatite (Sinkankas, 1959, p. 356). This deposit is now believed to be worked out, but similar occurrences are known in the area.

Almandine garnet, occurring as small but good quality grains and fragments, is abundant in the gravels of the Ruby River upstream from Alder, Madison County (No. 9). Rhodochrosite, a pink manganese carbonate ore, has been mined from deposits in Butte (No. 11) and Philipsburg (No. 12) and some specimens have been collected for gem material. Rhodonite, a pink manganese silicate, has also been mined at Butte. Gem quality quartz is known in a number of places, as is silicified wood. Clear calcite, which is sometimes used as a novelty gem, has been mined from several viens in Park (No. 13) and Sweet Grass (No. 14) Counties for use in optical instruments (Stoll and Armstrong, 1958). (See also chapter on optical calcite.)

GOLD

(By A. E. Weissenborn, U.S. Geological Survey)

Most of the data on the individual gold-producing districts of Montana have been abstracted from an unpublished treatise on the occurrence of gold in the United States by A. H. Koschmann and M. H. Bergendahl of the U.S. Geological Survey. Because of the untimely death of Mr. Koschmann, publication of this volume has been delayed. Mr. Bergendahl has kindly allowed the writer to make use of the chapter on Montana in preparing this report. Without access to the great mass of information so painstakingly compiled from many sources by these men, the following summary could have been prepared only in a most superficial form.

Gold has been prized since earliest times and has been mined in almost every part of the world. Because of its wide distribution, its relative scarcity, and its indestructibility, it has been used for monetary purposes since the beginning of history. Because of its beauty, its resistance to tarnish and corrosion, its malleability, and its high value, it is much used for jewelry and in the decorative arts. It has limited but important uses in industry.

Although Montana currently ranks only about ninth among the gold-producing States, the discovery of gold and the resultant influx of population had much to do with the early development of the State. Total gold production is not accurately determinable, but best estimates (U.S. Bureau Mines Minerals Yearbooks 1960 and 1961) credit Montana with a production from 1862 through 1961 of 17,657,400 ounces valued at $402,475,000, including both placer and lode gold, or about 6 percent of the total U.S. production. The bulk of the placer gold was produced before 1875 and probably most of it in the 1860's. From 1904 to 1961, as compiled from Mineral Resources and Minerals Yearbooks, the total gold production has been 6,219,865 ounces, of which 5,225,462 ounces has been derived from lode mining and 994,403 ounces from placer mining. Montana has 52 districts, in 17 counties, that have produced in excess of 10,000 ounces of gold each. Four districts—Butte, Helena, Marysville, and Virginia City—have produced more than 1 million ounces, and 27 districts have produced between 100,000 and 1 million ounces.

Many of the gold deposits of Montana and their associated placers are found near the margins of granitic rocks or in roof pendants in these rocks. As shown by Pardee and Schrader (1933), most of the principal gold districts are centered around the Boulder batholith and its satellite stocks (fig. 20[1] and fig. 4). All of the Montana gold deposits except those at Jardine are late Cretaceous or Tertiary in age; the Jardine deposits are regarded as Precambrian.

In Montana, as elsewhere in the West, placer gold deposits were the first ore deposits to be discovered. The placers along Gold Creek in Powell County, which were found in 1852, were the first discoveries of placer gold in Montana (Lyden, 1948, p. 118), but the discovery in 1862 of the placers along Grasshopper Creek near Bannock in Beaverhead County started the influx of prospectors into Montana (Winchell, 1914, p. 18). Other discoveries followed in rapid succession including the very rich deposits along Alder Gulch near Virginia City, which became the most extensive and productive in Montana. The Last Chance placers on the present site of Helena were discovered in 1864 (Knopf, 1913, p. 15) as were the placers in the Butte district (Weed, 1912, p. 18; Lyden, 1948, p. 144–145). Placer mining flourished during the late 1860's. Some of the deposits were quickly exhausted, but others were worked on a substantial scale until World War II. Since then very little placer mining has been done.

The first lode mine in Montana is said to have been discovered in 1862 in the Bannock district (Shenon, 1931, p. 27). Among the early rich lode discoveries were the Whitlatch-Union in the Helena district in 1864—the first patented claim in Montana—(Knopf, 1913, p. 15), several lodes in the Sheridan district (Winchell, 1914, p. 133), in the Argenta district (Winchell, 1914, p. 69), all in 1864, and several lodes in the Silver Star district in 1867 (Winchell, 1914, p. 139–140), including the Greene Campbell—the second claim patented in Montana. Lode production first became significant in the 1870's but until rail transportation became available in 1882 and 1883 only the richest ores could be mined.

Gold mining in Montana has followed a more or less regular pattern in most districts. Most of the bonanza placers and the richest and more easily mined lode deposits were exhausted in an initial period of feverish activity. Mining declined temporarily, but a second and longer period of activity ensued during which dredging and other mechanized methods replaced hand operations of the placer mines, and mills were constructed to treat lower grade ore at the lode mines. Production declined sharply as costs increased after the First World War. Mining reached a low ebb in the early 1930's but underwent a dramatic revival when the United States went off the gold standard in September 1933 and the price of gold was officially raised in January 1934 to $35 an ounce (fig. 21). Gold mining declined drastically after October 1942 when a governmental order (L–208) prevented acquisition of vital supplies. Many gold mines were reopened after the end of the Second World War but few were able to

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Table 5

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continue for more than a few years. In the face of rising costs, gold mining as such declined drastically, and since about 1950 most of Montana's production of gold has been derived as a byproduct from base metal mining—chiefly at Butte. Lode gold mining in Montana is now essentially confined to small operations, and placer gold mining has nearly ceased to exist; production from this source was only 132 ounces in 1961, and 135 ounces in 1960. Figure 21 illustrates this decline very clearly. The story of gold mining in Montana thus is largely a recital of past glories. Montana will continue to produce substantial quantities of gold from the operation of its base-metal mines but only a drastic change in the price of gold relative to that of other commodities would induce a revival of gold mining such as occurred in the 1930's.

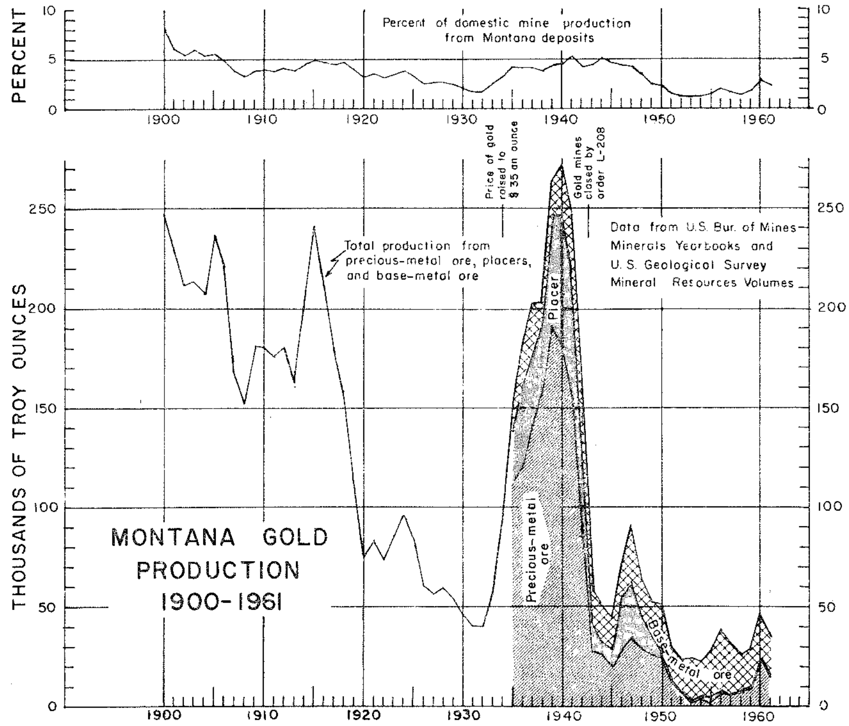

FIGURE 21.—Montana gold production, 1900–61.

The occurrence and production of gold by counties is summarized in the following pages and the salient features of all of the Montana districts which have produced 10,000 or more ounces of gold are tabulated on table 5. The locality numbers in the text and the tabulation correspond to the numbered locations on figure 20, which has been taken from Koschmann and Bergendahl's report (1962).

BEAVERHEAD COUNTY

Beaverhead County has produced at least 370,000 ounces of gold, but early records are incomplete. Before 1900, production from placers was probably considerably larger than production from lodes.

From 1904 through 1958 the county has a recorded production of 116,350 ounces of lode gold and 14,800 ounces of placer gold.

The gold deposits are found chiefly in the northern half of the county where the Mount Torry granitic stock and several smaller satellite lobes have intruded Precambrian, Paleozoic, and Mesozoic sedimentaty rocks (Corry, 1933, fig. 6). Most of the gold came from the Bannock, Argenta, and Bryant (Hecla) districts (localities 1, 2, and 3). The placer deposits in the Bannock district were the first significant gold discoveries in Montana and were responsible for the first rush to the territory. The Bannock district was also the site of the first lode discovery in Montana (Shenon, 1931, p. 27).

BROADWATER COUNTY

The placers of Broadwater County were among the most productive in the State. Records prior to 1903 are not available but from 1904 through 1959 the county has a recorded production of 318,000 ounces from lodes and 34,000 ounces from placers. Lode gold production prior to 1903 probably was small. The total gold production from the county from the beginning of mining through 1960 is probably between 900,000 and 1,225,000 ounces. Production has come mainly from two rich placer districts (Confederate Gulch and White Creek) (Nos. 4 and 5) on the west flank of the Big Belt Mountains, and the Winston, Park, and Radersburg districts (Nos. 6, 7, and 8) on the east side of the Elkhorn Mountains.

CASCADE COUNTY

Gold production in Cascade County came almost entirely from lode deposits in the Neihart (Montana) district (No. 9). Gold is chiefly a byproduct from the mining of silver-rich, base-metal ores. The total recorded gold output of the district is about 67,000 ounces. The more important ore deposits occur as veins in Precambrian gneisses, schists, and diorite; along contacts of these rocks with Tertiary intrusives and, in a few instances, as low-grade disseminated deposits in Tertiary intrusive bodies. Gold is dominant only in the Snow Creek area where the gold-silver ratio of the ores is high.

DEER LODGE COUNTY

Deer Lodge County has produced both placer and lode gold. The Georgetown district (No. 11) has yielded most of the lode gold; the French Creek district (No. 10) most of the placer gold. Records of early production, particularly of placer gold, were not kept but the county is believed to have yielded at least 470,000 ounces of gold, about 425,000 ounces of which was from lode mining. The most productive mines were the Cable and the Southern Cross in the Georgetown district.

FERGUS COUNTY

Although it is far east of the main mining area in the State, Fergus County has had a respectable production of gold, almost all of it from lodes. Most of the output has come from the Warm Springs district in the Judith Mountains (No. 12) and from the North Moccasin district in the North Moccasin Mountains (No. 13). Total production from 1886 through 1950 was about 653,000 ounces; periods of greatest activity were from 1901 through 1922 and from 1936 through 1942. Production of other metals has been insignificant.

GRANITE COUNTY

Early records are inaccurate or nonexistent but Granite County is estimated to have produced a minimum of about 710,000 ounces of gold from the beginning of mining through 1962. Of this, 332,000 ounces is thought to be placer gold and 376,000 ounces is lode gold. Most of the lode gold was a byproduct of ores that were mined for small amounts of copper, lead, and zinc. Chief districts are the First Chance (No. 14) in the Garnet Range, Henderson Gulch on the east flank of the John Long Mountains (No. 15), and Boulder Creek and Flint Creek (Philipsburg) in the Flint Creek Range (Nos. 16 and 17).

JEFFERSON COUNTY

Mining began in Jefferson County about 1864 with the discovery of silver, lead, and gold at Wickes (Pardee and Schrader, 1933, pp. 232–234) and has continued at a fluctuating rate to the present. Gold mining declined during the 1920's but activity increased after the price of gold was raised in 1934. Since 1950, gold mining again has been reduced sharply. Through 1960 Jefferson County has produced a minimum of about 735,000 ounces of gold—615,000 ounces from lodes and 125,000 from placers. Except for the Whitehall district (No. 21) all the gold-producing areas are in the northern part of the county. They include the Clancy-Wickes-Colorado, Basin and Boulder, and Elkhorn districts (Nos. 18, 19, and 20). The lode gold deposits are found in granitic rocks of the Boulder batholith and in the invaded sedimentary and volcanic rocks near the contact.

LEWIS AND CLARK COUNTY

Lewis and Clark County has produced well over 4 million ounces of gold, about equally divided between placer and lode gold. Two districts within the county—Helena and Marysville—has each produced in excess of 1 million ounces, and six others have produced in excess of 100,000 ounces.

Mining began in 1863 or 1864 with discovery of placer gold in the Sevenmile-Scratchgravel district (No. 25) 4 miles northwest of the present site of Helena. Other rich lode and placer deposits were discovered soon afterward in the Helena region. Most of the placers and some of the lodes were soon exhausted, and by 1900, mining had dwindled to small-scale operations. After the price of gold was raised in 1934, gold mining, both lode and placer, again became a major industry, but declined again after 1942.

The Helena (Last Chance) placers (No. 23) have been the most productive in the county; the Marysville district (No. 26) has been the largest producer of lode gold. Other gold districts are Missouri-York (No. 24) east of the Missouri River, and the Rimini-Tenmile, Stemple-Virginia Creek, McClellan, and Lincoln districts (Nos. 22, 27, 28, and 29).

LINCOLN COUNTY

The mining of gold has been a relatively minor activity in Lincoln County but the county has produced since 1901 a minimum of about 29,000 ounces from lodes and 2,500 ounces from placers. There is no record of earlier production although both lode and placer mines were worked prior to 1901. Most of the lode production has come from the Libby and Sylvanite districts (Nos. 30 and 31); the placer production has come chiefly from the former.

MADISON COUNTY

Madison County ranks third in gold production in Montana, following Silver Bow and Lewis and Clark Counties, and is one of the three counties that has produced more than 1 million ounces. The greater part of the Madison County production has come from placer deposits, and most of it came from Alder Gulch during the first few years following discovery. Small amounts have been produced from at least 40 other gulches, but none of these has been a consistent producer. Unlike other gold-producing areas, placer mining in Madison County was but little affected by the rise in the price of gold in 1934.

Gold lodes are numerous and are found chiefly near the contacts of Precambrian and Paleozoic rocks with the Tobacco Root batholith and smaller intrusives and satellitic stocks. Minimum total gold output of the county is 3,707,600 ounces—2,507,250 from placer and 1,200,000 from lode mining.

The chief gold-producing districts are Virginia City-Alder Gulch (No. 32), Norris (No. 33), Pony (No. 34), Renova (No. 35), Silver Star-Rochester (No. 36), Tidal Wave (No. 37), and Sheridan (No. 38).

MINERAL COUNTY

Practically the entire gold output of Mineral County has been derived from placer deposits along creeks that drain the east slope of the Bitterroot Mountains; the known lode deposits have produced only minor amounts of byproduct gold. The two most productive areas are the Cedar Creek and Trout Creek districts (Nos. 39 and 40). Output is estimated at 120,000 ounces, most of which was recovered before 1908.

MISSOULA COUNTY

Gold production in Missoula County has come mainly from placer deposits in the Ninemile and Elk Creek-Coloma districts (Nos. 41 and 42) which have yielded 152,000 to 225,000 ounces of gold. Lode mining in the Elk Creek-Coloma district in the Garnet Range north of the better known Garnet district (No. 14) accounts for an additional 17,000 ounces.

PARK COUNTY

Placer gold was discovered in 1862 near Gardiner, but the bulk of the gold has come from the lodes of the Jardine district (No. 44) with a smaller amount produced as a byproduct of silver-lead deposits in the New World district (No. 45). A still smaller amount has been contributed by the Emigrant Creek district (No. 43). Lodes and placers have produced a total of about 286,000 ounces of gold, of which placers have accounted for 16,000 ounces.

PHILLIPS COUNTY

The entire metal production of the county has come from two closely-spaced areas in the Little Rocky Mountains, the Zortman-Landusky or Little Rocky Mountains district (No. 46), the easternmost gold-producing area in Montana. Placers were discovered in 1884 and lode deposits in 1893. The deposits are chiefly gold- and silver-bearing veins in a porphyritic laccolith which has intruded Precambrian schist and Paleozoic sedimentary rocks. Of lesser importance are disseminated deposits in porphyry and replacement bodies in limestone. Early activity was sporadic but the district flourished between 1905 and about 1912 and, except for the war years, again from the early 1930's through 1950. It has been nearly dormant since.

Total lode gold production is estimated at about 380,000 ounces. Recorded placer production dating back only to 1928 has been trivial.

POWELL COUNTY

Most of the gold produced in Powell County has come from placer deposits in the southern part of the county. The discovery in 1852 of gold-bearing gravels along Gold Creek is said to be the first discovery of gold in Montana (Lyden, 1948, pp. 118–120) although the placers were not worked until 1862. Placer gold has come chiefly from the Finn, Ophir, and Pioneer districts (Nos. 47, 48, and 49); lode production from the Ophir and Zosell districts (Nos. 48 and 50). Estimated production totals 539,000 ounces of placer gold and 50,000 ounces of lode gold.

RAVALLI COUNTY

Most of the 9,000 ounces of gold produced in Ravalli County since 1903 has come from placer deposits in the Hughes Creek district (No. 51). These were discovered in the early days of mining. Since 1946 production has been small and sporadic. Total production is probably in excess of 10,000 ounces.

SILVER BOW COUNTY

Silver Bow County is the leading mining county in Montana. Most of the gold has come as a byproduct of mining copper and other base metal in the Summit Valley (Butte) district (No. 52), but the Highland district (No. 53) has also produced both lode and placer gold. Early records are lacking but the total amount of gold recovered from Silver Bow County may be in excess of 4 million ounces; 2,406,000 ounces is the recorded production of the Butte veins—the remainder has come from placer mining and the Highland district lodes.

GRAPHITE

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Graphite is pure crystalline carbon. It is characterized by its black color, extreme softness, complete opacity, high electrical and heat conductivity, and great resistance to chemical decomposition under all conditions. It is insoluble in all common chemical reagents, but decomposes slowly in the presence of oxygen if heated to 600°–700° C.

Graphite is a common and widespread mineral in metamorphic rocks, although minable concentrations are rare. It also occurs in veins and in thermally metamorphosed coal seams. The three geologic environments in which it occurs produce three distinctive commercial types: lump and chip, flake, and "amorphous." Vein graphite deposits, which produce lump and chip graphite, are rare; flake graphite is widespread in metamorphic rocks in many parts of the world. "Amorphous" graphite (actually extremely fine-grained crystalline graphite) comes only from metamorphosed coal seams.

Important uses are as carbon brushes for electric motors (lump); crucible and refractory wares, and lubricant (flake); foundry facings, paints, rubber, dry-cell batteries, and pencil leads (amorphous).

Montana has one known commercial graphite deposit located about 10 miles southeast of Dillon in Beaverhead County (Perry, 1948, p. 13). This deposit, the Crystal Graphite mine, has been worked intermittently since about 1902 (Cameron and Weis, 1960, p. 252), and total production is on the order of 2,200 tons. Most of the material was mined during World War I; no production is reported after 1948.

The deposit contains lump graphite in veins that cut the Precambrian Cherry Creek Group. Wall rocks are principally gneiss and schist, with local pegmatites and some quartzite and dolomitic marble (Armstrong and Full, 1950). Veins appear to be fracture fillings around the nose of a plunging isoclinal fold. The graphite resembles the material mined in Ceylon, which, for many years, has furnished, essentially, the entire world supply of this type. Although high-grade graphite is present in the deposit, tonnage does not appear to be great, and distribution is erratic and difficult to predict.

Crystalline graphite is also reported from an occurrence on Kate Creek, about 15 miles southwest of Armstead. Reserves and quality are not known (Sahinen and Crowley, 1959, p. 15).

GYPSUM AND ANHYDRITE

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Gypsum, the hydrated calcium sulfate, and anhydrite, the anhydrous form, are salts formed by the evaporation of sea or lake water of appropriate composition. The country's reserves of both minerals are very large, although some of the largest and purest deposits are too far from major markets to be worked profitably under present conditions (Withington, 1962, p. 1). Of the two minerals, gypsum is the most widely used.

Gypsum is used extensively in the building industry. It is calcined to drive off some of the water of hydration, then ground for use in plaster, wallboard, lath, sheathing, tile, and related interior construction materials (Havard, 1960, p. 485). Many other uses exist, but major uses in 1961 were as follows: building industry, about 9.1 million tons; calcined gypsum for industrial uses, 258,000 tons uncalcined gypsum used in cement, agricultural gypsum, etc., about 3.9 million tons. Of somewhat more than 13 million tons used in the

United States, about 9.3 million tons were from domestic deposits (Kuster and Jensen, 1962, p. 629–642).

Montana has large reserves of gypsum, but in 1961 only one deposit was being worked. Production in Montana for the period 1926–59 amounted to 2,827,726 short tons, valued at more than $12,768,000 (R. D. Geach, Montana Bureau of Mines and Geology, written communication, 1962). Deposits of commercially important gypsum are exposed in outcrops of four formations: the Ellis formation near Lewistown and in parts of Cascade and Meagher Counties (fig. 22,[1] localities Nos. 1 and 2); the Chugwater formation near Bridger, Lodge Grass Creek (No. 3); the Otter formation in central Montana near Riceville (No. 4); the Kibbey sandstone in central Montana near Kibbey and Lingshire (No. 5), and in southwest Montana near Lima (No. 6) (Sahinen and Crowley, 1959, p. 16; Perry, 1949).

In the Gravelly Range a large tonnage of gypsum formed from hot springs can be observed at irregular intervals along the north slope of the valley of Cottonwood Creek from the south end of Monument Ridge to stream level 2 miles west. Along the Gravelly Range Ridge road east of Monument Ridge there are several extinct geysers with mounds of white gypsum revealing their presence. The gypsum is in the Ellis group of Jurassic age (Mann, 1954).

In addition to the surface exposures of gypsum-bearing formations listed above, a large volume of gypsum-bearing material is present in buried sedimentary rocks in the Big Horn, Powder River, and Williston Basins (Withington, 1962). Montana's reserves of gypsum are therefore undoubtedly great enough to last for many decades; activity of the industry in the State depends on price of the commodity and demand for it, rather than presence of raw material.

IRON

(By R. D. Geach, Montana Bureau of Mines and Geology)

Iron and steel are the foundation of the industrial economy of the United States. No other metal is, or is likely to be, used in such large quantities for so many purposes.

Pure iron is too soft for most uses, and pig iron, the initial product of the blast furnace, is too brittle. Ultimate use is therefore mostly in the form of cast iron, wrought iron, steel, or one of the hundreds of alloys with iron and other metals. Much smaller quantities of iron are used for paint pigments, cements, and a host of other uses (Tucker, 1960). The United States consumes more than 100 million tons of iron ore each year.

Principal iron ore minerals are the oxides hematite (70 percent iron) and magnetite (72.4 percent iron). Smaller tonnages of iron have been produced from limonite, a mixture of hydrous oxides, and siderite, the iron carbonate, but neither has been a significant source of ore in this country. The largest iron deposits of the world are in Precambrian sedimentary iron formations or their metamorphosed equivalents, and ores of this type have provided by far the largest tonnage for world production.

Until the end of World War II, almost all of the iron ore mined in this country was shipped directly to the smelters without further

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

beneficiation other than washing. These crude and washed ores generally contained at least 50 percent iron; most shipping-grade ore contains from about 51 percent to about 60 percent iron, and a few deposits produced ore with as much as 68 percent iron. Since World War II, however, processes have been developed for concentrating and pelletizing lower grade ores, and the proportion of U.S. production that is upgraded has risen from less than 20 percent at the end of the war to 55 percent in 1960. As a result, low-grade deposits (25–45 percent iron) that were formerly considered to be of no value are now worth serious consideration as sources of iron ore.

Montana deposits are generally believed to contain no more than about 30 percent iron, but some appear to be large, and most of the iron-bearing mineral is magnetite which, if not too fine grained, can be easily and cheaply upgraded. Of importance to Montana deposits and to western ores in general is the accelerated growth of population and industry west of the Mississippi, which is creating a potential market in which western iron and steel may enjoy a competitive advantage over distant eastern sources.

The Carter Creek deposit (fig. 23,[1] No. 1), unknown until recently, is believed to contain reserves in excess of 60 million tons of iron ore. The ore body, consisting mostly of magnetite with minor amounts of hematite, is in the Precambrian Cherry Creek group, which is made up of hornblende-biotite-garnet gneisses and metamorphosed limestones. The iron-rich zone is 12,000 feet long and 700 to 900 feet wide. The grade of the deposit is not precisely known, but a limited number of samples show a range of iron content from 30 to 32 percent. Calculations made by the author of the results of a series of tests made by the Bureau of Mines (Holmes and others, 1962, p. 10) show that wet grinding the material to minus 200-mesh followed by wet-magnetic separation will yield a concentrate averaging 59.3 percent iron and recover 85 percent of the iron.

Montana contains several other deposits in the same geologic environment, specifically the Kelly, Ramshorn (Copper Mountain), Johnny Gulch, and Dry Boulder Creek deposits. Although the exact amount of ore reserves is unknown, it is believed that for each deposit quantities estimated at tens of millions of tons are realistic. It is also noteworthy that all of these deposits are within a few score miles of each other, and a thorough investigation of the entire area might well result in finds of great value and importance. There is little question that deposits of this type make up by far the most important iron ore reserves in Montana.

Concentrations of titaniferous magnetite of detrital origin are present along a belt of ancient beach deposits that extends intermittently from the Blackfoot Indian Reservation on the Canadian border southward to Radersburg, Mont., a distance of about 190 miles (Wimmler, 1946b). The ores have been examined superficially at outcrops, and it is believed that they are not contiguous from place to place. Iron-rich zones occur in two horizons, the Horsethief sandstone and the Virgelle sandstone, both of Late Cretaceous age. The deposits are lenticular in shape, and their thickness may taper from a few inches at the ends to 20 feet at the widest portion. The ore minerals are magnetite and ilmenite in a gangue of quartz and feldspar. The grade of these deposits is not precisely known, but a chemical analysis of a composite sample taken by the U.S. Bureau of

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Mines at the Choteau deposit showed 43.7 percent iron and 7.2 percent titania (Wimmler, 1946b, p. 7), whereas chemical analyses of channel samples from the other deposits give 10.5 to 55.6 percent iron and 2.01 to 12.7 percent titania (Hubbard and Hencks, written communication, 1962). The exposure near Radersburg, Mont., contains magnetite, hematite, and minor amounts of copper oxides and calcite veinlets. It is presently operated by Harris Brothers and John Ralls, and their product is shipped directly to the cement plant of the Ideal Cement Co. at Trident, Mont., where it is used in the manufacture of types II and V cements.

The more numerous, though smaller, iron occurrences known in Montana have a magmatic affiliation. The deposits are in general associated with limestones or shales at or near a contact with intrusive igneous rocks. They may, however, be entirely enclosed within the intrusive rock, as for example, the Elkhorn Mountain deposits near Boulder. Their shape is tabular or lenticular, and they swell and pinch horizontally and down dip. Reserves are not accurately known, but some deposits may contain more than several million tons. The iron minerals are predominantly magnetite, hematite, and limonite. Minor amounts of recoverable copper, lead, silver, and gold are also present. The ore mined was high grade, and many of these ores were especially sought in the early days, not for the manufacture of iron and steel, but as a fluxing material needed by the copper and lead industry.

At the Sheep Creek iron deposit in Meagher County two major steeply dipping veins are known, and each has been traced for about 1,300 feet along the strike. The width is variable but 38 feet may be an average. Bedded ores also occur nearly at right angles to the dip of the veins. The iron mineral in the veins is chiefly hematite; whereas the bedded ores contain more limonite than hematite. The difference in mineralogy is further emphasized because the iron content in the veins is higher, probably 48 percent iron and 4 percent silica as opposed to 39 to 46 percent iron with 4 to 21 percent silica in the bedded ores (Reed, 1949).

Notable other occurrences are the Running Wolf (Willow Creek) deposit in Judith Basin County (Roby, 1949), the Southern Cross and the Cable deposits in Deer Lodge County (Wimmler, 1946a), the Sweetgrass Hills deposit in Liberty County, Thunder Mountain deposit in Cascade County, and the Iron Mountain deposit in Meagher County.

The Running Wolf deposit is the only property in the State that has produced commercial iron ore for the steelmaking industry within the last 5 years. The ores were mined and shipped to the Great Lakes region and elsewhere by the Young-Montana Co.

The area south of Yogo Peak in Judith Basin County contains many small outcrops of high-grade magnetite deposits. It has been suggested that a magnetometer survey of this area might reveal larger hidden deposits (DeMunck, 1956, p. 49).

Numerous deposits derived from oxidation of preexisting pyritic veins are known in Montana, as well as limonite deposits attributed to hot spring deposition. Their value and potential as a source of metallic iron is probably doubtful due to the small tonnages of ore available and because of their isolation from transportation facilities.

The use of smelter slags as a source of iron has aroused considerable interest in Montana. In 1959, Webb & Knapp, Inc., announced that construction of an integrated steel plant utilizing natural ore and smelter slag derived from the Anaconda Co.'s reduction works at Anaconda, Mont., was being considered. It was explained that the Strategic-Udy process employing electric smelting techniques would be applied to reduce the raw material and that the final products would consist of finished shapes. It was also stated that initiation of the project would depend on obtaining investment capital, estimated at $40 million, and solving marketing problems. As of 1962, Gulf, State Lands & Industries, Inc., a subsidiary of Webb & Knapp, Inc. has applied to the Federal Area Redevelopment Administration for financial assistance. No decision is believed to have been reached (1962).

The slag dump at Anaconda is reported to contain 40 million tons of material. Other slag dumps comparable in size are at the plant of the American Smelting & Refining Co. at East Helena and at the plant of the Anaconda Co. at Great Falls.

Forty-five percent seems to be a realistic estimate of the iron content in the slags, although the exact grade is not known. Most of the iron evidently occurs as a synthetic silicate. Small amounts of copper, lead, and zinc are present, since nonferrous metal recovery is not complete.

It appears likely that Montana contains enough iron ore to provide for at least a moderate-size iron and steel industry. Chief obstacles at present are the distance from existing major markets, and the limited population and consumer demand within the area where Montana iron could realize an advantage in transportation costs.

LIMESTONE [1]

(By J. M. Chelini, Montana Bureau of Mines and Geology, Butte, Mont.)

Limestone, including dolomite, is the most widely used of all rocks. Over 450 million tons are consumed annually in the United States. It occurs in some form in every State, is produced in thousands of localities, and is sold as a low-cost mineral commodity to many different industries, which utilize it either in raw crushed form or calcined to lime.

In Montana, limestone is used for concrete aggregate, roadstone, flux, agriculture, railroad ballast, riprap, fill material, filler, sugar refining, portland cement, and lime. Important uses in other areas include coal mine dusting, filtration, limestone whiting, mineral food, and alkali, calcium carbide, glass, and paper manufacture.

In terms of total domestic production, concrete aggregate and roadstone consume the greatest volume of the raw product. However, cement and lime, the major products manufactured from limestone, exceed in dollar value that of all limestone sold or used in the United States in any one year. Lime is an essential material for more than 7,000 uses, involving many different industries (Patterson, 1960). By far the greatest number of uses are chemical and industrial. In 1961 the value of cement produced in the United States was $1,105,537,000 (West and Lindquist, 1962, p. 391), the value of lime was $210,141,000 (Patterson and Schreck, 1962, p. 799), and the

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[1] Including lime and cement.

combined value of crushed limestone and limestone dimension stone was $608,139,000 (Cotter and Jensen, 1962, p. 1145, 1156.)

Commercially, the word "limestone" is a general term for that class of rocks which contains at least 80 percent of the carbonates of calcium and magnesium. The marketed products are further defined depending upon composition and use. When calcium carbonate is present in excess of 95 percent, the rock is called a high-calcium limestone. High-calcium limestone, the variety used by lime and cement industries, should contain less than 2 percent magnesium carbonate and less than 3 percent of other impurities (commonly silica, alumina, and other insolubles). If 10 percent or more of magnesium carbonate is present, the rock is called magnesian or dolomitic limestone. This decreases its usefulness in the manufacture of lime and makes it unfit for the manufacture of cement; cement manufacturers do not like to use a limestone containing more than 5 percent magnesium carbonate and prefer even less. It does, however, find use for agricultural processes. Portland cement is commonly made from "natural cement" rock, an argillaceous limestone containing clay and silica in the correct proportions to make cement. However, some cement is made from high-purity limestone by adding the proper amount of clay and silica.

When the content of magnesium carbonate approaches 45 percent in a carbonate rock, it is known as a dolomite. Dolomite is used in the manufacture of high-magnesium lime; its predominant use is in the production of magnesium compounds and as a refractory.

Marine limestones are formed on the sea bottom by any one or combinations of the following processes: slow accretion of organic remains, such as shells; accumulation of carbonate detritus in the same manner as with other clastic sediments; and chemical precipitation.

The above types may be altered to dolomites or dolomitized limestones by replacement of part of the calcium carbonate by magnesium carbonate. Limestones may also be deposited in lakes or streams or from springs. Impurities such as sand, clay, iron oxide, or other detritus may be mixed or interbedded with the calcareous material. Limestones are named, in part, on the basis of these impurities. Thus, siliceous or cherty limestones contain considerable quantities of silica; ferruginous limestones contain iron oxides; and argillaceous limestones contain clay or shale.

Limestones are also classified according to their physical character. Lithographic stone is a very fine-grained crystalline variety, deriving its name from one of its early uses for making lithographs. Travertine is a banded variety of carbonate rock that has been deposited from ground or surface water or from hot springs. Its pleasantly variegated coloring and ease of polishing makes the travertine generally more valuable as building stone than for its calcium carbonate content. Waste material from travertine quarries is marketed as chicken feed, agricultural limestone, and for the manufacture of lime.

In Montana, limestone is found in strata of nearly every geologic age. However, three units of Paleozoic age are the major sources of limestone. These are the Mission Canyon and Lodgepole limestones of Mississippian age, and the Meagher limestone of Cambrian age. Exposures of these units are confined to the central and western part of the State; younger rocks form a thick cover to the east (fig. 24).[2]

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[2] NOTE.—Figure indicated appears as a folded map at the rear of this document.

The Mission Canyon limestone is the most important source of high-purity limestone in Montana and crops out in many places in the western part of the State. It characteristically contains more than 95 percent $CaCO_3$. At Limespur (fig. 1, locality No. 7) where the limestone was quarried for flux for the Butte smelters and for sugar refining, the calcium carbonate content exceeds 99 percent (Perry, 1949, p. 40). At Sappington (No. 8), where the rock was quarried for use in sugar refining, and at Elliston (No. 5), where rock is currently produced for the manufacture of lime, the calcium carbonate content exceeds 98 percent. Good quality limestone is also found in northwest Montana at the Stahl quarry near Roosville (No. 1).

The Lodgepole limestone contains thin-bedded limestone, interbedded with chert and shale. Its composition is suitable for cement manufacture, and the Ideal Cement Co., is quarrying it for that purpose at Trident (No. 10).

Cambrian carbonate formations in Montana are commonly dolomitic in composition, but the Meagher limestone is in places a very pure limestone. In the Helena-Townsend region the magnesium carbonate content of the Meagher is less than 3 percent (Perry, 1949, p. 39). Hanson (1952, p. 15) states, "East of a line connecting Ennis and Whitehall, the Meagher formation is entirely limestone, whereas west of a line connecting Butte and the Upper Ruby Valley it is entirely dolomitic.' Between these two areas there is a transition zone of intermediate composition.

The upper part of the Meagher is characteristically mottled in dark gray or black and buff and is sometimes termed "black and gold marble." A quarry in the Limestone Hills north of Radersburg (No. 9) was operated for a time by the Vermont Marble Co. Polished slabs for facing work were marketed under the name "Egyptain Limestone." The quarry has not been operated in recent years.

The Meagher limestone is quarried at two localities east and south of Helena. At Maronick (No. 14) it is quarried for flux for the American Smelting Refining Co. plant at East Helena. A few miles to the west it will be quarried for cement rock in the new plant of the Permanente Cement Co. (No. 13).

Other potentially important Paleozoic carbonate formations include the Pilgrim dolomite, the Big Horn dolomite, the Jefferson dolomite, and the Ellis formation (Perry, 1949, p. 32). These limestones are suitable for lime manufacture, but they are not likely to be sought because adequate limestone is generally available in more accessible localities. In addition, beds of impure limestone are found in Precambrian (Belt series), Mesozoic (Cretaceous), and Cenozoic (Tertiary-Quaternary) sedimentary rocks. In the northwestern and extreme western parts of Montana and in the Belt Mountains in the central part of the State, great thicknesses of rocks of the Belt series are found. The calcareous formations of this series are the Helena, the Wallace or Newland, the Siyeh, and the Altyn formations. Assay reports by Johns (1960 and 1961) show that the calcareous rocks of the Belt series in northwestern Montana generally average about 44 percent silica, 10 percent alumina, between 40 and 50 percent calcium carbonate, and 4 percent magnesium carbonate.

Also of potential value among Precambrian calcareous deposits are the massive marbles of the Cherry Creek group exposed in the low foothills of Ruby Range southeast of Dillon, in the vicinity of Virginia

City, in the low foothills of the Gravelly Range 15 miles south of Ennis, and in the Bridger Range 5 miles north of Bozeman. They range in composition from nearly pure calcite to nearly pure dolomite. Thicknesses range up to 800 feet. South of Ennis there is an area of magnesium-bearing marble about 2 miles wide and 5 miles long in which the strata stand nearly vertical (Perry, 1949, p. 33).

The only important Mesozoic limestone is the gastropod limestone member of the Cretaceous Kootenai formation. This member is present in southwestern Montana and ranges in thickness from 10 to 75 feet (Perry, 1949, p. 22); it has been quarried for lime burning near Drummond (No. 3). Recent assays of a grab sample from the quarry site show a calcium carbonate content of 87 percent; magnesium carbonate, 2 percent; insolubles, 9.38 percent; and alumina, 1.13 percent.

Cenozoic travertines of hot spring origin in Montana are believed to be of late Tertiary or early Quaternary age (Perry, 1949, p. 32). Two large, unusually pure deposits have been developed, and several smaller occurrences are known. The more important of these deposits is near Gardiner (No. 16) (Mansfield, 1933, p. 7). It is being quarried by the Montana Travertine Co. for use as interior and exterior decorative building stone.

Rock from the Gardiner quarry is used for building and ornamental stone, though the rock is chemically suitable for the manufacture of lime and chemical compounds. A typical analysis of the stone is: calcium carbonate, 95 percent; magnesium carbonate, 0.9 percent; silica, 0.9 percent; and iron oxide, 0.2 percent.

Another deposit of travertine is on the south flanks of the North Moccasin Mountains of central Montana, north and west of Lewistown (No. 19). The deposit is contained in an area of about 6 square miles and has a maximum thickness of 250 feet (Calvert, 1909, p. 36) and is presently being quarried for building stone, but it is also suitable for many uses requiring pure high-calcium carbonate rock. Other undeveloped travertine deposits occur in the general area north and east of Lewistown (Perry, 1949, p. 42).

MANGANESE

(By William C. Prinz, U.S. Geological Survey, Washington, D.C.)

Manganese is indispensable in the production of steel and is thus essential to our Nation's economy. The chief value of manganese is as a desulfurizer, and more than 13 pounds are consumed in the production of each ton of steel. Some is also used as an alloying metal in high-strength steels. More than 95 percent of the manganese consumed in the United States is for metallurgical purposes; the remainder is used, generally as oxide ore or concentrate, as the depolarizer in dry-cell batteries, in the manufacture of manganese chemicals, as a drying agent in paints and varnishes, as a pigment or to neutralize the effects of iron in glassmaking and ceramics, and in the leaching of uranium ores.

Manganese occurs in a variety of minerals in the earth's crust, but insofar as ore deposits are concerned only two types are important: (1) the manganese oxide minerals, which are too numerous to mention individually here, and (2) the manganese carbonate, rhodochrosite. Some manganese deposits are sedimentary in origin; others are in veins or replacement deposits that formed from hydrothermal solusolutions. Later action by ground water modified many deposits of both types by converting rhodochrosite and manganese silicates to manganese oxide minerals, changing original oxide minerals to different oxide minerals, and enriching or concentrating manganese.

Most of the manganese reserves of the United States are in low-grade sedimentary deposits which, except for the manganiferous iron ores of the Cuyuna Range, Minn., are not economical to mine at the present time. Domestic reserves of high-grade manganese ore are limited, and the United States therefore relies almost entirely on imported manganese. In 1958, production of ores and concentrates (+35 percent manganese) by domestic mines reached 22 percent of consumption (DeHuff and Fratta, 1959, p. 724); this was accomplished however, only because of Government purchases at premium prices for stockpiling. After Government purchasing ceased, domestic production declined sharply and in 1961 amounted to less than 3 percent of consumption. By the end of 1961, Montana was the only State producing high-grade manganese ores or concentrates. Montana is the leading State in total production of this type of material, most of which has come from two districts—Philipsburg and Butte (fig. 25).

The Philipsburg district (fig. 25,[1] locality No. 1), which started as a silver camp in 1864, first produced manganese in 1900 (Pardee, 1922, p. 146), and became the country's leading producer of high-grade manganese ore during World War I. This ore, all oxide, was used mainly for metallurgical purposes. After the war, the district was unable to compete in the metallurgical market because of its distance from steel-producing centers; however, it was found that manganese oxide concentrates from the district were well suited for the manufacture of dry-cell batteries. Since then, Philipsburg has been the leading, and for the most part sole, domestic source of natural battery-grade manganese dioxide. Oxide ore is upgraded in local mills to battery-grade concentrates containing 65 to 70 percent manganese dioxide. Middlings containing 10 to 35 percent manganese are also marketed. Through 1961, production from the Philipsburg district, including both oxide and carbonate ores, has accounted for approximately half of Montana's total production of more than 3,230,000 tons of manganese ore.

The Philipsburg district straddles part of the western border of an early Tertiary granodiorite batholith that was intruded into folded and faulted Precambrian and Paleozoic sedimentary rocks (Emmons and Calkins, 1913). Silver- and zinc-bearing quartz veins cut both the granodiorite and the sedimentary rocks. Although the veins have yielded a small amount of manganese ore, most has come from irregular manganese-rich replacement deposits which are distributed erratically in favorable limestone and marble beds adjacent to the quartz veins (Goddard, 1940, pp. 157–202). The primary manganese minerals in these deposits are the carbonates, rhodochrosite, and manganoan dolomite, which were deposited from hydrothermal solutions. Near the surface and to depths varying from 100 to more than 850 feet, the manganese carbonates were oxidized by ground water to manganese oxide minerals. The bulk of the ore produced

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

from the district has been oxide; some carbonate was mined during World War II and for Government stockpiles in the early and mid-1950's, but little, if any, carbonate has been sold commercially. Reserves of manganese oxide and carbonate ore at Philipsburg have been estimated at 710,000 long tons averaging 22.5 percent manganese (Hewett and others, 1956, p. 214).

The veins around the periphery of the famous copper, silver, and zinc district of Butte (No. 2) contain abundant rhodochrosite, and the area west and south of the heart of the district has yielded considerable manganese ore. The veins are in an early Tertiary quartz monzonite batholith, and in the manganese-rich areas they contain rhodochrosite, silver, lead, and zinc sulfides in a quartz gangue. The depth of oxidation at Butte is relatively shallow; thus manganese production from the district has been principally carbonate ore with only a minor amount of oxide.

Manganese was first mined in Butte during World War I, but, as with Philipsburg, production declined after the armistice. In the late 1920's and the 1930's, carbonate ore containing 38 percent manganese was roasted in revolving kilns to produce oxide nodules containing 56 percent manganese. However, reserves of these high-grade ores were limited and manganese production was small until 1941 when the Anaconda Co. built a manganese concentrating plant and its own kilns. Ores averaging 18 percent manganese were then treated by flotation to recover the associated zinc, lead, and silver sulfides and to produce rhodochrosite concentrates containing 38 percent manganese. The rhodochrosite concentrates were dried and then roasted to drive off CO_2 and produce nodules of manganese oxide grading 57 to 60 percent manganese (U.S. Congress, House Committee on Public Lands, Subcommittee on Mines and Mining, 1948, pp. 279–298). The high manganese and low impurity content of these nodules made them well suited for the manufacture of ferromanganese, the most common form in which manganese is added to steel, and in 1946 the Anaconda Co. began production of ferromanganese from its own nodules in an electric furnace at Great Falls. Furnaces were also built at Anaconda, and in the late 1940's and early 1950's Anaconda consumed a large quantity of its own nodules to make ferromanganese. However, high freight rates to the steel-producing centers in the East and competition from low-cost imported manganese ore forced Anaconda to reduce production in the late 1950's. The company's last remaining manganese mine, the Emma, was closed during the strike in 1959 and has not been reopened. The ferromanganese furnaces have been operated intermittently since then on stockpiled ore.

Many mines in the west Butte area other than those operated by the Anaconda Co. have also produced manganese ore, chiefly during times when the Government was paying premium prices. Reserves of the Butte district were reported in 1956 to be 4,460,000 short tons of carbonate ore averaging 14 percent manganese (Hewett and others, 1956, p. 214). Reserves of oxide ore are nil.

Manganese also occurs at many other places in southwestern Montana (Pardee, 1919; 1922, pp. 177–179; Sahinen and Crowley, 1959, p. 21), and some areas have yielded a little ore. Hydrothermal deposits similar to those at Butte or Philipsburg occur in the Wickes (No. 3), and Cataract Creek (No. 4), districts between Butte and

Helena, in the Niehart district in the southeastern part of Cascade County (No. 5), in the Castle Mountains 10 miles southeast of White Sulphur Springs (No. 6), in the Cramer Creek district east of Missoula (No. 7), in west-central Gallatin County (No. 8), and at several places in Beaverhead and Madison Counties (Nos. 9, 10, 11, and 12). Irregular lenses or pods of manganese that follow bedding in sedimentary rocks occur in central and northwestern Meagher County (Nos. 13, 14, and 15), southeastern Lewis and Clark County (No. 16), and in a few places in Beaverhead and Madison Counties (Nos. 17, 18, 19, and 20). It is not known whether the manganese was concentrated by ground water from that occurring in surrounding or overlying beds or whether it was introduced by hydrothermal solutions. A manganiferous bed of iron ore has been reported near Renova in northern Madison County (No. 21) (Pardee, 1919, p. 132).

MOLYBDENUM

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Molybdenum is a white metal that is commonly used as an alloy to increase hardness, strength, and resistance to corrosion of steel, particularly at elevated temperatures. It is also used in electrical equipment and in aircraft and missile parts.

The most important ore mineral is molybdenite (MoS_2). More than half of the world supply comes from molybdenite ores mined at Climax, Colo. Molybdenite is also an important byproduct of porphyry copper deposits. Less important are contact metamorphic tungsten deposits that yield molybdenum as a byproduct.

Montana has not produced molybdenum, although several low-grade deposits are known. The Big Ben deposit near Neihart, Cascade County, has been prospected and drilled, and it appears to contain between 3 and 4 million tons of material that averages 0.2 to 0.3 percent molybdenum (fig. 26,[1] locality No. 1) (Creasey and Scholz, 1945). Known tonnage and grade of the material do not favor production at present prices and mining costs, but further exploration may increase the estimates of reserves.

Molybdenite occurs with pyrite and chalcopyrite in quartz veins at the Bismarck mine, Madison County. The amount of ore is not known, and the grade appears to be low (Tansley and others, 1933, p. 31).

The copper deposits at Butte contain traces of molybdenite, and in a few local areas it is reported to be abundant (Weed, 1912, p. 79). None has been recovered as a byproduct, however.

Molybdenum is known to occur in aplitic quartz monzonite in NE¼ sec. 9, T. 1 N., R. 7 W., at the head of Blacktail Deer Creek about 10 miles south of Butte, and in the Emigrant Gulch area, Park County (Sahinen, U. M., written communication, 1962). The potential of these occurrences is unknown, but is probably not great. Neither occurrence is shown on the map.

An additional potential source of molybdenum in Montana, still essentially untested, is the occurrence of powellite, the calcium molybdate, in tactite bodies associated with Mesozoic intrusives. (See the chapter on tungsten for a more comprehensive discussion of these deposits.)

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

NIOBIUM

(By S. L. Groff, Montana Bureau of Mines and Geology, Butte, Mont.)

Columbite, the commonest ore mineral of niobium (columbium) is a niobate-tantalate of iron and manganese. It is an end member of an isomorphous mineral series (Fe, Mn) (Nb, Ta)$_2$O$_6$, of which tantalite, the principal ore of tantalum, is the other. Columbite is usually recognized by its iron-black, commonly irridescent color.

The minerals of the columbite-tantalite series are commonly found in pegmatites. The world's main source of supply comes from Nigerian alluvial deposits formed by the weathering of pegmatite dikes. Niobium is a steel-gray, lustrous metallic element used principally as an alloying agent in metals for jet aircraft engines. Niobium alloys are stable and retain their strength at temperatures up to 1,550° F. Minor uses of the metal include applications in the vacuum-tube industry, in tungsten-carbide cutting tools, and as a shielding material in some types of nuclear reactors.

Purchasers of columbite are the Electro-Metallurgical Division, Union Carbide & Carbon Co., Niagara Falls, N.Y.; and the Fansteel Metallurgical Corp., North Chicago, Ill. Columbite ore (65 percent pentoxide) was being purchased in October 1962, at the following prices:

Ratio Nb_2O_5-Ta_2O_5:	*Per pound*
10:1	\$1. 10–\$1. 25
8.5:1	1. 00– 1. 10

There is no record of columbite production from Montana, but columbite and other niobium-bearing minerals are found in several localities in Montana (fig. 27).[1] Minor amounts of columbite were reported in carbonate rocks in the Rocky Boy stock, Bearpaw Mountains, Hill County. Fergusonite—a complex mineral containing rare earths, niobium, and uranium—has been found in the Sappington pegmatites in northern Madison County, and in pegmatites near Hamilton, Ravalli County, and in placers at the head of California Gulch in Madison County (Heinrich, 1949, pp. 31–32).

The largest deposit in Montana is on Sheep Creek, a tributary of the West Fork, Bitterroot River, in southern Ravalli County (Crowley, 1960). In this deposit columbite is associated with euxenite and fersmite, along with the rare-earth minerals ancylite, allanite, and monazite. There has been extensive development, but the deposit is apparently subcommercial.

OPTICAL CALCITE

(By F. C. Armstrong, U.S. Geological Survey, Spokane, Wash.)

Optical calcite is the transparent variety of calcite (CaCO$_3$). It is used in polarizing microscopes, polariscopes, colorimeters, saccharimeters, and other optical devices. First-grade material, often referred to as Iceland spar, must be colorless, water clear, and free from cracks, twinning, inclusions, and other flaws.

Both before and during World War II a small but unknown amount of first-grade material was mined in Montana. For a short time during World War II optical calcite was mined in Montana for use

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

by the Navy in a special gunsight. Calcite for this purpose did not have to meet several of the specifications required of Iceland spar. During the period 1942–44 about 7,400 pounds of optical calcite suitable for the sight was mined from Montana deposits. The average grade of the deposits mined by Metals Reserve Co. was almost 0.3 pound of optical calcite per ton of vein material mined and the cost of mining this "gunsight" calcite was almost $60 per pound. This cost contrasts sharply with the peacetime price of $50 per pound for the best crystals of Iceland spar (Waesche, 1960, p. 697.)

Veins containing optical calcite occur in Park and Sweet Grass Counties, Mont. (fig. 28),[1] and have been described by Stoll and Armstrong (1958). Most of the optical calcite has been obtained from veins cutting the sedimentary rocks of the Livingston group of Late Cretaceous and Tertiary age. The veins occupy faults. The productive veins are large; many of them are conspicuously banded parallel to their walls, and the individual bands exhibit comb structure. Vugs created by incomplete filling of fissures have been the source of all optical calcite mined; most of the usable material came from the clear crystal tips that project into the vugs. The calcite veins were deposited in open fractures by rising hydrothermal solutions of low temperature and pressure. The veins appear genetically related to the local igneous activity, and may have been deposited during an earlier hypogene period of carbonate mineralization by ancient hot springs similar to the ones in the area today.

The demand for optical calcite has never exceeded several hundred pounds annually, and sales are usually individually negotiated. A factor adversely affecting the market is the increasing use of synthetic Polaroid in many instruments that formerly required calcite. If, however, uses demanding the unique qualities of optical calcite develop to the extent that cost is not a major factor, a limited amount of optical calcite could be recovered from the veins in Montana.

PEGMATITE MINERALS

(Bv S. L. Groff, Montana Bureau of Mines and Geology, Butte, Mont.)

Pegmatite minerals that may attain commercial importance include potash feldspar, quartz, muscovite, and lithium silicates, with smaller amounts of niobium-tantalum, rare-earth minerals, beryl, cassiterite, and wolframite. These minerals occur in pegmatite dikes, which are coarsely crystalline igneous rocks commonly associated with larger intrusive bodies of finer-grained rocks. Pegmatite bodies are believed to have formed during a late stage in the normal sequence of crystallization of a magma, when residual fluids were sufficiently enriched in volatile materials to permit the formation of coarse-grained rocks more or less equivalent in composition to the parent rock. Montana has, thus far, produced little material from pegmatites, and of the pegmatite minerals only mica, feldspar, and beryl are discussed here.

MICA

"Mica" is the name given to a group of hydrous aluminum silicates containing varying amounts of iron and magnesium. The more im-

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

portant members of this group are muscovite (white mica), phlogopite (amber mica), biotite (black mica), vermiculite (expanding mica), and lepidolite (lithia mica). Of these only vermiculite and muscovite have been mined in Montana. Vermiculite is not a pegmatite mica, and is treated elsewhere in this publication.

Muscovite mica has the general formula $K_2Al_4(OH)_4[(Al_2S_6i)O_{20}]$, but minor amounts of other elements affect its color and cause slight differences in its properties. Muscovite is valuable for its very low heat and electrical conductivity and the perfect basal cleavage which permits it to be split into flexible sheets as little as 1/1000 inch in thickness. The mineral occurs as rough crystals, called books, in pegmatites. Books with a high proportion of structural flaws, or too small for minimum sheet size, are classified as "scrap" or grinding mica.

Sheet mica is mostly used for electrical insulation and has many applications in electrical and electronic instruments and utensils. Mica board is made up of thin splittings bonded together and is widely used as forms for mounting electrical equipment. Ground mica is used in molded insulators, or it may be used in roof coating, plaster, paints, lubricants, or as a binder and filler.

Prices (North Carolina district) as of October 18, 1962, are quoted here as a general guide for prospective producers. Prices for punch mica (material that will yield trimmed, unflawed books of less than 1½ x 2 inches) and sheet mica vary considerably, depending on the degree of stain. Clear punch runs 7¢ to 12¢ per pound; clear sheet mica prices depend on the size of the trimmed sheets.

	Per pound		*Per pound*
1½ by 2 inches	$0.07–$1.10	3 by 4 inches	$2.00–$2.60
2 by 2 inches	1.10– 1.60	3 by 5 inches	2.60– 3.00
2 by 3 inches	1.60– 2.00	4 by 6 inches	2.75– 4.00
3 by 3 inches	1.80– 2.30	6 by 8 inches	4.00– 8.00

Scrap or grinding-quality mica is valued at $20 to $30 per short ton, depending on relative amounts of other mineral impurities. The nearest scrap mica buyer is in Colorado. Buyers of sheet mica are all east of the Mississippi River.

Mica-bearing pegmatites are shown on figure 29.[1] Some 10 tons of hand cobbed books were marketed from the Sappington deposit (fig. 1, locality No. 1) in northeast Madison County, and a small amount was mined from the Dulea and Montana deposit (No. 2) near Virginia City (Heinrich, 1949, p. 23; Stoll, 1950, p. 57). Beginning in 1958 small quantities of hand sorted mica were produced from the Thumper Lode (No. 4), Gallatin County, and from a deposit 15 miles south of Ennis (No. 3), Madison County. Small amounts have also been produced from the San Miguel district (No. 5), Judith Basin County (Robertson and Roby, 1952, p. 46).

FELDSPAR

The feldspar minerals are potassium, sodium, or calcium aluminum silicates and are the most abundant of the rock-forming minerals. The relative concentration of potash, soda, and lime determine the properties of the minerals. Silicic pegmatites may contain a concentration of large crystals of potash feldspar together with soda feldspar.

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

The chief use for feldspar is in ground form as a constituent of enamels, glasses, and pottery. It is the chief source of aluminum in glass and is also the chief flux. Additional uses are as fillers, bases for scouring powder, ceramic binders, poultry grit, and roofing granules. In the ceramic industry potash feldspar, chiefly the variety microcline, is used almost exclusively but soda feldspar can be used in enamels and glazes. Both types have been found suitable for glass manufacturing.

Most feldspar produced commercially has come from pegmatites containing concentrations of very large crystals. Hand sorting is necessary to separate the feldspar from the other minerals. Depletion of rich deposits throughout the Nation brought about a search for methods of beneficiation; as a result, the flotation method of feldspar separation and concentration is now a common process. Feldspar is sold in ground form. Maximum price is $17 per short ton.

No feldspar has been produced in Montana, mainly because of distance and shipping costs to areas of industrial use. Feldspar-bearing pegmatites are common in west and southwest Montana; most of those that have produced mica could also produce feldspar. Many more exist than are shown on the map (fig. 29).

BERYL

Beryl, found mainly in silicic pegmatites, is at present virtually the only ore mineral of the important strategic metal beryllium. Because of the need for beryllium, low-grade deposits of other beryllium minerals such as phenacite and bertrandite are being investigated in Nevada, Utah, Colorado, and elsewhere. Deposits of these minerals are not yet known in Montana.

Beryl, $Be_3Al_2(SiO_3)_6$, occurs as prismatic hexagonal crystals that may sometimes be confused with quartz. Beryl is brittle and hard (7.5–8), and, when pure, contains 13.9 percent BeO, though the usual range is 9–11 percent. It is commonly green, but occurs in several varieties with colors of emerald green, yellow, blue, white, and even pale-rose red. The emerald-green clear beryl (emerald) is one of the most valuable of all precious stones. Other gem varieties are the bluish-green "aquamarine," the yellowish "golden beryl" or "heliodor," and the rose-colored "morganite." Helvite, a beryllium mineral not associated with pegmatites, has been found at Butte, Mont.

Beryllium is the lightest of all metals except lithium. The largest single use is in copper alloys where beryllium imparts properties to copper somewhat analogous to those which carbon imparts to steel. The major uses of the pure metal are in X-ray tubes and in nuclear reactors. Beryllium oxide has a melting point of 2,400° C., low thermal expansion, high electrical resistance, and resists abrupt temperature changes, properties that make it useful for various purposes in rockets and missiles.

Beryllium is priced on the basis of BeO content. This is presently $30 to $32 per unit for ore containing 10 to 12 percent BeO, or $300 to $320 per ton for essentially pure beryl.

No beryl has been produced in Montana, but there are three known occurrences. It occurs in pegmatites of the Tobacco Root Mountains (No. 7), Madison County, and near Monarch (No. 6), 46 miles south of Great Falls. A pegmatite containing scattered green prisms of beryl up to 2 or 3 inches long in a clear quartz-feldspar matrix is located near Sula (No. 8) in southern Ravalli County. The pegmatites of the Sula area are perhaps the most promising in Montana.

PHOSPHATE

(By R. W. Swanson, U.S. Geological Survey, Spokane, Wash.)

Phosphorus, meaning light bringer, burns spontaneously in air. Because of its great affinity for oxygen, it is never found free or uncombined in nature but almost always as a phosphate. Having many valence states, it combines with many metals and nonmetals to form a great many compounds for industry. Phosphorus is so widely used that phosphorus compounds affect the everyday life of most Americans and much of American industry. It is an essential constituent of all life, hence its principal use is in fertilizers, yet the most commonly produced white variety of the element is highly toxic and must be used with appropriate caution. A large part of the elemental phosphorus produced in furnace treatment is used in the manufacture of detergents.

Most phosphorus in nature occurs as one of the apatite series minerals. Common apatite or fluorapatite, $(CaF)Ca_4(PO_4)_3$, is present in almost all igneous rocks, and this is the ultimate source of most phosphate on earth. It contains about 42 percent P_2O5 (or 18 percent P), 50 percent CaO, and 8 percent CaF_2.

The largest, richest, and most important occurrences of phosphate, including those of Montana, are the sedimentary apatite deposits (McKelvey and others, 1953a), composed of the mineral carbonate, fluorapatite. These deposits are marine in origin, deposition having occurred from cold phosphate-rich waters that upwelled from the ocean reservoir onto a Continental Shelf environment (McKelvey and others, 1953b).

Very little raw phosphate rock (phosphorite) is used directly. For most of the fertilizer industry sulfuric acid is added, freeing the phosphate of its combined fluorine and forming synthetic gypsum, which is usually filtered off. In the elemental phosphorus industry, phosphorite is smelted in an electric furnace, vaporizing the phosphorus which is then condensed and collected under water (see Ruhlman, 1958, and Waggaman and Ruhlman, 1960, for summary of industry methods). Most of the net value of phosphate stems directly from such treatment.

The United States ranks first in world production with 42 percent of the nearly 44 million tons of phosphate rock produced in 1961 (Lewis and Tucker, 1962). Montana ranks fourth among the States after Florida (74 percent), Tennessee (12 percent), and Idaho (9 percent). Montana and Wyoming production in 1961 was more than 1 million tons, having a value of more than $8 million, and the larger part of this came from Montana (data for the two States are combined to avoid disclosure of information from individual companies). In 1961, 55 percent of U.S. production was used in agriculture, 23 percent in industry, and 22 percent was exported (most of that was also used in agriculture).

TABLE 5.—*Montana gold districts*

BEAVERHEAD COUNTY

Locality	District	Placer					Lode						References
		Date of discovery	Principal period(s) of activity	Estimated production total (ounces of gold)	Status in 1962	Remarks	Date of discovery	Principal period(s) of activity	Manner of occurrence	Estimated production total (ounces of gold)	Status in 1962	Remarks	
1	Bannock	1862	1860's	132,000 (10,800 since 1903).	Essentially dormant	Most of production from Grasshopper Creek. First significant ore discovery in Montana.	1862	Pre-1903	Chiefly irregular replacement deposits in Madison limestone near granodiorite contact.	108,140	Small activity	First lode discovery in Montana. 35,571 ounces recovered since 1903.	Shenon (1931, pp. 39–40).
2	Argenta	Early 1860's	1870's	Minor	Inactive		1865	1926–42	In andesite sill and at contact with Devonian shale.	65,350	Small intermittent production.	First discovery was of lead-silver ore. Lode gold discovered in 1880. Chief gold production from Ermont mine, discovered in 1926. Production unknown prior to 1904.	Shenon (1931); Myers (1952, pp. 27–30).
3	Bryant (Hecla)	Placers unimportant					1873	1873–1904, 1934–49	Replacement deposits in Cambrian limestone; veins in quartz monzonite and along dikes.	17,400	Little activity since 1949.	Gold is byproduct of silver-lead mining. 11,700 ounces recovered prior to 1913.	Winchell (1914, pp. 80–86); Karlstrom (1948).
	BROADWATER COUNTY												
4	Confederate Gulch (Backer).	1864	1864–69	550,000 to 600,000	Inactive	Production declined rapidly after 1869; placers very rich.	Probably in 1860's.	1908–42, 1946–52	Gold quartz veins in quartz diorite or in bedding planes in Precambrian shale.	9,300 minimum; production prior to 1908 unknown.	Dormant since 1952	Nearly continuous production from 1908 to 1952 except for World War II.	Pardee and Schrader (1933, pp. 139–144; 162–163; 171).
5	White Creek	1865	1865–85	67,700 to 92,000	Nearly inactive since 1904.		Small amount of copper from lode mines but almost no gold						Lyden (1948, pp. 18 and 74).
6	Winston (Beaver Creek).	1866	Early years	12,000	No recorded activity after 1915.		1867	1908–18, 1926–53	Quartz sulfide veins in quartz monzonite and andesite.	106,000 minimum	Small production of lead, silver, and zinc.		Pardee and Schrader (1933, p. 214); Lyden (1948, p. 19).
7	Park (Hassel, Indian Creek).	1860	1870's, 1911–15, 1933–43, 1945–49.	43,000	Little activity since 1949.	Most of gold produced from 1940 to 1942.	Early 1860's	Prior to 1908, 1934–43	Quartz veins in andesite near quartz monzonite intrusion.	36,000	Intermittent operations continue.	Intermittent operations since discovery.	Stone (1911, pp. 87–91).
8	Radersburg (Cedar Plains, Cow Creek).	1866	1866–1904	25,000 to 49,000	Dormant	Only 850 ounces produced since 1904.	1866	1866–78, 1908–43	Gold veins in andesite flows; base metal—silver veins in sedimentary rocks and along contacts between sedimentary and intrusive rocks.	279,400	Only small, intermittent operation since 1943.	Largest producer of lode gold in country. Nearly continuous production to 1943.	Winchell (1914, pp. 173 and 182).
	CASCADE COUNTY												
9	Niehart (Montana)	Placers unimportant					1881	Gold production nearly continuous through 1952; sharp decline after 1949.	Veins in Precambrian gneiss and diorite and along contact with Tertiary intrusives; low-grade disseminated deposits in Tertiary intrusives.	67,000	Essentially dormant	In Little Belt Mountains. Gold mostly byproduct from silver-rich base metal ores. Gold important only in Snow Creek area.	Weed (1900, p. 404); Schafer (1935, p. 15).
	DEER LODGE COUNTY												
10	French Creek	1864	1864–69	Uncertain; 48,000 to several times this amount.	Production since 1905 intermittent and small.		Lode production insignificant						Lyden (1948, p. 24).
11	Georgetown	1866(?)	1870's	Significant but unknown production.	Dormant	Only trivial production recorded since 1931.	1866	Before 1932	Gold-copper in contact metamorphic deposits. Gold replacement veins in sedimentary rocks. Gold veins in granite.	300,000 since 1904; minimum total, 460,000 (including placers).	Little activity since 1952.	Most of production from Cable and Southern Cross mines. Fluctuating but nearly continuous production to 1952 except for 1943–48.	Emmons and Calkins (1913, pp. 221–264).
	FERGUS COUNTY												
12	Warm Springs (Maiden-Gilt Edge).	1879		Not known but probably small-scale production only.		Less than 100 ounces since 1904.	Soon after placer discoveries.	1901–21	Replacements in limestone near intrusive contacts. Gold, sylvanite, sulfides in chalcedonic quartz and fluorite.	200,000 to 210,000 (includes placers).	Production since 1932 small and intermittent.	In Judith Mountains, 150,000 ounces recovered since 1900.	Weed and Pirsson (1898, p. 457); Corry (1933, pp. 36–40).
13	North Moccasin (Kendall).	Placers unimportant					1893	1900–22, 1936–42	Ore mostly in bituminous and argillaceous layers near top of Madison limestone.	425,000 to 450,000	Only desultory operations since 1942.	In North Moccasin Mountains	Blixt (1933, pp. 5 and 21).
	GRANITE COUNTY												
14	First Chance (Garnet)	1865	Early years, 1939–42	260,000 to 355,000	Small-scale activity (1960).	Most of gold recovered in 1st few years.	1867	1896–1903	Pyritic gold-copper veins in granodiorite and adjacent quartzite schist.	85,000 to 90,000	Essentially inactive since 1951.	Continuous but fluctuating production maintained through 1942.	Pardee (1918a, pp. 159–195; 231–232).
15	Henderson Creek	1866	1866–1913, 1939–54	80,500	Inactive	Scheelite recovered with gold during last years of operation.	Following placer discoveries.	1932–42	Veins on Henderson and Sunrise Mountains.	1,300	Inactive	Lode production unimportant	Emmons and Calkins (1913, p. 263); Lyden (1948, p. 39).
16	Boulder Creek	1885	1909–10	Less than 1,500	Essentially inactive	Intermittent operation through 1942.	1885	1885–1906, 1932–43	Gold veins with silver in granite, Precambrian and Paleozoic siliceous rocks; a few replacement veins in Paleozoic limestone.	57,000	Small production reported in 1960.	Royal mine chief producer. Only minor production since 1943.	Lyden (1948, pp. 40–41); Emmons and Calkins (1913, pp. 246–250).
17	Flint Creek (Philipsburg).	?	1904–5, 1914–15	Minor	Inactive	Mining attempted sporadically along Flint Creek, generally unprofitably.	1864	1875–92, 1898–1904, 1951–60.	Most deposits occur as replacements in limestone and in veins cutting across Philipsburg anticline, but most productive mine is in granite.	260,000	Manganese production continues at reduced rate since 1958. Small base metal production.	Gold recovered as byproduct from mining of silver-base metal ores. Manganese mining important since 1951. 60 percent of gold produced from granite-bimetallic mine.	Lyden (1948, pp. 38–39); Emmons and Calkins (1913).
	JEFFERSON COUNTY												
18	Clancy, Wickes, Colorado (includes Warm Springs and Clancy Creeks and Lump Gulch).	1865	1933–42, 1946–48	100,500	2 small placers active in 1960 on Clancy Creek.	Dredging in Lump Gulch produced 93,760 ounces, 1923–48.	1864	Prior to 1893	Veins in quartz monzonite and volcanic rocks. Gold chiefly byproduct of silver-lead mining.	258,000		Nearly continuous production but sharply reduced since 1950. Chief gold production from Wickes area.	Pardee and Schrader (1933, pp. 185–186; 223–227); Lyden (1948, pp. 42–47); Knopf (1913, pp. 107–119); Sahinen (1959, p. 135).
19	Basin and Boulder (includes Basin, Cataract, and Lowland Creeks and upper Boulder River.	(?)	1932–41	12,000	In 1960, 1 hand placer reported working on Cataract Creek.	8,471 ounces recovered from Lowland Creek, 1938–41.	Before 1870	1905–8, 1916–20, 1924–26, 1935–41.	In veins of 2 ages in quartz monzonite. Older base metal veins. Younger gold-silver veins.	176,200	Minor activity since 1954.	Gold recovered partly as byproduct of silver and base metal mining.	Lyden (1948, pp. 48–50); Pardee and Schrader (1933, p. 287–299); Knopf (1913, pp. 121–128).
20	Elkhorn	(?)	1940	700	Inactive		do		Ore in contact metamorphic deposits (Dolcoath mine); auriferous silver-lead replacement deposits (Elkhorn mine); sulfides in augite gangue (Golden Curry mine).	79,800	Only small production since 1952.	On eastern margin of Boulder batholith. Gold is byproduct of silver-lead mining.	Pardee and Schrader (1933, pp. 299–300); Knopf (1913, pp. 128–139); Klepper and others (1957, pp. 67–72).
21	Whitehall (Cardwell)	Placers unimportant. Total production less than 150 ounces.					1896	1933–49	Quartz veins with pyrite, galena, and sphalerite in Belt series rocks and quartz porphyry.	100,000	No production recorded since 1957.	In south end of Bull Mountain Range. 75 percent of production from Golden Sunlight mine.	Winchell (1914, pp. 97–99); Roby and others, 1960.
	LEWIS AND CLARK COUNTY												
22	Rimini (Vaughn)-Tenmile.	1864		4,275			1864	Prior to 1907	Auriferous lead-zinc veins in Cretaceous volcanics and quartz monzonite. Low-grade disseminated deposits in Tertiary rhyolite.	194,000	Only minor activity since 1957.	Has also produced lead and silver	Knopf (1913, pp. 80–85).
23	Helena-Last Chance	1864	First few years; 1935–50.	940,000 minimum	Only minor activity since 1950.	Richest ground mined out by 1900.	1864	First few years; 1934–40.	District on north contact of Boulder batholith. Ore occurs as disseminated deposits in intrusive rocks, veins in sediments and instrusives, contact metamorphic deposits and replacements in carbonate rocks.	345,000 minimum	Only minor activity since 1940.	Most of production before 1900. Intermittent operations, 1900–1934.	Lyden (1948, pp. 56–57); Knopf (1913, pp. 85–102).
24	Missouri River-York (Trout Creek).	1864	Early years; 1909–13, 1934–44.	265,000	No production reported since 1950.		Prior to 1870	Early years; 1895–1900	Small quartz veins and replacements in quartz diorite dikes and along bedding in adjacent Belt shales.	70,000 minimum	Idle since 1942	On west side of Belt Mountains. Golden Messenger mine continued producing until 1942.	Pardee and Schrader (1933, pp. 176–182; 121–122).
25	Sevenmile-Scratchgravel.	1864	Early years	59,000	Only slight activity since 1930.	Early discoveries soon exhausted. Mining continuous to 1930 on Sevenmile Creek.	±1872	1916–18	Scratchgravel Hills, contact metamorphic deposits and pyritic veins in quartz monzonite. Sevenmile Creek, irregular pockets and pipelike deposits in limestone.	49,000	Desultory output from small mines since 1918.	First discovery silver. Rich gold found in 1913.	Pardee and Schrader (1933, pp. 35–62).
26	Marysville (Ottowa)-Silver Creek (includes Bald Butte south of main district).	1864	Early years, 1938–41	164,000	Essentially dormant since 1941.	Mostly idle 1904–33	1876	1876–90's, 1911–51	Gold-silver quartz veins in metamorphosed Belt Series rocks around small quartz diorite stock and in marginal portion of intrusive.	1,146,000	Intermittent small-scale operation of several small mines in 1960.	Most of production from Drumlummon mine. Last significant production in 1951. Drumlummon closed in 1956.	Barrell (1907); Knopf (1913); Pardee and Schrader (1933).
27	Stemple (Gould)-Virginia Creek.	Uncertain	Previous to 1927	29,200	Dormant since 1922		Prior to 1878	Early years, 1922–42	Vein in Belt sedimentary rocks and in quartz diorite stock.	216,000	Dormant	Intermittent work from discovery through 1951. Sharp decline after closing of Jay Gould mine in 1942. Gold accounts for 95 percent of value of production.	Lyden (1948, p. 63); Pardee and Schrader (1933, pp. 77–87).
28	McClellan Creek	1864	1864–75	340,000	Inactive	Placers small but spectacularly rich.	Little or no production from lode mining						Lyden (1948, p. 64); Pardee and Schrader (1933, p. 118).
29	Lincoln	1865	1865–75, 1941–42	341,000	Last recorded activity in 1954 and 1955.	Intermittent operation since 1904 has yielded 2,400 ounces.	Lode gold production less than a few hundred ounces						Lyden (1948, pp. 65–66); Pardee and Schrader (1933, pp. 115–117).
	LINCOLN COUNTY												
30	Libby (Snowshoe)	1867	1931–47	1,600 (production since 1901 only).	Inactive	Mining did not begin until early 1880's.	1890's	1931–45	Lead-silver and gold-quartz veins in shear zones and bedding plane faults in Belt senes sedimentary rocks. Gold veins mostly in small area 20 miles south of Libby.	16,300 (production since 1901 only).	No recorded production since 1945.	Lead-silver veins discovered earlier. Most of gold byproduct of lead-silver mining.	Gibson (1948, pp. 67–76); Lyden (1948, pp. 76–78).
31	Sylvanite (Yak)	No record on placer production					Not known	1932–40	Gold-bearing quartz-pyrite veins in sandstone.	10,850	Only desultory work since 1940.	Early history unknown. Was ghost camp by 1905.	Gibson (1948, pp. 69–70).
	MADISON COUNTY												
32	Virginia City-Alder Gulch.	1863	1863–66, 1899–1922, 1935–42.	2,475,000 minimum (some estimates much higher).	Essentially inactive since 1950.	Richest placers in Montana. Yielded $30,000,000 in 1st 3 years.	1864	1867–90, 1932–53	Quartz veins and stringers in Precambrian gneiss.	142,000	Only very small production since 1953.	Nearly continuous but fluctuating production to 1953.	Knopf (1913, p. 15); Lyden (1948, pp. 80–83); Tansley, Schafer, and Hart (1933, pp. 47–50).
33	Norris (includes Norwegian, Hot Springs, and Washington districts).	1864	1864–1902, 1936–42	29,000 minimum	Inactive		1864	Prior to 1902, 1933–42	Quartz veins in quartz monzonite and Precambrian gneiss near contact of two.	235,000	Only minor activity since 1953.	Production declined sharply after 1942.	Winchell (1914, pp. 111 and 118).
34	Pony district (includes Mineral Hill and South Boulder Creek).	Placers have yielded less than 250 ounces					Early 1870's	1870–1918, 1928–44	Quartz veins in Precambrian gneiss near contact with quartz monzonite of Tobacco Root batholith. Some veins in intrusive.	346,000	Only minor production since 1944.	Only small, sporadic production from 1919 to 1927.	Winchell (1914, p. 119); Tansley, Schafer, and Hart (1933, p. 24).
35	Renova	Placers unimportant					1896	1896–1905, 1934–42	Veins in Paleozoic limestone and Belt series sedimentary rocks. Ore at Mayflower mine chiefly tellurides.	162,000	No significant production since 1953.	Most of production from Mayflower mine. Activity declined sharply after 1942.	Winchell (1914, pp. 99–101).
36	Silver Star-Rochester	Placers small and unimportant					1860's	Early years, 1935–42	Near southern end of Boulder batholith. Veins in Precambrian gneiss; contact deposits in Paleozoic limestone.	225,000	Only minor activity since 1951.	Silver and base metals also recovered	Sahinen (1939, pp. 5–7); Winchell (1914, pp. 126–132; 139–144).
37	Tidal Wave (Twin Bridges).	Placer output negligible					1864	Early years, 1931–55	On west side of Tobacco Root batholith. Contact deposits in Paleozoic limestone. Veins in Precambrian gneiss. Some veins in quartz monzonite.	33,400 (production since 1904 only).	Only minor activity since 1955.	Little development until 1874	Winchell (1914, p. 145); Tansley, Schafer, and Hart (1933, pp. 34–89).
38	Sheridan (includes Ramshorn).	1864		2,000 (production since 1904 only).			1864	Early years, 1931–52	Veins and replacements in Precambrian gneisses, schists, quartzites, and limestone near quartz monzonite stock.	31,500 (production since 1904 only. Early production known to be substantial).	Regular production through 1952 with sharp drop after 1948		Tansley, Schafer, and Hart (1933, pp. 40–45).
	MINERAL COUNTY												
39 40	Cedar Creek and Trout Creek.	1869 and 1872	Early years	120,000	Only small-scale desultory operations since 1946.	Most of gold recovered before 1908.	No significant production of gold from lodes						Lyden (1948, pp. 98–103).
	MISSOULA COUNTY												
41	Ninemile Creek	1874	1874–1915, 1934–48	100,000 to 125,000	Only small-scale activity.	Gold in glacial moraine. Dredging in 1954 recovered 1,300 ounces. Nearly dormant since.	No significant production of gold from lodes						Lyden (1948, pp. 103–107); Pardee (1918, p. 234).
42	Elk Creek-Coloma	1865	Early years, 1938–40	52,000 to 100,000	Intermittent activity only since 1940.		1867	1897–1907(?), 1932–52	Quartz-pyrite-gold veins in granodiorite.	17,000	Only minor activity since 1952.	Most production from Coloma area. North side of Garnet Range adjacent to locality 14. Production declined sharply after 1942.	Pardee (1918, pp. 195–205; 231).
	PARK COUNTY												
43	Emigrant Creek	Uncertain	1941–42, 1946–47	15,600	Inactive	No records available before 1905. Mining prior to 1941 on small scale.	1870's	Lode production unimportant since 1901. Early production unknown					Reed (1950, pp. 14; 49–54); Lyden (1948, p. 110).
44	Jardine (Sheepeater)	1866	Small-scale production only. Only 400 ounces reported recovered since 1901.				1870		Replacement veins with arsenic and tungsten in Precambrian gneisses. Veins are Precambrian in age.	190,000 to 200,000	Idle	Produced until 1948 when mill burned	Seager (1944).
45	New World (Cooke)		Placer output negligible.				1870	1882–87, 1890's, 1933–53	Contact metamorphic deposits and sulfide veins.	66,000	Only small-scale mining since 1957.	Intermittent production since discovery but until 1933 mining confined mostly to silver base metal ores.	Reed (1950, pp. 8–9); Lovering (1930).
	PHILLIPS COUNTY												
46	Zortman-Landusky	1884	Recorded placer production small. Early records not available.				1893	1903–19, 1930–43, 1946–50.	Gold-silver veins in porphyritic laccolith intrusive into Precambrian schist and Paleozoic limestone. Also as disseminated bodies in porphyry and replacements in limestone.	380,000	Essentially dormant	In Little Rocky Mountains.	Emmons (1908, pp. 97–98; 104–106); Corry (1933, pp. 32–36).
	POWELL COUNTY												
47	Finn (includes Washington, Jefferson, and Buffalo Gulches).	Early 1860's	1908–16, 1931–42	81,000	No recorded activity	Production since World War II is small.	Lode production since 1933 is 600 ounces. No records of earlier production.						Lyden (1948, p. 128).
48	Ophir (Avon)	1865	1865–75, 1934–35	180,000	No recorded production after 1954.	Most production recovered before 1875.	1888	1909–18, 1936–44	Veins mainly in Paleozoic limestone surrounding quartz monzonite stocks.	8,500	Inactive	No recorded gold production since 1954.	Pardee and Schrader (1933, pp. 30–35); Lyden (1948, p. 127); Knopf (1913, p. 15).
49	Pioneer	1852	1862–98	275,000	No systematic work after 1947.	First discovery of gold in Montana.	Early		Quartz, calcite, pyrite, chalcopyrite veins in granite.	Less than 1,000	do		Lyden (1948, pp. 120–121); Emmons and Calkins (1913, p. 251); Pardee (1951).
50	Zosell (Emery)	1872	1872–92	3,600	Inactive since 1904		1888	1935–41	Narrow quartz-sulfide veins in volcanic rock of late Cretaceous or early Tertiary age.	39,400	Little activity after 1951.	Most production from Emery mine	Pardee and Schrader (1933, pp. 270–273, 280).
	RAVALLI COUNTY												
51	Hughes Creek	Early		In excess of 10,000	Small and sporadic since 1946.		No record of lode gold production						Lyden (1948, p. 132).
	SILVER BOW COUNTY												
52	Summit Valley (Butte)	1864		1,530,000	Inactive	Production, 1903–51, less than 6,000 ounces.	1875		Complex system of veins in quartz monzonite.	2,406,039 (estimated by the Anaconda Co., 1880–1961).	Continuing production	Gold is byproduct from mining of copper.	Weed (1912, p. 18); Lyden (1948, pp. 143–144); Sales (1914, pp. 3–109).
53	Highland district	1866	1866–76	(?)	do	Early production unknown. Production since 1932 trivial.	1866	Early days, 1931–44	Veins, chimneys, and contact deposits near contact of Paleozoic limestone and intrusive rocks of Boulder batholith.	63,000	Inactive	Only small, sporadic production since 1951.	Winchell (1914, pp. 89–90); Sahinen (1959, p. 135).

It should be noted that some apatite is present in virtually all rock and therefore all soils. This helps make the soil of any area a valuable resource. If the content is insufficient for agricultural needs (this may be due to cropping), as is true for some Montana soils, phosphate must be added for successful agriculture. It is partly in satisfaction of this type of need and partly to satisfy an evergrowing chemical industry that the minable phosphate deposits of southwest Montana attain their importance as one of the State's valuable mineral resources.

The western phosphate field of the United States, extending from western Montana through southeastern Idaho and western Wyoming to northern Utah, contains one of the world's largest occurrences of sedimentary apatite. These have been investigated extensively since World War II by the U.S. Geological Survey (Swanson and others, 1953); these investigations included the collection of more than 1,500 channel samples from more than 60 localities in Montana, and this report is based on these studies.

Most of the phosphate in the western phosphate field occurs in the Meade Peak (lower) and the Retort (upper) phosphatic shale members of the Phosphoria formation, which are part of a complex sequence of sedimentary rocks of Permian age (McKelvey and others, 1959). The Permian rocks near Lima, at the southwest corner, are more than 800 feet thick. They thin northward and eastward to near zero northeast of Three Forks and northwest of Drummond, partly by unconformable relations to underlying and overlying formations. The Meade Peak member pinches out between Dillon and Butte, but the Retort member has been identified in every area of southwest Montana in which Permian rocks have been found.

The phosphatic shale members are composed of interbedded shaly siltstone, phosphorite, and some chert, dolomite, and sandstone. Their dark-brownish-gray to black color is due chiefly to included organic matter. The phosphate is mostly pelletal to oolitic, with grains in the fine- to medium-sand-size range (⅛–½ mm), but some is nodular and some is composed of phosphatic shell and bone fragments. The grains occur scattered through other rock types, in thin layers interbedded with other rocks, and in thicker layers of mostly apatite. Beds of pure carbonate-fluorapatite (39.1 percent P_2O_5) do not occur. Minable thicknesses almost everywhere include thin layers rich in other rock materials that dilute the ore, and the quality of an ore is chiefly a function of the amount, and partly of the identity, of such dilution. Thus carbonate is undesirable for both acid and furnace treatment. Silica, on the other hand, is relatively inert in the acid treatment, but in the furnace it acts as a flux to help smelt the ore so it is a valuable ingredient and must be present in furnace feed in a fairly definite ratio to the phosphate.

Sedimentary rocks of Paleozoic and Mesozoic age, including the Permian strata, accumulated over all of southwest Montana, covering the older rocks like a blanket 10,000 to 15,000 feet thick. Later these rocks were folded and faulted and invaded locally by granite bodies. The region was uplifted, and much of the material from the higher areas was eroded, including the Permian rocks from some fairly large parts of the region. As a result the Permian rocks crop out in a narrow band that winds back and forth across southwest Montana, interrupted by faults, igneous intrusions, or later cover (fig. 30).[1] In some areas these rocks occur high on the mountains, in others they

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

lie deeply buried. In downfolded areas they are continuous from one outcrop band to the next, in places beneath many thousands of feet of younger rocks.

Unlike other stable minerals, such as gold and magnetite, sedimentary apatite in the western phosphate field is not known to have formed valuable placers. Of the phosphate rock that is now present, that which is deep below entry level is of little immediate economic interest, for the rock is so plentiful that its value per ton is low and the costs of deep mining are too great. Such rock is of interest from the standpoint of long-term resource appraisal, however. The tonnage estimates of phosphate present in western Montana (table 6) are based on minimum thicknesses of 3 feet and grade cutoffs of 31 percent (acid grade), 24 percent (approximate furnace grade), and 18 percent (potential beneficiation grade) P_2O_5. In addition estimates are made for rock above entry level, rock in the first 100 feet vertically below entry level, and the total tonnage in the block. This table combines the detailed estimates for southwest Montana (south of Butte) (Swanson, 1960) with less detailed estimates for the northern area (the detailed estimates for the northern area are in preparation). It shows the phosphate in the two shale members separately.

TABLE 6.—*Estimate of phosphate resources in Permian rocks of western Montana, in millions of short tons* [1]

Grade cutoff and reporting unit	Tonnage above entry level	Tonnage in 1st 100 feet below entry level	Total tonnage
Rock containing more than 31 percent P_2O_5:			
Retort member	40	16	450
Meade Peak member	35	4	150
Total	75	20	600
Rock containing more than 24 percent P_2O_5: [2]			
Retort member	200	53	4,000
Meade Peak member	150	32	3,500
Total	350	85	7,500
Rock containing more than 18 percent P_2O_5: [2]			
Retort member	820	250	17,000
Meade Peak member	230	50	7,250
Total	1,050	300	24,250

[1] Based on data already published (Swanson, 1960) plus rough estimates for area north of Butte.
[2] Includes tonnages in rock of higher grade.

A summary of the phosphate industry of Montana (Crowley, 1962) shows the rapid expansion of this industry since 1940. Phosphorite is being mined from the Retort member near Melrose for treatment in the electric furnaces of the Stauffer Chemical Co.'s Victor Chemical Works at Silver Bow southwest of Butte. It is mined at several places north of Garrison by the Montana Phosphate Products Co. for treatment in Canada at the fertilizer plants of the Consolidated Mining & Smelting Co. of Canada, Ltd. Another mine is being developed near Maxville to produce rock for shipment to Canada. The Relyea mine north of Garrison supplies phosphate rock to other producers. Phosphorite has been mined from the Meade Peak member in the Centennial Range west of Yellowstone Park by the

J.R. Simplot Co. Many other small mines have produced limited tonnages of phosphate.

Many other elements of economic interest occur with the western phosphate. Fluorine (see chapter on fluorite) is part of the phosphate mineral and is present in the approximate ratio of 1 part F for every 10 parts P_2O_5. There is thus 1 ton of F for every 32 tons of rock containing 31 percent P_2O_5, for every 40 tons at 25 percent grade, or for every 50 tons at 20 percent grade. The reserves of fluorine, therefore, are very large. Fluorine is being recovered from some of the Florida phosphorite, but none has been recovered on a commercial basis from Montana phosphorite.

Uranium, vanadium, chromium, nickel, molybdenum, and rare earths are present in small amounts in most western phosphorite. Vanadium has been recovered from phosphorite mined in Idaho (Caro, 1949). Uranium (see chapter on uranium) is being recovered from some Florida phosphorite, in which it occurs in comparable amounts to western phosphorite. Vanadium concentrates in ferrophosphorus, and it is being recovered from ferrophosphorus produced by electric furnace in Idaho (Fulkerson and others, 1962). Chromium and nickel also concentrate in the ferrophosphorus and can be recovered therefrom (Banning and Rasmussen, 1951). Data on the content of these metals in ferrophosphorus produced in Montana are not available.

Approximately 1¼ tons of synthetic gypsum is produced in the sulfuric acid treatment of phosphorite to make 1 ton of triple superphosphate (high quality) fertilizer. This is removed by filtration and it is discarded, but it could be recovered and used in a variety of building materials and for agricultural purposes.

Oil shale occurs in beds associated with much of the phosphorite in the Retort member in southwest Montana (Condit, 1920) (see chapter on oil shale). Beds 18 feet thick contain more than 18 gallons per ton at one locality and beds 24 feet thick contain nearly 15 gallons at another.

As the phosphate in the western phosphate field is a bedded deposit, like coal or oil shale, application of neither the lode nor the placer laws proved satisfactory for mining purposes. Western phosphate lands were therefore withdrawn from entry (Gale and Richards, 1910), but they are available under lease from the Government or the State for mining of phosphate, for which a small royalty is charged (see Crowley, 1962, p. 4). Most of western Montana underlain by Permian rocks is public land (Willey and others, 1954) and is subject to the leasing regulations.

SALT

(By A. F. Bateman, Jr., U.S. Geological Survey, Great Falls, Mont.)

Halite (NaCl) or rock salt is present in the subsurface throughout most of the Williston Basin. In the Montana portion of the basin there are 10 separate salt beds ranging in age from Devonian to Triassic (Pierce and Rich, 1962, p. 51–61; Anderson and Hansen, 1957).

The Prairie formation (Prairie evaporite formation of Canada) of Middle Devonian age, consists of a rather thin lower member that is mostly anhydrite and dolomite interbedded with shale and thin beds of halite and a thicker upper member that is mostly halite with some interbedded anhydrite (Baillie, 1955, p. 590–597; Sandberg and Hammond, 1958, p. 2304, 2307; Sandberg, 1961, p. 112–114). On the flanks of the Williston Basin an anhydrite bed overlies the salt. The salt is colorless to moderate reddish-orange and grayish-red, and varies from fine- to very coarse-grained, with the coarse-grained material chiefly in the upper part of the unit. The salt member is more restricted than the lower member and in Montana underlies about 3,800 square miles in Sheridan, Daniels, Roosevelt, and Richland Counties, as is shown on figure 31.[1] The formation attains a thickness of about 600 feet where best developed in south-central Saskatchewan, but in Montana it has a maximum thickness of about 250 feet in the northeast corner of the State, from which it thins southward and westward. West of this area, the salt has been removed by solution as a result of movement of ground water across this part of Montana in a general northeast direction (Milner, 1956, p. 111). Depth below ground surface ranges from 8,000 to 11,600 feet.

In Saskatchewan, the potash minerals sylvite (KCl) and carnallite ($KMg\ Cl_3.6H_2O$) occur with the halite in at least three zones in the upper 200 feet of the salt member (Goudie, 1957, unpublished report). These zones are continuous and recognizable over large areas. To date, potash minerals have not been reported in Montana, but no special search for potash seems to have been made. Tracing of the potash-bearing zones into Montana is difficult because of wide well-spacing, but two zones have been identified tentatively in a test for oil and gas in Sheridan County. In the last 3 years, potash has been produced commercially in Saskatchewan, where reserves of recoverable ore containing 25 percent or more potash, and lying at depths of less than 3,500 feet, are estimated at 6.4 billion tons (Pearson, 1960, p. 2).

During deposition of the Charles formation of Early Mississippian age, environmental conditions in the Williston Basin fluctuated between penesaline and evaporitic, resulting in a thick alternating sequence of carbonates (limestone and dolomite) and evaporites (anhydrite and salt) (Anderson, 1958; Andrichuck, 1955, p. 2175–2182, 2199–2206; Nordquist, 1953, p. 68). In Montana there are six salt beds designated "A" through "F" (Pierce and Rich, 1962, p. 56–57, Anderson and Hansen, 1957, pls. 1–2, figs. 4–9). The "A" bed is the thickest and underlies the greatest area. Data on the salt beds are as follows:

Bed	Usual thickness feet	Maximum thickness feet	Areal extent square miles	Depth of cover feet
A	30 to 60	110	12, 400	5,600 to 8,500.
B	20	50	6, 900	6,000 to 8,600.
C	20	30	4, 850	6,700 to 8,650.
D	30 to 40	70	11, 500	5,800 to 8,850.
E	20	30	1, 800	7,650 to 8,950.
F	30	75	6, 700	6,100 to 9,050.

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

PERMIAN SALT

A small part of Montana along the North Dakota border is underlain by a salt bed 30 to 80 feet thick in the Opeche formation of Permian age (Pierce and Rich, 1962, p. 58; Anderson and Hansen, 1957, pls. 1–2, fig. 3). The area covers about 1,300 square miles. Beneath a smaller, separate area of about 500 square miles, the salt occurs either in very thin layers or disseminated in the orange-red, anhydritic and dolomitic siltstones, shales, and sandstones. Cover ranges from 7,000 to 7,300 feet in the larger area and from 5,950 to 7,600 in the smaller area.

The Pine salt, one of the most extensive salt beds in the Williston Basin, underlies the extreme eastern edge of Montana from Carter County northward through Roosevelt County (Pierce and Rich, 1962, p. 59, fig. 24; Anderson and Hansen, 1957, pls. 1–2, fig. 2). Thickness ranges from a featheredge to more than 300 feet just east of the Montana-North Dakota line in Slope County, N. Dak. The Pine salt is predominantly halite, but contains thin interbeds of reddish-brown mudstone and anhydrite and is capped by a layer of anhydrite. It underlies approximately 6,200 square miles in Montana and has from 6,650 to 7,100 feet of overburden. A stratigraphically higher bed, the Dunham salt was restricted in deposition to the deeper part of the Williston Basin (Pierce and Rich, 1962, p. 59, fig. 26; Anderson and Hansen, 1957, pls. 1–2, fig. 1). It covers an area of about 1,150 square miles in Montana, mostly in Richland County; has a maximum thickness of nearly 50 feet; and has from 5,450 to 7,050 feet of overburden.

To date there has been no production of salt in Montana. Near Williston, N. Dak., however, the Dakota Salt & Chemical Co., a subsidiary of General Carbon & Chemical Corp., is mining salt by solution methods from the A bed of the Charles formation at a depth of about 8,200 feet, and propane gas is being stored in the cavities produced.

SAND AND GRAVEL

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Sand and gravel, so abundant that few people think of them as mineral deposits, actually comprise the largest mineral industry in the United States in terms of tonnage, and the fourth largest in terms of dollar value. Only crushed stone, petroleum, and portland cement exceed sand and gravel in value. U.S. production in 1961 amounted to 751,784,000 tons, valued at $751,301,000. During the period 1862–1961 Montana produced more than 137 million tons (written communication, R. D. Geach, Montana Bureau of Mines and Geology, 1961); in 1961 it produced 14,702,000 tons valued at $13,506,000 (D'Amico, Kathleen J., 1962, p. 138).

Major uses for sand and gravel are in aggregates such as concrete, mortar, plaster, and asphalt, and as ballast on railroads and highways. Construction of dams and highways consume the greatest tonnages, but hardly any construction of any type is undertaken without using sand or gravel in one form or another.

Sand and gravel constitute a low-cost commodity. Prices are generally less than a dollar per ton at the source for washed and graded products meeting various specifications. Transportation is a major cost item, and every attempt is made to locate large deposits as close as possible to major users; as a result there are thousands of sand and gravel producers, each supplying the needs of local markets. Where local supplies of sand and gravel are unavailable, it is a common practice to substitute locally manufactured crushed rock.

Sand and gravel deposits may be glacial, fluvial, marine or lake, or residual in origin. Because most operations require a substantial quantity of raw material with the highest possible proportion of grains within a preferred size range, selection of suitable sand and gravel deposits requires an understanding of the geologic processes responsible for their formation. As an example, glaciation can form a wide variety of unconsolidated deposits, ranging from unsorted till containing a high proportion of clay- and silt-size material mixed with boulders of almost unmanageable size, to deposits of outwash sands and gravels that are clean and well sorted, and suitable for immediate use. The success or failure of any enterprise dealing with such a low-cost commodity depends to a large degree on adequate geologic information.

Sand and gravel deposits in Montana are principally glacial or fluvial in origin. Major glacial deposits are therefore generally north of a line approximately halfway between the Missouri and Yellowstone Rivers (the area of continental glaciation) and in valleys in many of the mountain ranges where alpine glaciation occurred. Fluvial deposits are found in stream valleys, except where streams drain areas of soft bedrock, or where the valleys are too short or narrow to permit significant accumulation. Only major areas of sand and gravel deposits are shown on figure 32. [1]

SILICA

(By R. D. Geach, Montana Bureau of Mines and Geology)

Silica (SiO_2) is used in a wide variety of industrial applications. Quartz, its commonest mineral form, is the principal mineral in the silica of commerce. It is a common gangue mineral in veins of hydrothermal origin, where it is generally associated with other minerals, although veins in which quartz is essentially the only constituent are not uncommon. Quartz is also found as large masses in the cores of some pegmatites. Quartz in many rocks has been set free by weathering, and segregated during transportation and deposition into silica sand. Some ancient deposits of sand have been lithified into sandstone or quartzite. Some of these in turn have been weathered and reconcentrated into silica sands of exceptional purity.

Most of the silica of commerce is obtained from silica sand deposits. High-quality sands going into industrial uses are known as "industrial sands"; 17,128,000 tons of industrial sands valued at $50,929,000 was produced in the United States in 1961 (Cotter and Mallory, 1962, p. 1062). A much lesser quantity is quarried from deposits of massive silica. Whether sand or crushed rock from massive deposits is utilized depends in part on the type of material that is available but to a much greater extent on the use to which it is to be put. For some purposes physical properties are of paramount importance, for others the

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

chemical composition is the chief concern, for still others both chemical and physical properties are important.

Silica is used chiefly as an essential constituent in the manufacture of glass. It is also used in large amounts for metallurgical flux, for ferroalloys and for refractories, as well as for molding sands, engine sands, hydrafrac sands, and for a variety of other specialized uses. In much smaller quantities, silica is the source of metallic silicon, an element used for semiconductors which serve a variety of specialized electronic purposes. Silicon is also used for the manufacture of silicones, a group of plastics with many unusual properties.

Specifications vary greatly according to use. For many purposes, washing and sizing are the only treatments necessary. Other products have particular requirements as to purity; glass sand must contain less than 0.06 percent iron, as greater amounts impart color to the final product. Raw material for the production of silicon metal must contain at least 99 percent SiO_2, and only traces of certain impurities. For hydrafrac sand, which is packed into artificial openings in the producing rocks of oil wells to promote recovery, physical properties are of greatest importance. The sand must be made up of clean, tough, well-rounded grains. Material used for sandblasting must be tough and closely sized, but need not be especially pure.

The entire silica production in Montana through 1961 was as crushed rock. Little is known of specific sources of high-quality silica sand in the State, but it seems probable that several exist. The Tensleep Sandstone, of Pennsylvanian age, crops out in many places in eastern Montana (fig. 33),[1] and where surface weathering has separated the rock into individual grains, or cheap, mechanical treatment could do so, the formation may be of potential value as industrial sand. Other formations, such as the Quadrant formation (the correlative of the Tensleep in southwestern Montana), may also in places yield sands of value. The Quadrant formation of Pennsylvanian age is a persistent widespread stratigraphic unit in southwestern Montana. It has been quarried for silica rock in at least three localities. Should the demand develop, it is probable that numerous suitable sources of silica sand could be developed in Montana.

At the Dalys Spur deposit near Dillon, Mont. (fig. 33, locality No. 1), the Quadrant formation is more than 150 feet thick. It is a friable rock composed principally of small well-rounded clear quartz grains, with some drak minerals present in minor amounts. A quarry at this site has produced about 100,000 tons of metallurgical material and the remaining reserves are apparently very large. The Oregon Short Line (Union Pacific) Railroad is near the base of the quarry, and loading facilities and a connecting spur to the quarry have been constructed. Duplicate chemical analyses (Carter and others, 1962, p. 23) of a sample taken at the quarry face are:

[In percent]

	A	B
Fe_2O_3	0.05	0.049
SiO_2	98.9	97.5
Al_2O_3	.41	.45
CaO	$<.05$	$<.05$
MgO	$<.05$	$<.05$

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Metallurgical silica is also produced from the Quadrant formation by the Victor Chemical Co. from a deposit near Maiden Rock (No. 3), and by the Ideal Cement Co. from a deposit near Trident (No. 6).

The quartz cores of certain pegmatites are sources of silica in Washington. A few similar deposits are known to occur in southwestern Montana (Heinrich, 1949), though undoubtedly many more remain to be discovered. The quartz is generally pure and white, though some is clear or gray with minor iron staining along joints and fracture surfaces.

The white quartz mass between Basin and Boulder (No. 9) is evidently of pegmatitic origin. The deposit is estimated to contain 200,000 tons of high-purity silica and has in the past produced silica for metallurgical purposes. A spur from the main line of the Great Northern Railroad runs to the base of the deposit. Duplicate chemical analyses (Carter and others, 1962, p. 24) of a sample taken across the outcrop are:

[In percent]

	A	B
Fe_2O_3	0.029	0.036
SiO_2	98.9	99.2
Al_2O_3	.29	.31
CaO	.05	.05
MgO	.05	.05

The analyses indicate this quartz is suitable for use either as a glass sand or for making ferrosilicon.

The Sappington pegmatite deposit in Madison County (No. 6), contains a quartz core estimated to be 75 feet long, 30 feet wide, and about 70 feet deep (Heinrich, 1949, p. 24). The northern edge of the deposit is covered by surface debris and the extent of the quartz core northward is unknown. Other quartz-core pegmatites are the Rim Rock (No. 4) and Montana (No. 5) deposits in Madison County, and the Pohndorf Amethyst mine (No. 7) in Jefferson County, but their potential as silica sources is uncertain owing to limited exposures.

The Corral Creek (No. 11) and Brown (No. 10) deposits in Jefferson County, and the Crystal Butte deposit (No. 2) in Madison County are examples of quartz-filled fissure veins in granitic rock. The two Jefferson County deposits are estimated to contain in excess of 200,000 tons each of high-grade silica (Roby and others, 1960, p. 86). The reserves of the Crystal Butte deposit are not accurately known but are estimated to be more than 50,000 tons. The Corral Creek deposit is lenticular in shape and is reported to be about 150 feet wide and more than 160 feet long. The vein on the Brown property is 60 feet wide and 1,200 feet long. Both veins contain massive white quartz with minor iron staining along joint and fracture surfaces. Quartz from the Crystal Butte deposit is of the same general appearance, but slightly pinkish in color.

Chemical analyses (Carter and others, 1962, pp. 25–27) of samples from the Brown, Corral Creek, and Crystal Butte deposits, respectively, are:

[In percent]

	A	B[1]
Brown deposit:		
Fe_2O_3	0.02	0.07
SiO_3	99.59	99.63
Al_2O_3	.36	.14
CaO	.10	----------
MgO	.007	----------
Corral Creek deposit:		
Fe_2O_3	.02	----------
SiO_2	99.46	----------
Al_2O_3	.45	----------
CaO	0.09	----------
MgO	.011	----------
		B[2]
Crystal Butte deposit:		
Fe_2O_3	.032	.036
SiO_2	93.6	98.7
Al_2O_3	.26	.44
CaO	.05	.05
MgO	.05	.05

[1] Analysis furnished by owner.
[2] Duplicate chemical analysis.

Both the Corral Creek and Brown deposits contain extremely pure silica, and are thus potential sources of premium-grade material. The Crystal Butte deposit is of lower grade, but may be suitable for ferrosilicon production.

SILLIMANITE GROUP OF REFRACTORY MINERALS

(By S. L. Groff, Montana Bureau of Mines and Geology, Butte, Mont.)

A wide variety of refractory materials are required by industry, for many different uses. Among them are four minerals with identical applications: sillimanite, kyanite, andalusite, and dumortierite (Bateman, 1950, p. 297–299). The first three have identical composition ($Al_2O._3SiO_2$); dumortierite is a basic aluminum borosilicate. At high temperatures (1,100°–1,650° C.) all change over to mullite ($3Al_2O_3.2SiO_3$) and vitreous silica. This material remains stable up to 1,810° C., and is heat resistant, a good high-temperature insulator, and is particularly resistant to thermal shock. Although costly it is much used for spark plugs, electrical and laboratory porcelains, and in the high-temperature ceramic industry.

Kyanite is a common mineral of metamorphic rocks, and also occurs in some pegmatites and locally in quartz veins.

Andalusite occurs in metamorphic rocks, alkaline crystalline rocks, and in pegmatites.

Sillimanite usually occurs in highly metamorphosed alumina-rich rocks.

Dumortierite is commonly associated with pegmatites or quartz veins that cut aluminous rocks.

Prices for ground bagged kyanite in South Carolina (October 18, 1962) are as follows: 35 mesh, $47 per short ton; 200 mesh, $53 to $55 per short ton.

Apparently the kyanite price includes the other minerals of the sillimanite group (Eng. Mining Jour., Metal and Minerals Markets, October 18, 1962).

There has been no production of the sillimanite minerals in Montana to date, although deposits of these minerals of potential commercial importance exist within the State (fig. 34).[1] Industrial purchasers, however, are too far removed to permit the profitable working of such deposits.

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Montana's major deposits of kyanite, andalusite, and sillimanite are found 13 miles southwest of Ennis (fig. 1, locality No. 1) in Madison County, where they are associated with pegmatite dikes and Precambrian gneiss (Heinrich, 1948). These deposits are irregular and pockety, and accurate estimates of tonnage and grade cannot be made. However, there are vast tonnages of low-grade material with local concentrations of from 50 to 60 percent aluminum silicates (Sahinen and Crowley, 1959, p. 18). Other occurrences are the Bozeman deposit, 12 miles southwest of Bozeman (No. 2), with corundum in syenite; the Gallatin deposit, 17 miles southwest of Bozeman (No. 3), similar to the Bozeman deposit, of variable grade, developed for corundum during World War II; Bear Trap deposit, 10 miles southeast of Norris (No. 4), Madison County, has some high-grade sillimanite and corundum. Still other deposits about which little is known are found in the vicinity of Dillon (Nos. 5 and 6), Beaverhead County; 23 miles southeast of Dillon (No. 7) (Heinrich, 1950); in the Jardine district (No. 8), Park County; and in the Philipsburg area (No. 9), Granite County.

Only two deposits of dumortierite are known in Montana, one in secs. 3 and 4, T. 7 S., R. 6 W., about 14 miles east of Dillon (No. 10), Beaverhead County; the second, 7 miles north of Basin on Jack Creek, in sec. 7, T. 7 N., R. 6 W. (No. 11), in Jefferson County (Graham and Robertson, 1951, p. 916). No production has been recorded from either deposit, nor are tonnage estimates available.

SILVER, ZINC, AND LEAD

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Montana has 56 districts, scattered throughout 19 different counties, in which the sum of the recorded production plus the estimated reserves of metal exceeds 100,000 ounces of silver, 1,000 tons of lead, or 1,000 tons of zinc. Fifty-five, or all but one of these, have produced significant (i.e., more than the minimum stated above) amounts of silver. Of the 35 lead districts, 34 are silver districts as well; and of the 23 zinc districts, all are also lead and silver districts. Because of the intimate association of these metals, which in many instances are mined from the same deposits, all three are discussed together.

Gold is found in many of the same districts and even in the same deposits as silver, lead, or zinc, but gold occurrences have been described separately because gold was of great importance in Montana's early history; much of the gold was derived from placers rather than lode deposits; and 14 of Montana's 52 gold-producing districts did not produce significant amounts of silver, lead, or zinc.

The following discussion of the geology of silver, zinc, and lead deposits has been condensed from "Zinc in the United States" and "Lead in the United States" (McKnight, Newman, and Heyl, 1962 a and b) and from "Silver in the United States" (McKnight, Newman, Klemic, and Heyl, 1962). The tabulation of Montana's silver-zinc-lead districts which is at the end of this chapter has also been compiled with a few modifications from these same sources.

In Montana, as in other parts of the West, deposits of silver, lead, or zinc occur in areas where intrusive igneous rocks of intermediate to acidic composition are prominent (fig. 35). The deposits generally

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

are found in the bordering rocks, but they may also occur in intrusive rocks as at Butte. In either case, the ores are related to structural breaks that developed after consolidation of the igneous rock and they are believed to have been deposited from solutions of deep-seated origin. The ore may occur in veins closely confined to the original fractures in the rock or it may replace the adjacent wall rocks. Where there are carbonate rocks, the ore may replace certain beds for considerable distances.

The igneous bodies with which the deposits are affiliated are typically small bodies of porphyritic textures whose apices are truncated by erosion. Where deposits are associated with larger batholiths such association is with special parts, usually the smaller satellitic protuberances or cupolas.

Although the host rocks of the deposits range from Precambrian to Tertiary in age, most of the deposits appear to be related to igneous rocks that were intruded from about the end of the Jurassic Period to near the end of the Miocene.

For convenience, Montana's silver-zinc-lead districts have been grouped into the following categories:

First magnitude: Districts in which production plus estimated reserves totals more than 50 million ounces of silver, 1 million tons of lead, or 1 million tons of zinc.

Second magnitude: Districts in which production plus reserves totals from 5 to 50 million ounces of silver, 50,000 to 1 million tons of lead, or 50,000 to 1 million tons of zinc.

Third magnitude: Districts in which production plus reserves totals from 100,000 to 5 million ounces of silver, 1,000 to 50,000 tons of lead, or 1,000 to 50,000 tons of zinc.

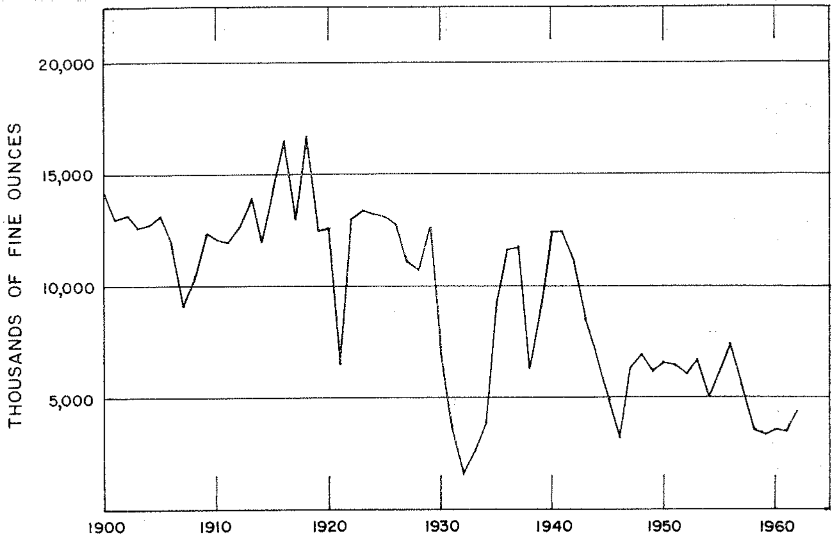
The locations of these districts are shown on figure 35; the numbers on the figure refer to districts mentioned in the text. Only districts on which production plus reserves is equal to or greater than magnitude 3 are considered.

Montana has three districts which by this definition are of the first magnitude silver districts—Philipsburg (No. 12), Butte (No. 30), and Colorado-Wickes (No. 36). Butte is also a first-magnitude zinc district and a second-magnitude lead district, Colorado-Wickes is a second-magnitude lead district. Three others—Bryant (No. 16), New World (No. 51), and Barker (No. 51)—are second-magnitude districts for both silver and lead. Four—Hog Heaven (No. 3), Elkhorn (No. 37), Marysville (No. 45), and Neihart (No. 50)—are second-magnitude districts for silver only. One—Eagle district (No. 4)—is a second-magnitude district for lead only. Of the 11 first- or second-magnitude districts, all but the Hog Heaven and Eagle districts have produced substantial amounts of gold and in some of them silver, lead, and zinc have been subordinate to gold. Butte's major importance is as a copper producer.

Since the inception of mining, Montana has been an important silver producer. The peak of production was reached in 1918 when Montana was the country's leading silver State (fig. 36). In that year Montana's mines produced 16,797,477 fine ounces of silver or nearly a fourth of the domestic mine production. Since 1957 Montana has ranked third or fourth as a silver-producing State but the amount produced has been steadily declining. In 1961 Montana's silver production was only 3,490,350 fine ounces or about 10 percent of domestic mine production.

FIGURE 36

MONTANA SILVER PRODUCTION 1900–1962



Although silver is, or has been, produced in many localities within the State, by far the greater part of the silver has been obtained as a byproduct of base-metal mining, especially at Butte. Through 1961 this district alone has produced 627,753,711 fine ounces of silver,[2] a figure that has been exceeded only by the Coeur d'Alene district in Idaho. In 1961 Silver Bow County (essentially the Butte district) accounted for 79 percent of the State's output of silver. Granite County (mostly the Philipsburg district) accounted for an additional 13 percent; the remaining 8 percent came from 16 other counties (Fulkerson and others, 1962, p. 624). The rise in the price of silver which resulted from the suspension in November 1961 of Treasury sales of silver will undoubtedly tend to stimulate mining of other silver or of other argentiferous lead-zinc deposits. However, the great bulk of the silver will be obtained in the future, as in the past, from the Butte area. Because of the size of the Butte reserves, Montana should remain an important silver-producing area for a long time to come.

Montana is an important zinc-producing State, but zinc production has been subject to extreme fluctuations (fig. 37). In terms of total zinc production, Montana is fifth in the Nation. The alltime peak was reached in 1916, when 114,630 short tons was produced from Montana deposits. Montana in that year accounted for about a fifth of the U.S. mine production and was second only to Missouri. In 1951, although mine output was only 85,551 short tons, Montana was the Nation's leading zinc producer. Zinc production has declined sharply since then; in 1961 Montana ranked only 13th in the listing of domestic producers. The 10,262 short tons credited to the

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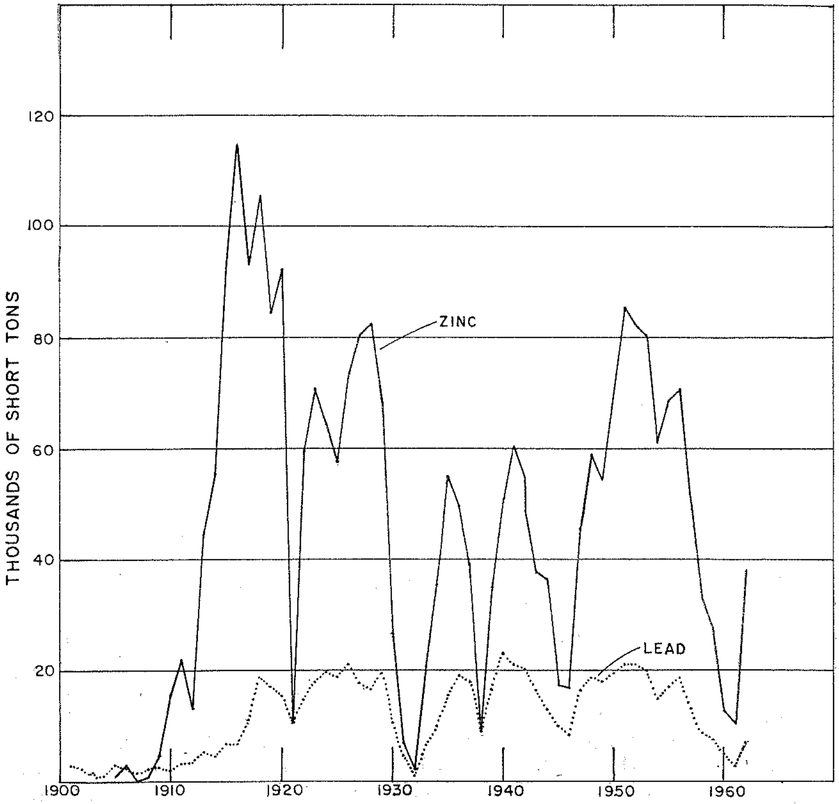
[2] The Anaconda Co.—Montana operations. Pamphlet published 1962 by the Anaconda Co.

FIGURE 37

MONTANA PRODUCTION OF LEAD AND ZINC
1900-1962



State accounted for only 2.2 percent of domestic mine production. Preliminary U.S. Bureau of Mines production figures for 1962 show a substantial rise to 38,830 short tons of zinc.

Zinc has been produced in quantity from 23 different districts in Montana but, as with silver, the Butte district has been by far the chief source of the State's zinc. Through 1961 over 2,290,000 short tons has been mined from this single district. In 1956, a typical year of fairly high zinc production, 90 percent of Montana's 70,520 tons of zinc was obtained from the Butte mines. Nevertheless, unlike silver, zinc production is nearly independent of copper mining. Some zinc is recovered as a byproduct of copper mining, but most of the zinc at Butte is obtained from zinc-lead-bearing veins peripheral to the copper-rich central part of the district. (See section on copper.) These deposits normally are worked only when market conditions make it economic to do so. Periods of high demand for zinc may or may not correspond with periods of demand for copper. Thus in 1956 Montana produced nearly seven times as much zinc as in 1961, although more copper was produced in 1961 than in 1956. The increased output of zinc in 1962 over 1961 reflects the opening of the Anaconda's Elm Orlu-Black Rock project at Butte.

The largest known reserves of zinc in Montana are in the Butte district but potential reserves both within and without the district are large. Wide fluctuation in the production rate can be expected from year to year but, under suitable market conditions, Montana will continue to be an important source of zinc.

Montana has been a substantial but not a major producer of lead. Lead output has fluctuated but this fluctuation has not been as pronounced as in the case of zinc (fig. 3). Peaks of production average about 20,000 tons of lead a year. From 1946 through 1956 Montana production has been maintained at an average rate of about 18,000 tons a year, or about 5 percent of U.S. mine production. Since 1956 there had been a progressive decline until in 1961 Montana produced only 2,643 short tons of lead or about 1 percent of domestic mine production. With the opening of Anaconda's Elm Orlu-Black Rock project this was increased to 6,556 short tons in 1962.

Lead is found with zinc in the veins in the peripheral part of the Butte district and the Butte veins have produced a total of 402,000 short tons of lead or about a fifth of the amount of zinc credited to the State. However, other districts in the State such as Colorado-Wickes, Eagle, and Bryant have been substantial producers in the past and in 35 different districts production plus reserves exceeds 1,000 tons of lead. In 1956, a year of relatively high lead production, 80 percent of the State's output of 18,642 short tons was derived from the Butte district. In 1961, a year of relatively low lead production, 23 percent of the 2,643 short tons produced came from mines in Lewis and Clark County, 16 percent from Granite County—mostly the Philipsburg district—and an equal amount from the Butte district. Eight other counties yielded the remainder (Fulkerson, Kauffman, and Knostman, 1962, p. 623).

Reserves of lead in the Butte district are large and potential reserves outside the Butte district are substantial, but market conditions in the lead industry do not at present encourage their extensive development. The rise in the price of silver resulting from the suspension in November 1961 of Treasury sales of that metal should tend to stimulate development outlying deposits of silver-rich lead ores which are marginal at present lead prices. However, any really significant increase in the current rate of lead production probably must await higher price levels for lead—or for zinc with which much of the lead is associated.

Pertinent statistics on Montana's silver, zinc, and lead districts are summarized in table 7.

TABLE 7.—*Silver-zinc-lead districts in Montana*

Map locality	District	County	Rank			Other metals produced	Manner of occurrence	References
			Silver	Zinc	Lead			
1	Troy-Grouse Mountain	Lincoln	3	3	3		Replacement veins and fissure filling in metadiorite dikes in Precambrian argillite.	Gibson, 1948.
2	Libby	do	3	3	3	Gold	Replacement veins in shear zones and faults in Precambrian argillite.	Do.
3	Hog Heaven	Flathead	2		3		Replacement bodies in stockwork in Tertiary porphyritic latite dike.	Shenon and Taylor, 1936.
4	Eagle (Jack Waite mine)	Sanders	3	3	2		Replacement veins in shears in Precambrian quartzite and argillite.	Hosterman, 1956.
5	Packer Creek (Last Chance) (Silver Cable mine).	Mineral	3	3	3		Replacement veins along faults and fractures in Precambrian argillite and quartzite.	Wallace and Hosterman, 1956.
6	Keystone (Iron Mountain) (Iron Mountain, Nancy Lee mines).	do	3	3	3		Replacement veins in Precambrian quartzite and argillite.	Campbell, 1960.
7	Curlew (Curlew mine)	Ravalli	3	3	3		Fissure filling along fault contact between granite or Pleistocene gravel and Precambrian(?) quartzite and limestone.	Sahinen, 1957.
7–A	Copper Cliff (Cramer Creek) (Blacktail mine).	Missoula			3		Replacement bodies in Cambrian(?) dolomitic limestone.	Do.
8	Garnet (First Chance)	Granite	3			Gold	Veins in granodiorite stockwork of Laramide age and along bedding in adjacent Precambrian and Cambrian quartzite and schistose shale.	Pardee, 1918a.
9	Dunkelberg (Forest Rose mine).	do	3	3	3		Veins near axis of anticline in Cretaceous sediments and in dioritic and gabbroic sills; replacement bodies in limestone.	Pardee, 1918b; Popoff, 1953.
10	Henderson (Black Pine) (Combination mine).	do	3			Gold and tungsten.	Fissure veins along bedding in Precambrian quartzite.	Emmons and Calkins, 1913.
11	Boulder and South Boulder	do	3			Gold	Fissure veins in Tertiary(?) granite stock and in adjacent sediments.	Do.
12	Philipsburg (Flint Creek)	do	1	2	3	Manganese and gold.	Replacement veins and bodies in Cambrian, Silurian, and Devonian limestones and sharles; veins in granodiorite.	Do.
13	Georgetown	Deer Lodge	3			Gold	Byproduct of gold mining. Replacement bodies and veins in Cambrian and Devonian limestone near granodiorite stocks.	Do.
14	Blue-eyed Nellie mine	do	3				Replacement bodies in Cambrian limestone.	Do.
15	Vipond (Quartz Hill) (Quartz Hill mine).	Beaverhead	3				Pipelike ore shoots along fissures; bedded replacement deposits in Paleozoic limestone.	Taylor, 1942.
16	Bryant (Hecla)	do	2	3	2	Gold	Replacement bodies along bedding in Cambrian dolomite on anticlinal crests near contact with quartz monzonite.	Karlstrom, 1948; Winchell, 1914.

17	Polaris (Lost Cloud)	do	3				Replacement bodies in Carboniferous limestone near contact with quartz monzonite batholith.	Winchell, 1914.
18	Agenta	do	3	3	3	Gold	Replacement bodies along bedding and fissures in Paleozoic limestones; veins in Precambrian shale and in quartz monzonite.	Shenon, 1931; Myers, 1951.
19	Blue Wing	do	3			do	Replacement veins in Mississippian limestone and in granodiorite stock.	Shenon, 1931.
20	Virginia City (Alder Gulch)	Madison	3			do	Byproduct of lode and placer gold mining	Tansley and others, 1933.
21	Norris	do	3			do	Byproduct of gold mining. Deposits along intersection of fissures in quartz monzonite and in adjacent Precambrian gneiss and schist.	Do.
22	Sheridan	do	3	3	3	do	Veins and replacement bodies along faults and bedding in Precambrian limestone and marble.	Do.
23	Pony (Mineral Hill, South Boulder).	do	3			Gold and tungsten.	Veins in Precambrian gneiss and schist and in aplite and quartz monzonite of Tobacco Root batholith.	Do.
24	Tidal Wave (Twin Bridges)	do	3		3	Gold	Fissure veins in Precambrian gneiss and in quartz monzonite; replacement bodies along fissures and bedding in Paleozoic limestone.	Do.
25	Rochester (Rabbit)	do	3		3	do	Veins in Precambrian schist and gneiss; replacement bodies along fractures in Cambrian limestone.	Sahinen, 1939.
26	Melrose (Camp and Soap Creeks).	Silver Bow	3			Gold(?)	Veins in Precambrian schist and argillite	Winchell, 1914; Sahinen, 1950.
27	Silver Star	Madison	3			Gold	Byproduct of gold mining. Contact metamorphic deposits in Paleozoic limestone; veins in Precambrian schist and gneiss.	Sahinen, 1939.
28	Renova (Cedar Hollow)	do	3			do	Byproduct of gold mining. Vein on fault nearly along bedding in Precambrian limestone.	Tansley and others, 1933.
29	Whitehall (Cardwell) (Golden Sunlight mine).	Jefferson	3		3	do	Veins in Precambrian calcareous shale, sandstone and limestone, and in porphyry dikes.	Winchell, 1914; Roby and others, 1960.
30	Butte (Summit Valley)	Silver Bow	1	1	2	Copper, gold, and manganese.	Replacement veins and lodes in quartz monzonite.	Sales, 1914; Hart, 1935.
31	Oro Fino (Champion mine)	Deer Lodge	3				Veins in quartz monzonite of Laramide age	Pardee and Schrader, 1933.
32	Zosell (Emery)	Powell	3		3	Gold	Replacement vein along faults in late Cretaceous(?) andesite.	Pardee and Schrader, 1933; Robertson, 1953.
33	Elliston	do	3		3		Veins in andesite and quartz monzonite	Pardee and Schrader, 1933.
34	Ramini (Vaughn)	Lewis and Clark	3	3	3	Gold	Lodes in sericitized quartz monsonite	Do.
35	Cataract (basin) and Boulder (Comet, Gray Eagle, Hope-Katie mines).	Jefferson	2	3	3	do	Replacement viens in quartz monzonite and aplite.	Do.
36	Colorado-Wickes	do	1	3	2	do	Veins in quartz latite and quartz monzonite	Do.
37	Elkhorn	do	2	3	3	do	Replacement bodies in Cambrian dolomite	Klepper and others, 1957.
38	Radersburg (Cedar Plains)	Broadwater	3	3	3	do	Veins in andesite and latite of early Tertiary (?) age, and in Paleozioc and Mesozoic sediments.	Pardee and Schrader, 1933; Reed, 1951.
39	Park (Indian Creek) (Iron Mask mine).	do	3	3	3	do	Veins in early Tertiary(?) andesite	Stone, 1911; Reed, 1951.
40	Beaver Creek (Winston)	do	3		3	do	Veins in andesite and quartz monzonite	Pardee and Schrader, 1933; Reed, 1951.

TABLE 7.—*Silver-zinc-lead districts in Montana*—Continued

Map locality	District	County	Rank			Other metals produced	Manner of occurrence	References
			Silver	Zinc	Lead			
41	Warm Spring	Jefferson	3				Veins in quartz monzonite	Pardee and Schrader, 1933.
42	Clancy (Lump Gulch)	do	3	3	3	Gold	Lodes along fault zones in quartz monzonite and aplite.	Do.
43	Helena (Last Chance)	Lewis and Clark	3			do	Byproduct of gold mining. Contact metamorphic deposits in Mississippian limestone; veins along crushed zones in quartz monzonite; placers.	Knopf, 1913; Pardee and Schrader, 1933.
44	Scratch Gravel	do	3		3	do	Contact metamorphic deposits in Precambrian limestone: veins in Precambrian shale, quartzite and limestone, and in adjacent quartz monzonite stock.	Pardee and Schrader, 1933.
45	Marysville	do	2		3	Gold and tungsten	Fissure veins in Precambrian limestone surrounding quartz monzonite stock.	Do.
46	Stemple-Gould	do	3			Gold	Byproduct of gold mining. Veins in contact-metamorphosed Precambrian argillite.	Do.
47	Heddleston (Mike Horse mine).	do	3	3	3		Tabular breccia filling with some replacement in Precambrian argillite and quartzite and igneous rocks.	Do.
48	Dry Gulch (York) (Golden Messenger, Old Amber mines).	do	3			Gold	Byproduct of lode gold mining.	Do.
49	Castle Mountain	Meagher	3		3		Replacement bodies along bedding and fissures in Mississippian and Cambrian limestone; and along porphyry sills and dikes.	Roby, 1950.
50	Neihart (Montana)	Cascade	2	3	3	Gold	Sheeted replacement vein in Precambrian gneiss and quartzite.	Schafer, 1935; Robertson, 1951.
51	Barker (Hughesville) (Block P mine).	do	2	3	2		Fissure vein in syenite stock and at contact with Cambrian or Carboniferous limestone.	Jackson and others, 1935; Weed, 1900; Spiroff, 1938.
52	North Moccasin (Kendall)	Fergus	3			Gold	Byproduct of lode gold mining	Blixt, 1933.
53	Warm Springs (Maiden-Gilt Edge).	do	3			do	do	Robertson, 1950; Weed and Pirsson, 1898.
54	Little Rockies (Zortman-Landusky).	Phillips	3			do	do	Corry, 1933.
55	New World (Cooke City)	Park	3	3	3	do	Contact metamorphic deposits, veins, and replacement bodies in Cambrian and Ordovician limestone and dolomite.	Lovering, 1930; Reed, 1950.

SODIUM SULFATE

(By U. M. Sahinen, Montana Bureau of Mines and Geology, Butte, Mont.)

The sodium sulfate of commerce is of two kinds: (1) natural sodium sulfate and (2) byproduct sodium sulfate. Until about 1925 the supply of byproduct sodium sulfate, or "salt cake," from the manufacture of hydrochloric and nitric acids tended to exceed the demand; but due to the changes in the processes for acid manufacture, the supply of salt cake was diminishing at about the same time that its demand in the manufacture of kraft paper was increasing. The increasing demand was partly offset by utilizing natural sodium sulfate, deposits of which are widespread throughout Western United States. Most of the demand, however, was met by imports. Prior to the last war, Germany was perhaps the main source of imported salt cake, although some was recovered from deposits in Belgium, Netherlands, and Canada. In later years Chile and Russia also contributed to United States imports.

Sodium sulfate is principally used by the pulp and paper industry in the manufacture of kraft paper, and the demand for this purpose is steadily rising. Each ton of pulp produced consumes 120 pounds of sodium sulfate. Sodium sulfate is also used in container and plate glass manufacture, in curing hides, in the dye and coal tar industry, in stock feeds, in the medical and chemical industries, in the manufacture of rayon and textiles, and in the metallurgical industry. The newest use is in soapless detergents.

The specifications of commercial sodium sulfate vary with industrial uses. The paper pulp industry acquires material that is from 94 to 98 percent anhydrous sodium sulfate, but different plants have different limits for different impurities. Dye industries prefer natural sodium sulfate to salt cake because the latter may contain nitrates or nitrites that oxidize the dyes.

The United States produces annually about 300,000 tons of sodium sulfate, about 40 percent of which is from natural sources. About 60 percent is produced as byproduct salt cake from various manufacturing industries. Price per ton ranges from $28 to $54 depending on grade. Imports exceed exports by about 130,000 tons. Montana has not produced sodium sulfate (production reported from Montana in 1951 was actually from North Dakota), but deposits in the State could readily supply the demands of the western paper pulp industry.

Sodium sulfate is a white salt that occurs in nature chiefly as the anhydrous mineral thenardite with the decahydrate mirabilite. It is found in different degrees of purity from pure mirabilite crystals to massive deposits containing mixed salts or minerals of a wide variety of composition together with insoluble impurities. In Montana sodium sulfate occurs as crusts, as crystals intermixed with mud, and as massive beds in certain intermittent lakes. Deposits in Chouteau and Sheridan Counties have long been known to exist and have been described by Sahinen (1956).

In Chouteau County the deposits occur along Shonkin Sag, a topographically low area which was formerly the course of the Missouri River (fig. 38).[1] The lakes, which are 2 to 24 miles southeast of Fort Benton, have no outlets and dry up during the summer. The C.M. St.P. & P. Railway traverses the Sag skirting both White and Big Lakes. The nearest rail shipping point is Geraldine, about 10

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

miles easterly from Big and Kingsburt Lakes. Four of the lakes, listed below, show thick crusts and concentrations of crystals in mud which suggest the possible existence of permanent crystal beds of economic significance; however, as yet no drilling has been done to verify this.

Name	Also known as	Area	Location
White Lake	Teal Lake	900 acres	Secs. 2, 3, 10, and 11, T. 22 N., R. 10 E.
Lost Lake		160 acres	Sec. 29, T. 22 N., R. 10 E.
Big Lake	Crane Lake	2 square miles	Secs. 25, 26, 35, and 36, T. 22 N., R. 10 E.
Kingsburt Lake	Mallard Lake	1.8 square miles	Secs. 17, 18, 19, and 20, T. 22 N., R. 11 E.

The reserves of these deposits cannot be estimated from the present state of knowledge.

In Sheridan County intermittent soda lakes form part of a chain extending from Saskatchewan through northeastern Montana into North Dakota. These lakes occupy shallow undrained depressions in channelways in glacial drift. Sulfate salts are deposited as the water evaporates during the hot summer months. Similar deposits in Canada and North Dakota have been thoroughly examined and described (Cole, 1926; Binyon, 1952; Witkind, 1959). There are some 66 lakes in Sheridan County, most of which are intermittent. Some contain deposits of sodium sulfate that warrant further investigations (Sahinen, 1956), but only 2 have been described in detail (Binyon, 1952; Witkind, 1959). Binyon (1952, p. 34) indicates a reserve of 2,824,000 tons for S.E. Brush Lake and 3,813,000 tons for Westby B. Lake, the latter partly in Montana and partly in North Dakota.

S.E. Brush Lake in secs. 26, 27, 34, and 35, T. 33 N., R. 58 E. (313 acres) has a permanent crystal bed 5.65 feet thick with 77.41 percent glauber's salt (commercial term for sodium sulfate). This bed contains 2,710,000 tons of salt; another 113,000 tons is contained in a mixture of salt and mud a few inches above and below the permanent bed.

Westby B. Lake in sec. 12, T. 36 N., R. 58 E. has an area of 386 acres, one-third of which is in Montana and two-thirds in North Dakota. The lake has a permanent crystal bed which is at least 9 feet thick.

Reserves for the entire lake are estimated (Binyon, 1952, p. 24) at 3,677,000 tons for the drilled portion of the permanent bed and 136,000 tons in about 1 foot of mixed mud and crystals overlying the permanent bed. About a third of the reserves, or 1,270,000 tons, should underlie the Montana portion of the lake.

Other lakes in this area that might be possible sources of sodium sulfate lie in sec. 13, T. 36 N., R. 58 E., just west of Westby B. Lake and the lake in secs. 24 and 25, T. 36 N., R. 58 E., south of the town of Westby.

Lakes northwest of these, near Sybouts, Saskatchewan, have been worked for sodium sulfate and there is no apparent reason why the Montana deposits could not also be worked to supply the paper pulp industry to the west. Lignite coal for power and processing the salt is plentiful in the area.

STONE

(By J. M. Chelini, Montana Bureau of Mines and Geology, Butte, Mont.)

Dimension stone and crushed and broken stone are the principal products of the stone industry. Dimension stone consists of natural blocks or slabs that are cut to definite shapes or sizes (Key, 1960b, p. 794). Crushed and broken stone consists of large irregular fragments of rock usually mined or quarried and crushed or ground to smaller size (Key, 1960b, p. 804). The raw material for the stone industry includes igneous, metamorphic, and sedimentary rocks. The principal varieties of rock used for dimension stone are limestone, granite, and marble, whereas many kinds of rock are used for crushed and broken stone. Broad classifications are "traprock," which in the trade is considered to be all dark dense fine-grained igneous rocks; and "granite," which includes all the lighter colored, coarser grained igneous rocks. Gneiss, a metamorphic rock, is usually grouped with granite. Sandstone and quartzite are locally used in large amounts. Limestone, a calcareous rock that includes dolomite and marble, is used in great quantities for fluxing in smelters and in the manufacture of lime. Of the crushed stone produced, nearly 75 percent is limestone, 8 percent is traprock, 6 percent is granite; the remainder is sandstone and miscellaneous rock types.

Dimension stone for interior use must be attractive in color and texture, have reasonable strength, and resist abrasion and cleaning solutions. For exterior use where it will be subjected to weathering, it must possess, in addition, resistance to stresses set up by repeated expansion and contraction, and resistance to chemicals naturally present or introduced into the atmosphere. Tests have been devised by the Bureau of Standards to determine these properties as well as the physical properties of toughness, elasticity, and density (Kessler and others, 1940 and 1927).

Physical features of rocks that determine their usefulness as dimension stone include jointing, sedimentary layering, and secondary cleavage. These are planes of weakness that influence the size and shape of the blocks that can be quarried. If properly distributed they may facilitate quarrying; if not, they may prohibit extraction of large-sized blocks.

The principal uses of dimension stone are in exterior and interior walls, windowsills, steps, fireplaces, piers, columns, trim, wainscoating, flooring, and ornamental structures such as arches. A large market has been developed in recent years for "split stone," "strip stone," ashlar, and rubble as veneer on residences and other small buildings. Other important uses are for monuments, curbing, flagging, paving, and roofing (Currier, 1960, p. 7).

The principal uses for crushed and broken stone are for concrete aggregate, road stone, and railroad ballast; however, large quantities are used in riprap and terrazzo.

Rigid requirements by consuming industries have produced many different specifications for crushed stone; therefore, reference is made to reports of the following organizations: American Association of State Highway Officials, American Roadbuilders Association, and U.S. Department of Commerce.

In 1961 the value of dimension stone sold or used by producers in the United States was $88,093,000; the value of crushed and broken stone was $862,467,000; and the value for all stone was $950,560,000 (Cotter and Jensen, 1961, p. 1139). During the same year, Montana stone production was worth $1,849,000, or only about 0.2 percent of the national total.

Numerous varieties of rock suitable for dimension stone can be found in many parts of the State, and stone has been quarried in the State for many years. However, not uncommonly a dimension-stone quarry was opened to produce stone for a specific project and then abandoned. Similarly, abandoned crushed and broken stone quarries are numerous owing to the plentiful and widespread occurrences of the raw material within the State. For economic reasons, producers move portable plants to new sites as existing markets shift.

At present, sandstone and quartzite for crushed and broken stone are being quarried by Victor Chemical Works in Beaverhead County (fig. 39,[1] locality No. 1); by Russken Mining Co. in Deer Lodge County (No. 2); by Ideal Cement Co. in Gallatin County (No. 3); by Lyons Construction Co. in Missoula County (No. 4); by the Great Northern Railway Co. in Cascade County (No. 5) and in Flathead County (No. 6); and by the Northern Pacific Railroad in Park County (No. 7). Limestone is quarried in a number of counties in western Montana. (See chapter on Limestone.)

Sandstone and quartzite are quarried for dimension stone by Montana Stone, Inc., in two quarries near Neihart in Cascade County (Nos. 8 and 9). At these quarries a very brilliant tan to maroon, and tan and maroon banded ashlar and flagstone are produced. The quarries are in the Flathead quartzite of Cambrian age. A green picture slate is quarried by the same company in Lewis and Clark County (No. 10). The Sesco Co. is quarrying a tan and chocolate-brown banded quartzite from the Striped Peak formation of Pre-cambrian age near Thompson Falls (No. 11).

Granite for the manufacture of monuments is quarried intermittently by Trevillion-Johnson Memorials Co. from three quarries within a 5-mile radius of each other in Jefferson County (No. 12). Granite is quarried near Gardiner, Park County (No. 13), by the Livingston Marble & Granite Works. This same company quarries travertine in the same area for manufacture of rubble, ashlar, and polished building stone. (See Chapter on limestone.)

Travertine is also quarried near Gardiner by the Montana Travertine Co., which produces at present only rubble for exterior and interior veneer. Montana Stone, Inc., quarries travertine northwest of Lewistown for manufacture of rubble (No. 14).

SULFUR

(By C. E. Erdmann, U.S. Geological Survey, Great Falls, Mont., and U. M. Sahinen, Montana Bureau of Mines and Geology, Butte, Mont.)

Sulfur is a nonmetallic element that constitutes only 0.06 percent of the earth's crust, yet is found widespread in nature, both in the native form and in combination with other minerals. Chief commercial sources are from deposits of native sulfur, from hydrogen sulfide (H_2S) gas associated with natural gas and petroleum, and from metallic sulfide ores such as pyrite (FeS_2). A potential source not utilized at present are the very large and widespread sedimentary deposits of gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$).

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

The uses of sulfur are so widespread and important that it is often mentioned as an indicator of economic development. Largest consumer is the fertilizer industry, which like the chemical, petroleum, rayon, and steel industries, uses it in the form of sulfuric acid (H_2SO_4). Large amounts are used by the paper industry for sulfite pulp, and the insecticide and rubber industries are major users of elemental sulfur. Annual consumption of sulfur in the United States in recent years has generally been in excess of 5 million long tons.

No commercial deposits of native sulfur are known in Montana, although small occurrences have been noted in a few places. Montana has produced important quantities of sulfuric acid from metallic ores, however. Metallic sulfides are found in every mining district in the State, and as the ores from these districts are smelted, the sulfur is driven off as sulfur dioxide, which is recovered and manufactured into sulfuric acid. The Butte district provides by far the greater bulk of the ores smelted at Anaconda, Mont. Sulfuric acid produced there was formerly used at the plant in the manufacture of treble superphosphate fertilizer; but since Anaconda has ceased fertilizer manufacture, the acid is marketed as such in tank cars, and much, if not all of it, finds its way into fertilizer industry in other States.

Up until 1959 pyrite concentrate from low-grade pyritic ores from the Butte district was made at Anaconda at a rate of about 50,000 long tons of equivalent pyrite annually. Production ceased after 1959 because of no intracompany demand for sulfuric acid.

Deposits of pyritic ores outside of the Butte district have been suggested as possible sources of sulfur for sulfuric acid, but to date no investigation has proceeded to the stage of delineating any such deposits.

In Montana there are extensive deposits of gypsum and anhydrite (calcium sulfate) interbedded with Paleozoic and Mesozoic strata, and deposits of sodium sulfate occur in intermittent lakes of Chouteau County in central Montana and in Sheridan County in northeastern Montana; but these materials are valuable mineral commodities in their own right and are not utilized as sources of sulfur or sulfuric acid.

Large quantities of hydrogen sulfide gas (containing 94.1 percent sulfur) are found in natural gas from some of Montana's gasfields. Because of its highly toxic nature and unpleasant odor, it must be removed before marketing the gas for domestic or industrial consumption when the concentration reaches 0.04 percent. Gas that contains more than this is known as sour gas.

Much of the petroleum and natural gas from the Paleozoic formations in the Rocky Mountain area contains hydrogen sulfide, and where present in sufficient amount it has become an important source of elemental sulfur. Concentrations are highly variable, even from place to place in the same formation or reservoir, and range from traces to more than 16 percent in the Tensleep sandstone at Elk Basin oilfield in Carbon County. On the whole, in Montana they are decidedly low. Those available from the Madison (Mission Canyon) limestone in Kevin-Sunburst Dome in Toole County, for example, range from 0.069 to 3.73 percent in the Rim Rock pool. The gas associated with the Mississippian, Silurian, and Ordovician oil on Cedar Creek anticline in the southeastern part of the State is for the most part considered "sweet." Where the amount of gas is sufficient for commercial use, but the hydrogen sulfide content is low, as at the Reagan field or Pine field, the H_2S is extracted and flared to prevent the possibility of dangerous accumulations in local topographic depressions.

The problem of what concentration of hydrogen sulfide is worth recovering for sulfur therefore becomes a matter of business judgment involving many factors, but a plant working with small percentages obviously requires very large reserves of gas. Thus, a sulfur plant in Wyoming, which operates on what is considered a minimum profit byproduct basis, extracts 9 or 10 long tons of sulfur per day from 15 million cubic feet of gas with an H_2S content of 2.5 percent, the beneficiated gas being delivered to a pipeline for commercial and domestic use. On the other hand, in some States where the H_2S concentration is sufficiently great to be processed for sulfur alone, and where no market for gas in available, the beneficiated gas may be returned to the reservoir to maintain pressure.

Production of elemental sulfur in Montana has developed some interesting discrepancies. The only plant that processes hydrogen sulfide gas originating in Montana is situated in Wyoming. This is the Pan American plant in the Elk Basin field, which handles over 16 million cubic feet of gas per day to extract some 60 or 70 long tons of sulfur daily from Tensleep sandstone gas with an H_2S content of about 16 percent and Madison limestone gas with 2 or 3 percent H_2S. Approximately 20 percent of the sulfur attributed to the Tensleep and about 8 percent of the sulfur from the Madison is consideredto come from the Montana portion of the field. Conversely, the only sulfur plant in Montana is the Montana Sulphur & Chemical Co. installation at Billings which produces about 50 long tons of sulfur per day from waste gases, mainly hydrogen sulfide and carbon dioxide, received from local refineries of the Continental Oil Co. and the Humble Oil Co. The origin of the hydrogen sulfide, however, is mainly from oil imported from Wyoming.

All things considered, the outlook for improvement of production of elemental sulfur from Montana is not attractive, chiefly for the following reasons: (1) Except for the northern part of the Elk Basin field, which is already contributing hydrogen-rich sulfide gas to a plant in the southern part of the field in Wyoming, the volume and H_2S content of natural gas from the State is low; (2) Montana is literally surrounded by large refineries in adjacent States that treat rich concentrations of hydrogen sulfide in large volumes of gas. Even if a new discovery of hydrogen sulfide suitable in quality and quantity were to be made in Montana, its competitive position against these established plants probably would be poor. Chief among these large sulfur plants are: The Texas Gulf Sulphur Co. plant at Worland, Wyo., which produces about 85 long tons of sulfur per day; the Signal Oil & Gas Co. at Tioga, in the Williston Basin of North Dakota, which produced about 107,180 long tons of sulfur during the first 6 months of 1962; and the British American Oil Co. plant in the Pincher Creek gas condensate field in southwest Alberta, which is capable of processing 170 million cubic feet of crude natural gas per day to recover 780 long tons of sulfur.

TALC AND PYROPHYLLITE

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Talc is a hydrous magnesium silicate. It is a very soft white, gray, or green micaceous mineral that occurs only in metamorphic rocks. It forms from serpentine, which in turn may be formed by the regional or contact metamorphism of magnesium-bearing rocks such as dunite, pyroxenite, and dolomite. The deposits themselves are generally closely associated with serpentine; more rarely they are enclosed by quartzite, phyllite, gneiss, or even granite.

Pyrophyllite, a hydrous aluminum silicate, resembles talc very closely in physical properties and appearances, hence is substituted for talc in some industrial applications. It also characteristically occurs in metamorphic rocks (Chidester and Worthington, 1962).

Talc has several physical properties which make it useful in industry. It is extremely soft, chemically inert, and has low thermal and electrical conductivity. Several grades are marketed, but steatite, the purest of the common commercial grades, and "lava," a pure, massive, fine-grained variety extensively used in the electrical industry, are the most valuable. They are machined or preformed into intricate shapes and fired for use as insulator plates in vacuum tubes and related electronic equipment.

Talc is used extensively as a filler in rubber, paint, paper, and roofing material, in the manufacture of high-fusion ceramic products such as high-frequency insulators, and it is used in the manufacture of whiteware, glazed wall, and floor tiles, and similar products, and as a carrier for insecticides. Special uses include: white shoe polish, cosmetics, dusting powders, finishing agent for leather and nails, lubricant for gunpowder, and crayons for marking hot metal castings and ingots. Prices for best quality talc in the period 1950–60 commonly ranged from about $9 to $12 per ton for the crude material at the mine. Pyrophyllite is competitive with talc in most uses where color is not a factor, and prices are, therefore, about the same as for talc.

Montana has possibly the largest reserve of steatite-grade talc in the United States (Engel and Wright, 1960, p. 840). All of the known deposits are in the highly metamorphosed rocks of the Cherry Creek Group in Beaverhead and Madison Counties, and all appear to have formed from serpentinized dolomitic marble. The greatest production has come from the Smith-Dillon deposit on Axes Creek, about 11 miles southeast of Dillon (fig. 40,[1] locality No. 1). The mineral occurs there both as thin veins and stringers, and as large masses of exceptional purity. The deposit is being worked by Tri-State Minerals Co.

Similar deposits occur about 8 miles to the northeast (Keystone mine) and about 3 miles to the south (Timber Gulch deposit). Talc, at these two deposits, contains some impurities, however, and neither is being worked at present, although both contain large reserves of talc suitable for many commercial purposes (Perry, 1948, p. 6).

Talc deposits are also worked at Johnny Gulch, about 20 miles south of Ennis, Madison County (No. 2). Considerable lava talc was produced, but known reserves of this grade appear small. Large quantities of ceramic-grade talc remain, and limited amounts of cosmetic-grade talc are also present.

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Talc occurs on Granite Creek, north of Virginia City (No. 3), and on Idaho Creek, southwest of Virginia City (No. 4), but these deposits appear to have less potential value than those described above. A deposit of good-quality talc was found in Cambrian rocks just south of Helena (No. 5), but was worked out a number of years ago.

Pyrophyllite occurs in a deposit about half a mile northeast of Argenta, 12 miles northwest of Dillon (No. 6) which appears to be of commercial quality and of sufficient size to permit exploitation, provided a suitable market can be found.

Current production figures are not available for Montana talc deposits. However, 250,000 tons, worth nearly $3½ million, was produced during the period 1952–61.

THORIUM AND THE RARE EARTHS

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Thorium and the rare earths are closely related in chemical properties, hence they are considered together in this report. Thorium is the only naturally radioactive element other than uranium that constitutes a potential source of atomic power. Natural thorium cannot be used in nuclear reactions, but it can be converted to U^{233} in a breeder reactor and then used in the same way as uranium (Olson and Adams, 1962). Although uranium reactors are apparently simpler and cheaper to build and fuel at present, much research is being done to develop the use of thorium for atomic power in the future. Thorium is also used as an alloy with magnesium, in gas mantles, refractories, polishing compounds, and chemical and medical products.

The rare-earth metals comprise fifteen elements. Lanthanum, cerium, praseodymium, neodymium, samarium, and europium are generally considered to form the cerium group. Yttrium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, lutetium, and ytterbium make up the yttrium group.

Rare-earth metals and their compounds are used for a wide variety of purposes, although none are used in large quantities (1960 consumption in the United States was equivalent to about 1,800 tons of rare-earth oxides). Cerium is used in sparking alloys, arc carbons, and in the glass industry. A variety of rare-earth elements are used in the iron and steel industries. Rare-earth oxides are used as polishing agents. A variety of minor uses exist, and considerable research is in progress to investigate further uses.

Principal minerals containing important amounts of thorium are few; thorite, thorogummite, and thorianite are the most common ones. Monazite, a cerium phosphate, commonly contains thorium as well as the rare earths. The euxenite group consists of several similar minerals that contain thorium and the rare earths along with tantalum, niobium, and uranium. Bastnaesite is a rare-earth carbonate. Thorium- and rare-earth-bearing minerals, although widely distributed in igneous and metamorphic rocks, are most abundant in alkalic rocks and carbonatites, in syenites and granites, in gneisses, and in veins, especially those associated with alkalic rocks. Because these minerals are, in general, resistant to weathering, most of the world supply of thorium and rare-earth minerals is found in placer accumulations.

The Lemhi Pass area of Montana and Idaho (fig. 41,[1] locality No. 1), near the crest of the Beaverhead Range, contains a considerable number of thorium-bearing quartz veins that cut metamorphic rocks of the Belt Series (Sharp and Cavender, in press). Some veins are more than 1,000 feet long and, in places, are as much as 35 feet thick (Armstrong, F. C., written communication, 1954). They consist of red to white quartz with barite, feldspar, thorite, specular hematite, and hydrous iron oxides, and with less widespread rare-earth minerals, and copper and iron sulfides (Anderson, 1958). Some of the veins locally contain as much as 20 percent ThO_2; average grade may be about 0.50 percent in some deposits (Sahinen and Crowley, 1959).

Thorium reserves in the Lemhi Pass area are estimated to be about 100,000 tons of ThO_2 in ore of probable commercial grade at current prices ($1.75 to $2.25 per pound of ThO_2 in 20 to 30 percent thorium concentrates) (Baker and Tucker, 1962).

Upper Cretaceous sandstones (Virgelle and Horsethief sandstones, St. Mary River formation) (Nos. 2, 3, and 4) in Glacier, Pondera, and Lewis and Clark Counties contain fossil black-sand placer concentrations (Stebinger, 1914) that are a potential source of monazite (Armstrong, 1957; Murphy and Houston, 1955), as well as zircon, ilmenite, and magnetite, and may constitute a worthwhile source of thorium and rare-earth elements.

Deposits of uncertain origin containing monazite, rare earths, and relatively small amounts of thorium, together with columbite and rutile, are known in southern Ravalli County (No. 5). The deposits are in a group of schists, gneisses, amphibolites, and carbonate rocks that extend from the headwaters of the West Fork of Bitterroot River, south into Idaho (Abbott, 1954; Sahinen, 1957; Anderson, 1958; Crowley, 1960). They may constitute a resource with considerable potential for the future, although their grade and location do not appear to be favorable for immediate exploitation.

Carbonatite veins in the Bearpaw Mountains on the Rocky Boy Indian Reservation, Hill and Chouteau Counties, contain as much as 3.5 percent rare earths (Pecora, 1956, p. 1546) (No. 6). This is much less than the amount present in the Mountain Pass carbonatite in California; nevertheless, the Bearpaw deposits may be a potential source of rare earths at some future date.

Other occurrences of thorium minerals in Montana are shown on the accompanying map (fig. 41). Most are in placers or associated with pegmatites. Their potential is unknown, but it appears likely that the principal reserves are in the four areas listed above. Thorium-bearing placer deposits of unknown potential are also known near Victor, Ravalli County (No. 7).

Although some of the deposits of thorium and rare earths have been known for a number of years, only a very small amount has been produced in Montana. Recent developments make it appear likely that this situation may change in the future. Much depends on the advances in technology that may come about as a result of current and projected research. Market conditions do not favor increased production at present, but the demand for thorium as a source of atomic energy, and of rare earths for a number of developing uses, may increase considerably in the not-too-distant future. At that time, some of the Montana deposits may well prove to be highly important.

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

TITANIUM

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Titanium is a light, lustrous, white metal. It is stronger for its weight than most metals, and is both strong and markedly corrosion resistant at temperatures up to 1,000° F. It is therefore used in airframes, jet engines, in a variety of apparatus exposed to salt water, and in heat exchangers, reactors, pumps, valves, and other equipment used in the chemical industry. Titanium is alloyed with other metals to increase corrosion resistance. Titanium metal is difficult and expensive to produce, and did not become available in usable amounts until 1948 (Lynd, 1960, p. 851). High cost is still one of the chief obstacles to its widespread use.

The chief use of titanium is in the form of titanium oxide, a brilliant white material with very high refractive index and great light-scattering ability. It is therefore without peer as a white pigment in paints, paper, rubber, and a wide variety of other materials, but the oxide is also used extensively for welding rod coatings. Titanium nitride, boride, and carbide are used in cutting tools, abrasive stones, and dies.

Titanium is a constituent of a large number of minerals, but only two are now, or are likely to become, ores. Ilmenite, iron titanium oxide, is the chief ore mineral. It occurs in large massive deposits associated with anorthosite and pyroxenite in several places in the world, and is also recovered from placer concentrations in beach sands. Rutile (TiO_2) is a widespread accessory mineral in igneous rocks but, with or without associated ilmenite, it forms minable concentrations in some ore bodies that are also typically associated with anorthosite. Like ilmenite, rutile occurs in beach sands in some places.

No commercial deposits of titanium minerals are known in Montana. Fossil beach sands containing ilmenite are present in the Virgelle, St. Mary River, and Horsethief formations of Cretaceous age in Glacier, Pondera, and Lewis and Clark Counties (Murphy and Houston, 1955), but reserves and grade have not been established. Although they may contain enough titanium to be a potential source in the future, they are too low grade and too far from existing markets to be of commercial value at present. (See fig. 41, thorium and rare earths in Montana, for the location of these deposits.)

TUNGSTEN

(By A. E. Weissenborn, U.S. Geological Survey, Spokane, Wash.)

Tungsten is a white metal which is ductile when pure and which has superior mechanical properties at high temperatures. Its melting point of 3,410° C. is higher than that of any other metal. Its uses are based chiefly on the extreme hardness and wear resistance of tungsten alloys and carbides; on the ability of tungsten alloys to retain hardness at elevated temperatures; and on the high melting point, low vapor pressure, or favorable electrical and thermionic properties of pure tungsten (Holliday, 1960, p. 903). Because of these characteristics, tungsten is used extensively in the machine-tool industry and is a metal of high strategic value. The United States has been considered deficient in tungsten resources, and except for the period 1953–56, consumption has exceeded domestic production. However, a large domestic productive capacity was demonstrated between 1950–56 under the influence of the price incentive of the Government stockpiling program. In the peak year of 1956, domestic production was nearly four times the average annual production achieved from 1946 through 1950, the 5 years immediately preceding the start of the program.

In the United States tungsten occurs principally in quartz veins that contain scheelite (calcium tungstate, which forms an isomorphous series with powellite, the calcium molybdate), minerals of the wolframite group (iron and manganese tungstates) or both, and in contact metamorphic deposits. Most of the tungsten deposits of the Western United States, including Montana, are related spatially to intrusive bodies of Cretaceous or early Tertiary age (Lemmon and Tweto, 1962, p. 1).

Tungsten has been produced in Montana from numerous lode deposits and from some alluvial deposits, in part in conjunction with the mining of gold (fig. 42),[1] but until 1954 Montana's tungsten output was insignificant. The entire production from 1900 to 1951 amounted only to the equivalent of 33,760 short ton units of WO_3, or about 0.40 percent of the domestic production of 10,216,720 short ton units (U.S. Bureau of Mines Minerals Yearbook, 1954, p. 1289). Previous to 1954 maximum shipments in any one year were in 1946 and these amounted only to the equivalent of 5,040 short ton units of WO_3, most of which was produced from the Henderson Gulch gold-tungsten placers. In 1952, under the influence of the Government buying program and Government aid to exploration available through the Defense Minerals Exploration Administration, there was a great increase in the exploration of Montana tungsten deposits. Montana production reached an alltime high of 73,800 short ton units (table 8) and Montana became the fourth largest tungsten-producing State. Production dropped rapidly at the termination of the Government domestic stockpiling program in December 1956, and at the end of 1958 no tungsten mines were operating in Montana. The Red Button mine was reopened in late 1959 but was closed again in December 1961. In 1962 there were no tungsten mines operating in Montana.

TABLE 8.—*Mine production of tungsten in Montana, 1950–62*

	Short-ton units of WO_3
1950	(1)
1951	60
1952	(1)
1953	840
1954	40, 680
1955	72, 660
1956	73, 800
1957	39, 600
1958	(2)
1959	None
1960	(3)
1961	(3)
1962	None

[1] None reported.
[2] Production from Brown's Lake and Red Button mines.
[3] Production from Red Button mine.

NOTE.—1 short ton unit = 20 pounds WO_3.

Source: U.S. Bureau Mines Minerals Yearbooks, 1950–62.

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Tungsten deposits are found in Beaverhead County along the eastern edge of a quartz monzonite pluton that forms the backbone of the Pioneer Mountains (Myers, 1952, pp. 16–17). In the Brown's Lake-Lost Creek area most of the tungsten deposits that from present knowledge give promise of commercial grades and tonnage lie in contact-metamorphosed carbonate rocks of the Amsden formation of Pennsylvanian age along the eastern edge of the main quartz monzonite mass, although older limestones have been mineralized in places south of Birch Creek. Five known areas of contact-metamorphosed Amsden formation are recognized between Birch Creek and Brown's Lake.

The chief producer has been the Brown's Lake or Ivanhoe deposit on Rock Creek about 6 miles northwest of Glen (fig. 42, locality 20). Up to the time it was closed in 1957 the mine produced 625,107 tons of ore averaging 0.35 percent WO_3 and during the brief span of its operation it ranked high among domestic producers (Pattee, 1960, p. 6). The deposit has long been known and a few hundred pounds of concentrates had been shipped, but previous to 1951 the low grade of the tactite and the high molybdenum content of the scheelite discouraged development.

The tungsten is found chiefly as fine-grained high-powellite scheelite in tactite near the base of the Amsden formation. The scheelite occurs mostly as tiny crystals sprinkled through interstitial quartz and the outer shells of garnet crystals (Myers, 1952, p. 39). Concentrates prepared at the Glen mill were shipped to Salt Lake City for refining. The successful operation of the property was due in large part to the development of a method of metallurgical treatment by which a high recovery was made from a low-grade ore (Mining World, 1955).

The Lost Creek deposits (No. 21) are about 3 miles southeast of the Brown's Lake mine and are in a similar geologic environment. The deposits were explored intensively in 1952 and 1953. Production from 1952 to August 1956 totaled 21,150 short tons of ore averaging 0.18 percent WO_3 (Pattee, 1960, p. 12), the grade of the ore produced being considerably lower than that from the Brown's Lake mine. The ore was treated at the Glen mill.

The Red Button, or Calvert, mine (No. 19) is reported to have been discovered in 1956 and was operated in 1957 and 1959–60. In 1960 the grade of the ore shipped was 1.13 percent WO_3 U.S. (Bureau of Mines Minerals Yearbook 1960, 1961, v. 3, p. 610). The ore occurs in recrystallized limestone of probable Precambrian age near the contact with a quartz monzonite intrusive. Other tungsten occurrences are known in this area, and some exploration has been done on the Fool Hen prospect about 2 miles to the southeast.

Numerous other tungsten occurrences in Beaverhead County are known in the Utopia or Birch Creek district (No. 22) south of the Lost Creek deposit, and in the Bald Mountain district (No. 22a) still farther south. All are along the edge of the intrusive. Many of these are described by Pattee (1960).

In Deer Lodge and Granite Counties, tungsten occurs in quartz veins near granitic intrusives in the Flint Creek and Anaconda ranges (Walker, 1960). Some contact deposits also occur. Many of these vein deposits were explored during the 1950's with the assistance of Defense Minerals Exploration Administration contracts.

Tungsten occurrences are numerous in the Black Pine-Henderson districts, north of Philipsburg. The chief production has come from a placer in Henderson Gulch (No. 7) where scheelite was identified in the black sand concentrate in 1933. According to Walker (1960, p. 17), from 1942–49 dredging yielded $940,000 in gold and scheelite; a total of 142 tons of scheelite concentrate containing 63 percent WO_3 was produced. The average gold content was 15.5 cents per cubic yard; the average tungsten recovery was 0.06 pound WO_3 per cubic yard. In the vicinity of Henderson Gulch, sediments of the Precambrian Newland Formation have been intensely metamorphosed by a granodiorite intrusive. Scheelite from the granodiorite and the contact zone is the probable source of most of the scheelite in the placer. Eluvial material on the adjacent hillslope also contains small amounts of scheelite (Walker, 1960, pp. 17–20).

The Combination (Black Pine) mine (No. 6) is in the eastern part of the John Long Mountains, about 3½ miles southwest of the Henderson Gulch placer. During its main period of production from 1882 to 1897 it produced a notable amount of silver from quartz-tetrahedrite veins with other sulfides (Emmons and Calkins, 1913, pp. 252–253). The principal ore-bearing structure of the mine is the Combination vein, one of four known parallel veins. The veins are enclosed in quartzite of the Precambrian Spokane Formation, and conform generally to the bedding. Huebnerite is a minor constituent of the ore and occurs as disseminated grains and in irregular concentrations which form narrow tungsten-rich bands or lenses of limited extent. In 1947 and 1948 the U.S. Bureau of Mines explored the property (Volin and others, 1952). Further exploration was done in 1952 and 1953 with the aid of a Defense Minerals Exploration contract. Only a small amount of tungsten ore was produced.

Other occurrences of tungsten in the district are the Bear and Float prospect and the Double Eagle prospect, both of which adjoin the Combination property, and the Franz prospect about 6 miles northwest (No. 5). All are similar to the occurrence at the Combination mine, as is the Sunrise vein on Sunrise Mountain, north of Henderson Gulch. At the Argo mine in the Harvey Creek district (No. 4),.T. 10 N., R. 16 W., to the north, tungsten occurs in a gold quarts bedding vein in the Belt series.

Tungsten minerals have been noted at a number of prospects in the Philipsburg area (Walker, 1960, pp. 20–25), but there is no recorded production of tungsten from any of these properties.

At least 17 tungsten occurrences are known in two closely spaced areas about 14 miles west of the city of Anaconda (Nos. 17 and 18). The tungsten is found in quartz veins or replacements in Paleozoic limy sedimentary rocks intruded by several small granodiorite outliers of the Philipsburg batholith. A large granodiorite stock lies about a mile north of Silver Lake (Walker, 1960, p. 28). The Trigger mine has produced about 1,000 tons of ore, averaging 1 percent WO_3 (Walker, 1960, p. 29, table 3) from replacement deposits in the Jefferson Formation. Smaller production has come from the H. L. M. and Storm Lake or Tarlach properties. The latter was explored in 1953 and 1954 by the Sunshine Mining Co.

Another tungsten area is in the Foster Creek district (No. 16) on the east slope of the Flint Creek range, approximately 8 miles west of Anaconda and 5 miles northeast of Silver Lake, where at least 15 occurrences of tungsten are known. The Tip Top, Day, and Smith prospects have shipped small amounts of tungsten ore, but none has made any substantial production. Tungsten occurs in veins and shear zones and in tactite bodies. Tungsten grade of some of the surface showings is good, but exploration has failed to find extensions of the ore in depth (Walker, 1960, pp. 44–52).

In the Marysville district of Lewis and Clark County (No. 9), veins mined chiefly for their gold content are found in and around a granodiorite stock about 3 square miles in extent. The stock intrudes the Helena limestone and the overlying Empire shale, and is surrounded by a contact aureole half a mile to a mile wide. Although the district produced much gold, there has been little activity in recent years. Scheelite was recognized in 1941 in placer concentrate from gold dredging in Piegan Gulch. Subsequently, scheelite-bearing tactite bodies were found in six or seven localities in the contact aureole (Knopf, Adolph, written communication, 1942). One of these localities, a tactite body on the Prentice property adjoining the Drumlummon mine, was explored in 1953 and 1954 by Ottawa Tungsten Co.

In Colorado Gulch (No. 10), 9 miles west of Helena, scheelite-bearing garnetiferous tactite masses are found on both sides of the gulch. The area is along the northern border of the Boulder batholith where the intrusive rocks are in contact with Three Forks formation and the Madison limestone (Knopf, Adolph, written communication, 1942).

In Lincoln County, scheelite has been reported (Lemmon and Tweto, 1962, p. 12) in a lead-zinc vein on Callahan Creek, about 8 miles west of Troy (No. 1). At this locality, veins with sphalerite and galena in a silicate gangue are enclosed in argillitic and quartzitic sediments of the Prichard and Burke formations (Calkins and MacDonald, 1909, pp. 99–102).

Gibson (1948, p. 87) mentions scheelite as a constituent of a quartz vein with galena and tetrahedrite at the Midas mine near Howard Lake, 21 miles south of Libby (No. 2). The country rock consists of calcareous shales of the Wallace formation.

Lemmon and Tweto (1962, p. 12) list an occurrence of scheelite in quartz streaks in a shear zone at the Waylett prospect on Miller Creek (No. 3) a short distance southeast of the Midas mine.

Numerous quartz-tungsten veins are known in the Potosi district, Madison County (No. 23), in extremely rugged country southwest of the town of Pony. These are associated with aplitic or alaskitic phases of the Tobacco Root batholith and are entirely within the batholithic rocks. These have been described by Hart (Tansley and others, 1933, p. 32) as follows:

> The tungsten mineral hubnerite occurs as seams in wide, massive, white quartz veins or dikes of pegmatitic character. Along the hanging wall, fluorite filling may be noted. The hubnerite occurrences, although of great extent, vary greatly in intensity and only lenslike zones constitute possible ore reserves, but it is apparent that under favorable market conditions the veins would warrant further exploration.

In the Jardine-Crevasse Mountain district, Park County (No. 25)—also known as the Sheepeater district—scheelite occurs with gold and arsenic, and was recovered for many years as a byproduct of gold mining. It is interesting to note that the Jardine mine is one of the earlier commercial sources of tungsten to be discovered in the United

States. Total production of scheelite through 1942, all of which came from the Jardine mine, is estimated at about 400 tons of concentrate with an estimated value of $305,000 (Seager, 1944, p. 1). In addition to gold, silver, and tungsten, the mine produced minor amounts of lead and copper, and a considerable quantity of arsenic, it being one of the few mines in the country where arsenic was a valuable by-product. The mine continued in operation until 1948, when a fire destroyed the cyanide plant. Production during the period 1942–48 was probably about 15 short tons of 60 percent WO_3.

The gold-tungsten-arsenic deposits of the Jardine-Crevasse Mountain district are found as replacement veins in Precambrian metamorphic rocks. Two types of veins are recognized: (1) quartz veins in quartz-biotite schist and biotite quartzite; and (2) arsenopyrite veins in quartz-cummingtonite-schist. The veins of the first type contain more tungsten and less gold than those of the second (Seager, 1944, p. 45).

In Powell County, several scheelite contact-metamorphic deposits have been found in the Ophir district (No. 8) 20 miles west of Helena on Snowshoe, Ward, Carpenter, and Ophir Creeks. Scheelite occurs scattered through garnetiferous tactite masses in the Madison Limestone. A small shipment of tungsten is reported to have been made from the Arnold and Ladysmith properties on Snowshoe Gulch in 1943 (Hobbs, S. W., written communication, 1944).

In the Ogden Mountain mining district (No. 8a) east of Helmville, gold-quartz veins with scheelite are found in rocks of the Belt series surrounding a quartz monzonite stock and also in the quartz monzonite stock itself. Scheelite is also said to occur in placer gravels. Some exploration was done in 1952 and 1953 on the New Progress and Old Timer claims, but there is no record of tungsten ore having been shipped from the area.

Huebnerite has been recognized (Weed, 1912, pp. 81–85) in some of the veins at Butte, Silver Bow County (No. 15), but has not been recovered commercially from the ore.

The presence of huebnerite in a quartz-silver shoot on the Birdie vein has long been known, and some tungsten ore is said to have been shipped in 1916. The mine is on the western slope of the Continental Divide, about 4 miles east of Butte, and is in granitic rocks of the Boulder batholith. The property was reopened and explored for tungsten by the West Slope Mining Co. during the period 1952–55. Sahinen (personal communication) also reports a scheelite-powellite occurrence in tactite along a limestone-quartz monzonite contact in the Highland district, 15 miles south of Butte.

Other localities where tungsten has been reported are in Broadwater County at the Diamond Hill mine (No. 13), near Kendall in Fergus County (No. 12), in the Woodville district in Jefferson County (No. 14), in the emigrant district in Park County (No. 24), and in tactite, near the Yogo Peak deposits in Judith Basin County (No. 11). Little is known about most of these occurrences.

The future outlook for tungsten mining in Montana depends on demand and economic factors. No tungsten mines are operating in Montana at the present time. Previous to 1953, Montana's small tungsten output came from mining of quartz veins usually with gold, silver, or other metals and as a byproduct from placer gold mining. With some possible exceptions, the tungsten-rich veins tend to be narrow and the ore shoots scattered, spotty, and marginal in grade. Some of them probably could be mined successfully during periods of high tungsten prices, and should gold prices increase, some tungsten might be recovered as a byproduct from lode gold or placer gold mining. The total amount of tungsten that could be recovered from these sources, even with abnormally high tungsten prices, would, however, be small.

The tactite deposits typified by the Bown's Lake or Red Button deposits are in a very different category. They can produce large tonnages of ore and probably can operate successfully at an appreciably lower price level than most of the vein mines. Experience during the Government tungsten program has shown that, given sufficient price incentive, the United States is not deficient in tungsten resources, but possesses a very substantial domestic productive capacity. Remaining known reserves of the Montana tactite deposits are probably insufficient for sustained large-scale production, but well-planned exploration might bring in new ore reserves. Not all of the numerous tactite bodies in Montana contain tungsten ore bodies, but prospecting of tactite bodies in carbonate sediments near their contacts with the younger granitic intrusive rocks might discover ore bodies similar to those at the Brown's Lake and Red Button mines.

These probably could not be worked profitably at present price levels of tungsten but the better ones might be able to produce, at price levels less than the $65 per unit price, which was current during the tungsten-buying program of the 1950's. The Montana tactite deposits thus are an important potential source of tungsten.

URANIUM

(By A. E. Weissenborn and P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Uranium is a mixture of the isotopes U^{238}, U^{235}, and U^{234}. U^{238} can be converted to plutonium, which, along with U^{235}, can be used in nuclear reactions. Atomic power and nuclear weapons are, therefore, the chief uses for uranium; minor amounts are used in the chemical, ceramics, and electrical industries.

Uranium is widely scattered in many types of rocks. The principal domestic sources of uranium are deposits in terrestrial sedimentary rocks. The largest and most numerous of these deposits are in sandstones and conglomerates in which uranium minerals occur as pore fillings and impregnations. Less important uranium deposits are found in lacustrine limestones. Coals and coaly sediments interbedded with clastic terrestrial sediments commonly contain minor concentrations of uranium; in a few localities, the coaly beds may contain up to several percent uranium and some deposits have been mined. Uranium is widespread in small concentrations in certain marine black shales and phosphorites such as the Permian Phosphoria Formation which underlies large areas of Idaho, Utah, Wyoming, and southwestern Montana (Schnable, 1955; Butler and others, 1962). Uranium is also found in many areas in veins, commonly of Tertiary age. Uranium is relatively soluble, and ground water solutions commonly transport and redeposit small quantities to places where its radioactivity is readily noticed. As a result, large numbers of small "radioactive occurrences" of little value are known.

Montana has not been an important producer of uranium. Numerous occurrences are known, however, and some deposits appear to have significant economic potential. (See fig. 43.[1]) Production data for Montana is as follows:

Uranium production in Montana

	Tons [1]
1949	Information not available.
1950	Do.
1951	Do.
1952	Do.
1953	"1 carload."
1954	"Small shipments."
1955	"1 shipment reported."
1956	"No large shipments."
1957	"Small tonnage."
1958	690 tons (ore).
1959	2,890 tons (ore).
1960	1,726 tons (ore).
1961	729 tons (ore).

[1] Data from U.S. Bureau of Mines Minerals Yearbooks.

Total value, 1956–61, $179,682.

Because of security restrictions which were in effect at the time, production data from 1949 to 1952 are not available.

The first discovery of uraniferous vein deposits in Montana was made in 1949 on the W. Wilson and adjacent claims near Clancy (Roberts and Gude, 1953a) and at the Free Enterprise mine near Boulder (Roberts and Gude, 1953b) in the northern part of the Boulder batholith. Subsequently more than 100 radioactivity anomalies were detected (Becraft, 1956, p. 117), all but 2 of which are in quartz monzonite, granodiorite, or related rocks of the Boulder batholith. In this area uranium is associated with chalcedony veins and vein zones which locally contain a little silver (Knopf, 1913, p. 103). Examples are the W. Wilson vein in the Clancy area and Free Enterprise vein near Boulder. A similar occurrence is at the Red Rock mine, one of the examples of uraniferous veins in prebatholithic volcanic rocks (Becraft, 1956, p. 120).

In the same area uranium also is associated with lead-silver veins and with minor amounts of zinc and copper as at the Comet and Gray Eagle mines or with mixed-type veins intermediate between the chalcedony and the lead-silver veins as at the Lone Eagle mine (Becraft, 1956, pp. 120 and 121). In all cases the uranium is believed to have been emplaced in a late stage of mineralization.

Uranium ore has been produced from only a very few of the numerous radioactive veins. A few tons of high-grade ore and about 150 tons of low-grade ore were produced from the Free Enterprise mine (Roberts and Gude, 1953b, p. 147) and several hundred tons of moderate-grade ore were mined from the W. Wilson mine (Becraft, 1956, p. 120). A small tonnage was produced from the Lone Eagle mine and a few tons have been obtained from other properties. No mines in the area are currently producing uranium ore.

Secondary uranium minerals are found coating small joints and fractures in Belt series quartzites near Saltese, Mineral County, but no production is known (Weis and others, 1958, p. 21).

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

Uraniferous veins or shear zones have been reported from Mineral, Ravalli, Beaverhead, and several other counties in western Montana (Butler and others, 1962).

In the Pryor Mountains in Carbon County, tyuyamunite ($Ca(UO_2)_2(VO_4)_2 5–8.5\ H_2O$) occurs in soft clayey material and silicified breccia that fills caves and solution cavities in the Madison limestone (Jarrard, 1957, p. 36). The largest productive mines of the Pryor Mountains are in Wyoming, but a number of deposits have been found in Montana. Although the individual ore bodies are small, the grade of the ore is relatively high and most of the Montana production of uranium has been from the Pryor Mountains.

Uranium-bearing lignite deposits underlie an area of approximately 13,000 square miles in North and South Dakota and adjacent parts of eastern Montana, near the eastern edge of the Great Plains physiographic province (Denson and Gill, 1956, pp. 413–418; Gill, 1959, pp. 167–179). The mineralized lignite beds occur throughout 2,000 feet of fluviatile deposits of Paleocene and late Cretaceous age. Overlapping the lignite-bearing sequence with marked regional uniformity are 250 feet or more of mildly radioactive tuffs and bentonitic clays of Oligocene and Miocene age. The uranium-bearing lignite beds underlie the more prominent buttes. Field evidence suggests that uranium was leached from the tuffs and concentrated in the underlying lignite. Megascopically identifiable uranium minerals are rare. Where they occur they coat or fill thin joints and fractures in the lignite and associated rocks. According to Denson and Gill (1956, pp. 4, 18) incomplete data indicate that deposits of radioactive lignite in eastern Montana and adjacent parts of North and South Dakota aggregate about 90 million tons. The beds average about 4 feet in thickness, and contain about 0.008 percent uranium. The uranium content of ash from the lignite ranges from 0.05 to 0.1 percent. The lignite beds are therefore a significant potential source of uranium particularly if uranium can be extracted from ash of lignite used industrially. The discovery of lignite containing as much as 5 percent uranium in the Cave Hills area of South Dakota suggests that other high-grade deposits of considerable size might be discovered.

Becraft (1958) has described uraniferous shale and lignite beds in the Townsend and Helena Valleys in Lewis and Clark, Broadwater, and Jefferson Counties. The uranium-bearing beds are in the lower part of a Tertiary sedimentary unit that consists largely of thin-bedded tuffs locally altered to bentonite. The uranium presumably was leached from the tuffs by meteoric water and concentrated in the carbonaceous shale and lignite. None of the uranium occurrences appear to be commercial, but they suggest that similar Tertiary sedimentary rocks which are present in many of the major valleys and intermontane basins in western Montana may be worth prospecting for uranium, particularly if they include light-colored, fine-grained tuff, bentonite, and coaly or carbonaceous beds.

Uranium is present in small amounts in all the bedded phosphorite deposits of southwest Montana (Swanson, 1960). The phosphorite occurs as part of the two phosphatic shale members of the Phosphoria formation of Permian age (McKelvey and others, 1959). Estimates by Swanson (1960, and oral communication) indicate that in the area south of Butte 35,000 short tons of uranium is present in rock 3 feet or more thick containing 31 percent P_2O_5 (acid-grade rock), with an average uranium content of 0.0090 percent. In rock of that thickness containing 24 percent P_2O_5 there are more than 400,000 tons of uranium, with an average content of 0.0066 percent. Estimates for the area farther north, which includes the deposits being mined near Garrison and Maxville, are not yet available. These figures reflect the total estimated phosphorite reserve, not just that part now accessible to mining. Uranium is recovered from some of the phosphorite mined in Florida, which is of comparable grade, but has not been recovered from any mined in the western field.

Although additional uranium discoveries very possibly could be made in veins and in deposits similar to those in the Pryor Mountains, production from these sources cannot be expected to be large. If the need were great enough, very large quantities of uranium could be recovered from the uraniferous lignite deposits of eastern Montana and from the phosphorite deposits of western Montana. Montana therefore is an important potential source for the future production of uranium.

VERMICULITE

(By P. L. Weis, U.S. Geological Survey, Spokane, Wash.)

Vermiculite is a hydrated magnesium-aluminum silicate mineral that expands greatly when heated. It occurs in nature as a platy brownish to greenish mineral with micaceous cleavage, and resembles biotite in appearance. When heated to about 1,500° F., vermiculite expands from 10 to as much as 30 times its original volume. Natural vermiculite is soft, and deposits have often been recognized by the presence of micalike flakes in a slippery soil that forms over the bedrock.

Minable bodies of vermiculite are generally found in intrusive bodies of pyroxenite, or less commonly with pyroxenite layers in metamorphic rocks. Commercial deposits require ore that contains a large proportion of vermiculite (30 to 50 percent or more), and the vermiculite must be sufficiently expandable so that the final product weighs from 4 to 10 pounds per cubic foot.

Expanded vermiculite is a good thermal insulator at temperatures ranging from subzero to 2,000° F.; it is lightweight, fireproof, granular, and free flowing; it is inert and will not decompose or decay; it is sterile and harmless to handle; it has the properties of a mineral sponge and will absorb large amounts of liquids and still remain free-flowing (Myers, 1960, p. 894). These properties result in its extensive use as loose grains as an insulator, or mixed with portland cement, clay, or plaster for lightweight aggregate, fireproof insulation, refractory blocks, and related products. It is used as a mineral filler, as a carrier for insecticides, fertilizers, and pesticides, as a culture medium for starting seeds and cuttings, and as a soil conditioner, in addition to a great many miscellaneous uses. The domestic industry produces about 200,000 tons of vermiculite annually.

Montana has large reserves of vermiculite. The large deposit controlled by the Zonolite Co. near Libby, Lincoln County, which began operation shortly after World War I, was the first deposit exploited in the United States (fig. 44,[1] No. 1).

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

The Libby deposit consists of masses of vermiculite formed by hydrothermal alteration in a large body of pyroxenite (Pardee and Larsen, 1929, pp. 22, 24). The deposit is cut by dikes of syenite, and it contains masses of hydrobiotite, biotite, and amphibole. The ore body is one of the largest ever worked; production ranged from a few hundred tons a year in the early 1920's to 20,000 tons in 1940 and to 75,000 tons in 1946. Present production is considerably greater. Reserves of ore-grade material are extensive.

Vermiculite deposits of a similar type are known near Hamilton, Ravalli County (No. 2) (Perry, 1948, p. 28), where the material also occurs in pyroxenite associated with syenite and pegmatite dikes. The vermiculite may be of commercial quality, but the amount of reserves is not known.

The vermiculite deposits near Boxelder, on the Rocky Boy Indian Reservation, Hill County (No. 3), are also associated with syenite and pegmatite. The Bearpaw Mountains, in which the deposits occur, are largely made up of an unusual potassium-rich group of igneous rocks. The deposits themselves appear to be limited in size, but commercial-quality material is believed to be present.

Vermiculite also occurs in metamorphic rocks of the Precambrian Pony series (Perry, 1948, p. 32). Such deposits that have been investigated include those near Pony (No. 4), Virginia City (No. 5), and Ennis (No. 6), Madison County; and near Dillon (No. 7), Beaverhead County. The vermiculite at these places is found in schistose bands and layers. Although the vermiculite is generally fine-grained, some commercial-quality material exists at these deposits, and reserves may be large.

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SELECTED REFERENCES

Abbott, A. T., 1954, Monazite deposits in calcareous rocks, northern Lemhi County, Idaho: Idaho Bur. Mines and Geology Pamph. 99, 27 p.

Altschuler, Z. S., Clarke, R. S., Jr., and Young, E. J., 1958, Geochemistry of uranium in apatite and phosphorite: U.S. Geol. Survey Prof. Paper 314–D, p. 45–90.

Am. Assoc. of State Highway Officials, 1955, Standard specifications for highway materials and methods of sampling and testing, pt. 1: Washington, D.C., 257 p.

Am. Roadbuilders Assoc., 1957, The highway construction industry in a long-range national highway program: 16 p.

Anderson, A. L., 1958, Uranium, thorium, columbium, and rare earth deposits in the Salmon region, Lemhi County, Idaho: Idaho Bur. Mines and Geology Pamph. 115, 81 p.

Anderson, S. B., 1958, Study reveals Mississippian series possibilities: North Dakota Geol. Survey Rept. Inv. No. 31. — p.

Anderson, S. B., and Hansen, D. E., 1957, Halite deposits in North Dakota: North Dakota Geol. Survey Rept. Inv. No. 28, — p.

Andrichuck, J. M., 1955, Mississippian-Madison Group stratigraphy and sedimentation in Wyoming and southern Montana: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 11, p. 2170–2210.

Armstrong, F. C., 1957, Eastern and central Montana as a possible source of uranium: Econ. Geology, v. 52, no. 3, p. 211–224.

Armstrong, F. C., and Full, R. P., 1950, Geologic maps of Crystal Graphite mine, Beaverhead County, Montana: U.S. Geol. Survey open-file maps.

Baillie, A. D., 1955, Devonian System of Williston Basin: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 5, p. 575–629.

Baker, D. H., Jr., Greenspoon, G. N., and Washington, W. F., 1962, Copper: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 495–534.

Baker, D. H., Jr., and Tucker, E. M., 1962, Thorium: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 1209–1214.

Banning, L. H., and Rasmussen, R. T. C., 1951, Processes for recovering vanadium from western phosphates: U.S. Bur. Mines Rept. Inv. 4822, 44 p.

Barrell, Joseph, 1907, Geology of the Marysville mining district, Montana, A study of igneous intrusion and contact metamorphism: U.S. Geol. Survey Prof. Paper 57, 178 p.

Bateman, A. M., 1950, Economic mineral deposits, 2d ed.: New York, John Wiley & Sons, Inc., 916 p.

Becraft, G. E., 1956, Uranium deposits of the Boulder batholith, Montana: U.S. Geol. Survey Prof. Paper 300, p. 117–121.

Becraft, G. E., 1958, Uranium in carbonaceous rocks in the Townsend and Helena Valleys, Montana: U.S. Geol. Survey Bull. 1046–G, p. 149–164.

Binyon, E. O., 1952, North Dakota sodium sulfate deposits: U.S. Bur. Mines Rept. Inv. 4880, 41 p.

Blixt, J. E., 1933, Geology and gold deposits of the North Moccasin Mountains Fergus County, Montana: Montana Bur. Mines and Geology Mem. 8, 25.

Brobst, D. A., 1958, Barite resources of the United States: U.S. Geol. Survey Bull. 1072–B, p. 67–130.

Brobst, D. A., 1960, Barite, *in* Industrial minerals and rocks, 3d ed.: Am. Inst. Mining Metall. Petroleum Engineers, p. 55–64.

Butler, A. P., Jr., Finch, W. I., and Twenhofel, W. S., 1962, Epigenetic uranium in the United States: U.S. Geol. Survey Mineral Inv. Resources Map MR–21

Calkins, F. C., and MacDonald, D. F., 1909, A geological reconnaissance in northern Idaho and northwestern Montana: U.S. Geol. Survey Bull. 384, 112 p.

Calvert, W. R., 1909, Geology of the Lewistown coal field, Montana: U.S. Geol. Survey Bull. 390, 83 p.

Cameron, E. N., and Weis, P. L., 1960, Strategic graphite—a survey: U.S. Geol. Survey Bull. 1082–E, p. 201–321.

Campbell, A. B., 1960, Geology and mineral deposits of the St. Regis-Superior area, Mineral County, Montana: U.S. Geol. Survey Bull. 1082–I, p. 545–612.

Caro, R. J., 1949, Anaconda phosphate plant, beneficiation and treatment of low-grade Idaho phosphate rock: Am. Inst. Mining Metall. Engineers Trans., v. 184, p. 282–284.

Carter, G. J., Kelly, H. J., and Parsons, E. W., 1962, Industrial silica deposits of the Pacific Northwest: U.S. Bur. Mines. Inf. Circ. 8112, 57 p.

Chidester, A. H., and Shride, A. F., 1962, Asbestos in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR–17.

Chidester, A. H., and Worthington, H. W., 1962, Talc and soapstone in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR–31.

Clabaugh, S. E., 1952, Corundum deposits of Montana: U.S. Geol. Survey Bull. 983, 100 p.

Cole, L. H., 1926, Sodium sulfate of western Canada; occurrence, uses, and technology: Canada Dept. Mines, Mines Branch, Pub. 646, 160 p.

Condit, D. D., 1920, Oil shale in western Montana, southeastern Idaho, and adjacent parts of Wyoming and Utah: U.S. Geol. Survey Bull. 711–B, p. 15–40.

Corry, A. V., 1933, Some gold deposits of Broadwater, Beaverhead, Phillips, and Fergus Counties, Montana: Montana Bur. Mines and Geology Mem. 10, 45 p.

Cotter, P. G., and Jensen, N. C., 1962, Stone: U.S. Bur. Mines Mineral Yearbook 1961, v. 1, p. 1139–1167.

Cotter, P. G., and Mallory, J. B., 1962, Sand and gravel: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 1061–1090.

Creasey, S. C., and Scholz, E. A., 1945, Big Ben molybdenum deposit, Neihart mining district, Cascade County, Montana: U.S. Geol. Survey open-file report, 29 p.

Crittenden, M. S., and Pavlides, Louis, 1960, Manganese in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR–23.

Crowley, F. A., 1960, Columbium-rare-earth deposits, southern Ravalli County, Montana: Montana Bur. Mines and Geology Bull. 18, 47 p.

——— 1962, Phosphate rock: Montana Bur. Mines and Geology Spec. Pub. 25, 8 p.

Currier, L. W., 1960, Geological appraisal of dimension stone: U.S. Geol. Survey Bull. 1109, 78 p.

D'Amico, K. J., 1962, Statistical summary of mineral production: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 135–182.

DeHuff, G. L., and Fratta, Teresa, 1959, Manganese: U.S. Bur. Mines Minerals Yearbook 1958, v. 1, p. 723–748.

DeMunck, V. C., 1956, Iron deposits in Montana: Montana Bur. Mines and Geology Inf. Circ. 13, 49 p.

DeMunck, V. C., and Ackerman, W. C., 1958, Barite deposits in Montana: Montana Bur. Mines and Geology Inf. Circ. 22, 30 p.

Denson, N. M., and Gill, J. R., 1956, Uranium-bearing lignite and its relation to volcanic tuffs in eastern Montana and North and South Dakota: U.S. Geol. Survey Prof. Paper 300, p. 413–418.

Dougan, C. W., 1947, Dickite-clay deposit of Fergus County, Montana: Montana Bur. Mines and Geology Misc. Contrib. 9, 11 p.

Emmons, W. H., 1908, Gold deposits of the Little Rocky Mountains, Montana: U.S. Geol. Survey Bull. 340, p. 96–116.

Emmons, W. H., and Calkins, F. C., 1913, Geology and ore deposits of the Philipsburg quadrangle, Montana: U.S. Geol. Survey Prof. Paper 78, 271 p.

Engel, A. E. J., and Wright, L. A., 1960, Talc and soapstone, *in* Industrial minerals and rocks, 3d ed.: Am. Inst. Mining Metall. Petroleum Engineers, p. 835–850.

Everett, F. D., and Agey, W. W., 1960, Field and laboratory studies of canal-lining materials, East Bench unit, Beaverhead and Madison Counties, Montana: U.S. Bur. Mines Prelim. Rept. 133 to Missouri Basin Field Comm.

——— 1961, Field and laboratory studies of canal-lining materials, Jefferson unit, Madison, Jefferson, and Broadwater Counties, Montana: U.S. Bur. Mines Prelim. Rept. 135 to Missouri Basin Field Comm.

Fisher, F. L., 1960, Germanium: U.S. Bur. Mines Minerals Yearbook, v. 1, p. 1252–1253.

Fleischer, Michael, 1961, Germanium content of enargite and other copper sulfide minerals: U.S. Geol. Survey Prof. Paper 424–B, p. 259–261.

Fulkerson, F. B., Kauffman, A. J., Jr., and Knostman, R. W., 1962, The mineral industry of Montana: U.S. Bur. Mines Minerals Yearbook, 1961, v. 3, p. 615–640.

Fulkerson, F. B., Knostman, R. W., and Petersen, N. S., 1962, The mineral industry of Idaho in 1962, Preliminary annual report: U.S. Bur. Mines Region I Area Rept. B–97, 7 p.

Gale, H. S., and Richards, R. W., 1910, Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U.S. Geol. Survey Bull. 430–H, p. 457–535.

Geehan, R. W., and Katlew, Charles, 1954, Tungsten: U.S. Bur. Mines Minerals Yearbook 1951, p. 1285–1298.

Gibson, Russell, 1948, Geology and ore deposits of the Libby quadrangle, Montana: U.S. Geol. Survey Bull. 956, 131 p

Gill, J. R., 1959, Reconnaissance for uranium in the Ekalaka lignite field, Carter County, Montana: U.S. Geol. Survey Bull. 1055–F, p. 167–179.

Goddard, E. N., 1940, Manganese deposits of Philipsburg, Granite County, Montana, a preliminary report: U.S. Geol. Survey Bull. 922–G, p. 157–204.

Graham, C. E., and Robertson, F. S., 1951, A new dumortierite locality from Montana: Am. Mineralogist, v. 36, nos. 11–12, p. 916–917.

Greene, L. M., and Agey, W. W., 1960, Field and laboratory studies of canal-lining materials, Helena Valley unit, Lewis and Clark County, Montana: U.S. Bur. Mines Prelim. Rept. 131 to Missouri Basin Field Comm.

Hanson, Alvin, 1952, Cambrian stratigraphy in southwestern Montana: Montana Bur. Mines and Geology Mem. 33, 46 p.

Hart, L. H., 1935, The Butte district, Montana, *in* Copper resources of the world: Internat. Geol. Cong., 16th, Washington, D.C., 1933, v. 1, p. 287–305.

Havard, J. F., 1960, Gypsum, *in* Industrial minerals and rocks, 3d ed.: Am. Inst. Mining Metall. Petroleum Engineers, p. 471–486.

Heiligman, H. A., Mikami, H. M., and Samuel, D. G., 1961, Transvaal chromite in basic refractories [abs.]: Am. Ceramic Soc. Bull., v. 40, p. 585.

Heinrich, E. W., 1948, Deposits of the sillimanite group of minerals south of Ennis, Madison County, with notes on other occurrences in Montana: Montana Bur. Mines and Geology Misc. Contr. 10, 22 p.

——— 1949, Pegmatite mineral deposits in Montana: Montana Bur. Mines and Geology Mem. 28, 56 p.

——— 1950, Sillimanite deposits of the Dillon region, Montana: Montana Bur. Mines and Geology Mem. 30, 43 p.

Herdlick, J. A., 1948, Investigation of the Four Chromes and other chromite deposits, Red Lodge district, Carbon County, Montana: U.S. Bur. Mines Rept. Inv. 4369, 13 p.

Hewett, D. F., Crittenden, M. D., Jr., DeHuff, G. L., Jr., and Pavlides, Louis, 1956, Manganese deposits of the United States, *in* Symposium sobre yacimientos de manganeso: Internat. Geol. Cong., 20th, Mexico 1956, v. 3, p. 169–230.

Holliday, R. W., 1960, Tungsten: U.S. Bur. Mines Bull. 585, p. 903–917.

Hosterman, J. W., 1956, Geology of the Murray area, Shoshone County, Idaho: U.S. Geol. Survey Bull. 1027–P, p. 725–748.

Holmes, W. T., Holbrook, W. F., and Banning, L. H., 1962, Beneficiating and smelting Carter Creek, Montana, iron ore: U.S. Bur. Mines Rept. Inv. 5922, 21 p.

Howland, A. L., 1955, Chromite deposits in the central part of the Stillwater complex, Montana: U.S. Geol. Survey Bull. 1015–D, p. 99–121.

Howland, A. L., Garrels, R. M., and Jones, W. R., 1949, Chromite deposits of the Boulder River area, Sweetgrass County, Montana: U.S. Geol. Survey Bull. 948–C, p. 63–82.

Jackson, C. F., Knaebel, J. B., and Wright, C. A., 1935, Lead and zinc mining and milling in the United States; current practices and costs: U.S. Bur. Mines Bull. 381, 204 p.

Jackson, E. D., 1962, Stratigraphic and lateral variation of chromite composition in the Stillwater complex, Montana: Am. Mineralogist (in press).

Jackson, E. D., Dinnin, J. I., and Bastron, Harry, 1960, Stratigraphic variation of chromite composition within chromitite zones of the Stillwater complex, Montana [abs.]: Geol. Soc. America Bull., v. 71, no. 12, Dec. 1960, p. 1896.

Jackson, E. D., Howland, A. L., Peoples, J. W., and Jones, W. R., 1954, Geologic maps and sections of the eastern part of the Stillwater complex, in Stillwater County, Montana: U.S. Geol. Survey open-file report.

Jahns, R. H., 1960, Gemstones and allied materials, *in* Industrial Minerals and Rocks, 3d ed.: Am. Inst. Mining Metall. Petroleum Engineers, p. 383–441.

James, H. L., 1943, The Silver Star Chromite deposit, Madison County, Montana: U.S. Geol. Survey prelim. report.

——— 1946, Chromite deposits near Red Lodge, Carbon County, Montana: U.S. Geol. Survey Bull. 945–F, p. 151–189.

Jarrard, L. D., 1957, Some occurrences of uranium and thorium in Montana: Montana Bur. Mines and Geology Misc. Contr. 15, 90 p.

Jenkins, G. F., 1960, Asbestos, *in* Industrial minerals and rocks, 3d ed.: Am. Inst. Mining Metall. Petroleum Engineers, p. 23–53.

Johns, W. M., 1960, Progress report on geologic investigation in the Kootenai-Flathead area, northwest Montana, 2. southeastern Lincoln County: Montana Bur. Mines and Geol. Bull. 17, 52 p.

——— 1961, Progress report on geologic investigations in the Kootenai-Flathead area, northwest Montana, 3. northern Lincoln County: Montana Bur. Mines and Geol. Bull. 23, 57 p.

Jones, Verner, 1931, Chromite deposits near Sheridan, Montana: Econ. Geology, v. 26, no. 6, Sept–Oct. 1931, p. 625–629.

Karlstrom, T. N. V., 1948, Geology and ore deposits of the Hecla mining district, Beaverhead County, Montana: Montana Bur. Mines and Geology Mem. 25, 87 p.

Kessler, D. W., Insley, Herbert, and Sligh, W. H., 1940, Physical, mineralogical, and durability studies on the building and monumental granites of the U.S.: Natl. Bur. Standards Jour. Research, v. 25, p. 161–206.

Kessler, D. W., and Sligh, W. H., 1927, Principal commercial limestones used for building construction in the U.S.: Natl. Bur. Standards Tech. Paper 349, 94 p.

Key, W. W., 1960a, Sand and gravel: U.S. Bur. Mines Bull. 585, p. 701–715.

——— 1960b, Stone: U.S. Bur. Mines Bull. 585, p. 793–813.

Kinkel, A. R., Jr., and Peterson, N. P., 1962, Copper in the United States (exclusive of Alaska and Hawaii): U.S. Geol. Survey Mineral Inv. Resource Map MR–13.

Klepper, M. R., Weeks, R. A., and Ruppel, E. T., 1957, Geology of the southern Elkhorn Mountains, Jefferson and Broadwater Counties, Montana: U.S. Geol. Survey Prof. Paper 292, 82 p.

Knechtel, M. M., and Patterson, S. H., 1956, Bentonite deposits in marine Cretaceous formations of the Hardin district, Montana and Wyoming: U.S. Geol. Survey Bull. 1023, 116 p.

Knechtel, M. M., and Patterson, S. H., 1962, Bentonite deposits of the northern Black Hills district, Wyoming, Montana, and South Dakota: U.S. Geol. Survey Bull. 1082–M, p. 893–1027.

Knopf, Adolph, 1913, Ore deposits of the Helena mining region, Montana: U.S. Geol. Survey Bull. 527, 143 p.

Koschmann, A. H., and Bergendahl, M. H., 1962, Gold in the United States (exclusive of Alaska and Hawaii): U.S. Geol. Survey Mineral Inv. Resource Map MR–24.

Kuster, W. V., and Jensen, N. C., 1962, Gypsum: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 629–642.

Kuster, W. V., and Schreck, V. R., 1962, Fluorspar and cryolite: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 567–583.

Lemmon, D. M., and Tweto, O. L., 1962, Tungsten in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR 25 and accompanying text.

Lenhart, W. B., 1960, Sand and gravel, *in* Industrial minerals and rocks, 3d ed.: Am. Inst. Mining Metall. Petroleum Engineers, p. 733–758.

Lewis, R. W., and Tucker, G. E., 1962, Phosphate rock: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 973–992.

Lindgren, Waldemar, 1933, Mineral deposits, 4th ed.: New York, McGraw-Hill Book Co., Inc., 930 p.

Lovering, T. S., 1930, The New World or Cooke City mining district, Park County, Montana: U.S. Geol. Survey Bull. 811–A, p. 1–87.

Lyden, C. J., 1948, The gold placers of Montana: Montana Bur. Mines and Geology Mem. 26, 152 p.

Lynd, L. E., 1960, Titanium, *in* Industrial minerals and rocks, 3d ed.: Am. Inst. Mining Metall. Petroleum Engineers, p. 851–880.

McInnis, Wilmer, 1960, Molybdenum, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 537–547.

McKelvey, V. E., Cathcart, J. B. Altschuler, Z. S., Swanson, R. W., and Lutz, Katherine, 1953a, Domestic phosphate deposits, *in* Soil and fertilizer phosphorus in crop nutrition, v. 4, p. 347–376, of Agronomy, a series of monographs prepared under auspices American Society of Agronomy: New York, Academic Press, Inc.

McKelvey, V. E., Swanson, R. W., and Sheldon, R. P., 1953b, The Permian phosphorite deposits of western United States: Internat. Geol. Cong., 19th, Algiers 1952, Comptes rendus, sec. 9, fasc. 11, p. 45–64.

McKelvey, V. E., Williams, J. S., Sheldon, R. P., Cressman, E. R., Cheney, T. M., and Swanson, R. W., 1959, The Phosphoria, Park City, and Shedhorn Formations in the western phosphate field: U.S. Geol. Survey Prof. Paper 313–A, p. 1–47.

McKnight, E. T., Newman, W. L., and Heyl, A. V., Jr., 1962a, Lead in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR–15.

——— 1962b, Zinc in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR–19.

McKnight, E. T., Newman, W. L., Klemic, Harry, and Heyl, A. V., Jr., 1963(?), Silver in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR–34 (in press).

Mann, John A., 1954, Geology of part of the Gravelly Range, Montana: Yellowstone-Bighorn Research Proj. Contr. 190, 91 p.

Mansfield, G. R., 1933, Some deposits of ornamental stone in Montana: U.S. Geol. Survey Circ. 4, 22 p.

Merewether, E. A., 1960, Geologic map of the igneous and metamorphic rocks of Montana showing locations of uranium deposits: U.S. Geol. Survey Misc. Geol. Inv. Map I–311.

Milner, R. L., 1956, Effects of salt solution in Saskatchewan [abs.], *in* North Dakota Geol. Soc. Williston Basin Symposium, 1st Internat., Bismarck, Oct. 1956: p. 111.

Mining World, 1955, How Minerals Engineering opens big low-grade tungsten deposits: Mining World, v. 17, no. 1, p. 38–43.

Murphy, J. F., and Houston, R. S., 1955, Titanium-bearing black sand deposits of Wyoming (and Montana): Wyoming Geol. Assoc. Guidebook, 10th Ann. Field Conf., Green River Basin, 1955, p. 190–196.

Myers, J. B., 1960, Vermiculite, *in* Industrial minerals and rocks, 3d ed.: The Am. Inst. Mining Metall. Petroleum Engineers, New York, p. 889–896.

Myers, W. B., 1952, Geology and mineral deposits of the northwest quarter of the Willis quadrangle and adjacent Brown's Lake area, Beaverhead County, Montana: U.S. Geol. Survey open-file report, 46 p.

Nordquist, J. W., 1953, Mississippian stratigraphy of northern Montana, *in* Billings Geol. Soc. Guidebook, 4th Ann. Field Conf., Sept. 1953: p. 68–82.

Olson, J. C., and Adams, J. W., 1962, Thorium and rare earth in the United States (exclusive of Alaska and Hawaii): U.S. Geol. Survey Mineral Inv. Resource Map MR–28.

Pardee, J. T., 1918a, Ore deposits of the northwestern part of the Garnet Range, Montana: U.S. Geol. Survey Bull. 660–F, p. 159–239.

——— 1918b, The Dunkleberg mining district, Granite County, Montana: U.S. Geol. Survey Bull. 660–G, p. 241–247.

——— 1919, Some manganese deposits in Madison County, Montana: U.S. Geol. Survey Bull. 690–F, p. 131–147.

——— 1922, Deposits of Manganese ore in Montana, Utah, Oregon, and Washington: U.S. Geol. Survey Bull. 725–C, p. 141–243.

——— 1951, Gold placer deposits of the Pioneer district, Montana: U.S. Geol. Survey Bull. 978–C, p. 69–99.

Pardee, J. T., and Larsen, E. S., 1929, Deposits of vermiculite and other minerals in the Rainy Creek district, near Libby, Montana: U.S. Geol. Survey Bull. 805–B, p. 17–28.

Pardee, J. T., and Schrader, F. C., 1933, Metalliferous deposits of the greater Helena mining region, Montana: U.S. Geol. Survey Bull. 842, 318 p.

Pattee, E. C., 1960, Tungsten resources of Montana: deposits of the Mt. Torrey batholith, Beaverhead County: U.S. Bur. Mines Rept. Inv. 5552, 41 p.

Patterson, C. M., 1960, Lime and calcium: U.S. Bur. Mines Bull. 585, p. 463–472.

Patterson, C. M., and Schreck, V. R., 1962, Lime: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 799–826.

Pearson, W. J., 1960, Western Canada potash and its future prospects: The Engineering Journal, August 1960, p. 2.

Pecora, W. T., 1956, Carbonatites, a review: Geol. Soc. America Bull., v. 67, no. 11, p. 1537–1556.

Peoples, J. W., and Howland, A. L., 1940, Chromite deposits of the eastern part of the Stillwater complex, Stillwater County, Montana: U.S. Geol. Survey Bull. 922–N, p. 371–416.

Peoples, J. W., Howland, A. L., Jones, W. R., and Flint, Delos, 1954, Geologic map, sections, and map of underground workings of the Mountain View Lake area, Stillwater County, Montana: U.S. Geol. Survey open-file report.

Perry, E. S., 1948, Talc, graphite, vermiculite and asbestos deposits in Montana: Montana Bur. Mines and Geology Mem. 27, 44 p.

——— 1949, Gypsum, lime, and limestone in Montana: Montana Bur. Mines and Geology Mem. 29, 45 p.

Pierce, W. G., and Rich, E. I., 1962, Summary of rock salt deposits in the United States as possible storage sites for radioactive waste materials: U.S. Geol. Survey Bull. 1148, 91 p.

Popoff, C. C., 1953, Lead deposits of the Dunkleberg district, Granite County, Montana: U.S. Bur. Mines Rept. Inv. 5014, 41 p.

Prokopovitch, A. S., and Heidrich, H. V., 1962, Chromium: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 431–443.

Reed, G. C., 1949, Investigation of Sheep Creek iron deposits, Meagher County, Montana: U.S. Bur. Mines Rept. Inv. 4400, 9 p.

——— 1950, Mines and mineral deposits (except fuels), Park County, Montana: U.S. Bur. Mines Inf. Circ. 7546, 64 p.

——— 1951, Mines and mineral deposits (except fuels), Broadwater County, Montana: U.S. Bur. Mines Inf. Circ. 7592, 58 p.

Reno, H. T., 1960, Iron: U.S. Bur. Mines Bull. 585, p. 403–421.

Roberts, W. A., and Gude, A. J., 3d, 1953a, Uranium-bearing deposits west of Clancey, Jefferson County, Montana: U.S. Geol. Survey Bull. 988–F, p. 69–87.

——— 1953b, Geology of the area adjacent to the Free Enterprise mine, Jefferson County, Montana: U.S. Geol. Survey Bull. 988–G, p. 143–155.

Robertson, A. F., 1950, Mines and mineral deposits (except fuels), Fergus County, Montana: U.S. Bur. Mines Inf. Circ. 7544, 76 p.

——— 1951, Mines and mineral deposits (except fuels), Cascade County, Montana: U.S. Bur. Mines Inf. Circ. 7589, 81 p.

Robertson, A. F., and Roby, R. N., 1952, Mines and mineral deposits (except fuels), Judith Basin County, Montana: U.S. Bur. Mines Inf. Circ. 7602, 51 p.

Robertson, F. S., 1953, Geology and mineral deposits of the Zosell (Emery) mining district, Powell County, Montana: Montana Bur. Mines and Geology Mem. 34, 29 p.

Roby, R. N., 1949, Investigation of Running Wolf iron deposits, Judith Basin County, Montana: U.S. Bur. Mines Rept. Inv. 4454, 7 p.

——— 1950, Mines and mineral deposits (except fuels), Meagher County, Montana: U.S. Bur. Mines Inf. Circ. 7540, 43 p.

Roby, R. N., Ackerman, W. C., Fulkerson, F. B., and Crowley, F. A., 1960, Mines and mineral deposits (except fuels), Jefferson County, Montana: Montana Bur. Mines and Geology Bull. 16, 122 p.

Ross, C. P., 1950, Fluorspar prospects of Montana: U.S. Geol. Survey Bull. 955–E, p. 173–224.

Ruhlman, E. R., 1958, Phosphate rock. Pt. 1, Mining, beneficiation, and marketing: U.S. Bur. Mines Inf. Circ. 7814, 33 p.

Sahinen, U. M., 1939, Geology and ore deposits of the Rochester and adjacent mining districts, Madison County, Montana: Montana Bur. Mines and Geology Mem. 19, 53 p.

——— 1950, Geology and ore deposits of the Highland Mountains, southwestern Montana: Montana Bur. Mines and Geology Mem. 32, 63 p.

——— 1956, Preliminary report on sodium sulphate in Montana: Montana Bur. Mines and Geology Inf. Circ. 11, 9 p.

——— 1957, Mines and mineral deposits of Missoula and Ravalli Counties, Montana: Montana Bur. Mines and Geology Bull. 8, 63 p.

——— 1959, Metalliferous deposits in the Helena area, Montana, *in* Billings Geol. Soc. Guidebook 10th Ann. Field Conference, Sawtooth-Disturbed Belt area, Montana, 1959: p.129–140.

——— 1962, Fluorspar deposits in Montana: Montana Bur. Mines and Geology i. 28, 38 p.

Sahinen, U. M., and Crowley, F. A., 1959, Summary of Montana mineral resources: Montana Bur. Mines and Geology Bull. 11, 51 p.

Sahinen, U. M., Smith, R. I., and Lawson, D. C., 1958, Progress report on clays of Montana: Montana Bur. Mines and Geology Inf. Circ. 23, 41 p.

——— 1960, Progress report on clays of Montana: Montana Bur. Mines and Geology Bull. 13, 83 p.

——— 1962, Progress report on clays and shales of Montana, 1960–1961: Montana Bur. Mines and Geology Bull. 27, 61 p.

Sales, R. H., 1914, Ore deposits at Butte, Montana: Am. Inst. Mining Engineers Trans., v. 46, p. 3–109.

Sandberg, C. A., 1961, Distribution and thickness of Devonian rocks in Williston basin and in central Montana and north-central Wyoming: U.S. Geol. Survey Bull. 1112–D, p. 105–127.

Sandberg, C. A., and Hammond, C. R., 1958, Devonian System in Williston basin and central Montana: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 10, p. 2293–2334.

Schafer, P. A., 1935, Geology and ore deposits of the Neihart mining district, Cascade County, Montana: Montana Bur. Mines and Geology Mem. 13, 62 p.

——— 1937, Chromite deposits of Montana: Montana Bur. Mines and Geology Mem. 18, 35 p.

Schnabel, R. W., 1955, The uranium deposits of the United States: U.S. Geol. Survey Mineral Inv. Resource Appraisals Map MR–2.

Seagar, G. F., 1944, Gold, arsenic, and tungsten deposits of the Jardine-Crevasse Mountain district, Park County, Montana: Montana Bur. Mines and Geology Mem. 23, 111 p.

Sharp, W. N., and Cavender, W. S., Thorium deposits of the Lemhi Pass district, Lemhi County, Idaho, and Beaverhead County, Montana: U.S. Geol. Survey Bull. 1126 (in press).

Shenon, P. J., 1931, Geology and ore deposits of Bannack and Argenta, Montana: Montana Bur. Mines and Geology Bull. 6, 80 p.

Shenon, P. J., and Taylor, A. V., 1936, Geology and ore occurrence of the Hog Heaven mining district, Flathead County, Montana: Montana Bur. Mines and Geology Mem. 17, 26 p.

Sinkankas, John, 1959, Gemstones of North America: Princeton, N.J., D. Van Nostrand Co., Inc., 675 p.

Spiroff, Kiril, 1938, Geological observations of the Block P. mine, Hughesville, Montana: Econ. Geology, v. 33, no. 5, p. 554–567.

Stebinger, Eugene, 1914, Titaniferous magnetite beds on the Blackfeet Indian Reservation, Montana: U.S. Geol. Survey Bull. 540, p. 329–337.

Stoll, W. C., 1950, Mica and beryl pegmatites in Idaho and Montana: U.S. Geol. Survey Prof. Paper 229, 64 p.

Stoll, W. C., and Armstrong, F. C., 1958, Optical calcite deposits in Park and Sweet Grass Counties, Montana: U.S. Geol. Survey Bull. 1042–M, p. 431–479.

Stone, R. W., 1911, Geologic relation of ore deposits in the Elkhorn Mountains, Montana: U.S. Geol. Survey Bull. 470, p. 75–98.

Swanson, R. W., 1960, Phosphate and associated resources in Permian rocks of southwestern Montana: U.S. Geol. Survey Prof. Paper 400–B, p. 65–66.

Swanson, R. W., McKelvey, V. E., and Sheldon, R. P., 1953, Progress report on investigations of western phosphate deposits: U.S. Geol. Survey Circ. 297, 16 p.

Tansley, Wilfred, Schafer, P. A., and Hart, L. H., 1933, A geological reconnaissance of the Tobacco Root Mountains, Madison County, Montana: Montana Bur. Mines and Geology Mem. 9, 57 p.

Taylor, A. V., Jr., 1942, Quartz Hill district, near Divide, Montana, *in* Newhouse, W. H., ed., Ore deposits as related to structural features: Princeton, N.J., Princeton Univ. Press, p. 215–216.

Thayer, T. P., 1946, Preliminary chemical correlation of chromite with the containing rocks: Econ. Geology, v. 41, p. 202–217.

———, 1960, some critical differences between alpine-type and stratiform peridotite-gabbro complexes: Internat. Geol. Cong. Rept. 21st Sess., Norden; pt. 13, p. 247–259.

Tucker, H. A., 1960, Ferroalloys: U.S. Bur. Mines Bull. 585, p. 291–304.

U.S. Congress, House Committee on Public Lands, Subcommittee on Mines and Mining, 1948, Strategic and critical minerals and metals, hearings, part 1, manganese: U.S. 80th Cong., 2nd sess., Comm. Hearing no. 38, Feb. 12, 13, 24, 25, 27, 1948, 497 p. (see especially statements of F. A. Linforth, Butte, Mont., Mining geologist and engineer, Assistant to the Vice President, Anaconda Copper Mining Co., p. 279–298; and H. A. Pumpelly, Vice President, Domestic Manganese and Development Co., Butte, Mont., p. 338–351).

U.S. Dept. of Commerce, 1948, Coarse aggregates, simplified practice recommendation: Natl. Bur. Standards R. 163–48, 17 p.

Volin, M. E., Robey, R. N., and Cole, J. W., 1952, Investigation of the Combination silver-tungsten mine, Granite County, Montana: U.S. Bur. Mines Rept. Inv. 4914, 26 p.

Waesche, H. H., 1960, Quartz crystal and optical calcite, *in* Industrial minerals and rocks: Am. Inst. Mining Metall. Petroleum Engineers, p. 687–698.

Waggaman, W. H., and Ruhlman, E. R., 1960, Phosphate rock. Pt. 2, Processing and utilization: U.S. Bur. Mines Inf. Circ. 7951, 36 p.

Walker, D. D., 1960, Tungsten resources of Montana: deposits of the Philipsburg batholith, Granite and Deer Lodge Counties, Montana: U.S. Bur. Mines Rept. Inv. 5612, 55 p.

Wallace, R. E., and Hosterman, J. W., 1956, Reconnaissance geology of western Mineral County, Montana: U.S. Geol. Survey Bull. 1027–M, p. 575–612.

Weed, W. H., 1900, Geology of the Little Belt Mountains, Montana, with notes on the mineral deposits of the Neihart, Barker, Yogo, and other districts: U.S. Geol. Survey 20th Ann. Rept., pt. 3–C, p. 257–461.

——— 1912, Geology and ore deposits of the Butte district, Montana: U.S. Geol. Survey Prof. Paper 74, 262 p.

Weed, W. H., and Pirsson, L. V., 1898, Geology and mineral resources of the Judith Mountains of Montana: U.S. Geol. Survey 18th Ann. Rept., pt. 3–D, p. 437–616.

Weis, P. L., Armstrong, F. C., and Rosenblum, Samuel, 1958, Reconnaissance for radioactive minerals in Washington, Idaho, and western Montana, 1952–1955: U.S. Geol. Survey Bull. 1074–B, p. 7–48.

West, J. M., and Lindquist, A. H., 1962, Cement: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 391–429.

Westgate, L. G., 1921, Deposits of chromite in Stillwater and Sweetgrass Counties, Montana: U.S. Geol. Survey Bull. 725, p. 67–82.

Willey, E. C., Cressman, E. R., Pierce, H. W., and Cheney, T. M., 1954, Status of ownership of part of the lands on which phosphate-bearing beds crop out in southwestern Montana and northeastern Idaho: U.S. Geol. Survey open-file report, 10 p.

Wimmler, N. L., 1946a, Exploration of Southern Cross iron deposits, Deer Lodge County, Montana: U.S. Bur. Mines Rept. Inv. 3979, 14 p.

——— 1946b, Exploration of Choteau titaniferous magnetite deposit, Teton County, Montana: U.S. Bur. Mines Rept. Inv. 3981, 12 p.

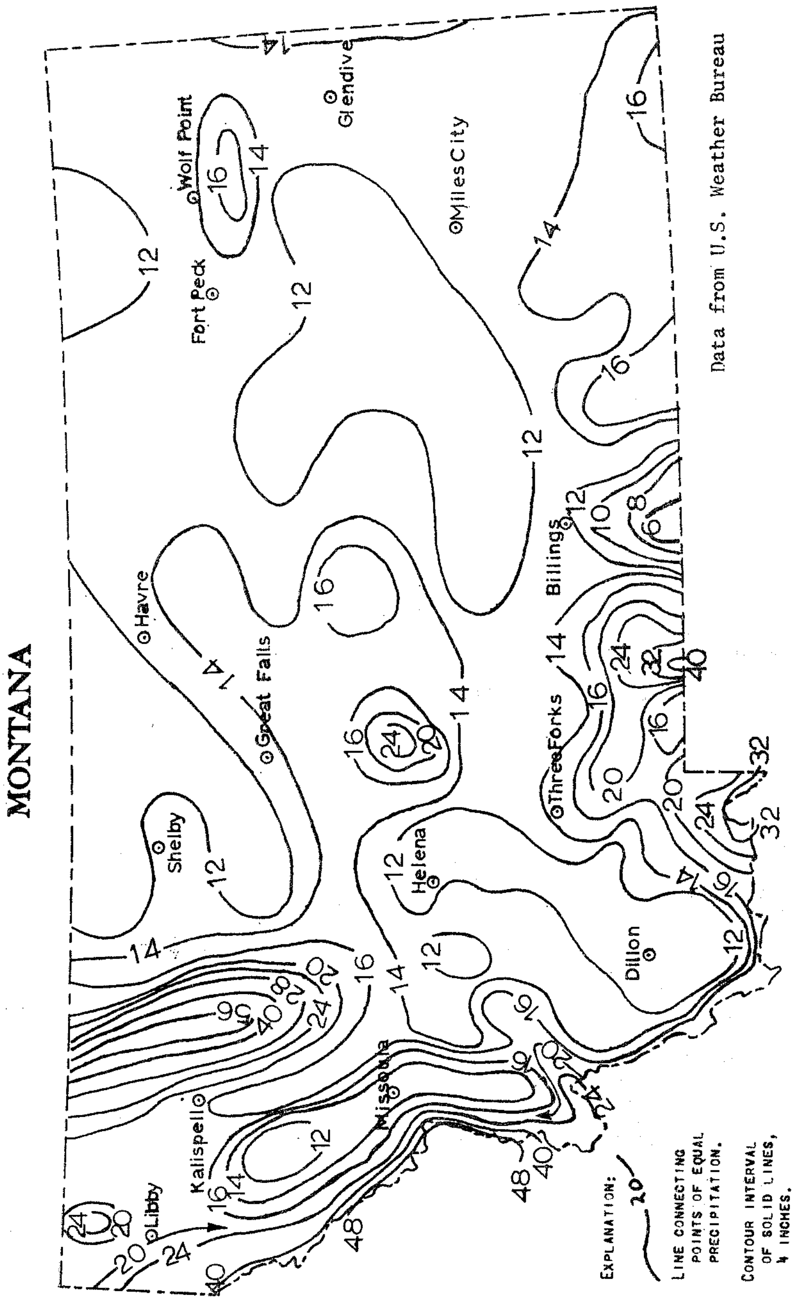
——— 1948, Investigation of chromite deposits of the Stillwater complex, Stillwater and Sweetgrass Counties, Montana: U.S. Bur. Mines Rept. Inv. 4368, 41 p.

Winchell, A. N., 1914, The mining districts of the Dillon quadrangle, Montana, and adjacent areas: U.S. Geol. Survey Bull. 574, 191 p.

Withington, C. F., 1962, Gypsum and anhydrite in the United States (exclusive of Alaska and Hawaii): U.S. Geol. Survey Mineral Inv. Resource Map MR–33.

Witkind, I. J., 1959, Quaternary geology of the Smoke Creek-Medicine Lake-Grenora area, Montana and North Dakota: U.S. Geol. Survey Bull. 1073, 80 p.

Zeiglar, D. L., 1956, Pre-Piper post-Minnekahta "red beds" in the Williston Basin (summary), *in* North Dakota Geol. Soc. Williston Basin Symposium, 1st Internat., Bismarck, Oct. 1956: p. 170–178.



Data from U.S. Weather Bureau

FIGURE 45.—Mean annual precipitation, in inches.

WATER RESOURCES

(By Frank Stermitz, Helena, Mont., T. F. Hanly, Worland, Wyo., and C. W. Lane, Billings, Mont., U.S. Geological Survey)

INTRODUCTION

An abundant supply of water prevails over much of Montana, particularly in the mountain areas and adjacent to the major watercourses. Surface-water supplies are of good quality in the mountain areas but are variable in both quantity and quality in the plains area. Ground-water supplies adequate for stock and domestic use are available in most of the State. Large ground-water supplies of good quality are generally available in the intermontane valleys and near major streams but are lacking in much of the plains area. Reservoir storage has greatly aided utilization of surface water for irrigation and electric-power generation. Large-scale development of the State's ground-water resources has only begun, and many opportunities exist for development and further utilization.

The climate of Montana deserves brief description as available water originates in the State or bordering areas of similar climatic characteristics. The mean annual precipitation is about 15 inches. It is heavy in the mountains and light in the foothills and plains. Figure 45, prepared by the U.S. Weather Bureau, shows the areal distribution of precipitation. Although the indicated range is from 6 to 56 inches, half of the State lies in the belt of 12 to 14 inches. About 60 percent of the annual precipitation in the high mountain areas occurs during the snow storage period of late October to early April. In the foothills and plains areas east of the Continental Divide, 65 to 80 percent of the precipitation occurs during the April to September period. The April to September precipitation in the mountain valleys west of the Continental Divide varies considerably and averages about half the annual amount. Winter temperatures are conducive to snow storage in the high mountains. Chinook or thawing winds of midwinter often deplete snow storage on the foothills and plains.

Chemical quality and sediment are factors that affect the water resources. In Montana the natural effects are hardness and variations in chemical and sediment content. Man's actions in the use of water result in problems involving irrigation return flows, sediment in reservoirs, and domestic and industrial wastes.

Man's actions such as disposing of domestic, industrial, and radioactive wastes can be controlled. Other problems such as return flows from irrigation, and reservoir sedimentation can be minimized by adequate planning and design of facilities.

Montana employs the doctrine of prior appropriation for the administration of water rights. These rights, which are also based upon the application of the water to beneficial use, are administered under supervision of district courts. Legislation that became effective January 1, 1962, places the administration of ground-water rights in the office of the State Engineer.

The water crossing the international boundary is subject to the general provisions of the Boundary Waters Treaty of 1907 and subsequent orders of the International Joint Commission. The latter are of particular significance on the Milk and St. Mary Rivers where definite apportionment is practiced. Interstate tributaries of the Yellowstone River are allocated by the Yellowstone River Compact.

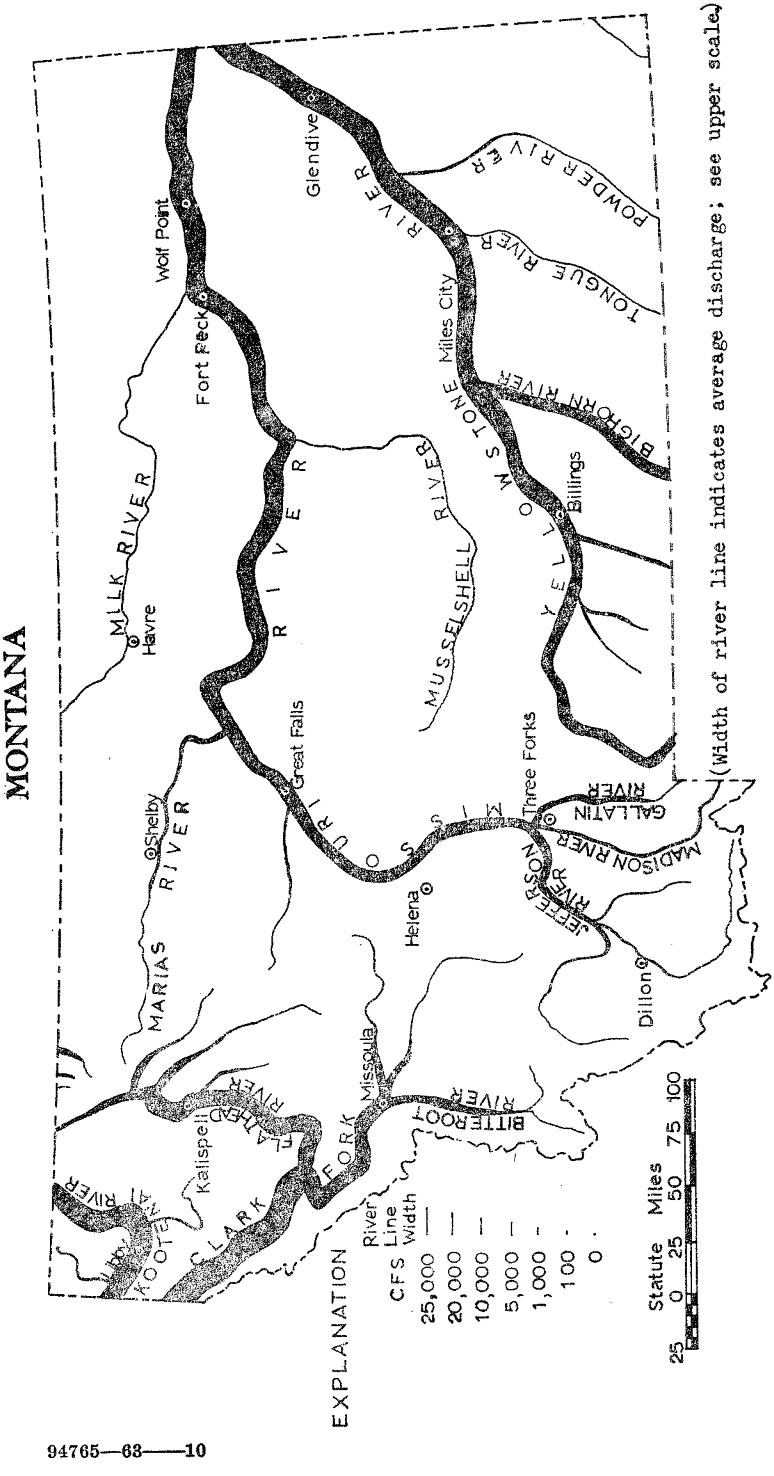
SURFACE WATER

The surface water of Montana drains to the Pacific Ocean, the Gulf of Mexico, and Hudson Bay. There are a few small closed basins near the northern border east of the Continental Divide and northwest of Billings. The relative discharge of the principal streams is shown in the schematic map of figure 46. The line width of streams represents the mean discharge. The width is varied as the square root of the discharge to permit visualization of major streams throughout their length. The streams entering Montana contribute about 21,000 cubic feet per second as an average and those leaving the State discharge an average of about 58,000 cubic feet per second. About 5,000 cubic feet per second is used consumptively in the State. The Columbia River basin constitutes 17 percent of the area of the State and has 58 percent of the total streamflow of 63,000 cubic feet per second. Approximately 82 percent of the State lies in the Missouri River basin and has 40 percent of the water supply. The Hudson Bay drainage area comprises less than half of 1 percent of the drainage area of the State and has about 2 percent of the streamflow.

A common measure of water for irrigation is the acre-foot, which is the volume required to cover an acre to the depth of 1 foot, and is equivalent to 326,000 gallons. A flow of 1 cubic foot per second is equal to 449 gallons per minute, 1.98 acre-feet per day, or about 724 acre-feet per year.

The mean annual runoff varies from more than 40 inches to less than 0.25 inch and averages about 3.5 inches for the State. The areal distribution as equivalent inches of depth over the land surface is shown generalized in figure 47. The generally mountainous areas west and east of the Continental Divide have relatively high runoff. About half the State has less than 1 inch of runoff.

The usefulness of streamflow is related to its seasonal and annual dependability. The large proportion of the annual precipitation that falls on the high mountains during the winter or snow-storage months has a marked effect on the runoff pattern. The snow-melt runoff from the mountains begins in April and reaches a peak rate in late May or early June. The runoff is essentially completed in July and the normal baseflow recession is modified slightly by summer rains. As vegetative uses decline and the fall rains begin, another increase in flow occurs before cold weather restricts streamflow to the ground-water outflow rate. In some winters, mild weather may bring about a brief increase in streamflow. The sustained minimum flows of the mountain streams generally occur during March when ground-water outflow reaches its lowest level. To illustrate this flow pattern, typical annual hydrographs for the Flathead River near Columbia Falls and the Yellowstone River at Corwin Springs are shown in



(Width of river line indicates average discharge; see upper scale)

FIGURE 46.—Mean discharge of principal streams.

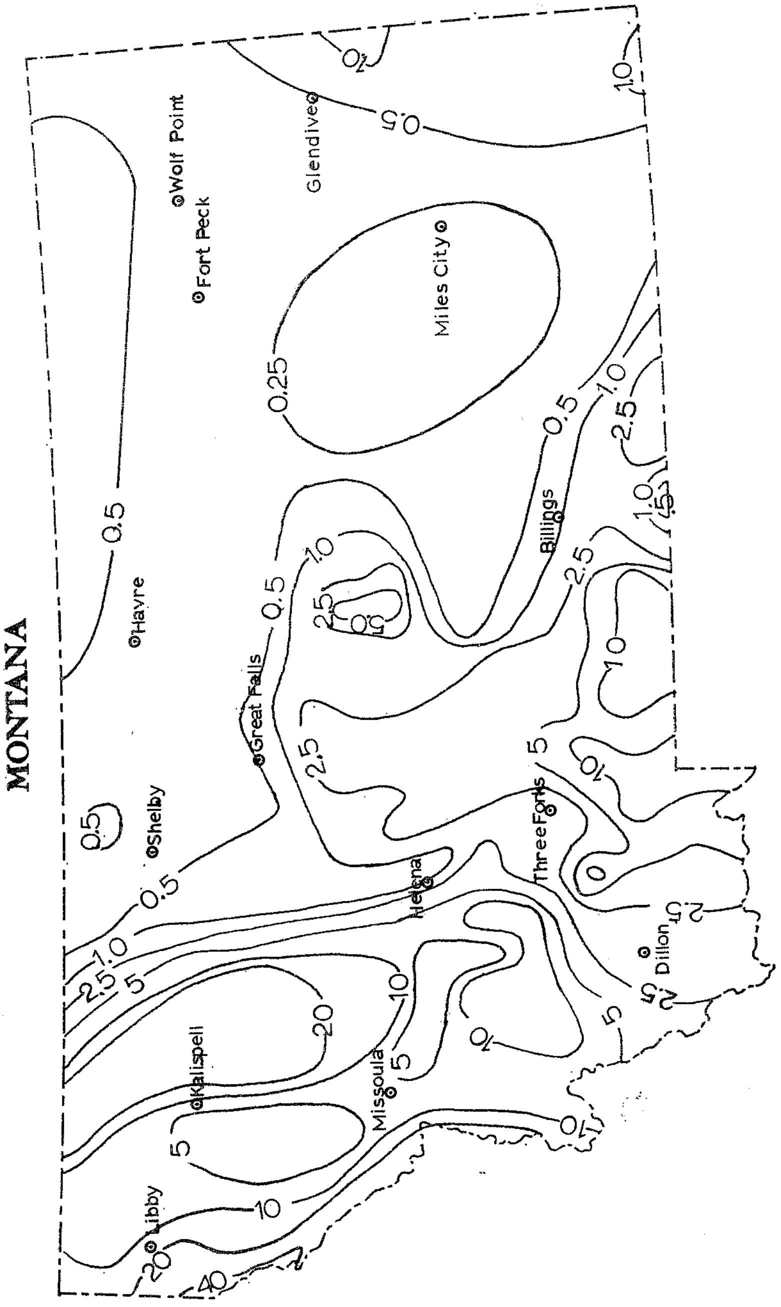


FIGURE 47.—Mean annual runoff, in inches (generalized).

figure 48. The latter stream passes through Yellowstone Lake and a smoother pattern of runoff is apparent from its hydrograph. The variability of annual flow is relatively small for most mountain streams. Annual discharges for the Clark Fork at St. Regis fall within plus 56 percent and minus 52 percent of the average discharge during the index period of 1931–60. A similar comparison for the Yellowstone River at Corwin Springs shows variations of plus 44 percent and minus 36 percent. Most of the low flows occurred during the general drought period of the 1930's.

Streams of the foothills and plains areas are usually at extremely low level or may cease flowing during the winter. The melt of snow and channel ice accumulated during the winter usually takes place in late March, although brief thaws as early as February are not uncommon. The spring rise may produce the peak flow of the year. The recession from the peak is quite rapid and subsequent increases in flow are dependent upon rains of sufficient intensity and duration to

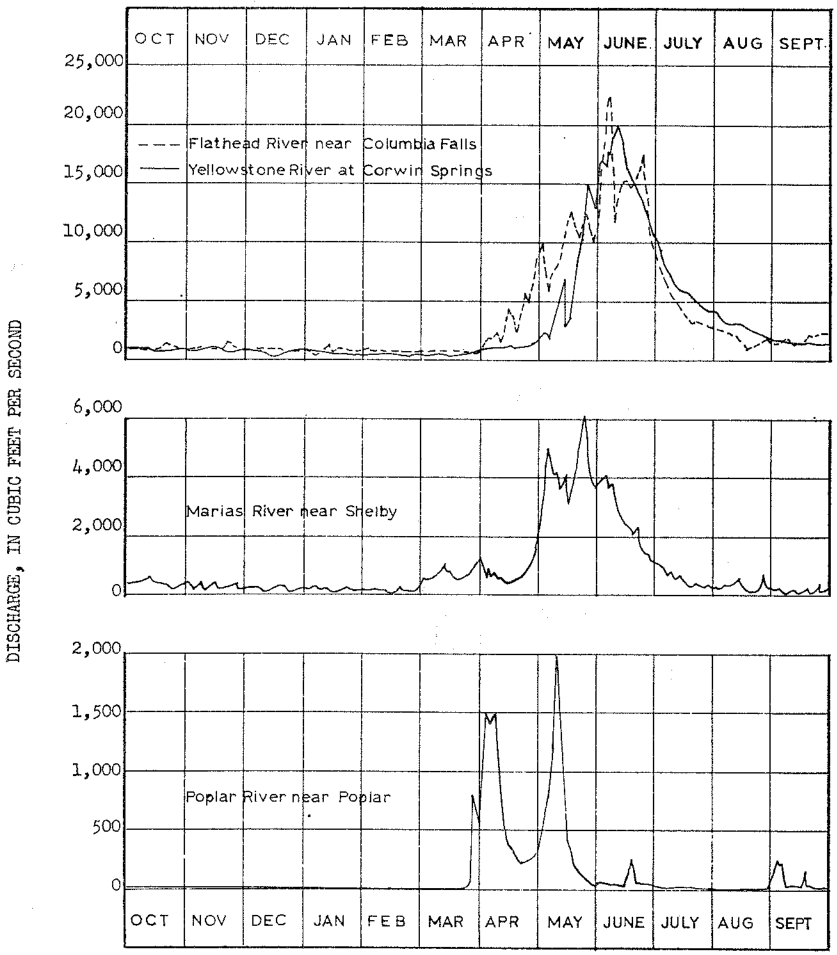


FIGURE 48.—Typical hydrographs of selected streams.

cause surface runoff. These streams may cease flowing during the hottest part of the summer, and resume flowing as evaporative and vegetative losses decrease. An annual hydrograph for Marias River near Shelby (fig. 48) shows the mixed influence of a mountain and foothill environment. The hydrograph for the Poplar River near Poplar (fig. 48) is typical of the plains streams, wherein variations in flow are the greatest. The annual discharges for the Marias River near Shelby fall within plus 89 percent and minus 62 percent of the average discharge for the index period of 1931–60. The lack of complete record before 1947 requires the use of a 1947–60 period for comparison of the variability of flows of the Poplar River near Poplar. During that shorter time period, the annual discharges lie within plus 173 percent and minus 77 percent of the average.

Few data are available to indicate the chemical quality of water in the Columbia River Basin in Montana. Based on these few data and on the geology of the area, it seems probable that the water is generally a calcium bicarbonate type with relatively low concentrations of dissolved solids. This type of water is also general in the Missouri River Basin upstream from Fort Peck Reservoir, and in the Yellowstone River Basin upstream from Billings. An exception is the Teton River below Priest Butte Lake drain, where the water is a sodium sulfate type with relatively high concentrations of dissolved solids. The water of the lower Missouri River, including Fort Peck Reservoir, the Milk River downstream from Havre, and the northern tributaries to the Missouri River below Fort Peck Reservoir, is a sodium bicarbonate type with relatively high concentrations of dissolved solids. Downstream from Billings the water of the Yellowstone River and its tributaries is a sodium sulfate type with relatively high concentrations of dissolved solids. Figure 49 [1] shows the general distribution of the water-quality types and the approximate range in the concentration of dissolved solids.

The sediment yield of Montana streams varies with geology, relief, stream velocity, vegetation in the drainage basin, precipitation, and abundance of flow. Some geologic formations such as shales and soft sandstones are easily eroded and are large producers of sediment. Transportation of sediment by flowing water is a natural geologic process that has been accelerated by man's actions.

Few data are available to indicate either the long term or the annual sediment yield in the Columbia River Basin in Montana. However, the few observations and a knowledge of the geology of the area indicate a relatively low sediment yield except in localities where mining and lumbering operations are active. This is also true throughout the upper Missouri River Basin and upper Yellowstone River Basin where more data are available. Farther east, where the surficial rocks are predominantly shales and soft sandstones, the sediment yield is relatively high. In the north-central part of Montana, streams flowing in Bearpaw shale have the highest sediment yield observed in the State. The general areas and rates of sediment yield are delineated on figure 50.[1]

The temperature of flowing streams during the winter period is near the freezing point. After the disappearance of channel ice in late March or early April, stream temperatures show a gradual rise to as high as 50° F. by late April. The water temperatures may drop to less than 40° F. as the mountain snowmelt progresses, according to

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[1] NOTE.—Figure indicated appears as a folded map at the rear of this document.

the relative contribution of snowmelt runoff to streamflow. Another warming trend begins in June as snowmelt runoff decreases. Water temperatures are generally between 60° F. and 70° F. in July and August. Temperatures as high as 80° F. have been measured on small streams in the plains area during periods of prolonged hot weather. A gradual downward trend in water temperatures usually begins by early September and the near freezing point is common by late November. The temperature of water released from large storage reservoirs approaches the mean annual air temperature.

GROUND WATER

Most of western Montana is mountainous but contains numerous large intermontane valleys. The mountains are composed principally of Precambrian crystalline and Tertiary igneous rocks but also include some rocks of Paleozoic and Mesozoic age. These rocks are not sources of ground water but do serve as catchment areas for precipitation, a part of which later enters the previous fill of the intermontane valleys to become ground water.

The fill underlying many of the intermontane valleys is quite thick, as much as several thousand feet in some valleys, and is composed of Cenozoic alluvium and lakebeds. The sediments filling many of these valleys are very permeable and form vast ground-water reservoirs, most of which are almost completely filled. Recharge of the ground water is by precipitation in the valleys, seepage of applied irrigation water, and seepage from streams. During periods of low flow in the major streams, ground water is discharged to the streams providing the base streamflow.

East of the Rocky Mountains, in a broad belt extending through the central part of the State, is an area of high plains broken by isolated mountain ranges. Most of the area is underlain by stratified rocks of Paleozoic and Mesozoic age. The rocks contain a number of sandstone and limestone formations that are permeable and contain large quantities of ground water. Many of the water-bearing rocks are exposed on the flanks of the isolated mountains, and thus are favorably situated to receive recharge from precipitation and from streams flowing from the mountains. Many of the water-bearing rocks are deeply buried away from the mountains, and the geologic structure is such that flowing artesian wells can be obtained in some areas.

The Fort Union formation and high terrace gravels of Cenozoic age are present over sizable but isolated areas in the central part of the State. These rocks are generally very permeable, and, where thick enough, are sources of ground water.

Most of Montana east of the isolated mountains is a high plain devoid of mountains but deeply incised by the Missouri and Yellowstone Rivers and their tributaries. Erosion adjacent to the streams gives considerable topographic relief to the area locally. In most of eastern Montana the Fort Union formation of Cenozoic age underlies the surface and is underlain by several thousand feet of Paleozoic and Mesozoic stratified rocks. Only the Mesozoic and Cenozoic rocks of eastern Montana are significant as sources of ground water, the older rocks being too deeply buried to be within economic drilling depth for water wells. Geologic structural conditions are favorable in parts of eastern Montana for obtaining flowing artesian wells. Most notable of the artesian areas are at low elevations in the Tongue, Powder, and lower Yellowstone River drainage basins. Ground-water recharge in the eastern part of the State is by precipitation in the area, and owing to the semiarid climate, is probably quite small.

Of great significance to the ground-water supply of the State are the alluvium and low terrace deposits in the inner valleys of most streams in the State. The alluvium and terrace deposits are composed principally of silt, sand, gravel, and cobbles and are the most permeable water-bearing rocks in the State. The deposits are readily recharged by precipitation, by streams during periods of high stage, and by applied irrigation water.

Unconsolidated deposits of silt, clay, sand, and gravel underlie the intermontane valleys of the West, are present in the valleys of most of the major streams, and mantle the consolidated bedrock in many parts of the State. The unconsolidated deposits generally contain an abundant supply of ground water. Development of this valuable resource for other than domestic and stock use has started in only a few areas of the State. Figure 51 shows the magnitude of the ground-water supplies that can be developed from wells in the unconsolidated rock deposits in various parts of the State. The areas shown are those in which wells within the indicated range of yield are known to be present. The indicated well yields may not be available at all locations within the areas shown, but the potential for such well yields is favorable. Moderate to large well yields from unconsolidated rocks may be available in other parts of the State but are not yet known.

The consolidated rocks of significance to the ground-water supply are the stratified rocks underlying most of the area east of the Rocky Mountains. Within this vast area, wells in the consolidated rocks provide water supplies for many towns, some industries, and a large percent of the domestic and stock use. There are many rock formations that are water bearing, but owing to the complexity of the geology, not all the formations will be found in any given area, and the depth of well required to tap a given formation will vary with location. The rock formations are nearly all named, and those yielding ground water are usually known to well drillers and to many residents of an area where they are utilized. The rock formation names common to individual areas will be used to describe the source and availability of ground water in the section that follows.

The quality of ground water in Montana varies greatly in chemical characteristics and dissolved-solids content. These variations depend mainly on the geology and the precipitation of an area. The Cenozoic and Mesozoic sedimentary rocks of eastern Montana yield water that is of poorer quality than the water obtained from the deposits in the intermontane valleys of western Montana. Water obtained from a geologic source in western Montana tends to be more uniform in chemical character and mineralization, whereas in eastern Montana considerable variation occurs in the quality of water obtained from any given formation, depending upon location and depth to supply. The igneous and metasedimentary bedrock of western Montana, with some exceptions, are much more dense than the Cenozoic and Mesozoic rocks of eastern Montana, and as a consequence, the soluble minerals are not as readily leached and thus do not contribute greatly

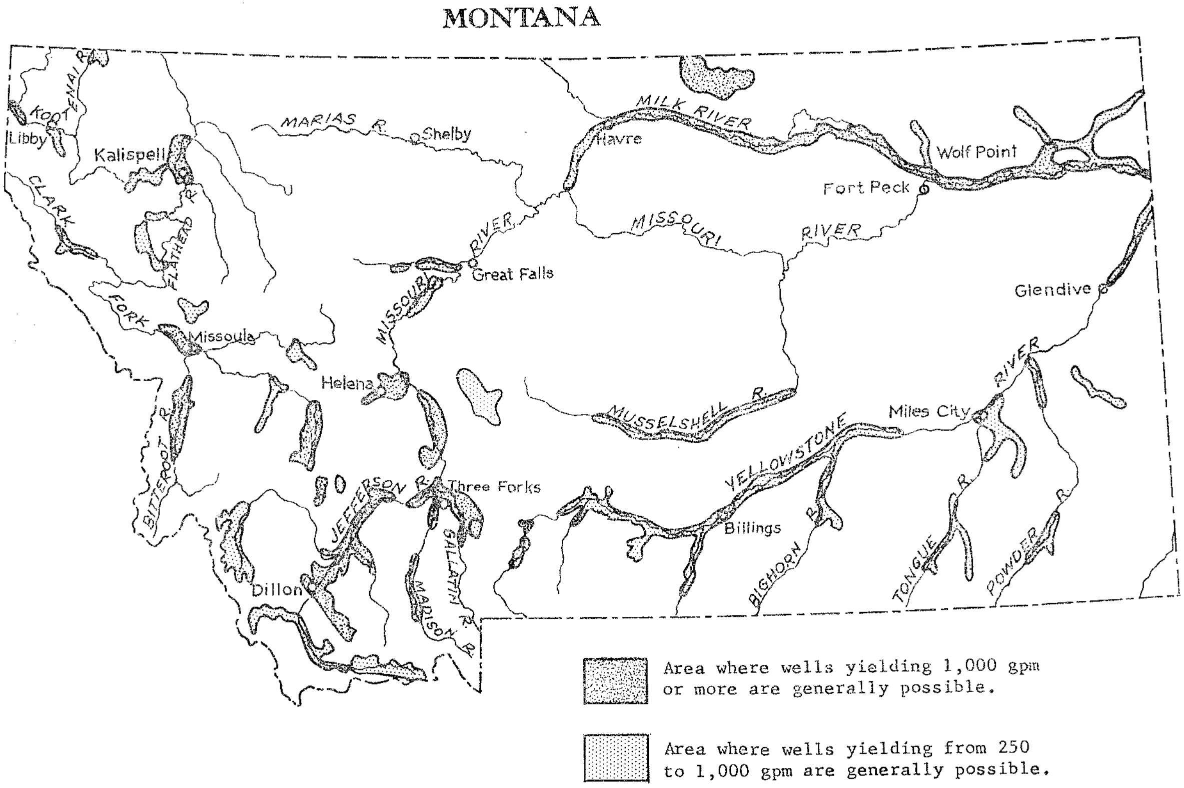

FIGURE 51.—Map showing real distribution of water-bearing unconsolidated rocks and potential well yields.

to the mineralization of the ground water. The chemical quality of ground water in eastern Montana shows considerable variation. The permeability and recharge characteristics of the rocks in this part of the State permit the contained water a longer but variable contact time to dissolve the available minerals.

Utilization and Storage

Irrigation throughout the State comprises most of the consumptive water use. Data from various sources indicate that generally more than 1,500,000 acres are irrigated annually with reasonably adequate water supplies. About 500,000 additional acres of pasture, wild hay, and early maturing crops are inadequately irrigated from intermittent or overappropriated streams. This latter acreage includes flood-irrigation and water-spreading projects that may receive little or no water in an unfavorable season. Numerous reservoirs provide a usable capacity of about 1,300,000 acre-feet exclusively for irrigation. The use of ground water for primary or supplemental irrigation has made a modest beginning in a few areas. This use, which constitutes less than 1 percent of the irrigation diversion, has been primarily in the intermontane valleys or in alluvial valleys where recharge from streams could be expected. Many of the irrigation enterprises are operated by individuals or small organizations, and information on quantities of water diverted, lost by conveyance, applied, and returned, are too incomplete to arrive at reliable data on water usage. Gross diversion may be as much as 10 million acre-feet annually, of which about 2,500,000 acre-feet is consumed or is lost by evaporation and transpiration. Some return flows are reused for irrigation downstream. The regimen of a few streams is sufficiently altered by irrigation use to lower the normal high water period of May and June, and the highest flow months may be in the late fall.

The significant use of surface and ground water for livestock has a high economic value. In many areas, the scarcity of water limits use of the range for this purpose. The quantity used for livestock, including evaporation loss from stock ponds, exceeds that used by municipalities. The evaporation loss from shallow stock ponds is several times greater than consumption by livestock from this source.

The municipal and industrial uses of water are respectively about 113 and 204 million gallons per day. This annual diversion is about 350,000 acre-feet or less than 1 percent of the average surface supply. Ground water is used exclusively by 92 municipalities; 40 are supplied by surface water and 19 use combinations of surface and ground water. Nearly 80 percent of the State's population is supplied by surface water of good quality. Ground water is the primary source of rural, domestic, and stock water supplies. About 18 percent of the commercial and industrial use is supplied from surface water sources.

Although the variability of annual flow of many Montana streams is relatively small, storage and redistribution to meet demands is essential to achieve a reasonable degree of utilization. The early storage facilities were based upon the single-purpose concept and were generally small and readily constructed. The application of the multipurpose approach and the consideration of benefits beyond the borders of the State has been a growing factor in recent major storage developments. The capacity of present surface storage facilities is about 28 million acre-feet, equal to two-thirds of the average annual runoff. However, the greater part of that storage is concentrated on a few streams and does not provide the degree of control within Montana that might be implied.

There are 59 reservoirs in Montana, each with a capacity in excess of 5,000 acre-feet. The 48 reservoirs devoted exclusively to irrigation have a combined capacity of 1,300,000 acre-feet and generally are on or are supplied by the smaller streams. The reservoirs with a capacity in excess of one-half million acre-feet each are Hungry Horse and Flathead Lake in the Columbia River Basin, and Canyon Ferry, Tiber, and Fort Peck in the Missouri River Basin. Hungry Horse Reservoir, on the South Fork Flathead River near Columbia Falls, has a usable capacity of 3,428,000 acre-feet for onsite power generation and flood control and for downstream hydroelectric power. The control of Flathead Lake through a range in stage of 10 feet provides 1,219,000 acre-feet of storage for hydroelectric power. Canyon Ferry on the Missouri River near Helena has a usable capacity of 2,043,000 acre-feet. Its primary use is for the reregulation of streamflow to supply prior downstream water rights, thus permitting an expansion of upstream irrigation. Onsite generation of hydroelectric power, municipal supply, and local irrigation are also involved. Tiber Reservoir, on Marias River near Chester, has a usable capacity of 1,313,000 acre-feet at controlled spillway elevation. It was designed for irrigation water storage as well as flood control, recreation, and stream regulation purposes which it now serves. Fort Peck Reservoir, on the Missouri River in northeastern Montana, has a usable capacity of 17,800,000 acre-feet for power generation, flood control, navigation, and downstream regulation of flows. This storage capacity is nearly triple the mean annual flow at the site. Yellowtail Reservoir is now (1963) being constructed on the Bighorn River south of Hardin in the Yellowstone River Basin. It will have a usable capacity of 1,375,000 acre-feet for power generation, irrigation, flood control, and sediment storage. This storage capacity is nearly twice the mean annual flow at the site.

Various State and Federal agencies and private interests have proposed additional reservoirs having a total capacity of 14 million acre-feet of water, about equally divided between the Columbia and Missouri River Basins. The choice of alternate plans might greatly increase or decrease the proposed storage.

The evaporation from surface reservoirs significantly alters the available water supply. It has been estimated that an average of more than 2 million acre-feet of water is evaporated each year from the reservoirs, lakes, and streams in Montana (Meyers, 1962), as follows:

	Acre-feet
From principal reservoirs and regulated lakes with usable storage of 5,000 acre-feet or more	1, 294, 000
From other large nonregulated lakes, with surface area of 500 acres or more	137, 000
From principal streams and canals	291, 000
From small reservoirs, lakes, and stock ponds	256, 000
From small streams	121, 000
Total for Montana	2, 099, 000

Annual evaporation rates range from less than 24 inches in the higher mountains to about 40 inches in the southeastern plains.

The storage of waters by recharge of aquifers may prove feasible in some places. Such storage generally would not interfere with present land uses and evaporative loss would be greatly reduced. Some use of the artificial recharge that occurs through irrigation in intermontane valleys has been made, and an appreciable effect is apparent on the streamflow regimen.

The numerous streams, lakes, and reservoirs are utilized by residents and visitors for various forms of recreation. The social and economic values are recognized and given consideration in development plans. Campers and picnickers are particularly attracted to mountain areas. The good chemical quality, suitable temperatures, low sediment content, and sustained flow of streams in the western two-thirds of the State promote good trout habitat. The natural lakes and the reservoirs are used extensively for water-based sports, and many homes have been built on the shores. A significant number of natural or artificial water bodies are used as refuges for migratory fowl. The tourist business ranks third in economic value in the State and the water resources play an important part in attracting visitors.

The development of reasonably firm power on Montana streams requires considerable storage capacity to redistribute variable seasonal flows for less variable power-generation needs. The runoff of mountain streams during May and June ranges from 45 to 60 percent of their total annual flow, depending mainly upon geographic location and altitude of the watershed. The runoff for April through July is about 65 to 75 percent of the annual flow. As the mountain streams traverse the plains areas, the incremental inflow tends to lengthen the high-flow periods and to increase the percentage of flow during the remaining months. Irrigation is also an important factor toward equalization of seasonal streamflow. Multipurpose storage for flood control, irrigation, recreation, downstream navigation, industrial and municipal supply, and fish and wildlife should be considered in power development plans.

The installed power capacity of each stream in the principal river basins is shown in table 9. The installed power capacity in kilowatts represents the manufacturer's rating of the maximum power output from the generating equipment. The average annual power produced is given in terms of kilowatt-hours as reported by the Federal Power Commission in 1960. The average power generation in the State is reported to be 59 percent of the installed capacity.

TABLE 9.—*Installed capacity and average yearly power data for existing projects in Montana*

Stream	Existing installed capacity (kilowatts)	Percent of State total	Existing average power (kilowatts)	Percent of State total
Columbia River Basin:				
Lake Creek	4, 500	0. 36	2, 854	0. 39
Flint Creek	1, 100	. 09	913	. 12
Clark Fork	315, 920	25. 04	186, 073	25. 23
South Fork, Flathead River	285, 000	22. 58	94, 406	12. 80
Swan River	4, 150	. 33	3, 539	. 48
Big Creek	360	. 03	126	. 02
Flathead River	168, 000	13. 31	121, 005	16. 41
Total, Columbia River Basin	779, 030	61. 74	408, 916	55. 45
Missouri River Basin:				
Missouri (main stem)	463, 800	36. 76	314, 269	42. 62
Madison River	9, 000	. 71	8, 333	1. 13
Yellowstone River Basin: West Rosebud Creek	10, 000	. 79	5, 936	. 80
Total, Missouri River Basin	482, 800	38. 26	328, 538	44. 55
Total for State	1, 261, 830	100. 00	737, 454	100. 00

The additional waterpower potential is estimated at nearly 18 billion kilowatt hours annually, or nearly three times the present production. Further investigation of potential power developments may be expected to result in reduction of potential because of unfavorable geologic conditions, incompatibility of interests, economic feasibility, and other causes. The data of table 10 were derived from information published by the Federal Power Commission except for the deletion of a few projects now believed unfeasible. The table does not include the added power available through the reconstruction or improvement of present projects.

TABLE 10.—*Installed capacity and average annual power data for undeveloped power resources in Montana*

Stream	Undeveloped installed capacity (kilowatts)	Percent of State total	Undeveloped average power (kilowatts)	Percent of State total
Columbia River Basin:				
Kootenai River (main stem)	1, 180, 000	24. 16	374, 772	18. 37
Yaak River	159, 200	3. 26	46, 233	2. 27
Clark Fork (main stem)	480, 000	9. 83	173, 402	8. 50
Rock Creek	51, 500	1. 05	23, 002	1. 13
Blackfoot River Basin	146, 300	3. 00	48, 208	2. 36
Flathead River Basin	1, 044, 800	21. 39	307, 191	15. 06
Thompson River	33, 000	. 68	41, 667	2. 04
Bull River	2, 200	. 04	1, 005	. 05
Total, Columbia River Basin	3, 097, 000	63. 41	1, 015, 480	49. 78
Missouri River Basin:				
Missouri River (main stem)	310, 500	6. 36	210, 160	10. 31
Jefferson River Basin	147, 000	3. 01	73, 516	3. 60
Madison River	36, 500	. 75	22, 375	1. 10
Gallatin River	20, 800	. 43	12, 329	. 60
Sun River	20, 500	. 42	6, 963	. 34
Marias River	3, 600	. 07	1, 027	. 05
Total, Missouri River above Yellowstone River	538, 900	11. 04	326, 370	16. 00
Yellowstone River (main stem)	920, 000	18. 84	536, 530	26. 30
Mill Creek	15, 000	. 31	7, 991	. 39
Boulder River	10, 000	. 20	6, 849	. 34
Stillwater River	40, 000	. 82	21, 689	1. 06
Bighorn River Basin [1]	255, 000	5. 22	121, 918	5. 97
Powder River	8, 000	. 16	3, 311	. 16
Total, Yellowstone River Basin	1, 248, 000	25. 55	698, 288	34. 22
Total, Missouri River Basin	1, 786, 900	36. 59	1, 024, 658	50. 22
Total for State	4, 883, 900	100. 00	2, 040, 138	100. 00

[1] Includes Yellowtail project now under construction with planned installed capacity of 200,000 kilowatts.

BASIN APPRAISALS OF WATER RESOURCES

The preceding discussion on the water resources of Montana presents a broad picture. Because interest is often directed to a specific locality, a somewhat more detailed discussion by river basins or subdivisions of major river basins follows.

COLUMBIA RIVER BASIN

Kootenai River.—The Kootenai River heads in Canada and flows through the extreme northwestern part of the State for a distance of 100 miles. The drainage area of about 4,000 square miles in Montana is mostly mountainous and heavily timbered. The main stream is well entrenched and has an average gradient of 5 feet per mile. The average unit runoff for the drainage in Montana is 11 inches and has a tendency to increase in a downstream direction. Nearly one-half the annual runoff occurs during May and June when rains generally augment runoff from mountain snowmelt. The recession during July and August is more gradual than the pattern illustrated in the hydrograph for the Flathead River near Columbia Falls (fig. 48). In the 51 years of discharge record for the Kootenai River at Libby, the annual discharge has varied from 57 to 138 percent of the average, a measure of high dependability. Some data regarding streams of the area are given below:

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Kootenai River at Newgate, British Columbia[1]	7,660.0	31	10,380	98,200	994	Minor
Fisher River near Jennings, Mont.	780.0	10	567	6,320	60	Minor
Granite Creek near Libby, Mont.	23.6	8	65	1,960	[2] 0	None
Kootenai River at Leonia, Idaho[3]	11,740.0	33	13,850	123,000	996	14,600

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[1] Near entry into Montana.
[2] Creek blocked by snowslide.
[3] Near entry into Idaho.

Ground water is available from unconsolidated deposits underlying the Kootenai River Valley and those of its principal tributaries. Wells yielding from 250 to 1,000 gallons per minute can be constructed in some parts of the drainage, notably in the valley of the Tobacco River near its mouth and in the Libby Creek Valley. Wells yielding over 1,000 gallons per minute are believed possible in the Kootenai Valley near the mouth of the Yaak River.

Little is known regarding the quality of the surface and ground water. The low turbidity of the water, geologic data, and current usage of surface and ground water indicate very favorable quality characteristics in all or most of the basin.

The utilization of water for irrigation is relatively minor and could be expected to vary greatly with the abundance of summer precipitation. Both surface and ground water are used for municipal purposes and the processing of lumber and minerals. Two hydroelectric powerplants on Lake Creek near Troy have an installed capacity of 4,500 kilowatts. The considerable hydroelectric power potential of the main stream, and some tributaries, periodically has received active consideration. The recreation associated with the water resources is enjoyed by a sparse local population.

Clark Fork above Flathead River.—The Clark Fork above the mouth of the Flathead River drains about 10,800 square miles of west-central Montana west of the Continental Divide. The main stream and a number of the tributaries flow through large intermontane valleys. The precipitation generally increases in a downstream direction, and the effect is apparent in the flow of streams and in the varying density of timber stands. The undepleted annual runoff is equivalent to an average depth of about 10 inches over the watershed. The annual runoff of tributaries may vary from less than 5 inches to more than 25 inches. The melt of the winter accumulation of mountain snow results in a peakflow period in May and June. Rains during that period contribute greatly to the runoff. Water use for irrigation has an appreciable effect on the regimen of some streams and to a lesser extent on the total annual flow. A few of the available data on the streams are below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Middle Fork, Rock Creek, near Philipsburg, Mont	123.0	24	119.0	1,430	4.5	Minor
Nevada Creek above reservoir near Finn	116.0	22	35.6	1,800	2.0	2,900
Clark Fork above Missoula	5,999.0	32	2,813.0	31,500	[1] 340.0	120,000
Blodgett Creek near Corvallis	26.4	14	71.3	836	1.2	0
Clark Fork below Missoula	9,003.0	32	5,162.0	52,800	388.0	235,000
Clark Fork at Saint Regis	10,709.0	51	7,376.0	68,900	1,000.0	244,000

[1] Minimum daily.

The use of the water and effects of use indicate good to excellent natural water quality. The deterioration of water quality through irrigation is minor. The industrial use of water for the mining and smelting of ores at Butte and Anaconda occasionally results in slightly acid water in the upper reaches of the Clark Fork. The control measures near Anaconda have improved water quality to the point that trout are found on the main stream above the mouth of the Little Blackfoot River.

The unconsolidated deposits in the several large intermontane valleys of the Clark Fork and major tributaries contain large quantities of ground water. Wells yielding more than 1,000 gallons per minute can be constructed in many parts of the Missoula, Bitterroot, Deer Lodge, and Divide Creek Valleys. Smaller ground water supplies of from 250 to 1,000 gallons per minute are generally available in the upper Blackfoot River Valley and the valley of Flint and Blacktail Creeks. Some ground water development has been undertaken in parts of these valleys, but the supply is very large and the potential for additional development is great.

The principal use of water is for the irrigation of about 244,000 acres of land. Nearly one-half the acreage is in the broad valley of the Bitterroot River. Development of ground water for irrigation is of recent origin and serves only a small part of the irrigated acreage. The annual depletion of streamflow by irrigation is estimated to be about 300,000 acre-feet or 5.6 percent of the available supply. A hydroelectric powerplant on the Clark Fork, downstream from the mouth of the Blackfoot River, has an installed capacity of 3,040 kilowatts. The industrial use of water for the processing of ore and the timber products is of considerable economic importance. The withdrawals for industrial use are principally from surface water sources as are those for municipal supply. The streams and lakes offer many opportunities for fishing, boating, and other water-based recreational uses.

Flathead River.—The Flathead River drainage comprises an area of 9,077 square miles of which 450 square miles lie in Canada. Prominent intermontane valleys, formed by block faulting, are occupied by the main stream and its major tributaries and form an unusual drainage pattern. Flathead Lake, with a surface area of nearly 200 square miles, occupies a part of one of these valleys. The drainage is mostly timbered, but grasslands are common in the semiarid southwest part. The annual runoff for the upstream one-half of the drainage area is equivalent to a water depth of 29 inches, and that for the entire drainage is about 18 inches. The general runoff pattern is typical of those basins with heavy winter precipitation in the form of snow and relatively light summer precipitation. Tributary streams of the southwest part of the drainage show some characteristics of plains-type runoff. Summary data on the flow characteristics of a few streams are presented below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Flathead River at Flathead, British Columbia	450	10	1,002	14,600	65	None
Flathead River at Columbia Falls, Mont.	4,464	33	9,543	102,000	798	Minor
Stillwater River near Whitefish, Mont.	325	20	340	4,330	40	Minor
Flathead River near Polson, Mont.	7,096	54	11,610	82,800	[1] 32	10,000

[1] Minimum daily.

Little is known of the ground-water potential of the large tributary valleys north of Flathead Lake. The supply is believed to be large, however, and wells of high yield could be developed locally. In the Flathead valley north of Flathead Lake, wells yielding more than 1,000 gallons per minute are possible and some development has taken place in the area. In the valleys of Ashley Creek, Little Bitterroot River, and Jocko River, wells yielding from 250 to 1,000 gallons per minute can be constructed locally.

Available information indicates water of excellent quality is present in most of the drainage area. In a few subareas, such as the Little Bitterroot River Basin, surface and shallow ground water supplies may be of poor quality.

The principal use of water is for the generation of hydroelectric power. The multiple-purpose Hungry Horse Reservoir on the South Fork Flathead River has a usable capacity of 3,428,000 acre-feet available for onsite power generation of 285,000 kilowatts and regulation for downstream hydroelectric power, flood control, and irrigation. The regulation of Flathead Lake through a range in stage of 10 feet provides 1,219,000 acre-feet of storage for the Kerr plant that has an installed capacity of 168,000 kilowatts. Powerplants on Swan River and Big Creek have a combined capacity of 4,500 kilowatts. About 91,000 acres of land are irrigated, principally from tributary streams south of Flathead Lake. The annual depletion by irrigation has been estimated at 109,000 acre-feet, less than 1 percent of the supply. A number of reservoirs on small tributaries provide storage capacity of more than 150,000 acre-feet of water for irrigation. Ground and surface water are used for municipal supply. Water-based recreation plays an important part in the economy of the area.

Clark Fork from Flathead River to State line.—The Clark Fork drainage is relatively narrow through this region of 2,200 square miles.

The crests of the Bitterroot and Cabinet Mountains form most of the boundary and intermontane valleys are small. In a number of reaches, the Clark Fork occupies a narrow bedrock channel parallel to a deeper filled channel of the ancestral Clark Fork. The stream gradient varies greatly but averages 4 feet per mile. The region is almost entirely timbered. The western part of the area has a high rate of precipitation, particularly in the Bitterroot Mountains. The gain in the discharge of the Clark Fork through this reach indicates an annual runoff equivalent of 11.6 inches. The runoff pattern is similar to that of the upstream areas described previously, although the main steam pattern is modified by regulation. The discharge records of a few streams are presented below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Clark Fork near Plains	19,958	51	19,570	134,000	3,200	335,000
Thompson River near Thompson Falls	642	5	502	4,960	89	Minor
Prospect Creek near Thompson Falls	182	5	266	2,860	36	None
Clark Fork at Whitehorse Rapids near Cabinet, Idaho	22,067	33	21,450	153,000	[1] 969	354,000

[1] Regulated minimum daily.

Large ground-water supplies are available in only a few areas because of the restriction of the Clark Fork Valley. Wells yielding from 250 to 1,000 gallons per minute can be constructed where the valley widens above Noxon Reservoir, but similar well yields are not known to be available elsewhere in the valley.

Surface and ground-water supplies of good quality are indicated by the geology and water utilization practices in the area.

Generation of hydroelectric power is the principal water use. The Thompson Falls hydroelectric plant with a capacity of 30,000 kilowatts, the Noxon plant with a capacity of 282,800 kilowatts, and the Cabinet Gorge plant, located a mile downstream from the Montana boundary and with a capacity of 200,000 kilowatts, utilize three-fourths of the power head of the Clark Fork. These plants rely mainly upon the water stored by Hungry Horse and Kerr Dams. Approximately 15,000 acres of land are irrigated along the main stem and tributaries. Ground water is used to irrigate a few small tracts. Municipalities utilize surface water and rural residents depend on ground-water supplies. The artificial water bodies and streams offer recreational opportunities that are enjoyed by the local population and visitors.

MISSOURI RIVER BASIN

Tributaries above Three Forks.—The Jefferson, Madison, and Gallatin Rivers drain all of southwestern Montana east of the Continental Divide, an area of about 14,000 square miles. The name Missouri River is properly used below the confluence of the Jefferson and Madison Rivers, and the Gallatin River enters a few miles downstream. These principal streams and their tributaries flow through a number of large intermontane valleys.

The Jefferson River drains about 9,700 square miles and the main stem is known successively as the Red Rock River and Beaverhead River to the mouth of the Ruby River. The main stream and the principal tributaries, the Big Hole, Ruby, and Boulder Rivers, flow through large valleys along parts of their courses. Much of the area receives less than 12 inches of precipitation and grasslands predominate. A few tributary streams have an April snowmelt runoff peak, although a May–June snowmelt runoff peak is characteristic. The extensive use of surface water for irrigation greatly modifies the natural flow pattern. The annual runoff adjusted for consumptive use is equivalent to about 4 inches from the watershed.

The Madison River heads in the high plateaus of Yellowstone National Park and drains about 2,500 square miles. The stream passes through a number of broad valleys, and grasslands are prominent at lower elevations. The basic mountain-streamflow pattern is modified by the effects of springs and ground-water storage. These effects are accentuated by irrigation. The natural runoff is equivalent to a depth of about 10 inches over the watershed.

The Gallatin River originates in the northwest part of Yellowstone National Park, and it flows through intermontane valleys before it enters the broad Gallatin Valley near Bozeman. Extensive irrigation in the Gallatin Valley reduces the May–June snowmelt runoff peak, particularly in years of low flow and light summer precipitation. The runoff from this drainage basin of 1,800 square miles is about 9 inches after adjustment for irrigation use.

Some discharge data and a few related facts for a number of gaging stations in the drainage area are given below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Red Rock River below Lima Reservoir near Monida	570.0	40	138	2,500	[1] 0	10,000
Beaverhead River at Blaine	3,619.0	26	390	3,130	7.0	115,000
Ruby River near Twin Bridges	935.0	16	188	1,500	[2] 1.8	28,000
Big Hole River near Melrose	2,476.0	38	1,091	14,100	49.0	136,000
Boulder River near Boulder	381.0	30	110	2,620	0	3,500
Jefferson River at Sappington	9,277.0	32	2,093	21,000	134.0	345,000
Madison River near West Yellowstone	420.0	46	471	2,150	100.0	0
Madison River below Ennis Lake near McAllister	2,186.0	23	1,594	7,750	[2] 210.0	23,000
Gallatin River near Gallatin Gateway	825.0	36	755	8,060	117.0	1,400
Bridger Creek near Bozeman	62.5	16	32	902	.9	1,200
Gallatin River at Logan	1,795.0	45	949	9,840	130.0	110,000

[1] Regulated.
[2] Minimum daily.

The surface and ground water of the basin is a calcium bicarbonate type with a relatively low concentration of dissolved solids. A minor amount of sediment is transported by the streams.

The thick unconsolidated deposits of the large intermontane valleys contain large quantities of ground water in storage. Supplies exceeding 1,000 gallons per minute are available from wells in the Jefferson and lower Beaverhead Valleys and in the Blacktail Creek Valley. Wells yielding from 250 to 1,000 gallons per minute can be constructed in the Red Rock, Horse Prairie, Ruby, and Big Hole

Valleys. Ground water supplies in excess of 1,000 gallons per minute are available in parts of the Madison Valley and in most of the Gallatin Valley.

The principal water use is for the irrigation of about 500,000 acres. The consumptive use for this purpose is about 20 percent of the supply. Storage of only 155,000 acre-feet of irrigation water makes much of the area dependent on currently available streamflow. Clark Canyon Reservoir, now (1963) under construction on the Beaverhead River near Dillion, will have a capacity of 261,000 acre-feet for the irrigation of 21,800 acres of new land and a supplemental irrigation supply for 28,000 acres. The use of ground water for irrigation has been started in a few scattered areas. Hebgen and Ennis Lakes on the Madison River provide 420,000 acre-feet of storage for hydroelectric power generation on the Missouri River. A powerplant below Ennis Lake has an installed capacity of 9,000 kilowatts. Municipalities rely on both surface and ground water supplies. A diversion from the Big Hole River is an important part of the municipal and industrial water supply for Butte in the Clark Fork of Columbia River drainage. The use of water for recreation is significant in the Madison, Gallatin, and Big Hole River drainage areas.

Missouri River, Three Forks to Great Falls.—In most of the reach between Three Forks and Great Falls, the Missouri River traverses a mountain area. It flows in a northerly direction through Townsend Valley, crosses the lower end of the Helena Valley and emerges from the mountains near the town of Cascade, flowing in a rather narrow valley. The tributary Smith River occupies a large intermontane valley in its upper reaches. The other major tributaries, the Dearborn and Sun Rivers, leave the steep Rocky Mountain front to traverse a region of foothills and high plains to enter the Missouri River. In the reach of 209 river-miles between Three Forks and Great Falls, the Missouri River has a fall of about 700 feet, the greatest amount in the upstream half of the reach. The incremental drainage area is 8,900 square miles, and the cumulative area to a point below the mouth of the Sun River is 22,900 square miles.

The runoff from the area is equivalent to a depth of 4.5 inches after adjustment for consumptive use. The principal contribution to streamflow in this reach is from the snowmelt runoff of May and June when precipitation is also the greatest. The natural streamflow pattern is greatly modified by regulation and irrigation use. During years of low flow, such as occurred in 1961, these modifications result in a rather uniform flow throughout the year. A few discharge data are given below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Missouri River at Toston	14,669	26	5,135.0	32,000	562.0	535,000
Prickly Pear Creek near Clancy	192	35	47.7	927	.5	700
Missouri River below Holter Dam near Wolf Creek	17,149	16	5,023.0	34,900	500.0	574,000
Dearborn River near Craig	325	16	216.0	7,960	8.0	3,300
Smith River near Eden	1,594	10	252.0	12,300	3.1	24,500
North Fork Sun River, near Augusta	258	17	360.0	4,840	27.0	0
Sun River near Vaughn	1,854	27	713.0	17,900	20.0	110,000

The largest ground water supplies are found in the unconsolidated alluvium and terrace deposits adjacent to the Missouri River and the lower reach of the Sun River. Supplies of 250 to 1,000 gallons per minute are generally available from this source. High terrace gravels mantle consolidated rocks adjacent to the mountains and, where thick enough, yield adequate water for domestic and stock use.

In much of the reach from the mountains to Great Falls, the consolidated rocks of Paleozoic and Mesozoic age are the only source of ground water supplies. The rock formations that are believed to be reliable sources of ground water include the Two Medicine formation, the Virgelle sandstone, the Kootenai formation (cut bank sand), the Swift formation, and the Madison limestone. Few of the formations are present at all locations and some are deeply buried little is known concerning the well yields available from these rocks, but large yields are obtained from the Madison limestone in the Great Falls area.

The surface water is generally of a calcium bicarbonate type with a relatively low concentration of dissolved solids. The shallow ground water is probably of the same type but has a higher concentration of dissolved solids. The water in the deeper consolidated rocks may vary as to type and probably has a greater concentration of dissolved solids.

The water of the Missouri River and its tributaries is used for the irrigation of about 295,000 acres in this area. Reservoirs on tributary streams have an aggregate capacity of 190,000 acre-feet to provide storage for irrigation. Canyon Ferry Reservoir on the Missouri River near Helena, with a usable capacity of 2,043,000 acre-feet, provides water storage for onsite and downstream hydroelectric power generation, irrigation, municipal supply, and recreation. Additional storage of 144,000 acre-feet of water for hydroelectric power is available in Hauser and Holter Lakes on the Missouri River near Helena. Nearly half the power head of the Missouri River is utilized in plants that have an installed capacity of 105,000 kilowatts. Surface water of good quality is the principal source of water for the larger municipalities, and ground water is generally used for the smaller community and individual supplies. Surface water generally supplies industrial users. The area has many opportunities for water-based recreation of all types and lands bordering the artificial water bodies are becoming increasingly popular as summer and permanent homesites.

Missouri River, Great Falls to Fort Peck Dam.—The Missouri River drainage from Great Falls to Fort Peck Dam extends from the Continental Divide in northwest Montana through the high plains and isolated mountain ranges to the plains of eastern Montana. There are 380 miles in this reach, and the drainage area increases from 22,900 to 57,500 square miles. Falls and rapids in the upper 50 miles account for about 700 feet of fall in the river. The natural gradient for the remaining 330 miles ranges from about 3 feet to 1 foot per mile with an average of 1.7 feet per mile. The principal tributaries are the Marias and Teton Rivers from the west and north, the Judith River, Musselshell River, and Dry Creek from the south. The tributary streams from the north are short. The runoff from the mountain areas reaches its peak in the May–June period as the winter accumulation of snow is melted. The plains area generally has a brief snowmelt period in March or early April and the subsequent runoff is the result of rains of high intensity or above-average duration. The blending of the two distinct runoff types is modified by regulation and irrigation use. The runoff from this area is highly variable and may average about 0.7 inch annually, after adjustment for consumptive use. Some information regarding the streamflow is given below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Missouri River at Fort Benton	24,749	71	7,539	140,000	[1] 627.0	730,000
Two Medicine Creek near Browning	317	27	389	7,950	4.4	10,000
Marias River near Shelby	3,242	53	948	40,000	10.0	65,000
Teton River near Dutton	1,308	7	143	1,310	16.0	44,000
Judith River near Utica	328	42	50	1,120	0	Minor
Missouri River near Zortman	40,763	27	8,404	137,000	1,120.0	850,000
Musselshell River at Harlowton	1,125	51	157	4,530	0	37,000
Musselshell River at Mosby	7,846	29	214	18,000	0	103,000
Dry Creek near Van Norman	2,554	20	58	24,600	0	Minor
Missouri River below Fort Peck Dam	57,556	18	[2] 9,252	51,000	[1] 0	950,000

[1] Regulated mean daily.
[2] Since operational level of Fort Peck Reservoir was reached.

The quality of the surface water in this part of the drainage area is generally good; the water is a calcium bicarbonate type with somewhat higher concentrations of dissolved solids. Exceptions are the Teton River downstream from Choteau, the Musselshell River downstream from Ryegate, and the Missouri River downstream from Virgelle. The water downstream from these points is a sodium sulfate type with relatively high concentrations of dissolved solids. Sediment concentrations are generally low throughout the basin except in the lower reaches of the Musselshell where the stream traverses the Bearpaw shale which is easily eroded and carried in suspension. Return flow from irrigation has an appreciable bearing on the quality of water in parts of the area.

The geology and the occurrence of ground water in this large area are complex. Most of the area north of the Missouri River has been glaciated, and glacial drift mantles much of the surface. Outwash gravels and buried gravel-filled valleys may be present locally and are sources of small ground water supplies. The availability of ground water supplies within this vast area can best be described for smaller tributary basins.

The geology of much of the Teton and Marias River drainages is similar, and in much of the area ground water supplies are difficult to obtain. Alluvium and terrace deposits adjacent to these streams and high terrace gravels near the mountains may yield small to moderate supplies of ground water. In the western part of the area the sandstones of the Two Medicine formation and the Virgelle sandstone are believed to be reliable sources of small ground water supplies. In the central part of the drainage area, ground water supplies are difficult to obtain except with deep wells, and the quality of the water is not known. North of the Teton River the Virgelle sandstone, Claggett formation, and Judith River formation underlie the area, and sandstones in these formations are generally reliable sources of small ground water supplies.

The Judith River and its tributaries drain a large topographic and structural basin, the Judith Basin, that is surrounded by isolated mountains. Much of the upland area of the Judith Basin is mantled by high terrace gravels that yield ground water supplies adequate for stock and domestic use. The alluvium of the Judith River and its principal tributary, the Ross Fork, also yields small to moderately large water supplies to wells. The consolidated rocks underlying the Judith Basin are important sources of ground water. Most of the consolidated rocks are exposed on the flanks of the surrounding mountains and are thus favorably situated to receive recharge. The Kootenai formation ("Cat Creek sand"), Swift formation, Amsden formation, Kibbey formation, and Madison limestone are all sources of ground water, and most are used to some extent. These formations are deeply buried in most of the basin, but the contained water is under sufficient artesian pressure to cause many wells to flow at the land surface. Small to moderately large ground water supplies can be obtained from the consolidated rocks, and the Madison limestone, although not used at present, is believed to be a potential source of large water supplies. A number of large springs issue near the base of the mountains forming the east side of Judith Basin and are important locally as sources of water.

The Musselshell River and its tributaries drain a large area in central Montana, and ground water supplies are available from a number of sources. The alluvium and terrace deposits adjacent to the river yield from 250 to 1,000 gallons per minute to favorably located wells. In the headwaters region high terrace gravels cover an extensive area and, where adequately thick, yield small water supplies. The consolidated rocks are an important source of water, and ground water can be obtained from several formations. Where present, the Fort Union, Hell Creek, Fox Hills, Judith River, Claggett, and Eagle formations are water bearing and yield small to moderately large water supplies adequate for domestic and stock use. The Madison limestone, deeply buried in most of the basin, is a potential but unexplored source of large water supplies.

The water of tributaries in this reach is used for the irrigation of about 220,000 acres. The water from ephemeral streams is used extensively for flood irrigation and the quantity used is dependent on the availability of flow. The water storage capacity available for irrigation is about 250,000 acre-feet exclusive of the 1,313,000 acre-feet in Tiber Reservoir on the Marias River. At present, that reservoir is used for flood control and recreation as the planned irrigation use has not developed. The five hydroelectric powerplants on the Missouri River in the upper reach have an installed capacity of 193,000 kilowatts. The powerplants are dependent on upstream water storage. Fort Peck Reservoir, with a normally usable water supply of about 14 million acre-feet, provides storage for flood control and the generation of hydroelectric power. The installed capacity of the plant is 165,000 kilowatts. The recreational use of water in the various reservoirs is enjoyed by the local population. The mountain tributaries offer trout fishing.

Missouri River, Fort Peck Dam to State line.—Half of the Missouri River drainage area of 44,500 square miles between Fort Peck Dam and the border of North Dakota is in the Milk River drainage. A similarity of its many water-resource characteristics and those of the strip that extends along most of Montana's northern border allows a joint discussion of the two areas. In preglacial times the Missouri River occupied the present valley of the Milk River from near Havre to the mouth of the Milk. From this point the Missouri flows in its preglacial valley to the vicinity of Poplar, where it once flowed northeastward toward Hudson Bay. Thick beds of unconsolidated alluvium were deposited in the preglacial valleys. The Milk River heads in Glacier National Park and passes through a part of southern Canada before returning to the United States northwest of Havre. The principal northern tributaries of the Milk and Missouri Rivers head in Canada. A plains-type pattern of tributary runoff similar to that of the Poplar River prevails except for the few square miles in Glacier National Park. The melt of snow on the plains in early spring produces a high runoff rate. Precipitation from April to September is about 75 percent of the annual total, but little runoff results except from rains of high intensity or long duration that usually occur in June. The natural runoff of the Milk River drainage and the remainder of the area is approximately 0.5 inch as an annual average. The discharge data at a few representative points is given below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Milk River at Milk River, Alberta	1,036	45	310.0	8,730	0	Minor
Milk River at Nashua	22,332	22	695.0	45,300	0.6	140,000
Missouri River near Wolf Point	82,290	[1] 18	10,010.0	46,800	[2] 680.0	1,000,000
Redwater Creek at Circle	547	26	16.6	6,730	0	Minor
Poplar River near Poplar	3,174	30	145.0	37,400	0	8,000

[1] Period 1943-61 after Fort Peck Reservoir on Missouri River was fully operational.

[2] Minimum daily.

The surface water originating in the area has relatively high concentrations of dissolved solids and is a sodium bicarbonate type. The sediment yield of the tributary streams is high as the shales and sandstones of the area are easily eroded.

Wells tapping the alluvium in the preglacial valley of the Missouri River yield over 1,000 gallons per minute at many locations. High terrace gravels are present in northeastern Blaine County and wells yielding 1,000 gallons per minute can be constructed locally. However, the low recharge rate will limit the number of such wells. Downstream from the Poplar River the alluvial fill in the Missouri Valley is thinner and wells yielding from 250 to 1,000 gallons per minute can be constructed. Water from the alluvium in this area is highly mineralized, but is usable for some purposes. In much of the area remote from valleys, small ground water supplies adequate for domestic and stock-water use can be constructed in consolidated rocks. These rocks include the Judith River, Fort Union, and Hell Creek formations. Other water-bearing rocks are present at depth, but the water is thought to be brackish.

Only a small part of the irrigated land is supplied with water from the Missouri River. Most of the 160,000 acres of irrigated land lies near the Milk River and along its major tributaries in the United States and Canada. The transbasin diversion of water from the St. Mary River to the Milk River is about 150,000 acre-feet annually. The water of the Milk River and the tributary areas in Canada is subject to apportionment determined by an international treaty. The irrigation-water storage capacity is about 205,000 acre-feet in the Milk River drainage in the United States and about 110,000 acre-feet in Canada. The utilization of ground water for irrigation has shown a considerable increase in recent years. Lake Bowdoin and Medicine Lake refuges play an important part in the propagation and preservation of waterfowl.

Yellowstone River and tributaries.—The Yellowstone River heads in the high mountains in Wyoming southeast of Yellowstone National Park and the principal tributaries have a high proportion of mountain drainage. The highest point in the State, Granite Peak of the Absaroka Range, lies in this drainage. The tributaries from the north are few and are generally short. There are about 12,000 square miles in this drainage, of which 9,000 are in Montana and 3,000 in Wyoming. The unit runoff from the Absaroka Range is high but tends to decrease progressively downstream. The main stream and the principal tributaries have flow patterns typical of high mountain areas where the melt of winter snow provides most of the runoff. The runoff from the area is somewhat greater than that of any other similar-sized part of the Missouri River Basin in Montana, and is highly dependable. After adjustment for irrigation use, the runoff from the entire area is about 8 inches. The use of water for irrigation greatly modifies the natural flow pattern of the tributary Shields River, Sweetgrass and Pryor Creeks. Some data for representative sites are given below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Yellowstone River at Corwin Springs	2,623	55	3,014	32,000	389.0	1,000
Yellowstone River at Livingston	3,551	36	3,556	30,600	[1] 590.0	24,000
Shields River at Clyde Park	543	32	152	4,500	1.8	19,500
Stillwater River near Absarokee	975	26	903	10,600	58.0	24,000
Clarks Fork Yellowstone River at Edgar	2,032	40	1,030	10,900	36.0	41,500
Yellowstone River at Billings	11,795	33	6,409	64,800	430.0	350,000

[1] Minimum daily.

Water in this part of the area is generally a calcium bicarbonate type with a relatively low concentration of dissolved solids and is suitable for most uses. Sediment concentrations also are low during most of the time.

Moderate to large ground water supplies are available from the alluvium and terrace deposits adjacent to the river. Wells yielding from 250 to 1,000 gallons per minute can be constructed at many locations in the valley, the most favorable sites being close to the river where the underlying gravels can be readily recharged. In parts of the area bordering the Yellowstone Valley, adequate ground water supplies are difficult to obtain. In areas remote from the valley, a number of consolidated rock formations yield water supplies adequate for stock and domestic needs and locally large supplies are available. North of the Yellowstone Valley, the Judith River, locally the Claggett, and the Eagle formations are sources of water supply. South of the Yellowstone Valley ground water supplies are difficult to obtain in much of the area, but adjacent to the Pryor Mountains large ground water supplies can be obtained locally. The Chugwater formation, Tensleep sandstone, and Madison limestone are sources of large water supplies, and wells yielding artesian flows of several thousand gallons per minute can be constructed. Ground water obtained from the formations listed as sources of supply generally is much less suitable in quality for most uses than that of surface water supplies.

The principal use of the water in this part of Montana is for the irrigation of about 350,000 acres along the main stream and tributaries. Assuming an average consumptive use of 1.5 feet per acre, the depletion would be 530,000 acre-feet or about 11 percent of the available supply. The natural flow is supplemented by about 50,000 acre-feet of irrigation water storage which has only a minor effect on stream regimen. The high head Mystic Lake development on East Rosebud Creek has a power generating capacity of 10,000 kilowatts. Most of the population is served by municipal water supplies obtained from surface sources. The Yellowstone River compact applies to the apportionment of part of the water of Clarks Fork of Yellowstone River. The water of the area has a high recreational value for fishing, and hot springs in some areas have been developed as resorts.

The Bighorn River enters the Yellowstone River about 55 miles northeast of Billings to increase the drainage area from about 13,600 to 36,500 square miles. About 19,000 square miles of the Bighorn Basin lie in Wyoming where the drainage is chiefly mountainous, and the natural flow of the Bighorn River is greatly modified by extensive irrigation and storage for hydroelectric power generation. The area of nearly 4,000 square miles in Montana includes a small part of the Bighorn Mountains and extends through the foothills and high plains area. The valleys of the Bighorn and Little Bighorn Rivers in the State are large. The natural runoff in Montana is typical of a combination of mountain and plains runoff. The data given below are indicative of the runoff characteristics.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Bighorn River near St. Xavier, Mont	19,626	27	3,426	37,400	228.0	375,000
Little Bighorn River near Hardin	1,294	8	181	3,000	.2	17,000
Bighorn River at Bighorn	22,885	16	3,558	26,200	[1] 540.0	465,000

[1] Minimum daily.

The quality of the surface water is affected by extensive irrigation in Wyoming. The water entering Montana is a sodium sulfate type with a relatively high dissolved solids content. There is slight dilution by tributary inflow in Montana. The sediment load of the Bighorn River as it enters the State is generally high.

Large ground water supplies are not generally available in this drainage. Supplies adequate for domestic and stock use can be obtained from the alluvium and locally from the high terrace gravels adjacent to the Bighorn and Little Bighorn Rivers. East of the Little Bighorn River small supplies of fair quality may be available where the Fort Union and Hell Creek formations are present.

The irrigation of about 3,000 acres of land in Montana is the principal use of the water. Storage of 23,000 acre-feet in the Lodgegrass Creek area supplies irrigation water for Indian lands in the Little Bighorn River Valley. Water for livestock is an important economic use. Yellowtail Dam currently (1963) is under construction on the Bighorn River where it leaves the mountains. The capacity of the reservoir will be 1,375,000 acre-feet; a large part of the storage area will be in Wyoming. A hydroelectric powerplant with a capacity of 200,000 kilowatts is planned with provisions for irrigation, flood control, and sediment storage.

The Yellowstone River drainage from the mouth of the Bighorn River to the State line includes most of the southeastern part of the State. The drainage area increases from about 36,500 to 69,000 square miles, one-third of the increase in area is in Wyoming. The drainage area is principally one of high plains. The main stream occupies a rather narrow central valley that occasionally widens to form broad lowlands. Snowmelt in the tributary drainage in March or early April results in runoff and the subsequent runoff peaks are caused by above average precipitation. Some of the tributaries head in the Bighorn Mountains of Wyoming and may show a peak from the May–June snowmelt. The high variability of streamflow from the tributaries affects the uniformity of flow of the main stream. The runoff equivalent of the area ranges from less than 0.5 inch to 1.5 inches after adjustment for consumptive use. Discharge data at a few representative points are given below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Tongue River at Miles City	5,739	18	341	12,000	0	90,000
Yellowstone River at Miles City	48,253	34	10,710	96,300	996	1,100,000
Powder River near Locate	13,189	23	570	31,000	0	52,000
Yellowstone River near Sidney	68,812	49	12,740	159,000	470	1,250,000

The water of the Yellowstone River and its tributaries is a sodium sulfate type with a relatively high dissolved-solids concentration. The sediment load of the Yellowstone River and its tributaries is relatively high.

Along the Yellowstone Valley and tributary valleys of the Tongue and Powder Rivers, ground water supplies of from 250 to 1,000 gallons per minute can be developed locally from the alluvium and terrace deposits adjacent to the streams. In areas remote from the streams, several consolidated formations yield adequate water for stock and domestic, municipal, and some industrial uses. The Fort Union, Hell Creek, and Fox Hills formations are the principal sources of water. At low elevations in the Yellowstone, Tongue, and Powder River Valleys, flowing artesian wells can be drilled in these formations. Along the crest of the Cedar Creek anticline in Fallon, Wibaux, and Dawson Counties, impermeable rocks are at the surface and ground water supplies are difficult to obtain.

There are about 180,000 acres of irrigated land in this reach, the greater part of which is along the Yellowstone River Valley. Flood irrigation is common along the smaller tributaries. The water of the Tongue and Powder Rivers is subject to allocation under the terms of the Yellowstone River compact. The surface and ground water used for livestock has a high economic value, and availability is often a limitation on range use. Municipal supplies are obtained from both surface and ground water. Water from the Yellowstone River is used in steam-electric powerplants with a combined capacity of about 55,000 kilowatts.

LITTLE MISSOURI RIVER BASIN

An area of about 3,500 square miles in the southeast part of the State is in the Little Missouri River Basin. The River crosses the flank of the Black Hills uplift but the area is one of low relief. The soils are dominantly clays with low infiltration capacity, and impermeable rocks underlie most of the area. Precipitation from April to September constitutes about 75 percent of the annual total and, when sufficient, results in a good native grass cover. The runoff varies widely from year to year and averages about 1.5 inches. A March or April runoff peak is typical of the streamflow pattern. Summer rains may cause runoff peaks between extended periods of low flow. The storage of tributary flow for stock water and flood irrigation of hay meadows modifies streamflow patterns. A few representative runoff records are given below.

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Little Missouri River near Alzada, Mont	904	41	79.8	[1] 6,000	0	Minor
Little Beaver Creek near Marmarth, N. Dak	615	23	39.7	12,700	0	Minor
Beaver Creek at Wibaux, Mont	351	23	24.2	[2] 3,780	0	150

[1] Maximum daily.

[2] Peak of 30,000 cubic feet per second determined for flood of June 7, 1929.

The supply of ground water is believed to be very limited in quantity because of the impermeable character of the soils and underlying rocks. The alluvium and terrace deposits of the principal streams may yield supplies adequate for domestic and stock use.

The quality of known surface and ground water supplies is generally poor. The streams of the basin traverse easily eroded shales and sandstones and as a result carry high concentrations of sediment.

The principal economic uses of the water supply are for stock and the occasional irrigation of hay or grasslands, as variable supplies permit. Ground water is the principal source for small municipal and domestic supplies.

SASKATCHEWAN RIVER BASIN

A small part of Montana east of the Continental Divide drains northward into the Saskatchewan River and thence to Hudson Bay. Most of this area of about 650 square miles is in Glacier National Park. The precipitation in the mountainous part is the highest in the State. A number of small glaciers in the area and the extremely heavy snowpack result in a prolonged high runoff period that extends well into July. The annual runoff of the three principal streams ranges from about 37 to 26 inches. The annual runoff of Grinnell Creek, as shown below, is equivalent to 97 inches of water. The lowest runoff is for the St. Mary River, which has a large part of its drainage in the foothills. The runoff data for a few streams are given below:

Stream	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)		Irrigated land served (acres)
				Maximum	Minimum	
Belly River at international boundary	74.8	10	262.0	2,450	[1] 12.0	None
Grinnell Creek near Many Glacier	3.47	12	24.9	242	.2	None
St. Mary River at international boundary	469.0	44	705.0	[2] 40,000	[1] 16	(3)

[1] Minimum daily.

[2] June 1908, prior to period of record.

[3] Diversion to Milk River Basin equivalent to about 200 cubic feet per second.

Because of abundant surface water supplies, ground water use is small. The prominent gravel terraces flanking the mountains might be expected to yield abundant water supplies of good quality. The surface water is a calcium bicarbonate type with a low concentration of dissolved solids. Sediment concentrations are also low.

The recreational use of the waters is high, as might be expected in a national park. The preservation of natural features in the park and the international boundary limit the extent of water use for other than recreational purposes. Sherburne Reservoir on Swiftcurrent Creek was created prior to the establishment of Glacier Park and has a storage capacity of 66,200 acre-feet of water for irrigation. The transbasin St. Mary Canal seasonally diverts an average of 150,000 acre-feet of water to the Milk River Basin. The water of the St. Mary River is apportioned between the United States and Canada in accordance with a treaty.

Selected References

Culler, R. C., 1961, Hydrology of stock-water reservoirs in upper Cheyenne River basin: U.S. Geol. Survey Water-Supply Paper 1531–A, 136 p., 20 figs.

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, 92 p., 5 pls.

Federal Power Commission, 1960, Hydroelectric power resources of the United States.

Fisher, C. A., 1909, Geology and water resources of the Great Falls region, Montana: U.S. Geol. Survey Water-Supply Paper 221, 89 p., 7 pls.

Groff, S. L., 1958, A summary report on the ground-water situation in Montana: Montana Bur. Mines and Geology Inf. Circ. 26, 45 p., 7 pls.

Hackett, O. M., Visher, F. N., McMurtrey, R. G., and Steinhilber, W. L., 1960 Geology and ground-water resources of the Gallatin Valley, Gallatin County Montana, with a section on surface-water resources, by Frank Stermitz and F. C. Boner, and a section on Chemical quality of the water, by R. A. Krieger: U.S. Geol. Survey Water-Supply Paper 1482, 282 p., 11 pls., 40 figs.

Hall, G. M., and Howard, C. S., 1929, Ground water in Yellowstone and Treasure Counties, Montana: U.S. Geol. Survey Water-Supply Paper 599, 118 p., 7 pls.

Hembree, C. H., Colby, B. R., Swenson, H. A., and Davis, J. R., 1952, Sedimentation and chemical quality of water in the Powder River drainage basin, Wyoming and Montana: U.S. Geol. Survey Circ. 170, 92 p., 44 figs.

Konizeski, R. L., McMurtrey, R. G., Brietkrietz, Alex, 1961, Preliminary report on the geology and ground water resources of the northern part of the Deer Lodge Valley, Montana: Montana Bur. Mines and Geology Bull. 21, 24 p., 1 pl., 7 figs.

——— 1962, Preliminary report on the geology and ground-water resources of the southern part of the Deer Lodge Valley, Montana: Montana Bur. Mines and Geology Bull. 31, 23 p., 2 pls., 8 figs.

Lohr, E. W., and Love, S. K., 1954, The industrial utility of public water supplies in the United States: U.S. Geol. Survey Water-Supply Paper 1300, Part 2, 462 p., 5 pls., 3 figs.

Lorenz, H. W., and Swenson, F. A., 1951, Geology and ground water resources of the Helena Valley, Montana, with a section on The chemical quality of the water by H. A. Swenson: U.S. Geol. Survey Circ. 83, 68 p., 4 pls., 11 figs.

Lorenz, H. W., and McMurtrey, R. G., 1956, Geology and occurrence of ground water in the Townsend Valley, Montana, with a section on Chemical quality of the ground water by H. A. Swenson: U.S. Geol. Survey Water-Supply Paper 1360–C, p. 171–290, pls. 19–20, figs. 29–40.

MacKichan, K. A., and Kammerer, J. C., 1960, Estimated use of water in the United States, 1960: U.S. Geol. Survey Circ. 456, 44 p., 10 figs.

McMurtrey, R. G., and Konizeski, R. L., 1956, Progress report on the geology and ground-water resources of the eastern part of the Bitterroot Valley, Montana: Montana Bur. Mines and Geology Inf. Circ. 16, 28 p., 2 pls., 5 figs.

McMurtrey, R. G., Konizeski, R. L., and Stermitz, Frank, 1959, Preliminary report on the geology and water resources of the Bitterroot Valley, Montana, with a section on Chemical quality of water by H. A. Swenson: Montana Bur. Mines and Geology Bull. 9, 45 p., 2 pls., 12 figs.

Meyers, J. S., 1962, Evaporation from the 17 Western States, with a section on Evaporation rates, by Tor J. Nordenson, U.S. Weather Bur.: U.S. Geol. Survey Prof. Paper 272–D, 100 p., 1 pl., 5 figs.

Moulder, E. A., and Kohout, F. A., 1958, Ground water factors affecting drainage in the First Division, Buffalo Rapids Irrigation Project, Prairie and Dawson Counties, Montana, with a section on Chemical quality of the water by E. R. Jochens: U.S. Geol. Survey Water-Supply Paper 1424, 198 p., 11 pls., 51 figs.

Moulder, E. A., Klug, M. F., Morris, D. A., and Swenson, F. A., 1960, Geology and ground-water resources of the lower Little Bighorn River Valley, Big Horn County, Montana, with a section on Chemical quality of the ground water by R. A. Krieger: U.S. Geol. Survey Water-Supply Paper 1487, 223 p., 13 pls., 37 figs.

Perry, E. S., 1931, Ground water of eastern and central Montana: Montana Bur. Mines and Geology Mem. 2.

——— 1933, Possibilities of ground water supply for certain towns and cities of Montana: Montana Bur. Mines and Geology Misc. Contr. No. 2, 49 p., 2 pls., 70 figs.

——— 1934, Physiography and ground-water supply in the Big Hole Basin, Montana: Montana Bur. Mines and Geology Mem. 12.

——— 1934, Geology and artesian water resources along Missouri and Milk Rivers in northeastern Montana: Montana Bur. Mines and Geology Mem. 11, 34 p., 1 pl., 15 figs.

——— 1935, Geology and ground-water resources of southeastern Montana: Montana Bur. Mines and Geology Mem. 14.

Renick, B. C., 1929, Geology and ground-water resources of central and southern Rosebud County, Montana: U.S. Geol. Survey Water-Supply Paper 600, 140 p., 12 pls.

Simons, W. D., 1953, Irrigation and streamflow depletion in Columbia River basin above The Dalles, Oregon: U.S. Geol. Survey Water-Supply Paper 1220, 126 p., 1 pl., 1 fig.

Swenson, F. A., 1955, Geology and ground-water resources of the Missouri River valley in northeastern Montana, with a section on the quality of the ground water by W. H. Durum: U.S. Geol. Survey Water-Supply Paper 1263, 128 p., 1 pl., 18 figs.

——— 1957, Geology and ground-water resources of the Lower Marias irrigation project, Montana, with a section on Chemical quality of the ground water by H. A. Swenson: U.S. Geol. Survey Water-Supply Paper 1460-b, pp. 41–98, pls. 2–4, figs. 1–6.

Swenson, H. A., 1953, Geochemical relationship of water in the Powder River Basin, Wyoming and Montana: Transactions, American Geophysical Union, Vol. 34, June, 1953, pp. 443–448.

Thomas, N. O., Harbeck, G. E., 1956, Reservoirs in the United States: U.S. Geol. Survey Water-Supply Paper 1360–A, 99 p., 1 pl., 3 figs.

Torrey, A. E., and Swenson, F. A., 1951, Ground-water resources of the lower Yellowstone River valley between Miles City and Glendive, Montana, with a section on The chemical quality of the water by H. A. Swenson: U.S. Geol. Survey Circ. 93, 72 p., 1 pl., 12 figs.

Torrey, A. E., and Kohout, F. A., 1956, Geology and ground-water resources of the lower Yellowstone River valley between Glendive and Sidney, Montana, with a section on Chemical quality of the water by H. A. Swenson: U.S. Geol. Survey Water-Supply Paper 1355, 92 p., 2 pls., 14 figs.

U.S. Geological Survey, 1914, Profile surveys in the basin of Clark Fork of Columbia River, Mont.-Idaho-Wash.: U.S. Geol. Survey Water-Supply Paper 346, 6 p., 3 pls.

——— 1914, Profile surveys of Missouri River from Great Falls to Three Forks, Mont.: U.S. Geol. Water-Supply Paper 367, 8 p., 1 pl.

——— 1949, Floods of May–June 1948 in Columbia River basin, with a section on Magnitude and frequency of floods by Rantz, S. E., and Riggs, H. C.: Water-Supply Paper 1080, 476 p., 12 pls.

——— 1955, Floods of April 1952 in the Missouri River basin: Water-Supply Paper 1260–B, pp. 49–302, pls. 2–4, figs. 11–35.

——— 1957, Floods of May–June 1953 in Missouri River basin in Montana: Water-Supply Paper 1320–B, pp. 69–153, pls. 3, 4, figs. 13–23.

Zimmerman, Everett A., 1956, Preliminary report on the geology and ground-water resources of parts of Musselshell and Golden Valley Counties, Montana: Montana Bur. Mines and Geology Inf. Circ. 15, 13 p., 1 pl., 2 figs.

——— 1960, Preliminary report on the geology and ground-water resources of northern Blaine County, Montana: Montana Bur. Mines and Geology Bull. 19, 19 p., 1 pl., 5 figs.

——— 1962, Preliminary report on the geology and ground water resources of southern Judith Basin, Montana: Montana Bur. Mines and Geology Bull. 32, 23 p., 1 pl., 4 figs.

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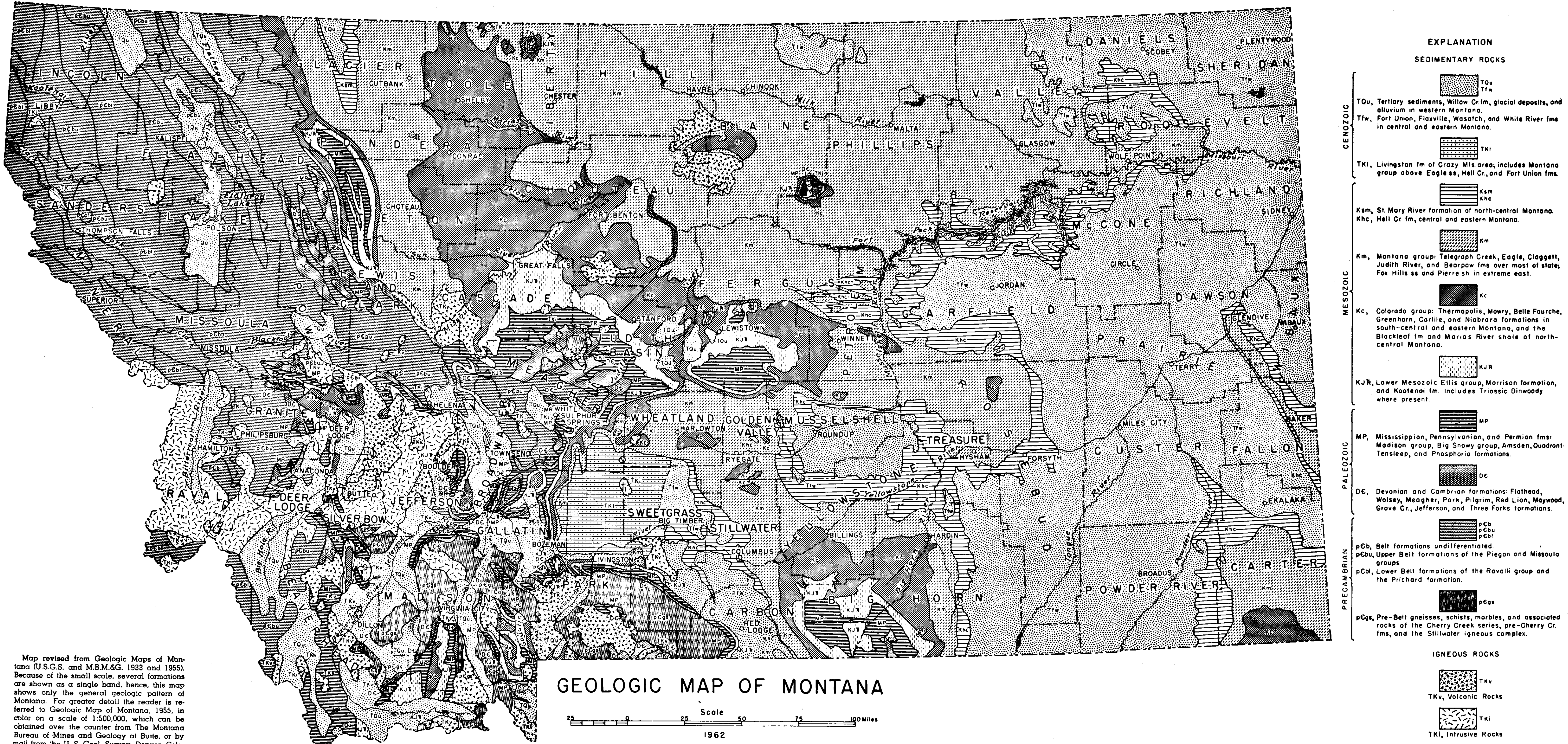
MONTANA BUREAU OF MINES AND GEOLOGY



EXPLANATION

SEDIMENTARY ROCKS

CENOZOIC

TQu, Tertiary sediments, Willow Cr. fm, glacial deposits, and alluvium in western Montana.

Tfw, Fort Union, Flaxville, Wasatch, and White River fms in central and eastern Montana.

TKl, Livingston fm of Crazy Mts. area; includes Montana group above Eagle ss, Hell Cr., and Fort Union fms.

MESOZOIC

Ksm, St. Mary River formation of north-central Montana.

Khc, Hell Cr. fm, central and eastern Montana.

Km, Montana group: Telegraph Creek, Eagle, Claggett, Judith River, and Bearpaw fms over most of state; Fox Hills ss and Pierre sh. in extreme east.

Kc, Colorado group: Thermopolis, Mowry, Belle Fourche, Greenhorn, Carlile, and Niobrara formations in south-central and eastern Montana, and the Blackleaf fm and Marias River shale of north-central Montana.

KJ₸, Lower Mesozoic Ellis group, Morrison formation, and Kootenai fm. Includes Triassic Dinwoody where present.

PALEOZOIC

MP, Mississippian, Pennsylvanian, and Permian fms: Madison group, Big Snowy group, Amsden, Quadrant-Tensleep, and Phosphoria formations.

D€, Devonian and Cambrian formations: Flathead, Wolsey, Meagher, Park, Pilgrim, Red Lion, Maywood, Grove Cr., Jefferson, and Three Forks formations.

PRECAMBRIAN

p€b, Belt formations undifferentiated.

p€bu, Upper Belt formations of the Piegan and Missoula groups.

p€bl, Lower Belt formations of the Ravalli group and the Prichard formation.

p€gs, Pre-Belt gneisses, schists, marbles, and associated rocks of the Cherry Creek series, pre-Cherry Cr. fms, and the Stillwater igneous complex.

IGNEOUS ROCKS

TKv, Volcanic Rocks

TKi, Intrusive Rocks

Map revised from Geologic Maps of Montana (U.S.G.S. and M.B.M.&G. 1933 and 1955). Because of the small scale, several formations are shown as a single band, hence, this map shows only the general geologic pattern of Montana. For greater detail the reader is referred to Geologic Map of Montana, 1955, in color on a scale of 1:500,000, which can be obtained over the counter from The Montana Bureau of Mines and Geology at Butte, or by mail from the U. S. Geol. Survey, Denver, Colo. (Price $3.50.)

FIGURE 3.—Geologic map of Montana.

94765 O - 63 (Face p. 166) No. 1

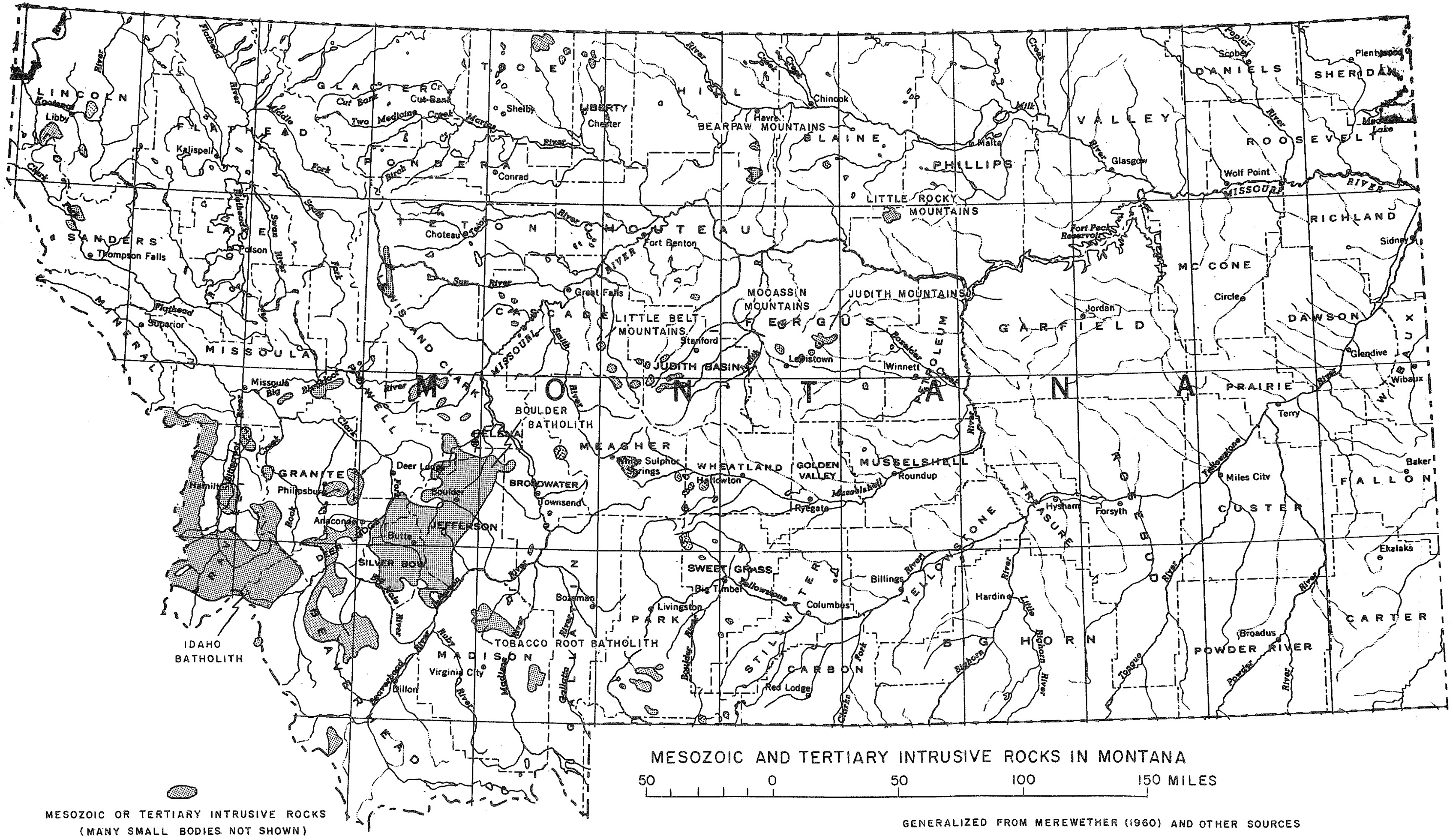
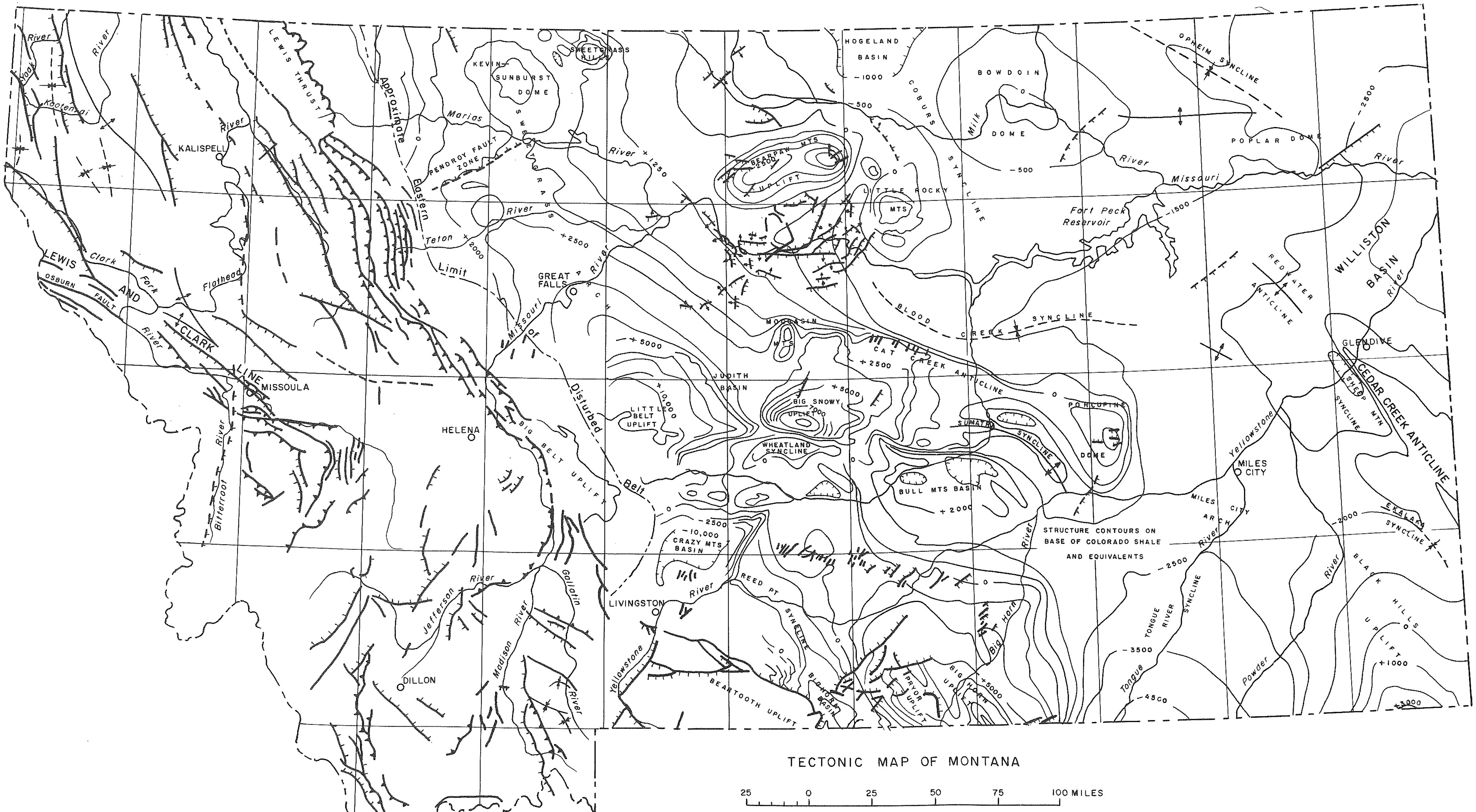


FIGURE 4.—Mesozoic and Tertiary intrusive rocks in Montana.

94765 O - 63 (Face p. 166) No. 2



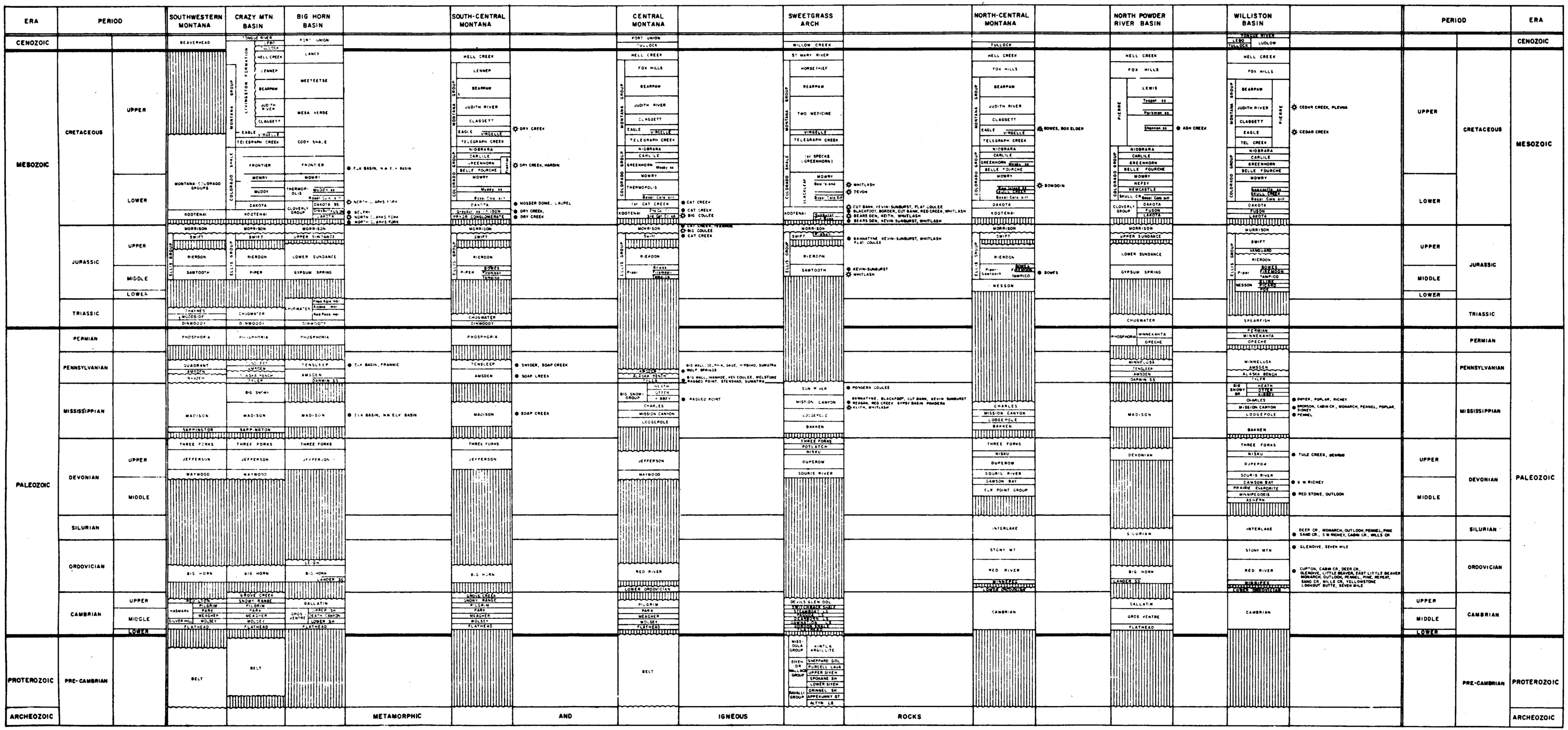
ADAPTED FROM THE TECTONIC MAP OF THE UNITED STATES BY THE U.S. GEOLOGICAL SURVEY AND THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS 1961

FIGURE 5.—Tectonic map of Montana.

94765 O - 63 (Face p. 166) No. 3

GENERALIZED STRATIGRAPHIC CORRELATION CHART

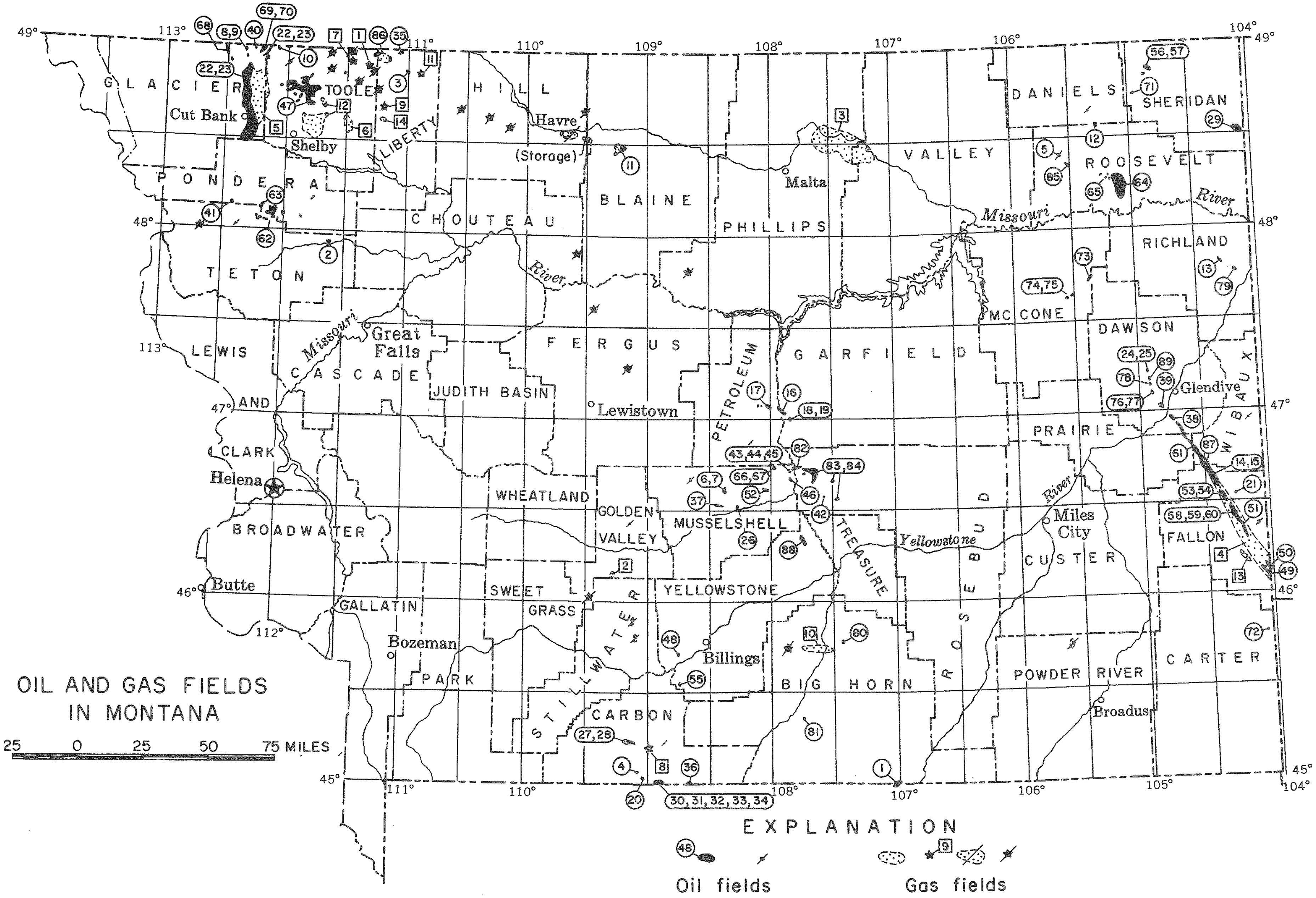
SHOWING PRODUCING HORIZONS — MONTANA OIL AND GAS FIELDS, 1961



Courtesy of Montana Oil and Gas Conservation Commission, An. Rev., Vol. 6, 1961.

FIGURE 6.—Generalized stratigraphic correlation chart.

94765 O - 63 (Face p. 166) No. 4



Some oil fields produce commercial amounts of natural gas. Diagonal line indicates shut-in or abandoned field. Circled numbers 1 through 89 refer to chart, "State of Montana – Summary of Producing Oil Fields." Numbers in squares refer to supplemental list of producing gas fields in text.

FIGURE 7.—Oil and gas fields in Montana.

94765 O - 63 (Face p. 166) No. 5

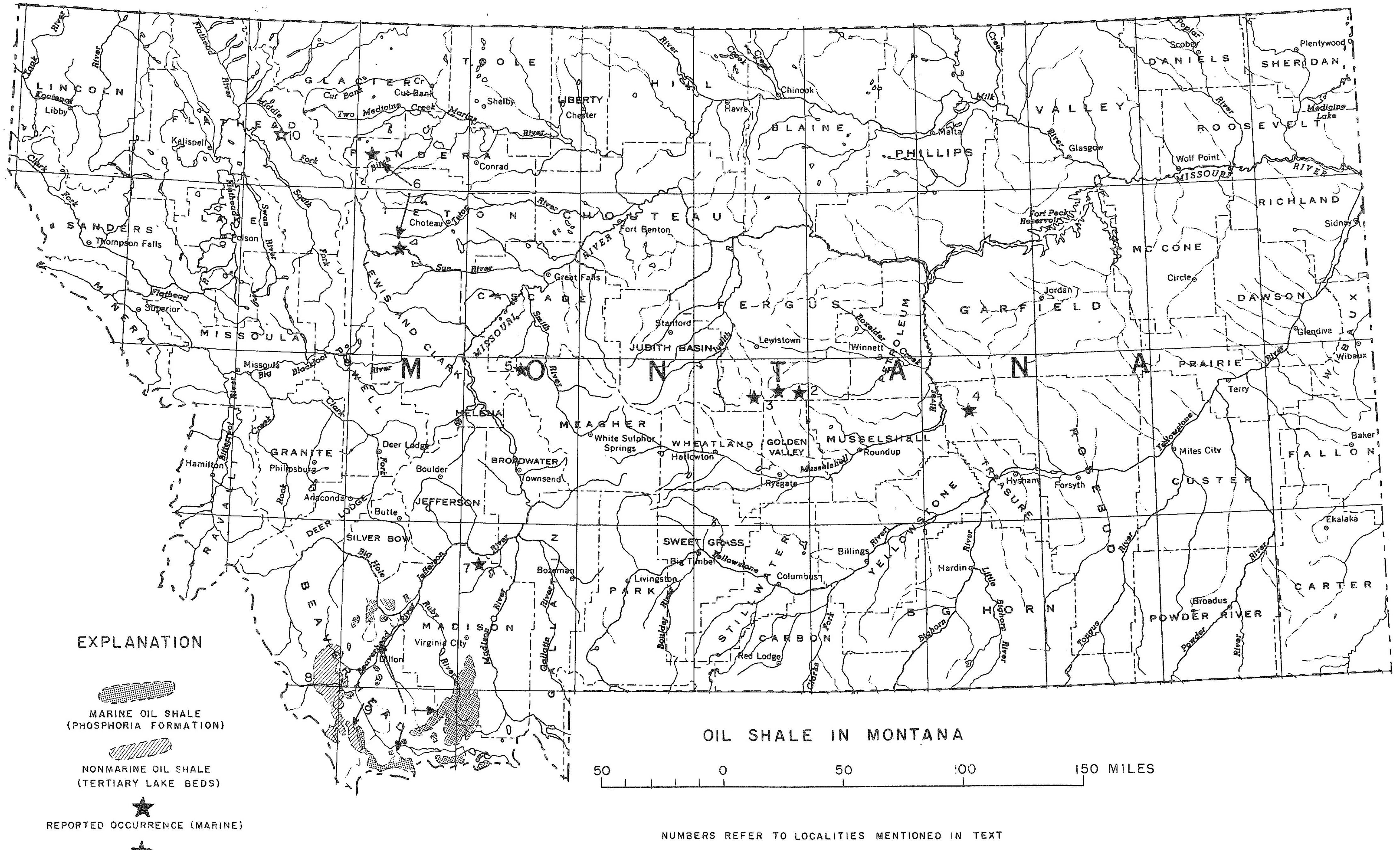


FIGURE 9.—Oil shale in Montana.

94765 O - 63 (Face p. 166) No. 6

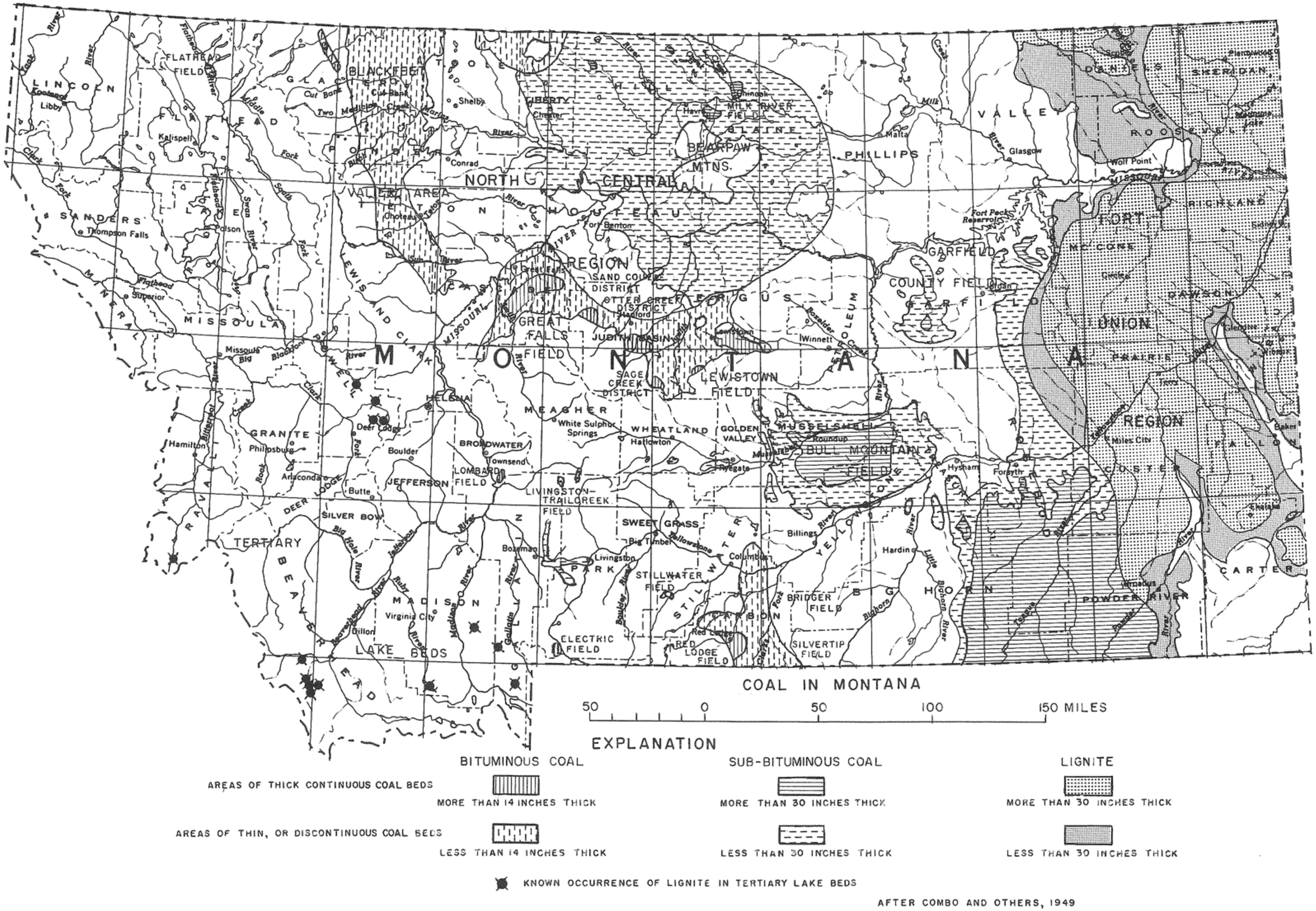


FIGURE 10.—Coal in Montana.

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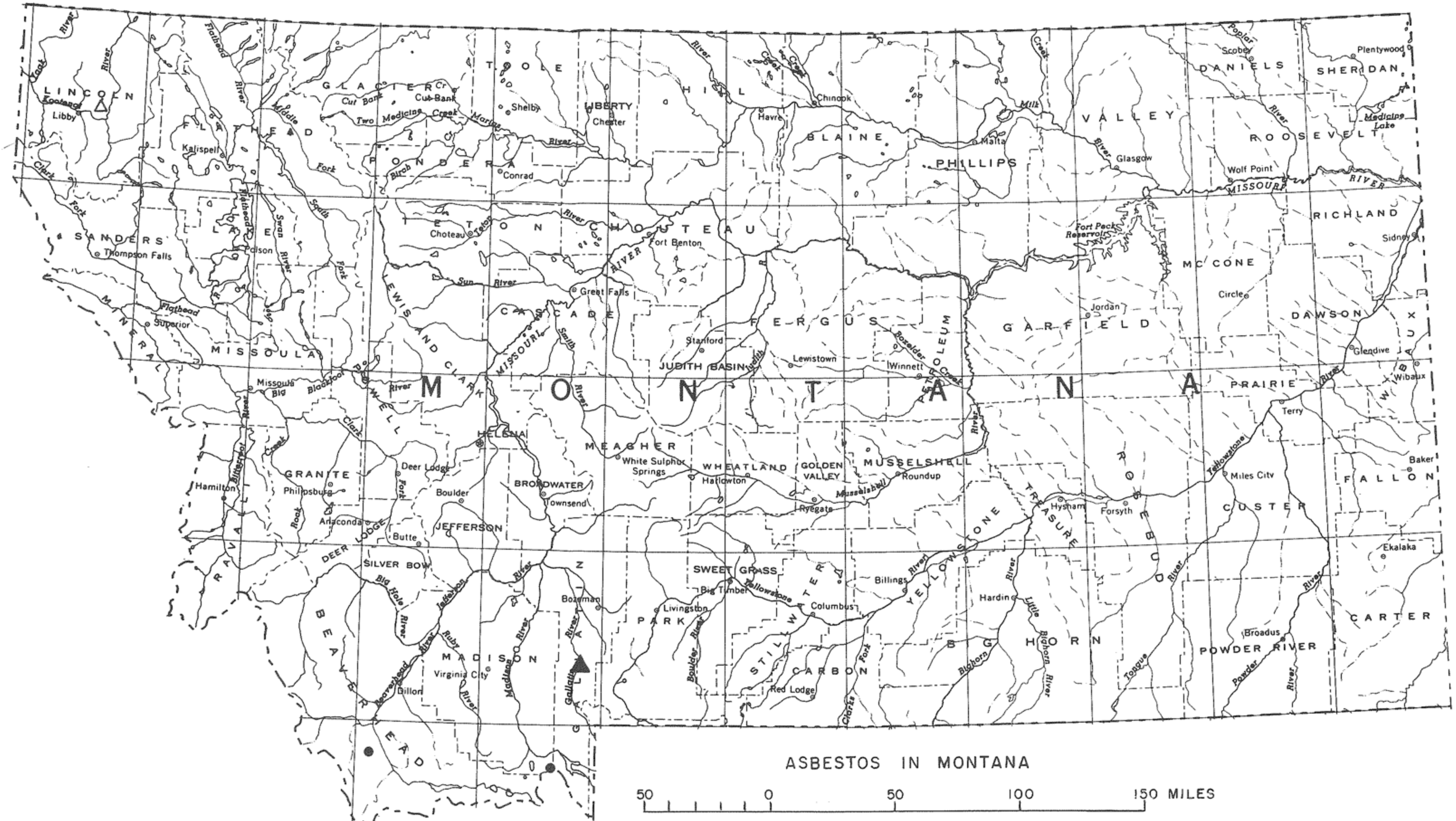

ADAPTED FROM CHIDESTER AND SHRIDE, 1962

EXPLANATION

MINERALOGIC TYPE	MINE OR GROUP OF MINES	PROSPECT OR GROUP OF PROSPECTS	OCCURENCE
CHRYSOTILE		●	
AMPHIBOLE	▲		△

FIGURE 12.—Asbestos in Montana.

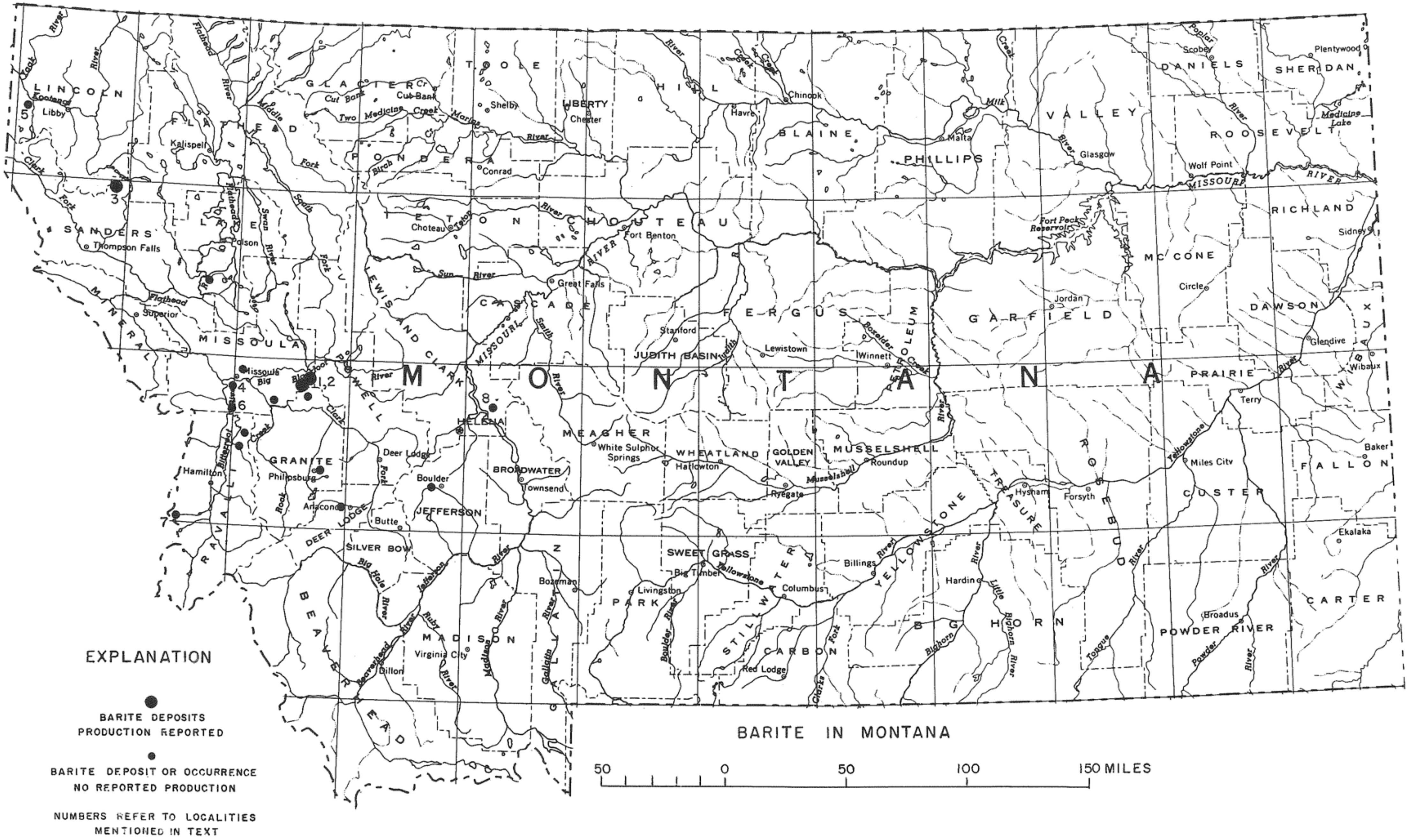

FIGURE 13.—Barite in Montana.

94765 O - 63 (Face p. 166) No. 9

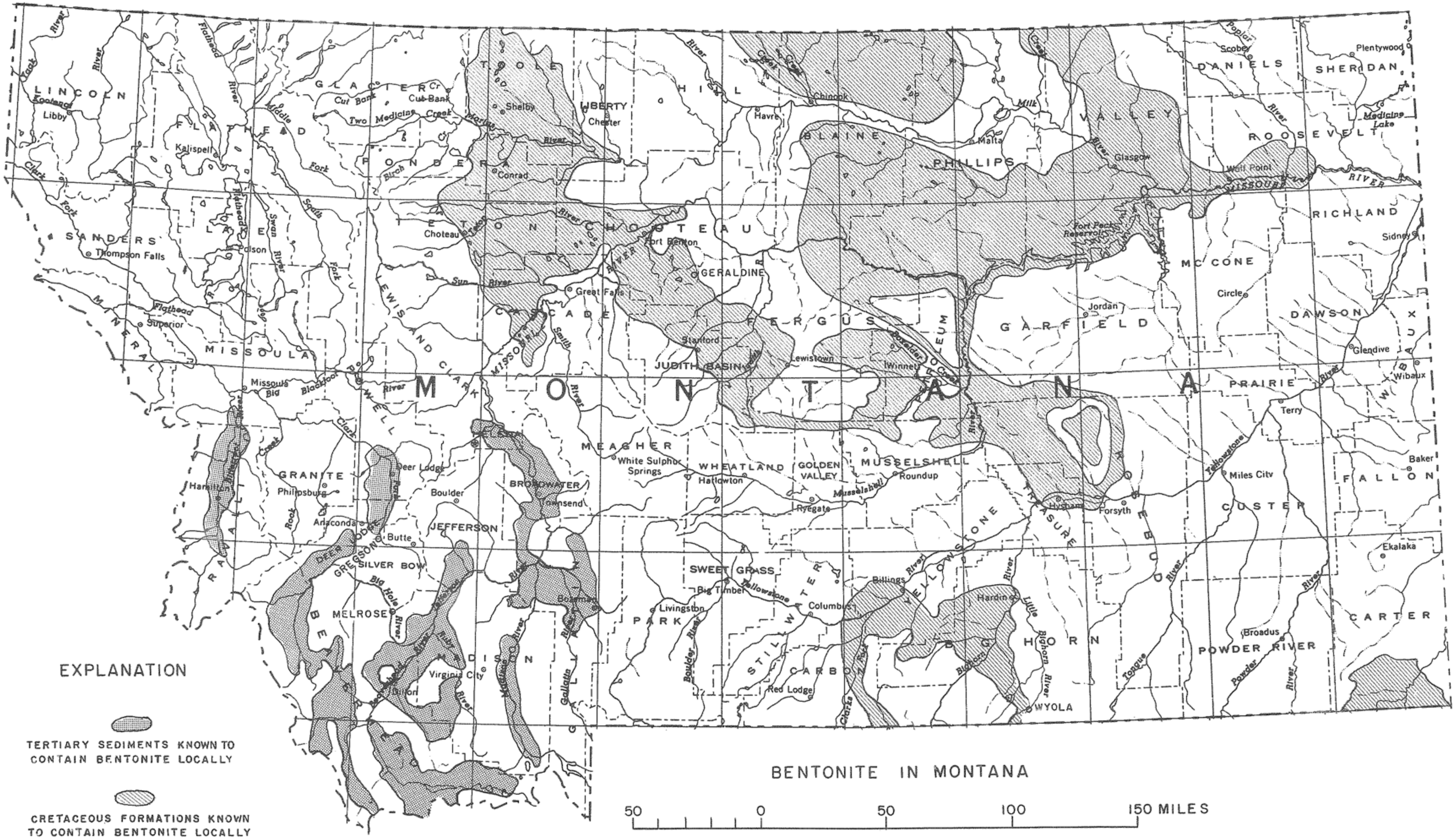

FIGURE 14.—Bentonite in Montana.

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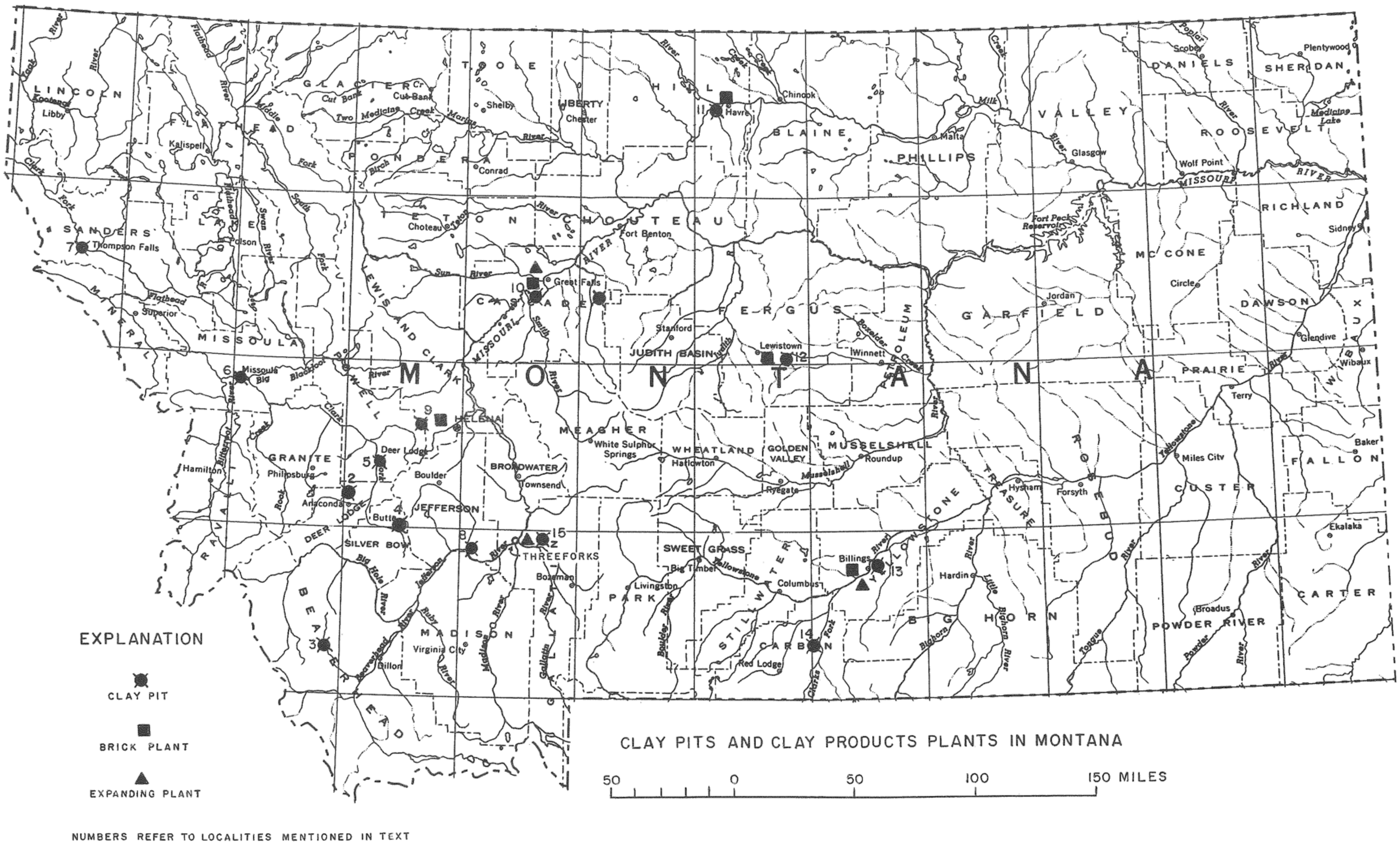
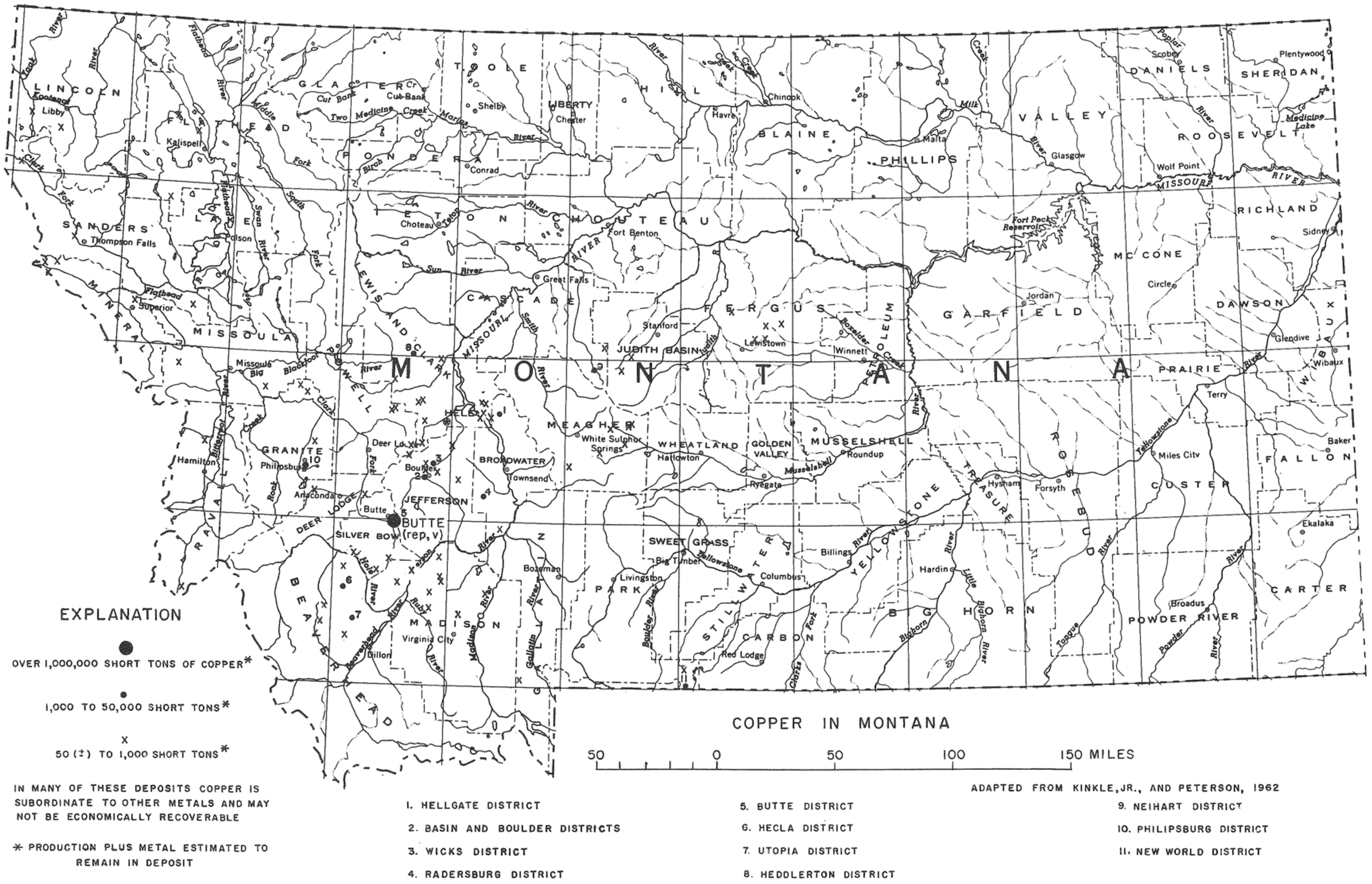


FIGURE 15.—Clay pits and clay products plants in Montana.

94765 O - 63 (Face p. 166) No. 11



EXPLANATION

● OVER 1,000,000 SHORT TONS OF COPPER*

• 1,000 TO 50,000 SHORT TONS*

x 50 (±) TO 1,000 SHORT TONS*

IN MANY OF THESE DEPOSITS COPPER IS SUBORDINATE TO OTHER METALS AND MAY NOT BE ECONOMICALLY RECOVERABLE

* PRODUCTION PLUS METAL ESTIMATED TO REMAIN IN DEPOSIT

COPPER IN MONTANA

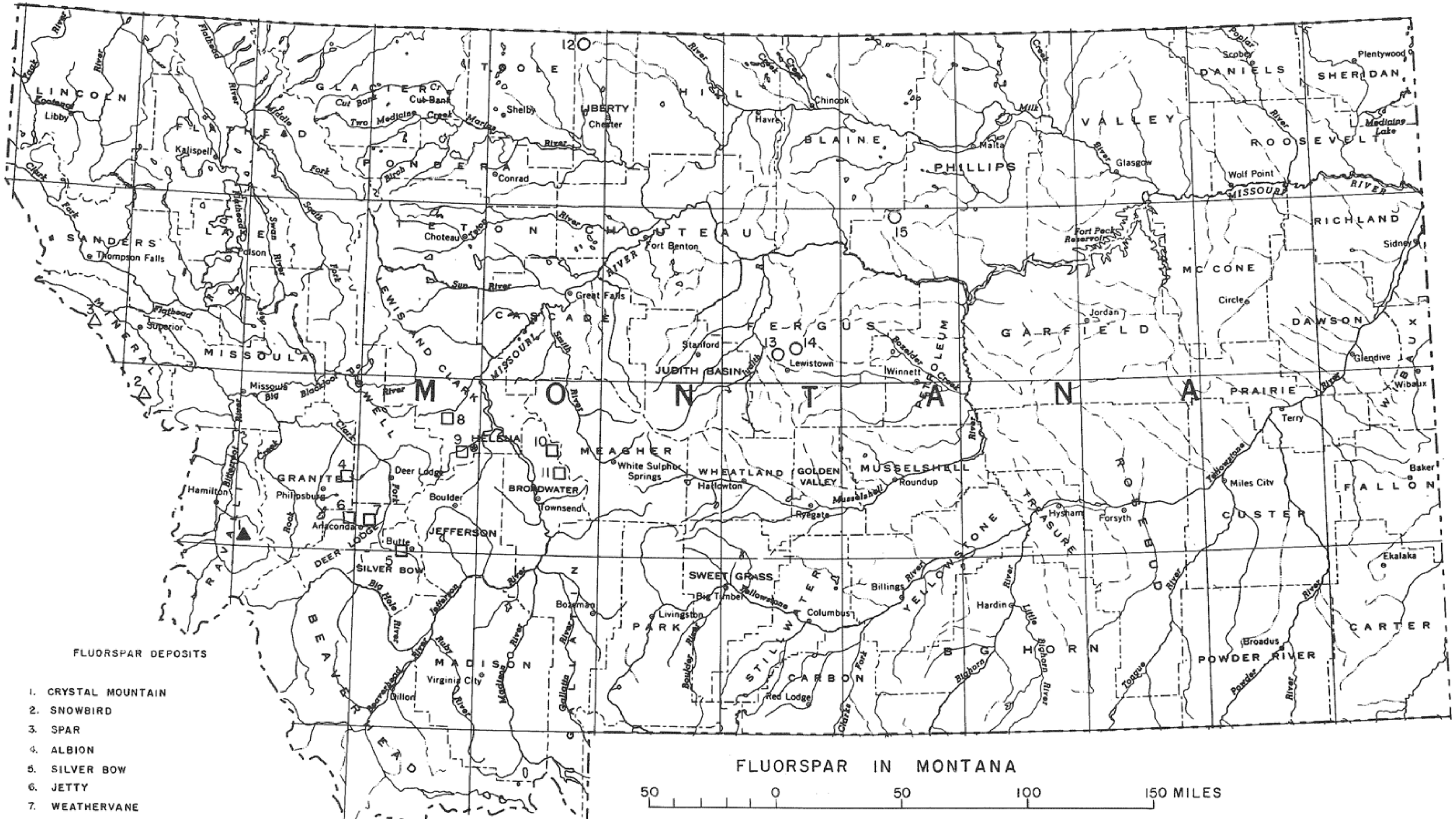
50 0 50 100 150 MILES

ADAPTED FROM KINKLE, JR., AND PETERSON, 1962

1. HELLGATE DISTRICT
2. BASIN AND BOULDER DISTRICTS
3. WICKS DISTRICT
4. RADERSBURG DISTRICT
5. BUTTE DISTRICT
6. HECLA DISTRICT
7. UTOPIA DISTRICT
8. HEDDLERTON DISTRICT
9. NEIHART DISTRICT
10. PHILIPSBURG DISTRICT
11. NEW WORLD DISTRICT

FIGURE 16.—Copper in Montana.

94765 O - 63 (Face p. 166) No. 12



FLUORSPAR DEPOSITS

1. CRYSTAL MOUNTAIN
2. SNOWBIRD
3. SPAR
4. ALBION
5. SILVER BOW
6. JETTY
7. WEATHERVANE
8. BALD BUTTE
9. BOEING
10. BOULDER MOUNTAIN
11. NORMANDY
12. TOOTSIE CREEK
13. SOUTH MOCASSIN
14. JUDITH MOUNTAINS
15. LITTLE ROCKY MOUNTAINS

EXPLANATION

TYPE OF DEPOSIT	SIGNIFICANT RESERVES	POTENTIAL UNEVALUATED
DEPOSITS RELATED TO IDAHO BATHOLITH	▲	△
DEPOSITS RELATED TO BOULDER BATHOLITH		□
DEPOSITS OF POTASSIC PROVINCE		○

FIGURE 18.—Fluorspar in Montana.

94765 O - 63 (Face p. 166) No. 13

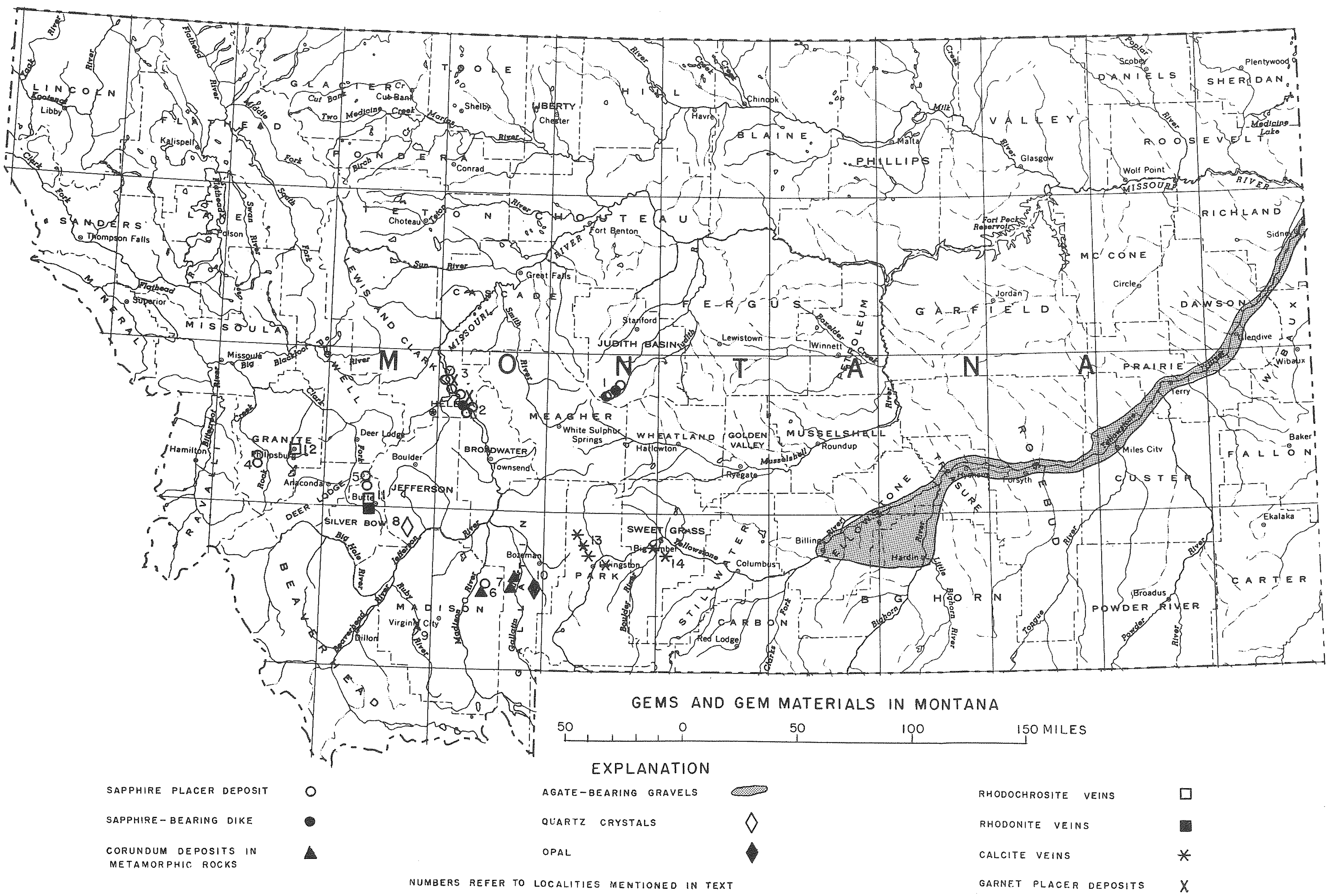
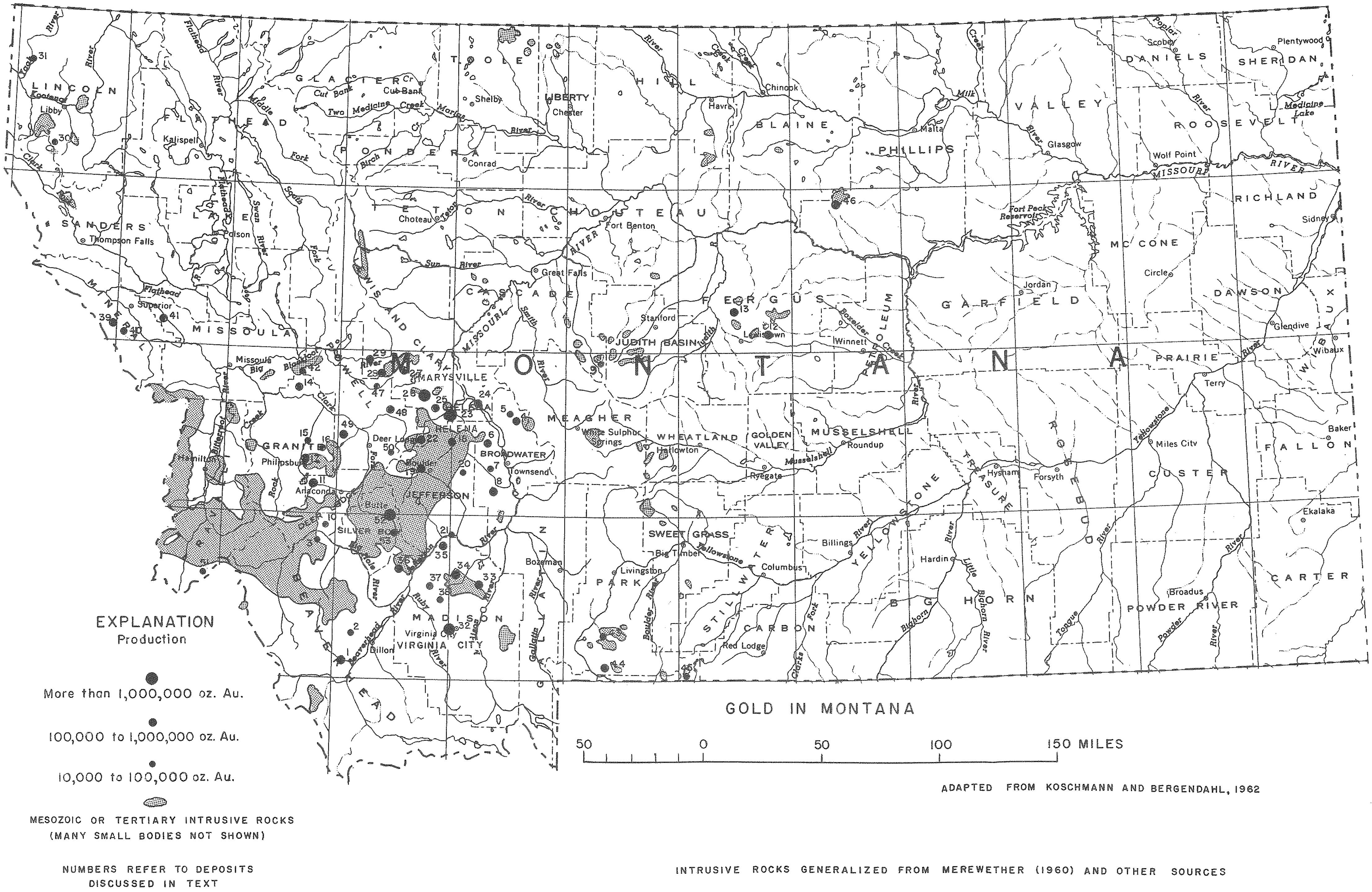


FIGURE 19.—Gems and gem materials in Montana.

94765 O - 63 (Face p. 166) No. 14

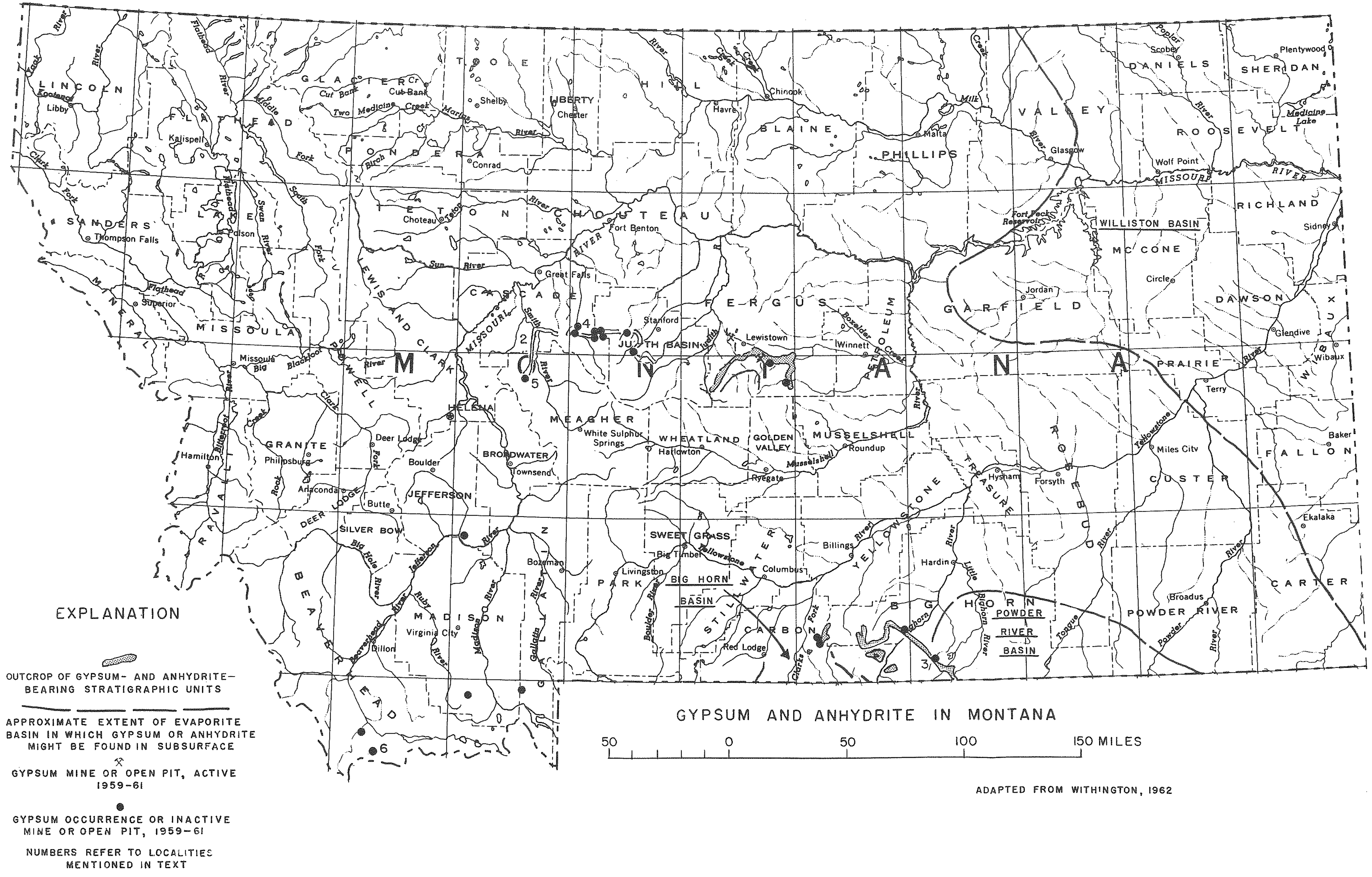


ADAPTED FROM KOSCHMANN AND BERGENDAHL, 1962

INTRUSIVE ROCKS GENERALIZED FROM MEREWETHER (1960) AND OTHER SOURCES

FIGURE 20.—Gold in Montana.

94765 O - 63 (Face p. 166) No. 15



EXPLANATION

OUTCROP OF GYPSUM- AND ANHYDRITE-BEARING STRATIGRAPHIC UNITS

APPROXIMATE EXTENT OF EVAPORITE BASIN IN WHICH GYPSUM OR ANHYDRITE MIGHT BE FOUND IN SUBSURFACE

GYPSUM MINE OR OPEN PIT, ACTIVE 1959-61

●

GYPSUM OCCURRENCE OR INACTIVE MINE OR OPEN PIT, 1959-61

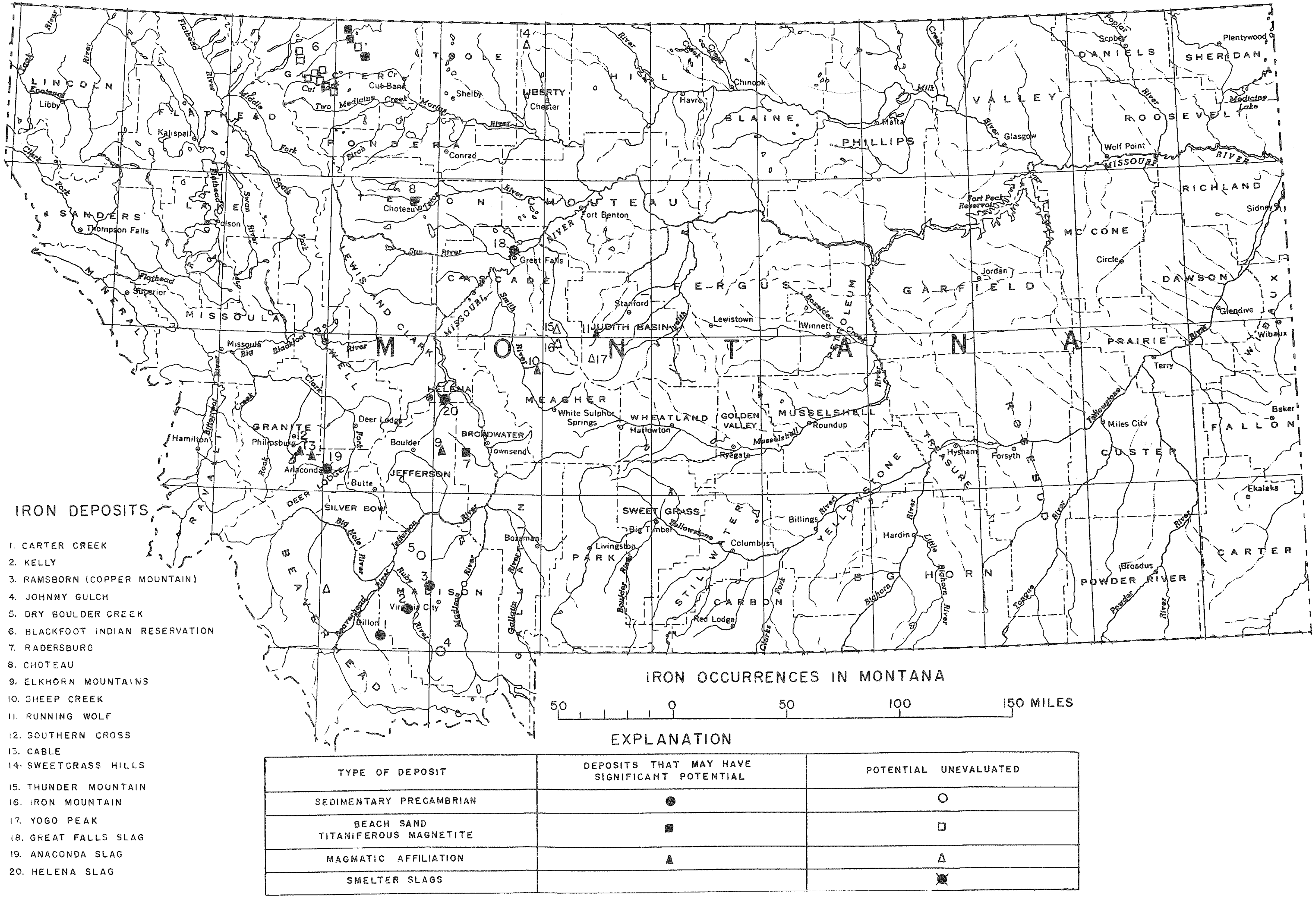
NUMBERS REFER TO LOCALITIES MENTIONED IN TEXT

GYPSUM AND ANHYDRITE IN MONTANA

50 0 50 100 150 MILES

ADAPTED FROM WITHINGTON, 1962

94765 O - 63 (Face p. 166) No. 16



IRON DEPOSITS

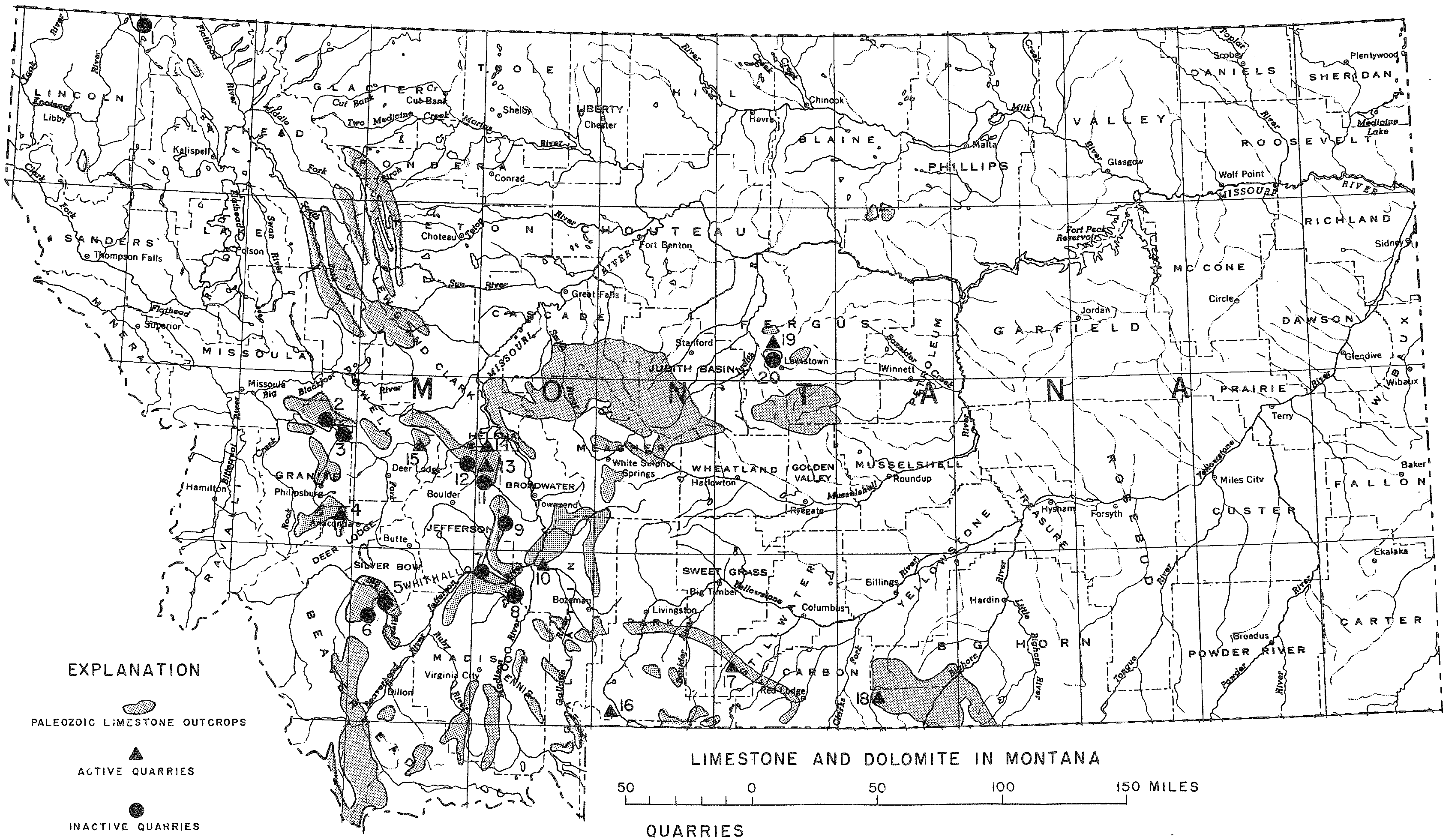
1. CARTER CREEK
2. KELLY
3. RAMSBORN (COPPER MOUNTAIN)
4. JOHNNY GULCH
5. DRY BOULDER CREEK
6. BLACKFOOT INDIAN RESERVATION
7. RADERSBURG
8. CHOTEAU
9. ELKHORN MOUNTAINS
10. SHEEP CREEK
11. RUNNING WOLF
12. SOUTHERN CROSS
13. CABLE
14. SWEETGRASS HILLS
15. THUNDER MOUNTAIN
16. IRON MOUNTAIN
17. YOGO PEAK
18. GREAT FALLS SLAG
19. ANACONDA SLAG
20. HELENA SLAG

EXPLANATION

TYPE OF DEPOSIT	DEPOSITS THAT MAY HAVE SIGNIFICANT POTENTIAL	POTENTIAL UNEVALUATED
SEDIMENTARY PRECAMBRIAN	●	○
BEACH SAND TITANIFEROUS MAGNETITE	■	□
MAGMATIC AFFILIATION	▲	△
SMELTER SLAGS		⊗

FIGURE 23.—Iron occurrences in Montana.

94765 O - 63 (Face p. 166) No. 17



QUARRIES

1. STAHL
2. HITCHCOCK
3. DRUMMOND
4. BROWNS
5. ANTONIOLI
6. MAIDEN ROCK
7. LIMESPUR
8. SAPPINGTON
9. VERMONT MARBLE
10. IDEAL CEMENT COMPANY
11. MONTANA CITY
12. HARRIS
13. PERMANENTE CEMENT COMPANY
14. MARONICK
15. ELLISTON LIME COMPANY
16. MONTANA TRAVERTINE COMPANY
17. AMERICAN CHROME COMPANY
18. WARREN
19. PARADISE TRAVERTINE
20. HANOVER

FIGURE 24.—Limestone and dolomite in Montana.

94765 O - 63 (Face p. 166) No. 18

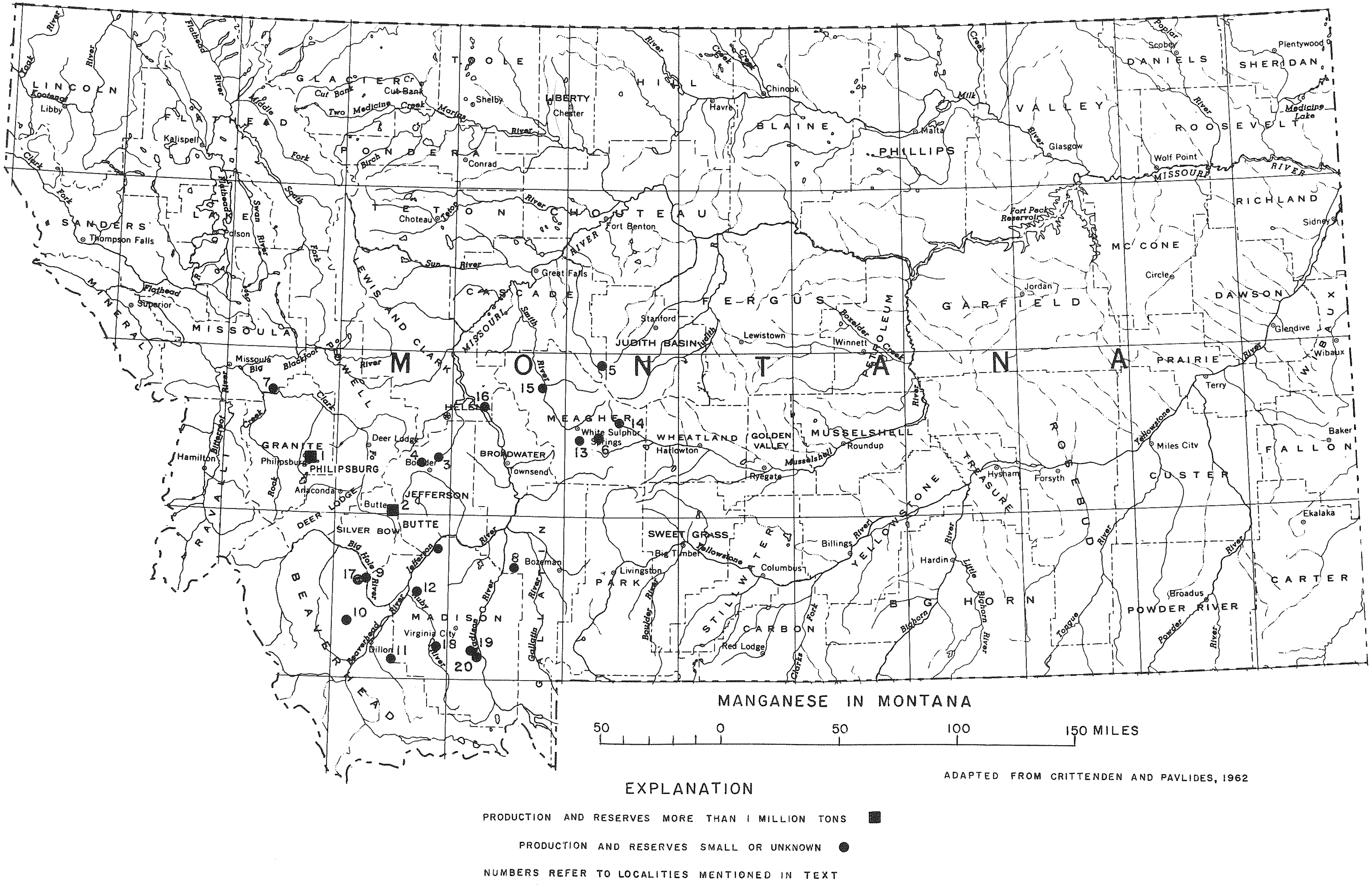


FIGURE 25.—Manganese in Montana

94765 O - 63 (Face p. 166) No. 19

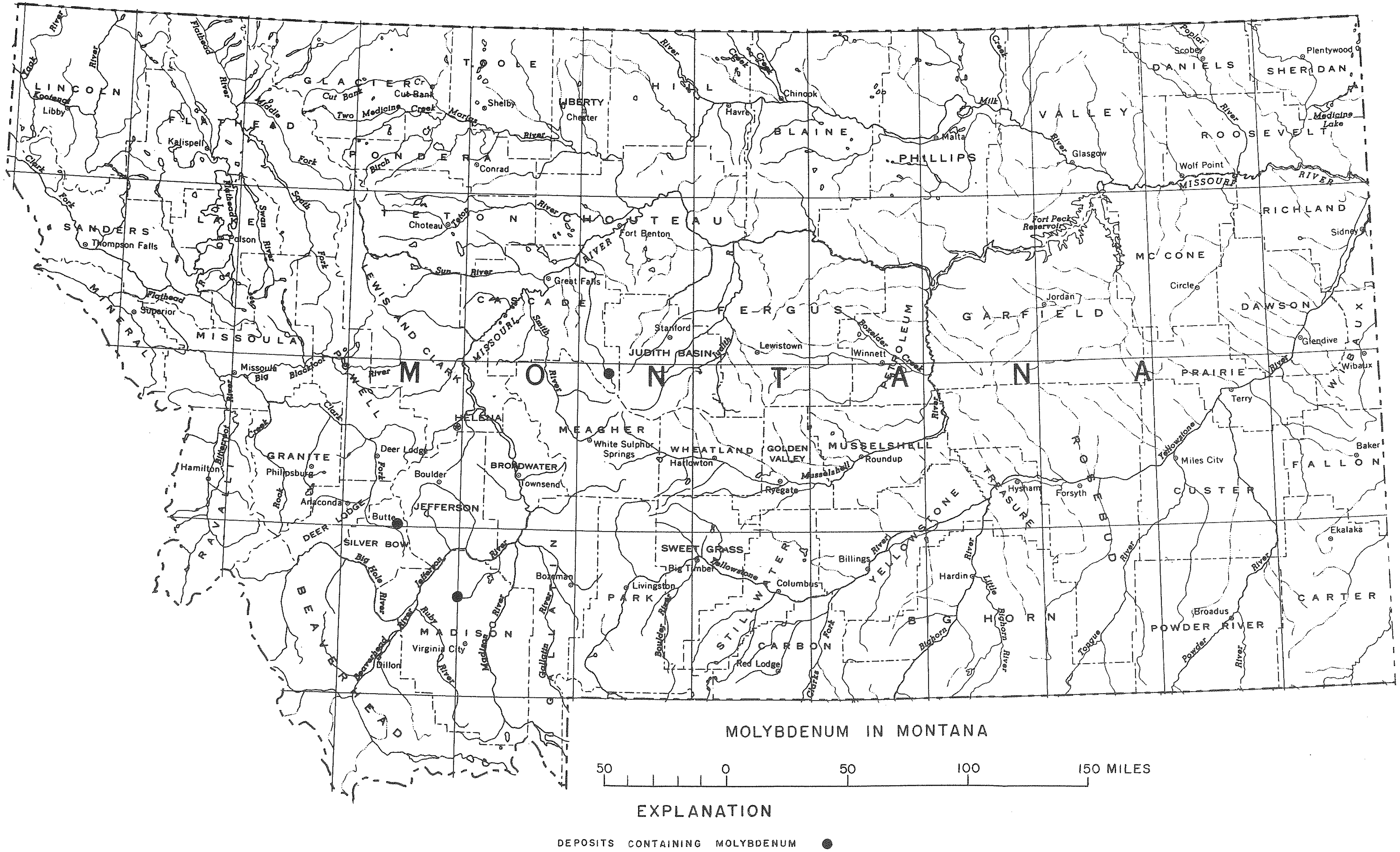


FIGURE 26.—Molybdenum in Montana.

94765 O - 63 (Face p. 166) No. 20

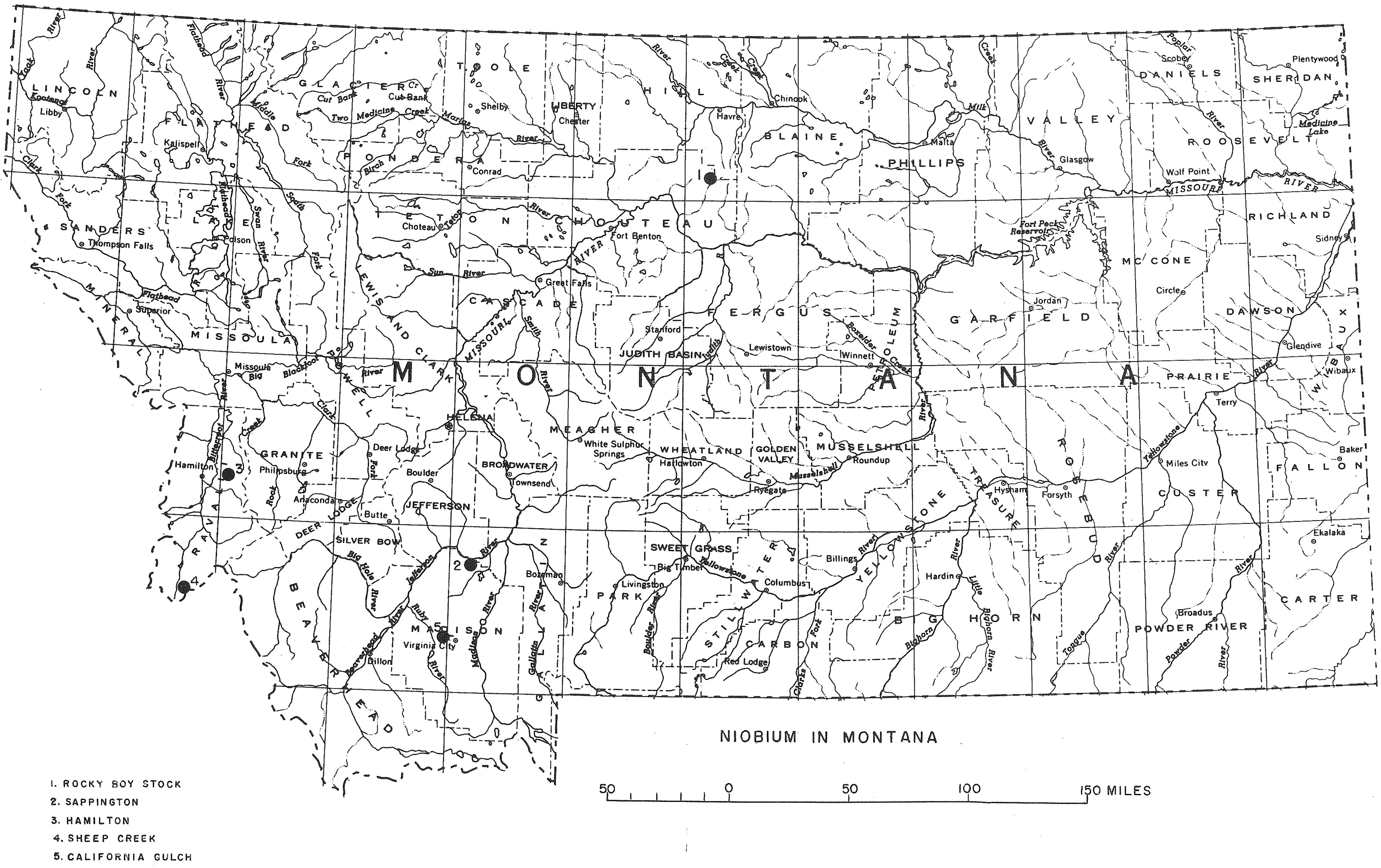
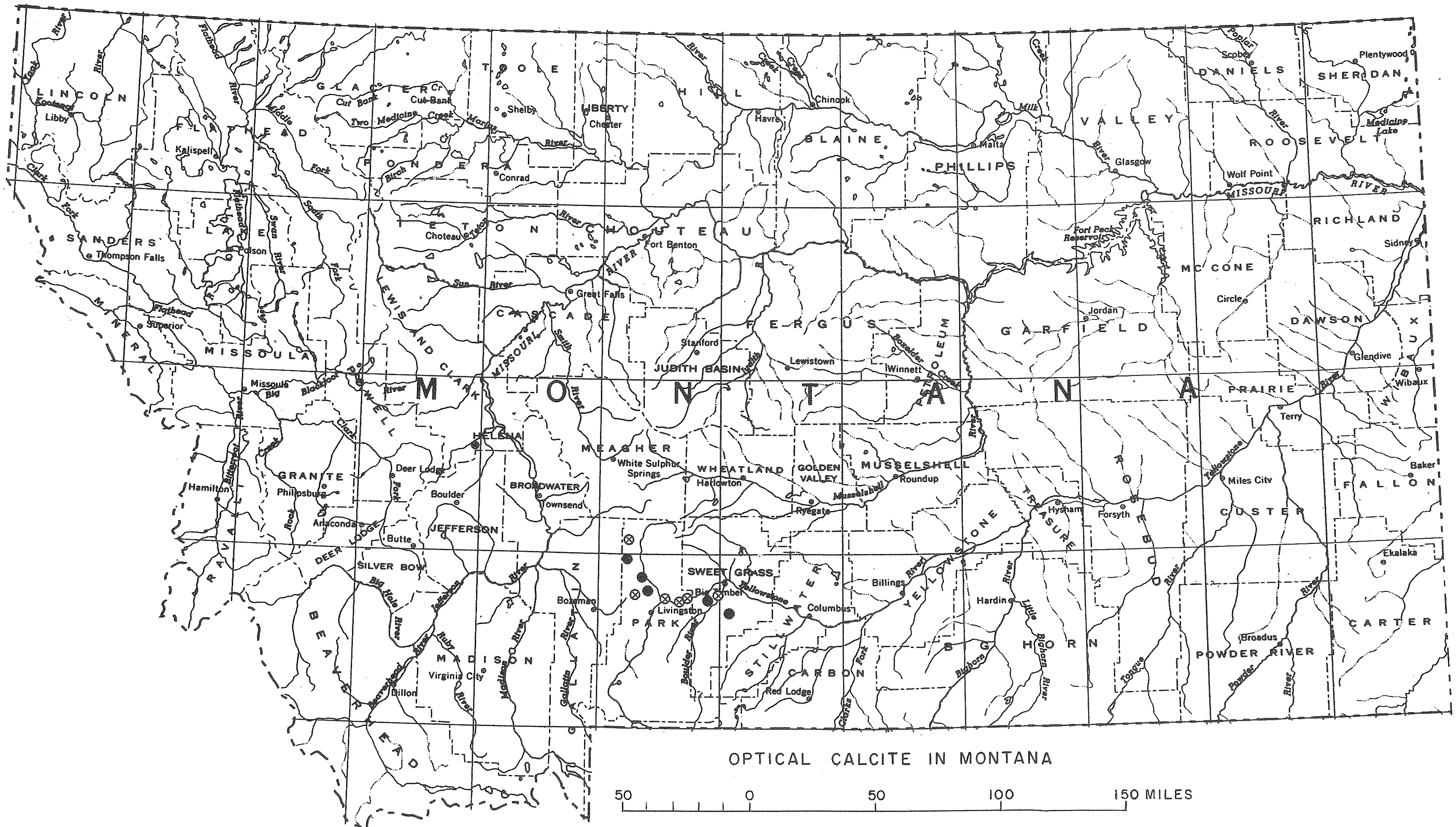


FIGURE 27.—Niobium in Montana.

94765 O - 63 (Face p. 166) No. 21



EXPLANATION

AREA FROM WHICH OPTICAL CALCITE PRODUCTION HAS BEEN REPORTED	●
OPTICAL CALCITE OCCURRENCES	⊗

FIGURE 28.—Optical calcite in Montana.

94765 O - 63 (Face p. 166) No. 22

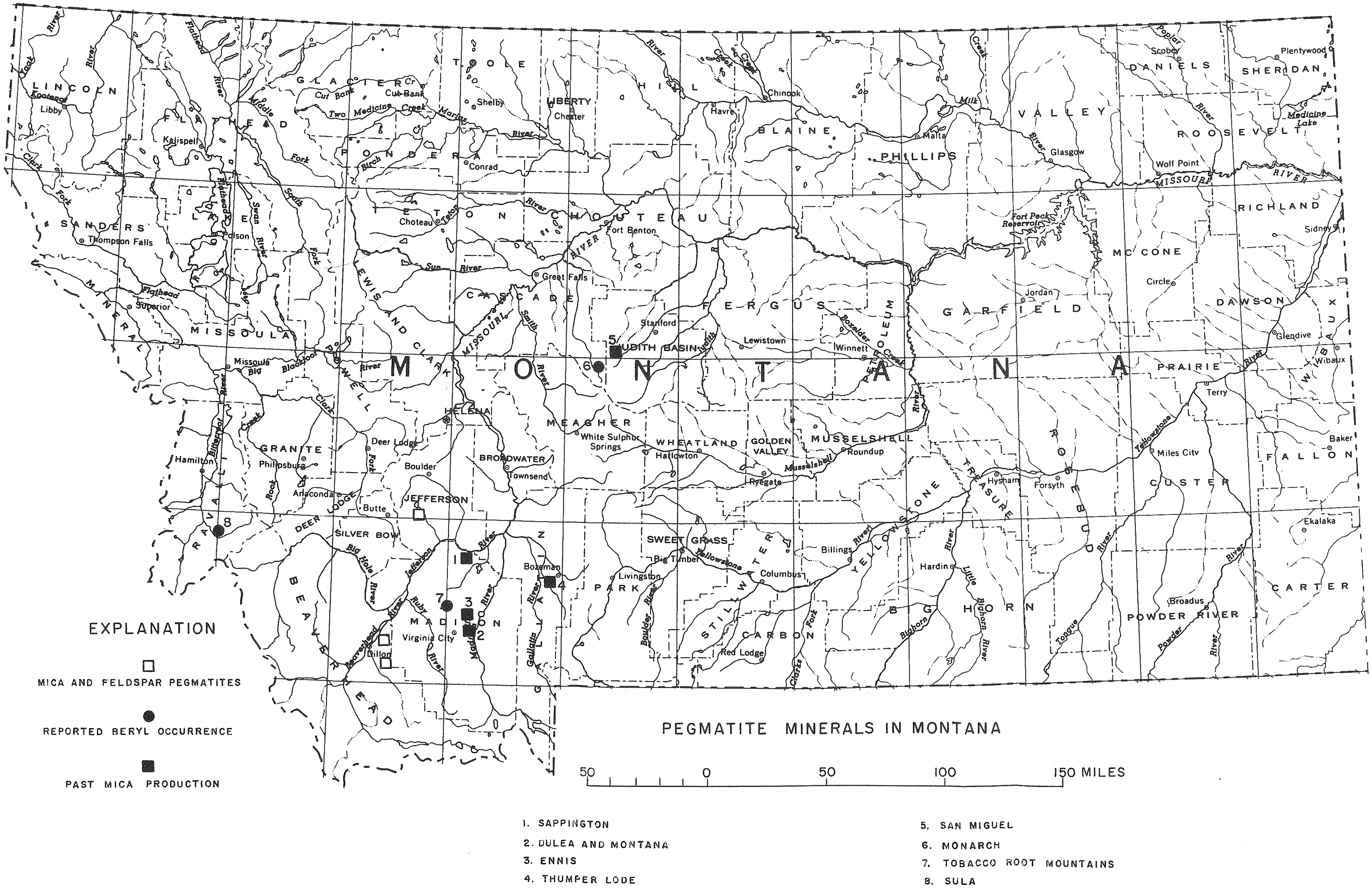


FIGURE 29.—Pegmatite minerals in Montana.

94765 O - 63 (Face p. 166) No. 23

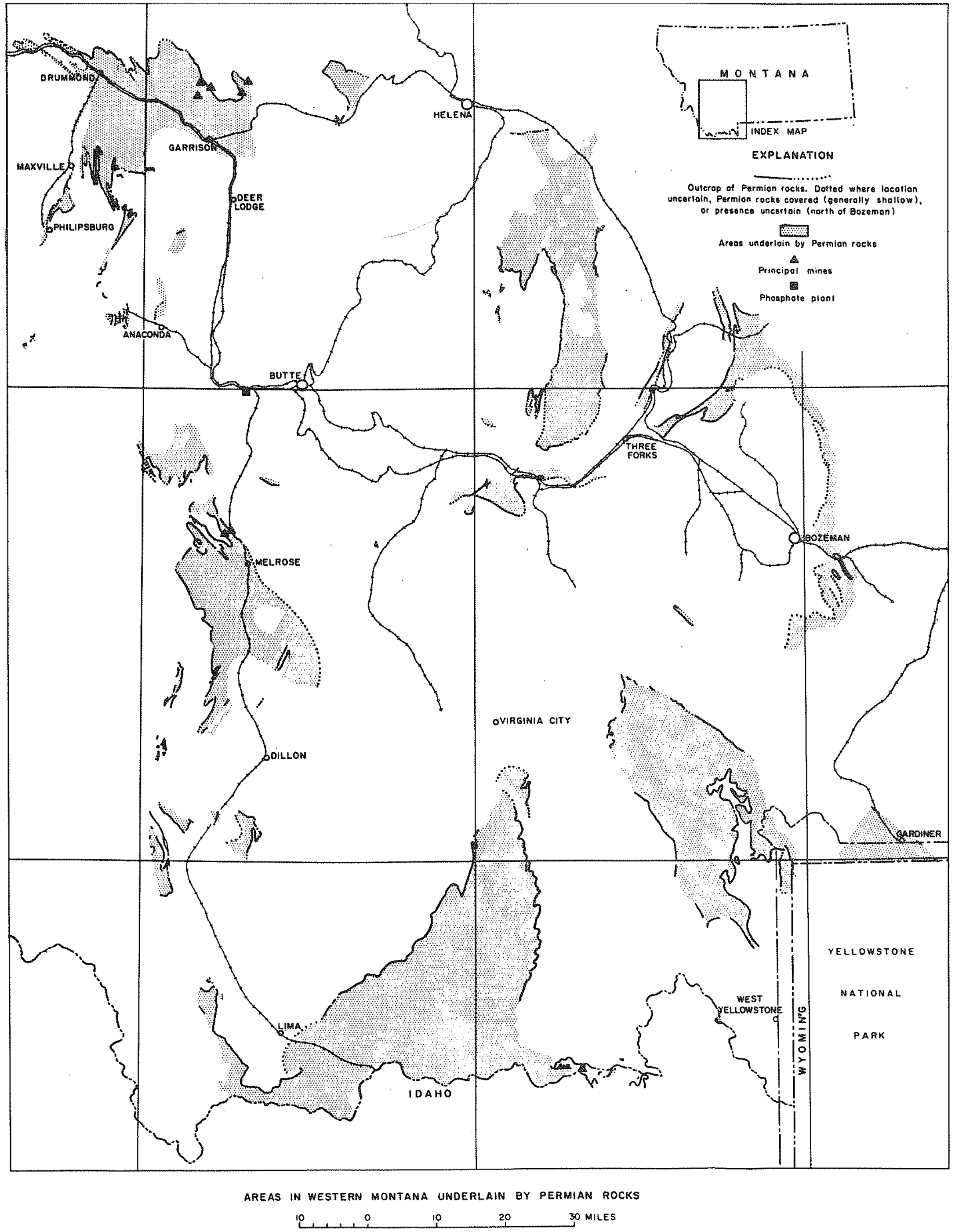


FIGURE 30.—Areas in western Montana underlain by Permian rocks.

94765 O - 63 (Face p. 166) No. 24

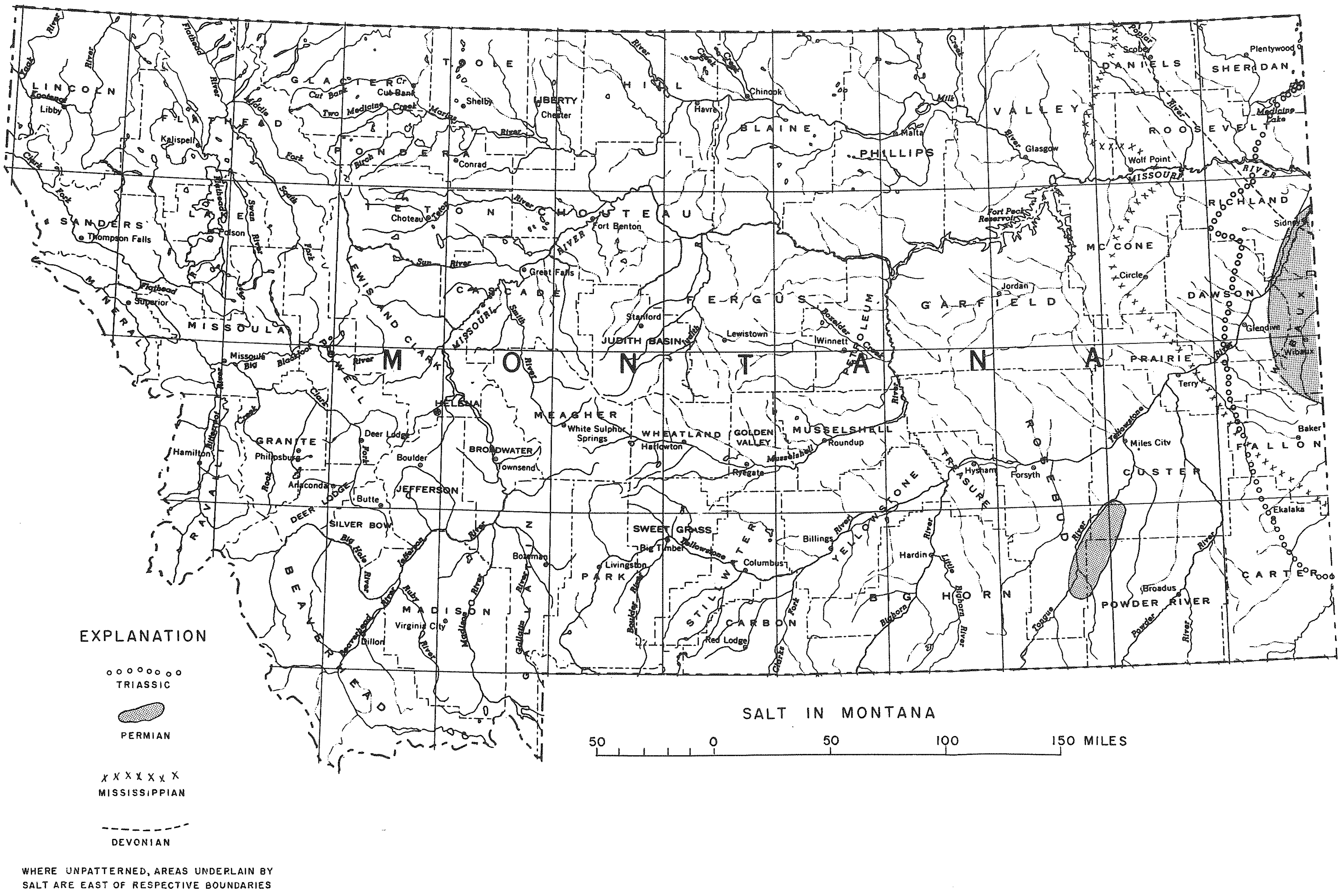


FIGURE 31.—Salt in Montana.

94765 O - 63 (Face p. 166) No. 25

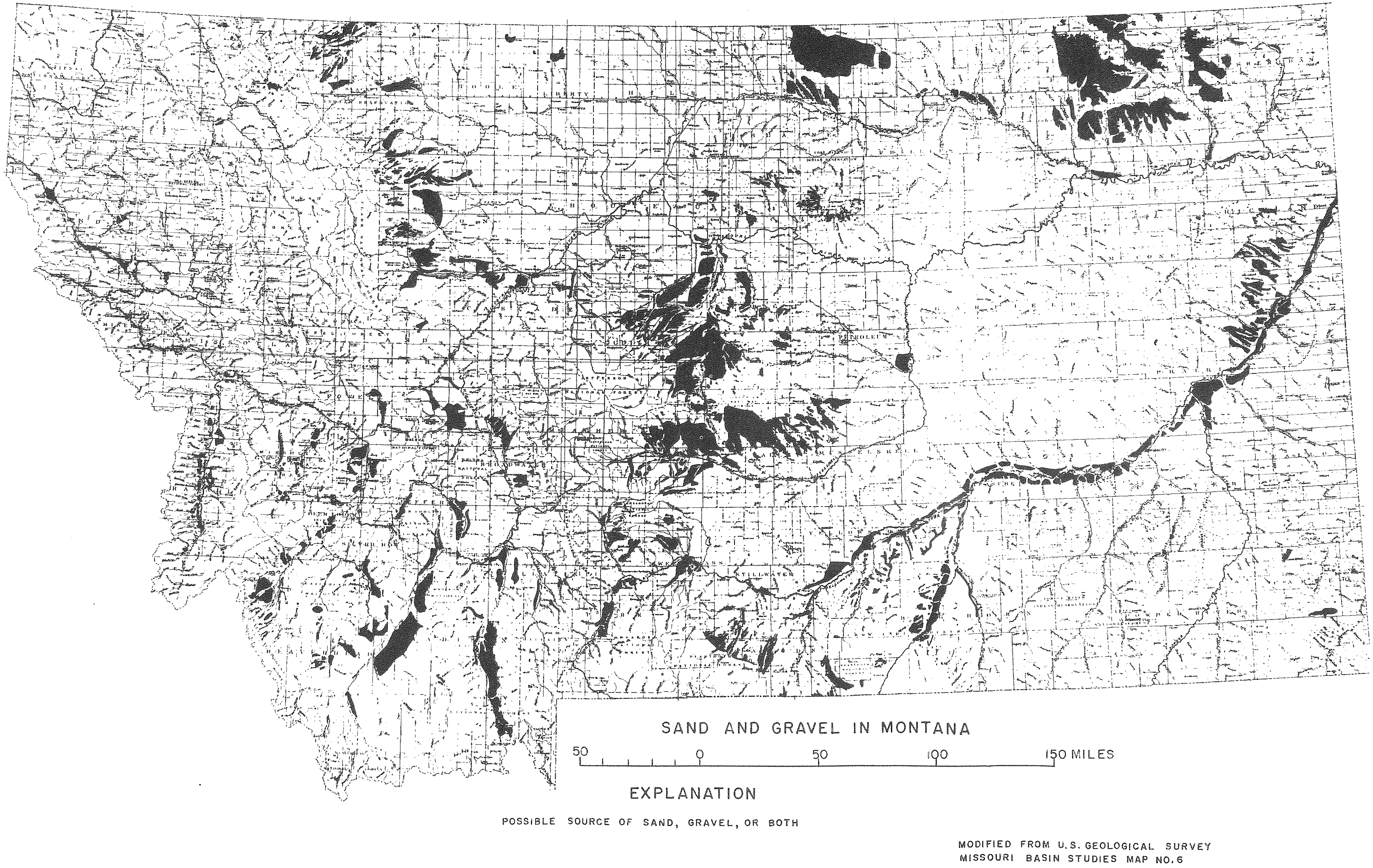
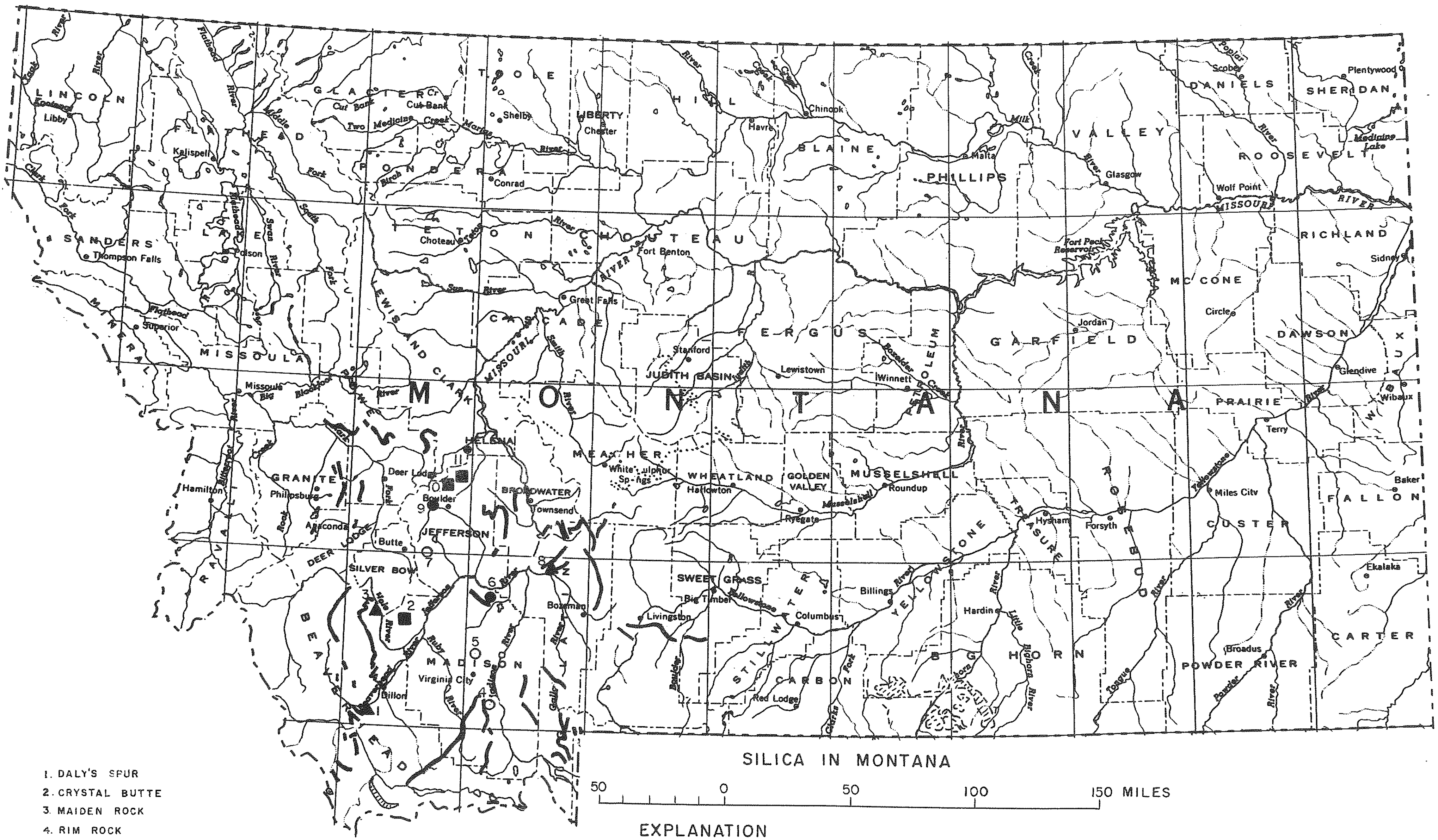


FIGURE 32.—Sand and gravel in Montana.

94765 O - 63 (Face p. 166) No. 26



1. DALY'S SPUR
2. CRYSTAL BUTTE
3. MAIDEN ROCK
4. RIM ROCK
5. MONTANA
6. SAPPINGTON
7. POHNDORF
8. TRIDENT
9. BASIN
10. BROWN
11. CORRAL CREEK

EXPLANATION

TYPE OF DEPOSIT	SIGNIFICANT POTENTIAL	POTENTIAL UNEVALUATED
SEDIMENTARY	▲	
QUARTZ-CORE PEGMATITE	●	○
QUARTZ VEINS	■	

QUADRANT FORMATION 〰
QUESTIONABLE QUADRANT FORMATION ·····
TENSLEEP SANDSTONE – – – –

FIGURE 33.—Silica in Montana.

94765 O - 63 (Face p. 166) No. 27

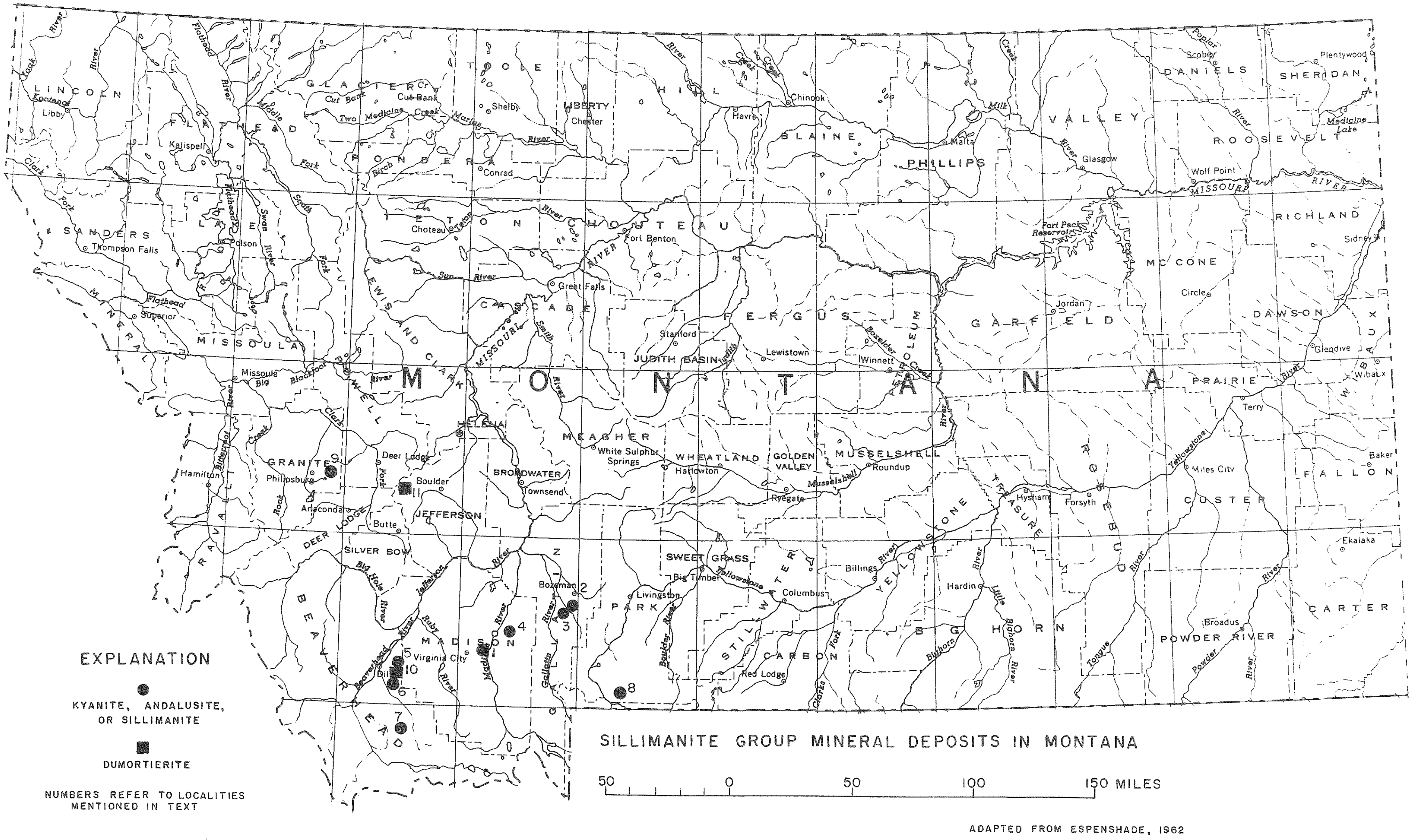
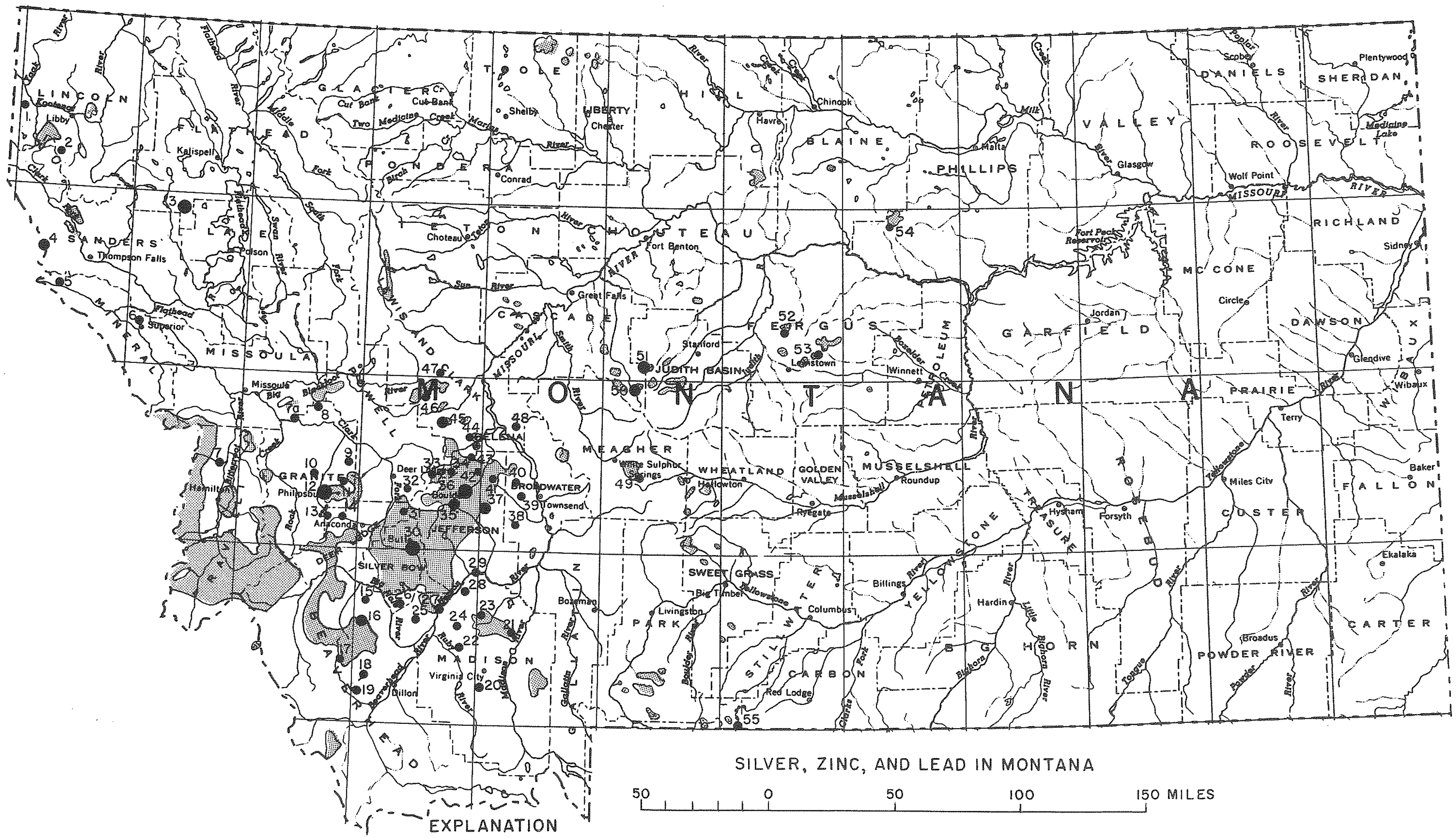


FIGURE 34.—Sillimanite group mineral deposits in Montana.

94765 O - 63 (Face p. 166) No. 28



SILVER, ZINC, AND LEAD IN MONTANA

50 0 50 100 150 MILES

EXPLANATION

● DISTRICTS IN WHICH PRODUCTION PLUS RESERVES ARE MORE THAN 50,000,000 OZ Ag, 1,000,000 TONS Zn, OR 1,000,000 TONS Pb

● DISTRICTS IN WHICH PRODUCTION PLUS RESERVES ARE FROM 5,000,000 TO 50,000,000 OZ Ag, 50,000 TO 1,000,000 TONS Zn, OR 50,000 TO 1,000,000 TONS Pb

● DISTRICTS IN WHICH PRODUCTION PLUS RESERVES ARE FROM 100,000 TO 5,000,000 OZ Ag, 1,000 TO 50,000 TONS Zn, OR 1,000 TO 50,000 TONS Pb

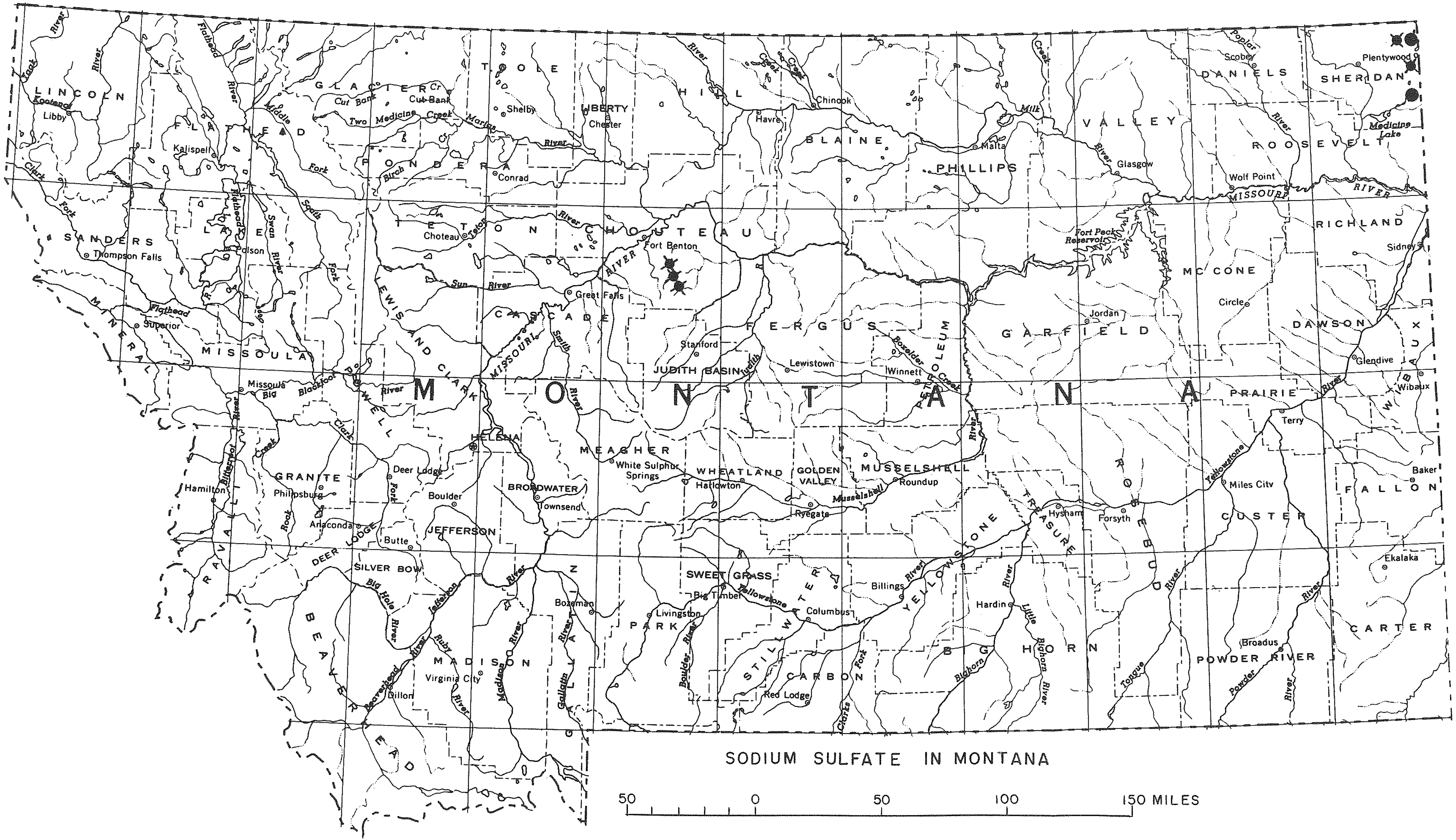
NUMBERS REFER TO DISTRICTS DISCUSSED IN TEXT.

▨ MESOZOIC OR TERTIARY INTRUSIVE ROCKS (MANY SMALL BODIES NOT SHOWN)

ADAPTED FROM McKNIGHT, NEWMAN, AND HEYL, 1962 a AND b AND McKNIGHT, NEWMAN, KLEMIC AND HEYL (IN PRESS)

INTRUSIVE ROCKS GENERALIZED FROM MEREWETHER, 1960, AND OTHER SOURCES

FIGURE 35.—Silver, zinc, and lead in Montana.



SODIUM SULFATE IN MONTANA

50 0 50 100 150 MILES

EXPLANATION

TYPE OF DEPOSITS	DEPOSITS WITH SIGNIFICANT POTENTIAL	POTENTIAL UNEVALUATED
INTERMITTENT LAKE DEPOSITS	●	⊗

94765 O - 63 (Face p. 166) No. 30

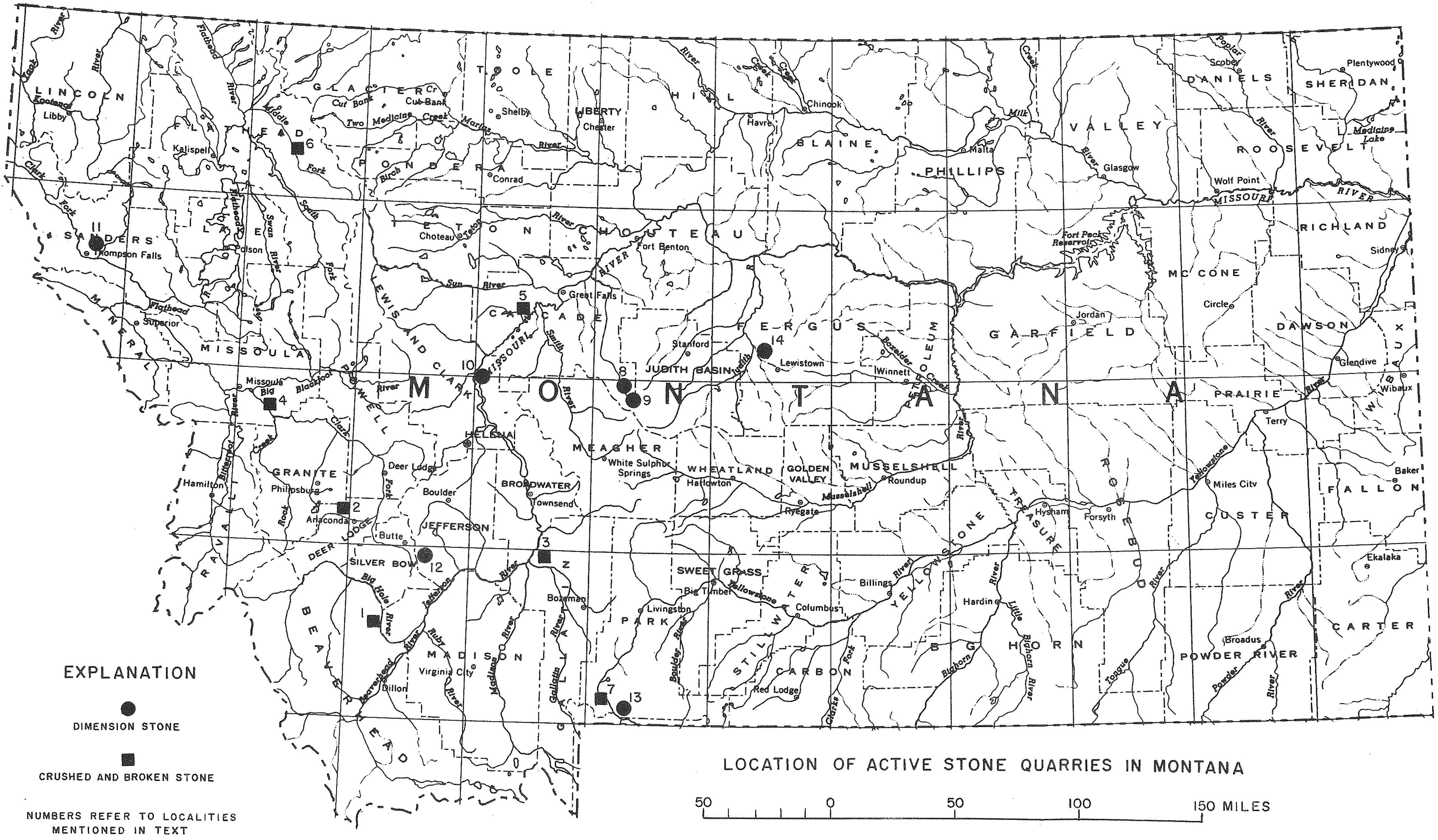
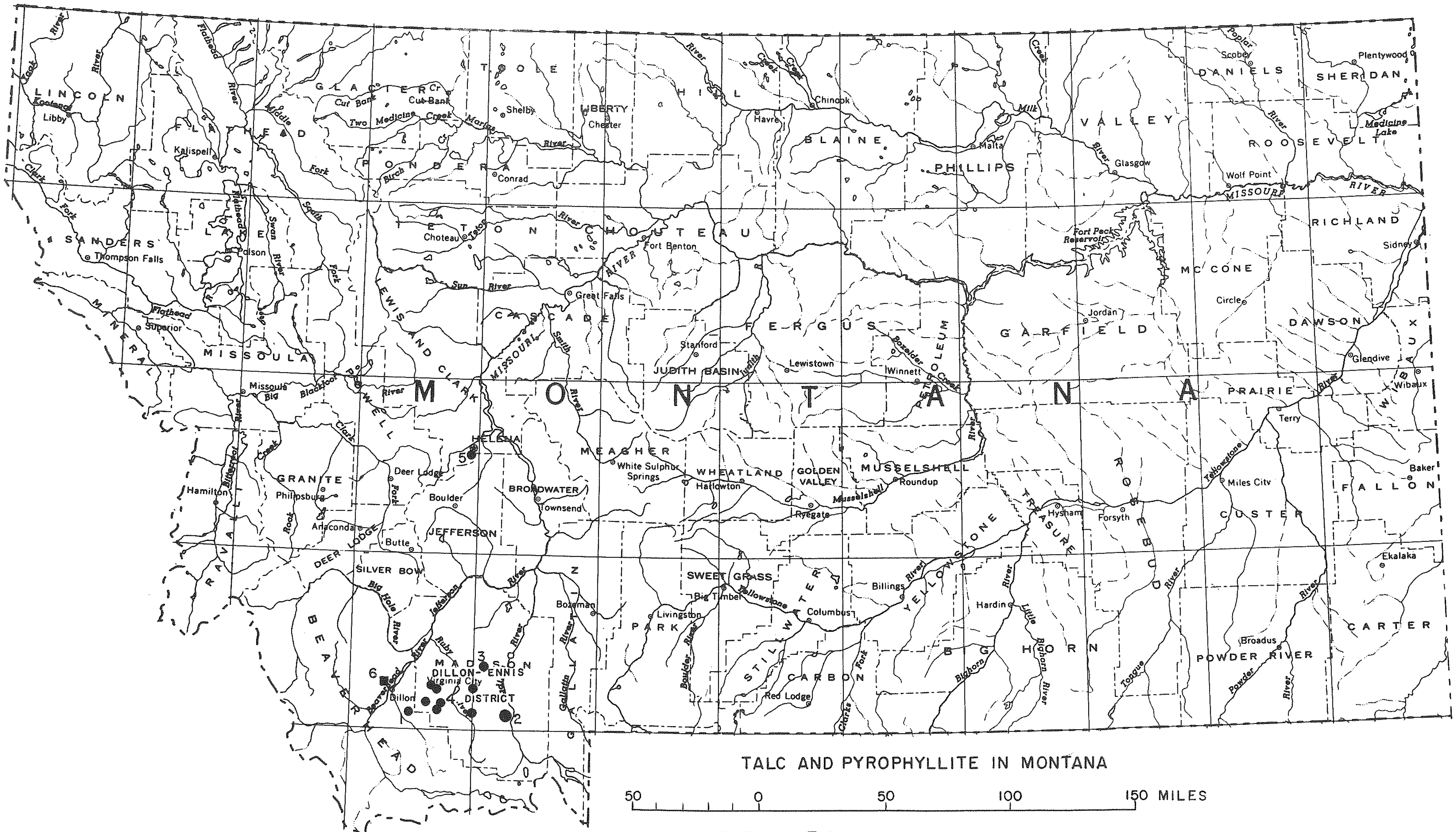


FIGURE 39.—Location of active stone quarries in Montana.

94765 O - 63 (Face p. 166) No. 31



EXPLANATION

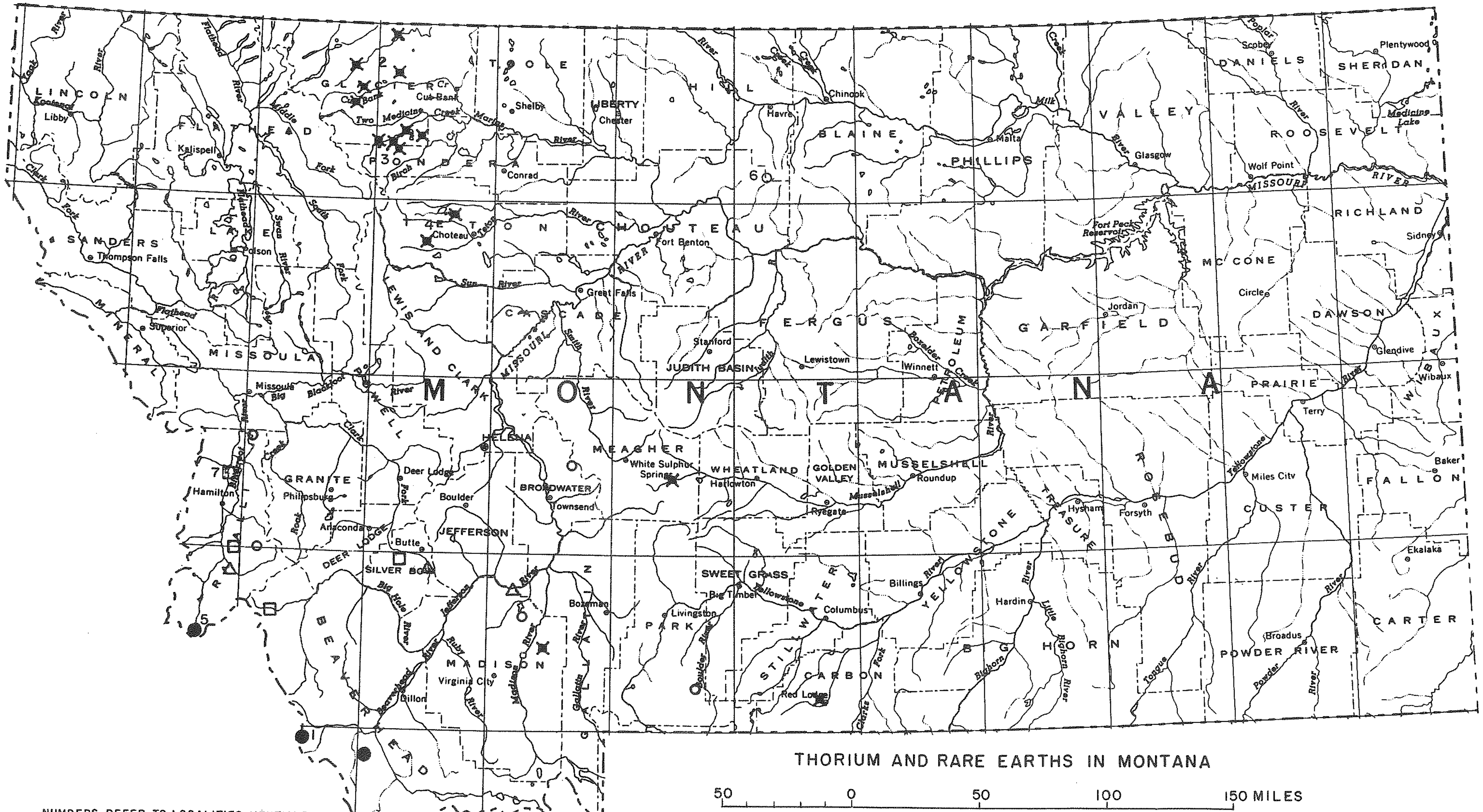
ADAPTED FROM CHIDESTER AND WORTHINGTON, 1962; ESPENSHADE, 1962

SIZE (PRODUCTION PLUS RESERVES)	TALC	PYROPHYLLITE
1,000,000-10,000,000 TONS	●	
LESS THAN 1,000,000 TONS	●	■

NUMBERS REFER TO LOCALITIES MENTIONED IN TEXT

FIGURE 40.—Talc and pyrophyllite deposits in Montana.

94765 O - 63 (Face p. 166) No. 32



NUMBERS REFER TO LOCALITIES MENTIONED IN TEXT

EXPLANATION

ADAPTED FROM OLSON AND ADAMS, 1962

TYPE OF DEPOSIT	OCCURRENCE, PROSPECT, MINE, OR GROUP OF DEPOSITS THAT MAY HAVE SIGNIFICANT POTENTIAL	OCCURRENCE, PROSPECT, OR GROUP OF DEPOSITS; POTENTIAL UNEVALUATED OR SMALL
LODE, VEIN, OR CONCENTRATION IN IGNEOUS OR METAMORPHIC ROCK	●	○
PLACER DEPOSIT	■	□
ANCIENT PLACER; CONCENTRATION IN SEDIMENTARY ROCK		✖
CONCENTRATION IN PEGMATITE		△

FIGURE 41.—Thorium and rare earths in Montana.

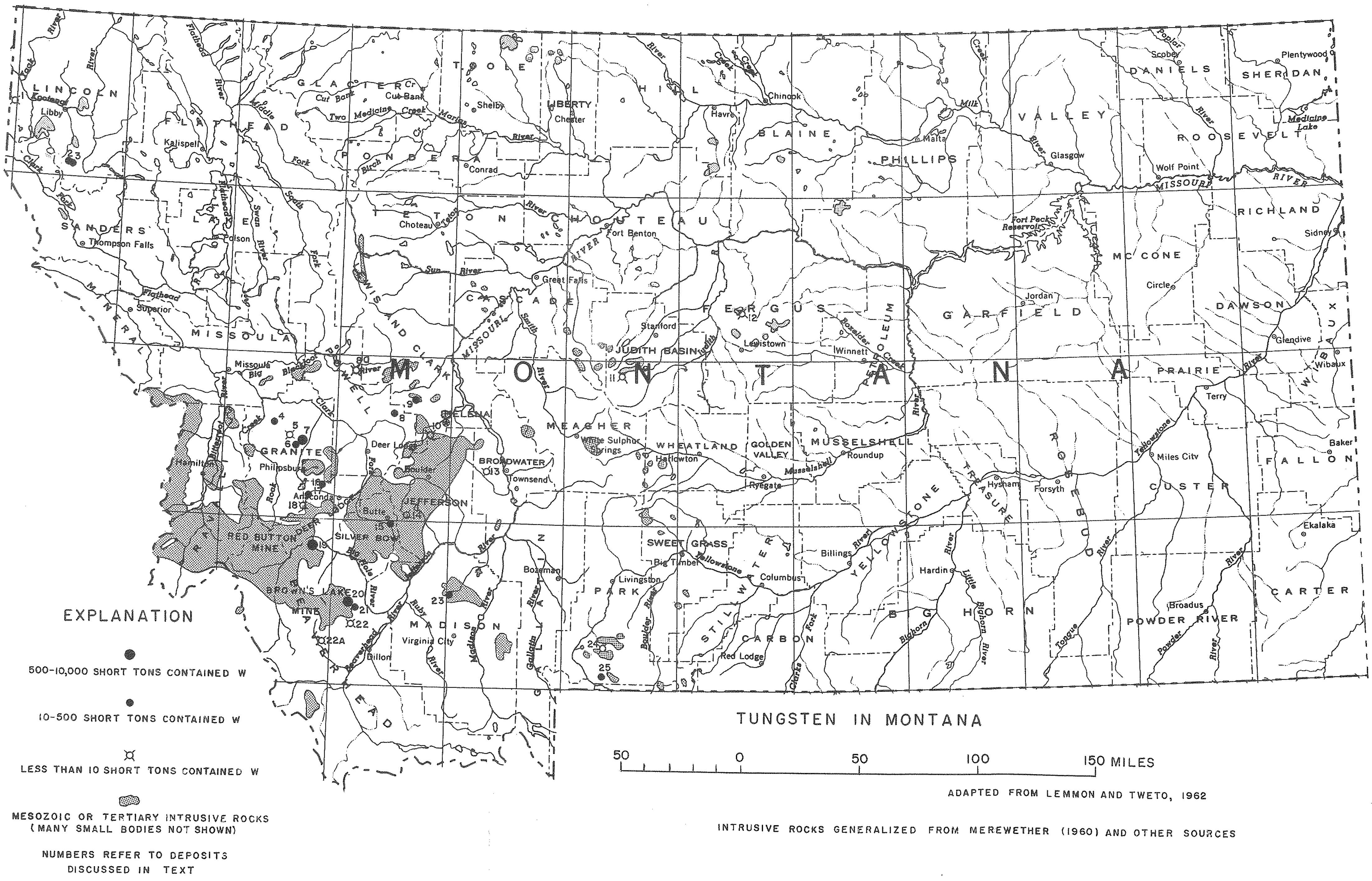
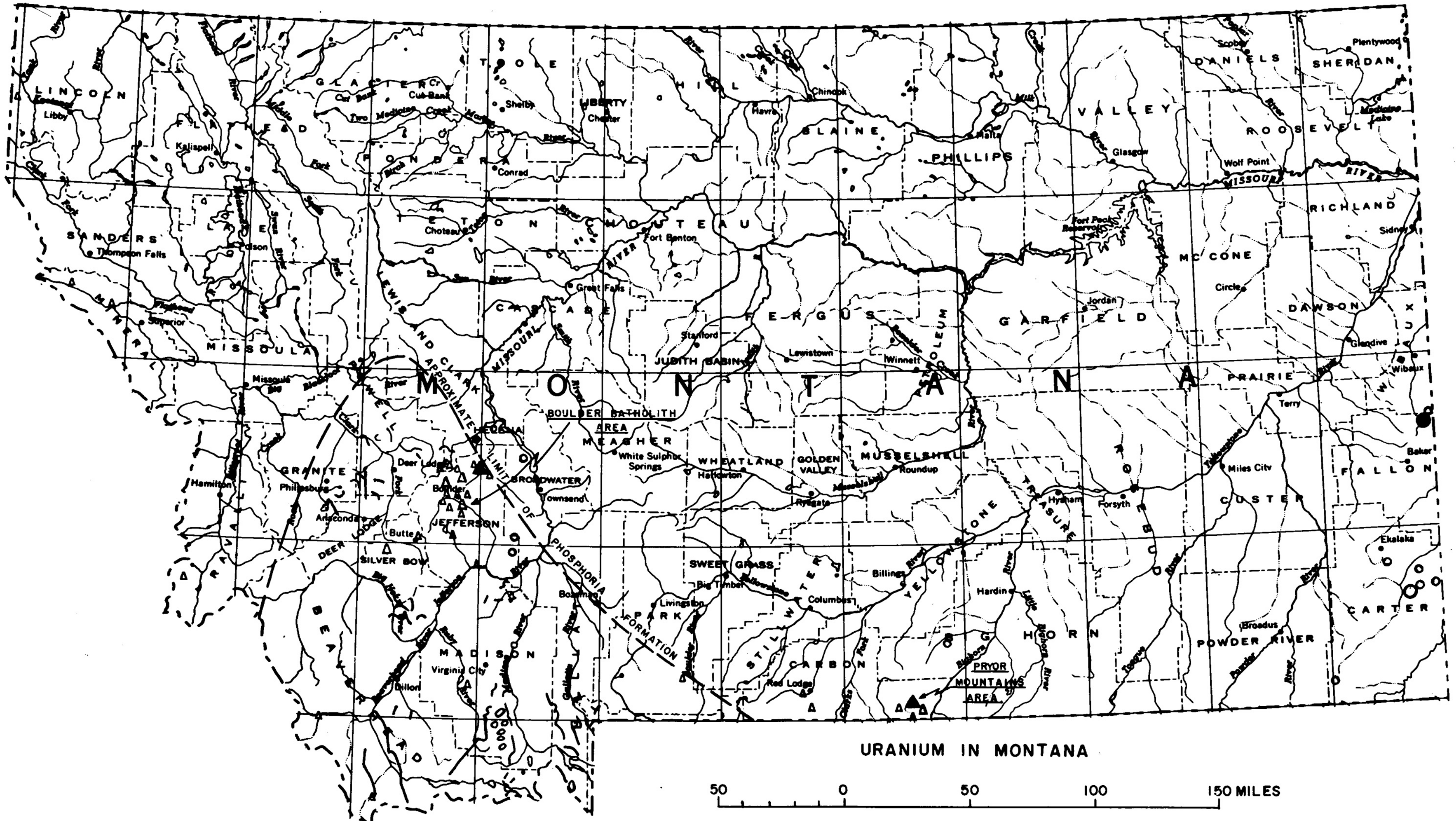


FIGURE 42.—Tungsten in Montana.

94765 O - 63 (Face p. 166) No. 34



ADAPTED FROM SCHNABEL, 1955; AND BUTLER AND OTHERS, 1962

EXPLANATION

GEOLOGIC TYPE	DEPOSITS		OCCURRENCES
	TONS OF "ORE" (PRODUCTION PLUS RESERVES) CONTAINING AT LEAST 0.1 PERCENT U_3O_8		MATERIAL CONTAINING AT LEAST 0.01 PERCENT U_3O_8, OR RECOGNIZABLE URANIUM MINERALS AND 0.01 PERCENT OR MORE eU_3O_8. ALSO INCLUDES DEPOSITS OF LESS THAN 1 TON CONTAINING AT LEAST 0.1 PERCENT U_3O_8
	1,000 TO 1,000,000	1 TO 1,000	
PENECONCORDANT WITH SEDIMENTARY FEATURES OF THE ENCLOSING ROCKS	●	○	○
VEINS, BRECCIA ZONES, STOCK-WORKS AND RELATED TYPES	▲	△	△
AREAS OF PHOSPHORIA FORMATION OUTCROP	— , - -		

FIGURE 43.—Uranium in Montana.

94765 O - 63 (Face p. 166) No. 35

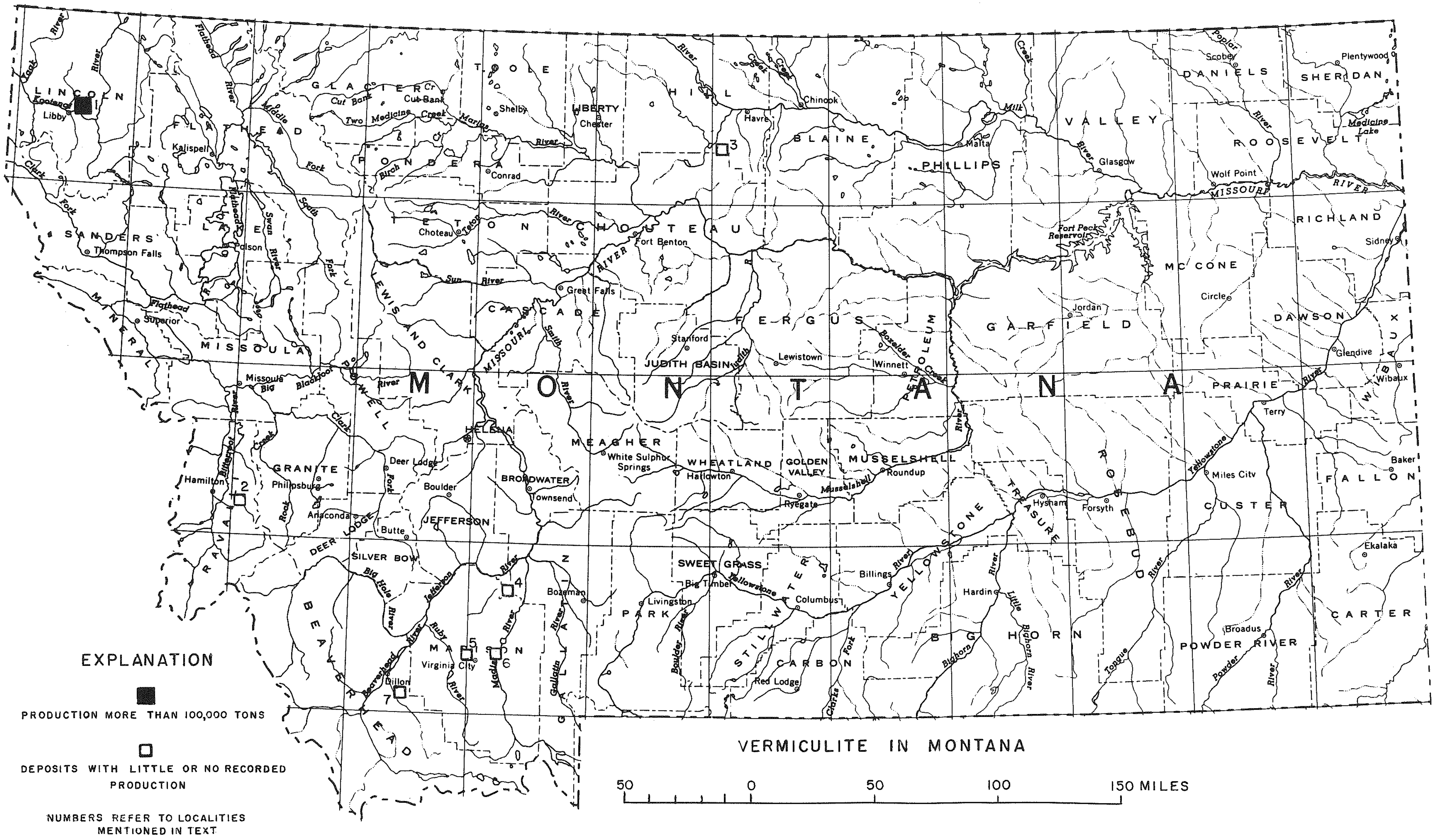


FIGURE 44.—Vermiculite in Montana.

94765 O - 63 (Face p. 166) No. 36

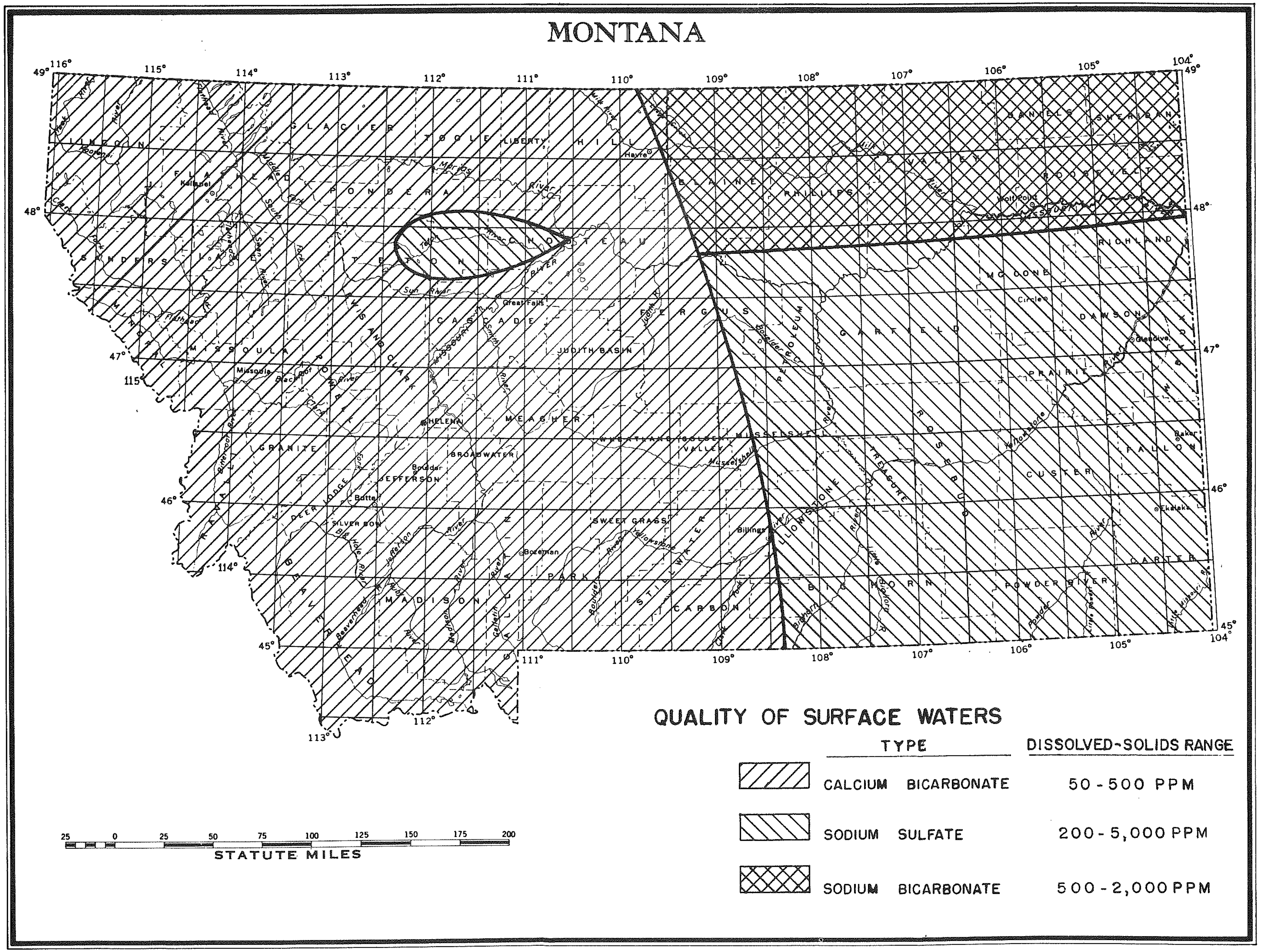


FIGURE 49.—Chemical quality of surface water, generalized.

94765 O - 63 (Face p. 166) No. 37

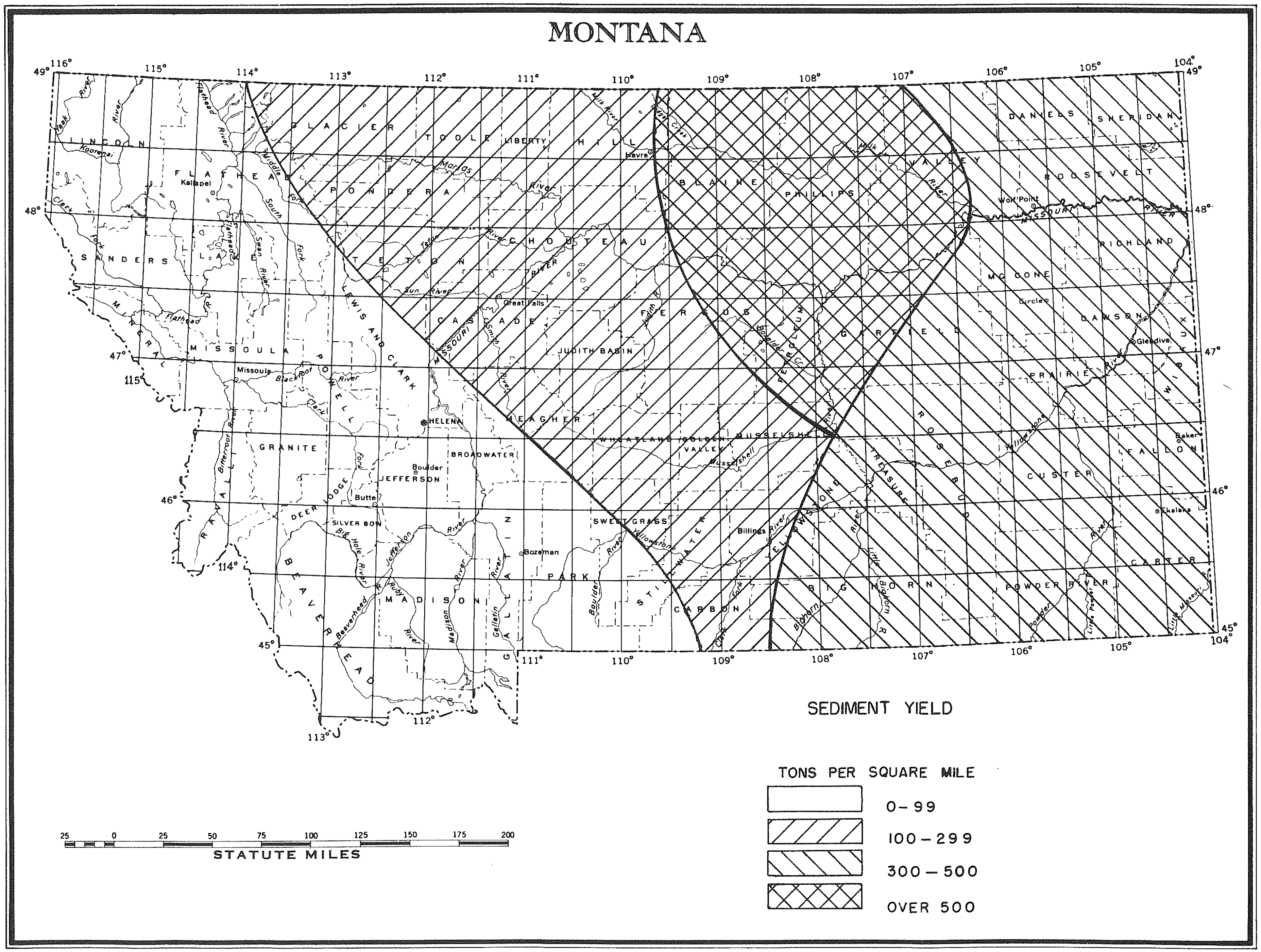


FIGURE 50.—Annual sediment yield, generalized.

94765 O - 63 (Face p. 166) No. 38