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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.

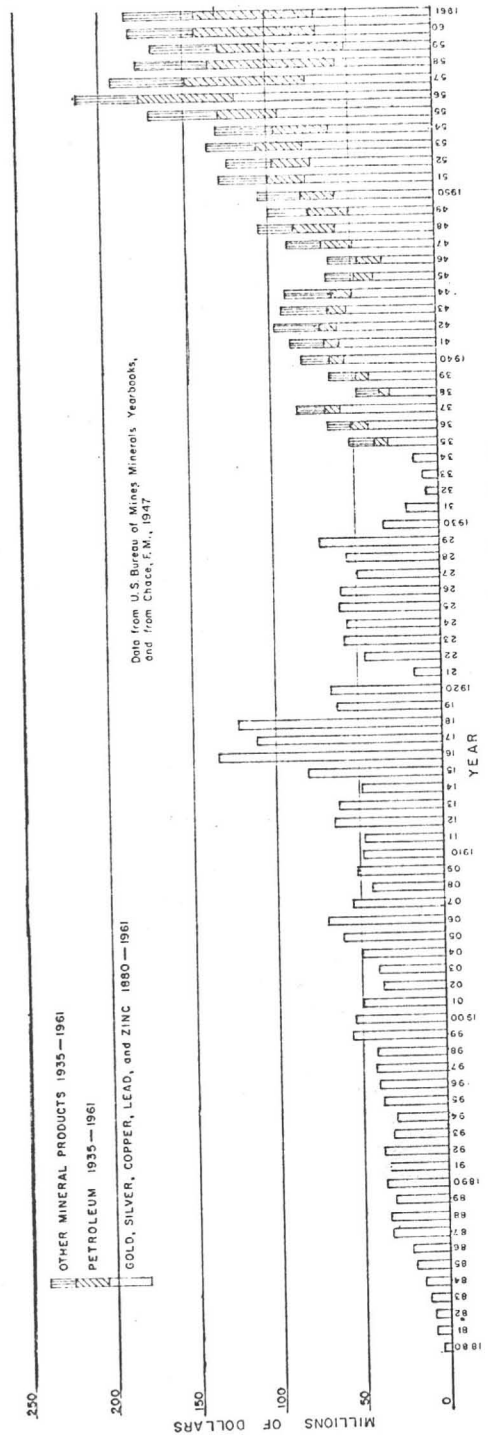

FIGURE 1.—Dollar value of Montana mineral production.

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MONTANA

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

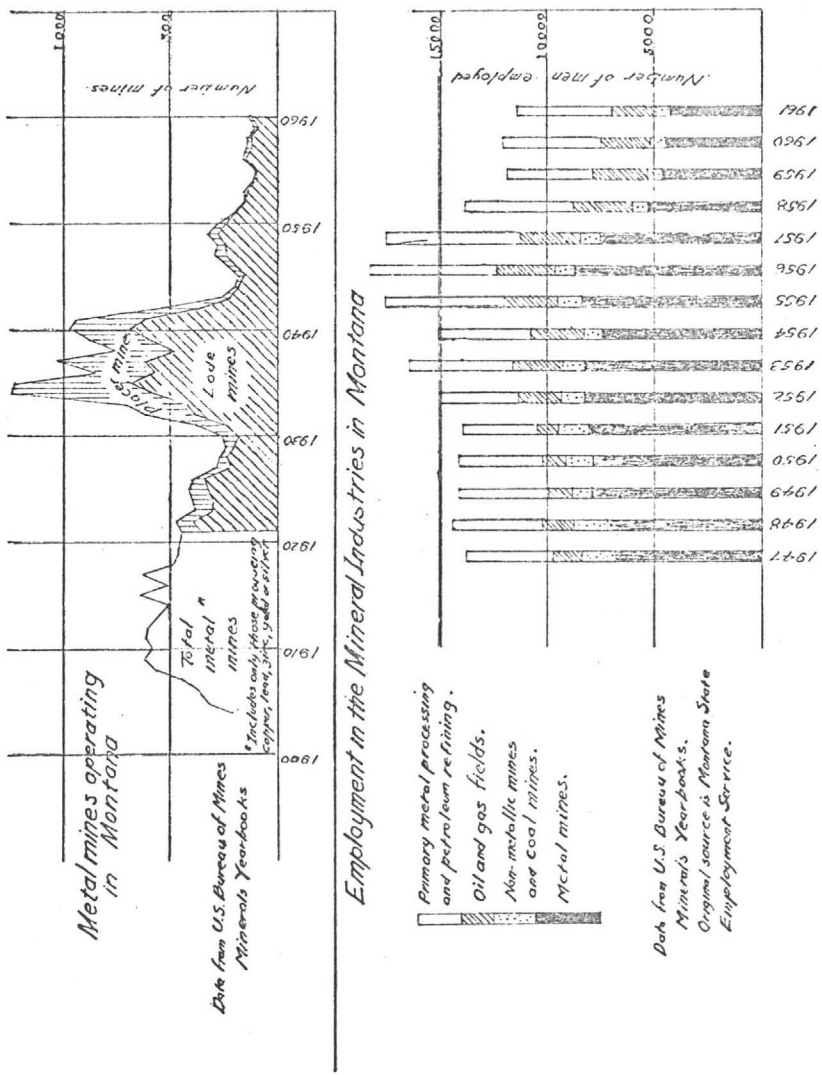

FIGURE 2.—Metal mines operating in Montana, and employment in the mineral industries in Montana.

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.

[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.

[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 recog-

nized 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.

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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 100 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

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

[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]

[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

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. 20, 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 ($CaSO_4$).

[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

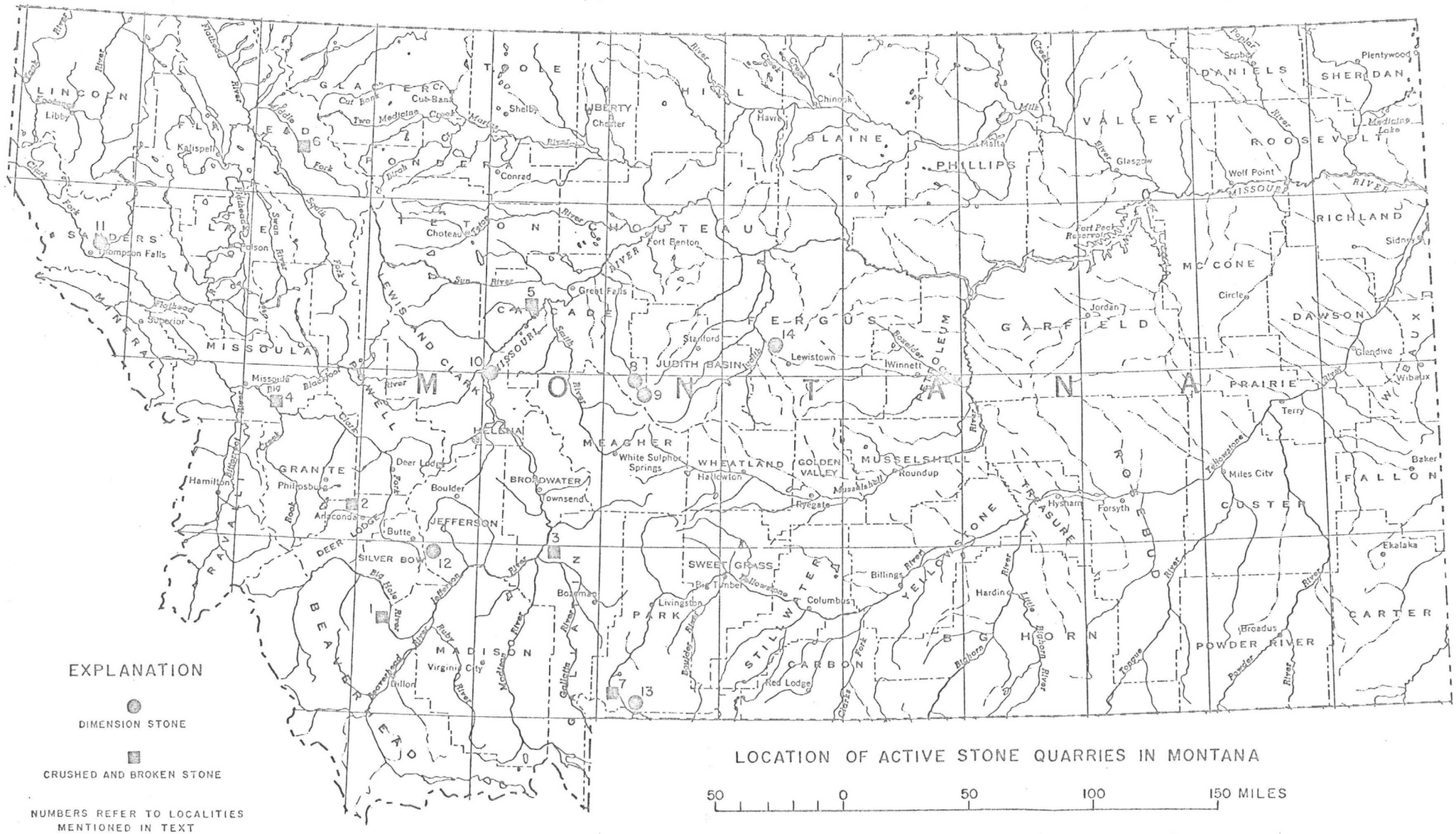


FIGURE 39.—Location of active stone quarries in Montana.

94765 O - 63 (Face p. 166) No. 31

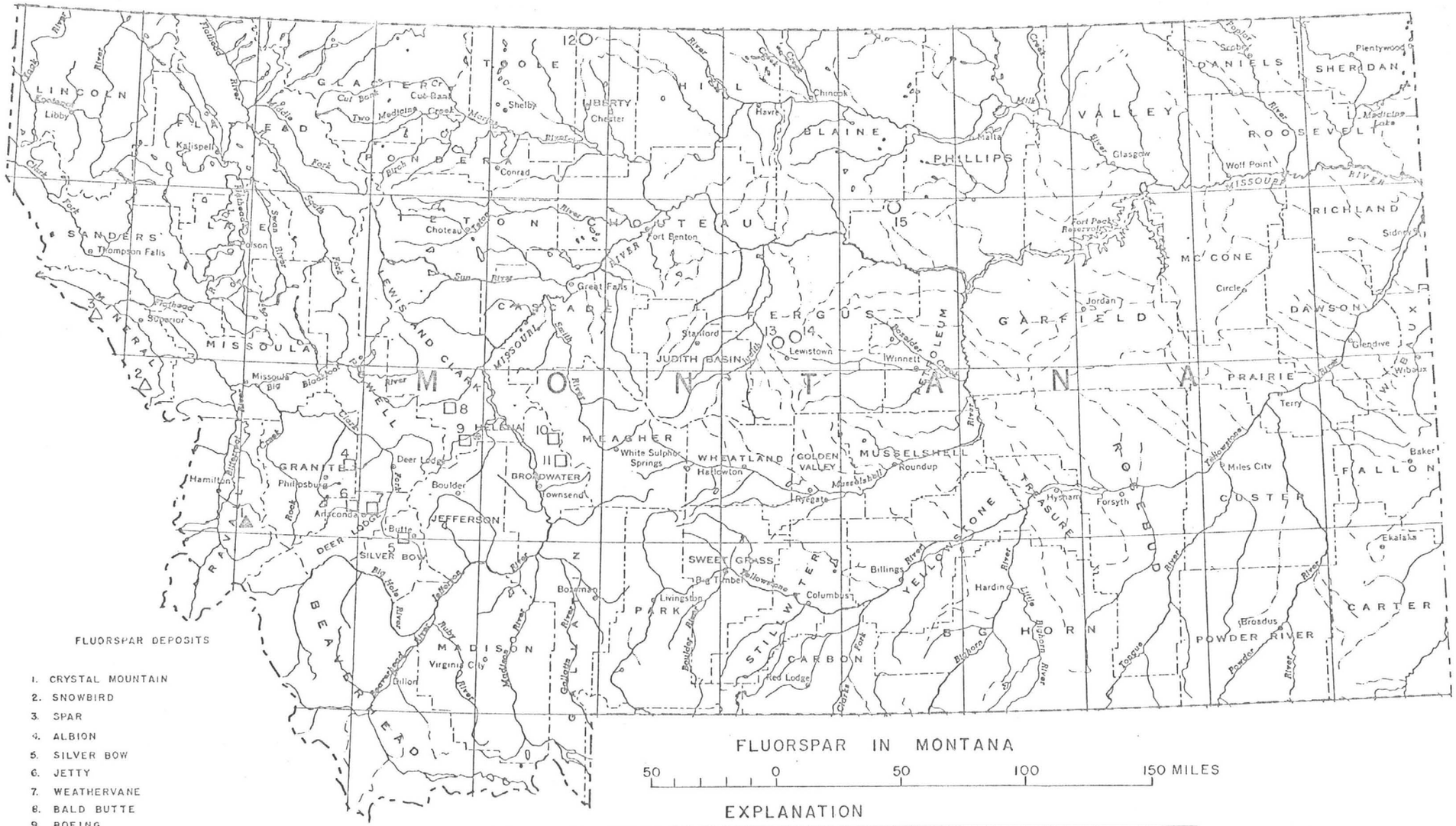


FIGURE 18.—Fluorspar in Montana.

94765 O - 63 (Face p. 166) No. 13

GENERALIZED STRATIGRAPHIC CORRELATION CHART

SHOWING PRODUCING HORIZONS — MONTANA OIL AND GAS FIELDS, 1961

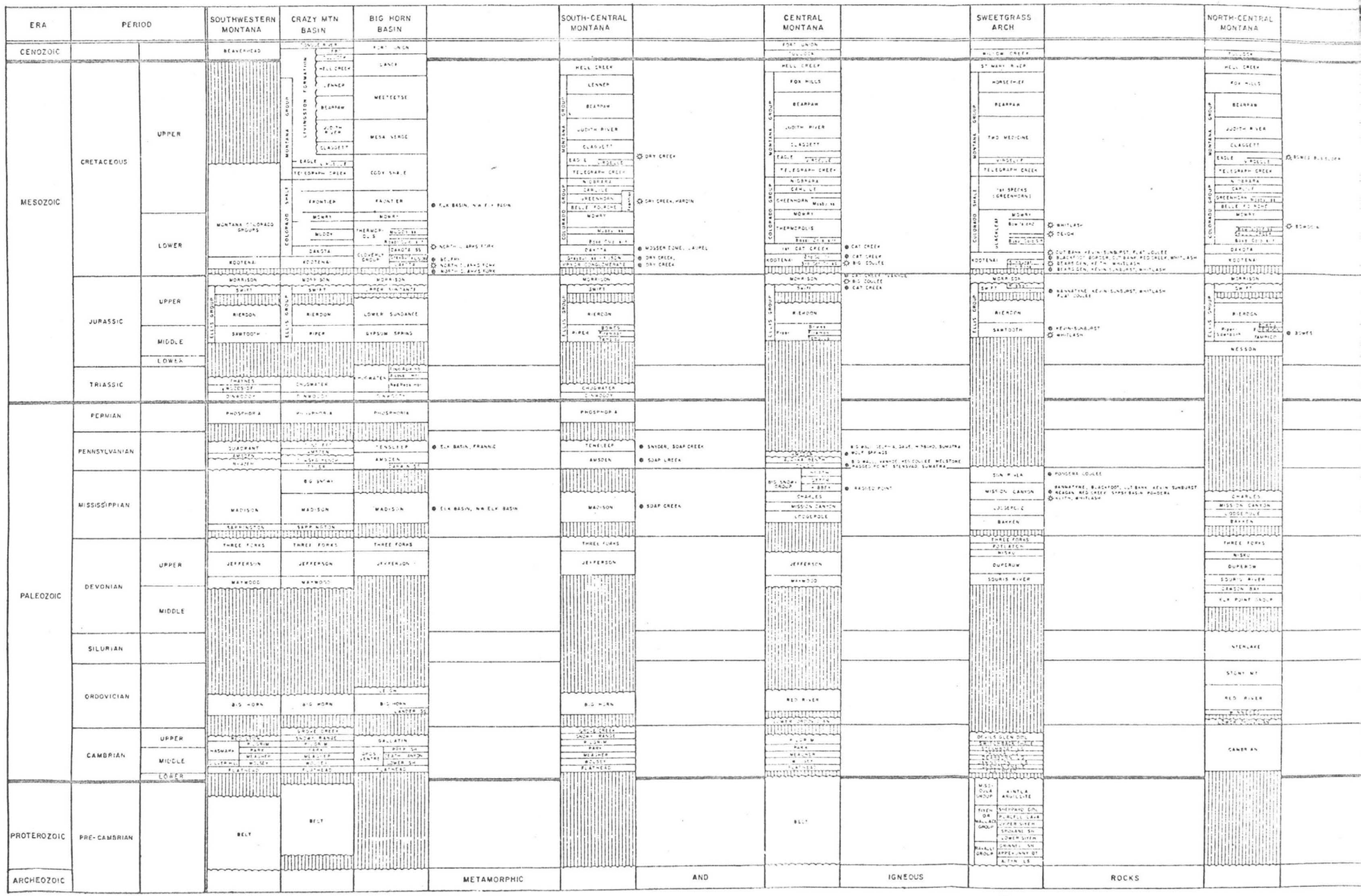
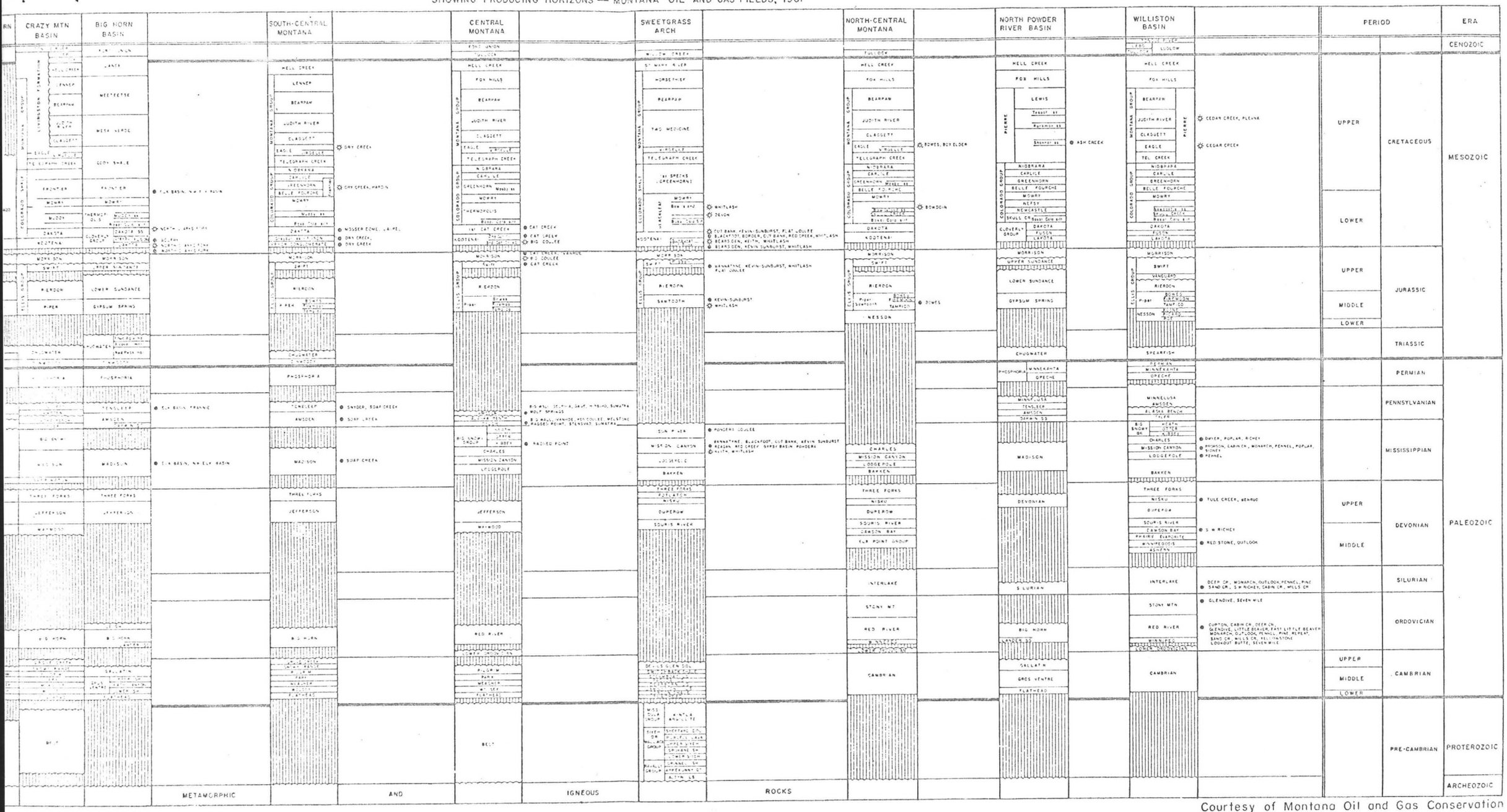


FIGURE 6.—Generalized stratigraphic correlation chart.

94765 O - 63 (Face p. 166) No. 4



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

FIGURE 6.—Generalized stratigraphic correlation chart.

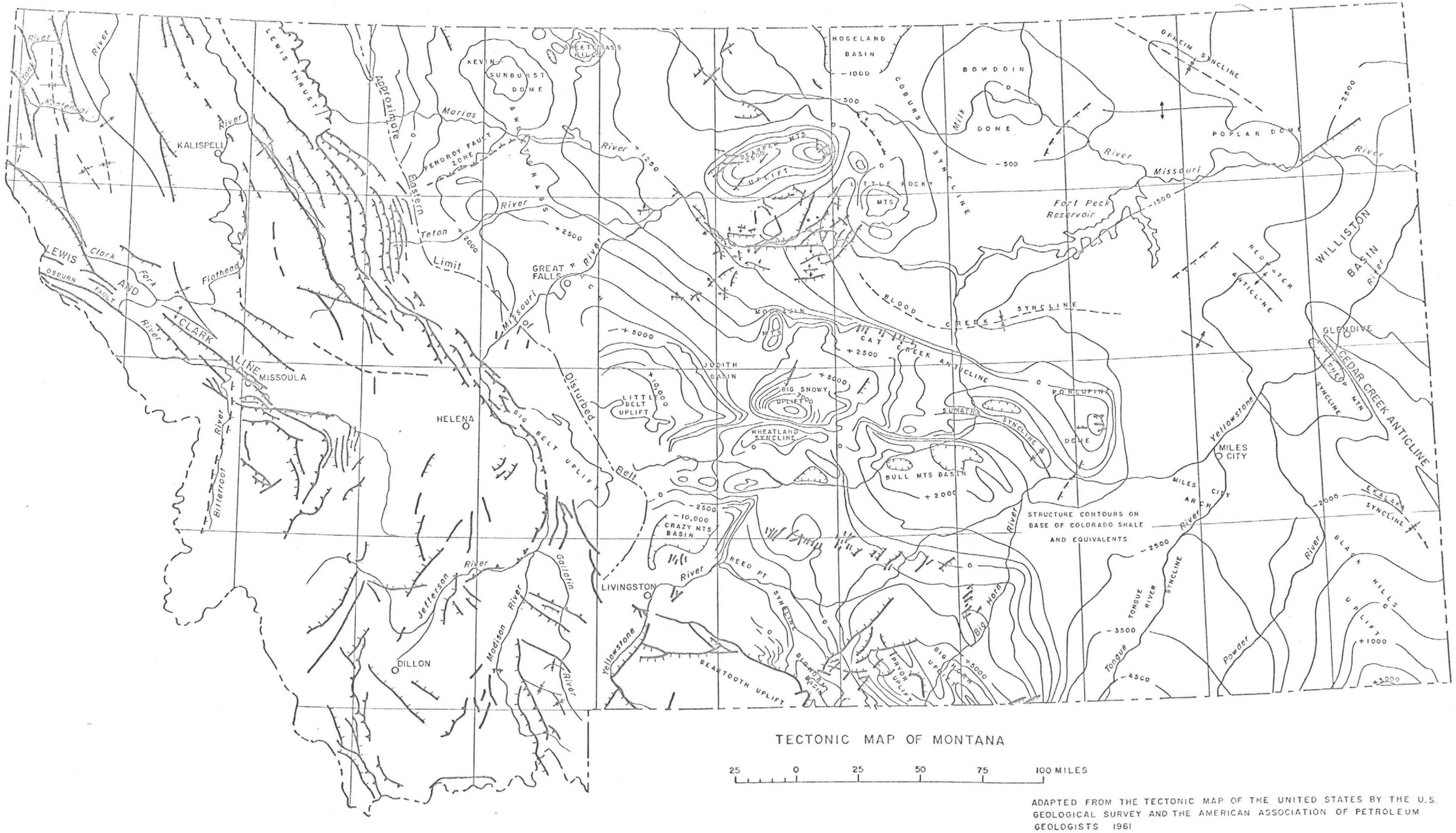


FIGURE 5.—Tectonic map of Montana.

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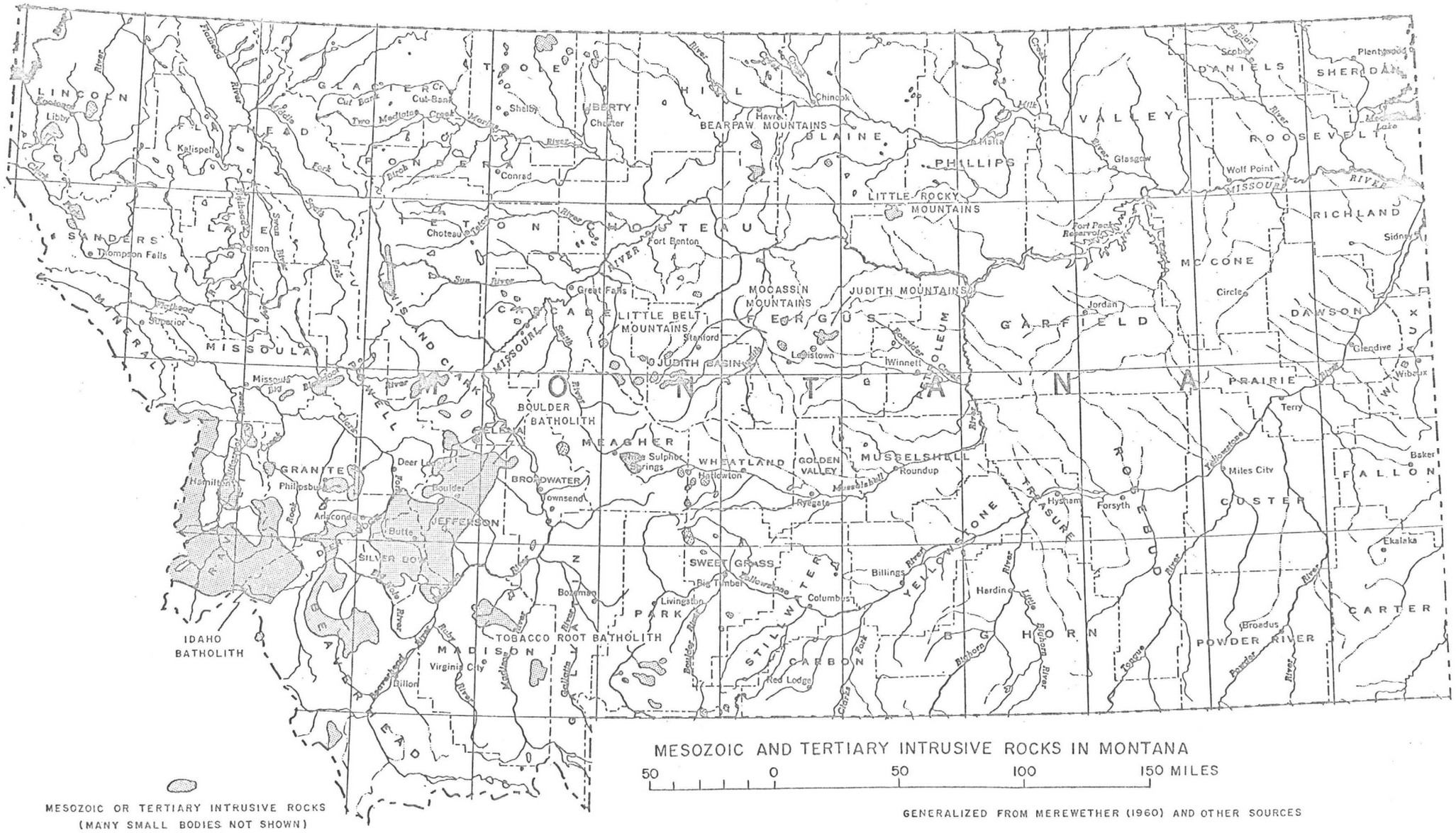

FIGURE 4.—Mesozoic and Tertiary intrusive rocks in Montana.

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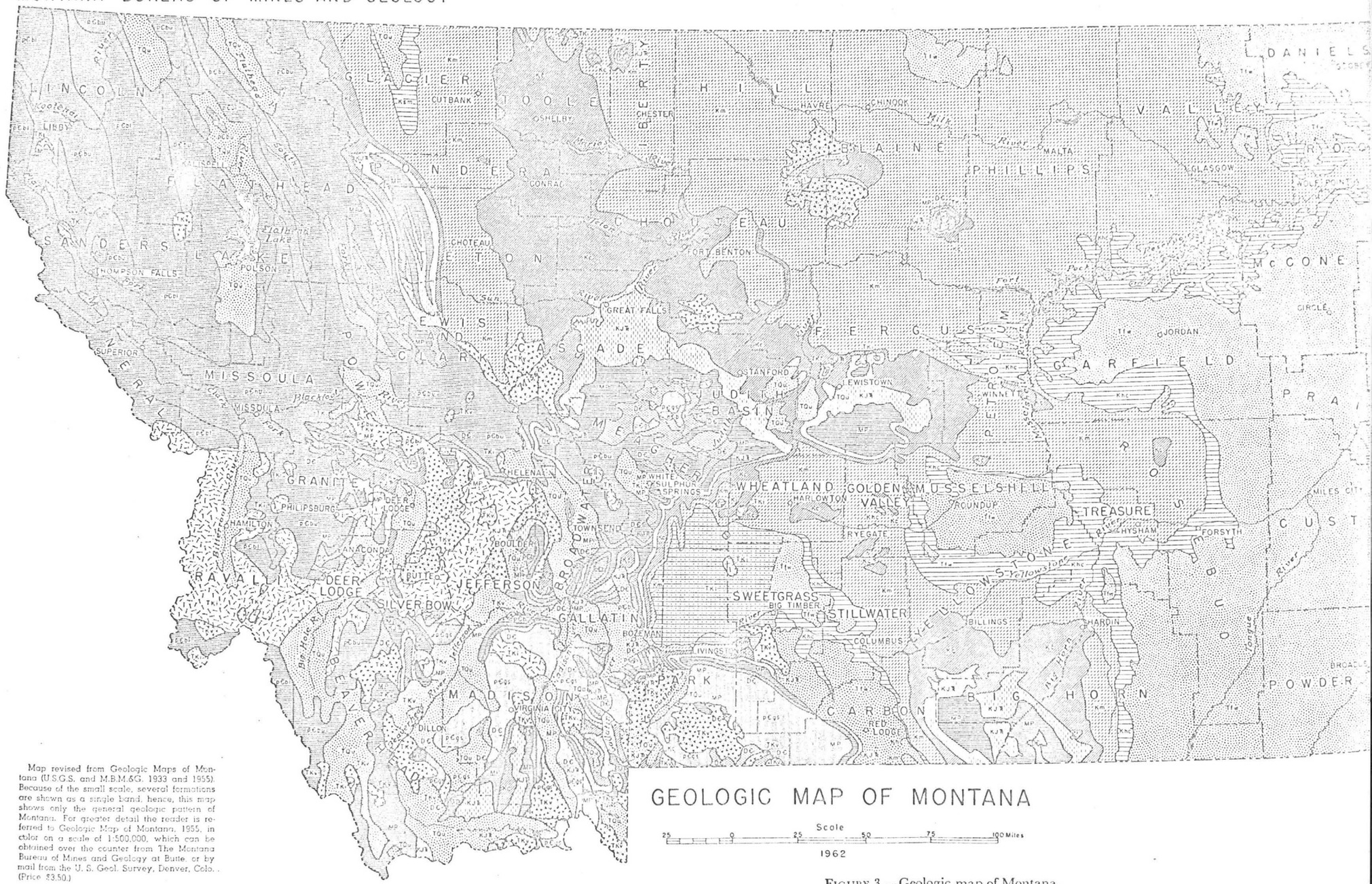

Map revised from Geologic Maps of Montana (U.S.G.S. and M.B.M.&G. 1933 and 1955). Because of the small scale, several formations are shown as a single band, hence, this map shows only the general geologic pattern of Montana. For greater detail the reader is referred to Geologic Map of Montana, 1955, 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.)

GEOLOGIC MAP OF MONTANA

Scale

25 0 25 50 75 100 Miles

1962

FIGURE 3.—Geologic map of Montana.

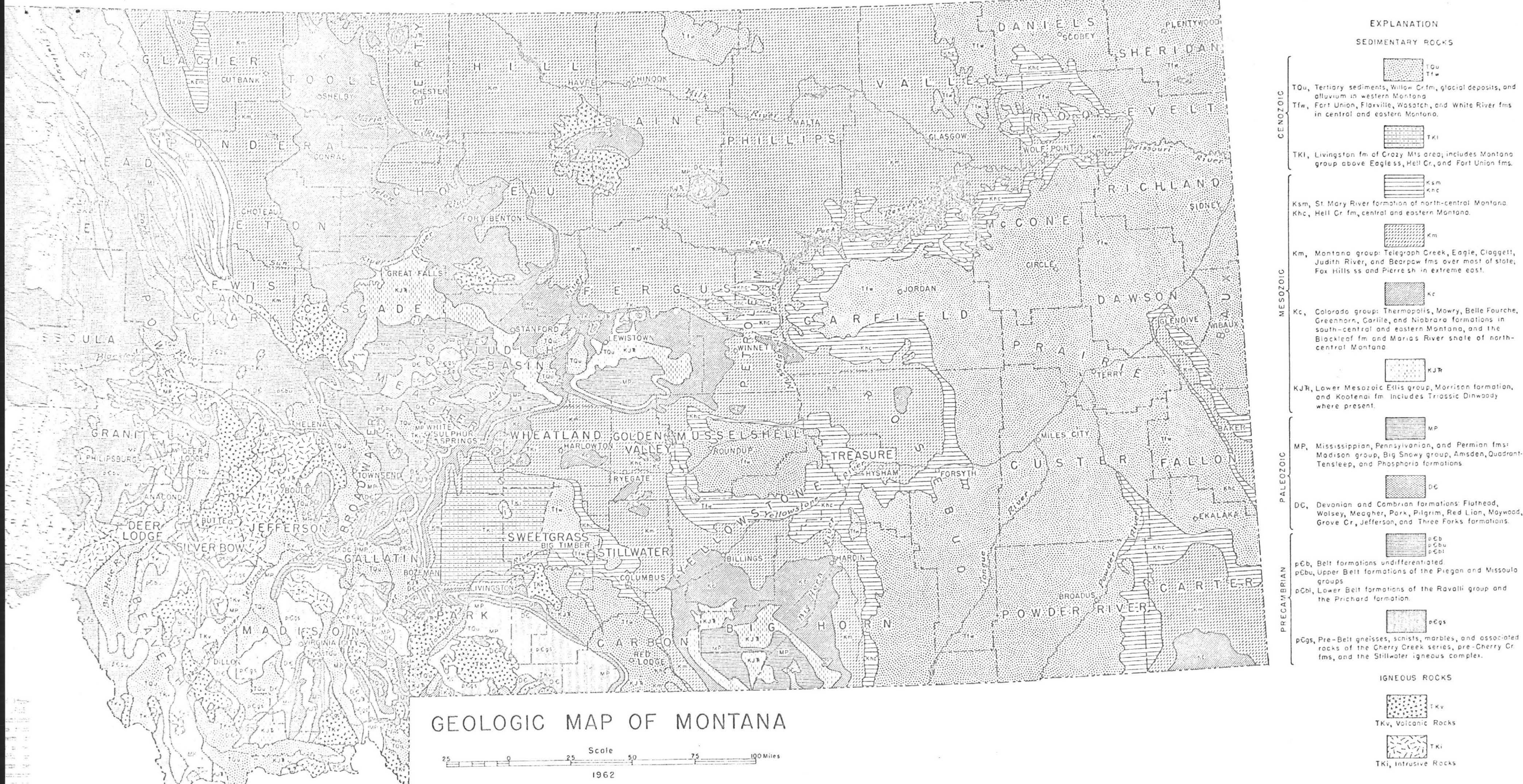

FIGURE 3.—Geologic map of Montana.