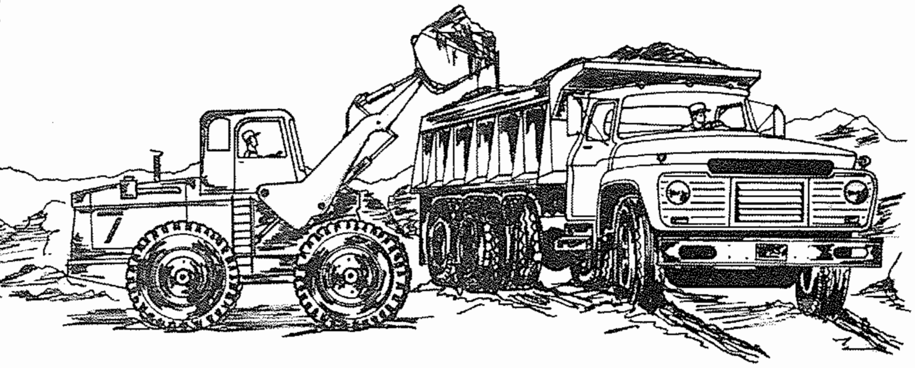
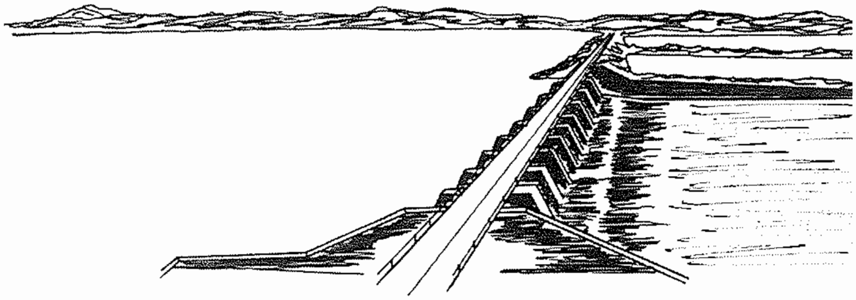
STATE OF SOUTH DAKOTA
Archie Gubbrud, Governor



Bulletin Number 16

MINERAL AND WATER RESOURCES OF SOUTH DAKOTA



SOUTH DAKOTA STATE
GEOLOGICAL SURVEY
Duncan J. McGregor
State Geologist

Science Center, University
Vermillion, South Dakota
1964

ACKNOWLEDGMENT

This report was prepared for the United States Senate Committee on Interior and Insular Affairs, at the request of the Honorable George McGovern, United States Senator from South Dakota.

I wish to express my gratitude to both Senator McGovern and Senator Karl Mundt for sending the South Dakota Geological Survey copies of the report. Permission to attach a cover and to distribute and/or sell the report as a bulletin of the South Dakota Geological Survey was granted and is most appreciated.

Duncan J. McGregor
State Geologist

88th Congress }
2d Session }
COMMITTEE PRINT

MINERAL AND WATER RESOURCES OF SOUTH DAKOTA

REPORT

PREPARED BY THE
UNITED STATES GEOLOGICAL SURVEY
AND THE
UNITED STATES BUREAU OF RECLAMATION
IN COOPERATION WITH
SOUTH DAKOTA STATE GEOLOGICAL SURVEY
AND THE
SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY
AT THE REQUEST OF
SENATOR GEORGE McGOVERN
OF SOUTH DAKOTA
OF THE
COMMITTEE ON INTERIOR AND INSULAR AFFAIRS
UNITED STATES SENATE

Printed for the use of the Committee on Interior and Insular Affairs

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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 South Dakota," prepared by the U.S. Geological Survey at the request of our colleague, Senator George McGovern.

This detailed survey will be particularly helpful to government and business leaders in South Dakota. 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

On August 13, 1963, I requested the Secretary of the Interior to determine if a comprehensive summary report on the mineral and water resources of South Dakota could be prepared for the use of citizens, professional personnel, and government, civic, and industrial leaders interested in mining, water, and industrial developments.

This report, prepared in response to my request by members of the U.S. Geological Survey, South Dakota State Geological Survey, South Dakota School of Mines and Technology, State Industrial Development Expansion Agency, the U.S. Bureau of Mines, and the U.S. Bureau of Reclamation, is such a thorough, detailed, and comprehensive work that I am sure it will be of great value to all interested in the fields.

I wish to express my thanks and appreciation to Secretary of the Interior Udall and each and every one of the persons in South Dakota, Washington, Colorado, and those with offices elsewhere who have contributed to making this such a fine report.

GEORGE MCGOVERN.

SECTION I

MINERAL AND WATER RESOURCES OF SOUTH DAKOTA

REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

IN COLLABORATION WITH THE

SOUTH DAKOTA STATE GEOLOGICAL SURVEY

AND OTHER AGENCIES

SECTION II

WATER RESOURCE DEVELOPMENT IN SOUTH DAKOTA

REPORT

OF THE

BUREAU OF RECLAMATION

PREPARED AT THE REQUEST OF

SENATOR GEORGE McGOVERN
OF SOUTH DAKOTA

OF THE

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS
UNITED STATES SENATE

LETTER OF TRANSMITTAL

U.S. Department of the Interior,
Office of the Secretary,
Washington, D.C., May 14, 1964.

Hon. George McGovern,
U.S. Senate,
Washington, D.C.

Dear Senator McGovern: In response to your letter of August 13, 1963, we are pleased to transmit herewith a summary report on the mineral and water resources of South Dakota.

Part I of the report was prepared by the U.S. Geological Survey in collaboration with the South Dakota Geological Survey and other agencies. This part describes the mineral resources known to occur in South Dakota, and it presents information on their manner of occurrence, distribution, and relative importance to the mineral industry of the State. The narrative discussions are supplemented by small-scale maps and other illustrations.

Part II was prepared by the Bureau of Reclamation. This portion of the report describes existing water resource development projects. Also discussed, in a future development section, are basin conditions and plans for projects intended to meet anticipated water requirements.

It is hoped that data in the report will be adequate to supply the information you desire.

Sincerely yours,

Stewart L. Udall,
Secretary of the Interior.

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SECTION I

MINERAL AND WATER RESOURCES OF SOUTH DAKOTA

U.S. Geological Survey

in Collaboration With the South Dakota State Geological Survey and Other Agencies

SUMMARY AND INTRODUCTION

(By N. M. Denson and W. J. Mapel, U.S. Geological Survey, Denver, Colo.)

In 1963 for the 15th consecutive year, South Dakota led the Nation in production of gold. Each year some $20 million worth of new precious metal is produced in the State, virtually all of it from operations of the Homestake Mining Co. at Lead. Significant as this production is, both in terms of new wealth and employment, the value of metals produced is now exceeded by the combined values of more prosaic nonmetallic mineral and rock products, including sand and gravel, stone, cement, and clay. Together, the varied mineral products of South Dakota were valued at $47.5 million in 1963.

The economy of South Dakota is even more vitally associated with the development and utilization of its water resources, for agricultural production would not be possible without adequate and controlled supplies of water. Existing surface water resources are large and varied, but commonly some control is needed to assure delivery of vital water in the desired locale when it is needed. Ground water constitutes a large and reliable source of water for most uses, and most of the State is underlain by water-bearing strata. Although extensively exploited for many years, this ground water is the largest remaining undeveloped source of water in South Dakota.

Many different useful minerals and potentially useful rocks are distributed broadly throughout South Dakota. Gold and associated byproduct silver are the chief metallic products, but in recent years the production of uranium has become important, with added value because of the recovery of byproduct vanadium and molybdenum. South Dakota was the world's principal source of lithium ores for over 50 years, and also has produced sizable amounts of beryllium ores. Pegmatite deposits in the Black Hills have been the source of the ores of both of these light metals. Other metals produced in small amounts from the State include lead, zinc, copper, tungsten, and tin. Although not yet exploited, some of the State's resources of iron are of potential interest. Large low-grade resources of manganese may ultimately be developed.

The largest segment of the mineral industry in South Dakota is concerned with the production of construction materials, including sand, gravel, crushed stone, cement, clay, and gypsum. Significant resources of these essentials of modern growth have been developed, for the most part in the vicinity of where they are used. Ample resources exist to support expansion of these industries as needed. Other nonmetallic mineral products with more specialized requirements and higher unit values also contribute to the mineral wealth, including feldspar for the glass and ceramic industry, mica, and monumental and ornamental stone. Future expansion of many of these stone and mineral products depends on development of new uses and new markets for known mineral resources. Mineral fuels, including coal, petroleum, and natural gas, have been produced in small amounts, and additional development can be expected.

The early history of South Dakota reflects the close dependence of the settlers on both mineral and water resources. Discovery of gold in the Black Hills in 1874 was responsible for opening of the territory west of the Missouri River. Early mining towns led to the need for locally produced foods. Both the towns and farms were located near perennial water supplies, which were more limited than had been the case in States to the east with their more humid climates. Development of the mines led to establishment of milling and smelting facilities which in turn required the shipment of heavy supplies and establishment of roads and eventually railroads. In much of the State, expansion of agriculture depended on development of controlled water supplies. Artesian flow of water from wells was important in the early development of irrigated farming, and literally thousands of wells produce the water on which South Dakota's economy thrives.

Part I of this report describes the mineral and water resources of South Dakota, their distribution and mode of occurrence, their uses in industry, and the factors affecting their exploration. Production figures and estimates of dollar values accompany descriptions of the various commodities, and the importance of the State as an actual source or potential producer of each commodity is discussed. The report contains a summary of the regional geology of the State and shows the relations of the resources to geologic features. Index maps show the status of topographic and geologic mapping in the State and areas for which maps are available.

Under part II of this report, a water supply forecast outlines the adequacy of South Dakota's water resources to meet future growth requirements and presents a summary of the State's water resource development projects, both operating and proposed.

Part I of the report has been prepared by members of the staffs of the U.S. Geological Survey, the South Dakota State Geological Survey, the South Dakota School of Mines and Technology, the State Industrial Development Expansion Agency, and the U.S. Bureau of Mines. The U.S. Bureau of Reclamation prepared the summary of the Water Resources Development Program in South Dakota presented under part II.

This document incorporates information from numerous Federal, State, and outside publications as well as from unpublished reports and personal observations of more than 25 geologists who have contributed to the various chapters which follow. The descriptions of the mineral commodities are necessarily brief, but comprehensive lists of references are appended to each major section of the report in order that the original sources may be examined by those who seek additional information. Specific reference is made to these sources throughout the text in order to give proper credit and to place responsibility for the data shown. Margret Dunbar of the U.S. Bureau of Mines and Ruth Willson of the U.S. Geological Survey compiled the production figures and estimated dollar values for most of the mineral commodities described. William H. Kerns of the U.S. Bureau of Mines supervised the compilation of the production data taken from the Bureau's files and provided the summary of the commodity values and percentages shown on figure 1.

THE MINERAL INDUSTRY IN SOUTH DAKOTA

(By N. M. Denson, U.S. Geological Survey, Denver, Colo.)

Mineral production in South Dakota has grown consistently from the days of the first records in 1879 to the present time. During this period gold has been the most important mineral commodity in the State's economy, accounting for 66 percent of the total mineral production (fig. 1). For the 15th consecutive year, South Dakota in 1963 led the nation in gold production. Virtually all of the gold is produced from the Homestake Mining Co. mine at Lead.

Other metals have not added significantly to the economy, although large resources of such metals as uranium, molybdenum, and iron make these commodities important potential contributors. The output of uranium ore in 1963, for example, was twice that of the preceding year because of the production from uranium-bearing lignite. The processing of the lignite ores also may yield molybdenum as an important byproduct. The State has never produced significant quantities of iron ore; however, with the increased demand for pellets by the iron and steel industry, the Precambrian taconite beds in the Black Hills region may someday become an important resource.

Second to gold in importance in South Dakota are the utilitarian nonmetallic commodities sand and gravel, stone, cement, and clay which have contributed 30 percent of the value of the State's total mineral output. In 1963, output of nonmetals accounted for more than half of the total value of the minerals produced in the State. Sand and gravel are the leading nonmetallic commodities, followed closely in value by stone, cement, and clay. Large resources of each of these commodities are present in South Dakota.

Mineral fuels including coal, petroleum, and natural gas have contributed a very small part to the State's economy. The northwestern part of the State is occupied by the southern part of the Williston basin, which in 1963 in the neighboring States of North Dakota and Montana yielded about 1½ percent of the total petroleum produced in the United States. With further exploration additional petroleum development may be expected.

South Dakota has a population of about 700,000 and an area of about 77,000 square miles. It ranks 16th in size and 40th in population in the Nation. Early inhabitants were dependent, to a large extent, on the mineral industry, but as the population of the State increased the value of agricultural products became greater than the value of the mineral products. In 1963, for example, cash receipts in South Dakota from farm marketing, according to the U.S. Bureau of Commerce, amounted to $535.8 million; the value of all mineral products during the same year was $47.5 million. Although now second to agriculture, the mineral industry nevertheless is an important part of the economy of the State.

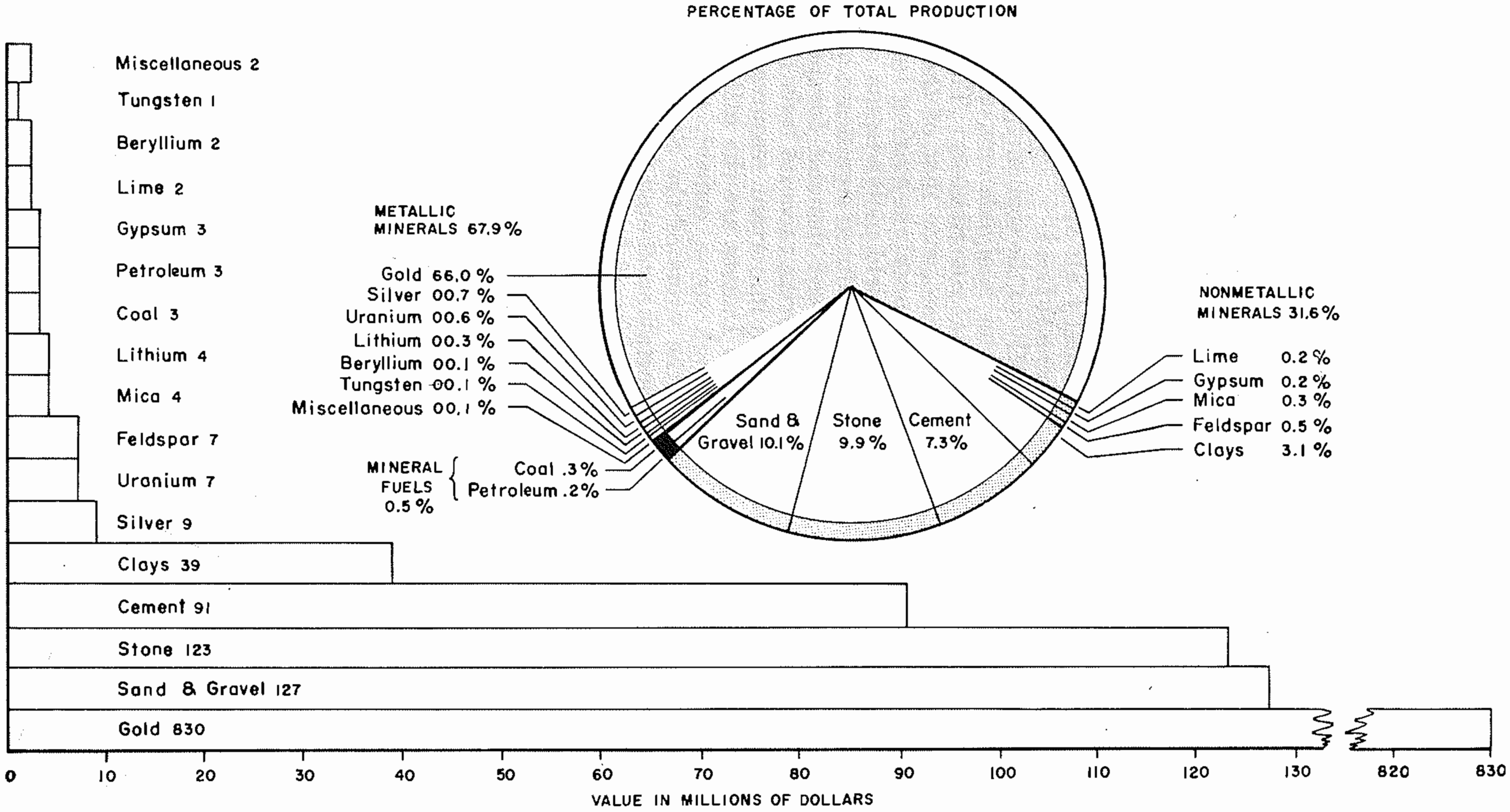

FIGURE 1.—Values of the principal mineral commodities in South Dakota, 1878–1963. Data from U.S. Bureau of Mines.

In the following sections of this report terms are used in describing the State's mineral potential which, for clarity and preciseness, are here defined and briefly discussed.

Resources: Materials in the ground that are minable today, plus materials that may be minable in the future.

Reserves: Materials that may or may not be completely explored but which can be quantitatively estimated and are considered to be economically exploitable.

Ore: A mineral material that may be mined at a profit.

Ore reserves: Mineral deposits currently being mined or known to be of such size and grade that they may be profitably mined.

Mineral resources are fixed in quantity and quality and are not renewable. Reserves, on the other hand, are a continually changing quantity, estimates of which are controlled by economics, technologic changes, and available information. A low reserve figure for a commodity today, for example, does not necessarily mean that the resource is near exhaustion but may indicate that its market value is at a point where the material cannot be mined at a profit.

In summary, the mineral output of South Dakota has been steadily increasing and has responded favorably to each period of increased demand. The industry relies on a substantial and varied resource base which should be able to expand as the demands of an increasing population dictate.

GEOLOGY

(By N. M. Denson, U.S. Geological Survey, Denver, Colo.)

TOPOGRAPHIC AND PHYSIOGRAPHIC SETTING

South Dakota lies within the Great Plains physiographic province and to a smaller extent the Central Lowlands province. The Great Plains province is a broad highland that slopes gradually eastward from the Rocky Mountains on the west to the Central Lowlands on the east (Fenneman, 1931, pl. 1, p. 1–19). The Central Lowlands province extends from the drainage basin of the James River eastward. The Lowlands abound in lakes and include the South Dakota part of the "prairie pothole" country.

Largely on the basis of differences in topography, land forms, and geologic history, the Great Plains in South Dakota includes three subprovinces: (1) the Black Hills—a large domal uplift which extends northwestward at a maximum elevation of about 7,200 feet across the southwestern part of the State; (2) the northernmost extension of the High Plains—a relatively flat tableland, which extends eastward at an elevation of about 3,000 feet along the South Dakota-Nebraska boundary; and (3) the Missouri Plateau—a region of relatively low, undulating farm and grass land which surrounds the Black Hills north and west of the High Plains. The principal land forms in the Plateau province are low scarps, broad flood plains, and isolated buttes and ridges. Large areas of picturesque badlands are present at places near the Black Hills and along the Missouri River.

South Dakota lies almost entirely within the drainage basin of the Missouri River. The Missouri River enters the State along the north-central boundary at an elevation of about 1,600 feet, flows 480 miles generally southeastward, and leaves the State at an elevation of about 1,100 feet a few miles north of Sioux City, Iowa. The area west of the Missouri River is drained by generally eastward- and northeastward-flowing streams. From north to south these are the Grand, Moreau, Cheyenne, Bad, and White Rivers. The Cheyenne, which drains the Black Hills area, is the largest of the western tributaries. The eastern part of the State is drained by the southward-flowing James, Vermillion, and Big Sioux Rivers. The first two join the Missouri near the southeast corner of the State, and the Big Sioux forms the east border of South Dakota where it adjoins Iowa. Of all the streams only the Missouri has a large and well-sustained flow. Nearly all the other streams have had a zero flow at one or more times during periods of record extending back into the 1940's, 1930's, or 1920's (McGuinness, 1962, p. 4).

STRATIGRAPHY AND PALEOGEOGRAPHY

About half of the surface of South Dakota consists of sedimentary rocks of Paleozoic, Mesozoic, and early Cenozoic age. These rocks have a maximum combined thickness of as much as 10,000 feet and consist largely of limestone, dolomite, sandstone, and shale, with minor amounts of bentonite, claystone, gypsum, anhydrite, and salt. The sediments from which these rocks were formed were deposited either on land or in shallow seas whose depths probably were never much greater than a few hundred feet. Periods of deposition alternated with a few short intervals when the entire State was above sea level and subjected to subaerial erosion. Because of more or less continuous subsidence or downwarping since early Paleozoic time, a considerable thickness of sedimentary rocks accumulated in what is now known as the Williston basin. This basin, one of the largest structural and sedimentary basins in North America, underlies approximately 200,000 square miles in northern and central South Dakota, eastern Montana, western and central North Dakota, southern and central Saskatchewan, and southwestern Manitoba (Porter and Fuller, 1959, fig. 1). In the Williston basin, subsidence was greatest in the vicinity of the Killdeer Mountains in west-central North Dakota, where the sedimentary rocks have a maximum thickness of about 16,000 feet. Southward from this center the sedimentary rocks between the top of the Pierre Shale and the top of the Precambrian thin markedly to less than 7,000 feet in most of western South Dakota.

During the Laramide Orogeny in latest Mesozoic and earliest Tertiary time, the Black Hills came into existence, and at about the same time as much as 1,500 feet of sandstone, shale, and lignite of continental origin were deposited in the northwestern part of the State. By the end of Eocene time (40 million years ago), the cover of Mesozoic and Paleozoic sedimentary rocks had been eroded from the region of the Black Hills, and Precambrian rocks were exposed in an area of more than 1,500 square miles. Sedimentary rocks of Eocene age are not known in South Dakota, although large masses of igneous rock were intruded in the northern Black Hills at this time. At the close of the Eocene most of the State was a gently rolling plain that was near sea level.

Sedimentation during middle Tertiary time was markedly different from that of any previous time in the State's geologic history. Large volumes of ash and associated materials from volcanoes in the vicinity of Yellowstone Park were transported by easterly flowing streams and deposited across the truncated edges of the older rocks. Remnants of Oligocene and/or Miocene rocks at elevations of 6,200 feet on the flanks of the Black Hills and at higher elevations on the crest of the Bighorn Mountains to the west of the Black Hills in Wyoming indicate that these rocks at one time extended across most of the region. Their average thickness is believed to have been about 800 feet.

During Pliocene time (1 to 12 million years ago) the general area of the Black Hills was again uplifted. Erosion predominated over deposition and most of the soft, semiconsolidated rocks of middle Tertiary age were stripped from the higher parts of the Black Hills and from the plains region to the north and east. Sediments of Pliocene age derived largely from reworking of the Oligocene, Miocene, and older rocks were deposited at this time on the plains east and southeast of the Black Hills.

During Pleistocene time advances and retreats of large continental ice sheets from Canada deposited an average of about 40 feet and as much as 700 feet of glacial drift and outwash across that part of South Dakota east of the Missouri River (Flint, 1955, p. 27).

South Dakota has many and varied mineral resources, some of which are related to the origin, character, and structural relations of the rocks that contain them. The general succession, areal distribution, and lithologic character of the rocks in South Dakota are shown in a much generalized geologic map of the State (fig. 2) and by a composite stratigraphic chart (table 1). The rock units are referred to and described by authors in the following sections. A structure map (fig. 3) shows the principal structural features in the State. The State's resources herein described are related to these structural features.

STRUCTURE

In South Dakota, rocks of Paleozoic and Mesozoic age dip very gently except near the Black Hills where they are steeply upturned (fig. 3). At most places middle and upper Tertiary rocks rest unconformably and nearly horizontally across the nearly parallel strata of older rocks. However, at a few places on the flanks of the Black Hills vertical uplift during the Pliocene produced gentle dips in the middle and upper Tertiary rocks.

Most of the Paleozoic and Mesozoic rocks now occupy the shallow southern part of the Williston basin lying between structurally high areas represented by the Black Hills on the west and the Sioux uplift and Precambrian rocks at Big Stone Lake on the east. The northwest-plunging axis of the basin trends through the western third of the State with a very gentle dip averaging about 30 to 40 feet per mile on top of the Precambrian.

Two major upward folds of rocks are present north and southwest of the Black Hills. They are: (1) the south end of the Cedar Creek anticline, a narrow asymmetrical fold which plunges northwest from the central part of Harding County through the northwest corner of South Dakota, and (2) the north end of the Chadron arch which extends from Nebraska for about 20 miles northwestward into Shannon County in the southwestern part of the State (fig. 3). Subsurface data indicate that the Cedar Creek anticline probably had its inception in Paleozoic time, was periodically reactivated, and was most recently elevated during latest Mesozoic and earliest Tertiary time, when the Black Hills were formed. The geologic history of the Chadron arch may have been similar to that of the Cedar Creek anticline. Also in the area south of the Black Hills are minor folds not indicated on figure 3. These include the Barker dome and Chilson anticline which are discussed in the section of this report dealing with petroleum and natural gas resources.

Relatively small areas along the south border of the State are included in the Denver-Julesburg, Kennedy, and Forest City basins. Major folds in the South Dakota portions of these basins are unknown, and dips probably are gentle. These basins extend southward into Nebraska where their principal structural features have been shown by Reed (1955).

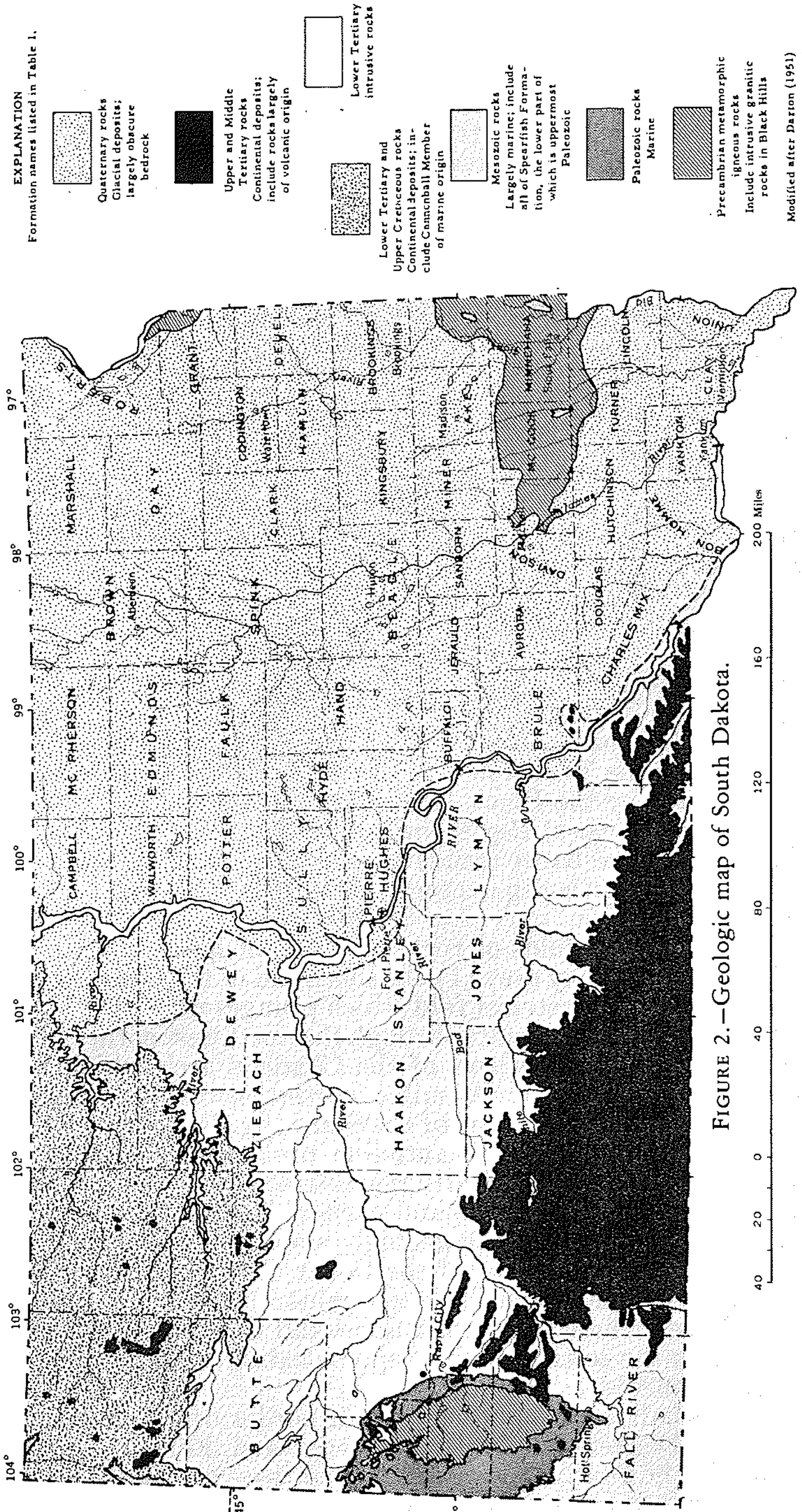

FIGURE 2.—Geologic map of South Dakota.

Table 1.--Generalized stratigraphic chart showing rock units present in South Dakota. The nomenclature shown on this chart is not necessarily that accepted by the U. S. Geological Survey. Rock unit shown in parentheses (Charles) present only in subsurface. ● , rock unit producing petroleum.

[After Sandberg (1962, fig. 6) except as noted: a, Flint (1955); b, Powell, Wagar, Petri (this report); c, Steece (this report)]

				Rock unit		Thickness (feet)	Map unit on geologic map of South Dakota (fig. 2)
CENOZOIC	Quaternary	Pleistocene		Glacial deposits		0 - 700[a]	Quaternary rocks Glacial deposits; largely obscure bedrock
	Tertiary	Pliocene		Ogallala		0 - 250[b]	Upper and middle Tertiary rocks Continental deposits; include rocks largely of volcanic origin
		Miocene		Arikaree		0 - 1,000[b]	
		Oligocene	White River Group	Brule		0 - 600[b]	
				Chadron			
		Paleocene		Fort Union	Cannonball	0 - 1,000[b]	Lower Tertiary intrusive rocks Lower Tertiary and Upper Cretaceous rocks Continental deposits; include Cannonball Member of marine origin
MESOZOIC	Cretaceous	Upper		Hell Creek		0 - 550	
				Fox Hills		0 - 250 [b]	Mesozoic rocks Largely marine; include all of Spearfish Formation, the lower part of which is uppermost Paleozoic
			Montana Group	Pierre		0 - 3,000	
			Colorado Group	Niobrara		0 - 1,400	
				Carlile			
				Greenhorn			
				Belle Fourche			
		Lower		Mowry	("D" sand)	0 - 600	
				Newcastle	("J" sand)		
				Skull Creek	Dakota		
			Inyan Kara Group	Fall River and Lakota	Minnewaste		
	Jurassic			Morrison	Unkpapa	0 - 225	
				Sundance		0 - 900	
				Gypsum Springs			
	Triassic			Spearfish	(Pine Salt)	0 - 775	
PALEOZOIC	Permian			Minnekahta		0 - 200	Paleozoic rocks Marine
				Opeche			
	Pennsylvanian			Minnelusa	●	0 - 1,200	
	Mississippian			(Kibbey)		0 - 100	
			(Madison Group)	(Charles)		0 - 1,250	
				(Mission Canyon)	Pahasapa		
				(Lodgepole)			
	Devonian			Englewood		0 - 80	
				(Three Forks)			
			(Jefferson Group)	(Birdbear)		0 - 400	
				(Duperow)			
				(Souris River)			
	Silurian			(Interlake)		0 - 300	
	Ordovician			(Stonewall)			
				(Stony Mountain)		0 - 750	
				Whitewood (Red River ●)			
				Winnipeg and (Harding ?)		0 - 180	
	Cambrian			Deadwood		0 - 700	
PRECAMBRIAN				Sioux Quartzite		0 - 3,800+[c]	Precambrian metamorphic and igneous rocks Include intrusive granitic rocks in Black Hills
				Igneous and metamorphic rocks undivided			

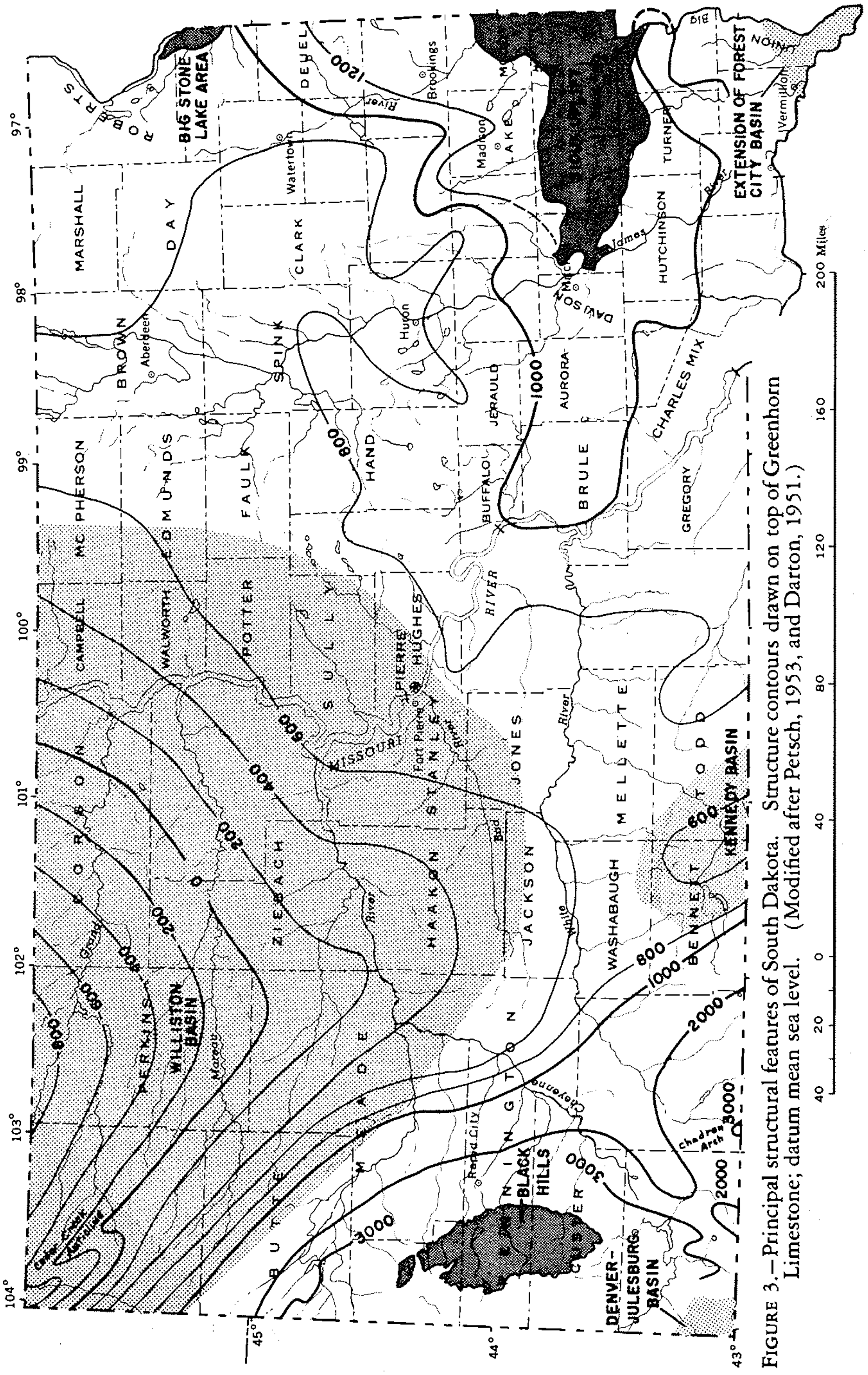

FIGURE 3.—Principal structural features of South Dakota. Structure contours drawn on top of Greenhorn Limestone; datum mean sea level. (Modified after Petsch, 1953, and Darton, 1951.)

GEOLOGIC HISTORY OF THE BLACK HILLS

(By J. P. Gries, South Dakota School of Mines and Technology, Rapid City, S. Dak.)

GENERAL DESCRIPTION

The Black Hills form a mountainous uplift astride the western South Dakota boundary. About two-thirds of the area is in South Dakota, the remainder in Wyoming. As measured by the rim of Cretaceous sandstones, which make foothills several hundred feet above the adjoining plains, the Black Hills are about 120 miles north-south, and up to 60 miles east-west.

The plains to the east have an elevation of about 3,200 feet; Harney Peak, the highest point in the Black Hills, has an elevation of 7,240 feet. Numerous other points on the western side of the Hills have elevations exceeding 7.000 feet.

The structure of the Hills is that of an elongate dome, with rocks steeply inclined on the east side and gently dipping on the west side. The present Black Hills were raised during the Laramide Revolution, about 60 million years ago. During and following the uplift, erosion removed approximately 6,000 feet of originally flat-lying sedimentary strata, and an undetermined thickness of granite and schists from the central part of the dome. Now a core of very ancient rocks forms the central Black Hills, and this is surrounded by concentric outcrops of successively younger rocks dipping away from the central area, affording an opportunity to study outcrops of rock strata that are deeply buried in other parts of the State (fig. 4).

PRECAMBRIAN ROCKS

The central part of the Black Hills is made of Precambrian rocks which cover an irregularly outlined area measuring about 60 miles long and 25 miles wide. Most of the rocks are drab gray quartzite, schist, and argillite. These were originally sandstone, siltstone, shale, and thin limestone beds that have been so intensely folded that they now lie in all attitudes from horizontal to vertical and even overturned. During the folding, intrusions of molten mafic igneous rock formed dikes and sills, now changed to dark-colored amphibolite. After folding, the south-central part of the area was intruded by great sheets of granite. In the Harney Peak area, the granite masses are so closely spaced as to appear as almost solid granite. Around the central mass, and mostly lying parallel to the planes of foliation in the schists into which they were intruded, are many thousands of small, tabular pegmatites that are only a few tens or hundreds of feet long. Some of the pegmatites are noted for their huge crystals of feldspar, quartz, mica, beryl, and lithium minerals. Thinner quartz veins in the Hill City area carry tin and tungsten.

Before the beginning of Cambrian time, the entire area had been deeply eroded, and worn to a nearly flat plain interrupted by low knobs of granite and ridges of resistant quartzite. The granite. which had been intruded and cooled at great depths, lay at the surface in what is now the southern Black Hills, and also in a broad belt extending southeastward from the Hills into northern Nebraska.

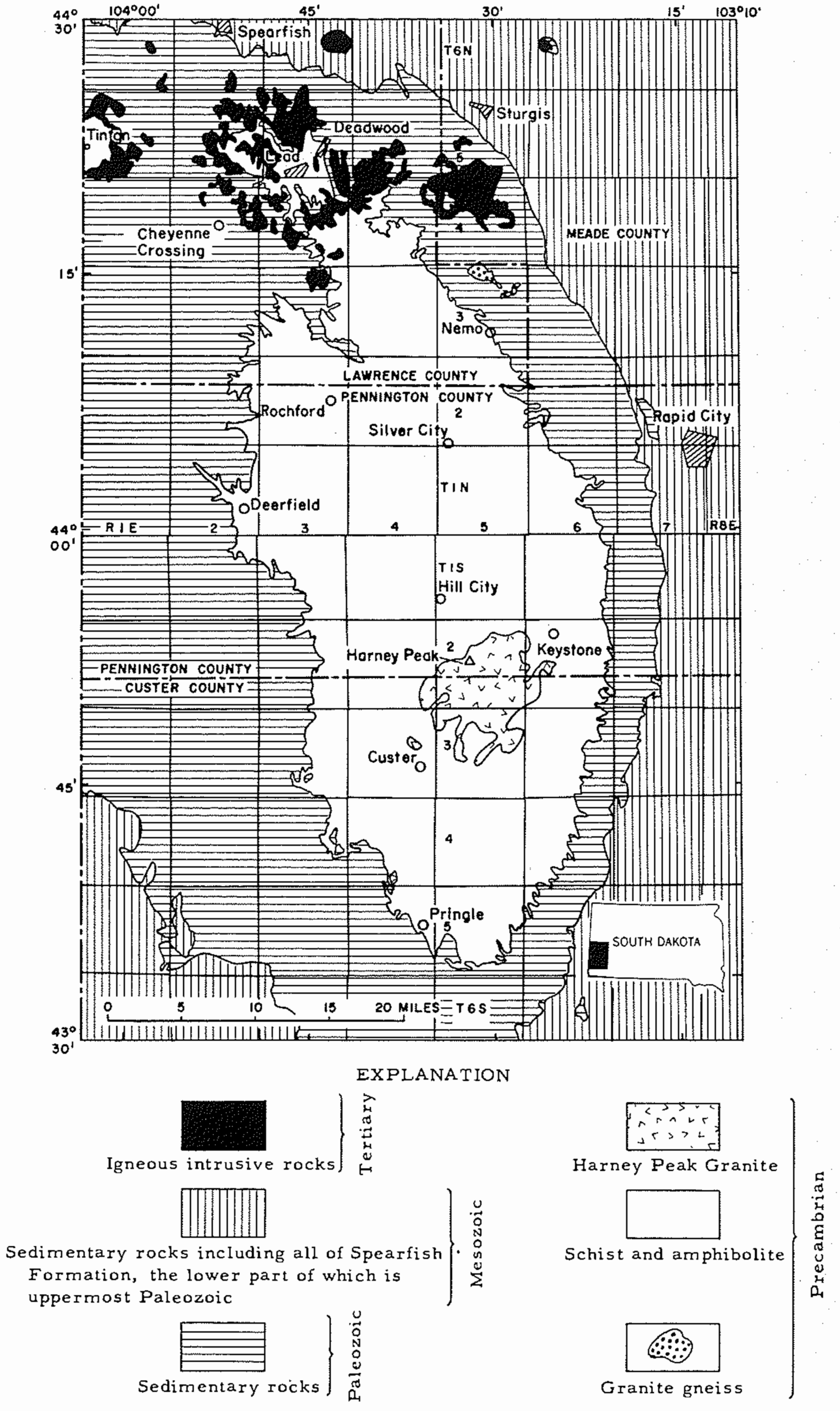

FIGURE 4.—Generalized geologic map of the Black Hills, South Dakota. Cenozoic sedimentary rocks not shown. Modified from Darton and Paige (1925) and Darton (1904 and 1905).

PALEOZOIC AND MESOZOIC ROCKS

The first sea to advance over the Precambrian surface covered the Hills area in Late Cambrian time. Initially it extended only a short distance to the south of the Hills. Slowly the sea retreated northwestward, and successively thicker and younger Cambrian rocks are found in that direction. The sequence of sandstone, limestone, and shale, which thickens from only a few feet in the southern Black Hills to nearly 400 feet at Deadwood, received the name Deadwood Formation from bold cliffs exposed in the lower end of that town. The uppermost beds at Deadwood contain fossils of Early Ordovician age.

A return of the sea in Middle Ordovician time permitted the deposition of about 100 feet of sandstone and green shale now called the Winnipeg Formation. These strata may be traced in deep wells to the vicinity of Winnipeg, Manitoba, where they were originally named. The Winnipeg beds are now present only in the northern Black Hills, about as far south as a line between Nemo and Cheyenne Crossing. If they originally extended farther, the record has been lost by erosion.

A readvance of the sea from the north in Late Ordovician time resulted in the deposition of the Whitewood Dolomite or the equivalent Red River Formation. It is about 60 feet thick near Deadwood, but thins southward and disappears at about the same line as the Winnipeg Formation. It probably extended farther south originally, but traces of sand in the outcrop area suggest that the southern shoreline may not have been far distant. The formation thickens to the north, and may be traced throughout the Williston Basin and westward into the Rocky Mountain area. It yields oil in the Buffalo Field in Harding County and in many fields along the Cedar Creek anticline in eastern Montana.

Many hundreds of feet of limestone and dolomite were formed in the Williston Basin during Silurian and Devonian time; these rocks thin southward and pinch out before reaching the Black Hills outcrop area. It is not known whether they once extended over the Black Hills.

In very late Devonian time, the sea again advanced from the north and submerged the Hills area. The initial deposit consisted of 35 to 50 feet of slightly pink, shaly limestone called the Englewood Formation. The lower part of the Englewood Formation contains Devonian fossils, the upper part, fossils of Early Mississippian age.

Deposition of a thick, pure, dolomitic limestone followed. It is called the Pahasapa Limestone in the Black Hills, and the Madison Group in adjacent areas. The Pahasapa thins to the southeast from over 600 feet in Spearfish Canyon to 250 or 300 feet in the southern Hills and to zero in deep wells in southeastern Fall River County. During Late Mississippian time, while sediments of the Kibbey Sandstone were being deposited to the north, the Black Hills area was subjected to weathering and erosion. Sink holes and caverns formed in the upper part of the old limestone surface, and a residual soil of red detrital clay and gravel accumulated in the low places.

In the Pennsylvanian Period, another sea invaded the area, this time from the south. Several hundred feet of sandstone, limestone, dolomite, anhydrite, and varicolored shale of the Minnelusa Formation were deposited. Periodically, the Hills area stood about at sea level, the anhydrites locally were dissolved, and overlying insoluble beds collapsed and were buried by sands deposited when the sea again deepened. This unstable condition continued into Permian time. The sea finally retreated and a period followed during which red shaly siltstone was laid down on a floodplain or in very shallow water. Occasionally, an arm of the sea encroached on the area, and anhydrite was precipitated. After about 100 feet of Opeche Formation redbeds and anhydrites was laid down, the sea returned long enough to permit deposition of 35 to 50 feet of very finely banded red and gray limestone known as the Minnekahta Formation. Redbed deposition was resumed to form red sandy siltstone and anhydrite of the Spearfish Formation. A period of erosion followed during which some of the Spearfish was removed. The Spearfish is difficult to measure on the outcrop, but just south of the Black Hills as little as 250 feet is present, whereas on the northwest flank over 700 feet is present.

A brief readvance of the sea from the northwest in Middle Jurassic time submerged at least the northern end of the Black Hills area, but most of the resultant deposits of anhydrite, sandstone, and limestone laid down in that sea were eroded before Late Jurassic time. Only thin remnants of the Gypsum Spring Formation of Middle Jurassic age are found in the northern Black Hills, though the formation is present in wells a short distance to the north. During Late Jurassic time, 250 to 300 feet of fine sand and greenish-gray shale accumulated to form the Sundance Formation. On the southeastern flank of the Hills area, an additional accumulation of up to 225 feet of fine white to highly colored sandstone is called the Unkpapa Sandstone. This is succeeded by the clays and sands of the Morrison Formation which were laid down on a vast floodplain that covered much of western North America. The plain was dotted with small lakes in which freshwater limestones were formed, and conditions were ideal for the burial and preservation of the bones of the countless dinosaurs that thrived in that environment.

During very early Cretaceous time, an uplift to the east caused meandering streams to spread coarse sand, silt, and clay over the entire area. This is now the Lakota Formation, which is generally less than 200 feet thick but reaches a thickness of over 600 feet on the southeast side of the present Black Hills. An encroachment of the Early Cretaceous sea caused additional fine sandstone to accumulate to form the Fall River Formation. As the sea deepened and the shoreline advanced eastward, sand deposition was followed by dark muds which now form the Skull Creek Shale. A rapid withdrawal and shoaling of the sea permitted streams from the east to distribute fine sand over the area in an irregular manner to form the Newcastle Sandstone. Shale deposition was resumed in the Black Hills area while a large delta of continental sands and clays was being built up in central and eastern South Dakota. The resulting wedge of sandstone, which reached a thickness of 400 feet in the south central part of the State, now constitutes the Dakota Sandstone and is the source of water for most of the artesian wells in eastern South Dakota. Gradually, the delta was submerged, and black muds of the Belle Fourche Shale extended nearly across the State. A brief period of deposition of limy muds and limestone formed the Greenhorn Limestone. Deposition of silty dark shales followed to make up the Carlile Shale, succeeded by another period when sufficient lime was available in the sea to form the 200-foot thick Niobrara Formation. An additional 1,700 to 3,000 feet of dark shale and claystone now known as the Pierre Shale was then deposited. Finally, the long period of submergence drew to a close, and the sea retreated to the southeast, leaving behind a final near-shore deposit of sandstone called the Fox Hills Sandstone. Sluggish streams continued to spread sand and clay of the Hell Creek and Fort Union Formations over the flat plains from which the sea had retreated.

BIRTH OF THE BLACK HILLS

At about the time the Cretaceous sea retreated from western North America, warping of the earth's crust along the western part of the old Cretaceous seaway formed the Rocky Mountains. Far to the east, in what is now western South Dakota, a similar folding and uplifting, on very much smaller scale, formed the Black Hills. As the Black Hills dome was formed, erosion actively attacked the soft shales, and finally the harder and older sediments. During the later stages of uplift and erosion, a period of intense igneous activity took place in the northern Black Hills. Great volumes of molten rock forced upward from deep within the earth's crust. As the magma approached the surface, it spread out between the weaker sedimentary strata, forcing them apart, and forming huge blisters called laccoliths. We see them today, partly dissected, in Vannocker, Deadman, and Green Mountains, and in Custer and Crow Peaks. At other places, the overlying rocks broke, and the molten rock forced itself up in steepsided plugs such as Bear Butte. Many of the mineral deposits in the northern Black Hills were formed during and immediately following this period of intense igneous activity.

LATER TERTIARY AND RECENT HISTORY

By early Oligocene time, stream gradients were so reduced that the streams could no longer carry away their erosion products, and deposition started on the plains adjacent to the Hills. Early Oligocene basal gravels include easily recognizable fragments of rose quartz, tourmaline, and feldspar derived from the southern Black Hills, indicating that by that time at least 6,000 feet of sedimentary cover had been removed, and that basement schists, granites, and pegmatites were being actively eroded. Gradually the Black Hills became buried by light-colored clays and sands, derived not only locally, but from mountain areas to the west. Volcanic activity, probably in the vicinity of Yellowstone Park, contributed huge volumes of windblown volcanic ash to the sediments. By the end of Oligocene time, it is possible that the Black Hills projected less than 2,000 feet above this apron of sediments.

Uplift, or a change in climate, or both, caused a renewal of erosion, the soft unconsolidated sediments were attacked, and gradually the lower part of the Black Hills were exhumed. They probably look today very much as they did at the end of the Eocene Epoch, 40 million years ago.

The Pleistocene and Recent history has been one in which intervals of local sedimentation in the stream valleys has alternated with periods of renewed downcutting of the streams. This history is shown by a series of benches or terrace remnants at successively lower elevations along the major streams in the area. Many of these are related to changes in the course of the Missouri River during the Ice Age, and to development of the present courses of the Cheyenne and White and Belle Fourche Rivers, but the exact history remains to be worked out. The Black Hills were not sufficiently high to support glaciers during the Ice Age, but the alternating periods of warm and cold climate must have influenced stream erosion during that time.

PRECAMBRIAN ROCKS OF EASTERN SOUTH DAKOTA

(By F. V. Steece, South Dakota Geological Survey, Vermillion, S. Dak.)

CHARACTER AND DISTRIBUTION OF THE ROCKS

Precambrian rocks of South Dakota, exclusive of the Black Hills, are composed of a wide variety of types. The youngest and most uniform rock unit is the Sioux Quartzite, which crops out in the southeastern part of the State. In the subsurface, this formation is underlain by a vast body of older granitic rocks interspersed with small areas of metamorphic rocks, and locally some rhyolite. The surface extent and subsurface distribution of the principal Precambrian units are shown on figure 5, together with information on types of Precambrian rocks encountered in wells throughout other parts of the State.

The Sioux Quartzite was deposited on an extremely irregular surface of older plutonic and other rocks. It ranges in thickness from zero to a known maximum of 3,800 feet, where penetrated in an oil test in southeastern South Dakota. Baldwin (1949) estimated the formation has a maximum thickness of more than a mile. Pipestone interbedded with the Sioux Quartzite at Pipestone, Minn., has been dated at 1.2 billion years (Goldich and others, 1959, p. 660).

At places, hills on the old surface of plutonic and metamorphic rocks protrude through "windows" in the Sioux Quartzite, as for example in Sanborn, Miner, and Kinsbury Counties shown in figure 5. A core of rhyolite was taken from a depth of 675 feet from a well in the "window" in Sanborn County, about 25 miles southeast of Huron. This rock has been dated[1] radiometrically at 1.64 ± 0.09 billion years. Other examples of "windows" in the quartzite are in Yankton, Minnehaha, and Lake Counties (fig. 5) where plutonic rocks make up the basement surface.

The Precambrian granitic rocks include the Milbank granite which is found in the subsurface in the northeastern part of the State, and generally is a potassium-rich granite or granodiorite composed essentially of quartz, microcline, biotite, and harnblende, with minor accessory minerals. This rock has been dated at about 2.0 billion years (Goldich and others, 1961, p. 146). Many wells drilled to the base-

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[1] "This radiometric age date is the result of a cooperative dating program on buried basement rocks between the Crustal Studies Laboratory, the University of Texas, and the Isotope Geology Branch, U.S. Geological Survey. The grant to the University of Texas supporting this work is contract No. AF 49(638)–1115 of the Air Force Office of Scientific Research as part of the Advanced Research Projects Agency Project VELA UNIFORM."

ment in South Dakota have penetrated granitic rocks that are similar to the Milbank and therefore are presumably part of the same rock mass. This correlation has been shown correct at least as far west of Milbank as Brown County where a core of pink biotite granite similar to typical Milbank granite was dated at 2.27 ± 0.11 billion years,[2] which fits well with dates at Milbank.

SURFACE ON THE PRECAMBRIAN ROCKS

The top of Precambrian rocks in South Dakota slopes generally from east to west across all but the southwestern part (fig. 6). The Sioux Quartzite crops out at the ground surface at elevations of more than 1,500 feet in Minnehaha County. The top of these rocks drops gradually westward toward the edge of the Precambrian outcrop area where at places there is an escarpment of several hundred feet. From this rim, the top of Precambrian or basement rocks slopes gently westward, beneath younger sedimentary rocks into the depths of the Williston basin in northwestern South Dakota. The lowest elevation recorded on South Dakota's Precambrian surface is about 6,500 feet below sea level. From a trough in the western part of the State, the basement rises gently southwestward toward the Black Hills. The slope steepens abruptly near the Black Hills, rising nearly 10,000 feet in a distance of about 40 miles. The maximum known relief on the top of the Precambrian in South Dakota is almost 14,000 feet.

A magnetometer study of the northeastern part of the State (Petsch, 1964) shows a series of extraordinary magnetic highs that trend northeastward into western Minnesota. Minnesota Precambrian metasedimentary rocks associated with the highs are dated at about 1.62 billion years[3] (Goldich and others, 1961, p. 4, 104), or between the ages of the Milbank granite and the Sioux Quartzite. It seems likely that the highly magnetic areas in South Dakota are caused by rocks of the same age, although such rocks have not yet otherwise been identified. The trend of the anomalies corresponds roughly to the trend of several of the "windows" in the quartzite. A sequence of events accounting for these relations is postulated as follows: the Milbank granite formed about 2 billion years ago. This was followed by deposition of iron-rich rock that now produces the high magnetic anomalies. Folding and erosion then gave rise to a northeast trending mountain range that subsequently was partly buried by deposition of the Sioux Quartzite. The anomalies perhaps mark places where iron-rich rocks protrude through the "windows" in the quartzite or are only thinly covered by quartzite along the crest of the buried mountains.

ECONOMIC POTENTIAL

Precambrian granite and quartzite long quarried in eastern South Dakota have contributed greatly to the State's economy as structural and ornamental stone.

Some geologists suggest that the Sioux Quartzite has been partly metamorphosed by the intrusion of certain granitic rocks. If this is true, then there may be undiscovered mineralized zones awaiting exploratory drilling.

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[2] See footnote 1, previous page.
[3] Date is for metasediments of the Cuyuna Range.

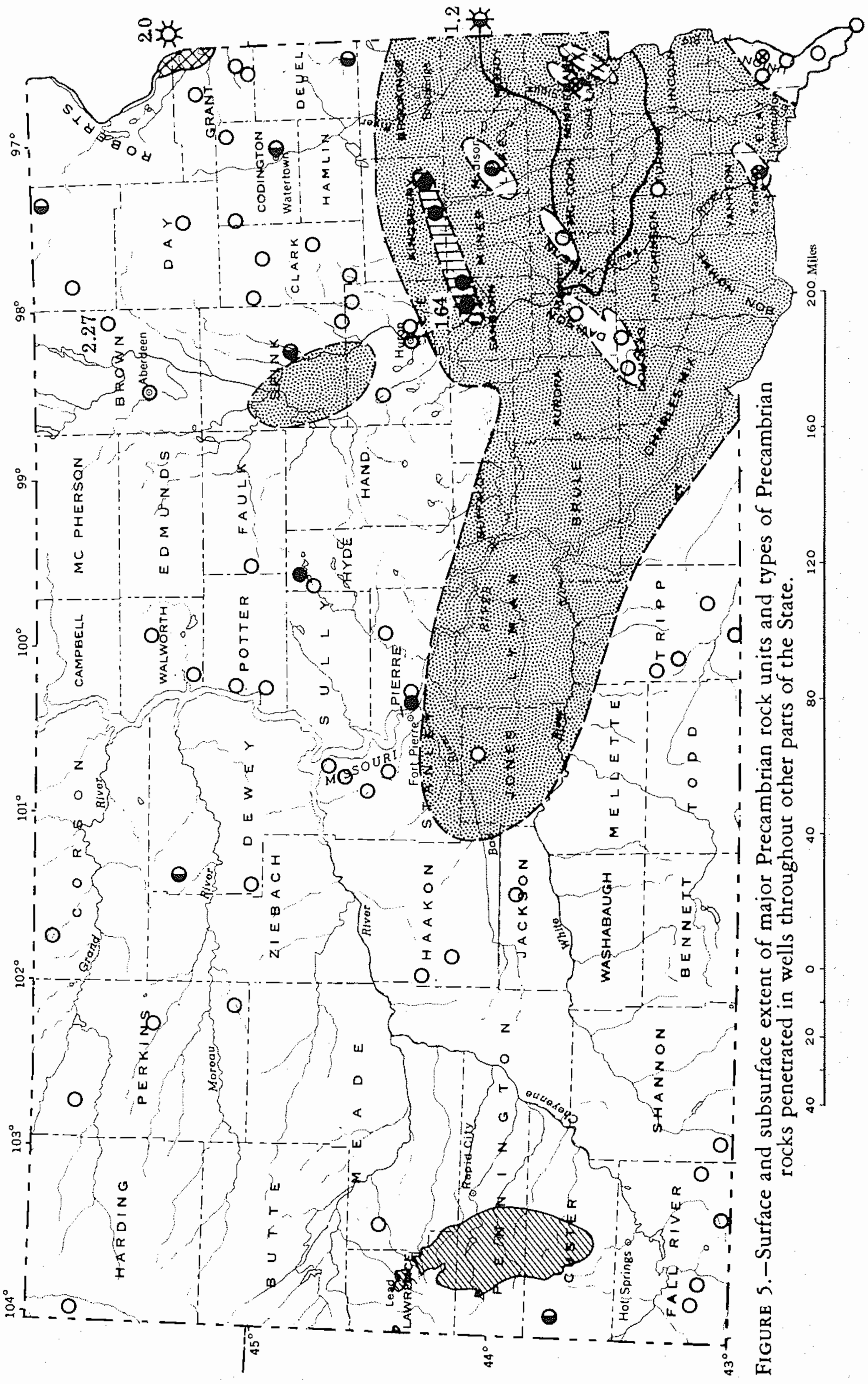

FIGURE 5.—Surface and subsurface extent of major Precambrian rock units and types of Precambrian rocks penetrated in wells throughout other parts of the State.

EXPLANATION

░ Sioux Quartzite

▩ Milbank Granite

▨ Metamorphic and igneous rocks

▥ Rhyolite

〜 Limit of outcrop

╌ Known subsurface extent

x Magnetite-bearing gabbro at surface

1.3
Age determination in billions of years

☼ Outcrop

○ Well

Outcrop and wells

Rock type (superimposed on well or outcrop symbol):

- ○ Granite
- ● Extrusive volcanic rocks
- ⊗ Magnetite-bearing gabbro
- ◐ Metamorphic rocks

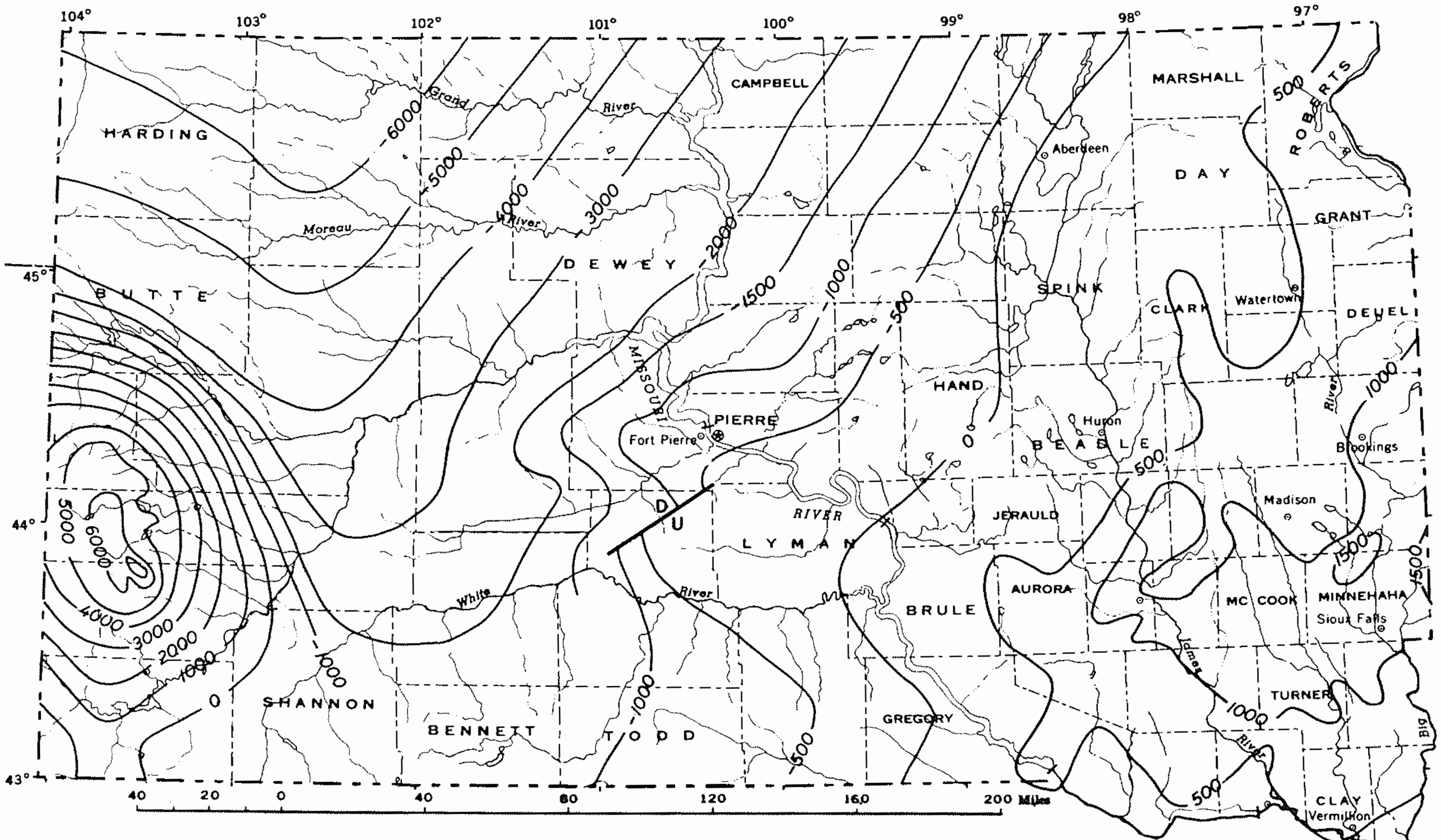

FIGURE 6.—Configuration of the top of Precambrian rocks in South Dakota. Datum is sea level. Fault displacing Precambrian shown by heavy line; D, downthrown side; U, upthrown side. Modified from Steece (1962).

Test drilling of magnetic anomalies in southeastern South Dakota has revealed small amounts of iron (Petsch, 1964). Precambrian rocks which produce more pronounced anomalies in the northeastern part of the State may prove much richer in iron, and possibly they may be of ore quality. Near the anomalies, Precambrian rocks lie beneath 750 to 1,050 feet of younger sedimentary rocks, and thus any mineral deposits present would be expensive to explore and mine. Test drilling would be necessary to determine the location, grade, and extent of these possible ore deposits.

ECONOMIC GEOLOGY

(By N. M. Denson and J. C. Ratte, U.S. Geological Survey, Denver, Colo.)

The character, quantity, and availability of mineral and water resources in South Dakota are the result of geologic processes that have acted over a long geologic history. These processes and the geologic factors affecting the State's resources are described in the sections of this report dealing with the metallic, nonmetallic, fuel, and groundwater commodities. The geologic environments of these commodities, their areal distribution, and relative importance to the State's economy are summarized here.

Because of marked differences in the origin, character, and structural relations of its surface rocks, the mineral resources of South Dakota are of a wide variety and are broadly distributed. About 75 percent by value of South Dakota's mineral production is represented by mineral commodities associated with Precambrian rocks, mainly in the metamorphic rocks and granite of the Black Hills, and in the granite of northeastern South Dakota. The list of these commodities is led by gold, which alone accounts for two-thirds of the total value of mineral products in South Dakota (fig. 1). Gold mining presently is confined to the Homestake mine in the northern Black Hills, where the deposits occur mainly in Precambrian schist, but some gold has been mined from basal Cambrian and Mississippian rocks in this area. The age of the gold deposits is uncertain; it may be predominantly of Precambrian age, entirely Tertiary in age, or part Precambrian and part Tertiary. Some silver is recovered from the gold ores.

Pegmatites associated with Precambrian granite in the southern Black Hills are the source of the light metals, beryllium and lithium, which occur mainly in the minerals beryl and spodumene, respectively; these, together with feldspar and mica constitute a small but significant part of South Dakota's mineral production. Tungsten and tin also occur in quartz veins and pegmatites associated with granitic rocks in the Black Hills. Precambrian iron formation in the Nemo area of the Black Hills is a mineral commodity of potential value.

In the northeastern part of South Dakota near the Big Stone Lake area (fig. 3) the Milbank granite of Precambrian age has been quarried extensively for monumental stone. Annual value of production of this resource alone amounts to about $3 million.

Peripheral to and surrounding the Precambrian rocks of the Black Hills is a thick sequence of steeply to gently dipping sedimentary rocks of Paleozoic and Mesozoic ages which have yielded important quantities of limestone, clay, gypsum, and uranium, and minor amounts of gold-silver, lead-silver, and tungsten. These account for about 10 percent of the State's total mineral production. The uranium industry in South Dakota is relatively new and shows promise of adding substantially to the State's economy. The possibility that additional mineral deposits can be found underneath the younger rocks on the flanks of the Black Hills has not been much investigated, and important concealed deposits may yet be found in western South Dakota.

Sand and gravel, which are widely distributed over most of the State have been produced in a larger volume than any other mineral product and are second only to gold in total value. They account for about 10 percent of the total mineral output. In the area east of the Missouri River, the sand and gravel deposits of South Dakota are found in glacial outwash, whereas in the western unglaciated portions of the State most of the deposits are confined to the terraces of the major streams and their tributaries. Alluvial fans and mountain outwash are valuable sources for the commodity in and around the Black Hills.

In northwestern South Dakota approximately 7,700 square miles is underlain by the Hell Creek and Fort Union Formations of Late Cretaceous and Paleocene age which contain lignite (fig. 2). In Fall River County in the southwestern part of the State small quantities of bituminous coal are present in the Lakota Formation of Early Cretaceous age. Both the lignite and the bituminous coal have been mined to a very limited extent and used largely for domestic heating. Nevertheless, the lignite deposits of northwestern South Dakota constitute a resource of considerable magnitude and potential value. Many of the thin impure lignite beds contain uranium of ore grade. Although most of the production of uranium from South Dakota has been from sandstone-type deposits in the Black Hills, the lignites constitute the greater reserve. Lignite with a uranium content less than ore grade, as currently valued, also underlies large areas in the northwestern part of the State. These low-grade deposits constitute a large potential resource of uranium, the development of which is dependent on the use of lignite as fuel and the recovery of the uranium as a byproduct.

South Dakota was considered a future petroleum-producing province at least 13 years prior to the discovery of commercial production in Harding County in 1954. To the present time, however, exploration has been limited and the State's petroleum potential has not been fully explored. Most of the State's production is from the Red River Formation of Ordovican age (at a depth of about 8,600 feet) in the Buffalo oil field in the northwestern part of the State, and from the Minnelusa Formation of Pennsylvanian and Permian age (at a depth of about 1,500 feet) in the Barker dome in Custer County, in the southwestern part of the State.

Production of natural gas in South Dakota is at present negligible. Small production accompanies the production of petroleum at the southeast end of the Cedar Creek anticline in the Buffalo oil field, and at Barker dome on the southwestern flank of the Black Hills uplift.

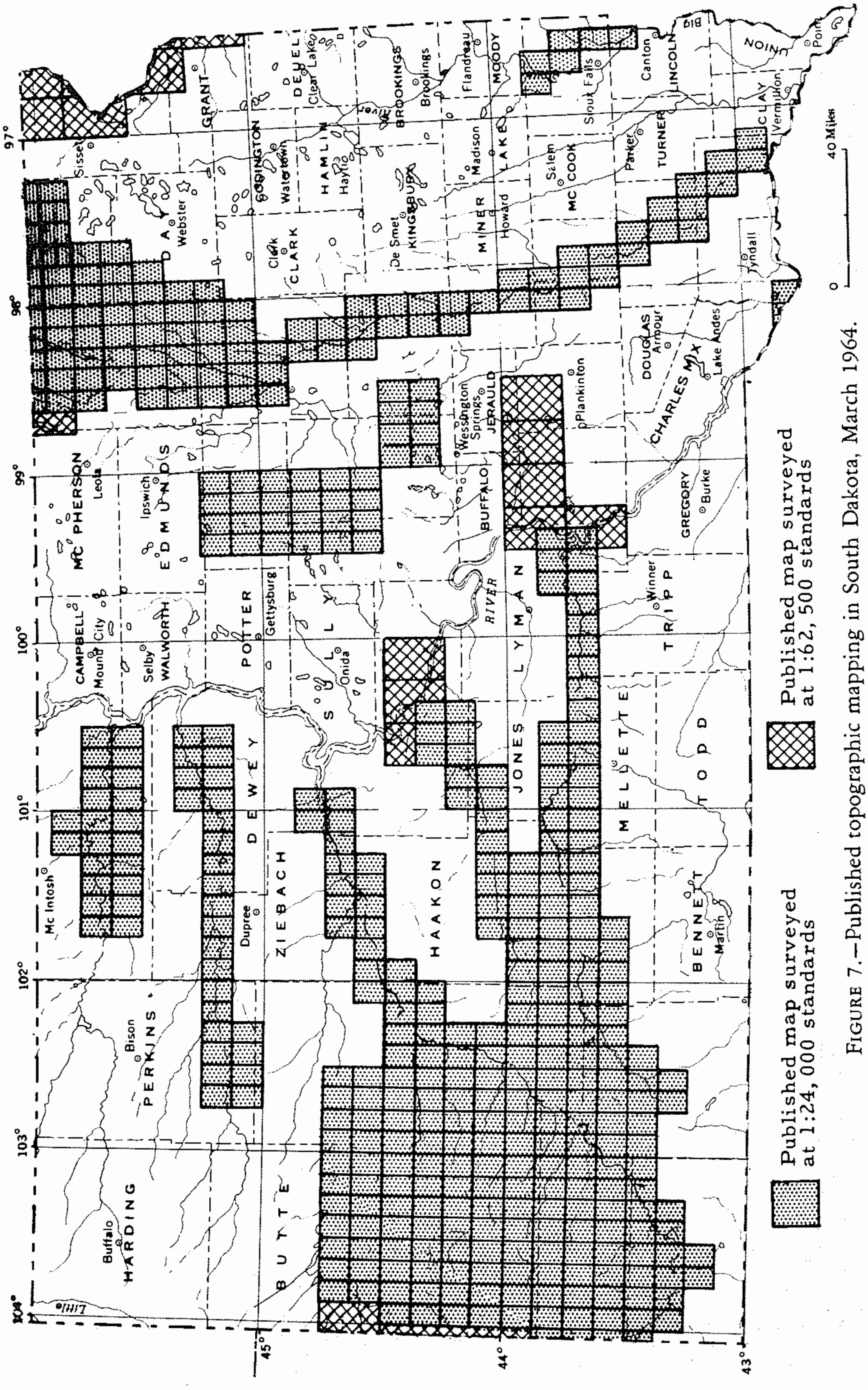

FIGURE 7.—Published topographic mapping in South Dakota, March 1964.

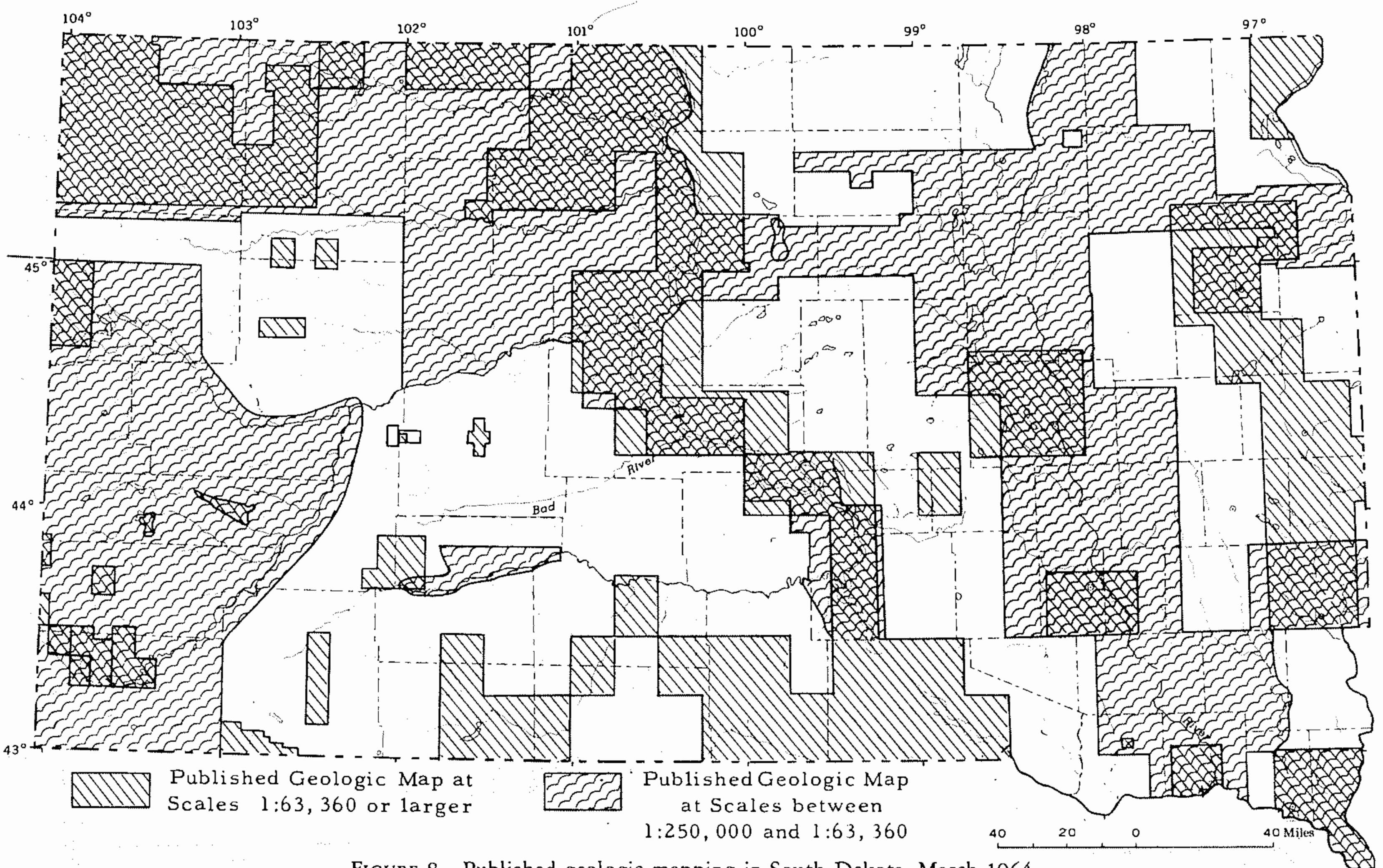

FIGURE 8.—Published geologic mapping in South Dakota, March 1964.

Water of generally good quality that has contributed much to the State's economy is produced from glacial drift in the area east of the Missouri River and from the semi-consolidated rocks of the Chadron, Brule, Arikaree, and Ogallala Formations of middle and late Tertiary ages in the High Plains section along the South Dakota-Nebraska border. The importance of these rocks as aquifers has long been recognized and much effort presently is being directed to their study.

Evaluation of the mineral and water resources of South Dakota is facilitated by topographic and geologic mapping. As shown on figure 7, modern topographic maps are available for only about a third of the State. Similarly, as shown on figure 8, less than two-thirds of the State has been mapped geologically. It is evident, therefore, that much mapping remains to be done.

Aeromagnetic maps by the U.S. Geological Survey in South Dakota are limited to two areas: (1) the central and eastern parts of Lawrence County—the Deadwood area (Meuschke, Philbin, and Petrafeso, 1962), and (2) the southwestern part of Custer County (Meuschke, Johnson, and Kirby, 1963). These maps, compiled on 7½-minute topographic sheets, are published at scales of 1/48,000 and 1/62,500, respectively, and cover approximately 800 square miles in southwestern South Dakota.

The U.S. Geological Survey (1963) has published a topographic base map of the State (1 inch=about 8 miles—contour interval 200 feet) which shows the principal highways, railroads, water facilities, county boundaries, all towns, and most of the smaller settlements.

Areas in South Dakota for which geologic maps are available—the source of publication, date, author, and approximate scale of each map—are given by Boardman and Brown (1958). Many of the publications to which these authors refer may be consulted in the following libraries in South Dakota:

Brookings: Lincoln Memorial.
Pierre: South Dakota Free Library Commission.
Rapid City: South Dakota School of Mines and Technology.
Sioux Falls: Carnegie Free Public.
Vermillion: South Dakota Geological Survey, University of South Dakota.

A more detailed description of the resources on a commodity-by-commodity basis is presented in the following chapters.

SELECTED REFERENCES

Baldwin, Brewster, 1949, A preliminary report on the Sioux Quartzite: South Dakota Geol. Survey Rept. Inv. 63, 34 p.

Boardman, Leona, and Brown, Annabel, compilers, revised by Bove, A., 1958, Geologic map index of South Dakota: U.S. Geol. Survey.

Darton, N. H., 1904, Description of the Newcastle quadrangle [Wyo.-S. Dak.]: U.S. Geol. Survey Geol. Atlas, Folio 107.

——— 1905, Description of the Sundance quadrangle [Wyo.-S. Dak]: U.S. Geol. Survey Geol. Atlas, Folio 127.

——— 1951, Geologic map of South Dakota: U.S. Geol. Survey.

Darton, N. H., and O'Harra, C. C., 1905, Description of the Aladdin quadrangle [Wyo.-S. Dak.-Mont.]: U.S. Geol. Survey Geol. Atlas, Folio 128.

Darton, N. H., and Paige, Sidney, 1925, Central Black Hills [South Dakota]: U.S. Geol. Survey Geol. Atlas, Folio 219.

Darton, N. H., and Smith, W. S. T., 1904, Description of the Edgemont quadrangle [S. Dak.-Neb.]: U.S. Geol. Survey Atlas, Folio 108.

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

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U.S. Geol. Survey Prof. Paper 262, 173 p., 7 pls., 36 figs.

Goldich, S. S., Baadsgaard, Hafdan, Edwards, G., and Weaver, C. E., 1959, Investigations in radioactivity-dating of sediments: Am. Assoc. Petroleum Geologists Bull. 43, p. 654–662.

Goldich, S. S., Nier, A. O., Baadsgaard, Hafdan, Hoffman, J. H., and Kreuger, H. W., 1961, The Precambrian geology and geochronology of Minnesota: Minnesota Geol. Survey Bull. 41, 193 p.

McGuinness, C. L., 1962, Water in South Dakota: South Dakota Geol. Survey and South Dakota Water Resources Comm., Water Resources Rept. 2, 33 p.

McMillan, W. D., 1946, Exploration of the Bourbon magnetic anomaly, Crawford County, Missouri: U.S. Bur. Mines Rept. Inv. 3961.

Meuschke, J. L., Philbin, P. W., and Petrafeso, F. A., 1962, Aeromagnetic map of the Deadwood area, Black Hills, South Dakota: U.S. Geol. Survey Geophysical Inv., Map GP–304.

Meuschke, J. L., Johnson, R. W., and Kirby, J. R., 1963, Aeromagnetic map of the southwestern part of Custer County, South Dakota: U.S. Geol. Survey Geophysical Inv. Map GJ–362.

Petsch, B. C., 1953, Structure map of South Dakota Greenhorn datum: South Dakota Geol. Survey.

——— 1962, Magnetometer survey of southeastern South Dakota: South Dakota Geol. Survey Mineral Resources Inv. Map 3.

——— 1964, Magnetometer survey of northeastern South Dakota: South Dakota Geol. Survey Resources Inv. Map —. In preparation.

Porter, J. W., and Fuller, J. G. C. M., 1959, Lower Paleozoic rocks of northern Williston basin and adjacent areas: Am. Assoc. Petroleum Geologists Bull., v. 43, no. 1, p. 124–189.

Powell, J. E., Wagar, J. E., and Petri, L. R., 1964, Water Resources of South Dakota, *in* this report, p. 320–412.

Reed, E. C., 1955, Structure contour map of Nebraska, *in* Oil and gas fields of Nebraska, 1956: Rocky Mtn. Assoc. Geologists.

Sandberg, C. A., 1962, Geology of the Williston basin, North Dakota, Montana, and South Dakota, with reference to subsurface disposal of radioactive wastes: U.S. Geol. Survey Rept. TEI–809, open-file rept., 148 p.

Steece, F. V., 1962, Precambrian basement rocks of South Dakota: South Dakota Acad. Sci. Proc., v. 41, p. 51–56.

U.S. Geological Survey, 1963, Topographic base map of South Dakota, scale 1:500,000 (1 inch=about 8 miles); contour interval 200 feet.

METALLIC MINERAL RESOURCES

(By R. H. Miller, State Industrial Development Expansion Agency, Pierre, S. Dak.)

INTRODUCTION

Historically gold has been, and is, the most important metallic mineral resource of South Dakota. The discovery of gold gave the impetus to rapid settlement of the Black Hills, and the production of gold has been economically important to the State for many years. In fact, such development of metallic mineral resources as there has been in South Dakota has come about, at least in part, as a result of the search for gold. Recently gold has been produced in amounts annually reaching a figure near $20 million, and the gold-mining industry is one of the leading employers in the State. Other metals have not fared as well over the years.

Silver has been produced primarily as a byproduct of gold, except during the early 1900's when silver was produced with lead mined from the Galena, Spokane, and Silver City areas in the Black Hills. Production from these areas rapidly declined after a few years. Improving prices for silver might eventually revive interest in some of these old mining areas.

Uranium and vanadium are latecomers to the South Dakota mining economy; first shipments of these metals were made to a buying station at Edgemont in 1952. A uranium processing plant began operation in 1956, and it had a stimulating effect on uranium ore production in the area. Production of byproduct vanadium from uranium processing began not long after. At the present time, molybdenum is being recovered from lignite ash processed with the uranium ore at the Edgemont plant.

South Dakota's iron ore resources include a wide variety of minerals, mostly in the Precambrian iron formation in the area between Steamboat Rock and Benchmark, which remains practically untouched. In relatively recent years similar ores elsewhere have become attractive in the production of beneficiated pellets for the steel industry.

Manganese is one of the few metals found in quantity outside of the Black Hills area. The manganese occurs as nodules in certain shales that crop out along the Missouri River. An immense body of low-grade manganiferous material has attracted interest from time to time, and several attempts have been made to find a cheap method of separating the manganese nodules from the enclosing shale. Production has occurred only intermittently, and has been related to pilot-plant operations. In recent years additional large resources of manganese nodules have been discovered in Pleistocene gravels that are widespread east of the Missouri River.

Production of most metals in South Dakota has fluctuated widely, except for gold, silver, and some of the metallic minerals that have come into prominence in recent times. Even gold production was reduced drastically by government order during World War II. Production of copper, lead, zinc, tungsten, tin, and some other metals reached their production heights, for the most part, 60 or more years ago. Reports of the State mine inspector show, for instance, that production of copper, lead, and zinc probably was greatest before 1888, with values estimated at $750,000 in the period around 1881 and 1883. After 1900 production dropped to practically nothing except for a brief revival during World War II when production valued at $36,000 was recorded in 1942. Small amounts of these metals are still mined from time to time.

Although tungsten is known to exist in several areas of the Black Hills, the only area that has produced tungsten in quantity is around Lead and Deadwood. Tungsten was mined in this area from 1913 through 1918, reaching a peak production of about $400,000 in 1916, but output has been practically nonexistent since. Association with low-grade gold ore, which permitted the recovery of both minerals, was an important factor in the production of tungsten. Higher prices for tungsten during World War I undoubtedly also had an important influence on production.

There has been, at one time or another, considerable interest in recovering tin from the mineral cassiterite; however, very little tin has been produced in South Dakota despite the flurries of mining and mill construction. Activity began in 1884 with the formation of the Harney Peak Tin Co., and centered around the Hill City area where cassiterite was found associated with small pegmatites and quartz veins. Interest later shifted to the Tinton area of Lawrence County. Tin produced in South Dakota sold for about $110,000 (table 5); most of it was mined more than 50 years ago.

Development of most of the known deposits of metallic minerals has been associated with the search for gold and most of it occurred before 1915. There have been very few discoveries since then. Nevertheless, it is most unlikely that South Dakota's metallic mineral deposits have all been discovered.

There is a chance that resources unknown today, in quantity and quality adequate to permit extraction, can be found, that interest in mining can be aroused, and production increased if some of the following techniques were applied:

1. Large-scale geophysical and/or geochemical exploration for geologic conditions favorable to ore deposits, followed by adequate core drilling in pertinent areas.
2. Review by the mining industry of some abandoned areas of the Black Hills, with a view toward reappraisal of mineral values in light of present day large-scale mining and metallurgical techniques.
3. Application of adequate capital and knowledge to the development of untested areas believed to be physically and mineralogically favorable to exploration and mine development.

Some small beginnings have already been made along these lines, and hopes for the future are bright.

GOLD AND SILVER

(By M. H. Bergendahl, U.S. Geological Survey, Denver, Colo.)

The precious metal mining districts of South Dakota are concentrated in a small area in the central part of the Black Hills, in the western part of the State (fig. 9). Gold is the principal commodity, most of which has come from the great Homestake mine in the Lead district. Silver has been more or less a byproduct of gold mining; there are no deposits that are mined for silver alone, with the possible exception of some in the Squaw Creek district in the 1880's. Total output of gold from 1876 through 1963 is 29,956,294 ounces; silver production for the same period is 11,873,069 ounces.[1] Figure 10 shows yearly output of gold and silver.

HISTORY

The first documented mineral discovery was made in 1874, during Gen. George A. Custer's reconnaissance expedition to the Black Hills. The actual discovery is credited to two miners attached to the expedition who found gold in gravel bars along French Creek. News of this discovery attracted many prospectors to the area, even though the country then belonged to the Sioux Indians, who were not overly enthusiastic at having their domain overrun. Equally adamant in this respect was the U.S. Government, which was bound by a treaty to keep whites out of the Black Hills. In 1875, another expedition under the direction of W. P. Jenney was sent to the Black Hills to appraise the potential mineral wealth of the region. The French Creek discoveries were confirmed, and numerous additional occurrences of placer gold were reported (Newton and Jenney, 1880, p. 226–294). In 1876 the Black Hills were ceded to the United States, and prospectors flooded into the area. By 1880 from $6 million to $8 million worth of placer gold had been mined, about half of which came from Deadwood Gulch (Lincoln, *in* Lincoln, Miser, and Cummings, 1937, p. 11, 12).

The first lode claims were located in December 1875 in the Lead district; these were later purchased to form the original holdings of the Homestake Mining Co. As the placers became depleted the Homestake Co., through judicious development and acquisition of other properties, became the leading operator in the Black Hills and the largest gold producer in the United States. Several smaller companies also developed lodes in the Deadwood, Garden, Bald Mountain, Squaw Creek, Hill City, and Keystone districts.

GENERAL CHARACTERISTICS OF THE DEPOSITS

The gold and silver deposits of South Dakota can be grouped into the following classes:

1. Replacement deposits and veins in Precambrian rocks (Lead, Hill City, Keystone districts)
2. Deposits that resemble placers in the basal Cambrian conglomerate (Deadwood, Lead districts)

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[1] Source of data, U.S. Bureau of Mines.

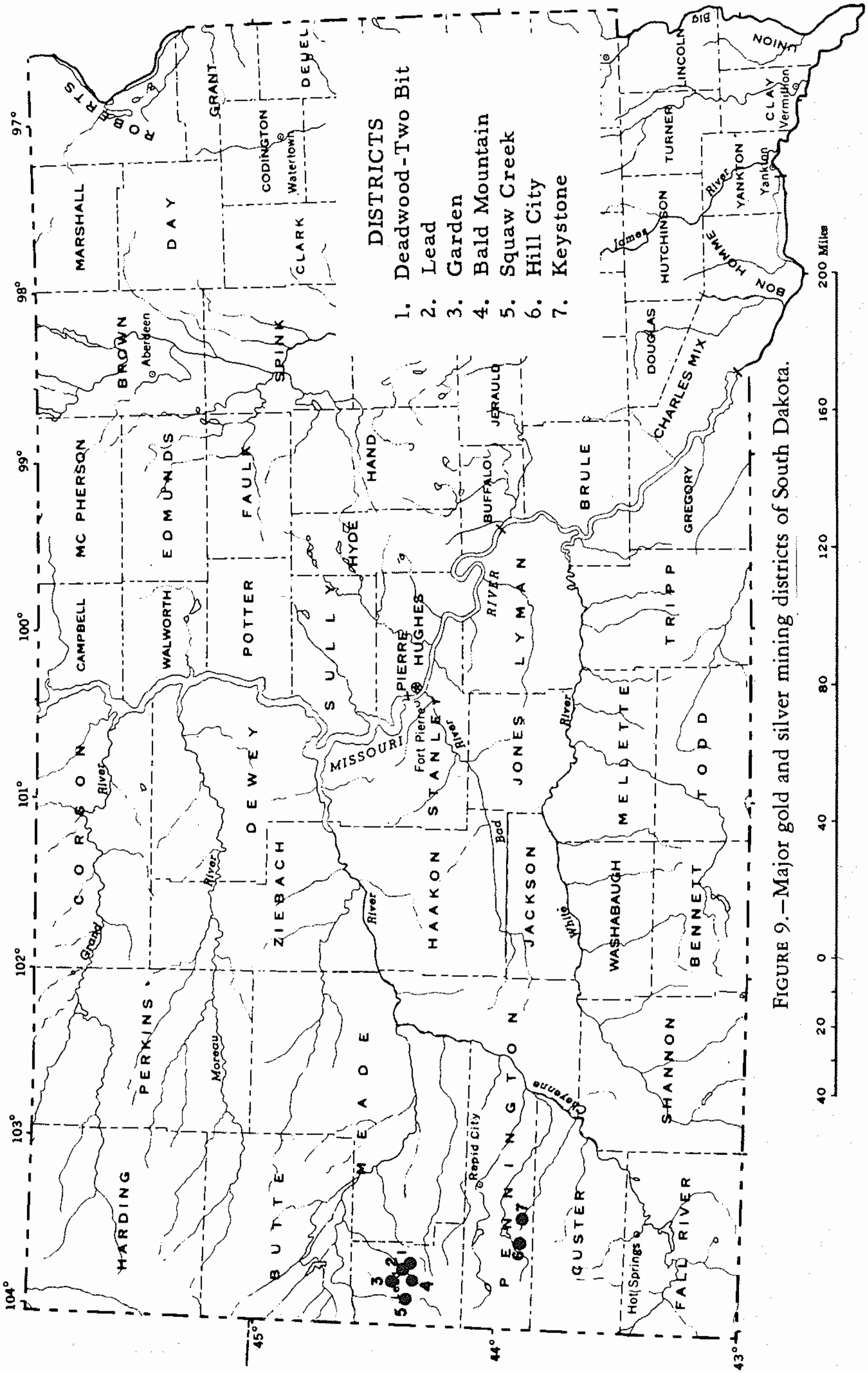

FIGURE 9.—Major gold and silver mining districts of South Dakota.

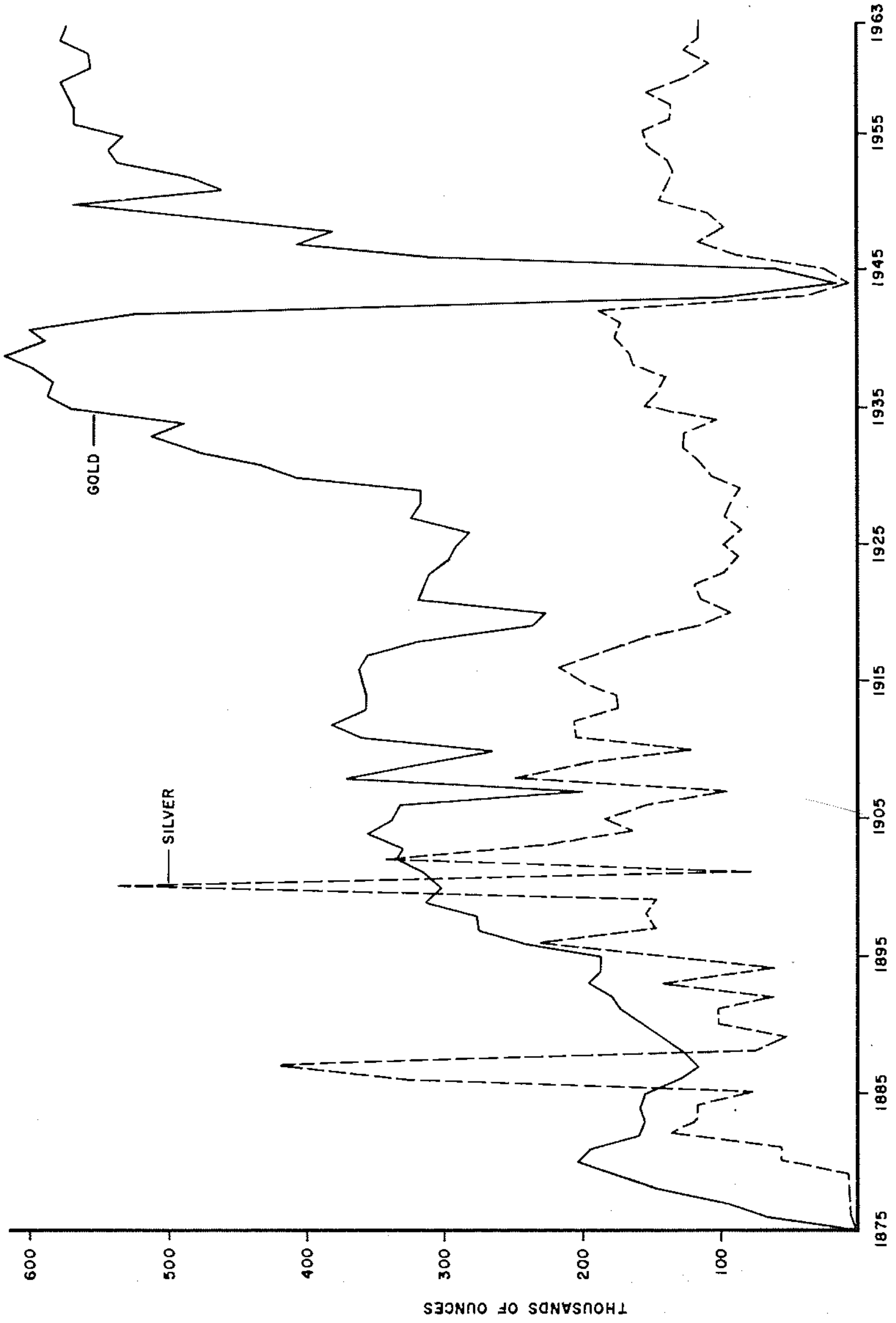

FIGURE 10.—Annual gold and silver production of South Dakota, 1875–1963. Source of data: U.S. Bureau of Mines.

3. Replacement deposits of Tertiary age in the Deadwood Formation of Cambrian age and the Pahasapa Limestone of Mississippian age (Deadwood, Lead, Garden, Bald Mountain, Squaw Creek districts)
4. Deposits in the Tertiary eruptive rocks (Deadwood district)
5. Placer deposits (Deadwood, Squaw Creek districts)

More detailed discussions of the major districts follow. A few districts that are not described here have produced small quantities of gold and silver: the Galena district (Connolly and O'Harra, 1929, p. 188–198, Tullis, this report, p. 60), and the Silver City district (Connolly and O'Harra, 1929, p. 185–188, Tullis, this report, p. 62).

LAWRENCE COUNTY

Deadwood-Two Bit district

This district is in the vicinity of the town of Deadwood in the east-central part of Lawrence County and includes mining camps in Deadwood Creek, Two Bit Creek, Strawberry Creek, and Elk Creek. Both placers and lodes have been productive; however, most of the gold has come from placers along Deadwood Creek. Total output is at least 284,000 ounces of gold and 28,700 ounces of silver. The data for silver are incomplete, and total production may be several times the amount given here. The Deadwood Gulch placers, discovered in 1875, yielded an estimated $4 million in gold by 1880. Stimulated by the rich placer finds, prospectors combed the area and soon found a variety of other gold-bearing deposits, including placer-like deposits in the basal conglomerate of the Deadwood Formation of Cambrian age. The history of the Deadwood-Two Bit district is characterized by sporadic activity, and there has been no major producer with sustained output. The district has been virtually dormant from 1937 through 1963.

In 1878 gold ore was found in Precambrian rocks in the Clover Leaf mine in the southeastern part of the district, near Roubaix. It was worked for only about 10 years, but during this period $400,000 in gold was extracted. Periodic operations were undertaken in later years, and the mine was closed in 1937 (Allsman, 1940, p. 14). The Clover Leaf deposit is in Precambrian mica schist, slate, chlorite schist, quartzite, and amphibolite. The ore consists of galena, sphalerite, pyrite, and native gold in a saddle-shaped mass of quartz on a southeast-plunging anticlinal fold in the mica schist (Connolly and O'Harra, 1929, p. 113).

From 1876 to 1881 the so-called placer deposits of the Deadwood Formation yielded large amounts of gold. Activity declined rapidly after 1881 when these deposits were virtually exhausted (Allsman, 1940, p. 22). One of the most productive properties was the Hidden Treasure mine (Irving, Emmons, and Jaggar, 1904, p. 106). These deposits consist of a gold-bearing conglomerate overlying the Precambrian rocks. Pebbles and small boulders of quartz, quartzite, and schist are cemented by pyrite or iron oxide where the conglomerate is gold bearing. The barren conglomerate is characterized by a quartzitic or calcareous matrix. Though Irving and Emmons (*in* Irving, Emmons, and Jaggar, 1904, p. 99, 111) did note that some of the gold may have been introduced with the pyrite and some may have been chemically reprecipitated in the conglomerate by ferric sulfate solutions, they postulated that much of it was of detrital origin, derived from erosion of the gold lodes in the Precambrian rocks nearby. Noble (1950, p. 246), on the other hand, doubted that any of the gold is of placer origin, but rather that it was introduced by hydrothermal solutions.

Gold and silver have also been mined from replacement deposits in dolomite beds in the Deadwood Formation. The earliest record of production from these deposits is 1892, when the Mascot mine, about 3½ miles east of Deadwood, began shipping ore (Allsman, 1940, p. 50). Two zones, known as the "lower contact" and "upper contact," contain the ore bodies. The "lower contact," which ranges from a few feet to 30 feet in thickness, consists of several dolomite beds interlayered with shale beneath an impervious shale and immediately overlying the basal quartzite unit. The "upper contact" is near the top of the formation and consists of from two to six beds of dolomite separated by shale. The ore bodies are lenticular masses parallel to bedding and consist of aggregates of quartz, chalcedony, barite, and fluorite, in which are disseminated fine-grained pyrite, arsenopyrite, and locally stibnite. Gold and silver cannot be recognized in the ore, but tellurium is present in analyses, and the gold and silver probably occur in fine-grained telluride minerals (Irving, Emmons, and Jaggar, 1904, p. 124–143). Replacement deposits in the lower zone have yielded small amounts of gold and silver in the Belle Eldridge mine (Davis, 1948, p. 2, 3; Tullis, this report, p. 60).

A few gold deposits in the vicinity of Strawberry Gulch, about 3 to 4 miles southeast of Deadwood, occur in Tertiary eruptive rocks and in brecciated Precambrian and Cambrian rocks in the vicinity of the intrusives. These discoveries date back to about 1893, when the Oro Fino property of the Gilt Edge Mines, Inc., was worked (Allsman, 1940, p. 56). Most of the ore is in the form of auriferous limonite fissure fillings in a large mass of decomposed quartz monzonite porphyry. The limonite gives way at depth to pyrite, a little galena and copper sulfides (Allsman, 1940, p. 57).

Lead district

The Lead district is in central Lawrence County and contains the Homestake mine, the leading gold producer in the United States and the only major operation in the district.

The total production of the district is about 26,133,000 ounces of gold and roughly 6,100,000 ounces of silver through 1962.

The Homestake Mining Co., which was incorporated in 1877, originally held only two fractional claims covering about 14 acres. These were purchased from the prospectors who located them in 1876 and and took out about $5,000 in gold. Other companies—the Father de Smet, Highland, and Deadwood-Terra—were organized and in operation in 1878, but they were gradually assimilated by Homestake (Irving, Emmons, and Jaggar, 1904, p. 57). By 1931 the Homestake Co. controlled 654 mining claims covering 5,639 acres (Eng. and Mining Jour., 1931, p. 290). The scale of operations has been in continual expansion; production since 1953 has been more than 500,000 ounces of gold and about 100,000 ounces of silver per year.

Rocks in the Lead district are Precambrian in age and consist of six formations with a total thickness of about 20,000 feet. A few erosional remnants of the basal conglomerate of the Deadwood Formation, of Cambrian age, cap some of the hills and ridges. Igneous rocks are of two ages: amphibolite bodies derived from Precambrian gabbroic rocks, and small stocks, plugs, and dikes of Tertiary porphyries that range in composition from granite to syenite (Noble and Harder, 1948, p. 942–954).

The Precambrian rocks are dominantly iron-magnesium schistose rocks in the lower part of the sequence and argillaceous phyllites and schists in the upper part. They were isoclinally folded in Precambrian time and deformed further during the time of Tertiary intrusive activity. In the vicinity of the Homestake mine the lower three Precambrian formations of Hosted and Wright (1923)—the Poorman, Homestake, and Ellison—are exposed. All of the major ore bodies occur in the Homestake Formation, which is a sideroplesite schist containing many bands of recrystallized chert. Where the metamorphism of Precambrian rocks reached the garnet grade of progressive metamorphism, the sideroplesite schist of the Homestake Formation is converted to cummingtonite schist (Noble and Harder, 1948, p. 963–965).

The ore bodies are linear or pipelike chloritized portions of the Homestake Formation, with fairly abundant veins and masses of quartz and less abundant pyrrhotite, pyrite, and arsenopyrite (Noble, 1950, p. 231–236). Minor constitutents are ankerite, cummingtonite, biotite, garnet, albite, calcite, sericite, fluorite, galena, sphalerite, chalcopyrite, specularite, magnetite, gypsum, and gold. Four distinct stages of mineralization have been recognized: quartz-chlorite-arsenopyrite, quartz-ankerite, pyrrhotite, and pyrite-calcite. Most of the gold is associated with the quartz-chlorite-arsenopyrite stage, and the presence of arsenopyrite is used as a rough guide for ore, although gold also occures sporadically where arsenopyrite is absent.

Noble (1950, p. 224–231) noted that the ore bodies are localized in zones of younger cross folds superimposed on the older isoclinal folds. Dilatancy, or increase of porosity, in these zones permitted a free circulation of mineralizing fluids.

The age of mineralization of the Homestake deposits has been postulated as both Precambrian and Tertiary. In reviewing the evidence and the opinions of earlier workers, Noble (1950, p. 245–247) concludes that the problem is far from being solved.

In addition to those just described, two other types of gold deposits have been mined on a small scale in the district. Auriferous conglomerate in the thin remnants of the Deadwood Formation in the hills just north of the town of Lead supported small gold mining operations, and replacement deposits in the lower zone of the Deadwood Formation in the Yellow Creek area yielded about 125,070 ounces of gold and at least 158,000 ounces of silver (Connolly and O'Harra, 1929, p. 137–142; Allsman, 1940, p. 40).

Garden district

The Garden district is from 1 to 3 miles northwest of Lead in Blacktail and Sheeptail Gulches and False Bottom Creek.

Though some properties were probably worked in the 1880's, the principal mine in the district, the Maitland mine, was not operative until 1902. Total gold production of the district is at least 176,000 ounces. Total silver output has not been ascertained, but Allsman (1940, p. 41) lists 76,249 ounces from the Maitland mine from 1902–37.

Bedrock in the district consists of slate, schist, and quartzite beds of Precambrian age, the Deadwood Formation of Cambrian age, and bodies of intrusive quartz monzonite porphyry and rhyolite of Tertiary age (Darton and Paige, 1925, geologic map). The ore deposits are replacement bodies in dolomite beds in the lower part of the Deadwood Formation, directly above the basal conglomerate. Fractures, parallel to the foliation of the Precambrian rocks, extend upward into the Deadwood Formation and provided avenues for the mineralizing solutions. Primarily ore consists of finely divided gold and silver in pyrite, but most of the ore mined was oxidized and was probably mostly gold- and silver-bearing limonite (Allsman, 1940, p. 42).

Bald Mountain district

The Bald Mountain district is 3½ miles southwest of the Lead district in Lawrence County.

Claims were located in the Portland area in 1877, but early mining was handicapped by the highly refractory nature of the ore. By 1891 the milling and metallurgical difficulties were overcome by the chloridation process, and in 1892 cyanidation of the ore proved successful (Connolly and O'Harra, 1929, p. 143–147). The district entered a period of prosperous development that was terminated at the close of World War I because of high costs. The increased price of gold in 1934 caused a pronounced reactivation which lasted until World War II. After the war mining was resumed on a small scale, but high costs again forced the owners to close in 1959.

Total gold production is roughly 1,400,000 ounces. Silver output since 1902 is about 2,300,000 ounces.

Rocks of the district are chiefly southwest-tilted strata of the Deadwood Formation of Cambrian age. Numerous sheets, dikes, and irregular bodies of phonolite and rhyolite porphyry of Tertiary age cut the Deadwood and the underlying Precambrian rocks (Irving, Emmons, and Jaggar, 1904, p. 144, 145).

The ore deposits are in replacement bodies in dolomite beds of both the upper and lower zones of the Deadwood Formation. They are the most productive deposits of this type in the Black Hills, some shoots being as much as several hundred feet long. Two types of ore are recognized: blue ore, which is the primary ore, and red ore, which is oxidized ore. The primary ore consists of pyrite and probably arsenopyrite, most of which is very fine grained. In some ore the gold telluride, sylvanite, has been found, but most of the gold is believed to be associated with the fine-grained pyrite (Connolly and O'Harra, 1929, p. 162). Small amounts of galena and sphalerite are seen in polished sections of the ore. The gangue is chiefly quartz, some fluorite, gypsum, and barite. Most of the ore mined is the red ore, which consists essentially of gold-bearing limonite.

Squaw Creek district

This district is in the western part of Lawrence County, west of the Bald Mountain and Garden districts. For the purpose of this report, the smaller Carbonate district is included with the Squaw Creek district.

Recorded gold production is about 76,000 ounces; incomplete records of silver output total about 30,500 ounces (Allsman, 1940, p. 51–56).

Lead and silver ores were discovered in the Carbonate area in the early 1880's, and production was at its peak from 1885–1891. Only small amounts of gold were recovered as a byproduct from this ore (Allsman, 1940, p. 53). In 1896 considerable excitement was caused by the discovery of boulders of silicified limestone containing gold in the Ragged Top Mountain area. Shortly thereafter gold lodes were found west and south of Ragged Top Mountain and in the Squaw Creek and Annie Creek areas. After 1914, activity in the district declined, and only a few ounces of gold from scattered placers were recovered from 1915 through 1962.

The Squaw Creek district is a plateau 2½ miles wide and 5 miles long on the northwest side of the Black Hills dome. The Pahasapa Limestone of Mississippian age, which forms the cap rock on the plateau, is underlain by the Cambrian sedimentary rocks which are exposed along streams that have cut through the limestone. The sedimentary rocks are intruded by Teritiary porphyry bodies, and in the Ragged Top Mountain area a laccolith of phonolite is intruded at the base of the Mississippian beds (Irving, Emmons, and Jaggar, 1904, p. 172). The ore bodies occur in the flat-lying Pahasapa Limestone adjoining the phonolite mass.

The richest deposits are west of Ragged Top Mountain, in flat-lying masses of silicified Pahasapa Limestone which apparently are the lateral extensions of the tops of vertical fissure veins. According to Allsman (1940, p. 52), a thin, relatively impervious capping appears to cover most of the deposits, indicating that the capping caused the rising mineralizing solutions to spread below the cap, thus forming the flat ore bodies.

PENNINGTON COUNTY

Hill City district

The Hill City district includes several widely scattered gold deposits in western Pennington County, in the vicinity of Hill City and to the northwest around Rochford. Incomplete data show the district produced at least 35,400 ounces of gold, but silver output apparently has been negligible.

Country rock in the district is complexly folded and distorted Precambrian schist and quartzite. A short distance to the southeast, the metasedimentary rocks are intruded by the Precambrian Harney Peak granite (Darton and Paige, 1925, p. 3–5; Connolly and O'Harra, 1929, p. 129–134).

The lode gold deposits occur in quartz fissure veins and lenses and mineralized shear zones. The deposits southwest and east of Hill City are chiefly quartz veins that cut the metamorphic rocks (Allsman, 1940, p. 69). The veins vary in width from a few inches to 6 feet. Most of them are shallow, although a few have been mined to depths of a few hundred feet. The veins consist predominantly of quartz in which free gold is irregularly distributed. West of Silver City a quartz vein in the schist contains masses and streaks of lead-antimony sulfide, arsenopyrite, pyrite, a little sphalerite, and free gold (Paige, *in* Darton and Paige, 1925, p. 28).

The mineralized shear zones are most common in a belt extending northwest from Hill City (Allsman, 1940, p. 69). These are zones of brecciated schist cemented by granular quartz with arsenopyrite, pyrite, sphalerite, and free gold. Most of these deposits are of low grade.

In the Rochford area gold deposits are found in quartz veins and lenses that cut the cummingtonite schist (Connolly and O'Harra, 1929, p. 129–134). The ore minerals are arsenopyrite, pyrite, pyrrhotite, chalcopyrite, a little magnetite, and gold which is associated particularly with the arsenopyrite. The gangue minerals are cummingtonite, quartz, carbonates, biotite, garnet, and chlorite. The general character of the ore and the geologic relations are analogous to those in the Homestake deposit (Noble and Harder, 1948, p. 954–955).

Keystone district

The Keystone district is in the western part of Pennington County, in the vicinity of the town of Keystone. Total gold production has been about 85,000 ounces, most of which has come from the Keystone-Holy Terror mine. Silver has been of little importance.

The Keystone district is on the northeast side of the Harney Peak granite batholith near the eastern margin of the core of Precambrian rocks of the Black Hills (Darton and Paige, 1925, Structure sections, Central Black Hills region). Precambrian schist, quartzite, and amphibolite, with many granite and pegmatite dikes, are the predominant rocks of the district. The rocks are tightly folded and are cut by faults and shear zones, some of which are mineralized (Connolly and O'Harra, 1929, p. 120–121).

The ore bodies are in quartz veins or lenticular replacement deposits which trend parallel to the foliation of the enclosing schist. The Holy Terror vein was mined for a maximum distance of 1,200 feet and had a width ranging from a few inches to 6 feet. The gangue consists of white quartz, and the ore mineral was coarse flaky gold (Allsman, 1940, p. 91). Other deposits contained a wider variety of minerals, including arsenopyrite, pyrrhotite, pyrite, chalcopyrite, sphalerite, and native gold as ore minerals and quartz, horneblende, biotite, ankerite, chlorite, graphite, and garnet in the gangue. In some deposits the gold is very fine grained.

OUTLOOK FOR FUTURE

As in the past, the eminent position of South Dakota as a producer of precious metal is dependent largely on the Homestake mine, which despite constantly increasing costs and slight decreases in the grade of ore, achieved a record high output of $20,270,973 [1] in bullion in 1962. The future of gold and silver production not only from the Homestake mine but also from other deposits in the area is largely dependent on unpredictable economic factors. Labor and material costs, depth of mining, grade of ore, and technology of milling all profoundly affect the gold and silver reserve picture. Undoubtedly production will continue for years to come, and the history of past production suggests that the general area has a resource potential in these metals of considerable magnitude which could support future mining activity.

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[1] 85th Annual Report of the Homestake Mining Co.

URANIUM

(By G. B. Gott and G. N. Pipiringos, U.S. Geological Survey, Denver, Colo.)

Uranium is the basic raw material from which atomic energy is derived. Its major use, therefore, is in atomic weapons and as a fuel for various kinds of reactors. Small quantities of uranium are also used in the ceramic, electrical, and chemical industries. Uranium is composed of isotopes U^{238}, U^{235}, and U^{234}. Over 99 percent of the naturally occurring uranium is U^{238}. The isotope U^{235} is fissionable, and U^{238} can be converted to fissionable plutonium by neutron bombardment.

Figure 11 shows the distribution of uranium deposits in South Dakota. The names of these deposits are shown in table 2. Deposits of uranium-bearing sandstone and lignite are the only commercial sources of this metal in South Dakota. Significant but non-economic concentrations also occur in organic-rich shales (fig. 11, locality 33). Uranium minerals occur in Precambrian rocks in the Black Hills but these minerals are so disseminated that they do not constitute a commercial source.

TABLE 2.—*Uranium deposits in South Dakota*

[Numbers refer to deposits shown on fig. 11]

	Name of deposit	*Remarks*
1	Lodgepole area [1]	Includes Johnson outlier data from Zeller and Schopf (1959, p. 69); constitutes unnamed locality 1 of Butler, Finch, and Twenhofel (1962, p. 20).
2	Teepee Butte area	
3	Flattop Butte claims [1]	
	In North Cave Hills area.	
4	Riley Pass area [1]	
5	Cub Lode [1]	
6	Table Mountain claims	
7	Lonesome Pete mine [1]	Includes another occurrence of uranium in phosphatic claystone. See D No. 2 claims, Anonymous (1956).
8	Blue Jay claims [1]	
9	McKenzie Butte [1]	
10	Sheep Mountain area	Constitutes unnamed locality 10 of Butler, Finch, and Twenhofel (1962, p. 20).
11	Falcon group	Location revised from that shown on map of Butler, Finch, and Twenhofel (1962).
12	Calamity Jane group	
13	Bar H area	Data from Zeller and Schopf (1959, p. 69).
14	Thybo claim [1]	
15	Mendenhall mine	Data from Gill, Zeller, and Schopf (1959, p. 113).
16	Dot No. 1 claim	
17	Flattop Butte [1]	
	In Slim Buttes area.	
18	Cedar Canyon area [1]	Sandstone-type deposit. Locality includes State lease claim—a lignite-type deposit.
19	Quad claim group [1]	Lignite-type deposit. Locality includes Lucky Strike and Hinds claims which are sandstone-type deposits.
20	West Short Pine Hills area	Uranium occurs in limestone and siltstone beds. Data from Gill (1954, p. 153).
21	Kling group [1]	Includes Bonata, Apland, McKay, and Engelson leases.
22	Lamberton prospect	Includes an unnamed prospect on U.S. Government land.

See footnote at end of table, p. 51.

TABLE 2.—*Uranium deposits in South Dakota*—Continued

	Name of deposit	*Remarks*
23	Mill Lode	Includes Ross Hannibal mine and others nearby.
24	Caylor-Preston ranch	
25	Dakota prospect [1]	Includes Grizzly Creek and Dorothea prospects.
26	Harney No. 2 prospect	
27	Rube claims [1]	Includes other nearby occurrences.
28	Sec. 7 occurrence	
29	Elkhorn No. 1	
30	Lost Canyon No. 1 mine [1]	Includes other nearby claims.
31	Jim Rab claim	
32	Triangle mine [1]	Includes other nearby mines.
33	Hot Brook Canyon area	Uraniferous black shale of marine origin in Minnelusa Formation.
34	Coal Canyon group [1]	Includes all adjacent mines in the Fall River Formation.
35	Hot Point group [1]	Includes all adjacent mines in the Lakota Formation.
36	Runge mine	
37	Upper Chilson Canyon [1]	Includes numerous mines and claims in the vicinity of Upper Chilson Canyon.
38	Washboard group [1]	Includes the Accidental, Lord, and Baxter leases.
39	Canyon Lode	Carnotite in Fall River sandstone.
40	Lake No. 1	Uranium minerals in Fall River sandstone.

[1] Includes other claims. Localities 1 to 20 are lignite-type deposits and localities 21 to 40 are sandstone-type deposits except as noted in remarks. Data from Butler, Finch, and Twenhofel (1962, p. 20–21) except where indicated otherwise.

The search for uranium resources in recent years has been very successful. The U.S. uranium ore reserves have been estimated at 74 million tons containing 0.28 percent U_3O_8, which represents about one fourth of the free world uranium ore supply (Baker and Tucker, 1962). South Dakota uranium reserves include 68,300 tons of sandstone-type ores containing 0.22 percent U_3O_8 and 206,900 tons of lignite containing about 0.33 percent U_3O_8. Most of the uranium production in South Dakota has been from the sandstone-type ores in the Black Hills area, which has totalled some 367,497 tons of ore containing 1,352,000 pounds of U_3O_8 as of October 1, 1963. Some 33,135 tons of lignite containing 311,000 pounds of U_3O_8 has been produced from the Cave Hills and Slim Buttes areas (localities 2 to 10 and 12 to 19, fig. 11, respectively).[1] The average U_3O_8 content of the lignite ores has been 0.47 percent and of the sandstone ores has been 0.18 percent.

The production and reserve figures given by the Atomic Energy Commission indicate that the potential future production from lignite beds containing about 0.33 percent uranium is about equal to that already produced from the sandstone-type deposits in the Black Hills.

In addition, large areas in Harding and Perkins Counties are underlain by lignite whose uranium content is less than 0.1 percent. According to Denson, Bachman, and Zeller (1959, p. 41–47), the uraniferous lignite and related beds of northwest South Dakota probably contain on the order of about 340 million tons of lignite whose uranium content approaches 0.01 percent. Gill, Zeller, and Schopf (1959, p. 111–112), using core-drilling data, supplemented by several hundred outcrop samples and measurements, have estimated that the Slim Buttes area alone is underlain by more than 330 million tons of lig-

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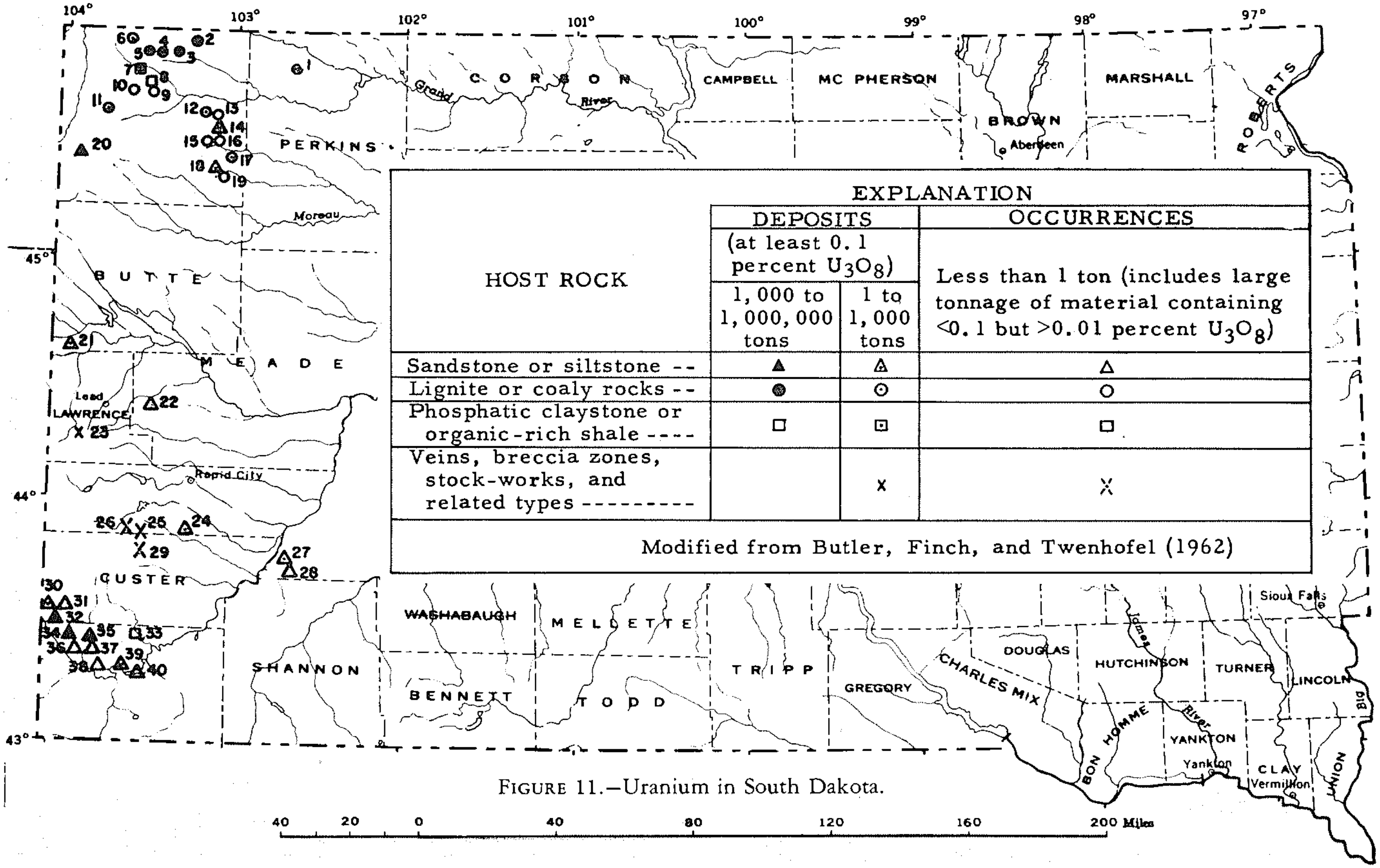
[1] Reserve estimates and production data from U.S. Atomic Energy Commission, written communication, Dec. 13, 1963.



EXPLANATION

HOST ROCK	DEPOSITS (at least 0.1 percent U_3O_8)		OCCURRENCES
	1,000 to 1,000,000 tons	1 to 1,000 tons	Less than 1 ton (includes large tonnage of material containing <0.1 but >0.01 percent U_3O_8)
Sandstone or siltstone --	▲	◬	△
Lignite or coaly rocks --	●	⊙	○
Phosphatic claystone or organic-rich shale ----	□	⊡	□
Veins, breccia zones, stock-works, and related types ---------		x	x

Modified from Butler, Finch, and Twenhofel (1962)

FIGURE 11.—Uranium in South Dakota.

nite that contain an average of 0.007 percent uranium in beds averaging 5 feet in thickness. Although these low-grade uraniferous lignite beds constitute a large potential source of uranium, their exploitation is contingent on using the lignite for fuel and subsequent recovery of uranium as a byproduct.

URANIUM IN SANDSTONE

The first discovery of a commercial uranium deposit in South Dakota was in 1951 in Craven Canyon (locality 35, Fig. 11) in the southern part of the Black Hills (Page and Redden, 1952; Gott and Schnabel, 1963). This deposit and those discovered later are of the sandstone-type uranium-vanadium deposit that occur abundantly on the Colorado Plateau and elsewhere in the western United States. The deposits are lens-shaped bodies of sandstone that have been impregnated with uranium and vanadium minerals. Depending on the kinds of minerals, three types of ores are recognized: yellow oxidized, purplish-black partly oxidized, and black unoxidized ores.

The uranium and vanadium minerals from the Black Hills that have been identified from the oxidized, partly oxidized, and unoxidized zones are tabulated below. The oxidized and partly oxidized minerals are largely uranium or calcium vanadates, and the black unoxidized ores are largely uranium and vanadium oxides.

TABLE 3.—*Minerals in the Black Hills uranium-vanadium deposits*

Mineral and composition	Oxidized zone (dominantly yellow)	Partly oxidized zone (purplish-black to yellow)	Unoxidized zone (black)
Carnotite—$K_2(UO_2)_2(VO_4)1\text{–}3H_2O$	X	X	
Tyuyamunite—$Ca(UO_2)V_2O_8 \cdot 5\text{–}8H_2O$	X	X	
Metatyuyamunite—$Ca(UO_2)_2(VO_4)_2 \cdot 3\text{–}5H_2O$	X		
Autunite—$Ca(UO_2)_2(PO_4)_2 \cdot nH_2O$	X		
Uranophane—$Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$	X		
Corvusite—$V_2O_4 \cdot 6V_2O_5 \cdot nH_2O$		X	
Rauvite—$CaO \cdot 2UO_3 \cdot 5V_2O_5 \cdot 16H_2O$		X	
Hewettite—$CaV_6O_{16} \cdot 9H_2O$		X	
Uraninite—UO_{2+}			X
Coffinite—$U(SiO_4)_{1-x}(OH)_{4x}$			X
Haggite—$U_2O_3 \cdot V_2O_4$ $3H_2O$			X
Paramontroseite—VO_2			X

The ore deposits are restricted to the sandstones in the Lakota and Fall River Formations in the Inyan Kara Group. Most of the production has been from thick sandstone in both formations, but a significant proportion has been from thin, tabular sandstone interbedded with carbonaceous siltstone in the lower part of the Fall River Formation. The thick sandstones were deposited by ancient rivers, are channel-like in shape, are approximately 1 to 5 miles in width, and are at least several tens of miles in length. These sandstones have been referred to as the Nos. 1 and 4 sandstones in the Lakota Formation and the No. 5 sandstone in the Fall River Formation (Gott and Schnabel, 1963).

The localization of the ore in the southern Black Hills has been influenced by vertical and lateral pathways through which the mineralizing solutions could migrate. The porous sandstones are the pathways of lateral migration. Vertical migration of the mineralizing solutions probably has been principally through superimposed channel sandstones and through fractures, faults, and subsidence structures.

In the southern Black Hills the uranium deposits occur in three somewhat different environments: (1) Along the erosional contact at the base of the Fall River Formation, (2) in the interbedded sandstone and carbonaceous siltstone in the lower part of the Fall River Formation, and (3) in association with carbonaceous material in the Lakota Formation.

Deposits of the first type are localized along the erosional contact between the Nos. 4 and 5 sandstones (Gott and Schnabel, 1963, p. 180–181) indicating that contiguity of the channel sandstones influenced the formation of the ore deposit. Carbonaceous rocks probably have produced hydrogen sulfide and organic acids that were introduced into the ground water. The presence of these reducing agents may have caused precipitation of the ore-forming minerals. The uranium-vanadium ratio is about 1.

Deposits of the second type are marginal to a series of en echelon faults through which mineralizing solutions could have migrated into the carbonaceous environment in which the deposits are now found. The uranium-vanadium ratio of these deposits is about 2.

The deposits in the No. 1 sandstone of the Lakota Formation are associated with carbonaceous materials and all of the deposits that have been mined have been in the oxidized zone. Carnotite and tyuyamunite are the dominant uranium minerals. These deposits are unusually low in vanadium, with an average uranium-vanadium ratio of only about 0.4. This is little more than enough vanadium to form carnotite and tyuyamunite. The vanadium in excess of the amount in these two minerals apparently is in the clays.

URANIUM IN LIGNITE

A second source of uranium as yet largely undeveloped is in lignite and associated coaly rocks of Harding and Perkins Counties, in the northwestern part of the State. This area also contains smaller amounts of uranium in phosphatic mudstone. The uraniferous coaly rocks are of swamp origin; the phosphatic mudstone may be of marine or brackish water origin; and all are in the Fort Union Formation of Paleocene age. Their location and approximate size are shown in figure 11, localities 1 through 20.

Most of the uranium occurs as organo-uranium compounds absorbed in lignite and other carbonaceous materials (Breger, Duell, and Rubinstein, 1955). Uranium in this form is not present in a visible uranium-bearing mineral and can be detected only by radiometric instruments, or by chemical analyses, even though one sample of lignite contained 4.4 percent uranium (Gill, 1955, p. 153). Locally, however, green or yellow secondary minerals do occur as films and crusts on joint faces of the lignite.

Small quantities of uranium were found in the lignite beds of North and South Dakota in 1948 (Wyant and Beroni, 1950) but it was not until 1954 that uranium deposits of commercial quality were discovered in the E coal bed of the Tongue River Member of the Fort Union Formation in the Riley Pass area of the North Cave Hills (locality 4, fig. 11). Other deposits were found in the E coal bed at Teepee Butte, Flattop Butte, and in the vicinity of the Traverse Ranch (localities 2, 3, and 5, fig. 11). Uranium deposits were also found in coal beds of the Ludlow Member of the Fort Union near the Traverse Ranch, at Table Mountain, and in the Slim Buttes (localities 4, 6, 15, and 19, fig. 11). These deposits are, for the most part, amenable to strip mining and account for nearly all of the production and reserve figures given on page 51. They are also those in which most of the yellow and green uranium minerals have been found. Table 4 shows the various uranium minerals associated with lignite and other coaly rocks in northwest South Dakota.

The areas discussed above have been described in detail by Gill (1954, 1955), Kepferle and Chisholm (1956), King, Foran, and Speal (1955), King and Young (1956), Pipiringos, Chisholm, and Kepferle (1957, and in press), and White (1958).

TABLE 4.—*Minerals in lignite and coaly rocks of northwest South Dakota*

Abernathyite	$K_2(UO_2)_2(AsO_4)_2 \cdot 8H_2O$
Metazeunerite	$Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$
Metanovacekite	$Mg(UO_2)_2(AsO_4)_2 \cdot 8\text{–}10H_2O$
Meta-autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 2\frac{1}{2}\text{–}6\frac{1}{2}H_2O$
Metatorbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$
Metauranocircite	$Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$
Saleeite	$Mg(UO_2)_2(PO_4)_2 \cdot 8H_2O$
Sodium-autunite	$Na_2(UO_2)_2(PO_4)_2 \cdot 8H_2O$
Uranophane	$Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$
Carnotite	$K_2(UO_2)_2(VO_4)1\text{–}3H_2O$
Metatyuyamunite	$Ca(UO_2)_2(VO_4)_2 \cdot 3\text{–}5H_2O$
Uraninite [1]	UO_2

[1] Only uraninite occurs in the unoxidized state; all of the others occur in the oxidized or partly oxidized state.

Uranium deposits in rocks other than lignite and carbonaceous shale are rare in northwestern South Dakota. In the South Cave Hills a 1- to 2-foot-thick phosphatic silty claystone is present at or near the top of the Ludlow Member of the Fort Union Formation. The phosphatic beds contain as much as 0.85 percent uranium and 17 percent phosphate (King and Young, 1956, p. 430; Pipiringos, Chisholm, and Kepferle, 1957, p. 266). The areal extent of this type of material is unknown, but it is possible that similar phosphatic beds may occur in the Cannonball Member in northeastern Harding and Perkins Counties.

Small occurrences of yellow uranium minerals have been found in sandstones in the Chadron Formation of Oligocene age at Cedar Canyon (Gill and Moore, 1955) and in the White River badlands (Moore and Levish, 1955); in the upper part of the Ludlow Member of the Fort Union Formation of Paleocene age in Reva Gap area of the Slim Buttes (Gill, 1955); in the upper part of the Arikaree Formation of Miocene age in the West Short Pine Hills; and in the basal part of the Tongue River Member of the Fort Union Formation in the North Cave Hills. These occurrences are, for the most part, of passing interest only.

The uranium deposits and occurrences in lignite and carbonaceous rocks in the Fort Union Formation are topographically no more than 200 feet below the unconformable surface on which rocks of Oligocene and Miocene age were deposited.

Rocks of Oligocene and Miocene age, which cap some of the larger buttes in this area, contain abundant volcanic material, minute quantities of uranium, and locally even small concentrations of yellow secondary minerals, as at Slim Buttes and the West Short Pine Hills (localities 14, 18, and 20, fig. 11). The proximity of the uranium deposits to overlying potential uranium source rocks led Denson, Bachman, and Zeller (1959) to theorize that uranium was leached from beds of Oligocene and Miocene age, and carried downward and deposited in underlying lignite and carbonaceous beds by ground water. This theory is now widely accepted for the origin of uranium deposits in this area, and suggests that coal-bearing areas now overlain, or formerly overlain, by rocks of Oligocene or Miocene age are favorable areas for uranium prospecting (Denson and Gill, in press).

IRON

(By C. M. Harrer, U.S. Bureau of Mines, Denver, Colo.)

Iron in its many applications is the basis of the Nation's economy and enormous amounts of natural iron oxides (ores), coal, water, limestone, and other raw materials are consumed annually in its production. During 1962 the United States produced over 143 million long tons of crude iron ore and consumed almost 102 million long tons of usable iron ore and iron ore agglomerates, including net imports of almost 28 million long tons, to produce 65.638 million short tons of pig iron and 98.328 million short tons of steel (Minerals Yearbook, 1962, pp. 662, 665, 669, and 688).

Following World War II, the use of beneficiated ore in the form of sinter or pellets has greatly increased and in 1962 only 15 percent of the iron ore mined was used directly in furnaces; the remaining 85 percent was treated in some type of beneficiating plant (Minerals Yearbook, 1962, p. 659). This trend to increased use of beneficiated and agglomerated material is expected to continue.

South Dakota has not produced iron oxides as raw material for making iron and steel to date (1964); production has been small and only for specialized uses other than as metal. However, with the increased use of pellets by the iron and steel industry, the Black Hills taconite may become an important source of iron ore. South Dakota iron ore resources are considered sufficient to sustain production for uses other than steel making at present or slightly higher levels for the foreseeable future.

Iron mining began in South Dakota in about 1890. Since then, bog limonite has been mined from small cuts and pits for nonferrous smelter flux and mineral paint pigment, and since 1925, hematite and limonite have been mined intermittently for use as an ingredient in cements produced at the State cement plant at Rapid City. Production of iron oxides through 1963 totals only about 167,000 tons and maximum annual production has been less than 34,000 tons.

Principal iron minerals in South Dakota are the oxides hematite (70 percent iron) and magnetite (about 72 percent iron), the hydrated oxides goethite, turgite, and lepidocrocite, commonly referred to as limonite (about 60 percent iron), the carbonate siderite (48 percent iron), and various manganese-iron carbonates of differing manganese and iron content.

South Dakota has a variety of types of iron deposits. In the Black Hills region they include Precambrian taconite beds containing hematite-magnetite, Cambrian detrital hematite-limonite deposits, recent bog deposits of limonite-goethite-turgite, and hematite-limonite deposits resulting from the oxidation of Precambrian pyritic-pyrrhotitic quartzite.

In northwestern South Dakota accumulations of concretions and nodules of siderite from the Cretaceous Hell Creek Formation and their oxidized equivalents, hematite-limonite, are exposed as gravels along streams. They are a low-grade iron resource.

Very low-grade but large accumulations of iron-manganese carbonate-oxide concretions and nodules occur in the Cretaceous DeGrey Member of the Pierre Shale and in certain gravel beds along the Missouri River and its tributaries, south of Pierre. They comprise a low-grade iron-manganese resource for the future. The more prominent of the State's iron occurrences are shown on figure 12, and described below.

Many large to small bog deposits of limonite-goethite-turgite of Recent origin are in the vicinity of Rochford in Pennington County and Nahant in Lawrence County (fig. 12, No. 1). They occur along the swampy portions of Rapid Creek and many of its tributaries, adjacent to oxidizing pyritic-pyrrhotitic Precambrian slates and schists from which the iron oxides are derived. Bog-limonite accumulations in Pennington and Lawrence Counties are inferred to contain about 500,000 tons of material that ranges between 25 and 56 percent iron. Bog limonite is still being deposited.

Hematite-limonite deposits in the Two Bit Gulch area of Lawrence County (fig. 12, No. 2) are derived from oxidizing pyrite-pyrrhotite in shale of the Cambrian Deadwood Formation. Deposits are inferred to contain about 100,000 tons of material that ranges from 20 to 40 percent iron.

In the Iron Mountain area of Custer State Park, a hematite-limonite deposit straddles the Custer-Pennington County line (fig. 12, No. 3). The deposit is in a triangular area of Precambrian pyritic-pyrrhotitic quartzite, which extends from its one-half-mile-wide base along Toll Creek towards the 1-mile distant apex and summit of Iron Mountain. Iron oxides occur as masses of hard, bluish-black, nearly pure hematite, as boxworks, botryoidal growths, coatings, interstitial fillings, and films in the quartzite, and as a low-grade enrichment and red- to yellow-staining of the quartzite. Generally, hematite is mixed with limonite, goethite, and turgite. About 750,000 tons of material containing 30 to 60 percent iron are inferred in this deposit.

Hematite-limonite occurs along the Cambrian-Precambrian contact at Strawberry Ridge in Lawrence County, and at Hayward and Bobcat Gulch in Pennington County (fig. 12, Nos. 4, 5, and 6). At Strawberry Ridge, the hematite-limonite is in 5- to 8-foot-thick lenticular beds of well-rounded grains, pebbles, and cobbles, as hematitic shale, and as interstitial filling and cement, overlain by about 25 feet of quartzite in the Cambrian Deadwood Formation. The hematite-limonite appears to have been derived from more or less well-sorted erosion detritus of the underlying Precambrian iron forma-

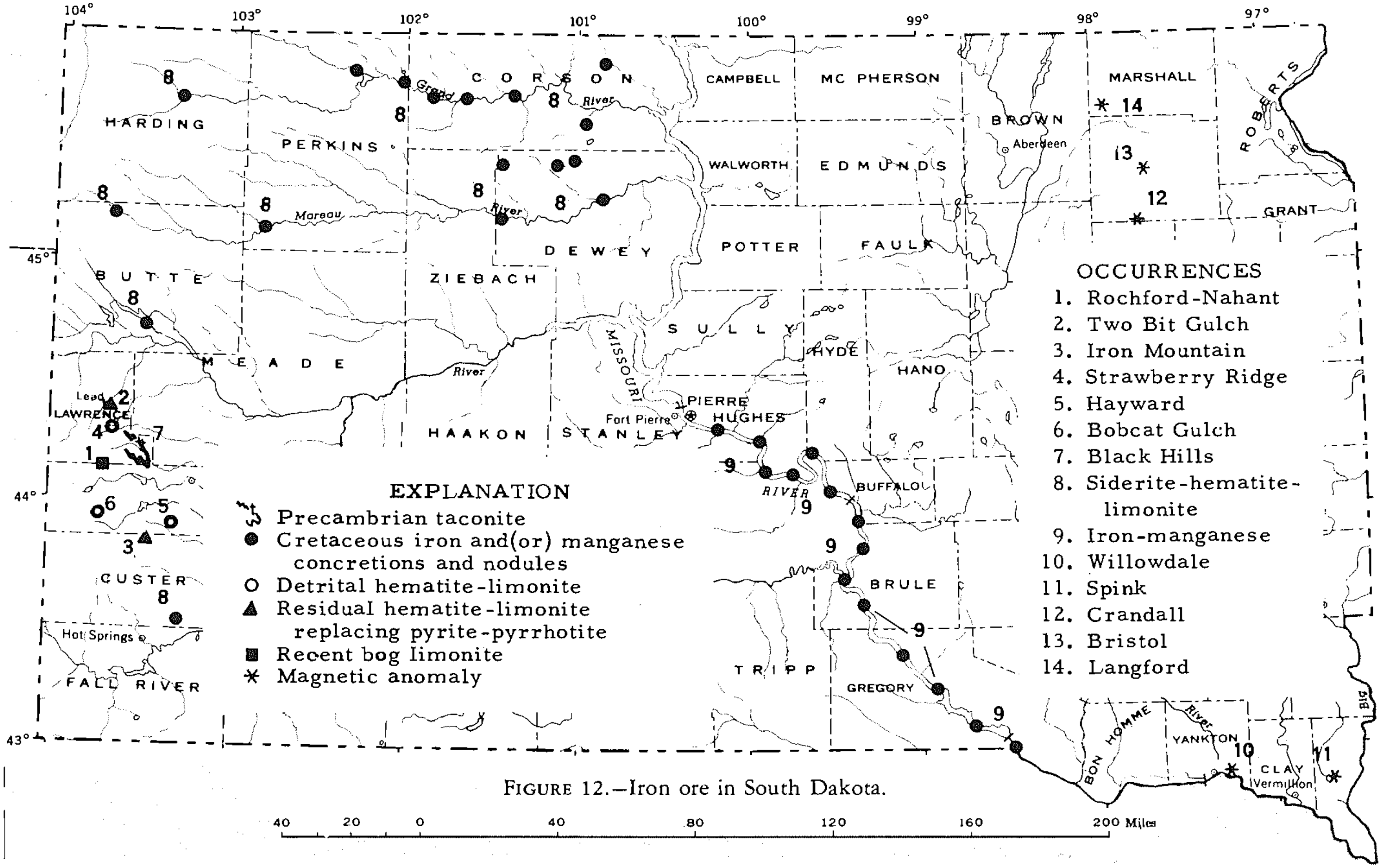


FIGURE 12.—Iron ore in South Dakota.

tion and possibly from pyritic-pyrrhotitic Precambrain rocks. Deposits are inferred to contain about 100,000 tons of material that ranges from 35 to 45 percent iron.

Precambrian specularite-martite-magnetite taconite (fig. 12, No. 7), can be traced interruptedly for about 14 miles in the Black Hills Nemo district of Lawrence County. As much as one-half billion tons of material containing 20 to 43 percent iron, and averaging about 30 percent may be present, but exploration has not reached the stage where tonnages of minable material can be determined. The iron formation is severely folded and crumpled (Woo, 1952). Its thickness ranges from about 135 feet to 2,000 feet—the latter due to repetition of structure by complex folding. The iron formation is considered a resource of great potential.

In northwestern South Dakota iron-manganese concretions and nodules from the Cretaceous Hell Creek Formation have been concentrated in the terrace gravels of the Grand, Moreau, and Cheyenne Rivers and may prove to be a future resource. The quantity of iron-manganese available, while not estimable presently, is inferred as very large but low grade. Pioneer beneficiation tests made on gravels along the Grand River, Corson County (fig. 12, No. 8), by the State's Industrial Development Expansion Agency, reportedly resulted in concentrates containing 45 percent iron, 1 percent manganese, and 15 percent silica.

Low-grade but extensive accumulations of iron and manganese carbonate occur as concretions and nodules comprising about 7 percent of the 26- to 87-foot-thick DeGrey Member of the Pierre Shale of Cretaceous age. The iron and manganese carbonate concretions and nodules crop out and can be traced for about 150 miles along the Missouri River southeast from DeGrey (fig. 12, No. 9); they also occur as gravel accumulations along the Missouri River Valley of central South Dakota. These sources have been variously estimated to contain over 300 million (Dupuy et al., 1946, p. 20) to several billion (Miller, 1959, p. 71) tons. Composition of the concretions and nodules reportedly ranges from 13 to 22 percent Mn and 4 to 14 percent iron (Pesonen, Tullis, and Zinner, 1949, p. 57) and averages 15.5 percent Mn and 9.1 percent Fe (Zinner and Grosh, 1949, p. 13).

During 1961–63 the South Dakota Geological Survey mapped 5 magnetic anomalies (fig. 12, Nos. 10 through 14) in the eastern part of the State. The Willowdale and Spink anomalies in Yankton and Union Counties, respectively, have been prospected. A coredrill hole on the Willowdale anomaly penetrated 4 feet of gabbro containing 14.00 percent iron (Fe) and 2.40 percent titania (TiO_2). The Precambrian base is estimated as 755 feet deep, covered by alluvium and Cretaceous rocks. A coredrill hole prospecting the Spink anomaly penetrated 4.5 feet of diabase containing 13.61 to 14.47 percent iron (Fe) and 2.2 to 4.1 percent titania (TiO_2). The iron minerals are hematite and magnetite. Overlying Paleozoic and Mesozoic cover is about 500 feet thick.

The other anomalies may be indications of similar ultramafic or mafic rocks or of taconite or other types of iron occurrences in the buried Precambrian rocks of eastern South Dakota.

LEAD AND ZINC

(By E. L. Tullis, South Dakota School of Mines and Technology, Rapid City, S. Dak.)

Lead ores, with or without zinc, are found in six districts in three counties of the Black Hills of South Dakota (fig. 13). Lead, zinc, and minor amounts of silver and gold have been produced from the Belle-Eldridge mine in the Spruce Gulch area. Lead has been produced, and zinc is present along with moderate amounts of silver and a little gold at the Spokane mine. Lead, silver, and moderate amounts of gold have been produced in the Galena and Carbonate districts. Gold may be economically the most important metal in the lead-silver-gold ores of the Silver City district. Ore in the Calabogia district is similar to that at Silver City except that no gold is reported.

Except at the Belle-Eldridge mine, where zinc also is important, lead probably would not have been produced except for the associated silver or gold, as in the Silver City district. According to figures of the U.S. Bureau of Mines, lead mined in the Black Hills from 1908 through 1963 totaled 1,003,813 pounds valued at $73,236. The only lead-silver ore mined in the area during 1963 was at the Silver Queen mine in the Galena district, where a total of 10,500 pounds of lead valued at $1,484 was produced during 1961–63. Production prior to 1908 probably was several times greater (Lincoln, 1937), but was not reported or the production statistics were combined with those of other states. In two of the earlier years, 1887 and 1889, recorded production was 1,121 and 116 short tons, respectively, mostly from the Carbonate district. Based on Lincoln's (1937) estimate for the early years and recorded production the total lead produced in the period 1881–1963 in the Black Hills was valued at about $480,000.

Zinc production in the Black Hills in the period 1942–63 was 530,000 pounds valued at $45,406. All of this came from the Belle-Eldridge mine in 1942–48. Eleven tons of zinc from South Dakota is reported in the U.S. Geological Survey Mineral Resources of the United States in 1906, but no mines that might have produced zinc are believed to have been operating at that time.

LAWRENCE COUNTY

Galena district

The lead-silver ores in the Galena district are found at two stratigraphic zones in the Upper Cambrian Deadwood Formation, which, in this area, dips east at angles of as much as 20 degrees (Connolly and O'Harra, 1929). Both ore zones are in dolomite although the lower one is quartzitic in places. Deposits of the lower zone are just above a quartzite unit that forms the lower 20 feet of the formation. The upper zone is more than 300 feet stratigraphically higher and is 15 feet below the top of the formation. The ore bodies that have been mined were replacement lenses along vertical fractures ranging in length from a few inches to many feet. The larger ore bodies generally were 1½ to 4 feet thick, several tens of feet in length, and ranged in width from several feet to more than 10 feet.

The ore is genetically related to numerous sills and dikes of several compositions found in the area, and is early Tertiary in age. Pyrite, galena, and quartz are the principal minerals. Sphalerite generally

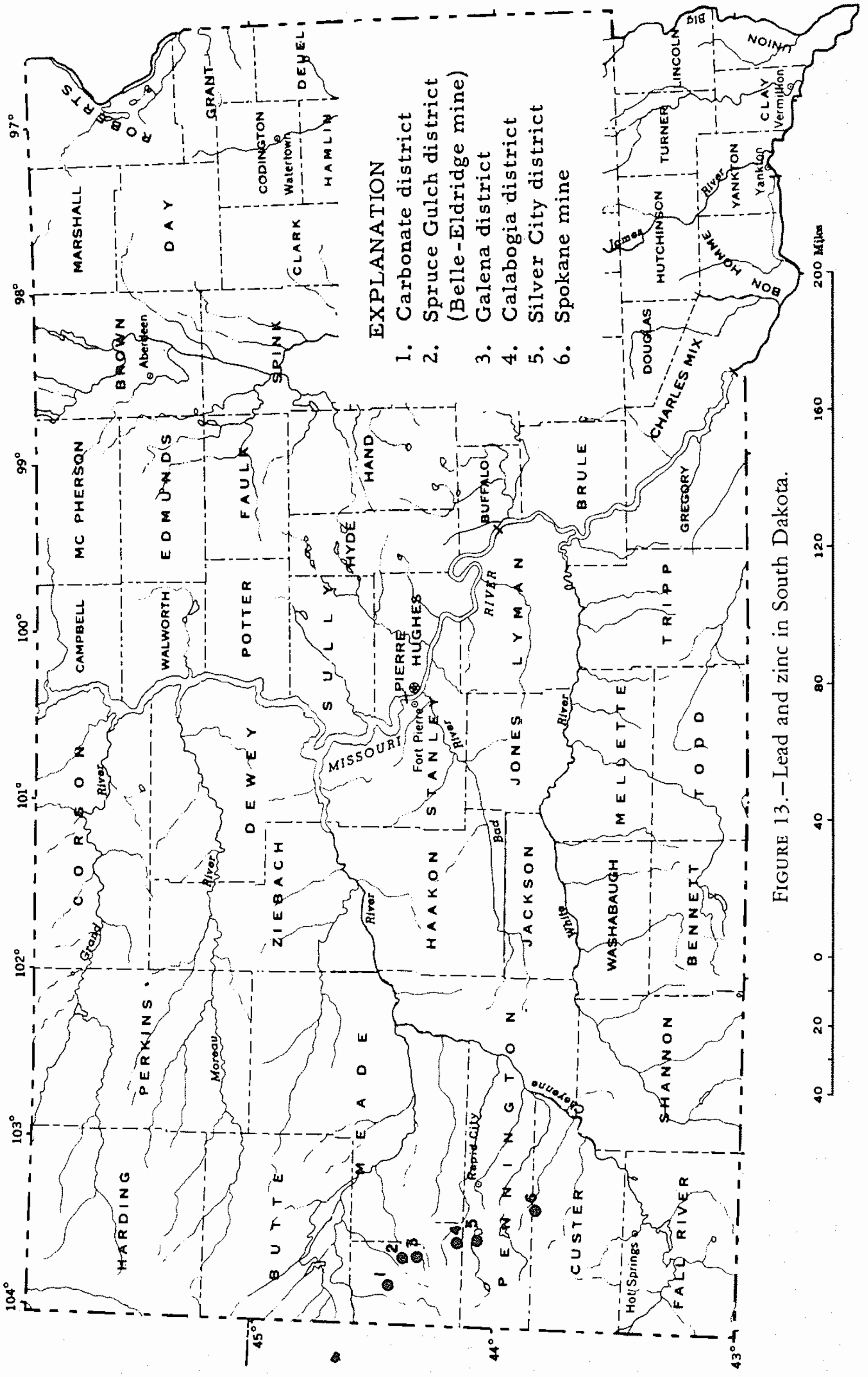


FIGURE 13.—Lead and zinc in South Dakota.

is not abundant except at one locality in the lower zone. Minor minerals include arsenopyrite, lollingite, chalcopyrite, and tetrahedrite. Oxidation has converted much of the mineralized rock to a mixture of iron and manganese oxides; the lead and silver minerals in these oxidized deposits are largely undetermined (Connolly and O'Harra, 1929). Oxidized deposits in the lower zone at the Silver Queen mine contain vanadium.

Spruce Gulch district

The genesis and stratigraphic position of the ore bodies at Spruce Gulch are similar to those at Galena, except that ore was mined only in the lower zone. The ore minerals replaced dolomite beds that are interbedded with shale. The ore bodies were just above a monzonite porphyry sill a few feet above the quartzite at the base of the Deadwood Formation (Schwartz, 1937; Davis 1948). The ore bodies are in a faulted area, and dense shale overlies the ore zone. Two ore bodies were mined, each several tens of feet wide, a few hundred feet long, and 5 feet in average thickness. The principal minerals in the ore deposits were pyrite, galena, sphalerite, arsenopyrite, and lesser quartz. Minor minerals were marcasite, pyrrhotite, chalcopyrite, gold, and carbonates.

Carbonate district

Ores in the Carbonate district were formed in the same early Tertiary period of mineralization as those at Galena and Spruce Gulch, but are in the Mississippian Pahasapa Limestone adjacent to sills and dikes of prophyritic intrusive rocks. One type of deposit consists of "large irregular bodies of lead carbonate merging into galena" (Irving, 1904), and this type largely follows contacts between limestone and the porphyritic igneous rocks. Other minerals include vanadinite, cerargyrite, matlockite, wulfenite, pyromorphite, plattnerite, and atacamite. This type of deposit is rich in silver.

The other principal type of ore body consists of "the partial filling of veins with galena, lead carbonate, and cerargyrite in connection with extensive replacement of the limestone by ferruginous jasper" (Irving, 1904). This type of deposit is rich in gold. Several of the mines are along one fracture that can be traced for 2,700 feet.

Calabogia district

Little is known about the mineralization at the Calabogia district except that it is said to be similar to that at Silver City (discussion of Silver City district follows). There has been no mention of gold.

PENNINGTON COUNTY

Silver City district

In the Silver City district, steeply dipping veins up to 2 feet wide cut across foliation and bedding of the Precambrian metamorphic rocks. Quartz is the principal vein mineral, and sericite and siderite are minor. Connolly and O'Harra (1929) reported the principal metallic minerals to be jamesonite and arsenopyrite, but Berry and Thompson (1962) found the "jamesonite" to be boulangerite. There may be small amounts of jamesonite plus zinkenite, meneghenite, semseyite, geocronite, and warrenite reported by Ziegler (1914), on the basis of chemical analyses. Minor minerals are pyrite, sphalerite, chalcopyrite, and gold. The better grade ores average 0.8 ounce of gold per ton and are of value chiefly for their gold content, although there are reports of the production of lead-silver concentrates. Connolly and O'Harra (1929) believed the ores to be of Precambrian age.

CUSTER COUNTY

Spokane mine

The Spokane mine is developed to a depth of 300 feet on a steeply dipping vein in Precambrian schist and pegmatite. The vein can be traced on the surface for 723 feet, and it ranges in width from a few inches to a horsetailed aggregate of veinlets 25 feet wide. The principal minerals are quartz, galena, sphalerite, pyrite, and marcasite. Minor minerals include chalcopyrite, gold, arsenopyrite, argentite, muscovite, and microcline (Connolly and O'Harra, 1929). The ore body was believed by Connolly and O'Harra (1929) to be of Precambrian age, but an age determination by Kulp (1956), on the basis of the ratios of lead isotopes, indicates less than 400 million years. Previously, Tullis and Toland (1940) had suggested the possibility of an early Tertiary age, based on the nature of the mineralization.

RESOURCES

Of the six districts, Galena probably has had the greatest production of lead, and perhaps has the greatest potential for the future. Large ore bodies that cropped out were discovered in the early days; however, there are large unprospected areas in the Galena district in which the ore zones may be 100 to 600 feet below the surface. At the eastern edge of the district a diamond drill hole put own by the U.S. Bureau of Mines in 1954 found significant amounts of pyrite, galena, and sphalerite in 2 feet of core from the lower zone in the Deadwood Formation at a depth of 525 feet. Only pyrite was found in the upper zone. This hole is about a third of a mile from the nearest mine.

The Double Rainbow mine in the upper ore zone has been the most productive mine in the district. Diamond drill holes in the valley between the Double Rainbow and the Florence mines would explore the lower zone at moderate depths.

Most of the mining in the Galena district was abandoned following the decline in the price of silver after 1890 and the extraction of the high-grade ore bodies. Since then the most systematic sampling has been at the Double Rainbow mine where samples have been low in values, although locally some contain as much as 40 ounces of silver or 0.52 ounce of gold per ton. These silver and gold samples generally are not assayed for lead.

Rich ore bodies in the Pahasapa Limestone were mined during the early days of mining in the Carbonate district. Zones of the underlying Deadwood Formation that are productive at the Galena and other districts might offer an exploration target in the Carbonate district.

At the Spokane mine unpublished reserve estimates made by F. C. Lincoln in 1931 show the shaft shoot, between the 200- and 300-foot levels, to contain 10,620 tons of rock averaging 1.78 percent lead, 1.63 percent zinc, 0.0054 ounce of gold, and 0.81 ounce of silver per ton. In the east shoot, between the 200- and 300-foot levels, Lincoln estimated 4,825 tons of rock averaging 10.89 percent lead, 6.20 percent zinc, 0.0138 ounce of gold, and 4.37 ounces of silver per ton.

Drilling done at Spruce Gulch by the U.S. Bureau of Mines in 1943 found nothing of economic significance. However, the ore bodies that were mined at Spruce Gulch were of sufficient size to lead to the belief that more ore may exist in the area. Possibly a combination of geochemical prospecting and drilling in places geologically favorable may prove successful.

MANGANESE

(By J. P. Gries, South Dakota School of Mines and Technology,
Rapid City, S. Dak.)

Manganese ore consists primarily of the black oxide minerals wad, pyrolusite, and psilomelane; a very small quantity is derived from the pink carbonate, rhodochrosite. The manganese content of commercial ores normally is 35 percent or more. Most of the 2 million tons consumed annually in the United States is used in the manufacture of iron and steel; the remainder is divided between the manufacture of storage batteries, the chemical industry, and a host of minor uses. The United States normally produces less than 3 percent of its own needs and depends upon imports for the remainder.

The Black Hills area of western South Dakota (fig. 14) has produced small quantities of manganese in times of national emergency. No large commercial reserves are known. Vast resources of low-grade material along the Missouri River are not competitive with domestic and imported ores of higher grade.

Known shipments of South Dakota manganese-bearing material are listed below. The large shipments of Chamberlain nodules were for experimental work conducted by laboratories outside of the State.

South Dakota manganese ore shipments

Date	Nature of material shipped	Source	Amount
1892	Oxide ore from Minnelusa Formation	Custer County	19 tons.
1918	Ore of Mn, Au, Ag, Davis mine	Lawrence County	1 carload.
1940	Crude nodules, Chamberlain area	Lyman County	600 tons.
1941	do	do	2,500 tons.
1942	do	do	5,356 tons.
1942	Oxide ore from North Star mine	Lawrence County	2 carloads.

Source: From State mine inspector's reports.

BLACK HILLS DEPOSITS

Connolly and O'Harra (1929, p. 340) describe a small deposit of pyrolusite in the Minnelusa Formation of Pennsylvanian and Permian age near Argyle, Custer County. The pyrolusite occurs in disseminated form, and as layers and irregular bodies within a sandstone unit about 35 feet thick. They report that small shipments were made prior to 1900, including one shipment of 19 tons in 1892. An analysis (Weeks, 1895, p. 423) is given below:

Custer County manganese ore

	Percent
Metallic manganese	46.05
Metallic iron	3.93
Phosphorus	.05
Silica	8.0
Moisture	4.70

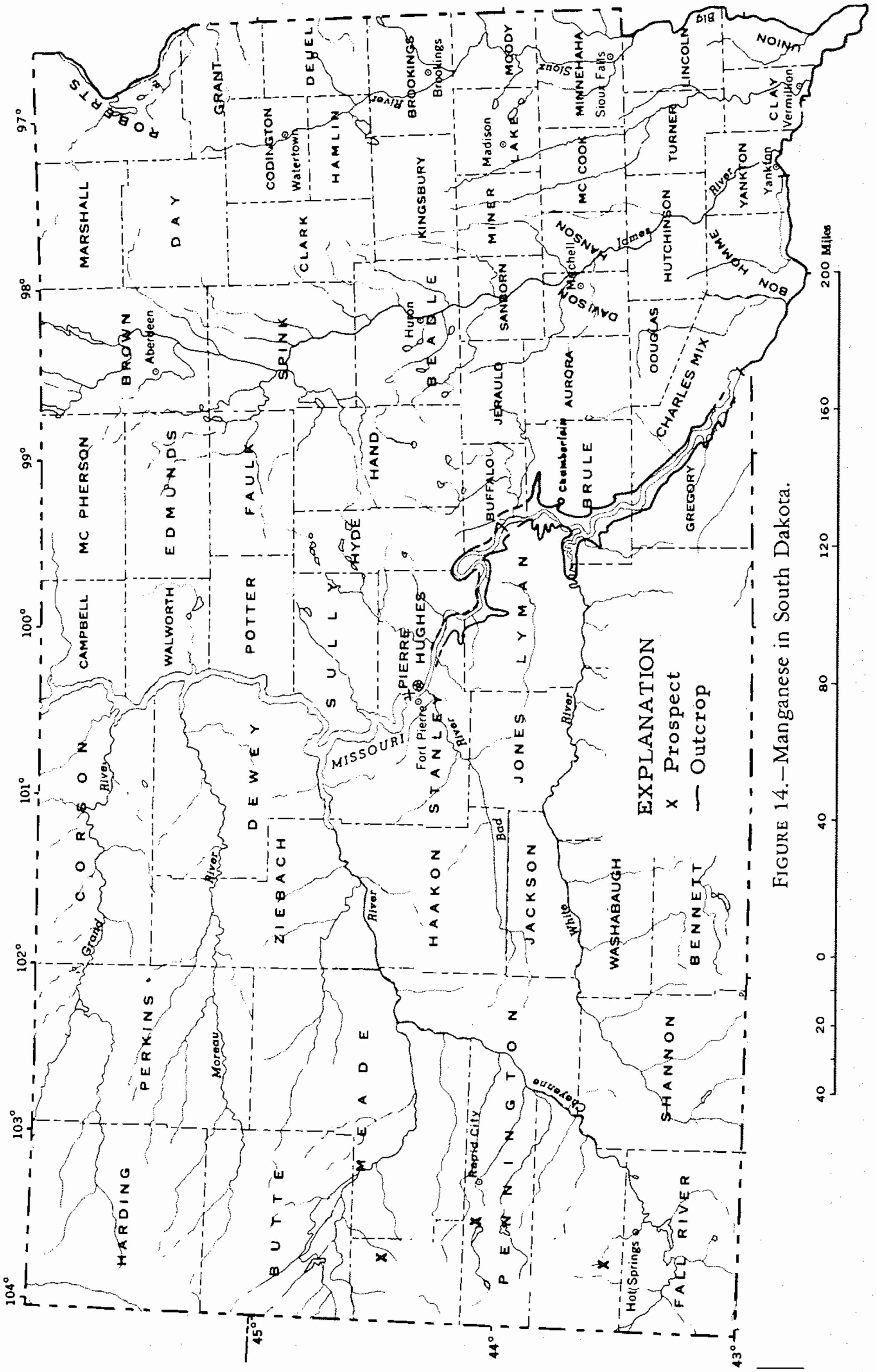


FIGURE 14.—Manganese in South Dakota.

Small concentrations of manganese minerals are associated with Tertiary mineralization in the northern Black Hills. Managanese oxides have been reported in Cambrian rocks at Galena, Spruce Gulch, Strawberry Hill, and Two Bit, and in Pahasapa Limestone ores in the Carbonate district and at Ragged Top. Lincoln (1937, p. 163) also reports one manganese prospect in Precambrian rocks 1 mile north of Pactola. Apparently none of these occurrences is commercial.

Two carloads of manganese ore were reported to have been shipped from the North Star mine near Deadwood during World War II (Mine Inspector's Report for 1942). This ore was produced under a government buying program established to permit mining of material which would normally be noncommercial, either because of small volume or low grade.

MISSOURI RIVER DEPOSITS

History of exploration.—Concretions which weather out of a part of the Pierre Shale form a continuous black band along the Missouri River breaks in central South Dakota (fig. 14). Mr. Albert Amundsen of Lake Andes, S. Dak., discovered in 1927 that these concretions, or nodules, were unusually high in manganese. This aroused the interest of John A. Savage Co., of Duluth, and of Mr. K. M. Leute of Minneapolis, who sponsored a program of test pitting and sampling of the manganese-bearing beds both north and south of Chamberlain. Results of a brief field investigation by D. F. Hewett of the U.S. Geological Survey were released in February 1930 (Hewett, 1930).

Stratigraphic studies in 1934–35 indicated that the manganese-bearing zone formed a laterally continuous member of the Pierre Formation, and a systematic program of section measuring, mapping, trenching, and sampling was conducted by the South Dakota Geological Survey in 1940 and 1941 (Gries and Rothrock, 1941).

The U.S. Bureau of Mines inaugurated an extensive evaluation of the manganese deposits of the Missouri Valley in 1940. A pilot plant was built on the outcrop 8 miles west of Chamberlain in 1941. Experiments in mining and transportation of concretion-bearing shale, and in separating nodules from shale, continued from 1941 to 1947. A summary of the Bureau's activities and conclusions was published in 1949 (Pesonen and others, 1949; Zinner and Grosh, 1949).

In the late 1950's, the Pittsburgh Pacific Co. became interested in the concentration of manganese nodules in terrace gravels along the Missouri River north of Fort Thompson, Buffalo County. An experimental plant was built to devise methods of separating the gravel into (1) a manganese nodule concentrate, and (2) gravel, free of concretions, clay pebbles, and other undesirable constituents, and suitable for concrete aggregate.

Description of the deposits.—The manganese nodules in the Pierre Shale are concentrated in the DeGrey Member. The DeGrey consists of dark gray shale, numerous thin bentonite beds, and abundant iron-manganese concretions. It is underlain by the thin, light colored marl of the Crow Creek Member, and overlain by the dark, gumbo-forming shale of the Verendrye Member.

The nodules occur in distinct layers parallel to the bedding of the enclosing shale. The average nodule has the size and shape of a large baking potato. They may be widely separated, or so closely spaced as to form a nearly continuous pavement. The average thickness is perhaps 2 inches, though concretions up to 8 inches thick have been observed. Horizontal dimensions range from less than 2 inches to a foot or more. The concretions average nearly 5 percent of the dry weight of the formation.

The Bureau of Mines has recognized three types of concretions: (1) hard concretions having a hardness of 4.0 to 5.0 on Moh's scale are the most abundant, (2) soft concretions that have a hardness of 2.5 to 3.5 and that may be soft throughout or may have a hard core, and (3) a still softer type that grades into the shale; fractures are as likely to go through this type of concretion as around it. Types (1) and (2) easily break free of the enclosing shale. The third type is referred to as "shaly" concretions in Bureau of Mines reports.

Fresh unweathered concretions of the hard variety are medium gray to olive. Weathered nodules have a gray center, surrounded by a rusty brown halo, and a purplish-black outer crust. The soft varieties are usually white to cream colored when fresh, and light brown after weathering. The concretions are mostly carbonates of manganese, iron, calcium, and magnesium. The non-carbonate constituents are mainly silica and alumina, probably present in the form of clay. A typical nodule contains 14 to 17 percent manganese and 6 to 10 percent iron. Extreme values reported by the Bureau of Mines are 5.03 to 26.61 percent manganese and 2.61 to 24.00 percent iron (Pesonen and others, 1949, pt. I, p. 58).

The Bureau of Mines conducted an intensive sampling program along both sides of the Missouri River from T. 102 N. to T. 107 N., and up the White River as far as T. 104 N., R. 74 W. Samples from bucket drill holes at 1-foot intervals were dried and hand sorted to separate the concretions from the shale. The top of the concretion zone was taken at the top of the highest manganese concretions, and the base was taken at the point where the concretions averaged less than one percent of the shale or where the manganese content of the concretions dropped below 10 percent. Using these criteria, the concretion zone ranged in thickness from 12 feet at Wheeler Bridge, Charles Mix County, to 72 feet near the Big Bend. The average thickness used in tonnage estimates was 40 feet.

Concretions in the drilled zone ranged from 2.45 percent by weight near Big Bend to 6.11 percent near Oacoma, Lyman County; the average, over all areas drilled, was 4.85 percent of the dry material in the zone. If the minus one-half inch material was excluded, the percentage dropped to 3.19.

The average of all analyses of all concretions in 9 out of 10 of the areas drilled by the Bureau was 15.68 percent manganese and 8.7 percent iron. Considering only the plus one-half inch concentrate, the percentages increased to 16.09 and 10.26, respectively.

Using 4.85 percent as the nodule content of the dry shale, and 15.83 percent as the average manganese content of the nodules, the average manganese content (of the concretions but not the enclosing shale) of the dry tonnage mined from the concretion zone was 0.77 percent. If only the plus one-half inch concentrate was considered, the tenor dropped to slightly over 0.5 percent.

Resources.—In calculating resources, all material has been included that is under overburden less than one-half the thickness of the concretion zone. From the many mapped and measured sections, an average mining width of 365 feet was established. Pesonen and others (pt. I, p. 87) state:

> It has been shown that an outcropping and lightly covered manganiferous zone 582 miles in peripheral length, and 365 feet wide contains approximately 12 million tons of manganese in 77,700,000 tons of concretions, and that within the same zone the enclosing shale itself contains at least an equal but probably a much greater tonnage of manganese.

Mining and beneficiation.—The Bureau of Mines experimental mining indicated that mining of the concretion zone in a single bench, using a 3-yard or larger shovel, would be practical. Mining and hauling would be difficult in periods of continued wet weather.

After much testing, a two- or three-stage wet jigging process appeared to be the most satisfactory method of separating the nodules from the shale. Methods that resulted in a shale-free concentrate recovered an appreciably smaller percentage of the total manganese than methods that permitted a small percentage of shale to remain in the concentrate. Zinner and Grosh (1949) noted that whereas present methods of recovery of the manganese from the nodules require a shale-free concentrate, it would be desirable to devise a metallurgical process that could handle a concentrate with no less than 10 percent shale.

There is no known practical method of recovering the manganese disseminated in the shale.

Prospects for development.—At present there is no market for the manganese nodules. Both the Bureau of Mines and private laboratories have shown that it is technically possible to use the nodules directly in the production of basic pig iron, or to produce metallic manganese by an electrolytic method. Neither is economically feasible at present. Manufacture of ferro-manganese by complex pyrometallurgical processes, or recovery of manganese by leaching and other chemical processes is also technically possible but uneconomic in the foreseeable future.

In summary, the central South Dakota manganese deposits comprise a large low-grade resource, development of which must await the time when it can be exploited in competition with higher grade ores from other areas.

TIN

(By J. C. Ratté, U.S. Geological Survey, Denver, Colo., and J. J. Norton, U.S. Geological Survey, Washington, D.C.)

Tin in the mineral cassiterite was discovered in gold placers in the northern Black Hills in 1876 (Hess, 1909); the first lode tin was mined at the Etta pegmatite in the southern Black Hills in 1884. Between 1884 and 1936, approximately 180 tons of metallic tin valued at about $95,000 was produced from placers, veins, and pegmatites (Cummings and others, 1936, p. 2). Since then another 10 tons of tin has been added (table 5). The last recorded production was in 1952 when a very small amount of tin from the Black Hills was reported with the production from Alaska in the U.S. Bureau of Mines Minerals Yearbook.

The history of tin activity in the Black Hills has been mainly one of exploration, not actual production. The production is minute in relation to the size of the world tin industry, which annually yields 150,000 to 200,000 tons of tin. No sizable tin deposit has ever been mined in the United States, and the mere occurrence of tin, in the Black Hills or anywhere else, tends to generate widespread interest. During the "tin boom" of the southern Hills between 1884 and 1894, English interests alone were reported to have invested at least $3 million (Eng. Mining Jour., 1894, v. 58, p. 463). How much additional money has been spent in the search for tin in the Black Hills is not known.

TABLE 5.—*Tin production in South Dakota, 1884–1963*

Year	Quantity (pounds)	Value	Year	Quantity (pounds)	Value
1884–1912 [1]	314,000	$76,500	1938	2,000	$900
1913	2,000	660	1939	(3)	608
1914–16	----------	----------	1940	4,000	1,710
1917	20,000	12,300	1941	3,210	(3)
1918	240	200	1942	4,000	1,560
1919	----------	----------	1943	2,000	750
1920	12,000	6,000	1944	(3)	(3)
1921–26	----------	----------	1945–47	----------	----------
1927	325	200	1948	(3)	(3)
1928	4,000	2,000	1949–63	----------	----------
1929	500	200			
1930–36 [2]	3,045	1,100	Total, 1884–1963	[4] 379,979	[4] 110,276
1937	2,000	1,000			

[1] Estimated.
[2] Data shown for the period of years to avoid disclosure of confidential figures.
[3] Confidential figure; included in total.
[4] Includes confidential figures as indicated by footnote 3.

Source: U.S. Department of the Interior, Bureau of Mines.

Deposits of the Tinton district, in the northern Black Hills near the Wyoming border (fig. 15) have accounted for much of the exploration and about one-third of the total production. Most of this has been from cassiterite-bearing lenses or layers in pegmatite at the Rough and Ready mine. Tin also has been found in the Giant-Volney and other pegmatites, and in the small placer deposits of this area, as in Bear Gulch astride the Wyoming-South Dakota border.

Most of the rest of South Dakota's production has been from the Hill City district, chiefly from quartz veins that contain muscovite, beryl, and cassiterite. A typical vein at the Cowboy mine is less than 1 foot wide over most of its length, and in places narrows to a mere seam. The vein has been explored to a depth of 300 feet beneath the surface; on the 100-foot level, it is continuous for 425 feet. The vein has a single narrow ore shoot. Broken ore in the stopes averages about 0.5 percent tin (Dougherty, Munson, and Cummings, 1945).

Cassiterite is also sparsely distributed in zoned pegmatite of the southern Black Hills. Its main habitat is mica-rich environment, some of them in outer zones, some in replacement bodies, and some elsewhere. The distribution of cassiterite is erratic, and tin is recovered only as a minor byproduct in mining for other pegmatite minerals.

In their appraisal of tin resources of the Tinton district, Smith and Page (1941) estimated that there are about 200 tons of metallic tin in the Rough and Ready pegmatite, and they suggest only a modest potential for the Giant-Volney pegmatite and other deposits. Estimates

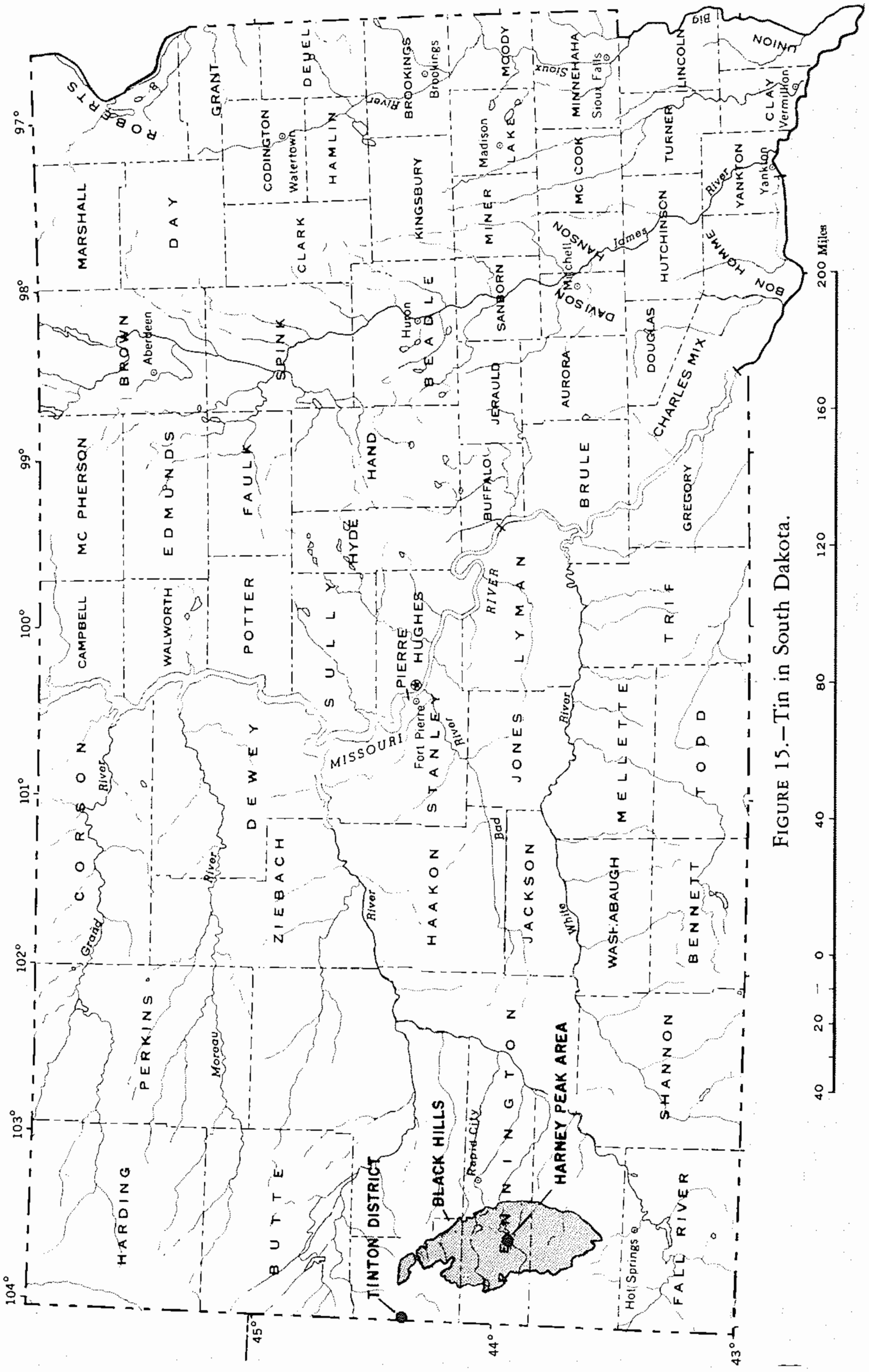


FIGURE 15.—Tin in South Dakota.

for the Hill City district, based largely from examination of the deposits in 1941–43 by geologists of the U.S. Geological Survey, suggest measured and indicated resources of 60 tons of tin and inferred resources of the same magnitude. Data published for the tin content of several of the pegmatites in the southern Black Hills suggest a tin content of several hundred tons, but at a grade that in no deposit exceeds 1 percent tin (Page and others, 1953, p. 78; Sheridan and others, 1957, p. 7, 24; Norton and others, 1962, p. 112; and Staatz and others, 1963, p. 182, 194).

In short, it has been demonstrated that tin is a widely distributed but minor constituent in the rocks of the Black Hills, as in many geologically similar localities throughout the world. Whether larger and richer deposits, suitable for full-scale mining, can be found in the Black Hills is a different question. This history of the extensive and largely unsuccessful search for such deposits can be viewed only as discouraging. The bibliography accompanying this report includes but a small part of the many published statements that have resulted from the periodic resurgence of interest in South Dakota tin deposits. The existing evidence indicates that the Black Hills is unlikely ever to be a significant source of tin.

TUNGSTEN

(By S. W. Hobbs, U.S. Geological Survey, Denver, Colo.)

Tungsten is a metal of high strategic value whose importance depends mainly on the unusual physical and mechanical properties of the element, its alloys, and certain special compounds. In its pure form, tungsten is a white metal whose melting point of 3,410° C. is higher than that of any other metal. It has unusually high density, low vapor pressure, and favorable electrical and thermionic properties. Tungsten alloys and carbides are notable for their extreme hardness and wear resistance and particularly for retaining hardness at elevated temperatures. Industrial uses of tungsten evolve from these special properties.

Pure or substantially pure tungsten metal is important in electric lighting, electronics and electrical contact applications. However, the greatest use of the metal is in alloy tool steel and in tungsten carbide used for cutting edges, dies, drill bits, wear-resistant machine parts and other applications where extreme hardness is desirable. Over 70 percent of the consumption has recently been in tool steel and tungsten carbide.

The United States has in general imported tungsten in amounts that exceed domestic production. Although the U.S. tungsten mining industry has operated continuously (except for 1921 and 1922) for over 50 years, the rate of production has ranged widely due to various economic factors and particularly the Government stockpiling program. Only a few domestic producers have been able to compete consistently on the open market with foreign producers (Holliday, 1960, p. 914). However, a large domestic productive capacity was demonstrated twice in the last two decades under conditions of special need or incentive: in 1943–45, to fill heavy demand of the war effort, and between 1950 and 1956 under the influence of the price incentive of the Government stockpiling program during the Korean crisis. In 1955, production reached an all-time peak that was nearly four times the average annual production of the immediate postwar period 1946–50. Subsequent to the end of Government stockpile purchases in December 1956, the price dropped drastically and consequently production from many mines was stopped or radically reduced. In 1956, nearly 600 operation reported some production; in 1958, only two producers were active (U.S. Bureau of Mines Minerals Yearbook, 1956, p. 1227, and 1958, p. 1091). These facts illustrate dramatically the tungsten resource situation of the United States: there is a substantial supply of tungsten available if the need warrants paying the price to extract it.

Tungsten minerals are widely distributed in various rock types of the earth's crust, but for the most part seem to be genetically associated with igneous rocks of granitic composition. About 11 minerals contain tungsten as an essential component, but of these the only commercially important ones are those of the wolframite group—ferberite, $FeWO_4$, wolframite, $(Fe, Mn) WO_4$ and huebnerite, $MnWO_4$—and scheelite, $CaWO_4$. Although the wolframite group is economically the more important in the world as a whole, and also in South Dakota, scheelite has accounted for nearly three-fourths of the United States output.

In the United States, tungsten occurs principally in quartz veins that contain minerals of the wolframite group, scheelite, or both, in contact metamorphic deposits containing scheelite and as hydrothermal replacement bodies of wolframite and scheelite in igneous, sedimentary or metamorphic rocks. Some is also found in pegmatites.

Tungsten was first discovered in the Black Hills of South Dakota in the early 1880's but no production is recorded prior to 1898, and up until 1915 only about 300 tons of concentrates and high grade ore valued at $25,000 had been produced. The "boom days" of production were from 1915 to 1918 when over 50,000 units[1] (850 short tons—60 percent WO_3 basis) valued at nearly $1,132,000 were produced—mostly from the northern hills in the vicinity of Lead. A revival of activity in the period 1926–29 added approximately $165,000 to the production record, and small intermittent production during the last 25 years has been valued at approximately $100,000. Total production through 1963 has amounted to less than 100,000 short ton units WO_3 valued at approximately $1,379,000. This is about 0.6 percent of the total U.S. production. Table 6, based on information supplied by the U.S. Bureau of Mines, shows the detailed production record.

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[1] One unit equals 1 percent WO_3 per ton or 20 pounds WO_3.

TABLE 6.—*Tungsten ore and concentrates production in South Dakota, 1898–1963* [1]

Year	Quantity (short tons, 60 percent WO_3 basis)	Value	Year	Quantity (short tons, 60 percent WO_3 basis)	Value
1898–1914	[2] 300	$25,000	1941	(3)	(3)
1915	240	181,000	1942–43	----------	----------
1916	239	404,775	1944	7	(3)
1917	270	299,644	1945	4	(3)
1918	201	247,100	1946	1	(3)
1919–23	----------	----------	1947–51	----------	----------
1924	(3)	(2)	1952	(4)	$335
1925	----------	----------	1953	2	(3)
1926	90	41,900	1954	(4)	500
1927	141	(3)	1955–63	----------	----------
1928	(3)	(3)			
1929	5	(3)	Total, 1898–1963	[5] 1,638	[5] 1,378,694
1930–40	----------	----------			

[1] Data for 1963 are preliminary.
[2] Reported as concentrates and high grade ore. Probably not converted to 60 percent WO_3 basis.
[3] Confidential figure; included in total.
[4] Less than 1 ton.
[5] Includes confidential figures as indicated by footnote 3 and/or 4.

Source: U.S. Department of the Interior, Bureau of Mines.

The occurrence of tungsten in South Dakota is restricted entirely to the Black Hills either in or very near to the Precambrian core rocks. The general geology of the Black Hills is described in pages 23–28 of this report and historical details of the tungsten mining industry in South Dakota as well as detailed descriptions of the geology and the deposits are contained in publications of the South Dakota School of Mines by Runner and Hartman (1918), Connolly and O'Harra (1929), and Lincoln, Miser and Cummings (1937). These papers as well as reports for the U.S. Geological Survey by J. W. Irving (1901) and F. L. Hess (1908) have supplied much information for this brief summary. The tungsten deposits have been divided into two major types based on the age and mode of occurrence: (1) quartz veins and pegmatites probably of Precambrian age in Precambrian schists, and (2) replacement bodies in dolomite of the Deadwood Formation (Cambrian) and in silicified rhyolite and presumed to be related to a Tertiary period of mineralization. Wolframite is the principal mineral in both modes of occurrence although some huebnerite is found; scheelite is usually associated with all the deposits, and in some few places either huebnerite or scheelite is the dominant mineral.

Pegmatites and quartz veins occur widely in the Precambrian rocks of the southern Black Hills, but the important tungsten-bearing bodies are largely restricted to two areas, the Hill City district, a few miles south and southeast of Hill City, and the Spokane district, southeast of Keystone. General characteristics of the pegmatites of the Black Hills are described elsewhere in this report. Although tungsten minerals occur in these pegmatites and some have been mined from them, the amount is small. The tungsten-bearing quartz veins which have been the main source of interest range in width from a fraction of an inch to four feet or more and exhibit a strong tendency to pinch, swell, and branch. Usually no single vein can be traced for more than a few hundred feet, although the vein zone of which it is a part may continue a greater distance. The occurrence of tungsten minerals within the vein is as erratic as the veins themselves. The crystals vary greatly in size, form, and distribution, and rich spots occur both in the thin parts as well as in the thick parts of the veins.

The major tungsten production from the Black Hills has come from replacement deposits of wolframite in Cambrian dolomite near Lead, Lawrence County. Two operations, the west end of the Homestake gold mine open pits about 0.5 miles northwest from Lead, and the Wasp No. 2 mine, 2 miles south from Lead, were the principal producers of this type of ore. Other less productive occurrences are known.

At both mines, wolframite ore bodies replace part of a 3-foot layer of sandy dolomite interbedded with shale, conglomerate, and quartzite, near the base of the Cambrian Deadwood Formation. These rocks overlie unconformably the highly folded Precambrian schists that contain the principal gold ore bodies of the Homestake mine. The ore consists of small grains of wolframite in a siliceous matrix accompanied by a little scheelite, gold, and barite. A small amount of wolframite has also been produced from silicified zones in rhyolite.

The Black Hills of South Dakota yielded a very appreciable output of tungsten in World War I, but very little has been produced since that time. Most of the output was from small, relatively high-grade deposits and the history of discovery and production makes it apparent that most, if not all, of the ore bodies that could be found easily were prospected or mined during the 1915–17 "boom" period. The Black Hills area is a tungsten-bearing province in which numerous concentrations of tungsten minerals occur. However, the ore shoots, like those in many other tungsten districts, are small, erratically disposed in the veins, pegmatites or other host rock, and are not arranged according to any predictable pattern. Considering the geologic occurrence and history of discovery and production, many more tungsten ore bodies can be presumed to exist, but as they are expected to be small in size and difficult or costly to find and exploit, the future for a revival of major production is not bright. A small amount will undoubtedly continue to be recovered at times of higher prices or as a byproduct of operations for other mineral commodities.

MOLYBDENUM

(By R. U. King, U.S. Geological Survey, Denver, Colo.)

The metal molybdenum is of primary importance to our modern industrial economy. Its economic importance is due chiefly to its versatility as an alloying element in the ferrous metal industry. About 75 percent of the molybdenum consumed in the United States is used in the manufacture of high temperature alloy steels, stainless steels, and castings (Fischer and King, 1964). The demand for molybdenum in the future, therefore, is to a large degree dependent on the consumption of steel. The remaining 25 percent of the domestic consumption not going into steel is used in special alloys, metal products, refractories, chemicals, pigments, catalysts, lubricants, and agricultural products. New uses for molybdenum are being developed in the nuclear power field and in the missile and aerospace industries, which give promise of an ever-increasing demand for this versatile metal.

Its importance derives from the beneficial properties of hardness, toughness, and resistance to wear and corrosion that are imparted to steel when alloyed with molybdenum. In these respects molybdenum compares favorably with other alloy metals such as chromium, nickel, tungsten, manganese, vanadium, cobalt, and columbium.

Molybdenum is a silvery white metal, somewhat softer than steel, and it has a melting point of about 4,750° F., which is higher than all other metals except tungsten, rhenium, osmium, and tantalum. It is ductile and is resistant to acids and oxidation at ordinary temperatures.

Molybdenum is widely distributed in small amounts over the surface of the earth; its abundance in the rocks of the earths' crust is estimated to be from 1 to 2.5 parts per million (0.0001 to 0.00025 percent). It is present in trace amounts in many igneous, metamorphic, and sedimentary rocks, in soils, in water, and in plant and animal tissue. It occurs in nature only in combination with nonmetallic elements such as sulfur and oxygen and with other metals such as iron, calcium, tungsten, and lead. Its most common naturally occurring form, and the only one of current commercial importance, is the mineral molybdenite (molybdenum disulfide, MoS_2). Other molybdenum minerals of interest include wulfenite (lead molybdate), ferrimolybdite (iron-molybdenum oxide), powellite (calcium molybdate, commonly with tungsten), jordisite (amorphous molybdenum sulfide), and ilsemannite (a water soluble molybdenum oxide). A number of rarer minerals of doubtful commercial significance have been identified in which molybdenum is combined with one or more of the following elements: bismuth, copper, magnesium, vanadium, cobalt, and uranium.

Although the mineral molybdenite was identified in the latter part of the 18th century, it was not until the early part of the present century that its potential value to the metals industry was recognized and wide applications for its use were developed. Intensive search for the metal followed, which resulted in the discovery of high-grade vein deposits of wulfenite in Arizona and of molybdenite in New Mexico, and of large tonnages of low-grade molybdenite ore at Climax, Colorado.

Commercial production of molybdenum in this country began in 1898, but output was relatively small and intermittent until 1914. Since 1914 production has increased yearly with few exceptions, to a current annual rate of more than 65 million pounds. During the first quarter of this century the United States contributed only a small portion of the world's molybdenum supplies, but since about 1925 from 65 to 90 percent of the world's molybdenum has been produced in the United States. Excellent summaries of world resources of molybdenum are given by Vanderwilt (1942) and by Creasey (1957); the reader is directed to these publications for further information.

The marketable forms of molybdenum are either molybdenite concentrates (95 percent MoS_2) or molybdenum oxide (MoO_3), which is produced by roasting molybdenite concentrates. The nominal market price is currently quoted at $1.40 per pound of contained molybdenum. Molybdenite is worth about 85 cents a pound but it is not usually marketable in small, individual lots. Such limitations should be kept in mind when evaluating the economic potential of individual molybdenum deposits.

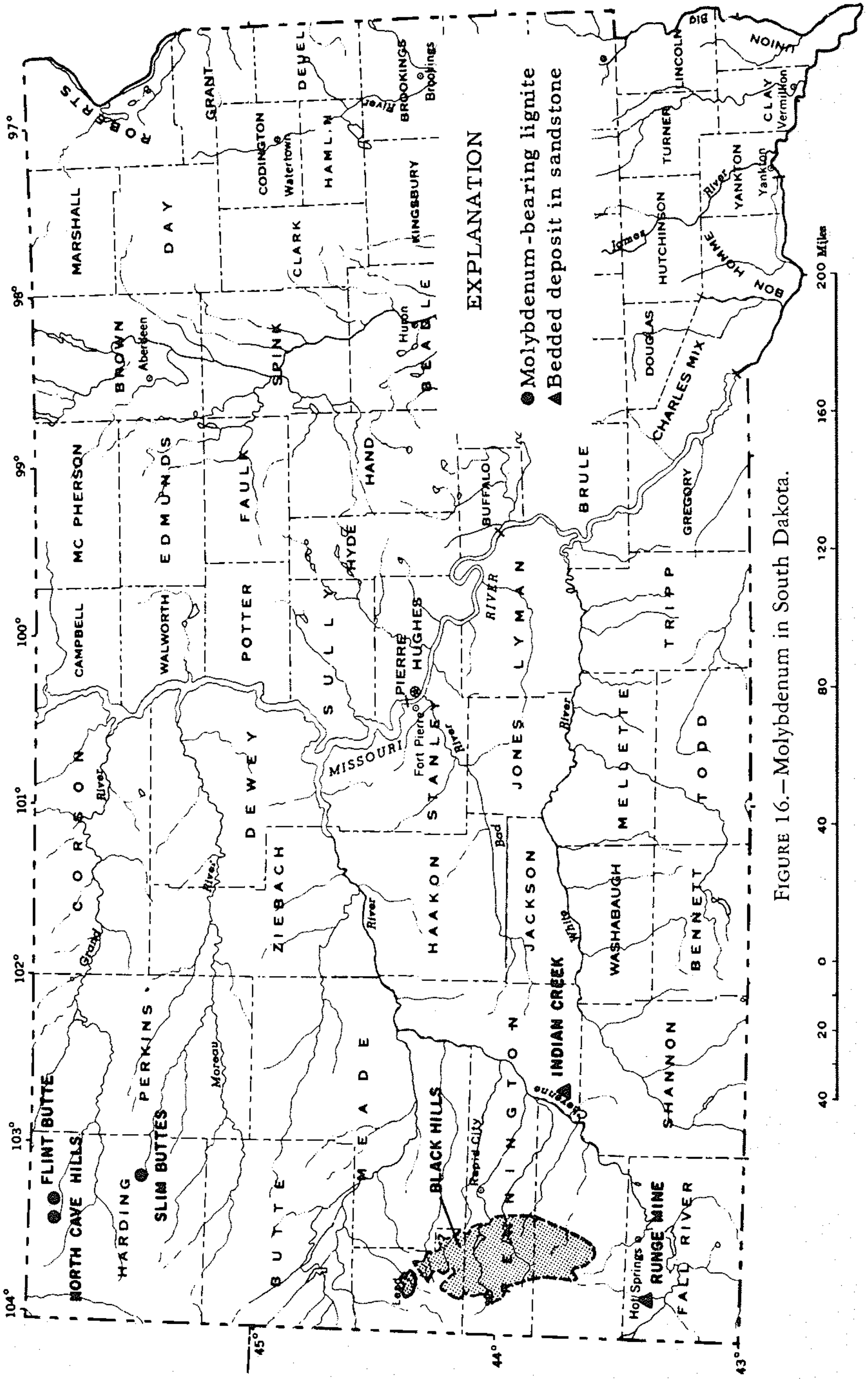

FIGURE 16.—Molybdenum in South Dakota.

Molybdenum deposits are of five genetic types: porphyry deposits in which metallic sulfides are dispersed through large volumes of altered and fractured rock; contact metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive granitic rocks in which the molybdenum commonly is associated with tungsten, bismuth, or copper; quartz veins; pegmatites and aplites; and bedded deposits in sedimentary rocks. The known molybdenum deposits of South Dakota fall in the last three of these types.

Molybdenite is reported to accompany tin, tungsten, bismuth, and copper minerals in quartz veins and pegmatite deposits in the crystalline rocks of the central part of the Black Hills (fig. 16). Because of the limited size of these deposits and their low average content of molybdenum, they are not likely to be of commercial significance. No molybdenum has been produced from these deposits in South Dakota.

Small but significant amounts of molybdenum are present in many of the uranium-bearing lignites and coaly rocks in the northwestern part of the State. According to Pipiringos (written communication, 1964), important reserves of uraniferous lignite and carbonaceous shale, containing more than 0.1 percent uranium, are present in the North Cave Hills (including Flint Butte) and Slim Buttes areas (fig. 16) of Harding County. The average molybdenum content of the more uraniferous rocks is in excess of 0.2 percent. Although this amount of molybdenum is too small to be minable for the molybdenum alone, the reserves of minable uranium-bearing lignites are large, and the deposits therefore constitute a significant potential source of by-product molybdenum.

A potential source of molybdenum also exists in the recently discovered Indian Creek molybdenum deposits (fig. 16) in the Badlands of southwestern South Dakota. These deposits consist of lenticular bodies of sandstone impregnated with molybdenum oxides. The deposits are from a few inches to several feet thick, and the molybdenum content ranges from a few hundredths of 1 percent to as much as 10 percent. Sufficient exploratory work has not been done to permit estimation of tonnage and grade of these deposits.

Small quantities of molybdenum in the minerals jordisite and ilsemannite are associated with the uranium-vanadium ore in the Runge mine (fig. 16), Fall River County (Myers and others, 1960), Fall River County. Although selected material contains as much as 0.7 percent molybdenum, the average content for the mineralized sandstone is probably not over a few hundredths of a percent. Molybdenum has not been recovered from this deposit.

THORIUM AND THE RARE EARTHS

(By J. W. Adams, U.S. Geological Survey, Denver, Colo.)

Thorium and the rare earth metals are treated together in this report as they are commonly associated in nature and are closely interrelated economically.

Thorium is a silver gray metal that, like uranium, is the parent of a series of radioactive decay products ending in a stable isotope of lead. Its geochemical behavior, however, is quite different from uranium in that it tends to be dispersed rather than to be concentrated in significant deposits.

The chief uses of thorium are in magnesium alloys and in the manufacture of gas mantles. A major potential use is in atomic reactors where thorium may be converted into a fissionable uranium isotope by neutron capture. The use of thorium for nuclear energy is, however, in the experimental stage and is in competition with relatively cheap, abundant uranium (Kelly, 1962, p. 25).

The rare earth metals comprise the 15 elements having atomic numbers 57 to 71, including lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europeum (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). One of these, promethium, is not known to occur in nature. Yttrium (Y), with atomic number 39, is also classed with the rare earths because of its chemical similarities and geochemical affinities.

The first seven elements listed above (La through Eu) are included in the cerium group of rare earths, so called because cerium is their most abundant member. The remaining eight elements (Gd through Lu) together with yttrium are called the yttrium group. The two groups are also referred to respectively as the "light" and "heavy" rare earths. The properties of the members of the two groups of rare earths are sufficiently distinct to cause one group to predominate over the other in most minerals, even though all or nearly all are ordinarily present (Olson and Adams, 1962).

The rare earths have many industrial applications such as in the steel industry, nonferrous alloys, glass manufacture and glass polishing, sparking alloys, and carbon electrodes for arc lights and projection lamps. Rare earth requirements are, however, relatively small compared to many other metals, domestic consumption in 1958 being only about 1,600 short tons of rare earth oxides (Baroch, 1960, p. 687). The rare earth industry is developed almost entirely around the cerium group elements, primarily cerium, lanthanum, praseodymium, and neodymium. Although considerable research is being directed to finding uses for yttrium and the heavy rare earth elements the current demand for these is small.

The marketing of ores of thorium and the rare earths is difficult as there is no established market comparable to those of the more widely used metals, and prices of their ores are generally determined by negotiation between buyer and seller. Detailed information on the economic factors of thorium and rare earths is given in a recent publication of the U.S. Bureau of Mines (Kelly, 1962).

Thorium and the rare earths are found in a large number of minerals, but only a few of these have been found in sufficient concentration to be used as ores. The most important source mineral for thorium is monazite, a phosphate of the cerium group. The thorium content of this mineral is variable, but commercial monazite commonly contains between 3 and 10 percent thoria (ThO_2) and from 55 to 60 percent combined rare earth oxides (Kelly, 1962, p. 5). Other potential sources of thorium are thorianite, thorite, and thorogummite, and multiple oxide minerals such as euxenite.

Monazite is also the principal ore mineral of the rare earths, but important deposits of bastnaesite, a rare earth fluocarbonate, are currently being mined at Mountain Pass, Calif. Both monazite and bastnaesite contain dominantly cerium group elements. Minerals in which the yttrium group predominate include xenotime, an yttrium phosphate, and euxenite.

Minerals containing thorium and the rare earths are found in many geologic environments. Most of the world production of these elements has come from placer deposits in which monazite and other heavy minerals have been concentrated in sands formed from the weathering of igneous and metamorphic rocks. Beach placers along the coasts of Brazil, India, and Florida, and stream placers in the southeastern United States and Idaho are among the best known deposits of this type. Some sedimentary rocks contain placer deposits that were formed along ancient beaches or river banks. Such consolidated, or "fossil" placers are found in sandstones of Upper Cretaceous age in several Western states (Dow and Batty, 1961), where they have been investigated primarily as a source of titanium. Fossil placers, of interest because of their monazite content, are also found in the basal conglomerate of the Deadwood Formation of Cambrian age in the Big Horn Mountains, Wyoming (Eilertsen and Lamb, 1956; Osterwald and others, 1959).

Although South Dakota, particularly the Black Hills area, is known as a source of a wide variety of valuable minerals, there have been very few reported occurrences of minerals containing thorium or the rare earths.

In an early description of the mineralogy of the Black Hills (Scott, 1897), monazite is reported as occurring "throughout the tin region around Harney Peak." It was also listed as occurring to the extent of 6 pounds per ton in a black sand concentrate from the vicinity of Tinton, T. 5 N., R. 1 E., in Lawrence County (Day and Richards, 1905). Monazite is not a common accessory mineral in the pegmatites of the Black Hills and was not noted during the intensive study of these deposits made by Page and others (1953).

Radioactive limonitic layers are found near the base of the Deadwood Formation in T. 2 N., R. 2 E., in Lawrence County, northwest of Rochford. These layers contain appreciable thorium, but have a very low rare earth content. Specific thorium-bearing minerals have not been identified, but the thorium is thought to be contained in the limonitic component. The deposits in the basal Deadwood Formation probably represent fossil placers similar to those in the Big Horn Mountains, but monazite, if originally present, may have been dissolved by solutions that selectively removed the rare earths leaving the thorium behind as a co-precipitate with hydrated iron oxides.

Several radioactivity anomalies, some of which are due largely to thorium, occur in the Bald Mountain gold mining district in secs. 1 and 2, T. 4 N., R. 2 E., and secs. 35 and 36, T. 5 N., R. 2 E., in Lawrence County (Vickers, 1954). These anomalies are mostly in altered zones in siltstone of the Deadwood Formation and in intrusive igneous rocks of Tertiary age. Concentrations of rare earth elements are also found in some localities (Vickers, 1954, table II), but neither thorium nor rare earths appear to be present in sufficient concentrations to be of economic interest at the present time.

No minable deposits of thorium or rare earth minerals are known in South Dakota, but the possibility of their future discovery should not be discounted. Ores of these elements are unfamiliar to many prospectors, and except for the radioactivity of thorium, they would commonly be unnoticed. Thorium and rare earth concentrations are found associated with alkalic rocks in many parts of the world, and as some rocks of this type are present in the northern Black Hills (Darton and Paige, 1925) this area would appear to offer the most promise for future discoveries.

VANADIUM

(By R. P. Fischer, U.S. Geological Survey, Denver, Colo.)

About 2,000 short tons of vanadium have been consumed annually in the United States in recent years. Three-quarters of this has gone into special engineering, structural, and tool steels, where it is used as an alloy to control grain size, impart toughness, and inhibit fatigue. The other principal domestic uses have been in nonferrous alloys and chemicals (U.S. Bur. Mines, 1960; Busch, 1961).

The bulk of domestic supplies of vanadium, and about half of the world supplies, has come from deposits of vanadium- and uranium-bearing sandstone in southwestern Colorado and the adjoining parts of Utah, Arizona, and New Mexico; similar deposits in western South Dakota and eastern Wyoming have also yielded a small amount of vanadium as a byproduct of the uranium mill at Edgemont, S. Dak. Other principal sources of vanadium have been a deposit of vanadium-bearing asphaltite in Peru, vanadate minerals from the oxidized zones of base-metal deposits in Africa, and vanadium-bearing iron deposits in Europe and Africa. These iron deposits and similar ones in many parts of the world contain very large resources of vanadium. Probably they will become increasingly important as sources of vanadium in the future.

The productive vanadium deposits in South Dakota occur only in sandstone beds of Cretaceous age in Fall River and Custer Counties (fig. 11). A brief description of these deposits is given below, but the section on uranium in this report (p. 50) gives more information on their geologic occurrences and the literature describing them.

The first deposit of this type in South Dakota was found in 1951 in the Craven Canyon area (no. 35, fig. 11). Intensive prospecting by private individuals, industry, and the government quickly resulted in the discovery of other deposits. A mill was built at Edgemont to treat these ores, and it began producing uranium concentrates in 1956. A vanadium circuit was added to the uranium mill in 1960; the recovery of vanadium concentrates was reported by U.S. Bureau of Mines Minerals Yearbook in 1960, 1961, and 1962. Figures of the amount of vanadium recovered are not published, but the amount is small relative to other sources. The vanadium content of the uranium-bearing sandstone mined in South Dakota averages only about 0.15 percent V_2O_5, approximately a tenth of the content of vanadium-bearing sandstone ores mined in Colorado, Utah, and Arizona. Furthermore, the mill at Edgemont also processes considerable ore mined in Wyoming, so probably some of the vanadium recovered by this mill has come from Wyoming ores. No significant production of vanadium can be expected from the known deposits in South Dakota.

The productive vanadiferous uranium ore deposits occur chiefly in thick lenses of sandstone in the Lakota and Fall River Formations of the Inyan Kara Group; some ore has been mined from thin beds of sandstone interbedded with carbonaceous siltstone in the lower part of the Fall River Formation. The ore minerals impregnate the sandstone, forming irregular tabular bodies that range in size from only a few tons to several thousands of tons of ore. The primary ore minerals consist of oxides of vanadium and an oxide and a silicate of uranium; these minerals oxidize to a variety of secondary minerals (see table 3, p. 53).

These ore deposits are thought to have formed from metals carried in solution in moving ground waters. The metals were precipitated at points where the chemical environment was strongly reducing. In places the ore-bearing sandstone contains carbonized plant fossils, which could cause the reducing conditions. In ore bodies where plant remains are lacking, the necessary reducing conditions could have been caused by the ore-bearing solutions mixing with waters containing dissolved organic acids or hydrogen sulfide.

Indicated and inferred reserves of uranium-bearing sandstone ore in South Dakota total nearly 70,000 tons (p. 51). The vanadium content of this material is so low, however, that its production potential is small. If conditions in the future justify intensive exploration, this work might result in the discovery of reserves totaling several times the current supply, but even so, no large production of vanadium can be foreseen.

ANTIMONY AND OTHER MINOR METALS

(By M. D. Dasch, U.S. Geological Survey, Washington, D.C.)

Minor amounts of antimony, arsenic, bismuth, selenium, sulfur, and tellurium are present in South Dakota. Several of these commodities have been recovered as byproducts during the smelting and refining of metallic ores mined in the Black Hills. With the exception of sulfur, a nonmetal, these elements conduct electricity in minor and varying amounts and are commonly referred to as semi-metals or metalloids. Their characteristics, uses, and production are discussed briefly in the following paragraphs. Occurrences of these commodities in South Dakota are summarized by mining district, rather than by individual commodity.

Antimony is an element that can occur in several different forms, a property referred to as allotropy. In the common form, it is a brittle, tin-white material with a metallic luster. The element is alloyed with certain metals in order to harden them and to inhibit corrosion. In 1962, the most recent year for which complete production statistics are available, the greatest consumption outlet for antimony was as antimonial lead. Significant quantities of the element were also used in plastics, flameproofing chemicals and compounds, pigments, and in ceramics and glass (Spencer and den Hartog, 1963a, table 7). Although antimony possesses no indispensable properties, it is technologically superior to other elements in many of its uses. Furthermore, it is relatively cheap and can be substituted for more expensive metals.

Antimony is found in two types of deposits: one type is simple both mineralogically and structurally, the other is complex. The simple type consists predominantly of stibnite (antimony trisulfide), native antimony, and in places their oxidized equivalents. The minerals occur in siliceous gangue and may be accompanied by small quantities of pyrite and other metallic sulfides. In the complex type of deposit, antimony is present in sulfo-salts of copper, lead, and silver, or in sulfides of copper, lead, zinc, and silver. The antimony is locked within the complex crystal lattice of certain ore minerals such as tetrahedrite (copper antimony sulfide). Stibnite less commonly is the principal antimony mineral in these complex ore bodies. Antimony mined in the United States has come primarily from the complex type of deposit. In the Black Hills of South Dakota, antimony locally occurs as jamesonite (lead antimony iron sulfide) and less commonly as stibnite and tetrahedrite in the complex type of ore body.

Antimony generally is a byproduct, at times a coproduct, recovered from metallic ores, especially those of lead. Commercial antimony ores range from low grades of 1 to 2 percent to high grades of 71.5 percent, or nearly pure stibnite. Minor amounts of antimony have been produced in South Dakota, but production figures are not available (Lincoln, Miser, and Cummings, 1937, table 5).

Arsenic is a brittle, poisonous, allotropic element that is widespread in small quantities. In the common form, it has a near metallic luster and is tin-white or silver-gray; exposure to air turns it black. Arsenic seldom occurs in the native state. More commonly it is found in one of three minerals: arsenopyrite (sulfarsenide of iron), orpiment (arsenic trisulfide), or realgar (arsenic monosulfide). In places arsenic is mineralogically associated with copper, lead, cobalt, nickel, iron, and silver, with or without sulfur.

Arsenic is recovered as a byproduct during the processing of copper, lead, and less commonly, gold and silver ores. No domestic deposits are mined solely for arsenic content at the present time. Elemental arsenic has not been recovered as a byproduct in this country since 1950. Instead, the element has been produced and consumed as arsenic trioxide or arsenious oxide, commercially called white arsenic. It is used primarily in the manufacture of calcium and lead arsenate insecticides. Since 1944 there has been a marked decrease in its consumption, owing to public preference for less toxic, organic insecticides, such as DDT. The only extensive application of white arsenic, other than as a poison, is in glassmaking.

In 1924 and 1925, 89 tons of white arsenic worth $7,167 was recovered from gold ores mined in the Black Hills (U.S. Bureau of Mines Staff, region V, 1954, table 1). At that time the commodity commanded a high price owing to serious crop damage in the south by the cotton boll weevil. Arsenic production was suspended in South Dakota a short time later when the market price declined sharply.

Bismuth is a brittle, reddish-silver element that has a metallic luster and is chemically similar to antimony and arsenic. It is present in small quantities throughout the world. Native bismuth, bismuthinite (bismuth trisulfide), and a number of other bismuth-bearing minerals generally occur in stringers and pockets in hydrothermal veins. In some places, bismuth enters into the crystal lattice of certain ore minerals, such as galena (lead sulfide). Few deposits are concentrated enough to be mined solely for bismuth. Generally it is produced as a byproduct of lead ores, and to a lesser extent of copper, tungsten, and gold ores.

In 1962, 65 percent of the bismuth metal consumed in the United States was used in fusible and other types of alloys. Thirty-four percent was used in pharmaceuticals, and in other industrial and laboratory chemicals (Spencer and den Hartog, 1963b, p. 322). In the future, bismuth may become increasingly important in nuclear and electronic applications, and in thermoelectric elements and liquid metal reactors. Although other metals can be substituted for the element in some of its uses, bismuth has a relatively stable position in the present economy.

Minor occurrences of bismuth are reported in the Black Hills region, but there has been no recorded production.

Selenium is an allotropic element that is widely distributed in small quantities in the earth's crust. It occurs as a brick-red amorphous powder, a brownish-black glassy mass, a gray metallic crystalline mass, or as red crystals. Selenium can act either as metal or nonmetal, electrical conductor or insulator, hydrogenator or dehydrogenator, colorant or decolorant. It is highly toxic and is the only element that may be present in healthy plants in great enough quantities to be lethal to browsing animals.

Selenium rarely occurs in the native state. Most commonly it is in a combined form in native sulfides and selenides, and is associated with copper, iron, uranium, and other metals. No known selenium-bearing ores can be profitably mined only for the element. Copper sulfide minerals are the most common source of selenium, although lesser quantities are recovered from lead-smelter flue dusts.

High-purity selenium is used chiefly in electronic applications; commercial-grade selenium is consumed by the chemical, rubber, metallurgical, ceramic, and glass industries. Although selenium has been reported in sedimentary formations that crop out over wide areas of South Dakota only minor amounts are present and none has been produced.

Sulfur is a soft, brittle, yellow nonmetal that is widely distributed in both the free and combined states. It is obtained from native sulfur deposits, pyrites and other metallic sulfides, petroleum, natural gas, coal, gypsum and anhydrite. Sulfur, hydrogen sulfide, and sulfur dioxide are recovered from refinery and smelter gases. Approximately 80 percent of the sulfur and all of the pyrite produced in the United States is used in making sulfuric acid. The acid is consumed in the manufacture of fertilizers, chemicals, and countless other products. Sulfur is of vital importance to the Nation's industries.

Most domestically produced native sulfur comes from deposits associated with salt domes on the Texas and Louisiana Gulf Coast.

In the combined form, sulfur generally occurs as sulfates and as metallic sulfides. Base metals are derived from many of the metallic sulfides which are commonly referred to as "pyrites." Pyrites in which sulfur is of primary importance include three iron sulfides—pyrite, pyrrhotite, and marcasite. Pyrite, the most abundant of the metalliferous minerals, is present in rocks of all ages and types; it occurs in veins, as disseminated deposits, and as masses along the contact between intrusive and sedimentary rocks. In spite of the abundance of pyrite, deposits generally are not extensive or pure enough to be of commercial importance.

There are no commercial deposits of native sulfur in South Dakota. Significant amounts of pyrite, pyrrhotite, and other metallic sulfides such as chalcopyrite are present in the western part of the State. In the past, when smelters were active in the Black Hills, small pyrite deposits were worked intermittently; they have not been in operation for many years, owning to the low price of the ore. South Dakota pyrite production totaled approximately $130,000 to 1928; it has not been reported since then (U.S. Bureau of Mines Staff, region V, 1954, table 1).

Tellurium is a toxic, tin-white element that resembles antimony in appearance and is related to sulfur and selenium. It is neither widespread nor concentrated in large quantities. It rarely occurs in the native state, but is present in more than 40 minerals, none of which is processed solely for the element. Tellurium is recovered as a byproduct of copper and lead ores. It is commonly associated with gold, and in places with silver.

Only small quantities of tellurium are required in its many applications. It is used in the ceramic, chemical, metallurgical, and rubber industries. Tellurium was satisfactorily substituted for selenium when that element was not available in sufficient quantities during the early 1950's. The future of tellurium is uncertain. It is potentially useful in thermoelements, which convert heat from solar energy or radioactivity to electricity, and which may become increasingly important in space travel.

In the Black Hills region, tellurium occurs as sylvanite (telluride of gold and silver) and as calaverite (gold telluride), but there is no record of its production.

Reported occurrences of these six elements in the mines and mining districts of South Dakota have been summarized by the U.S. Bureau of Mines Staff, region V (1954 and 1955). Bismuth occurrences in the State have been listed by Cooper (1962) and references to selenium occurrences in South Dakota have been annotated by Luttrell (1959).

Custer County:
- Spokane district (fig. 17, No. 14): Arsenic (arsenopyrite) and abundant pyrite are associated with a vein carrying silver-lead-zinc ores in the Spokane mine.
- Unorganized district (No. 15): Tellurides are present in gold- and silver-bearing quartz veins of the Turk group and the Rough Rider (Roosevelt) group. The Rough Rider group also contains bismuth.

Custer and Pennington Counties:
- Unorganized district (No. 13): In 1916 pyrite was mined and shipped to Cleveland from Precambrian graphite slate of the Cuyahoga mine.

Fall River County:
- Edgemont district (No. 16): Elemental crystalline selenium has been reported from the Road Hog No. 1A mine. It occurs in the uranium-bearing Cretaceous Lakota Formation.

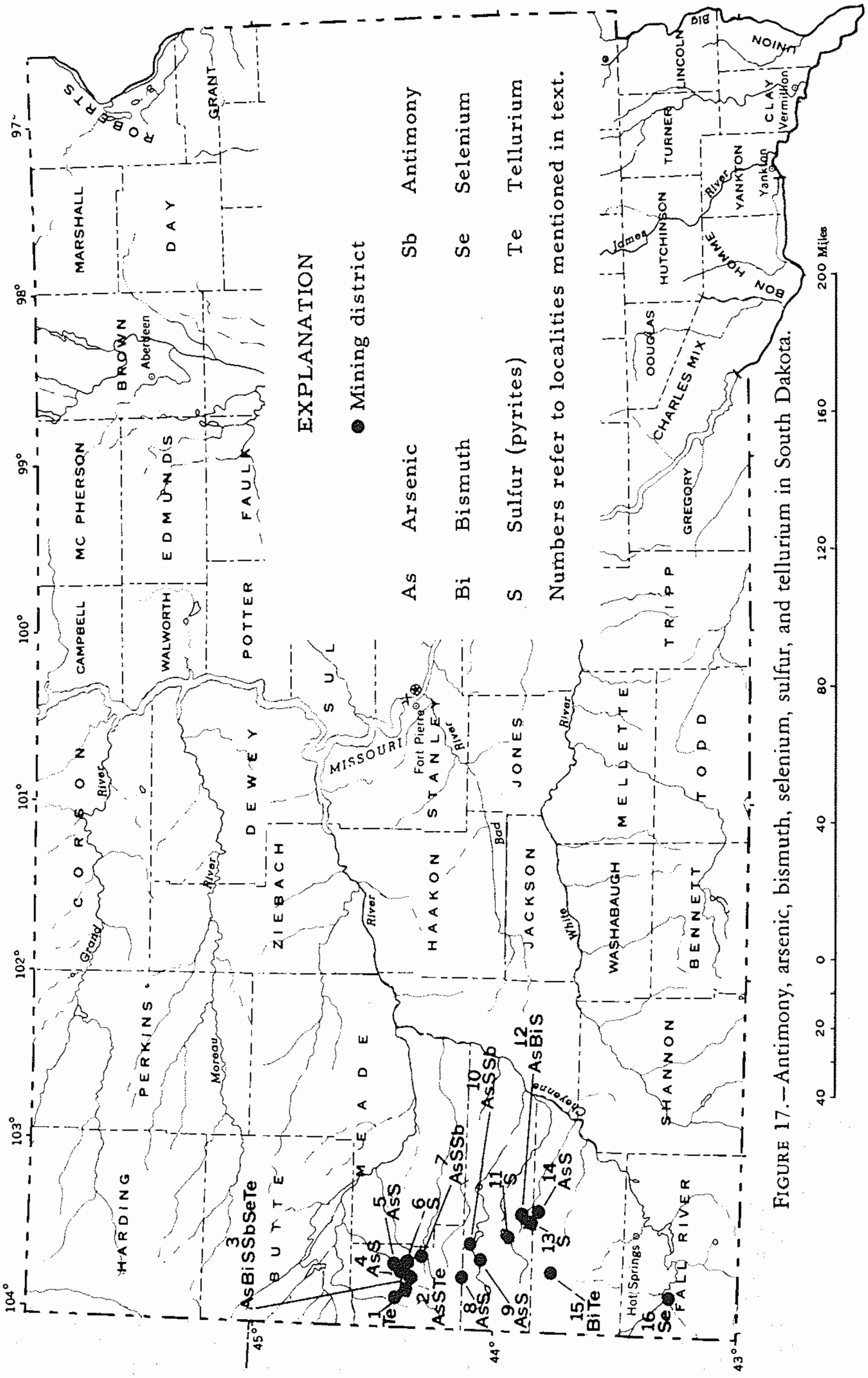

FIGURE 17.—Antimony, arsenic, bismuth, selenium, sulfur, and tellurium in South Dakota.

Lawrence County:

Bald Mountain and Ruby Basin districts (No. 2): Abundant pyrite, some arsenic (arsenopyrite) and tellurium (sylvanite) are reported from many mines in the district. The ore occurs as replacement deposits in the Cambrian Deadwood Formation (Connolly and O'Harra, 1929, p. 142–171).

Deadwood (No. 4): Gold-bearing quartz and pyrite are present in Precambrian black graphitic schist. The Montezuma and Whizzers mine, formerly a major pyrite producer for the Deadwood smelter, was active from 1900 to World War I. More than 27,000 tons of pyrite, averaging $2 a ton in gold, was mined in 1902. The Olaf Seim (Gotland) mine was worked as early as 1890. From 1900 to 1901 about 50 tons of pyrite was shipped daily to the Deadwood smelter, and in 1918, 1,150 tons of ore was produced.

Pyrite and arsenic (arsenopyrite) also occur in gold-silver-lead-zinc replacement ores in dolomite and dolomitic shale of the Deadwood Formation.

Galena district (No. 7): Pyrite and less abundant arsenic (lollingite) and antimony (tetrahedrite) are associated with gold-silver-lead replacement ores in the lower ore horizon of the Deadwood Formation.

Pyrite has been produced from several mines, among them the Horseshoe-Comet; ore was shipped from this property to the Deadwood smelter in the early 1900's. In some parts of the district brecciated porphyry and schist are cemented by gold-bearing pyrite.

Lead district (No. 3): Pyrite occurs as the cementing material in the gold- and silver-bearing basal conglomerate of the Cambrian Deadwood Formation, and also is present in a pyritic bed in Precambrian graphitic schist. In the 1890's, pyrite was supplied to the Deadwood smelter by the Slavonian mine. Antimony (tetrahedrite) and tellurium (calaverite) are associated with gold and silver ore along brecciated fault zones in several mines.

The Homestake mine, one of the great gold producers of the world, is in the Lead district. The replacement ore body is in an intensely folded bed of schist. Gold is the common ore mineral with pyrrhotite, pyrite, and arsenopyrite as gangue minerals. A bismuth telluride and minor amounts of selenium have also been reported (Connolly and O'Harra, 1929, p. 71–111).

Ragged Top district (No. 1): Gold, partly in the form of tellurides, is disseminated through silicified Mississippian Pahasapa Limestone in the Ulster mine. In the Old Ironsides mine, sylvanite (telluride of gold and silver) is associated with mineralization along vertical fractures that cut porphyry sill in the Deadwood Formation.

Spruce Gulch district (No. 5): Abundant pyrite and arsenic (arsenopyrite) occur with zinc and lead sulfides in the lower contact horizon of the Deadwood Formation (Connolly and O'Harra, 1929, p. 198–199).

Two Bit district (No. 6): Gold-bearing pyrite occurs in the Deadwood Formation on the Hardin properties. In 1899 about 30 tons of pyrite were shipped daily to the Golden Reward smelter at Deadwood.

Lawrence and Pennington Counties:

Rochford district (No. 8): Pyrite, pyrrhotite, and other metallic sulfides are present in gold- and silver-bearing replacement ore bodies in Precambrian schist. Arsenic (arsenopyrite) with associated gold has been reported from a number of mines.

Pennington County:

Hill City district (No. 11): In places, pyrite and pyrrhotite are associated with copper ores and with tungsten and tin deposits in shear zones that cut Precambrian schists, slates, and quartzites.

Keystone district (No. 12): Abundant pyrite, pyrrhotite, and arsenic (arsenopyrites) are present in the district. These minerals are associated with gold-bearing quartz veins and replacement deposits in shear zones in schist. Between 1924 and 1931, 100,000 pounds of white arsenic was recovered from concentrates shipped from the Bullion mine to the Globe smelter. Bismuth has been reported from the Etta mine pegmatite.

Mystic district (No. 9): Arsenic (arsenopyrite) and pyrite are associated with gold-silver ores of the Inca (Fairview) group. The ore occurs in quartz stringers that cut Precambrian schists.

Silver City district (No. 10): Antimony (jamesonite), arsenic (arsenopyrite), pyrite, and pyrrhotite are present in significant quantities in gold-silver-lead ores of the district. The minerals occur in quartz veins that cut Precambrian schist. Sulfides in the Alexander Lode assay up to 35 percent antimony.

In South Dakota, the production of antimony, arsenic, bismuth, sulfur (pyrites), and tellurium is, for the most part, dependent upon the mining, smelting, and refining of ore mined for the major metals. Arsenic is present in copper and lead ores, antimony and bismuth are associated with lead ores, and tellurium occurs in gold and silver ores. The availability of pyrite is determined primarily by the rate of production of the main mine product, such as copper, lead, or zinc. The recovery of smelter byproducts is relatively inflexible, and problems arise when the demand is great. Arsenic and sulfur (metallic sulfides) are locally present in significant amounts in ores of the Black Hills region. Recent production figures for these commodities are not available from the out-of-State smelters that process the metallic ores; it is not possible to determine if these byproducts are wasted or conserved when the ore is treated. Furthermore, there are no reserve estimates for these commodities in South Dakota. Antimony and bismuth occur in limited amounts in the Black Hills and probably will never be regarded as commercially important.

Selenium occurs in varying amounts in all of the Cretaceous formations of South Dakota. It probably was derived from volcanic debris that was deposited along with other sediments. The Pierre Shale, which crops out over one-half of the western part of the State, and the Niobrara Formation, which crops out in a narrow area encircling the Black Hills, and in the Missouri River Valley in the southern part of South Dakota, contain concentrations of selenium. Soils derived from the selenium-bearing bedrock are seleniferous and support vegetation that is toxic to livestock. The deposits are too low grade to be processed for selenium at the present time.

Uranium-bearing lignites in Harding County have been analyzed for selenium content. Should the lignites be processed for the contained uranium, selenium would be a potential byproduct (Rosenbaum and others, 1958, p. 11).

In addition to the metallic sulfides of the Black Hills, potential sulfur deposits are present in other parts of the State. Sulfur can be extracted from anhydrite (calcium sulfate), one of the most important sulfur-bearing minerals, and from gypsum (hydrous calcium sulfate). At present, sulfur is not recovered in the United States from these two sources, for the deposits cannot be worked profitably. In South Dakota, the Black Hills area is encircled by the Permian and Triassic Spearfish Formation. This stratigraphic unit contains extensive gypsum beds which are mined locally for use in the plaster industry. Gypsum-bearing strata also are present in the northern part of the State, in the subsurface deposits of the Williston basin. South Dakota has considerable sulfur resources in the form of anhydrite and gypsum: in time of great demand, these widespread strata may be utilized.

SELECTED REFERENCES

METALLIC MINERAL RESOURCES

Allsman, P. T., 1940, Reconnaissance of gold-mining districts in the Black Hills, South Dakota: U.S. Bur. Mines Bull. 427, 146 p.

Baker, D. H., Jr., and Tucker, E. M., 1962, Uranium: U.S. Bur. Mines Minerals Yearbook 1961, v. 1, p. 1291.

Baroch, C. T., 1960, Rare earth metals, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 679–690.

Berry, L. G., and Thompson, R. M., 1962, X-ray powder data for ore minerals, *in* The Peacock Atlas: Geol. Soc. America Mem. 85, p. 12–13; 278.

Breger, I. A., Deul, Maurice, and Rubinstein, Samuel, 1955, Geochemistry and mineralogy of a uraniferous lignite: Econ. Geology, v. 50, no. 2, p. 206–226.

Busch, P. M., 1961, Vanadium, a materials survey: U.S. Bur. Mines Inf. Circ. 8060.

Butler, A. P., Jr., Finch, W. I., and Twenhofel, W. S., 1962, Epigenetic uranium in the United States (exclusive of Alaska and Hawaii): U.S. Geol. Survey Mineral Inv. Resource Map MR–21.

Cole, W. A., 1952, Iron resources of the Black Hills, South Dakota: U.S. Bur. Mines Missouri Basin Prelim. Rept. 62, 24 p.

Connolly, J. P., and O'Harra, C. C., 1929, The mineral wealth of the Black Hills: South Dakota School Mines Bull. 16, 418 p., 64 pls., 35 figs.

Cooper, J. R., 1962, Bismuth in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR–22 and accompanying text, 19 p.

Creasey, S. C., 1957, Geology and resources, *in* McInnis, Wilmer, Molybdenum, a materials survey: U.S. Bur. Mines Inf. Circ. 7784, p. 6–15.

Cummings, J. B., Basham, Lester, and Lincoln, F. C., 1936, Tin deposits in South Dakota: State Plan. Board, Brookings, S. Dak., 35 p.

Darton, N. H., and Paige, Sidney, 1925, Description of the central Black Hills (South Dakota): U.S. Geol. Survey Geol. Atlas, Folio 219.

Davis, V. C., 1948, Belle-Eldridge lead and zinc deposits, Lawrence County, South Dakota: U.S. Bur. Mines R.I. 4215, 8 p., 2 pls.

Day, D. T., and Richards, R. H., 1906, Useful minerals in the black sands of the Pacific slope: U.S. Geol. Survey Mineral Resources U.S., 1905.

Denson, N. M., Bachman, G. O., and Zeller, H. D., 1959, Uranium-bearing lignite in northwestern South Dakota and adjacent states: U.S. Geol. Survey Bull. 1055–B, p. 11–57 [1960].

Denson, N. M., and Gill, J. R., Uranium-bearing lignite and carbonaceous shale in the southwestern part of the Williston Basin, a regional study: U.S. Geol. Survey Prof. Paper 463 (in press).

Dougherty, E. Y., Munson, G. A., and Cummings, A. M., 1945, Cowboy Tin mine, Pennington County, South Dakota: U.S. Bur. Mines War Minerals Rept. 377.

Dow, V. T., and Batty, J. V., 1961, Reconnaissance of titaniferous sandstone deposits of Utah, Wyoming, New Mexico, and Colorado: U.S. Bur. Mines Rept. Inv. 5860, 52 p.

Dupuy, L. W., Calhoun, W. A., and Rasmussen, R. T. C., 1946, Mining and concentration of Missouri Valley manganese at Chamberlain [S. Dak.]: U.S. Bur. Mines Rept. Inv. 3839, 103 p.

Eilertsen, D. E., and Lamb, F. D., 1956, A comprehensive report of exploration by the Bureau of Mines for thorium and radioactive black mineral deposits: U.S. Bur. Mines RME–3140, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Engineering and Mining Journal, 1931, Gold mining and milling at Lead, South Dakota, 1876–1931: Eng. Mining Jour., v. 132, no. 7, p. 287–342.

Fischer, R. P., and King, R. U., 1964, Trends in the consumption and supply of molybdenum and vanadium: Am. Inst. Mining Metall. Engineers Preprint 64–K–2, New York.

Gardner, E. D., 1939, Tin deposits of the Black Hills, South Dakota: U.S. Bur. Mines Inf. Circ. 7069.

Gill, J. R., 1954, Uranium in carbonaceous rocks, coal and lignite, northwestern South Dakota, southwestern North Dakota, and eastern Montana, *in* Geologic investigations of radioactive deposits—Semiannual progress report, June 1 to Nov. 30, 1954: U.S. Geol. Survey TEI–490, p. 149–155, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Gill, J. R., 1955. Uranium in carbonaceous rocks, lignite, investigations, northwestern South Dakota, southwestern North Dakota, and eastern Montana, *in* Geologic investigations of radioactive deposits—Semiannual progress report, Dec. 1, 1954 to May 31, 1955: U.S. Geol. Survey TEI–540, p. 153–158, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Gill, J. R., and Moore, G. W., 1955, Carnotite-bearing sandstone in Cedar Canyon, Slim Buttes, Harding County, South Dakota: U.S. Geol. Survey Bull. 1009–I, p. 249–264.

Gill, J. R., Zeller, H. D., and Schopf, J. M., 1959, Core drilling for uranium-bearing lignite, Mendenhall area, Harding County, South Dakota: U.S. Geol. Survey Bull. 1055–D, p. 97–146 [1960].

Gott, G. B., and Schnabel, R. W., 1963, Geology of the Edgemont NE quadrangle, Fall River and Custer Counties, South Dakota: U.S. Geol. Survey Bull. 1063–E, p. 127–190.

Gries, J. P., and Rothrock, E. P., 1941, Manganese deposits of the Lower Missouri Valley in South Dakota: South Dakota Geol. Survey Rept. Inv. 38, 96 p., map.

Hess, F. L., 1908, Tin, tungsten, and tantalum deposits of South Dakota: U.S. Geol. Survey Bull. 380–D, p. 131–163.

Hewett, D. F., 1930, Manganese-iron carbonate near Chamberlain, South Dakota: U.S. Geol. Survey Press Memo., Feb. 5, 1930, 9 p.

Holliday, R. W., 1960, Tungsten, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 903–917.

Hosted, J. O., and Wright, L. B., 1923, Geology of the Homestake ore bodies and the Lead area of South Dakota: Eng. and Min. Jour.-Press, v. 115, p. 793–799, 836–843.

Irving, J. D., 1904, Economic resources of the northern Black Hills: U.S. Geol. Survey Prof. Paper 26, 212 p., 20 pls., 16 figs.

Kelly, F. J., 1962, Technological and economic problems of rare-earth-metal and thorium resources in Colorado, New Mexico, and Wyoming: U.S. Bur. Mines Inf. Circ. 8124, 38 p.

Kepferle, R. C., and Chisholm, W. A., 1956, Uranium in carbonaceous rocks, lignite investigations, Cave Hills, Harding County, South Dakota, *in* Geologic investigations of radioactive deposits—Semiannual progress report, Dec. 1, 1955 to May 31, 1956: U.S. Geol. Survey TEI–620, p. 243–254, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

King, J. W., Foran, J. F., and Speal, A. J., 1955, Preliminary examination of uraniferous lignites, Harding County, South Dakota (revised): U.S. Atomic Energy Comm. RME–1062, 16 p.

King, J. W., and Young, H. B., 1956, High grade uraniferous lignites in Harding County, South Dakota, *in* Page, L. R., Stocking, H. E., Smith, H. B., compilers, Contributions to the geology of uranium and thorium, by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 419–431.

Kulp, J. L., Eckelmann, W. R., Gast, P. W., and Miller, D. C., 1956, Age of the Black Hills gold mineralization: Geol. Soc. America Bull., v. 67, p. 1557–1558.

Lincoln, F. C., 1937, Mining in South Dakota, *in* Lincoln, F. C., Miser, W. G., and Cummings, J. B., The mining industry of South Dakota: South Dakota School Mines Bull. 17, pt. 1, p. 9–42.

Lincoln, F. C., Miser, W. G., and Cummings, J. B., 1937, The mining industry of South Dakota: South Dakota School Mines Bull. 17, 201 p.

Luttrell, G. W., 1959, Annotated bibliography on the geology of selenium: U.S. Geol. Survey Bull. 1019–M, p. 862–972.

Miller, R. H., 1959, Mineral resources of South Dakota—Iron ore: South Dakota Indus. Devel. Expansion Agency, p. 51–54.

Moore, G. W., and Levish, Murray, 1955, Uranium-bearing sandstone in the White River badlands, Pennington County, South Dakota: U.S. Geol. Survey Circ. 359, 7 p.

Myers, A. T., and others, 1960, A study of rhenium and molybdenum in uranium ore from the Runge mine, Fall River County, South Dakota, by means of a spectrographic and concentration method, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B39–B41.

Newton, Henry, and Jenney, W. P., 1880, Geology and resources of the Black Hills of Dakota: U.S. Geog. and Geol. Survey of the Rocky Mtn. region, 566 p.

Noble, J. A. 1950, Ore mineralization in the Homestake gold mine, Lead, South Dakota: Geol. Soc. America Bull., 61, p. 221–252.

Noble, J. A., and Harder, J. O., 1948, Stratigraphy and metamorphism in a part of the northern Black Hills and the Homestake mine, Lead, South Dakota: Geol. Soc. American Bull., v. 59, no. 9, p. 941–975.

Norton, J. J., Page, L. R., and Brobst, D A., 1962, Geology of the Hugo pegmatite, Keystone, South Dakota: U.S. Geol. Survey Prof. Paper 297–B, p. 49–127.

Olson, J. C., and Adams, J. W., 1962, Thorium and rare earths in the United States: U.S. Geol. Survey Mineral Inv. Resource Map MR–28.

Osterwald, F. W., Osterwald, D. B., Long, J. S., Jr., and Wilson, W. H., 1959, Mineral resources of Wyoming: Wyoming Geol. Survey Bull. 50, 249 p.

Page, L. R., and others, 1953, Pegmatite investigations 1942–1945, Black Hills, South Dakota: U.S. Geol. Survey Prof. Paper 247, 228 p.

Page, L. R., and Redden, J. A., 1952, The carnotite prospects of the Craven Canyon area, Fall River County, South Dakota: U.S. Geol. Survey Circ. 175, 18 p.

Pennington, J. W., 1960, Tin, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 873–882.

Pesonen, P. E., Tullis, E. L., and Zinner, Paul, 1949, Missouri Valley manganese deposits, South Dakota, pt. 1, General investigations, stratigraphic studies, and tonnage and grade estimates: U.S. Bur. Mines Rept. Inv. 4375, 90 p., pt. 2, Drill-hole logs and sections; U.S. Bur. Mines Rept. Inv. 4428, 63 p.

Pipiringos, G. N., Chisholm, W. A., and Kepferle, R. C., 1957, Cave Hills, Harding County, South Dakota, *in* Geologic investigations of radioactive deposits—Semiannual progress report, Dec. 1, 1956 to May 31, 1957: U.S. Geol. Survey TEI–690, p. 257–271, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— Geology and uranium deposits in the Cave Hills area, Harding County, South Dakota: U.S. Geol. Survey Prof. Paper 476–A (in press).

Rosenbaum, J. B., Everett, F. D., Dannenberg, R. O., and Bauerle, L. C., 1958, Final report on reconnaissance, exploration, and extraction of selenium: U.S. Bur. Mines, Open File Research Rept. 36.17, 30 p.

Runner, J. J., 1934, Precambrian geology of the Nemo district, Black Hills, South Dakota: Am. Jour. Sci., v. 28, p. 353–372.

Runner, J. J., and Hartmann, M. L., 1918, The occurrence, chemistry, metallurgy, and uses of tungsten: South Dakota School Mines Bull. 12.

Schwartz, G. M., 1937, Paragenesis of iron sulphides in a Black Hills deposit: Econ. Geology, v. 32, p. 810–825.

Scott, S. E., 1897, Map of Black Hills of South Dakota and Wyoming with full descriptions of mineral resources: Philadelphia, E. P. Noll Co., 40 p.

Searight, W. B., 1937, Lithologic stratigraphy of the Pierre Formation of the Missouri Valley in South Dakota: South Dakota Geol. Survey Rept. Inv. 27, 63 p.

Sheridan, D. M., Stephens, H. G., Staatz, M. H., and Norton, J. J., 1957, Geology and beryl deposits of the Peerless pegmatite, Pennington County, South Dakota: U.S. Geol. Survey Prof. Paper 297–A, p. 1–47, pls. 1–7, figs. 1–2.

Smith, W. C., and Page, L. R., 1941, Tin-bearing pegmatites of the Tinton district, Lawrence County, South Dakota, a preliminary report: U.S. Geol. Survey Bull. 922–T, p. 595–630, pls. 90–94.

Spencer, R. N., and den Hartog, E. E., 1963a, Antimony: U.S. Bur. Mines Minerals Yearbook 1962, v. 1, p. 243–252.

——— 1963b, Bismuth: U.S. Bur. Mines Minerals Yearbook 1962, v. 1, p. 321–326.

Staatz, M. H., Page, L. R., Norton, J. J., and Wilmarth, V. R., 1963, Exploration for beryllium at the Helen Beryl, Elkhorn, and Tin Mountain pegmatites, Custer County, South Dakota: U.S. Geol. Survey Prof. Paper 297–C, p. 129–197.

State Mine Inspector's Reports, 1891–1959, Annual reports of the Inspectors of Mines to the Governor of South Dakota.

Tullis, E. L., and Toland, David, 1940, Lead-silver ore deposits in the southern Black Hills [abs.]: Nebraska Acad. Sci. Proc.

U.S. Atomic Energy Commission, 1956, Location of uranium deposits in south-western North Dakota and the Cave Hills and Slim Buttes areas, Harding County, South Dakota: U.S. Atomic Energy Comm., RME–1076, Tech, Inf. Service, Oak Ridge, Tenn., 12 p.

U.S. Bureau of Mines, 1954, Black Hills mineral atlas, South Dakota, pt. 1: U.S. Bur. Mines Inf. Circ. 7688, 123 p.

U.S. Bureau of Mines, 1955, Black Hills mineral atlas, South Dakota, pt. 2: U.S. Bur. Mines Inf. Circ. 7707, 208 p.

U.S. Bureau of Mines, 1960, Mineral facts and problems: U.S. Bur. Mines Bull. 585, 1015 p.

Vanderwilt, J. W., 1942, The occurrence and production of molybdenum: Colorado School Mines Quart., v. 37, no. 4, p. 78.

Vickers, R. C., 1954, Occurrences of radioactive minerals in the Bald Mountain gold-mining area, northern Black Hills, South Dakota: U.S. Geol. Survey Circ. 351, 8 p.

Weeks, J. D., 1895, Manganese, *in* Mineral resources of the U.S. for 1894: U.S. Geol. Survey 16th Ann. Rept., pt. 3, p. 423.

White, E. W., 1958, Uranium mineralization in some North and South Dakota lignites: Pennsylvania State Univ., College of Mineral Industries Tech. Rept. NYO–7948, 79 p.

Woo, Ching Chang, 1952, The Precambrian geology and amphibolites of the Nemo district, Black Hills, South Dakota: Chicago Univ. Ph. D., thesis, 145 p.

Wyant, D. G., and Beroni, E. P., 1950, Reconnaissance for trace elements in North Dakota and eastern Montana: U.S. Geol. Survey TEI–61, issued by U.S. Atomic Energy Comm. Tech. Inf., Service, Oak Ridge, Tenn. 29 p.

Zeller, H. D., and Schopf, J. M., 1959, Core drilling for uranium-bearing lignite in Harding and Perkins Counties, South Dakota, and Bowman County, North Dakota: U.S. Geol. Survey Bull. 1055–C, p. 59–95 [1960].

Ziegler, Victor, 1914, The minerals of the Black Hills: South Dakota School Mines Bull. 10, 250 p., 31 pls., 73 figs.

Zinner, Paul, and Grosh, W. A., 1949, Missouri Valley manganese deposits, pt. 3, Mining and beneficiation studies: U.S. Bur. Mines Rept. Inv. 4429, 56 p.

NONMETALLIC AND INDUSTRIAL MINERAL RESOURCES

INTRODUCTION

(By D. J. McGregor, South Dakota State Geological Survey, Vermillion, S. Dak.)

Nonmetallic and industrial minerals make up a class of large-bulk, low-priced materials that generally are used essentially as mined or quarried with little or no processing, except for washing, crushing, sizing, and some type of fabrication. Of the 35 or more different industrial minerals and rocks of fundamental importance to industry, South Dakota mines or quarries at least 10.

The gold rush of earlier days may never be matched by a sand-and-gravel or a crushed-stone rush in South Dakota; nevertheless the values of these unglamorous but very necessary commodities now equal or exceed those of the metals in South Dakota. South Dakota mineral statistics for 1963, prepared by the U.S. Bureau of Mines in cooperation with the State Geological Survey, show that industrial minerals and rocks accounted for about 52 percent of the total mineral production of the State. Chief contributors were cement, sand and gravel, and stone. One interesting aspect of industrial minerals and rocks is that the use of one commonly involves the use of others. For example, the use of sand and gravel generally involves the use of cement, which is made from limestone.

The following section will discuss the industrial minerals and rocks produced in South Dakota and will show their importance to the economy of the State. This important segment of the mineral industry will continue to grow with the increasing population of the State, and this growth is possible because the potential resources are available to support significant increases.

SAND AND GRAVEL

(By R. L. Bruce, South Dakota State Geological Survey, Vermillion, S. Dak., and R. A. Weeks, U.S. Geological Survey, Washington, D.C.)

Sand and gravel have become such an indispensable part of the modern economy that they are produced in a larger volume than any other mineral product, and nationally rank fifth in total value of all mineral products. The production of sand and gravel in South Dakota is the major nonmetallic mineral industry, and is second only to gold in total value. Since 1889, over 255 million tons have been produced, with a value of over $127 million. The amount of sand and gravel being used is increasing at a very significant rate: for example, there has been nearly a threefold increase between 1952 and 1962. If the trend continues, many more deposits of sand and gravel will have to be developed.

Many natural forces such as water, wind, gravity, and temperature changes, are constantly at work disintegrating the crust of the earth, and moving the resulting rock and mineral fragments. Useful deposits of sand and gravel develop by several processes, especially those that tend to remove the smaller and softer fragments, and those that have sorted the materials. Economic deposits of sand and gravel exist in all 67 counties of the State, and in 1962, some sand and gravel was produced in 58 of these. Figure 18 illustrates some of the more extensive areas in which sand and gravel may be found. Due to the small scale of this map, the areas containing numerous deposits have been highly generalized and economic deposits locally may not be shown.

The sources of sand and gravel are as variable as the geology in South Dakota. The area east of the Missouri River was extensively glaciated, and sand and gravel deposits in this area are found in numerous recognizable glacial landforms. Most sand and gravel pits in eastern South Dakota are found in glacial outwash in plains, valley trains, and terrace remnants. Secondary sources include end moraines, kames, kame terraces, eskers, and beaches of glacial lakes. Distribution of glacial deposits in this part of the State is effectively shown by Flint (1955, plate 1).

In the western half or unglaciated portion of South Dakota most sand and gravel sources are confined to the terraces of the major streams and to some of their larger tributaries. Mountain outwash presents a valuable source in and around the Black Hills. Distribution of such deposits is shown by Larrabee (1946).

Sand and gravel are used in many different applications where they impart strength, durability, and bulk at low unit cost. Largest amounts are used in all phases of road construction. In recent years about 90 percent of all sand and gravel produced in the State has gone into highway fill, base course, and as aggregate in the final surfacing. All major construction projects such as dams, airports, public buildings, and railroad ballast require large supplies. The more specialized uses such as molding sand, abrasive blasting sand, and hydrafrac sand account for a very small part of the production (Bieniewski and Agnew, 1962, p. 963).

The value of this expendable commodity is dependent on many factors including transportation, quality, quantity, and demand. Sand and gravel is a low cost commodity; therefore, as the distance of haul from the source to the market increases the profit margin decreases. There is, therefore, a point where transportation costs eliminate profit. This varies however with the quality, since most sand and gravel must be washed or in some other way processed. A higher quality sand and gravel which needs very little processing could be transported farther than one of poorer quality. The source must, of course, contain adequate quantities of sand and gravel to meet the demands of the consumer.

The construction of new highways in South Dakota has expanded considerably, as the use of gravel shown in table 7 clearly indicates. It will expand even more as the population increases. This expanded construction schedule and the accompanying rigid specifications will demand more high quality sand and gravel. This demand will deplete the known reserves until it will be feasible to transport a poorer quality product a greater distance. It is therefore certain that this mineral commodity will be in great demand for many years to come.

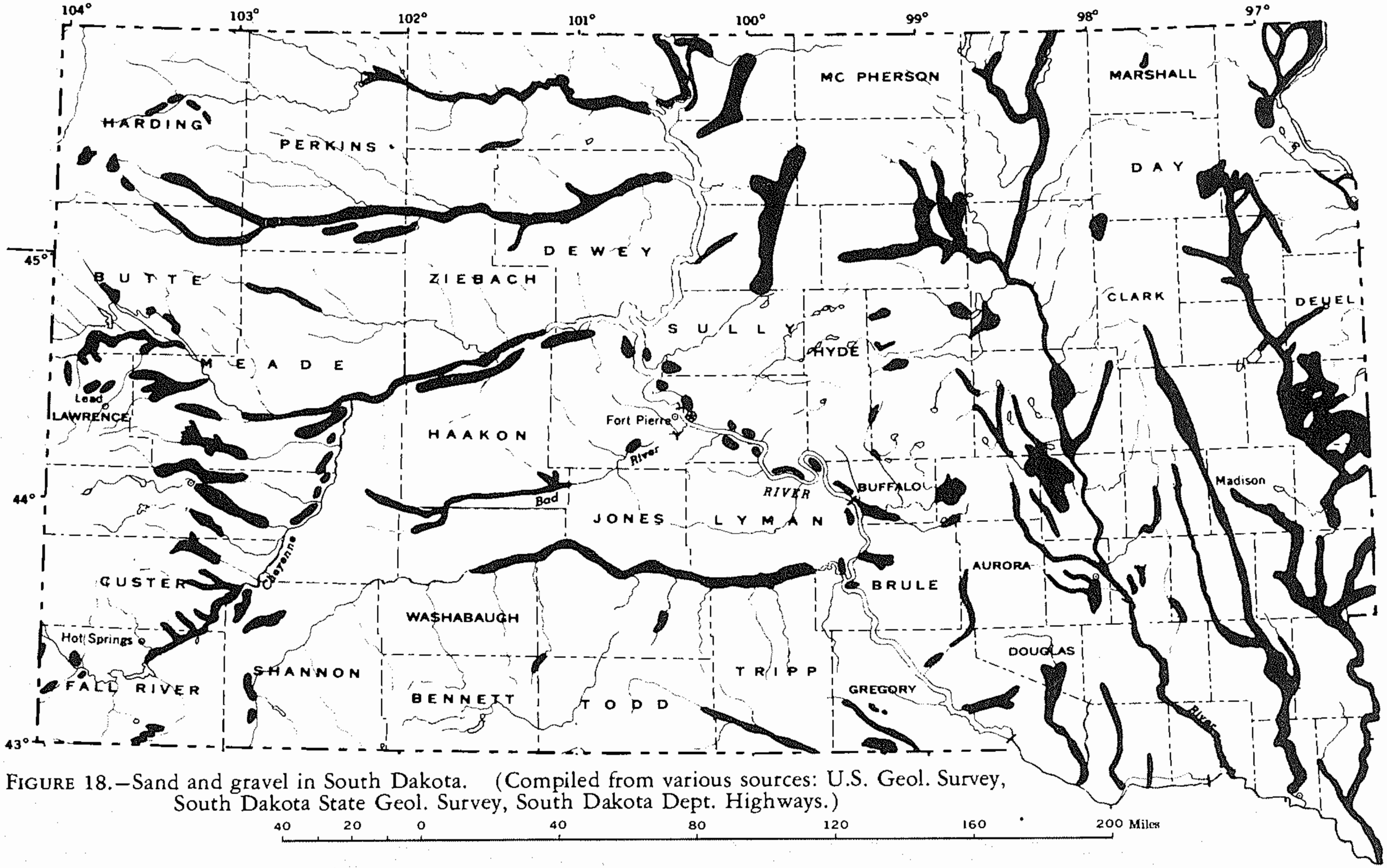

FIGURE 18.—Sand and gravel in South Dakota. (Compiled from various sources: U.S. Geol. Survey, South Dakota State Geol. Survey, South Dakota Dept. Highways.)

TABLE 7.—*Sand and gravel production in South Dakota, 1889–1963*[1]

Year	Quantity (short tons)	Value	Year	Quantity (short tons)	Value
1889–1908[2]	4,500,000	$900,000	1937	3,845,432	$612,552
1909	1,526,714	271,260	1938	4,677,593	627,344
1910	849,800	157,738	1939	2,539.417	722,046
1911[3]	600,000	90,000	1940	2,910,331	524,842
1912	545,622	69,348	1941	2,627,059	559,766
1913	1,068,833	89,306	1942	3,577,983	1,443,908
1914	232,395	40,215	1943	2,291,450	701,034
1915	256,270	45,717	1944	2,501,431	956,178
1916	1,095,594	133,755	1945	2,642,494	1,106,983
1917	194,520	49,654	1946	3,215,608	1,537,822
1918	229,787	48,362	1947	3,122,409	1,672,253
1919	648,939	231,390	1948	4,687,055	3,247,428
1920	572,259	253,614	1949	5,456,742	2,315,430
1921	185,639	136,152	1950	5,392,247	2,750,847
1922	200,408	121,690	1951	5,037,384	2,502,340
1923	304,768	156,914	1952	5,846,140	2,478,314
1924	323,303	113,602	1953	5,402.378	2,817,726
1925	1,769,922	576,248	1954	14,819,228	7,840,393
1926	2,013,350	286,591	1955	13,537,801	10,096,828
1927	1,162,823	231,218	1956	12.539,000	8,423,050
1928	2,461,963	1,301,075	1957	14,758,000	8,001,000
1929	2,729,271	578,204	1958	14,705,000	9,179,000
1930	2,419,441	931,814	1959	17,775,000	11,058,000
1931	2,369,279	931,137	1960	13,548,000	9,359,000
1932	2,065,282	248,173	1961	11,324,000	7,336,000
1933	3,233,940	624,428	1962	15,371,000	9,207,000
1934	3,863,410	773,559	1963	16,000,000	9,400,000
1935	4,178,035	794,276			
1936	3,325,490	746,711	Total, 1889–1963	255,082,239	127,409,235

[1] Data for 1963 are preliminary.
[2] Estimated.
[3] Revised.

Source: U.S. Department of the Interior, Bureau of Mines.

Silica sand is mined locally in sec. 11, T. 1 S., R. 2 E. (Ditch Creek 7½-minute quadrangle), Pennington County, from the basal portion of the Cambrian Deadwood Formation on the west central flank of the Black Hills uplift, near the contact between Precambrian rocks and the overlapping Palezoic formations. At present, silica sand constitutes less than 1 percent of the total value of sand and gravel produced in South Dakota. Most of the silica sand is being utilized in the hydrafrac process as an aid in the recovery of oil and gas, a relatively new application for rounded quartz sand. Other industrial uses for sand of the quality being developed from the Deadwood Formation include filter, molding, and filler sands.

LIMESTONE[1]

(By J. P. Gries, South Dakota School of Mines and Technology, Rapid City, S. Dak.)

Limestone is one of the most important mineral products of South Dakota. Including its locally manufactured forms of lime and cement, it ranks second only to gold in value of annual production. Most of the limestone-bearing formations crop out only in the Black Hills area, but the marketing area for the prepared stone and products from it extends 250 to 300 miles in all directions from the outcrop area.

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[1] Including lime and cement.

Limestone in massive pieces has been used in South Dakota as building stone and riprap. In crushed form, it is used for railroad ballast, concrete and asphalt aggregate, road metal, and filter beds. In pulverized form, it is utilized as agricultural lime and fill sand. In the Black Hills it is used in the manufacture of Portland cement and lime, and in earlier days, it was used as smelter flux, lithographic stone, and ornamental stone.

Available deposits include high-calcium rock, magnesian or dolomitic limestones, argillaceous high-carbonate rock, and metamorphosed siliceous dolomitic marble.

OCCURRENCE

The formations that may serve as sources of limestone are considered below in decreasing order of geologic age.

Precambrian rocks.—Dolomitic marble is known in several areas within the Precambrian core of the Black Hills. Before the turn of the century, efforts were made to exploit a serpentinized, metamorphosed magnesian limestone southwest of Harney Peak (Connolly and O'Harra, 1929, p. 295). Considerable rock was quarried but no market developed for a cut and polished finished product and the project was abandoned. So far as is known, none of the other carbonate deposits within the Precambrian has been exploited either for its ornamental value or its lime content.

Deadwood Formation.—The middle portion of the Deadwood Formation includes up to 200 feet of slabby limestone and intraformational limestone conglomerate in the northern Black Hills, but thins to the south. Some is high-calcium, but most is dolomitic in composition; individual beds range from nearly pure, to highly argillaceous and sandy carbonate. There is no record to show that this material has ever been utilized in the Black Hills.

Whitewood Dolomite.—The Whitewood Dolomite crops out in the northern part of the Black Hills. It thins from about 60 feet in its most northerly exposures near Deadwood, to a feather edge at its southern limits near Nemo on the east side, and Spearfish Crossing on the west. The formation is a mottled, irregularly dolomitized limestone that weathers to shades of buff and red-brown. It is normally free of sand in the subsurface to the north and west, but contains some thin sandy zones within the Black Hills outcrop area.

The formation is thin bedded, and prior to World War I was used as a building stone in the mining camps, notably at Deadwood and Galena. It was also extensively mined near Deadwood for use as a smelter flux between about 1885 and 1904. No quarries are now operated in this formation.

Pahasapa Limestone.—The Pahasapa Limestone is a white to very light gray carbonate rock ranging in thickness from 300 feet in the southern Hills to over 600 feet in the northernmost outcrops. It crops out in an elliptical belt around the central part of the Hills (fig. 19). The outcrop belt averages 2 to 5 miles wide on the east flank of the Hills where dips vary from 5 to 10 degrees, and is as much as 10 miles wide on the western side of the Hills. The formation is usually dolomitic, but sections of considerable thickness are nearly pure calcium carbonate, as indicated in the table below. In general, the distribu-

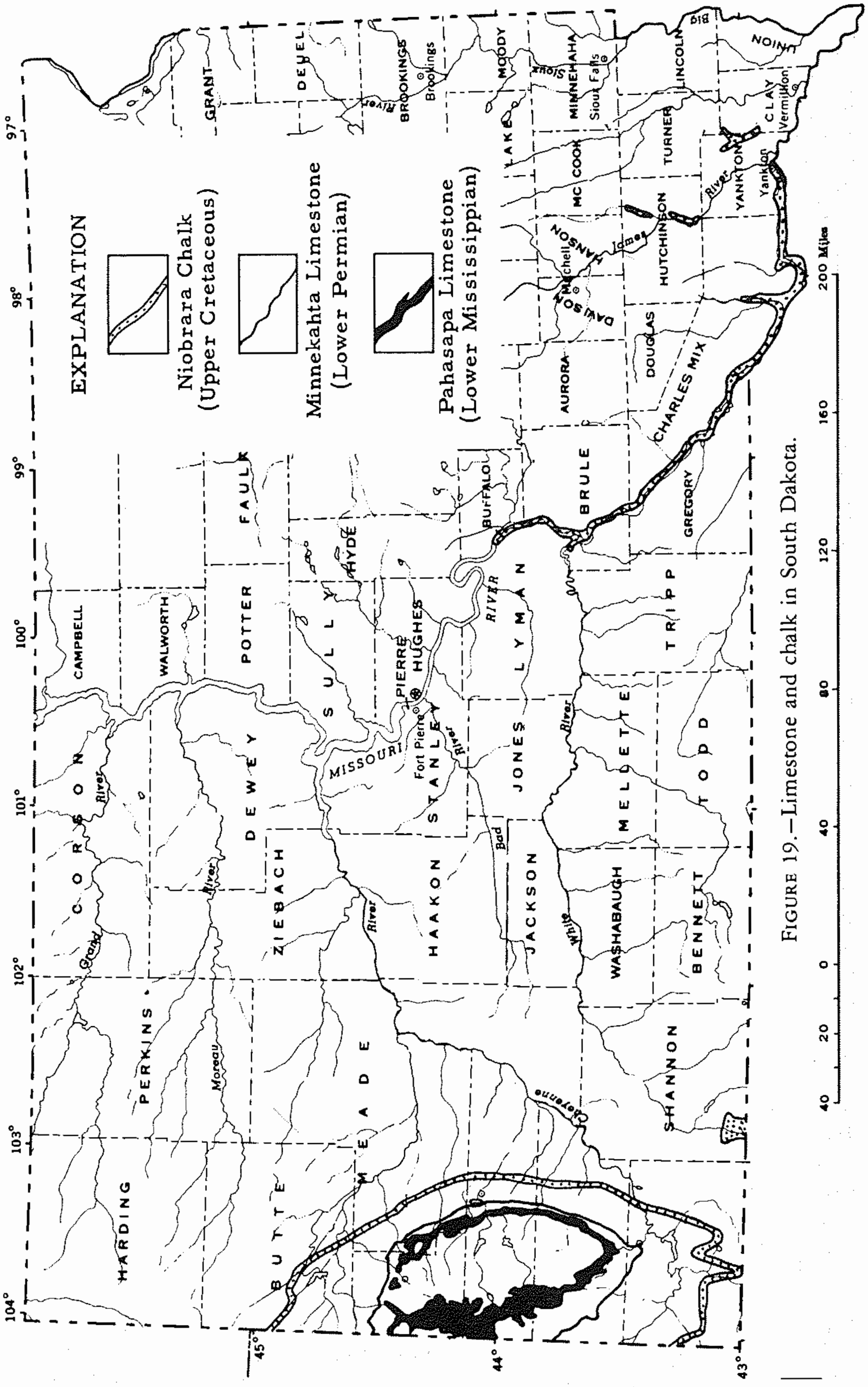

FIGURE 19.—Limestone and chalk in South Dakota.

tion of the two types of carbonate has not been determined; in the Rapid Canyon area, the lower 280 feet is dolomitic and the upper 60 feet is almost free of magnesia (Ellis, 1960, p. 51, 68).

TABLE 8.—*Typical analyses, South Dakota carbonate rocks*

[In percent]

Formation and location (section, township, range)	CaO	MgO	Ignition loss	SiO_2	Fe_2O_3	Al_2O_3	SO_3
Whitewood Dolomite Golden Reward Smelter flux (Lincoln, 1930, p. 43)	35.18	17.12	46.41	0.42	0.40		------
Pahasapa Limestone, B. H. Lime Co., Pringle; 22 or 23, 5S, 4E (Connolly & O'Harra, 1929, p. 286)	53.98	1.64	43.77	.56	0.20	0.06	tr.
Pahasapa Ls., Black Hills Marble Quarries; 13, 1N, 6E (Lincoln, 1930, p. 43)	38.00	14.10	45.32	2.10	.36		tr.
Pahasapa Ls., lithographic stone; 16, 4S, 3E (Connolly & O'Harra, 1929, p. 341)	56.08	.16	43.73	tr.	.12		------
Minnekahta Limestone, Quarry face at Calcite; 30, 4N, 6E (Connolly & O'Harra, 1929, p. 288)	53.91	.39	42.74	2.12	.42	.60	0.08
Minnekahta Ls., Grab sample at Spearfish Quarry (Connolly & O'Harra, 1929, p. 288)	54.96	.71	43.00	1.92	.28		tr.
Minnekahta Ls., Cement Plant Quarry; 33, 2N, 7E (State Plan. Board, no date, p. 31)	54.46	.48	42.95	1.22	.44	.34	.03
Niobrara Fm., Antelope Cr., Meade County (O'Harra and others, 1908, p. 20)	38.85	1.08	36.67	15.51	5.80		tr.
Niobrara Fm., White chalk near Chamberlain; 36, 105N, 71W (State Cement Comm., no date, p. 12)	44.88	.77	31.20	10.72	1.86	9.20	.43
Niobrara Fm., Gray chalk near Chamberlain; 36, 105N, 71W (State Cement Comm., no date, p. 12)	33.83	.75	33.23	9.02	4.68	3.30	3.07
Niobrara Fm., White Chalk, Yankton Quarry; 17, 93N, 56W (State Cement Comm., no date, p. 40)	51.64	--------	39.11	3.50	1.60	.14	1.33
Mobridge Mem. of Pierre Shale, Corson County; 19, 18N, 30E (State Cement Comm., no date, p. 75)	3.98	2.60	7.02	52.56	4.27	18.36	2.78

Quarries in the Pahasapa have generally been located along the railroads. Quarries along the Chicago, Burlington and Quincy Railway route through the central Hills have been operated at Loring Siding, Pringle, and Dumont. At Loring Siding, two quarries, no longer in operation, supplied burned lime and limestone for sugar beet plants in Nebraska and Wyoming. A quarry and plant at Pringle produces lime and various rock products. The Burlington has obtained roadbed ballast from a pit near Pringle. At Dumont, 9 miles south of Lead, Pahasapa limestone was quarried for the Deadwood smelters.

Prior to about 1930, a quarry in the Pahasapa limestone west of Rapid City was served by the Rapid City, Black Hills & Western Railroad, since abandoned. Dolomitic limestone was crushed and sized for use principally as concrete aggregate. Some of the fines were utilized in the manufacture of light-colored cement brick. An early-day quarry along the Chicago & Northwestern right-of-way northeast of Deadwood also supplied lime and flux to that community.

Limestone and dolomitic limestone resources in the Pahasapa are virtually limitless at the present rate of consumption.

Minnelusa Formation.—Carbonate beds in the lower half of the Minnelusa Formation are widespread. Most of the beds are dolomitic, but a few high-calcium layers are often present near the base. Except for local construction of culverts, retaining walls, and ranch building foundations, no use has been made of these limestones.

Minnekahta Limestone.—The Minnekahta Limestone consists of approximately 40 feet of thin-bedded purplish limestone sandwiched between the underlying Opeche Formation and the overlying Spearfish

Formation. It stands up as a low but conspicuous escarpment completely encircling the Black Hills (fig. 19). The outcrop width varies from one quarter to about 2 miles, and the dip slope is usually studded with pine trees.

The writer has proposed the following fourfold subdivision of the Minnekahta Limestone in the Black Hills (Gries, 1952, p. 83), based upon the lithologic appearance of the outcrops, and the insoluble residues:

1. Upper pure zone: Limestone, dense, finely banded gray and purple; much solution along bedding planes with development of stylolites.
2. Upper shaly zone: Limestone, dense to earthy, dark red; little solution; outcrops appear massive, and may break into irregular plates and slabs.
3. Lower pure zone: Description like zone 1.
4. Lower shaly zone: Limestone, very argillaceous, brick red, residue high, largely clay.

Sampling of a face at the State cement plant quarry at Rapid City shows the following (Bagan, 1950, graph II):

	Thickness (feet)	Insoluble residue, percent composition
Upper pure zone	14	1½ clay and silt.
Upper shaly zone	14	4 clay.
Lower pure zone	7	<2 clay.
Lower shaly zone	8	50 clay.

The Minnekahta is generally a high calcium limestone containing less than 1 percent magnesia. Darton and Paige (1925, p. 31) mention an occurrence west of Hot Springs with nearly 20 percent magnesia, but this is apparently unusual. Quarry owners report layers of very pure high-calcium rock, which they may save for shipment to sugar beet processors.

The Minnekahta Limestone has been burned for lime since the early settlement of the Hills. The early demand was for building plaster, mortar, and whitewash, but after the advent of the cyanide process for recovering gold, about 1900, most of the limestone has gone to the gold mills for neutralizing mill feed. Minnekahta Limestone has at one time or another been burned in kilns near Spearfish, Deadwood, Piedmont, Rapid City, and Hot Springs. A new kiln will be placed in operation at Rapid City in the spring of 1964.

Quarries for raw stone for riprap, sugar refining, building stone, aggregate, and highway use have been operated at Spearfish, north of Deadwood, Sturgis, Rapid City, Minnekahta, and Hot Springs. Pits to produce crushed rock for local construction jobs have been operated at many intermediate points along the outcrop.

The State Cement Commission operates a quarry at Rapid City, adjacent to their plant, solely to supply their own needs. Because argillaceous material is useful to their feed, they are able to quarry the entire thickness of 38 to 40 feet of the Minnekahta Limestone whereas commercial operators producing rock aggregate must leave the lower 8 to 10 feet of argillaceous rock unmined.

Reserves of limestone in the Minnekahta under less than 40 feet of overburden are estimated to be sufficient for 12,000 years at the present rate of consumption.

Morrison Formation.—A high-calcium but rather argillaceous limestone in the Morrison Formation reaches a local thickness of more than 30 feet near Bear Butte. No attempt has been made to utilize it.

Minnewaste Limestone Member of Lakota Formation.—The Minnewaste is a local deposit of rather pure high-calcium limestone that crops out in the southeastern part of the Black Hills. It reaches a maximum known thickness of 33 feet, but is generally 10 feet or less in thickness. This rock reportedly was burned for local use southeast of Hot Springs, but, because of its restricted distribution and inaccessibility, it has not been widely exploited.

Greenhorn Limestone.—The Greenhorn Limestone consists of an alternating sequence of calcareous shale and flaggy ledges of granular detrital limestone. The thickness of the flaggy part of the formation is generally given as about 40 feet; probably the aggregate thickness of limestone in this interval is less than 10 feet. The formation crops out as a low escarpment entirely around the Black Hills. The flagstone slabs have been extensively used in rural areas adjacent to its outcrop for building foundations, walks, culverts, and as riprap on stock dams, but there is no record that the formation has been used as a source of lime or aggregate.

Niobrara Formation.—The Niobrara Formation consists of 150 to 225 feet of calcareous beds that change from a firm chalk in the southeastern part of the state to a chalky shale around the Black Hills. In eastern South Dakota, the formation may be divided into an upper Smoky Hill Shale Member, and a lower Fort Hays Limestone Member. As shown on figure 19, the formation crops out continuously along the Missouri River and its major tributaries from below Yankton to the vicinity of Fort Thompson. It also occurs in a small area west of Pine Ridge in Shannon County, and in an irregular band surrounding the Black Hills (fig. 19).

Because of the ease of working, and apparent durability, the Niobrara was extensively used as a building stone in the southeastern corner of the State prior to about 1880. A cement plant using Niobrara chalk and shale from the Gregory Member of the Pierre Shale as raw materials was operated at Yankton between 1890 and 1909. High cost of selective mining necessary to avoid excessive gypsum, high fuel costs, and competition with Portland cement plants in nearby States are given as reasons for shutting down the operation.

Private interests attempted to establish a cement plant at Chamberlain between about 1903 and 1910; Niobrara chalk was to be mined along American Creek. The mill was never completed, and the project was apparently abandoned about 1910.

Immediately subsequent to World War I, the State of South Dakota considered construction of a cement plant at Chamberlain to utilize the Niobrara chalk. It was concluded, however, that a location in Rapid City had advantages in raw materials and in fuel, and the Chamberlain proposal was abandoned.

No use has been made of the Niobrara chalk in Western South Dakota.

Pierre Shale.—Extensive sampling of the calcareous Mobridge Member of the Pierre Shale in the vicinity of Mobridge was done by the State Geological Survey at the request of the State Cement Commission in 1950 (State Cement Comm., p. 68–80) to determine if sufficient calcium carbonate was present to constitute a source of cement rock. Sampling showed the formation to be low in calcium carbonate and high in magnesia.

Tertiary formations.—Thin lenticular limestones occur in the Oligocene Chadron Formation in the Big Badlands and in the Black Hills, and in the Miocene Monroe Creek Sandstone of Arikaree age on the Rosebud and Pine Ridge Indian Reservations. These slabby limestones have been used locally for culverts and as riprap on stock dams. The thicker beds in Mellette County are reported to have been crushed for aggregate or road metal. Both limestones are reported to be low in magnesia. The quantities available under shallow overburden are extremely limited.

PRODUCTION

The first commercial quarry in the Black Hills is believed to have been opened in 1887, and the first commercial lime kiln was completed in 1893. Prior to 1920, only the value of lime and limestones was reported. The last year for which production figures for South Dakota limestone are available is 1956, when lime and limestone output totaled 1,228,960 tons, with a value of $1,826,664. A critical analysis of early production figures is given by Lincoln (1930, p. 43–44). The current annual production of limestone in South Dakota is estimated by the writer to total about 2 million tons, of which approximately 600,000 tons is utilized in the manufacture of Portland cement.

The old Western Portland Cement Co. plant at Yankton produced a total of 1,913,738 barrels of cement between the years 1891 and 1909 (Planning Board Rept. p. 4). The plant was extensively overhauled and modernized in 1904, and no production was recorded that year.

The plant operated at Rapid City by the State Cement Commission has sold a grand total of 36,412.294 barrels of cement of all types between 1925 and the end of 1963. In 1963 1,928,916 barrels were marketed.

Table 9 shows production of limestone and cement for selected years:

TABLE 9.—*Lime, limestone, and cement production for South Dakota*

Year	Lime and limestone		Cement (barrels)[1]	Year	Lime and limestone		Cement (barrels)[1]
	Tons	Value			Tons	Value	
1895	----	$4,000	61,725	1930	36,770	$65,324	557,495
1900	----	33,382	38,000	1935	----	----	439,274
1905	----	6,653	248,000	1940	51,470	35,857	446,033
1910	----	17,150	0	1945	97,690	143,085	351,004
1915	----	17,485	0	1950	351,320	628,827	339,040
1920	43,350	75,274	0	1955	760,620	1,156,117	1,592,146
1925	73,080	97,880	337,192	1960	----	----	2,366,733

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[1] 1 barrel equals 378 pounds.

Sources: Mineral Resources, U.S. Bureau of Mines Minerals Yearbook, and reports of State mine inspector and State Cement Commission.

DIMENSION STONE

(By D. J. McGregor, South Dakota State Geological Survey, Vermillion, S. Dak.)

The strength and durability of stone has made it a favorite building material from the very earliest developments of man. The practical experience gained in man's early attempts to defend himself behind stone walls enriched him in another way, in that he learned to shape stones for a specific use. He also recognized that some stones could be shaped and polished to form attractive durable monuments. The history of many early cultures is preserved in such shaped and enscribed rocks. South Dakota pioneers recognized many sources of rocks suitable for their use in local building needs, and more especially that some of the rocks were particularly attractive and suitable for monuments. From the rather small demand of pioneer days, two significant industries are now based on South Dakota monumental stone. The Mount Rushmore memorial, certainly one of the world's largest single uses of stone, is one basis of the large and growing tourist industry, while the Milbank granite provides the basis for a $2½ to $3 million annual volume of business in northeastern South Dakota.

The Milbank granite, which is an attractive dark to medium red stone that takes a high polish, is produced in a number of quarries in a relatively small area in Grant County. The stone is used extensively for monumental purposes and is marketed throughout the country. The Milbank granite is Precambrian in age and crops out as small bosses in shallow stream valleys. Local relief on the granite surface is about 100 feet. Quarrying has extended outward from outcrop to where thickness of overburden exceeds the economic limits of its removal. Thickness of the granite is not known, but depth of quarrying has exceeded 200 feet, with no indication that total thickness has been reached.

The Milbank granite is composed of plainly visible mineral grains or crystals of which 60 percent are dark red feldspar, 25 percent clear quartz, 14 percent biotite, and 1 percent accessory minerals. Variation in the color of the granite is due chiefly to variation in the color of the feldspar.

About 90 percent of the dimension-stone granite produced in South Dakota is used for monuments and distributed to a few dealers in each State. Dealers generally do not stockpile such stone, and thus sales are based almost exclusively on a made-to-order basis. The best markets are in Ohio and the Western States. The nearest competitors for the South Dakota granite industry are plants in Minnesota and Wisconsin. The value of dimension stone over the period 1958–63 averaged about $2.7 million, ranging from a low in 1958 of about $2.3 million to a high of about $3 million in 1959 and 1960.

Six companies quarry granite in Grant County, S. Dak. Four of these companies fabricate the finished product outside the State, whereas two companies have fabricating mills in the State. Total number of employees involved in quarrying granite and in fabricating products in South Dakota is about 200. Although the dimension-stone industry in South Dakota employs a relatively small number of people, it nevertheless has a tremendous economic impact on the area with an annual payroll of about $750,000. Table 10 lists the quantity and value of stone produced in South Dakota.

TABLE 10.—*Stone production in South Dakota, 1889–1963* [1]

Year	Quantity (short tons)	Value
1889–1899 [2]	750,000	$1,500,000
1900	(3)	174,552
1901	(3)	171,368
1902	(3)	197,394
1903	(3)	202,333
1904	(3)	367,784
1905 [4]	(3)	200,061
1906 [4]	(3)	156,360
1907 [4]	(3)	155,875
1908 [4]	(3)	131,994
1909 [4]	(3)	167,357
1910 [4]	(3)	173,726
1911 [4]	(3)	148,190
1912 [4]	(3)	162,295
1913 [4]	(3)	172,736
1914 [4,5]	(3)	156,907
1915 [4]	(3)	159,089
1916 [4]	(3)	205,497
1917 [4]	(3)	182,907
1918 [4]	(3)	97,894
1919 [4]	140,400	222,490
1920 [4]	196,880	489,753
1921 [4]	181,600	386,906
1922 [4]	133,920	272,152
1923 [4]	250,730	479,288
1924 [4,5]	166.970	362,508
1925 [4,6]	211,880	456,342
1926 [4,6]	211,340	472,032
1927 [4,6]	264,500	535,232
1928 [4,6]	172,360	451.869
1929 [4,6]	250,440	635,890
1930 [4,6]	166,020	666,201
1931 [4,6]	222,510	636,841
1932 [4,6]	196,100	442.507
1933 [4,6]	133,520	376,078
1934 [4,6]	237,510	$497,200
1935 [4,6]	229,420	585,434
1936 [4,6]	259,130	693,496
1937 [4,5,6]	407,270	982,906
1938 [4,6]	320,740	899,190
1939 [4,6]	408,730	998,444
1940 [4,6]	255,600	878,866
1941 [4,5,6]	401,550	1,189,564
1942 [4,6]	714,750	1,763,790
1943 [4,5,6]	269,410	1,304,370
1944 [4,5,6]	255,530	1,412,141
1945 [4,5,6]	303,500	1,605,904
1946 [4,5,6]	379,880	2,385,543
1947 [4,5,6]	885,650	3,554,096
1948 [4,5,6]	763.000	3,911,000
1949 [4,5,6]	1,024,000	4,473,000
1950 [4,5,6]	1,206,000	4,861.000
1951 [4,6]	1,263,322	4,660,074
1952 [4,6]	1,671,187	4,806,882
1953 [4,6]	1,189,444	4,997,497
1954	1,614,818	4,928,855
1955	2,262,246	5,679,444
1956	2,200.000	5,725,000
1957	1,718.000	5,068,000
1958	1,395.000	4,095.000
1959	2,721.000	7,243.000
1960	3,149.000	7,909.000
1961	2,806.000	6,642.000
1962	2,852,000	6,533,000
1963	3,044,000	6,829.000
Undistributed [7]	6,484,973	5,072,416
Total, 1889–1963	46,341,830	123,955,520

[1] Data for 1963 are preliminary.
[2] Estimated.
[3] Not reported; estimate included in "Undistributed."
[4] Excludes stone used to make lime; included in "Undistributed."
[5] Excludes some stone that must be concealed to avoid disclosure of confidential figures; included in "Undistributed."
[6] Excludes stone used to make cement; included in "Undistributed."
[7] Includes estimated 2,000,000 tons for period 1900–18 as indicated by footnote 3; 214,973 tons valued at $317,666 for confidential figures indicated by footnote 5; estimated 385,000 tons valued at $481,250 used to make lime during the period 1905–53 as indicated by footnote 4; and estimated 3,885,000 tons valued at $4,273,500 used to make cement during the period 1925–53 as indicated by footnote 6.

Source: U.S. Department of the Interior, Bureau of Mines.

In the exploration for future sources of granite, enough weathered material should be removed from outcrops to expose the fresh surface of the rock for careful examination. Features to look for are freedom from cracks or closely spaced joints, uniformity of texture and color, and ability of the rock to take a polish. Favorable surface examination should be supplemented by core drilling to give thickness and nature of the rock underground, and to provide samples for further appraisal.

The Harney Peak granite in the Black Hills has not been quarried extensively for dimension stone. Although the mineral and chemical composition of the granite is similar to that in Grant County, its texture is unsuitable. Mineral crystals are large, and the rock chips easily when carved. Much of the granite contains small veins that detract from its esthetic appeal.

In addition to monumental uses, dimension stone includes all types of rocks that are shaped for a wide variety of structural uses. A number of rocks found in many parts of the State have been used for local buildings but are not currently being exploited. Present construction practice favors less costly and more easily worked materials, and the use of stone is reduced except for architectural accents.

Because of its durability and good bedding, the Minnekahta Limestone has been widely used as a building stone, particularly for retaining walls, culverts, patios, and rustic buildings in public parks. The rock has recently come into vogue as a facing stone, with large slabs mounted on edge in random pattern. Notable examples of its use are the First National Bank Building and the several new buildings at St. Martin's Academy at Rapid City.

Other rocks in the Black Hills area meet the durability and strength requirements but do not possess the textural qualities for use as dimension stone. Many such rocks are condemned because of their appearance.

The Sioux Quartzite once was used extensively as dimension stone, and many buildings in the State attest to the durability and beauty of the quartzite. The Sioux Quartzite is an extremely hard rock, and fabricating it is expensive; thus, it no longer is used as dimension stone. Other quartzites known in the Black Hills are not used as dimension stone for the same reason.

Glacial boulders constitute a source of dimension stone but more for local domestic use in fireplaces, patios, and home veneer than for commercial production.

South Dakota granite has been produced continuously since the first block was quarried in 1907. However, in recent years the use of dimension stone in building has met with stiff competition from more cheaply produced building materials and the introduction of lightweight building products. Future expansion of South Dakota's dimension-stone industry is one of developing new uses and new markets for a known mineral resource.

CLAYS, BENTONITE, AND LIGHTWEIGHT AGGREGATE

(By S. H. Patterson, U.S. Geological Survey, Beltsville, Md., and E. J. Cox, South Dakota State Geological Survey, Belle Fourche, S. Dak.)

The clays now mined in South Dakota are swelling-type bentonite used for drilling mud, foundry sand-bonding material, and a number of other purposes; common clay used for brick, tile, and cement; and shale used for making lightweight aggregate. Clays mined in the State in the past but no longer produced include fire clay for low- and moderate-grade refractory products, fuller's earth for decolorizing and purifying fats and oils, and nonswelling bentonite used in the manufacture of water softeners.

During the period 1888 to the close of 1963 a total of 6.6 million tons of clay valued at $39.2 million were produced in South Dakota, according to records of the U.S. Bureau of Mines which are listed in the following table:

TABLE 11.—*Clay production in South Dakota, 1888–1963* [1]

Period [2]	Number of years	Total		Yearly average	
		Quantity (short tons)	Value	Quantity (short tons)	Value
1888–1920 [3]	32	465, 000	$584, 000	14, 530	$18, 250
1921–35 [4]	15	230. 000	523. 000	15, 333	34, 866
1936–40	5	136, 622	947, 289	27, 324	189, 458
1941–45	5	646, 876	4, 224, 232	129, 375	844, 846
1946–50	5	1, 207, 120	9, 127, 068	241, 424	1, 825, 414
1951–55	5	1, 481, 229	11, 150, 096	296, 246	2, 230, 019
1956–61	6	1, 890, 914	10, 090, 357	315, 152	1, 681, 726
1962	1	249, 000	690, 000	249, 000	690. 000
1963 [5]	1	299, 000	1, 884, 000	299, 000	1, 884, 000
Total, 1888–1963	75	6, 605, 761	39, 220, 042	88, 077	552, 934

[1] Includes bentonite.
[2] Data are shown by periods of years to avoid disclosure of confidential data.
[3] Estimated from record of brick and miscellaneous clay production.
[4] Revised from figures published.
[5] Preliminary figures.

Source: U.S. Department of the Interior, Bureau of Mines.

The quantity and value of the clays produced in South Dakota in 1962 were less than the previous year (Bieniewski and Agnew, 1963, p. 961), but both recovered considerably in 1963. In 1962 only a small tonnage of bentonite was produced by the American Colloid Co., Belle Fourche; common clay was mined by the Black Hills Clay Products Co., Belle Fourche, Butte County, and the South Dakota Cement Commission, Rapid City, Pennington County; and shale was mined by the Lightweight Aggregates, Inc., Rapid City.

The suitability of clays in South Dakota for various uses depends on physical properties which are controlled by the mineral and chemical composition of the clay. Clays are natural earthy materials composed of very fine particles (clay minerals) that are principally hydrous aluminum silicates, but may contain small amounts of iron, magnesium, potassium, sodium, calcium, and other ions. The clay minerals that are common in South Dakota include kaolinite, montmorillonite, illite, chlorite, and mixed-layer clays. Nonclay minerals and other impurities are present in all clays in varying quantities. Quartz, gypsum, cristobalite, feldspar, and mica are common impurities in bentonites; and quartz, titanium minerals, feldspar, and organic materials are common in other types of clay. Barite occurs in some South Dakota bentonites. For most uses the value of the clay varies directly with the purity of the clay mineral present; however, for some products nonclay minerals or organic matter having certain properties are important. Physical properties of clays, one or more of which make them suitable for different uses, including plasticity, bonding strength, color, vitrification range, deformation with drying and firing, resistance to high temperatures, gelation, wall-building properties, viscosity of slurries, swelling capacity, ion-exchange capacity, adsorbent properties, etc. The composition, mineral structure, methods of identification, and testing of various clays for different uses have been summarized by Murray (1960). Books by Grim (1953 and 1962) contain detailed information on these subjects.

Bentonite.—Bentonite is a clay that has altered from volcanic ash or tuffs, and it is ordinarily composed chiefly of montmorillonite. One type of bentonite known as "Wyoming type" or "sodium type" has a high swelling capacity, extremely fine particle size and other properties that make it of value for use in drilling mud; as a bonding material for foundry sands and pelletizing fine-grained iron ores; where high dry strengths are required; as a relatively impervious lining for reservoirs, irrigation ditches, and stock tanks; and many other uses. A second type of bentonite called "calcium bentonite," "southern type," or "nonswelling bentonite" is mineralogically similar to "Wyoming" bentonite but has different physical properties. This type of bentonite was formerly mined in South Dakota and used in making water softeners; similar deposits in other States are used for foundry sand-bonding material requiring high green strengths, as a bleaching clay for decolorizing oils, floor sweep, as petroleum catalysts after treatment with acid, and for other purposes. Both the "Wyoming" and nonswelling types of bentonite have high ion-exchange capacities, and it is generally accepted that the kind and abundance of exchangeable ion present are important factors controlling the physical properties.

Bentonite mining began in South Dakota in 1915 when deposits in the lower part of the Pierre Shale were opened near Buffalo Gap, Custer County (Connolly and O'Harra, 1929, p. 326). Mining of these deposits lasted only 2 years and about 300 tons was mined. Mining of nonswelling bentonite near Ardmore, Fall River County, for use in the manufacture of water softeners began in 1917 and continued intermittently until the early 1950's. Attention was focused on the high swelling "Wyoming type" bentonite deposits northwest of Belle Fourche, Butte County (fig. 20), before 1923, but only a few carloads were shipped until the first plant was built in 1934. The district northwest of Belle Fourche became one of the leading bentonite producers in the United States during the 1940's. Production declined rapidly in the next decade as reserves of high-quality bentonite under light overburden were depleted, and mining shifted to parts of the northern Black Hills in Wyoming and Montana. In 1962 only one company mined a small tonnage of bentonite in South Dakota (Bieniewski and Agnew, 1963, p. 961). Production may continue, however, for several years, as a lease for mining bentonite on State-owned land northeast of Belle Fourche was obtained by the American Colloid Co. in 1963 (Bieniewski, 1964) and reserves may be present on other lands in this area.

The high swelling bentonite mined in the South Dakota portion of the northern Black Hills is in the Clay Spur bed which is in the uppermost part of the Mowry Shale. This bed crops out in a belt more than 11 miles long extending northwestward from Belle Fourche to the South Dakota-Wyoming boundary. Thicknesses of bentonite in this bed range from 1 to about 5 feet. A second swelling bentonite bed referred to as bed F (Knechtel and Patterson, 1962, p. 982–986, pl. 60) occurs near the top of the Belle Fourche Shale, which overlies the Mowry Shale. Considerable resources of bentonite are present in this bed; however, the quality of the bentonite is not as good as that in the Clay Spur bed, and only a small tonnage has been mined for experimental purposes.

The nonswelling Ardmore bentonite bed of Spivey (1940, p. 3), which was mined for water softener in Fall River County, crops out at the bottom of the Sharon Springs Member of the Pierre Shale

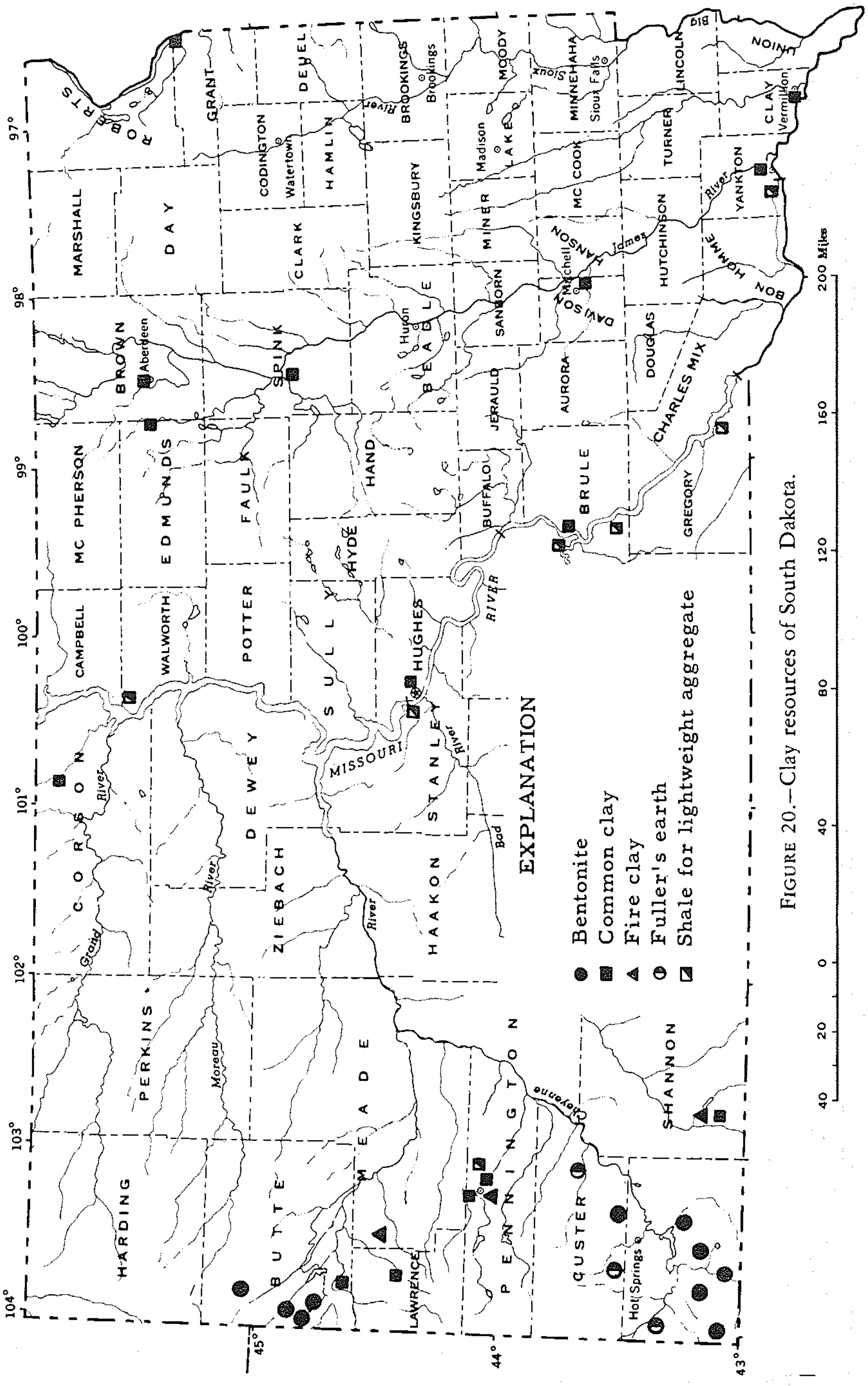


FIGURE 20.—Clay resources of South Dakota.

(Connor, 1963, p. 115) some 60 to 70 feet above the base of the formation. The average thickness of this bed is about 3 feet. No estimates of the resources of bentonite in this bed are available, but it crops out intermittently for about 100 miles along the south and southeast sides of the Black Hills, from the South Dakota-Wyoming State line to the general vicinity of Rapid City; therefore, very large tonnages of bentonite must be present. The Ardmore bed also crops out in a broad area 18 to 20 miles north of Belle Fourche (bed I of Knechtel and Patterson, 1962, p. 990–994; and Gill and Cobban, 1961, fig. 352.4). Samples of clay from this bed that were tested had very high green-bonding strengths but had no value as drilling mud(Knechtel and Patterson, 1962, table 4).

Common clays.—In the 1890's nearly every town on the Missouri River had a small brick plant (Rothrock, 1944, p. 203) ; several plants were located in Rapid City and each town in the Black Hills had one or more plants (Connolly and O'Harra, 1929, p. 305) ; and plants have been in operation in several towns in other parts of the State. Most of these plants were small and supplied only local markets and were abandoned when demands were satisfied. The only brick plant in operation in South Dakota in 1963 is at Belle Fourche, Butte County. The clay used in this plant is mined from the Fuson Member of the Lakota Formation at a locality 3 miles south of the plant (Connolly and O'Harra, 1929, p. 305–309). Common clay weathered from the Pierre Shale is also produced and used in making cement at Rapid City, Pennington County (Bieniewski and Agnew, 1963, p. 968).

The clay mined south of Belle Fourche is 20 to 30 feet thick. Most of it is dark gray, but much is mottled with purple, and parts of the deposit are light colored. The purplish clay produces a red brick and tile. A band of light clay fires yellowish tan. This clay is probably in the same stratigraphic position and of similar composition to clay in a mottled zone at the top of the Lakota Formation in the western and southern Black Hills, which is rich in kaolinite (Schultz and Mapel, 1961, p. C172–C175).

Clays, shales, and other fine-grained materials of several types have been used for brick and other structural clay products in South Dakota, and every center of population in the State is located near resources that could be used for these purposes. The Pierre Shale of Late Cretaceous age crops out over much of the central and western parts of the State and has been used for bricks at a number of places. Residual weathered material from red beds in the Spearfish Formation of Permian and Triassic age and beds in the lower part of the Graneros Shale of Cretaceous age were once used at Rapid City (Connolly and O'Harra, 1929, p. 309–310). Other materials that have been used for brick and tile include alluvium, glacial drift, loam that accumulated in glacial lakes, loess, and shales and clays from formations other than those listed. Not all of these materials will produce brick that will be accepted by the present-day consumer.

A small tonnage of low-grade pottery clay is mined and used in making art pottery primarily for sale to tourists. The clays that have been used for pottery have been dug from the Fuson Member of Lakota Formation (Rothrock, 1944, p. 201), from a small deposit near Hermosa (Bryson and others, 1947), and from deposits in the southwestern corner of the Pine Ridge Indian Reservation (Schultz, 1961, p. 17). The clay dug on the Reservation is in a bed about 3 feet thick, occurring in a weathered noncalcareous zone at the top of the Niobrara Formation.

Fire clay.—Fire clays suitable for low- or moderate-heat-duty refractory products occur in the Fuson Member of the Lakota Formation, in a few places in the Morrison Formation (Connolly and O'Harra, 1929, p. 306), and in weathered surficial material on the Pine Ridge Indian Reservation (Schultz, 1961, p. 18). Certain siliceous shale in the Mowry Shale in the Black Hills region and parts of the Pierre Shale at two localities in the Missouri Valley have been suggested as possible sources of refractory materials (Rothrock, 1944, p. 205); however, there are no reports of these materials being used or tested for this purpose, and probably they have little value as refractories.

The fire clay in the Fuson Member crops out in several places on the northern, eastern, and southern flanks of the Black Hills. Deposits reported to be 45 feet thick were mined many years ago at a locality 2 miles south of Rapid City. These clays were used for refractory bricks for lining smelters in the Black Hills region. The Al_2O_3 contents range from 6.56 to 18.30 percent in analyses of clays from south of Rapid City and in a pit south of Belle Fourche (Connolly and O'Harra, 1929, p. 307–308). Clays having alumina contents in this range are rarely suitable for more than moderate-heat-duty refractory products, and clays now mined in other States for high-heat-duty products ordinarily contain about 35 percent Al_2O_3.

Clays consisting of as much as 50 percent kaolinite occur in weathered noncalcareous parts of the Niobrara Formation in the southwestern part of the Pine Ridge Indian Reservation (Schultz, 1961, p. 5–6). These clays are suitable for use in low-heat-duty refractory products. They have little value, however, because they are of no better quality than the clays in the Fuson Member, and there is no demand for refractory products on the Reservation.

Fuller's earth.—Small tonnages of fuller's earth were processed in the 1890's in a plant at Hot Springs. Most of the material processed was mined from a deposit 5 miles southeast of Fairburn and one 2 miles west of Argyle, Custer County. Other deposits of fuller's earth are reported to be located 2 miles south of Buffalo Gap, Custer County, and 1¼ miles west of Minnekata and 8 miles west of Edgemont, Fall River County (Ries, 1898, p. 334–335). Parts of the Titanotherium beds in the White River Badlands are probably similar to the material that was processed at Hot Springs (Connolly and O'Harra, 1929, p. 315–316).

The deposits southeast of Fairburn are 9 feet thick and consist of yellowish gritty clay having a nodular structure. Deposits west of Argyle are 18 feet thick and are of the same type of clay that occurs at Fairburn (Ries, 1898, p. 333-334).

Samples of fuller's earth from near Fairburn and Argyle tested in recent years (Miller, 1959, p. 23) were rated as 90 percent efficient for bleaching and purifying cottonseed oil as compared with commercial fuller's earth now in use. Though resources of fuller's earth in the southern Black Hills are probably very large, they are of a grade that cannot compete with more efficient materials for distant markets, and no local demands for these clays exist; they, therefore, have little value at present.

Nonswelling bentonite in the southern Black Hills region is efficient for use in filtering and purifying mineral and vegetable oils (Miller, 1959, p. 11–12). These bentonites, therefore, might properly be referred to as fuller's earth, and the fuller's earth described by Ries (1898, p. 334–335), as located 2 miles south of Buffalo Gap is now known to be part of the Ardmore bentonite bed of Spivey (Gill, J. R., written communication, January 20, 1964). There are large resources of nonswelling and low-swelling bentonite in the southern Black Hills and elsewhere in the State; however, the quantity of these clays that are suitable for decolorizing oils and for use as bleaching agents has not been determined.

Lightweight aggregate.—The only lightweight aggregate plant in South Dakota has been in operation at Rapid City, Pennington County, since 1952. The raw material used in this plant is mined from the Pierre Shale (Cole and Zetterstrom, 1954, p. 15). This mine is located approximately 8 miles east of Rapid City. Very large reserves of shale are located in this region.

Shales that have been tested in laboratories and found suitable for use in making lightweight aggregates occur in a number of places in South Dakota, and the possibilities of establishing plants at localities other than Rapid City have been considered. Shale that is reported to have superior expanding properties occurs in the Pierre Shale west of Yankton (Miller, 1959, p. 24), and the construction of a plant in this vicinity has been recommended. Other areas where the Pierre Shale contains material favorable for use in making lightweight aggregates are located near Mobridge, Iona, Chamberlain, Fort Pierre, and in Gregory County (Cole and Zetterstrom, 1954, p. 5, 22–29; Zetterstrom and Cole, 1956). Total resources of potential bloating material for lightweight aggregate in the Pierre Shale in South Dakota are virtually inexhaustible, and other formations probably contain shales and clays suitable for making lightweight aggregate.

Economic consideration and resource potential.—South Dakota is amply supplied with common clay suitable for making brick, tile, and structural clay products, and shale resources for lightweight aggregate and cement are virtually inexhaustible. Most products made from common clay and shale are heavy or inexpensive and supply markets within the State or in nearby areas.

Practically the only existing demand for bentonite in South Dakota and adjacent States is for the high-swelling type that occurs in the Clay Spur bed. Bentonite of this type is consumed in nearly every State in the United States and is shipped to many foreign countries. The outlook for mining this type of clay in South Dakota is not bright, because reserves in the Clay Spur bed under light overburden are largely exhausted. The two bentonite plants located on a railroad spur 2 miles northwest of Belle Fourche operated by the American Colloid Co. and the International Minerals and Chemical Corp. are supplied chiefly by mines in Crook County, Wyo., and will not be closed by the exhaustion of deposits in South Dakota. The resources of bentonite in the Clay Spur bed under thick overburden will have little value for many years, because reserves of cheaply mined clay in Wyoming and Montana are adequate to last several decades. The prospects of bentonite mining in South Dakota would be greatly improved if demands would develop for the nonswelling type, a possibility that has been suggested by Miller (1959, p. 12; Lee and others, 1961). Large resources of nonswelling bentonite are present in Fall River and Butte Counties and other parts of South Dakota.

The possibility for extraction of alumina from the Pierre Shale has been considered a number of times (Gries, 1942, p. 63–66; Rothrock, 1944, p. 65–66), and several research projects carried on by chemical engineering students of the South Dakota School of Mines and Technology were concerned with this problem (Miller, 1959, p. 26). The most serious attempt to use raw materials other than bauxite for alumina commercially in the United States in recent years has been directed at kaolinitic clays in Latah County, Idaho (Stephens, 1960), and high-grade kaolins in Georgia (Anonymous, 1963, p. 43). Latah County, Idaho, contains large resources of clay averaging more than 20 percent Al_2O_3 (Hosterman and others, 1960, p. 37), and the Al_2O_3 in Georgia kaolins is 35 to 40 percent (Kesler, 1963, p. 8). Inasmuch as the Pierre Shale contains only 12.37 to 17.93 percent Al_2O_3 (Tourtelot, 1962, table 7) and no commercial extraction of alumina from the Idaho or Georgia clays has yet been made, the prospects for using Pierre Shale for alumina cannot be considered good.

PEGMATITE MINERALS

(By J. J. Norton, U.S. Geological Survey, Washington, D.C.)

The chief mineral products of the southern Black Hills, Custer and Pennington Counties, have been the pegmatite minerals—especially potash feldspar, mica, beryl, and lithium minerals. A smaller pegmatite district at Tinton, in the northwest part of the Black Hills, have been a source of lithium. The Black Hills has produced $16,540,000 worth of these minerals. Of this total, more than 80 percent has been mined in the last 25 years, and 50 percent has been mined since 1950.

"Pegmatite" is the name of an unusual form of granitic rock. It consists, in the main, of the same minerals as granite—quartz and feldspar. It differs from granite in its abundance of very large crystals, several inches or several feet across. Bodies of pegmatite that have been profitably mined have one other very important characteristic: parts of them are very rich in one or more minerals that have commercial value. Both the coarse crystal size and the abundance of a commercial mineral are of key significance—the size because it permits selective recovery of the product by the hand methods ordinarily used, and the abundance because it permits a high yield of the mineral sought.

The pegmatite mineral that ranks first in importance in the southern Black Hills is potash feldspar. Its uses in the ceramic and glass industries have made it one of the most stable parts of the economy of the southern Black Hills during recent decades, through depression and prosperity, and war and peace.

The southern Black Hills has had an important, though sporadic, commerce in "sheet mica," and also yields an output of "scrap mica" that has been steadier but of much lower total dollar value. Sheet mica includes any muscovite mica that is cut into sheets of 1 square inch or larger. It is further divided into a great number of categories, in which price depends on the size and quality of individual sheets. The combination of physical and electrical properties of sheet mica are such that it has a wide variety of uses in the electronic and electrical industries. A quite different but also important product is "scrap mica," which is reduced by grinding to a finely divided form. Its chief uses are in roofing materials, paint, and rubber.

Beryl has been produced at the rate of a few hundred tons per year for many years. Production in 1962 was 144 tons, which was sold to the U.S. Government for $77,000. The Government purchase program came to an end in 1962, and there has been little or no beryl mining since then. Beryl is the source of the metal beryllium, which has been used chiefly in an alloy with copper.

Lithium minerals—spodumene, amblygonite, and lepidolite—have also been important in the Black Hills, but in recent years production has become virtually nil. Other products of Black Hills pegmatites include tantalum and columbium from the mineral tantalite-columbite, a small quantity of tin, and mineral specimens and decorative material, especially rose quartz.

HISTORY OF MINING

Pegmatite mining began in 1879 when the Crown mine, near Custer, was opened as a source of sheet mica. Mining for sheet mica was vigorously pursued from 1879 to 1884 and again from 1906 to 1911, chiefly at the Crown, Lost Bonanza, New York, and White Spar mines. The mica output during these years had a total value of about $1 million. After 1911 production was at a modest level until World War II. The demand for sheet mica for military uses, largely in electronic equipment, led to the establishment of a Government purchase program in which a buying station in Custer was active from 1942 to 1945. A smaller program of similar nature lasted from 1952 to 1962. Total sales were about $1,900,000.

Mining for lithium minerals began at the Etta mine, near Keystone, in 1898. From then until 1952 the Black Hills was the dominant source of the world's lithium. Production was greatest during the two World Wars and the Korean war. Most of the mining was for spodumene at the Etta, Edison, Tin Mountain, Mateen, Beecher No. 2, and Bob Ingersoll No. 2 mines. Amblygonite was extracted from many properties. Lepidolite was obtained chiefly from the Bob Ingersoll No. 1 mine. During the 1950's there was a great change in the world's lithium mining industry: large mines were developed in North Carolina, Quebec, and Southern Rhodesia, and world production increased from 28,128 tons of lithium minerals in 1952 to at least 170,000 tons in 1957 (Schreck, 1961, tables 9 and 11). For a time the several lithium mines and mills of the Black Hills held a place in this expanding industry, but ultimately they proved to be too small to compete at this scale. Since the closing of the Etta mine in 1960, lithium mining in the Black Hills has been nearly dormant.

Potash feldspar was first mined at the Hugo mine near Keystone in 1923. When a grinding mill was built at Keystone in 1929 and another at Custer in 1935, feldspar mining took firm roots in the Black Hills economy that it has held to the present day. Total production through 1963 has been 1,382,081 long tons worth $6,684,111. Both the Keystone and Custer mills were destroyed by fire in the late 1950's, and a new mill constructed at Custer has treated most of the 20,000 to 45,000 tons of feldspar produced annually since then.

Beryl was the last of the pegmatite minerals to come into prominence. Though mined sporadically as a by-product in early years, it first became important in World War II. With the stimulus of Government purchase programs in World War II and again between 1952 and 1962, annual production has generally been between 150 and 400 tons. Production through 1963 totals 4,964 tons valued at $1,654,260.

Production figures for all the pegmatite minerals are presented in tables 12 to 17, provided by the U.S. Bureau of Mines. Some figures for early years, when productiton records were less exact than now, are estimates based on published statements and other source material, not all of which are consistent with one another. The figures here used are the most authoritative now available. Other estimates, some of them in more detail, have been published by the South Dakota State Planning Board (1937), by Page and others (1953, table 1), and in the annual reports of the South Dakota State mine inspector.

GEOLOGY OF PEGMATITES

Approximately 20,000 pegmatites are distributed across a broad area surrounding the Harney Peak granite, but only about 200 are known to have characteristics that make them suited for mining. These 200 are the so-called zoned pegmatites.

The structure of a zoned pegmatite can be most easily visualized by examining a map of such a body, which shows its characteristics in a horizontal plane, or by use of a cross section, which shows how the pegmatite would look in a vertical slice. Figure 21 is a cross section of the Hot Shot pegmatite, which is about 4 miles east-southeast of Custer. This illustration shows the inferred nature of the entire pegmatite, from top to bottom; the information used to make the cross section comes from surface exposures, mine workings, and drill holes, all of which are shown on the original maps and sections (Norton and others, 1964, plate 27) from which this was made.

Many of the characteristics illustrated by this cross section are typical of zoned pegmatites. The pegmatite is approximately elliptical in form, but has a rounded top, a keel-like bottom, and many irregularities or "rolls" along its border. The interior of the pegmatite is divided into six zones, each of which has a different suite of minerals. Some of these minerals have economic value, and units in which industrial minerals are abundant can be selectively mined.

The outermost part of the pegmatite is a wall zone consisting of quartz, albite (soda feldspar), and muscovite mica, some of it in books large enough to be used for sheet mica. The wall zone is very thin at the top of the pegmatite and much thicker at the bottom. In this, as in other pegmatites, the wall zone is richest in muscovite at its outer border, along the contact with the country rock; the inner part of the wall zone consists mainly of albite and quartz. In the Hot Shot pegmatite this trend is so prominent that a separate zone of albite-quartz pegmatite has been developed everywhere except in the upper part of the body.

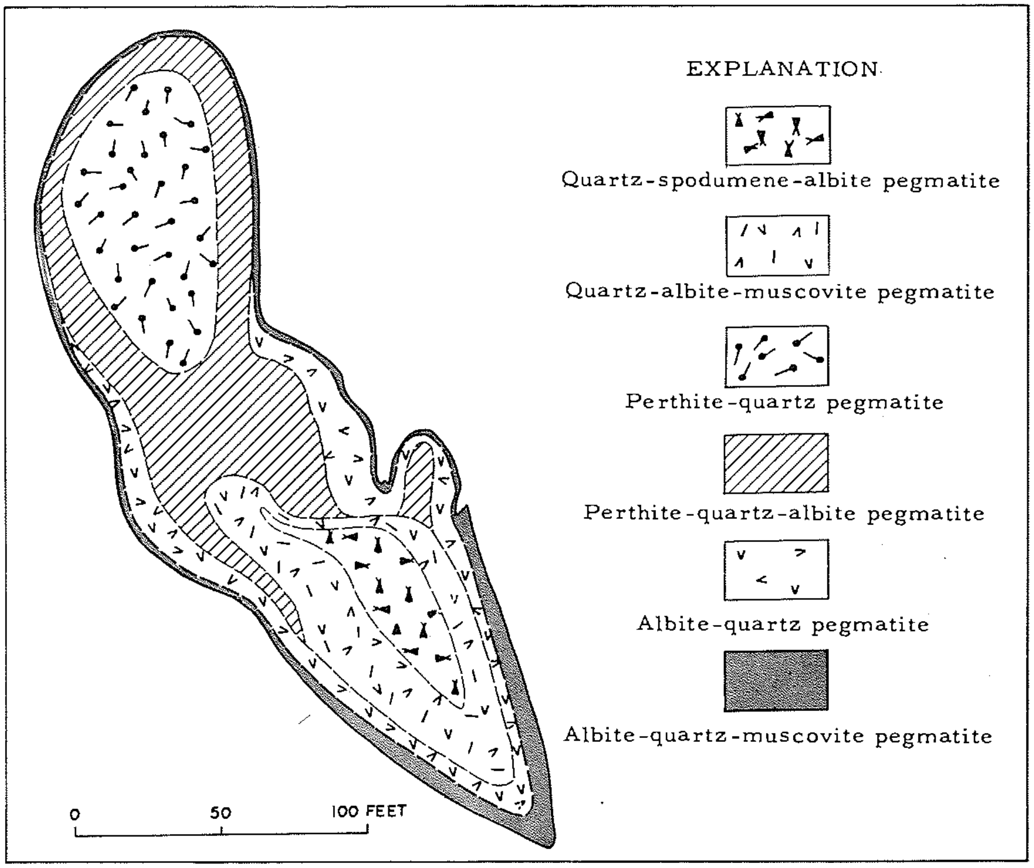


FIGURE 21.—Pegmatite zones, as shown in a cross section of the Hot Shot pegmatite; based on Norton and others (1964, pl. 27, sec. B–B′).

Two zones in the upper part of the Hot Shot pegmatite contain potash feldspar in the form of "perthite." Strictly speaking, perthite is not a mineral but a combination of two minerals: the predominant member is microcline (potassium feldspar), but it contains within it many small streaks and patches of albite (sodium feldspar). The perthite-quartz-albite and perthite-quartz zones at the Hot Shot are, like all zones of this composition in the Black Hills, in the inner and upper part of the pegmatite. The lower part of the pegmatite lacks a perthite zone, and has a quartz-albite-muscovite zone in its place.

The inner zone, or "core," consists of quartz-spodumene-albite pegmatite. All three Black Hills lithium minerals—spodumene, amblygonite, and lepidolite—have been found in this part of the Hot Shot pegmatite, but their tonnage is so small that no effort has been made to extract them.

Though the Hot Shot is here cited as a "typical" zoned pegmatite, one must bear in mind that every zoned pegmatite is at least a little different from every other zoned pegmatite. Some have very simple shapes; some are very irregular. Some have large mica-rich wall zones, and carry little or no potash feldspar in their inner zones. Some have only sparse mica, but very large potash feldspar zones. Many pegmatites have a core that consists entirely of quartz. In others, the core carries feldspar and perhaps lithium minerals; a few have zones containing lithium minerals that occupy the greater part of the pegmatite. Many pegmatites, like the Hot Shot, have several zones that can be mined for economically valuable minerals, and thus a single pegmatite can be a source of several marketable products. The wide variety in the characteristics of zoned pegmatites is described in the extensive literature on these deposits.

The chacteristic of overriding importance is the zoned structure itself. Only the zoned pegmatites contain units rich enough to have been mined for potash feldspar, mica, beryl, or lithium minerals.

The unzoned pegmatites are, in a sense, varieties of the Harney Peak Granite. This so-called granite is itself pegmatitic in many respects. Not only its minerals—chiefly feldspar and quartz—but also its variety in grain size, the presence of very large crystals, and the sparsity of dark minerals are such that all of it could as well be called pegmatite as granite.

The unzoned pegmatites are not greatly different from certain large bodies of pegmatitic rock in the Eastern States that are sites of large mining and milling operations to produce feldspar, largely for the glass market. A geographic location near the principal markets, so that freight costs are low, is one of the most importance characteristics of such large volume feldspar sources. The unzoned pegmatites of the Black Hills are too far from markets to have been utilized in this way, and at present have no economic value.

DISTRIBUTION OF PEGMATITES

The search for an economically profitable pegmatite is a search for a zoned pegmatite that has a sizable zone enriched in one or more industrial minerals. The locations of 64 of the more important deposits are shown on figure 22.

Figure 22 also shows the distribution of all types of pegmatites, unzoned as well as zoned, by means of isograms signifying the number of pegmatites per square mile. The outer limit of the pegmatite-bearing area (the zero isogram) runs from near Keystone to Hill City and then south-southwest to the edge of the Precambrian rocks. A small area near Bear Mountain, 9 miles west-southwest of Hill City, also has a few pegmatites, none of which now have commercial importance. In summary, the map indicates that the pegmatite-bearing area—where deposits of commercial value may be found—includes the entire extent of Precambrian rocks south and east of the Harney Peak granite, and also a strip a few miles wide around the north and west sides of the granite. Pegmatites are most abundant near the Harney Peak granite and in an area extending south from Custer to Pringle.

The 64 zoned pegmatites that have been mined intensively are widely distributed in the region surrounding the Harney Peak granite. Most of them are in the outer parts of the pegmatite-bearing region: 47 are between the 0 and 100 isograms, 12 are between the 100 and 200 isograms, and only 5 are above the 200 isogram. The localities containing the greatest number of deposits are southeast and southwest of Custer and in a small area near Keystone. There is only a scattering of zoned pegmatites along the north and west sides of the Harney Peak granite. The absence on the map of zoned pegmatites on the southeast side of the granite in Custer State Park is probably because prospecting and mining have been prohibited in this area for many decades, not because there are no deposits.

The zoned pegmatites on the map are divided into four categories, each shown by a separate symbol. The four kinds of zoned pegmatites have recognizable but gradational differences. Furthermore, they show a tendency to occur in different places.

The sheet mica pegmatites, shown as black dots on the map, are those in which a mica-rich wall zone is well developed. They have quartz-feldspar inner zones, and some have a quartz core; the predominant feldspar is plagioclase. Virtually all the important sheet mica deposits of the southern Black Hills are in the Custer district, on the southwest and south sides of the Harney Peak granite. Many of them lie between the granite and the 100 isogram, rather than in the outlying areas that are favored by the other kinds of zoned pegmatites. The possible reasons for this peculiarity in the distribution of mica pegmatites go beyond the scope of this report, but whatever the reasons, the point stressed here is that anyone searching for undiscovered mica deposits should direct his efforts chiefly to the belt of pegmatites extending south from Custer and the region north and east of Custer near the edge of the granite.

Zoned pegmatites with potash feldspar as the dominant industrial mineral are more abundant than any other variety. The potash feldspar occurs either with quartz alone or with both quartz and plagioclase in intermediate zones or cores, ordinarily in the manner shown in the section through the Hot Shot pegmatite. Figure 22 shows the location of 27 of the more important deposits of this kind. A great many smaller deposits throughout the region have also been mined, for in times of economic adversity many persons in the Black Hills have mined feldspar, either independently or in partnership with others, as a short-term source of income.

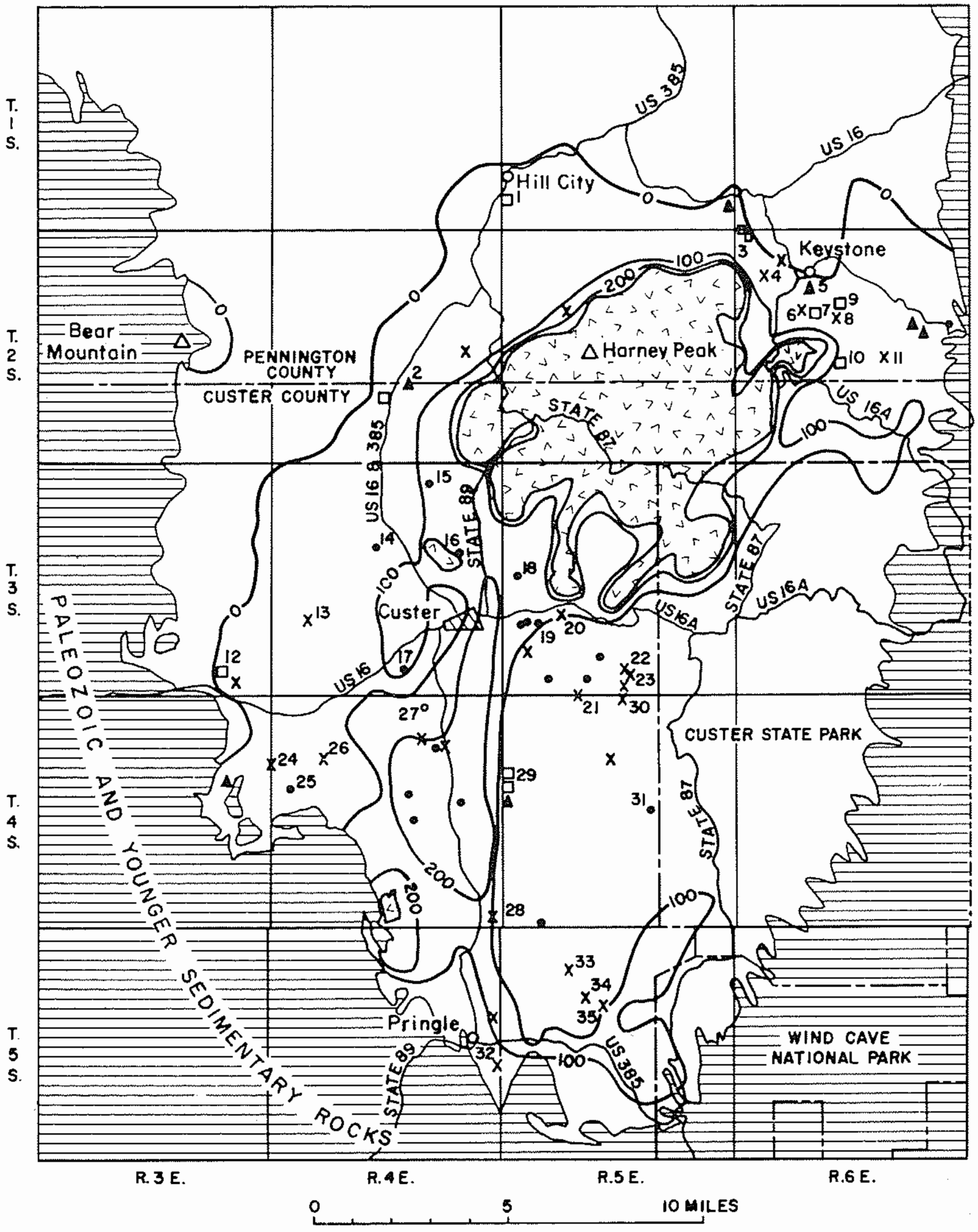


FIGURE 22.—Distribution of pegmatites in the Southern Black Hills, South Dakota. Geology by J. J. Norton and J. A. Redden (1963). Contact between Precambrian and Paleozoic rocks is modified from Darton and Paige (1925).

EXPLANATION

▨ Harney Peak Granite

☐ Metamorphic rocks

PRECAMBRIAN

~ Contact

—100— Isogram showing number of pegmatites per square mile

ZONED PEGMATITES

□ Lithium deposit

▲ Scrap mica-beryl deposit

x Potash feldspar deposit

● Sheet mica deposit

PRINCIPAL PEGMATITE MINES SHOWN ON FIGURE 22.

1. Mateen
2. High Climb
3. Bob Ingersoll
4. Dan Patch
5. Peerless
6. Hugo
7. Etta
8. White Cap
9. Edison
10. Dyke
11. Big Chief
12. Tin Mountain
13. Highland
14. Crown
15. Old Mike
16. Lost Bonanza
17. White Spar
18. Victory
19. Climax
20. Agnew
21. Bull Moose
22. Townsite
23. Hot Shot
24. Helen Beryl
25. New York
26. Tiptop
27. Buster
28. White Elephant
29. Beecher group
30. St. Louis
31. Red Deer
32. Townsite
33. Dakota Feldspar
34. Greene
35. Smith

Lithium minerals occur not only in the southern Black Hills, but also in the vicinity of Tinton in Lawrence County. The economically most important lithium mineral is spodumene, but lepidolite and amblygonite have also been mined.

The cross section of the Hot Shot pegmatite shows a small inner zone that carries spodumene. In the principal spodumene deposits of the Black Hills, a zone of this kind is very large and the outer zones are correspondingly smaller. Pegmatites having abundant spodumene tend to be on the fringes of the pegmatite region. In the Keystone and Hill City districts and at the Tin Mountain mine west of Custer, most of the spodumene pegmatites are within 1 mile of the zero isogram. The Beecher Group, which has the only other sizable spodumene deposits, is at the east edge of the pegmatite-rich region that extends south from Custer.

All the lithium pegmatites shown on the map are spodumene deposits except the Bob Ingersoll No. 1 pegmatite near Keystone, which has been an important source of lepidolite. Amblygonite has not been the principal product of any pegmatite; it occurs in pegmatites that have other lithium minerals, and also in pegmatites mined for feldspar, mica, and beryl.

The scrape mica-beryl pegmatites, shown on the map as black triangles, have many of the characteristics of the other three categories. Their truly distinctive feature is the abundance of beryl and scrap mica in an outer zone. Most of them also have inner zones that contain potash feldspar and lithium minerals. The pegmatites of this category, like those of the lithium category, occur mostly near the outskirts of the pegmatite region.

POTASH FELDSPAR

Potash feldspar mining has been a significant element in the economy of the southern Black Hills for 30 years. Nearly all feldspar is mined in open pits, and the only processing at the mine consists of handsorting. It is then trucked to the grinding plant, and from there shipped to market.

The largest operations are by the Consolidated Feldspar Department of the International Minerals & Chemical Corp. Its present grinding plant at Custer was built in 1959, replacing an earlier plant that operated from 1936 until 1958. The same corporation had a grinding plant at Keystone from 1929 to 1957. All but a small part of the potash feldspar mined in the Black Hills has been processed at these two localities.

Feldspar production (table 12) from the southern Black Hills has been relatively consistent from year to year, in contrast to the feast-or-famine pattern of other pegmatite minerals. The rate of annual output first rose above 40,000 long tons in 1937, and was between 40,000 and 75,000 tons in all but one year from 1937 through 1957. Yearly output since then has ranged from 20,900 to 45,588 long tons.

The potash feldspar or perthite mined in the Black Hills consists mostly of microcline (potassium feldspar) but also carries albite (sodium feldspar). Potash feldspar concentrates also have quartz and muscovite as impurities, but contamination by iron-bearing minerals, such as tourmaline, garnet, or biotite, is avoided.

TABLE 12.—*Feldspar production in South Dakota, 1923–63* [1]

Year	Quantity (long tons)	Value
1923 [2]	150	$600
1924–30 [3]	27,913	153,887
1931	11,062	39,013
1932	6,067	22,256
1933	3,220	12,058
1934	9,190	30,892
1935	22,099	62,498
1936	32,144	103,671
1937	41,392	158,976
1938	42,297	122,467
1939	48,328	133,893
1940	54,692	157,323
1941	59,015	170,723
1942	64,842	225,410
1943	70,913	342,643
1944	64,806	288,188
1945	68,374	314,787
1946	74,540	299,852
1947	58,959	284,378
1948	54,037	$271,000
1949	32,272	157,000
1950	43,875	249,000
1951	48,559	290,520
1952	40,163	220,954
1953	50,601	321,026
1954	44,498	281,810
1955	42,164	267,286
1956	45,000	289,000
1957	41,316	267,000
1958	23,229	145,000
1959	30,825	196,000
1960	45,588	292,000
1961	29,354	186,000
1962	29,697	191,000
1963 [4]	20,900	137,000
Total, 1923–63	1,382,081	6,685,111

[1] No production prior to 1923.
[2] Estimated.
[3] Data shown for a period of years to avoid disclosure of confidential figures.
[4] Preliminary figures.

Source: U.S. Department of the Interior, Bureau of Mines.

Potash feldspar is obtained chiefly from perthite-rich units in the upper parts of pegmatites; the cross section of the Hot Shot mine illustrates the typical arrangement. Not only must the deposit be rich enough and large enough for mining, but also the perthite crystals must be sufficiently large and free of inclusions to be concentrated by hand methods. Perthite crystals are nearly all a foot or more long and some reach dimensions measurable in tens of feet. Deposits that have been profitably mined carry at least 30 percent perthite, and commonly much more. A large deposit may contain as much as 300,000 tons of perthite. At the other extreme, many small deposits, of a few tons or a few hundreds of tons, have been mined in one- or two-man operations.

MICA

"Mica," as a commercial term in the Black Hills, applies only to the mineral more precisely known as muscovite. Commercial mica is generally divided into two categories: (1) "sheet mica," which is any mica that is cut into sheets of approximately 1 square inch or larger, and (2) "scrap mica," which is reduced by dry grinding to 16 mesh or smaller, or by wet grinding to 160 mesh or smaller.

Sheet mica has been far more important than scrap mica in the Black Hills. Most of the scrap mica has been a byproduct of mining for other pegmatite minerals. Only the Peerless mine, which has been operated nearly continuously since 1924, has been a regular and continuous source of scrap mica.

The sheet mica industry has a technical background and a body of trade practices, specifications, and customs that are far too elaborate to describe here. The best published reference is by Chand Mull Rajgarhia (1951), whose knowledge of the subject was based on a lifetime of experience in the sheet mica business in India, which supplies most of the world's mica. Excellent references written in the United States are by Skow (1962), Montague (1960), Jahns and Lancaster (1950), and Wierum and others (1938). A fully satisfactory description that applies particularly to the Black Hills deposits was written by L. R. Page and others (1953, p. 27–33).

TABLE 13.—*Production of sheet and punch mica from South Dakota, 1879–1963* [1]

Year	Quantity (pounds)	Value	Year	Quantity (pounds)	Value
1879–1912 [2]	5,000,000	$1,000,000	1945	56,570	$178,696
1913	19,225	2,206	1946	17,400	8,432
1914	27,323	1,336	1947	188,380	28,704
1915	25,992	8,230	1948	------	------
1916	115,392	49,298	1949	8,367	3,000
1917	37,523	5,975	1950	13,018	2,000
1918	(3)	(3)	1951	------	------
1919–23	------	------	1952	4,308	32,034
1924	(3)	(3)	1953	11,174	77,352
1925	1,555	207	1954	16,299	65,222
1926	(3)	(3)	1955	4,854	21,383
1927–29	------	------	1956	12,000	67,000
1930	(3)	(3)	1957	9,093	46,000
1931	(3)	(3)	1958	16,772	68,000
1932	852	149	1959	38,775	158,000
1933–38	------	------	1960	30,887	145,000
1939	(3)	(3)	1961	18,086	37,000
1940	107,062	12,509	1962	2,085	12,000
1941	298,693	37,925	1963	10,000	300
1942	399,224	75,687			
1943	333,424	447,209	Total, 1879–1963	[4] 7,067,537	[4] 3,074,160
1944	146,383	472,026			

[1] Data for 1963 are preliminary.
[2] Estimated.
[3] Confidential figure; included in total.
[4] Includes confidential figures indicated by footnote 3.

Source: U.S. Department of the Interior, Bureau of Mines.

TABLE 14.—*Scrap mica production in South Dakota, 1899–1963* [1]

Year	Quantity (short tons)	Value	Year	Quantity (short tons)	Value
1899–1912 [2]	800	$12,000	1944	2,558	$51,405
1913	591	10,403	1945	1,192	21,534
1914	515	6,138	1946	2,806	63,692
1915	179	2,684	1947	1,499	37,225
1916	527	10,472	1948	988	29,000
1917	272	5,033	1949	1,125	31,000
1918–20 [3]	519	10,138	1950	1,902	25,000
1921	92	2,290	1951	2,292	42,714
1922	(4)	(4)	1952	915	24,148
1923	324	6,480	1953	1,687	27,388
1924	458	9,267	1954	1,510	26,943
1925	996	19,220	1955	1,322	26,853
1926	835	15,907	1956	1,000	31,000
1927–31 [3]	2,208	41,589	1957	1,626	43,000
1932	------	------	1958	1,003	24,000
1933	(4)	(4)	1959	158	5,000
1934	515	6,665	1960	205	10,000
1935–39 [3]	7,691	96,872	1961	1,054	32,000
1940	2,240	32,074	1962	210	6,000
1941	1,611	27,616	1963	(4)	(4)
1942	2,545	44,579			
1943	2,234	42,764	Total, 1899–1963	[5] 52,049	[5] 1,006,619

[1] Data for 1963 are preliminary.
[2] Estimated.
[3] Data shown for the period of years to avoid disclosure of confidential figures.
[4] Confidential figures: included in total.
[5] Includes confidential figures indicated by footnote 4.

Source: U.S. Department of the Interior, Bureau of Mines.

The process of preparing sheet mica for market consists, in brief, of four steps: (1) extracting the micra crystals or "books" from the rock and cobbing away any adhering waste matter; (2) splitting or "rifting" the mica into sheets one-eighth inch or less in thickness; (3) "trimming" off cracked or otherwise imperfect material so that what remains is a nearly clear and flat sheet; and (4) classifying the mica according to the size of the sheets and their quality. The various categories of "quality" are defined chiefly on the basis of three characteristics: (1) abundance of inclusions of extraneous materials, which are called "stain"; (2) abundance of such physical imperfections as waves, buckles, or cracks; and (3) toughness and resiliency. Very small mica that is incompletely trimmed is called "punch mica"; its production is included with sheet mica in table 13.

The selling price can range greatly, from only a few cents per pound for punch or small sheet mica of low quality to many dollars for large sheets of the better qualities. In 1958 the price schedule under the U.S. Government purchase program for sheet mica of superior quality (good stained or better) ranged from $17.70 per pound for the smallest sizes to $70 per pound for large sizes. Priced in 1958 for India mica of similar quality ranged from $2.50 to $37 per pound (Montague, 1961, table 8). Lower qualities brought lower prices, but in general it has been the higher qualities that have attracted interest in South Dakota mica deposits.

Black Hills mica ranges in color from white through light brown to red in color. The greater part of it is of the kind known in the trade as "ruby mica," having a color that is some shade of red or brown. Air inclusions, or "air stain," is a prominent defect in the mica of many deposits, but other kinds of stain are uncommon in the Black Hills.

Most of the sheet mica of the Black Hills has been obtained from quartz-albite-muscovite wall zones comparable to the outer unit of the Hot Shot pegmatite. A single deposit, mined by a few men, and in some instances lasting only a few years from its discovery to its exhaustion, can yield an extraordinary amount of mica. The Victory mine, from June 1943 through December 1944, had a production of 75,459 pounds of sheet mica valued at $488,256 and 239 tons of scrap mica worth $7,693 (Page and others, 1953, p. 209). The New York mine, which was operated chiefly between 1906 and 1911, probably produced several times as much mica as the Victory. Several other deposits—notably the Crown, Buster, Old Mike, White Spar, Lost Bonanza, Climax, and Red Deer—have yielded some tens of thousands of pounds of sheet mica. Smaller producers, some profitable and some not, are too numerous to mention.

Most of the sheet mica from the Black Hills has been produced during short periods of vigorous mining activity; little or no sheet mica was produced during the intervening times. The first period of mining was from 1879 to 1884, when the Crown and the Lost Bonanza were the chief mines. The second period was from 1906 to 1911, when the Westinghouse Electric & Manufacturing Co. operated the New York, White Spar, Crown, and other mines. There were only modest increases in activity during World War I and again in the mid-1920's, and the next notable period was in World War II. Under the stimulus of a Government purchase program, $1,174,000 worth of sheet and punch mica was mined between 1942 and 1945. A new Government purchase program lasting from 1952 to 1962 maintained sheet mica mining at a modest level, but in 1963 production dropped to a value of only $300.

LITHIUM MINERALS

The Black Hills was the world's chief source of lithium minerals from 1898 until 1952. In the early 1950's, however, the nature of the world's lithium mining industry underwent a vast change. Large deposits, amenable to mechanized operations and high rates of production, were developed in North Carolina, Quebec, and Southern Rhodesia, and the greater part of the then rapidly expanding lithium market was supplied by them. In the meantime, the Black Hills deposits, which are small and operated at moderate rates of output, soon came to have only a minor role in the industry.

Three lithium minerals have been mined in the Black Hills. The chief one is spodumene, a lithium aluminum silicate that has been the principal source of lithium chemicals used by industry. Lepidolite, a lithium mica used mainly in the glass industry, has been obtained in sizable quantities from one mine. The third mineral is amblygonite, a lithium aluminum phosphate, for which there is only a sporadic market.

TABLE 15.—*Lithium minerals production in South Dakota, 1898–1963* [1]

Year	Quantity (short tons)	Value	Year	Quantity (short tons)	Value
1898–1904 [2]	1,250	$50,000	1925–29	4,510	$136,750
1905	--------	--------	1930–39	9,034	248,031
1906–09	980	15,600	1940–49	29,585	942,707
1910–14	2,153	41,080	1950–63 [3]	47,811	2,240,642
1915–19	5,679	134,770			
1920–24	5,545	115,115	Total, 1898–1963	106,547	3,924,695

[1] No production prior to 1898. Data shown for a period of years to avoid disclosure of confidential figures.
[2] Estimated.
[3] 1963 data included are preliminary figures.

Source: U.S. Department of the Interior, Bureau of Mines.

The Etta spodumene mine at Keystone was mined from 1898 until 1960, and dominated Black Hills lithium mining during nearly all this time. Other important sources of spodumene have been the Edison, Mateen, Beecher No. 2, and Tin Mountain, all in the southern Black Hills, and the Giant-Volney pegmatite at Tinton in the northwest part of the Black Hills. The spodumene of these deposits occurs, with quartz and feldspar, in large zones in the central part of the pegmatite. In some deposits—notably the Etta and Tin Mountain—the spodumene crystals are several feet long and can be readily recovered by hand-cobbing. Finer-grained spodumene requires milling techniques: in the 1940's and early 1950's, flotation mills were operated at Tinton and at the Mateen mine near Hill City, and a sink-float plant processed the ore at the Edison mine near Keystone.

The only notable lepidolite mine in the Black Hills, and one of the few in the world, is the Bob Ingersoll No. 1. The center of this pegmatite was very rich in lepidolite, most of which has been mined. About 8,000 tons of lepidolite were extracted between 1937 and 1945. (Page and others, 1953, p. 76).

Amblygonite, though it has been produced in carload lots, is best described as a byproduct of Black Hills pegmatite mining. Total production probably is slightly less than 9,000 tons. About one-fifth of this came from an amblygonite-rich zone in the inner part of the Hugo pegmatite, where crystals of tens and perhaps hundreds of tons in size have been exposed during the course of mining for feldspar, which is the chief product of this deposit. Much of the other amblygonite from the Black Hills has also been obtained from feldspar mines. All of it is recovered by hand-cobbing.

BERYL

Nearly 5,000 tons of beryl has been produced from Black Hills pegmatites. This is a sizable total by the standards of the past, for few pegmatite districts in the world have done better.

A point of overriding importance in any review of beryl resources made under the conditions existing in 1964 is that the beryllium industry seems to be on the threshold of a major change. In the past, beryllium has been used mainly in high cost beryllium copper alloy, which has many specialized applications. The only source of beryllium has been hand-cobbed beryl from pegmatites. Maximum consumption in a single year by the United States, which is by far the greatest user, has been 9,692 tons of beryl in 1960 (U.S. Bur. Mines Minerals Yearbook). The light weight and other properties of beryllium, however, make it attractive for many potential uses, possibly in much larger quantities than heretofore. Nonpegmatitic deposits that are large enough to satisfy a greatly expanded demand, and at the same time are adapted to mechanized mining and concentrating, have been discovered in several parts of the world during recent years. The long-term future of beryllium mining appears to lie with such deposits.

TABLE 16.—*Beryl production in South Dakota, 1914–63* [1]

Year	Quantity (short tons)	Value	Year	Quantity (short tons)	Value
1914–38 [2]	520	$23,600	1952	334	$166,251
1939	84	2,390	1953	392	157,656
1940	74	2,064	1954	337	139,663
1941	151	7,067	1955	294	157,046
1942	205	18,148	1956	195	95,000
1943	238	28,843	1957	268	145,000
1944	305	44,565	1958	240	129,000
1945	38	5,776	1959	156	84,000
1946	95	17,422	1960	167	88,000
1947	70	11,762	1961	238	130,000
1948	43	8,000	1962	144	77,000
1949	139	40,000	1963	----------	----------
1950	96	30,000			
1951	138	46,007	Total, 1914–63	4,964	1,654,260

[1] No production prior to 1914.
[2] Estimated.

Source: U.S. Department of the Interior, Bureau of Mines.

Currently, however, the market continues to be supplied by hand-cobbed beryl from pegmatites. The output from the Black Hills was generally between 100 and 350 tons each year from 1949 through 1962. A U.S. Government buying program, in which an average of about $500 per ton was paid to encourage domestic mining of beryl, maintained production at a high level from 1952 to 1962. The return to the price level of conventional markets, which was about two-thirds the Government price, was the chief reason why no Black Hills beryl was marketed in 1963.

Nearly every zoned pegmatite in the Black Hills has at least a few crystals of beryl, and probably at least a dozen pegmatites have yielded more than 100 tons of beryl. The three highest ranking producers are the Peerless, Ingersoll, and Beecher No. 3 mines, which together have yielded nearly one-third of the Black Hills beryl.

Much of the beryl comes from the so-called scrap mica-beryl pegmatites of figure 22. In these the beryl is in mica-rich outer zones, mostly as crystals 1 inch to 1 foot in diameter. Several such units contain more than 0.5 percent beryl, but a content of more than 2 percent beryl is generally confined to small shoots.

In other kinds of pegmatites the beryl is mainly in inner zones, sometimes as gigantic crystals weighing many tons. It is abundant in many zones containing lithium minerals and also along the margins of quartz cores. In addition, it occurs in potash feldspar zones.

Beryl is commonly obtained as a byproduct or coproduct with other minerals. Beryl was produced even at prices of less than $30 per ton in some years prior to 1941, for it was recovered in the course of mining for scrap mica, feldspar, or lithium minerals. In other instances, deeply buried beryl-bearing units may be exposed, but not mined, when other minerals are mined; the recovery of the beryl may be at a later time, perhaps by another operator and oftentimes only after an increase in the price. In the occasional efforts to develop milling techniques for the recovery of beryl, the coproducts obtainable with it are an important consideration. Few, if any, bodies of rock large enough to support a milling operation are rich enough in beryl for sustained profitable operation unless other products can be sold.

OTHER PEGMATITE MINERALS

Black Hills pegmatites have been the source of several other mineral products. Tin, which has been mined in small quantities from several pegmatites, is the subject of a separate section of this report. Tantalum and columbium have been minor byproducts. Probably about half the recorded production of 187,862 pounds of tantalite-columbite came from Tinton, and the rest was from the southern Black Hills (table 17). Rose quartz, which is valued for decorative purposes, is obtained mainly from the Rose Quartz mine southeast of Custer, but also from several other pegmatites. Gemstone varieties of such minerals as beryl, spodumene, and tourmaline are sparse in Black Hills pegmatites, but specimens attractive to mineral collectors and to tourists are collected and sold by several mineral dealers.

TABLE 17.—*Columbium and tantalum concentrate production in South Dakota, 1905–63* [1]

Year	Quantity (pounds)	Value	Year	Quantity (pounds)	Value
1905–9 [2]	2, 000	$1, 000	1939	(3)	(3)
1910–17	-----	-----	1940–41	-----	-----
1918	4, 500	2, 250	1942	200	$175
1919	300	90	1943	872	1, 354
1920	4. 000	1, 450	1944	(3)	(3)
1921	3, 400	1, 150	1945	85	(3)
1922	600	240	1946	1, 702	3, 246
1923	1, 350	540	1947	-----	-----
1924	1, 197	598	1948	500	(3)
1925	-----	-----	1949–50	-----	-----
1926	2, 100	650	1951	(3)	(3)
1927	1, 100	378	1952	(3)	(3)
1928	34, 899	26, 332	1953	4, 431	9, 022
1929	22, 117	17, 261	1954	25, 447	43, 260
1930	4, 100	(3)	1955	5, 638	9, 584
1931	(3)	(3)	1956	237	403
1932–33	-----	-----	1957	2, 311	6, 000
1934	425	168	1958	4, 294	10, 000
1935	7, 681	4, 521	1959–63	-----	-----
1936	-----	-----			
1937	13, 376	11, 307	Total, 1905–1963	[4] 187, 862	[4] 196, 853
1938	33, 922	33, 406			

[1] Data for 1963 are preliminary.
[2] Estimated.
[3] Confidential figure; included in total.
[4] Includes confidential figures as indicated by footnote 3.

Source: U.S. Department of the Interior, Bureau of Mines.

RELATION OF THE GEOLOGY OF THE DEPOSITS TO THE ECONOMICS OF MINING AND MARKETING

Two characteristics of pegmatities are important in appraising the feasibility of a mining operation. One is the segregation into zones, which determines what parts of a pegmatite will be mined. The other is the size of crystals, which determines whether or not they can be hand-cobbed.

These and other characteristics of pegmatites can also have more far-reaching influence. In recent years the mining of zoned pegmatites, always a small industry, has lost rather than gained ground in its competitive standing. The efficiency achievable in large-scale mining, in the use of heavy equipment, in large mills, and in large-scale marketing of products have given rise to a trend toward bigness in most segments of the mining industry. Such small bodies as zoned pegmatites have not participated in this trend. Their chief merit lies in the benefits of selective small-scale mining confined to a single zone, to take fullest advantage of the enrichment of that zone. This is an effective way to obtain such specialized products as high quality potash feldspar and sheet mica. The small capital requirements enable single individuals or partnerships to enter pegmatite mining, though they may lack the resources to enter most other parts of the mining field. Small business units of this kind have been an important element in the economy of the southern Black Hills.

Mining operations of this sort are frequently shifted from one deposit to another. The reason may be that the first deposit has become mined out and a new one must be found. Or it may be that market fluctuations force a change to a different commodity, found in another deposit. Whatever the causes, small-scale mining in pegmatites has had, as its least wanted characteristic, a large measure of instability.

In the search for a way of enlarging the size and increasing the efficiency and stability of mining in zoned pegmatites, the method that has been most successfully pursued is to carry on mining at many small mines and to do the milling or other processing at one or two central locations. This is essentially what the Consolidated Feldspar Corp. has done in feldspar for 30 years, and it is what the Westinghouse Corp. did in the sheet mica business from 1906 to 1911.

Another method, often discussed but rarely applied successfully for any length of time, is to mine a pegmatite or group of pegmatites for all the economic products. The objective is not to direct attention mainly at a single mineral, such as feldspar or sheet mica, but to attempt to obtain all products at once. Some of the larger Black Hills pegmatites contain many economically valuable minerals, and there is obvious appeal to a proposal that a mining and milling operation be designed to recover such a wide assortment of products and byproducts as feldspar, sheet and scrap mica, beryl, lithium minerals, tantalite, cassiterite, high-purity silica, and crushed rock.

Probably the chief reasons this has not been done lie in the difficulty of marketing numerous products that go into widely diverse trade channels. Feldspar is used mainly in ceramics and glass, lithium minerals go to chemical markets, sheet mica to the electrical industry, scrap mica to roofing materials and paint, beryl mainly to beryllium copper, and so on. The minerals are present in a pegmatite in a fixed ratio, and the market demand for them has no direct relation to this ratio. Furthermore, selling most pegmatite minerals is quite unlike selling metals or farm commodities for which there are relatively simple specifications and recognized central markets with regular quotations of prices at which anyone can buy or sell. Mica and feldspar, in particular, have a wide variety of specifications, and the seller must adapt his products to the needs of an individual buyer or a small group of buyers. The capacity to hold a strong position in such markets and the flexibility to react to the fluctuations of these separate markets are difficult to maintain.

Pegmatite mine operators generally meet these problems by directing their efforts toward a single mineral at a time when its market is most advantageous. With a change in market conditions, they change to another mineral, perhaps in a different zone of the same pegmatite or perhaps in an entirely different pegmatite.

All this is not to say that the only feasible approach to pegmatite mining in the Black Hills is to mine a single commodity from a single zone of a pegmatite. The efficiencies and stability of larger operations are real advantages, and in the future they may prove vital to the existence of a pegmatite mining industry in the southern Black Hills. The chief needs of an enterprise for the mass mining of pegmatite are to take fullest advantage of the varying mineral content of a single pegmatite or of several pegmatites, and to have the flexibility to vary the output of the different industrial minerals as the market fluctuates. By drawing from a wide variety of pegmatites, this, at least theoretically, would be possible.

RESERVES AND RESOURCES

The resources of all pegmatite minerals in the Black Hills are large enough to support at least as much mining in the future as has been done in the past. Deposits as rich and easily accessible as the well-exposed deposits opened up in the early years of the district are, of course, now very difficult to find. Nevertheless, the great abundance of zoned pegmatites in the southern Black Hills leaves little doubt that additional ones can be found. How intensive the search will be may depend more on economic incentives than on whether or not the deposits exist.

The word "reserves," in the strictest sense, applies only to rock that can be profitably mined and for which the grade, tonnage, and location have been ascertained. The chief reason for making a reserve estimate is to be sure that a deposit is large enough to enable the operator to recover his capital and obtain a suitable profit. The process of making a detailed reserve estimate is expensive, and inasmuch as mines in zoned pegmatites are small and require little capital, it is ordinarily not done by pegmatite mine operators.

Broader estimates of the resources of the district have, however, been made from time to time. A feldspar or lithium company that plans to draw raw material from many deposits makes such estimates when planning its operation. Similarly, the Federal Government's purchase programs for mica and beryl were started partly on the basis of estimates of the potential of this district.

The most comprehensive resource estimates have been made for beryl. Table 18, summarizing data from 26 of the larger deposits, shows a total of 17,400 tons of beryl in deposits in which the grade exceeds 0.2 percent beryl and the amount of contained beryl is more than 100 tons. Probably the 3,500 tons of beryl in deposits having more than 1.0 percent beryl more accurately reflects the resources of material that could be profitably mined under recent conditions. Most such deposits either can be mined for beryl alone or they contain other marketable products that help pay the costs. Where the grade is in the 0.2 to 1.0 percent bracket, the beryl is a byproduct and the output of other minerals controls the rate at which beryl is obtained.

TABLE 18.—*Resources in deposits containing more than 100 tons of beryl*

	Keystone district	Hill City district	Custer district	Total
Number of deposits	10	2	14	26
Deposits that contain 1.0 percent or more beryl:				
Tons of rock	250,000	10,000	30,000	290,000
Tons of beryl	3,000	100	400	3,500
Deposits that contain 0.2 to 1.0 percent beryl:				
Tons of rock	[1] 2,100,000	50,000	2,000,000	4,150,000
Tons of beryl	6,300	100	7,500	13,900
Total tons of beryl	9,300	200	7,900	17,400

[1] Includes 380,000 tons of dumps.

The table does not take into account deposits containing less than 100 tons of beryl, for even though such deposits do yield beryl, they can have little influence on the resource figures. The reason is most easily explained by some arithmetic: an estimate of 50 deposits containing, say, an average of 30 tons of beryl probably is not too large for the Black Hills; these would contain 1,500 tons of beryl, which would increase the resource figures less than 10 percent. Nevertheless, in times of high prices, such deposits do contribute noticeably to the production of the region, and their existence takes on a greater short-term importance than the resource figures imply.

The lithium resources of the Black Hills were the object of detailed geologic study in the latter part of World War II, during a period of emergency demand for lithium. Additional contributions to knowledge of the lithium deposits came in the late 1940's and early 1950's, when the Lithium Corp. of America and other companies were especially active in this region. Most of the exploration and mining was for spodumene, which is concentrated in a few large deposits. Amblygonite is more widely distributed, but it too is abundant in only a few pegmatites. The resource figures in table 19 apply only to spodumene and amblygonite deposits that contain more than 0.4 percent Li_2O. No sizable lepidolite resources are known.

TABLE 19.—*Resources of Li_2O in spodumene and amblygonite in deposits containing more than 0.4 percent Li_2O*

	Keystone district	Custer district	Hill City and Tinton districts	Totals
Number of deposits	7	5	3	15
Spodumene deposits:				
Tons of rock	500,000	1,200,000	400,000	2,100,000
Average grade, in percent Li_2O	0.8	0.9	1.1	------------
Tons of Li_2O	4,000	11,000	4,500	19,500
Amblygonite deposits:				
Tons of rock	120,000	150,000	0	270,000
Average grade, in percent Li_2O	0.4	0.7	0	------------
Tons of Li_2O	500	1,000	0	1,500
Total tons Li_2O	4,500	12,000	4,500	21,000

At the cut-off grade of 0.4 percent Li_2O, the total estimated resources are 21,000 tons of Li_2O. Only deposits that contain more than 1.0 percent Li_2O can ordinarily be mined for lithium alone; in deposits of lower grade, the lithium minerals can be extracted only as a byproduct. Black Hills deposits having a grade exceeding 1.0 percent carry at least 12,000 tons of Li_2O.

Sheet mica resources are more difficult to ascertain than are the resources of beryl or lithium, and the available data are less satisfactory. The bulk of sheet mica production comes from rich deposits that are small and hard to find, and once found are rapidly mined until exhausted, or at least until they are believed to be exhausted. A measure of the concentration of sheet mica in a few deposits can be obtained from production figures for 1943–45, which was the most active period of mica mining in World War II. During this time about 190,000 pounds of sheet mica was produced and about 70 deposits were active enough to be called mines; yet 116,000 pounds of sheet mica, or 61 percent of the total, came from only three deposits, the Victory, Buster, and White Spar (Page and others, 1953, p. 88, 206 and 217; and U.S. Bur. Mines Minerals Yearbooks). The Victory was discovered in 1943, and the Buster in 1942; even the White Spar, though it had been mined early in the century, was for all practical purposes a new discovery when it was reopened in 1942.

An evaluation of the sheet mica resources depends more on estimates of the potential for finding important new deposits than on estimates of the resources in known deposits. The argument can be offered that the intensive search of recent years has uncovered the most promising deposits. Yet despite a longer and more intensive period of mica mining in comparable areas in the Southeastern States, new deposits have been found even in very recent years. There was a large element of good fortune in the discovery of the Buster and the Victory deposits; both were concealed beneath the surface, and either one of them could have remained undiscovered to the present day. At least a few other deposits of the same size surely still exist in the Black Hills. It is likely that the resources of mica, like those of both lithium and beryl, are at least as great as past production.

In turning from sheet mica, beryl, and lithium minerals to a resource evaluation of scrap mica and potash feldspar, one enters a field with quite different problems. For scrap mica and potash feldspar are normal rock-forming minerals that are found, in greater or less quantities, in nearly all Black Hills pegmatites. They can in no way be described as "rare minerals," as the others are so commonly called.

The richest deposits mined for scrap mica are in zones that carry 20 to 30 percent muscovite. Additional scrap mica is obtained as a byproduct of sheet mica and feldspar mines, where the mica content may be much lower. At the Peerless mine, which has produced a large share of the scrap mica from the Black Hills, the mica is a coproduct with beryl. Scrap mica depends, in fact, so much on other pegmatite minerals that a quantitative evaluation of its resources, standing separately from the other minerals, would be misleading. Probably all that should be said is that scrap mica output in the future is likely to hold the same relation to other pegmatite minerals that it has had in the past.

Potash feldspar deposits range from very rich zones containing as much as 75 percent potash feldspar, through lower grade but still minable deposits that generally have 30 to 50 percent potash feldspar, to the great mass of unzoned pegmatites and Harney Peak granite, which contain an average of about 20 percent potash feldspar. The richer deposits yield more product per ton of rock mined, and they tend to have large crystals that are relatively free of impurities, and thus are better adapted to hand-cobbing methods. Nevertheless, the difference between a good deposit and a poor one is entirely gradational. Many of the lower grade deposits are of large size, which itself is an advantage because large-scale mining brings lower costs per ton of rock. Another point of prime importance is distance from the mill, for trucking costs are a large part of the total cost. The direct test of a feldspar mine is the cost per ton of feldspar delivered to the mill, and this test incorporates many variables besides the strictly geologic ones.

The resources in deposits containing 30 to 50 percent potash feldspar probably more than equal past production. Higher grade but undiscovered deposits may also exist in concealed inner parts of some pegmatites. The search for these is not likely to be vigorous, for potash feldspar is of too low value to encourage subsurface exploration or to support underground mining.

In recent years the feldspar mining industry of the United States has turned very strongly toward mining large deposits and concentrating the feldspar in flotation mills. Approximately two-thirds of domestic feldspar is now obtained in this way, chiefly from North Carolina. Such operations also yield byproduct quartz and scrap mica. Some of the larger deposits in the Black Hills have geologic characteristics suitable for such operations, but shipping costs over the long distances to major markets put them at a competitive disadvantage with the deposits of other feldspar-producing areas.

FUTURE OUTLOOK

The Black Hills pegmatite area has experienced many vicissitudes in the past, and will surely experience them in the future. Sheet mica is the most extreme example, for the demand for Black Hills mica has sometimes been so great that it could not be fully met, and at other times the demand has, for all practical purposes, been nonexistent. On the other hand, potash feldspar has held a fairly steady, though now declining, market for three decades.

To one who must assess the future outlook, the magnitude of the resources must be ranked first among the various considerations, for without resources there can be no future production. The existing data from Black Hills pegmatite leaves no real doubt that the resources are adequate to yield at least as much production in the future as in the past.

Questions about the conditions of the future, which surely will differ from the conditions of the past, are harder to answer than are simple inquiries about resources. Trends in the methods and costs of exploration, mining, and processing are hard to predict. These will change as the richer and more easily found deposits are exhausted, and their places taken by other deposits, probably of lower average grade. The likelihood of major changes in markets over a long period of years and the possibility of other economic changes introduce even greater uncertainties.

The competitive position of Black Hills pegmatite mining is now being eroded by several economic developments that arise from outside sources. These, for the most part, are beyond the scope of this report, but some have been mentioned on the foregoing pages. The lithium mining industry, which surely is the most striking example, was long dominated by the Black Hills, yet during its great expansion in recent years it has become centered at large mines with enormous reserves in North Carolina, Quebec, and Southern Rhodesia. Beryl mining may be entering a similar phase; for when the beryllium market expands to a point at which large nonpegmatitic deposits, such as those at Spor Mountain, Utah, go into production, they may be expected to take over much of the market.

The more prosaic minerals, feldspar and mica, are subject to changes of a different nature. Sheet mica is losing some of its uses to various substitutes, but its total consumption remains fairly stable. Hand-cobbed potash feldspar, on the other hand, is losing ground to flotation feldspar. The total U.S. feldspar production was 498,057 long tons in 1957 and 492,476 long tons in 1962; the production of hand-cobbed feldspar went from 227,826 long tons in 1957 to 113,168 long tons in

1962, thus giving up about half its market to the flotation product (U.S. Bur. Mines Minerals Yearbooks). The chief advantage of the hand-cobbed feldspar is that it contains much less sodium feldspar than does the flotation product. The feldspar industry of the Black Hills currently depends on hand-cobbed material processed at a centralized grinding plant serving many small mines. Whether a flotation mill and larger mines will ultimately be established depends more on economic factors than on the geology of the deposits.

These trends, whatever their long-run importance, are of indirect rather than direct concern to a pegmatite mine operator. The conventional pegmatite mine of the Black Hills is a small operation sending products to somewhat specialized markets—hand-cobbed feldspar, sheet mica, beryl, amblygonite, rose quartz, and so on. The nature of such operations is likely to be much the same in the future as in the past.

GYPSUM AND ANHYDRITE

(By E. J. Cox, South Dakota State Geological Survey, Belle Fouche, S. Dak., and C. G. Bowles, U.S. Geological Survey, Denver, Colo.)

Gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$), the hydrous and anhydrous forms of calcium sulfate, respectively, are formed by evaporation of sea water and less commonly by evaporation of lake water. Calcium sulfate beds, which are usually anhydrite where deeply buried, are generally hydrated to gypsum in the presence of near surface ground-water circulation. Gypsum deposits are mined primarily for the manufacture of plaster and plaster products (wall board, lath, sheathing, and tile, etc.), but in addition, large quantities of gypsum are used as a retarder in portland cement and as an agricultural mineral. About 2 percent of the total production of calcium sulfate in the United States comes from the mining of anhydrite for use in cement and as an agricultural mineral.

Selective mining of gypsum rather than anhydrite reflects the lower cost of manufacturing plaster from gypsum rock. The preparation of plaster requires crushing and calcining, i.e., the conversion of gypsum to hemihydrate ($CaSO_4 \cdot \frac{1}{2}H_2O$) by heating to 170° C. (338° F.) (Withington and Jaster, 1960) in order to drive off three-fourths the water of crystallization. When water is added to the plaster, the hemihydrate becomes a rigid interlocking network of gypsum crystals, suitable for use as a construction material. Anhydrite can be used in the manufacture of plaster only after it is hydrated to gypsum, an additional step that increases the costs of processing.

The United States leads the world in production of gypsum. In 1962 about 9,969,000 tons of gypsum, about one-fourth of the world production, was mined in the United States (Kuster and Mallory, 1963). That same year 23,000 tons of gypsum, representing less than 0.2 percent of the U.S. production, were mined in South Dakota for use in cement. Total production of gypsum in South Dakota from 1884 to 1963 was 553,548 tons, with a value of $2,531,134 (W. H. Kerns, written communication, 1964). More than one-fourth of the total production of gypsum in South Dakota has been mined in the past 8 years.

TABLE 20.—*Gypsum production in South Dakota, 1884–1963*[1]

Years	Quantity (short tons)	Value	Years	Quantity (short tons)	Value
1884–1955	409,548	$1,941,134	1961	22,000	$89,000
1956	16,000	63,000	1962	23,000	93,000
1957	13,000	53,000	1963	19,000	76,000
1958	12,000	49,000			
1959	19,000	78,000	Total 1884-1963	553,548	2,531,134
1960	20,000	89,000			

[1] Data for 1963 are preliminary.

Source: U.S. Department of the Interior, Bureau of Mines.

Gypsum was one of the first nonmetallic minerals to be utilized in the Black Hills, where, since 1884 (So. Dak. State Planning Board, 1936, p. 50), it has been mined from rocks that were assigned by Darton (1901) to the Spearfish Formation. It is not known whether some gypsum was mined from beds now considered to be part of the Gypsum Spring Formation of Jurassic age (Imlay, 1947). Available records show that nine plants have processed gypsum in the Black Hills. In addition to the six processing plants listed below and located on figure 23, other early small producers operated at Sturgis, Whitewood, and Hot Springs. The U.S. Gypsum Co. was the most persistent processor of gypsum. Their plant at Piedmont was closed in 1948. Since 1948, the only gypsum being produced is that which is mined by the State cement plant at Rapid City for use as a retarding agent in the manufacture of Portland cement.

Plant location	Name of plant	Operating dates
1 Hot Springs	Hot Springs Gypsum Co	1911–12(?)
2 Hot Springs	Hot Springs Plaster Co. (purchased by U.S. Gypsum Co. in 1907)	1893–1909
3 Rapid City	Black Hills Gypsum Co. (purchased by U.S. Gypsum Co. in 1908)	1907–15
4 Blackhawk	Dakota Plaster Co. (purchased by U.S. Gypsum Co. in 1930)	1910–30
5 Piedmont	U.S. Gypsum Co	1917–48
6 Spearfish	Pettigrew Stucco Co	1898–1912

Throughout most of western South Dakota anhydrite beds of Mississippian to Jurassic age are abundant in the subsurface, but in the Black Hills these beds are generally missing from the outcrops as a result of solution by circulating ground water. Only in the Spearfish Formation of Permian and Triassic age and the Gypsum Spring Formation of Jurassic age do gypsum beds persistently crop out.

The Madison Group of formations of Mississippian age contain anhydrite beds in the subsurface throughout the northwest corner of the State and as far east as west-central South Dakota, but in the Black Hills the beds do not crop out in the Pahasapa Limestone, a partial equivalent of the Madison Group. The Kibbey Sandstone of Late Mississippian age also contains anhydrite beds in the subsurface in the extreme northwest corner of the state. Outside the Black Hills rocks of Mississippian age are present at depths ranging from 2,500 feet in Stanley County to 7,500 feet in Perkins County. Total aggregate thickness of anhydrite in these rocks ranges from 150 to 190 feet in eastern Harding County and western Perkins County, and individual beds are 25 to 30 feet thick (R. P. Sheldon, oral communication, 1964).

The Minnelusa Formation of Pennsylvanian and Permian age contains an aggregate thickness of as much as 250 feet of anhydrite in the subsurface of western South Dakota (Bowles and Braddock, 1963), but only in Hell Canyon in the southern Black Hills (Braddock, 1963) and in the Sundance-Beulah area of Wyoming (Brady, 1958) do gypsum beds crop out. Beds of Pennsylvanian age in the Minnelusa contain nearly 100 feet of anhydrite in the subsurface at the east margin of the Powder River basin, and beds of Permian age contain as much as 200 feet of anhydrite. The thickest individual beds of anhydrite measuring 25 to 30 feet are present in the upper part of the formation. The eastern limit of the area underlain by anhydrite beds of the Minnelusa lies between 100° and 101° west longitude (fig. 23).

The Opeche Formation of Permian age contains beds of anhydrite in the subsurface and beds of gypsum crop out locally in Hell Canyon and elsewhere in the Black Hills. Beds are generally less than 10 feet thick.

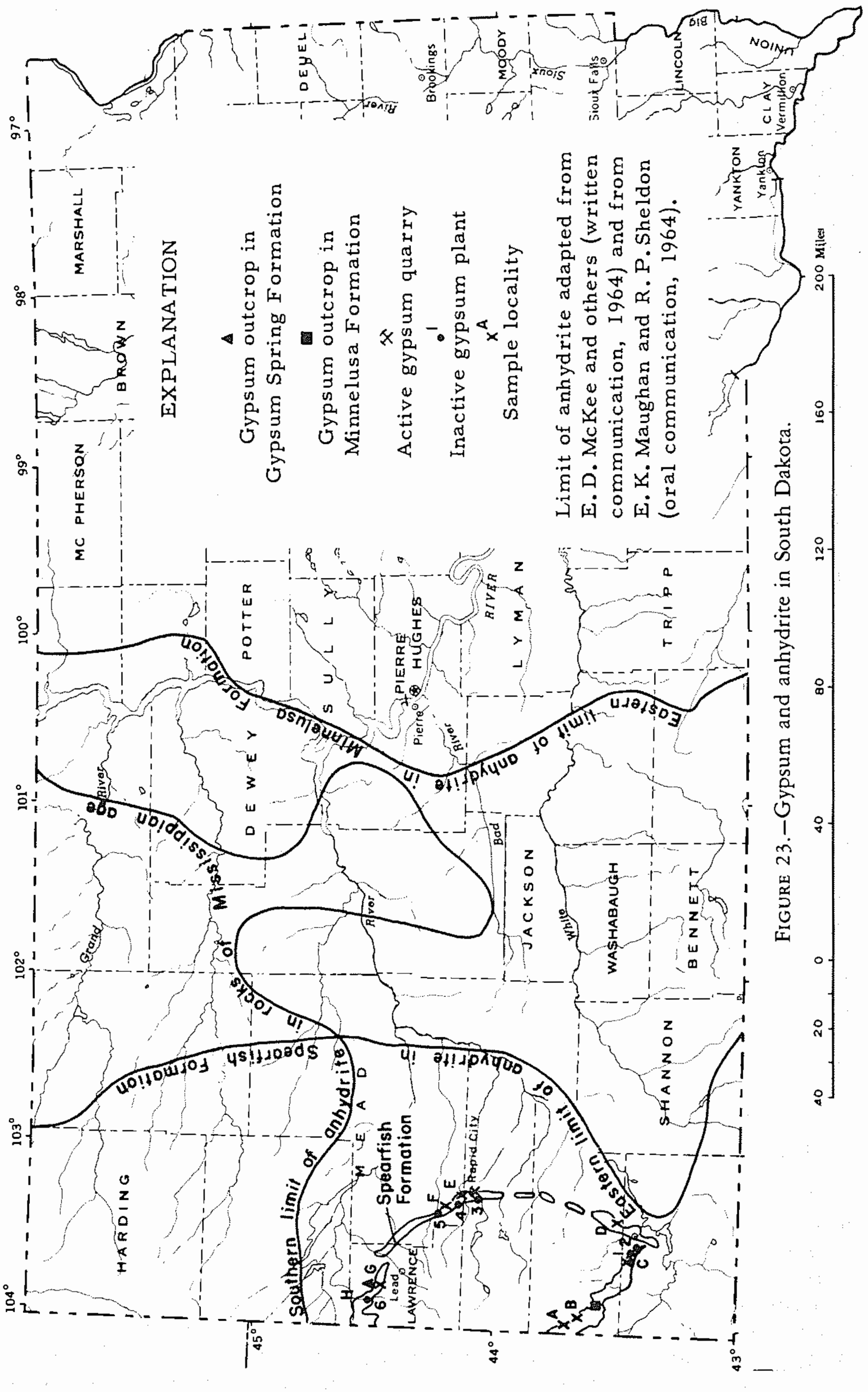
The Spearfish Formation of Permian and Triassic age contains anhydrite beds intercalated in a 350- to 700-foot-thick section of red shales and siltstones. The formation encircles the Black Hills in an outcrop measuring as much as 3 miles across. Gypsum beds which are mined at the outcrop extend down dip and grade into anhydrite beds that underlie the plains as far east as 102°15′ longitude (fig. 23).

Gypsum beds in the outcrop of the Spearfish Formation are restricted almost entirely to rocks of Permian age in the lower 200 to 250 feet of the formation. A bed of gypsum 10 feet thick is present locally at the base of the Spearfish in an area 20 miles northwest of Edgemont (Braddock, 1963). The lowermost persistent bed of gypsum is 75 to 100 feet above the base of the formation. This bed is as much as 25 feet thick in the Hot Springs area (Darton and Smith 1904). The bed thickens to about 40 feet in an area 7 miles northeast of Hot Springs, but is commonly 6 feet thick along the eastern flank of the Black Hills (Kulick, 1961, unpublished manuscript, p. 29). A gypsum bed 170 feet above the base of the formation (Gott and Schnabel, 1963) is present throughout the southern Black Hills. This bed, measuring 30 to 50 feet in thickness, marks the top of the Permian System in the Black Hills. A 5- to 10-foot bed of gypsum is present in rocks of Triassic age, 25 to 50 feet above the main gypsiferous unit of the Spearfish.

In the northern Black Hills an "upper gypsum" bed near the top of Spearfish Formation of Darton is now considered to be in the Gypsum Spring Formation of Jurassic age (Imlay, 1947).

The Gypsum Spring Formation contains beds of gypsum in outcrop in the Black Hills and in the subsurface in the northwest corner of the State. A massive 25- to 30-foot-thick ledge of white gypsum is reported in the formation 1 mile northeast of Spearfish (Mapel and Bergendahl, 1956). This bed that was described by Darton (1925) in sections in the northern Black Hills thins and wedges out southward and is not recognized south of Rapid City.

Preliminary field examinations indicate that the Spearfish and Gypsum Spring Formations contain large reserves of gypsum that are adaptable to exploitation by surface mining. Samples from localities located in figure 23 were analyzed to indicate the quality of the gypsum (Darton and Paige, 1925; Ehle, 1911; Connolly and O'Harra, 1929). These analyses expressed in percent are given in table 21.



Limit of anhydrite adapted from E. D. McKee and others (written communication, 1964) and from E. K. Maughan and R. P. Sheldon (oral communication, 1964).

FIGURE 23.—Gypsum and anhydrite in South Dakota.

TABLE 21.—*Analyses of gypsum from South Dakota*

Location	H_2O	SiO_2	Fe_2O_3 Al_2O_3	CO_2	SO_3	MgO	CaO	$MgCO_3$	NaCl	Total
A	16.67	6.44	1.20	4.69	38.63	2.30	30.09	--------	0.04	100.06
B	19.94	.10	.36	.80	46.30	.15	32.29	--------	.19	100.13
C	19.49	.20	.30	1.30	45.63	.30	32.29	--------	--------	99.91
C	20.80	.10	.12	.85	45.45	.33	32.44	--------	--------	100.09
C	20.85	.12	.13	--------	45.77	.10	33.00	--------	--------	99.97
C	21.41	.09	.06	--------	44.86	.28	32.89	--------	--------	99.59
D	19.29	.28	.52	1.52	45.41	.32	32.72	--------	--------	100.06
E	20.48	.16	.12	--------	44.59	--------	32.27	0.58	--------	98.20
E	15.44	.32	.32	2.70	46.36	.33	34.37	--------	--------	100.20
E	18.44	.36	.30	2.23	45.28	.51	33.06	--------	.03	100.21
F	21.65	.10	.12	--------	45.45	.33	32.44	--------	--------	100.09
G	19.82	.44	.26	.56	46.10	.17	33.04	--------	--------	100.39
H	19.35	.80	.40	1.50	45.25	.37	32.70	--------	--------	100.37

NOTE.—A commercial grade of gypsum, which must be 90 to 98 percent pure gypsum (Withington and Jaster, 1960), was indicated by all analyses except that taken at location A.

The total resources of gypsum and anhydrite in western South Dakota are very large, but only in the Black Hills does gypsum crop out. Large reserves of commercial grade gypsum, with very little overburden, exist in the Spearfish and Gypsum Spring Formations in the Black Hills. If a gypsum processing plant were established in the Black Hills, it would meet strong competition from existing plants. Plants presently producing prefabricated gypsum products are located at Heath, Mont., Cody, Wyo., Florence, Colo., Blue Rapids, Kans., and Fort Dodge, Iowa. Plants which produce only calcined material but do not prefabricate are located at Fort Collins, Colo., and Medicine Lodge, Kans.

A southern Black Hills processing plant could competitively deliver prefabricated material to 900,000 people (So. Dak. University Director, Business Research Bureau, 1961, written communication), but only two-thirds of this population could be competitively supplied with calcined material that was not prefabricated. Based on the national consumption (Kuster and Jensen, 1962, p. 629–642) of gypsum products used per capita, these 900,000 people would use about 35,000 tons of finished product per year.

SALT AND BRINE

(By C. G. Bowles, U.S. Geological Survey, Denver, Colo.)

Salt or halite (NaCl) from evaporation of brines was used chiefly for domestic purposes during the colonization and settling of the United States, but with industrialization new uses have absorbed the major and ever increasing portion of salt production. By 1959, domestic consumption of salt had fallen far behind industrial and governmental consumption. Uses of salt for the manufacture of chlorine and soda ash ($NaCO_3$) consumed 69 percent of all salt production in the United States during 1959. Other uses of salt for (1) snow and ice removal from roads, (2) manufacture of textiles, dyes, soap (including detergents), and all other chemicals, (3) livestock, and (4) meat packing and tanning (MacMillan and Foley, 1960) also exceeded domestic consumption.

Sodium sulfate salts are also produced in the United States from natural deposits in addition to byproduct production from manufacturing processes. Sodium sulfate is used principally in the manufacture of glass, detergents, stock feeds, dyes, textiles, and medicines. Salt deposits have also been an important source of potash and borate salts, in addition to brines rich in calcium, magnesium, boron, lithium, and bromine.

Caverns dissolved out of thick beds of halite have been used for underground storage of gas and petroleum products (Matheny and Billue, 1950) as well as for production of salt. Application of this storage technique to the disposal of radioactive wastes has been studied (May, Schnepfe, and Naeser, 1961), but as yet no wastes are stored in salt solution caverns.

The United States ranks first in the world production and consumption of salt. In 1959, the United States produced about 25 million tons of salt (NaCl) compared to the total world production of 88,900,000 tons (MacMillan and Foley, 1960). Not included in the above production figures is the annual production of 300,000 tons of sodium sulfate of which about 120,000 tons are produced from natural deposits of the salts thenardite and mirabilite.

Salt deposits or brines exist in the majority of states (Lang, 1957), but no production is recorded for South Dakota. However, in 1878 minor amounts of salt were produced from a spring in Wyoming near the South Dakota-Wyoming line. Brine from this spring in Salt Creek north of Newcastle, Wyoming, was evaporated over wood fires until the salt precipitated (Connolly and O'Harra, 1929). This method of salt production no longer is used in the United States. Salt lakes in northwestern North Dakota contain large deposits of sodium sulfate which were mined as late as 1951 (Hainer, 1956). Similar deposits are present in Montana and some may be present in South Dakota.

Bedded salt deposits are formed by the evaporation of brines of marine or continental origin. Marine salt deposits are formed by precipitation of soluable minerals in lagoons, bays, or ther shallow coastal areas where circulation of sea water is restricted and exaporation exceeds recharge from the ocean, rivers, and streams. The brine is concentrated until saturation is reached, and evaporites are precipitated in the order of increasing solubility; first, calcium sulfates; secondly, sodium chlorides; and finally bittern potassium and magnesium chlorides. Salt deposits of continental origin are formed in shallow lakes and playas in internal drainage basins. These deposits commonly differ in composition from deposits of marine origin because soluble minerals which comprise continental deposits are limited to elements leached from nearby rocks and soils. Evaporites deposited on the plains of the north-central United States contain sodium sulfates and sodium carbonates.

Beds of halite are present in rocks of Permian and Triassic age in the subsurface of northwestern South Dakota (fig. 24). Halite beds are present in the Opeche Formation of Permian age and the lower part of the Spearfish Formation of Permian and Triassic age. Beds in the Opeche are thin in this area and probably are of little economic value. In the Spearfish Formation a maximum aggregate thickness of 125 feet of halite has been drilled at depths ranging from

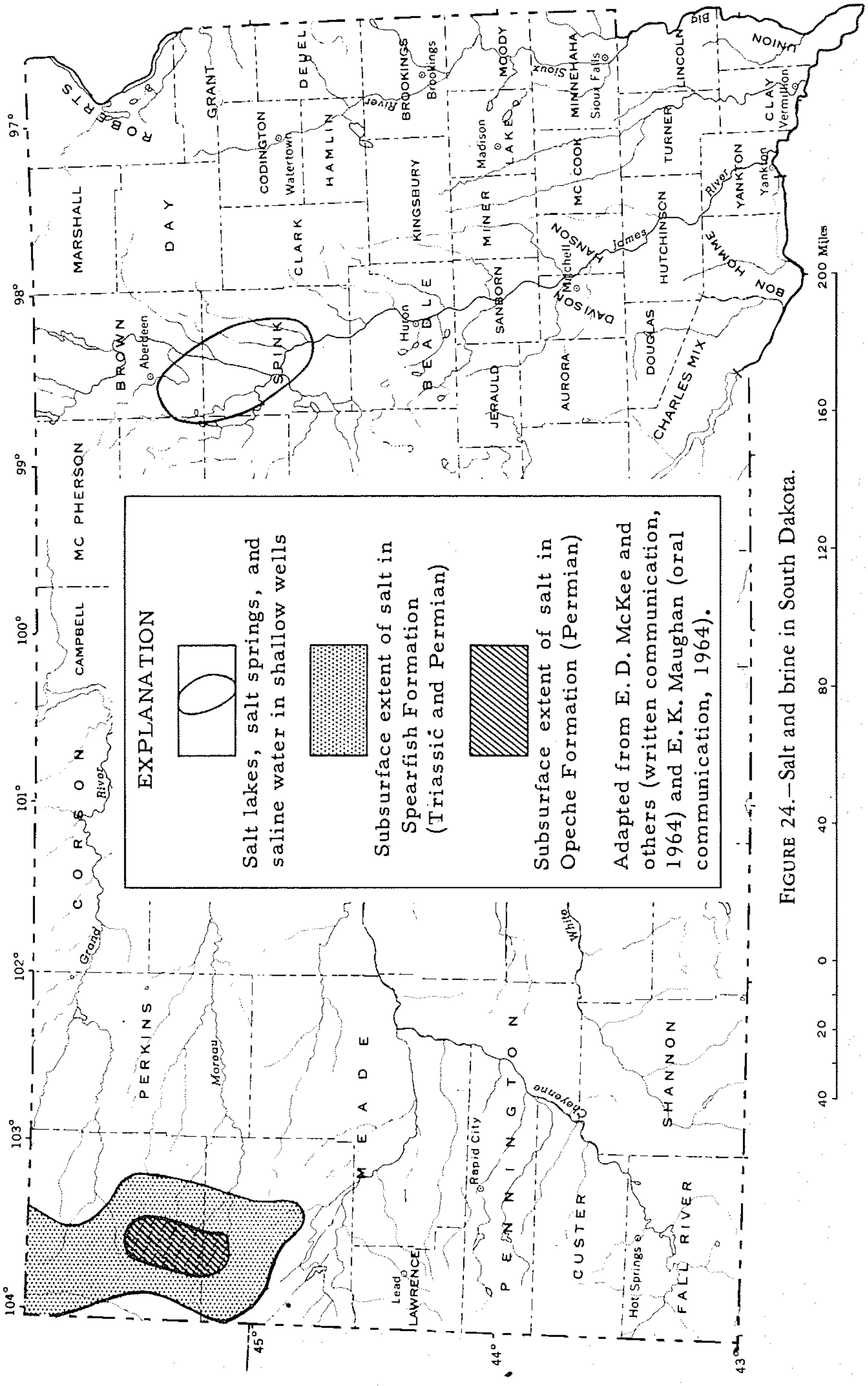


FIGURE 24.—Salt and brine in South Dakota.

4,500 to 6,000 feet. Within these rocks, informally termed the Pine salt by Zieglar (1955), individual beds attain a thickness of 45 feet. These beds range greatly in thickness where erosion and local solution of salt has occurred prior to deposition of sediments of Jurassic age.

Halite is present in eastern South Dakota in glacial till of Pleistocene age and in the underlying Pierre Shale of Cretaceous age. Todd (1909) reports that near Northville patches and encrustations of halite are found in draws, ravines, and shallow basins. Waters from many shallow wells and some lakes in this area contain calcium, magnesium, iron, sodium sulfate, and sodium carbonate and were reported by Todd (1909) to be too saline for ordinary uses. The extent and maximum concentration of the brine in these waters are relatively unknown. The occurrences of salt and brine appear to be similar to those found in the Smoke Creek-Medicine Lake-Grenora area of Montana and North Dakota where deposits of sodium sulfate are present (Witkind, 1959).

The salt resources of western South Dakota might be developed by a joint program involving solution mining of halite and the construction of underground caverns for storage of radioactive wastes or petroleum products. Salt is now being mined by solution at a depth of 8,500 feet near Williston, N. Dak. (Mullen, 1962). Halite beds of the Spearfish Formation are at shallower depth in northwest South Dakota and might be considered for future mining. Sandberg (1962) has suggested that halite beds of the Pine salt of the Spearfish Formation might be used for the disposal of radioactive wastes. The low permeability of the enclosing redbeds would be advantageous in the control of any slight leakage of wastes from the storage chambers.

Additional investigation of the salt lakes area in eastern South Dakota is necessary before the economic potential of this area for halite or other salts or brine can be evaluated.

GEM STONES AND GEM MATERIALS

(By W. L. Roberts and George Rapp, Jr., South Dakota School of Mines and Technology, Rapid City, S. Dak.)

A wide variety of minerals and rocks have been mined during the recorded history of man as gems and semiprecious stones. Artisans have fashioned these materials into many forms. The demand for semiprecious stones, particularly, is subject to wide fluctuation. Much of the production of semiprecious stones is due to the efforts of amateur hobbyists and other part-time collectors. Thus it is difficult to obtain any figures on the amount of raw material produced or even the variety of minerals sought as objects for the gem and rock polishing trade.

The economic importance of semiprecious stones in South Dakota seems to be rising slowly as increasing numbers of collectors journey to the Black Hills region in search of gem minerals. It is estimated that during 1963 in excess of about $20,000 worth of gem raw material was produced in South Dakota. The value of the finished product would be considerably more. Table 22 gives production values for gem and precious stones from South Dakota, 1906–63.

TABLE 22.—*Gem and precious stone production in South Dakota, 1906–63* [1]

	Value		*Value*
1906–52 [2]	$75, 000	1959	$20, 000
1953	5, 000	1960	20, 000
1954	5, 000	1961	18, 000
1955	7, 400	1962	20, 000
1956	10, 000	1963	20, 000
1957	15, 000		
1958	16, 000	Total 1906–63	231, 400

[1] Data for 1963 are preliminary.
[2] Estimated.

Source: U.S. Department of the Interior, Bureau of Mines.

Occurrences of gem material in South Dakota are geologically of three types. The most important is in pegmatites, a granitic rock composed of large crystals of feldspar and a number of other, commonly rare, minerals. A second type is in sedimentary rocks where circulating ground water has deposited secondary silica in various forms. At places, broken fragments of the silica are concentrated in stream gravels. A third and minor mode of occurrence is in the metamorphic rocks of the Black Hills.

These varieties are discussed by Pearl (1948, p. 120, 211, 219, and 223) and Ziegler (1914) gives descriptions of these gemstones. Hartwell (1960, p. 331) gives a list of localities where gem materials have been found in South Dakota.

Several pegmatite minerals are recovered for their value as semiprecious stones. Rose quartz is mined at the Scott Rose mine, which is the largest producer, and material has also been recovered from the Wiley, White Elephant, and Big Chief pegmatites. Hiddenite, a variety of spodumene, is in great demand for faceting; colorless triphane, another variety, is also faceted. Green, pink, and white spodumene have all been marketed. Cats-eye material is in demand for cabochons. Major producers have been the Helen Beryl (chatoyant specimens), Etta and Tin Mountain mines. Specimens of beryl free from flaws and up to three carats in weight are found, and a few hundred carats a year are produced from the Duncan Wonder, Ross, and Helen Beryl mines. Perthite, a red variety of microcline, is mined near Pringle, South Dakota, for tumbling into baroques. Minor amounts of green tourmaline (from the Ingersoll pegmatite) and amethyst are also recovered from time to time.

With the exception of barite, all of the gem material found in the sedimentary rocks is some form of silica. Chief among those sought are varieties of agate. Four varieties are well known for their occurrence in South Dakota: Fairburn, from Pleistocene gravels southeast of the Black Hills; Tepee Canyon, from the Minnelusa Formation; Park, from the Minnelusa Formation; and Black, from the Chadron Formation.

Petrified wood, including fossil cycads, is recovered at several localities. Jasper is found in Pleistocene deposits. Two varieties of chalcedony, blue chalcedony and plume chalcedony, are recovered from Tertiary formations.

Golden barite has gained in popularity since it was first faceted in 1951. It is found at several localities east and southeast of the Black Hills. Production has been sporadic but has reached $2,000 per year.

In the early 1900's gem almandine garnet was mined from placer deposits near Custer, S. Dak., and sold locally.

As yet unexploited is an occurrence of a gem andalusite from metamorphic rocks of the Black Hills. The occurrence is the only one in the United States.

Nearly all the gem materials come from Pennington and Custer Counties and the adjacent area extending to the east of the southern Black Hills. Isolated occurrences are known of petrified wood and cycads at Lemmon and of agate along the Missouri Valley but these occurrences do not constitute a significant part of the known resources.

Resources of gem materials cannot be precisely stated. Production of some materials could certainly be expanded; however, most of the mining is done by hobbyists and part-time collectors instead of commercial firms; hence it is difficult to determine the amount of raw material produced or the quality of the material sought.

SELECTED REFERENCES

NONMETALLIC AND INDUSTRIAL MINERAL RESOURCES

[Unpublished theses are included in this list, although they are not readily available]

Bagan, R. J., 1950, The stratigraphy and insoluble residues of the Minnekahta limestone: South Dakota School Mines and Tech., unpub. B.S. thesis, 28 p., 2 graphs.

Bieniewski, C. L., 1964, Mineral production in South Dakota in 1963: U.S. Bur. Mines Mineral Industry Surveys, Jan. 2, 1964.

Bieniewski, C. L., and Agnew, A. F., 1963, The mineral industry of South Dakota: U.S. Bur. Mines Minerals Yearbook 1962, v. 3, p. 957–975.

Bowles, C. G., and Braddock, W. A., 1963, Solution breccias of the Minnelusa Formation in the Black Hills, South Dakota and Wyoming, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 475–C, p. C91–C95.

Braddock, W. A., 1963, Geology of the Jewel Cave S.W. quadrangle, Custer County, South Dakota: U.S. Geol. Survey Bull. 1063–G, p. 217–268.

Brady, F. H., 1958, Evaporite deposits in the Minnelusa Formation in the Sundance-Beulah area, Crook County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 13th Ann. Field Conf., 1958: p. 45–47.

Bryson, R. P., Fox, E. L., Larrabee, D. M., Weeks, R. A., and Fischer, E. C., 1947, Map showing construction materials and nonmetallic mineral resources of South Dakota: U.S. Geol. Survey Missouri Basin Studies No. 12.

Cameron, E. N., Jahns, R. H., McNair, A. H., and Page, L. R., 1949, Internal structure of granitic pegmatites: Econ. Geology Mon. 2, 115 p.

Cole, W. A., and Zetterstrom, J. D., 1954, Investigation of lightweight aggregates in North and South Dakota: U.S. Bur. Mines Rept. Inv. 5065, 43 p.

Connolly, J. P., and O'Harra, C. C., 1929, The mineral wealth of the Black Hills: South Dakota School Mines Bull. 16, 418 p.

Connor, J. J., 1963, Geology of the Angostura Reservoir quadrangle, Fall River County, South Dakota: U.S. Geol. Survey Bull. 1063–D, 126 p.

D'Amico, K. J., 1962, Statistical summary of mineral production: U.S. Bur. Mines Minerals Yearbook 1961, v. 3, p. 1–48.

Darton, N. H., 1901, Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming: U.S. Geol. Survey 21st Ann. Rept., pt. 4, p. 516–519, 584–585.

Darton, N. H., and Paige, Sidney, 1925, Central Black Hills [South Dakota]: U.S. Geol. Survey Geol. Atlas, Folio 219.

Darton, N. H., and Smith, W. S. T., 1904, Edgemont quadrangle [S. Dak.-Nebr.]: U.S. Geol. Survey Geol. Folio 108, 10 p.

Ehle, C. G., 1911, Gypsum deposits and the stucco industry in the Black Hills: South Dakota School Mines and Technology, unpub. thesis.

Ellis, M. J., 1960, Use of chemical analysis for correlation of carbonate rocks: South Dakota School Mines and Technology, unpub. M.S. thesis, 103 p.

Fisher, D. J., 1942, Preliminary report on some pegmatities of the Custer district: South Dakota Geol. Survey Geol. Survey Rept. Inv. 44, 35 p.

Fisher, D. J., 1945, Preliminary report on the mineralogy of some pegmatities near Custer: South Dakota Geol. Survey Rept. Inv. 50, 92 p.

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U.S. Geol. Survey Prof. Paper 262, 173 p.

Georgia Geological Survey, 1963, Notes on industrial minerals and ores: Georgia Geol. Survey Mineral Newsletter, v. 16, nos. 1–2, 54 p.

Gill, J. R., and Cobban, W. A., 1961, Stratigraphy of lower and middle parts of the Pierre Shale, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D185–D191.

Gott, G. B., and Schnabel, R. W., 1963, Geology of the Edgemont NE quadrangle, Fall River and Custer Counties, South Dakota: U.S. Geol. Survey Bull. 1063–E, p. 127–190.

Gries, J. P., 1942, Economic possibilities of the Pierre Shale: South Dakota Geol. Survey Rept. Inv. 43, 79 p.

——— 1952, Paleozoic stratigraphy of western South Dakota: Billings Geol. Soc. Guidebook 3d Ann. Field Conf., p. 70–72.

Grim, R. E., 1953, Clay mineralogy: New York, McGraw-Hill, 384 p.

——— 1962, Applied clay mineralogy: New York, McGraw-Hill, 422 p.

Guiteras, J. R., 1940, Mining of feldspar and associated minerals in the southern Black Hills of South Dakota: U.S. Bur. Mines Inf. Circ. 7112, 104 p.

Hainer, J. L., 1956, The geology of North Dakota: North Dakota Geol. Survey Bull. 31, 46 p.

Hartwell, J. W., 1960, Gem stones, *in* Mineral facts and problems: U.S. Bur. Mines Bull. 585, p. 325–340.

Hosterman, J. W., Scheid, V. E., Allen, V. T., and Sohn, I. G., 1960, Investigation of some clay deposits in Washington and Idaho: U.S. Geol. Survey Bull. 1091, 147 p.

Imlay, R. W., 1947, Marine Jurassic of Black Hills area, South Dakota and Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 2, p. 227–273.

Jahns, R. H., and Lancaster, F. W., 1950, Physical characteristics of commercial sheet muscovite in the southeastern United States: U.S. Geol. Survey Prof. Paper 225, 110 p.

Kesler, T. L., 1963, Environment and origin of the Cretaceous kaolin deposits of Georgia and South Carolina: Georgia Geol. Survey Mineral Newsletter, v. 16, nos. 1–2, p. 3–11.

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. 893–1030.

Kulik, J. W., 1961, The limestone and gypsum deposits of the Black Hills of South Dakota: South Dakota School of Mines and Technology, unpub. ms. p. 29–47.

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 Mallory, J. B., 1963, Gypsum: U.S. Bur. Mines Minerals Yearbook 1962, v. 1, p. 633–648.

Lang, W. B., 1957, Annotated bibliography and index map of salt deposits in United States: U.S. Geol. Survey Bull. 1019–J, p. 715–753.

Larrabee, D. M., 1946, Preliminary map showing sand and gravel deposits of South Dakota: U.S. Geol. Survey Missouri Basin Studies, No. 4.

Lee, K. Y., Petsch, B. C., Rothrock, E. P., and Agnew, A. F., 1961, Mineral investigations map 1: South Dakota Geol. Survey.

Lincoln, F. C., 1930, Quarrying limestone in the Black Hills of South Dakota: Rock Products, v. 32, no. 11, p. 42–47.

MacMillan, R. T., and Foley, J. M., 1960, Salt: U.S. Bur. Mines Minerals Yearbook 1959, v. 1, p. 901–913.

Mapel, W. J., and Bergendahl, M. H., 1956, Gypsum Spring Formation Black Hills, Wyoming and South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 1, p. 84–93.

Matheny, W. F., and Billue, G. H., 1950, Underground storage tanks: Chem. Eng., v. 57, no. 12, p. 115.

May, Irving, Schnepfe, Marian, and Naeser, C. R., 1961, Interaction of anhydrite with solutions of strontium and cesium, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, D336–D338.

Miller, R. H., 1959, Mineral resources of South Dakota: South Dakota Indus. Devel. Expansion Agency, Pierre, S. Dak., 96 p.

Montague, S. A., 1960, Mica, *in* Industrial minerals and rocks, 3d. ed.: Am. Inst. Mining Metall. Petroleum Engineers, p. 551–566.

Mullen, D. H., 1962, The mineral industry of North Dakota: U.S. Bur. Mines Minerals Yearbook 1961, p. 779–792.

Murray, H. H., 1960, Clays, *in* Industrial minerals and rocks, 3d ed.: Am. Inst. Mining Metall. Petroleum Engineers, p. 259–284.

Needham, A. B., 1950, Investigation of mica deposits at the White Bear, Silver Dollar, Buster Dike, and Hot Shot mines, Custer County, South Dakota: U.S. Bur. Mines Rept. Inv. 4693, 54 p.

Norton, J. J., Griffitts, W. R., and Wilmarth, V. R., 1958, Geology and resources of beryllium in the United States, *in* United Nations, Survey of raw material resources: Internat. Conf. Peaceful Uses Atomic Energy, 2d., Geneva, 1958, Proc., v. 2, p. 21–34.

Norton, J. J., and Page, L. R., 1956, Methods used to determine grade and reserves of pegmatites: Mining Engineering, v. 8, p. 401–414.

Norton, J. J., and others, 1964, Geology and mineral deposits of some pegmatites in the southern Black Hills, South Dakota: U.S. Geol. Survey Prof. Paper 297–E, p. 293–341.

Norton, J. J., Page, L. R., and Brobst, D. A., 1962, Geology of the Hugo pegmatite, Keystone, South Dakota: U.S. Geol. Survey Prof. Paper 297–B, p. 49–127.

Norton, J. J., and Schlegel, D. M., 1955, Lithium resources of North America: U.S. Geol. Survey Bull. 1027–G, p. 325–350.

O'Harra, C. C., and others, 1908, Cement resources of the Black Hills: South Dakota School Mines, Bull. 8, 55 p.

Page, L. R., and others, 1953, Pegmatite investigations 1942–1945, Black Hills, South Dakota: U.S. Geol. Survey Prof. Paper 247, 229 p.

Pearl, R. M., 1948, Gems from South Dakota, *in* Popular Gemology: Denver Sage Books, p. 120, 211, 219, and 223.

Petsch, B. C., 1948, A geophysical study of the Milbank Granite area: South Dakota Geol. Survey Rept. Inv. 60, 22 p.

Rajgarhia, Chand Mull, 1951, Mining, processing, and uses of Indian mica: New York, McGraw-Hill Book Co., Inc.

Redden, J. A., 1959, Beryl deposits of the Beecher No. 3–Black Diamond pegmatite, Custer County, South Dakota: U.S. Geol. Survey Bull. 1072–I, p. 537–559.

——— 1963a, Diamond-drilling exploration of the Beecher No. 3–Black Diamond pegmatite, Custer County, South Dakota: U.S. Geol. Survey Bull. 1162–E, p. E1–E11.

Redden, J. A., 1963b, Geology and pegmatites of the Fourmile quadrangle, Black Hills, South Dakota: U.S. Geol. Survey Prof. Paper 297–D, p. 199–291.

Ries, Heinrich, 1898, The fuller's earth of South Dakota: Am. Inst. Min. Eng., Trans., v. 27, p. 333–335.

Rothrock, E. P., 1934, The geology of Grant County: South Dakota Geol. Survey Rept. Inv. 20, 48 p., 7 figs.

——— 1944, A geology of South Dakota, Pt. 3, Mineral Resources: South Dakota Geol. Survey Bull. 15, 255 p., 13 figs. 39 pl.

Sandberg, C. A., 1962, Geology of the Williston Basin, North Dakota, with reference to subsurface disposal of radioactive wastes: U.S. Geol. Survey Rept. TEI–809, open-file report, 148 p.

Schreck, A. E., 1961, Lithium, a materials survey: U.S. Bur. Mines Inf. Circ. 8053, 80 p.

Schultz, L. G., 1961, Preliminary report on the geology and mineralogy of clays on the Pine Ridge Indian Reservation [with a chapter on usability tests by H. P. Hamlin, U.S. Bur. Mines]: U.S. Geol. Survey open-file rept. 629, 60 p., map, fig., table.

Schultz, L. G., and Mapel, W. J., 1961, Clays in the Inyan Kara Group (Cretaceous) Black Hills, Wyoming and South Dakota, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C172–C174.

Sheridan, D. M., 1955, Geology of the High Climb pegmatite, Custer County, South Dakota: U.S. Geol. Survey Bull. 1015–C, p. 59–98.

Sheridan, D. M., Stephens, H. G., Staatz, M. H., and Norton, J. J., 1957, Geology and beryl deposits of the Peerless pegmatite, Pennington County, South Dakota: U.S. Geol. Survey Prof. Paper 297–A, p. 1–47.

Skow, M. L., 1962, Mica, a materials survey: U.S. Bur. Mines Inf. Circ. 8125, 240 p.

Smith, W. C., and Page, L. R., 1941, Tin-bearing pegmatites of the Tinton district, Lawrence County, South Dakota: U.S. Geol. Survey Bull. 922–T, p. 595–630.

South Dakota State Cement Commission, [no date], Report of the South Dakota State Cement Commission to the Thirty-Second Session of the Legislative Assembly of the State of South Dakota : 81 p.

South Dakota State Planning Board, 1936a, Tin deposits in South Dakota: Brookings, S. Dak., 35 p.

——— [no date], Portland cement, gypsum, and lime industries in South Dakota—a preliminary report of the Mineral Resources Committee: 71 p.

——— 1936b, Portland cement, gypsum, and lime industries in South Dakota: Brookings, S. Dak., p. 37–53.

——— 1937, Pegmatite mining in South Dakota: Brookings, S. Dak., 80 p.

Spivey, R. C., 1940, Bentonite in southwestern South Dakota: South Dakota Geol. Survey Rept. Inv. 36, 56 p., maps.

Staatz, M. H., Page, L. R., Norton, J. J., and Wilmarth, V. R., 1963, Exploration for beryllium at the Helen Beryl, Elkhorn, and Tin Mountain pegmatites, Custer County, South Dakota: U.S. Geol. Prof. Paper 297–C, p. 129–197.

Stephens, E. C., 1960, Eastern Washington-Idaho clay basin: Am. Inst. Min. and Metall. Eng. Trans., v. 217, p. 405–412.

Sterrett, D. B., 1923, Mica deposits of the United States: U.S. Geol. Survey Bull. 740, 342 p.

Todd, J. E., 1909, Description of Aberdeen-Redfield district, South Dakota: U.S. Geol. Survey Geol. Atlas, folio 165, 9 p.

Tourtelot, H. A., 1962, Preliminary investigations of the geologic setting and chemical composition of the Pierre Shale, Great Plains region: U.S. Geol. Survey Prof. Paper 390, 74 p.

U.S. Bureau of Mines, 1960, Mineral facts and problems: U.S. Bur. Mines Bull. 585, 1015 p.

Wierum, H. F., and others, 1938, The mica industry: U.S. Tariff Comm. Rept. 130, 2d ser.

Withington, C. F., and Jaster, M. C., 1960, Selected annotated bibliography of gypsum and anhydrite in the United States and Puerto Rico: U.S. Geol. Survey Bull. 1105, 126 p.

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.

Zetterstrom, J. D., and Cole, W. A., 1956, Expansion of clays and shales from North and South Dakota in a rotary kiln: U.S. Bur. Mines Rept. Inv. 5202, 13 p.

Zieglar, D. L., 1955, Pre-Piper post-Minnekahta "red beds" in the Williston Basin: *in* North Dakota Geol. Soc., Guidebook South Dakota Black Hills [3d] Field Conf., Sept. 1955; p. 49–55.

Ziegler, Victor, 1914, The Minerals of the Black Hills: South Dakota School Mines Bull. 10, 250 p.

MINERAL FUEL RESOURCES

COAL

(By E. R. Landis, U.S. Geological Survey, Denver, Colo.)

INTRODUCTION

A large area in northwestern South Dakota is underlain by rocks that contain lignite. In the southwestern part of the State small quantities of bituminous coal are present. Both the lignite and the bituminous coal have been mined to a very limited extent in the past, and almost all of the coal has been utilized for domestic heating within relatively short distances of its point of origin. Though the amount of bituminous coal in the State is small, the lignite of northwestern South Dakota constitutes a resource of considerable magnitude and potential value.

GEOLOGIC SETTING

The coal-bearing rocks of South Dakota are of Cretaceous and Tertiary age. Bituminous coal is reported to be present in the Lakota Formation of Early Cretaceous age at scattered places in the southern part of the State, but known resources were delineated only in Fall River County where the coal was mined in the past. A total of about 11 thousand tons of bituminous coal is estimated to have originally been present. The bituminous coal is not discussed further in this report because it is quantitatively insignificant compared to the lignite.

The lignite of the northwestern part of the State is in the Hell Creek Formation of latest Cretaceous age and in the Fort Union Formation of earliest Tertiary age. The Hell Creek Formation underlies most of the northwestern quarter of the State and contains lignite through much of this area. Lignite from the Hell Creek is at present mined in the Isabel-Firesteel field of Dewey and Ziebach Counties, and was formerly mined in central Corson, northern Meade, southern Perkins, and eastern and northern Harding Counties.

The Fort Union Formation in South Dakota comprises the Ludlow, Cannonball, and Tongue River Members, in ascending order. The Ludlow and Tongue River are nonmarine and coal bearing. The marine Cannonball Member does not contain coal. It interfingers with the Ludlow and is present only in the northern parts of Harding, Perkins and Corson Counties. The Ludlow Member "is the most prolific lignite-bearing rock unit in South Dakota" (Brown, 1952, p. 12), and is present over a considerable part of the lignite area of South Dakota. The Tongue River Member is poorly represented in South Dakota and is present only in the northern parts of Harding and Perkins Counties. It contains coal beds as much as 9 feet thick in northern Perkins County. However, the total amount of coal in the Tongue River in South Dakota is small compared to the amount in the Ludlow and Hell Creek because of the small area in which the unit is present.

PRODUCTION

Earliest recorded lignite production in South Dakota is for the year 1913, but lignite had been mined by ranchers and settlers for many years prior to that date. Total recorded production to January 1, 1964, is about 1,357,000 tons, which had a total value of about $3,223,000 (table 23). The peak production year was 1941 when about 70,000 tons were mined. Brown (1952, p. 17) suggests that production has a tendency to decrease in prosperous times and to increase during periods of depression.

TABLE 23.—*Coal production in South Dakota, 1895–1963* [1]

Year	Quantity (short tons)	Value	Year	Quantity (short tons)	Value
1895–1912	[2] 95, 200	[2] $192, 400	1939	49, 495	$69, 000
1913	10, 540	20, 648	1940	66, 085	88, 000
1914	11, 850	20, 456	1941	70, 825	108, 000
1915	10, 593	16, 384	1942	53, 538	104, 000
1916	8, 886	18, 021	1943	40, 664	78, 000
1917	8, 042	23, 346	1944	26, 827	55, 000
1918	7, 942	22, 230	1945	24, 445	53, 000
1919	14, 417	45, 707	1946	16, 946	36, 362
1920	12, 777	46, 000	1947	14, 618	35, 727
1921	7, 553	21, 200	1948	29, 000	86, 000
1922	7, 752	22, 000	1949	26, 000	92, 000
1923	10, 379	25, 000	1950	[2] 27, 000	[2] 95, 000
1924	12, 043	36, 000	1951	28, 350	99, 008
1925	14, 447	42, 000	1952	[2] 25, 000	[2] 60, 000
1926	14, 428	42, 000	1953	23, 671	82, 117
1927	12, 507	38, 000	1954	[2] 20, 000	[2] 70, 000
1928	13, 929	39, 000	1955	25, 782	90, 240
1929	12, 854	38, 000	1956	25, 000	90, 000
1930	12, 810	31, 000	1957	21, 000	79, 000
1931	27, 485	64, 000	1958	20, 000	78, 000
1932	49, 074	87, 000	1959	22, 000	88, 000
1933	59, 375	104, 000	1960	20, 000	83, 000
1934	42, 407	76, 000	1961	18, 000	75, 000
1935	13, 243	21, 000	1962	18, 000	77, 000
1936	41, 331	55, 000	1963	18, 000	77, 000
1937	46, 979	63, 000			
1938	48, 058	65, 000	Total, 1895–1963	1, 357, 000	3, 223, 000

[1] Data for 1963 are preliminary.
[2] Estimated figures.

Source: U.S. Department of the Interior, Bureau of Mines.

MINING

Most of the lignite produced in South Dakota has probably come from strip mines. Strip mining is more economical and more productive than underground mining in areas like South Dakota where the coal beds are overlain by a relatively thin overburden composed of soft rocks. At present, and for some time past, all recorded production has come from one or two strip mines in Dewey and Corson Counties. Though there may be some small underground mines active periodically, the amount of coal produced from them is usually too small to be recorded.

UTILIZATION

Most of the lignite mined in South Dakota, past and present, is used locally for domestic heating. In other Northern Great Plains States lignite is extensively used for electric power generation. Lignite lends itself to processes such as carbonization and gasification, and a great variety of organic chemical substances can be derived from it (U.S. Bureau of Mines, 1954 and 1963).

Uranium-bearing lignite, impure lignite, and lignitic shale are present locally in northwestern South Dakota (Vine, 1962, p. 127, 130, and 132). These beds are in the Ludlow Member in the northern Slim Buttes area, and in the Tongue River Member in northwestern Perkins County, and are discussed in the uranium section of this report.

KNOWN RESOURCES

Known coal resources can be defined as that part of the total amount in the ground (the total resource) that has been determined to be present by mapping and exploration. The original known resources of South Dakota were estimated by Brown (1952), using the standard methods in use by the U.S. Geological Survey (Averitt, 1961, p. 14–22), for a State total of 2,032.91 million short tons in 6 counties (table 24 and fig. 25).

TABLE 24.—*Original known resources of lignite in South Dakota, by counties*

[In millions of short tons]

County	Measured				Indicated			
	In beds 2½ to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2½ to 5 feet thick	Inbeds 5 to 10 feet thick	In beds more than 10 feet thick	Total
Corson					0.54	0.02		0.56
Dewey	104.42	33.68		138.10				
Harding					843.40	628.12	51.49	1,523.01
Meade					1.38			1.38
Perkins					141.85	44.66		186.51
Ziebach					5.31	.69		6.00
State total	104.42	33.68		138.10	992.48	673.49	51.49	1,717.46

County	Inferred				Total in all categories			County total
	In beds 2½ to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	Total	In beds 2½ to 5 feet thick	In beds 5 to 10 feet thick	In beds more than 10 feet thick	
Corson					0.54	0.02		0.56
Dewey					104.42	33.68		138.10
Harding	177.29	0.06		177.35	1,020.69	628.18	51.49	1,700.36
Meade					1.38			1.38
Perkins					141.85	44.66		186.51
Ziebach					5.31	.69		6.00
State total	177.29	0.06		177.35	1,274.19	707.23	51.49	2,032.91

The resources determined by mapping and exploration are classified by the standard reliability of information categories—measured, indicated, and inferred—and by the standard (for lignite and subbituminous coal) thickness categories of 2½ to 5 feet, 5 to 10 feet, and more than 10 feet. Overburden thickness categories were not used because all of the known coal in South Dakota is less than 1,000 feet below the surface (Brown, 1952, p. 7).

Sixty-three percent of the known resources of South Dakota are in the thin category and only 3 percent are in the thick category. Because the lignite of South Dakota normally occurs in very lenticular

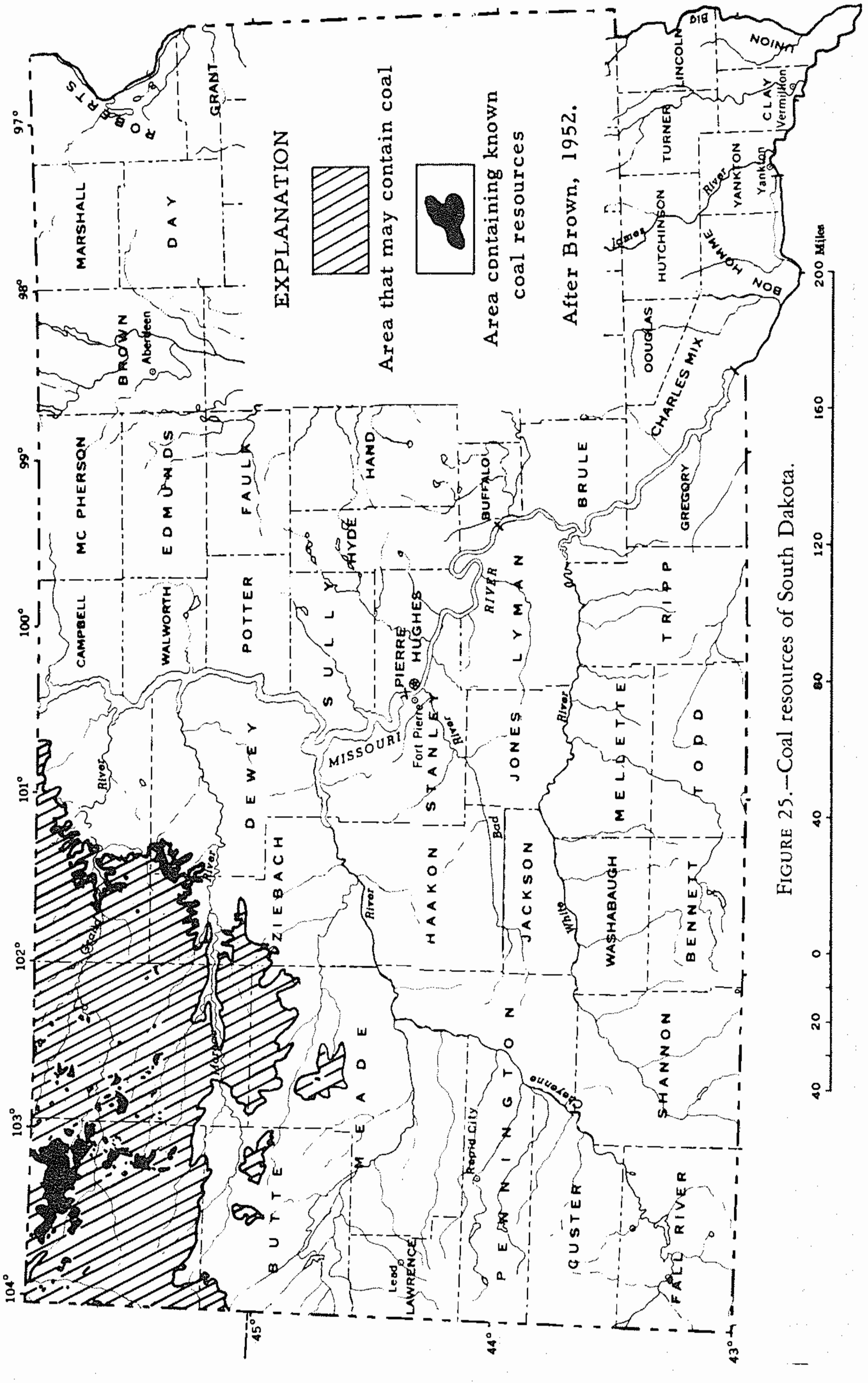


FIGURE 25.—Coal resources of South Dakota.

beds and because information points were widely spaced and largely confined to outcrops, 84 percent of the known resources of South Dakota was classed as indicated, 9 percent was classed as inferred, and only about 7 percent was classed as measured (Brown, 1952, p. 1).

RECOVERABILITY AND REMAINING RESOURCES

For every ton of coal produced, a certain amount of coal is left unmined in pillars, roof, or floor, discarded as undersize, lost in washing or other preparation, or is unrecoverable due to cultural features, other mining in the area, or oil, gas, or water wells. The ratio of the coal actually produced to the sum of the coal produced and the coal lost in mining or unrecoverable is expressed in percentage as the recoverability factor. A standard recoverability factor of 50 percent is used by the U.S. Geological Survey in areas, such as South Dakota, where precise information is lacking (Averitt, 1961, p. 23–26). Therefore, the remaining known resources of South Dakota are the original known resources minus twice the total past production. To the end of 1963, the past coal production of South Dakota totaled about 1,357,000 tons (table 23) and the remaining known lignite resources as of January 1, 1963, were about 2,030 million tons.

If we assume that the 50 percent recoverability factor will be valid in the future, the recoverable known lignite resources of South Dakota would be about 1,015 million tons. The applicable recoverability factor for South Dakota should possibly be larger than the factor for the nation as a whole. As much as 80 percent of the known resources may be under less than 500 feet of overburden (Brown, 1952, p. 1) and a large part of the known resources of the State are probably strippable. A recoverability factor of 80 percent is commonly used for strip mining and recoverability is reported to be as much as 90 percent under favorable conditions (Averitt, 1961, p. 25). For many years all of the reported coal production of the State has come from strip mines, and most of the coal produced in the foreseeable future will probably come from strip mines.

Although about 7,700 square miles of South Dakota is underlain by lignite-bearing rocks, available information allowed delineation of known resources in only a small part of the area (fig. 25). Though it is probable that lignite is either very thin or absent in much of the large area outlined on figure 25, it is obvious that the known resources comprise only a part of the total amount of lignite present in South Dakota.

PETROLEUM AND NATURAL GAS

(By C. A. Sandberg and G. E. Prichard, U.S. Geological Survey, Denver, Colo.)

Petroleum, or crude oil, provides gasoline, motor and fuel oils, kerosene, and many other fuels, lubricants, and solid, liquid, and gaseous byproducts. Natural gas is an important domestic and industrial heating fuel.

Petroleum and natural gas, which may or may not be associated, are found at shallow to great depths beneath the land surface and most commonly in natural reservoirs formed by pore spaces in sedimentary rocks. Such rocks most commonly were derived from weathering and decomposition of preexisting rocks, deposited in shallow seas, embayments, or sedimentary basins adjacent to or on the continents, and buried beneath thousands of feet of younger rocks. Organic debris that was trapped in sedimentary rocks as they were deposited has been transformed during millions of years of burial through heat, pressure, and chemical processes into crude oil and natural gas. As these rocks were being deformed by folding or faulting, the crude oil and natural gas either were retained in the source rocks or migrated because of lower specific gravity and hydrodynamic and hydrostatic pressures into adjacent rocks. If no barrier to their movement was encountered, the oil and gas finally reached the surface and were dissipated. At a barrier, however, they were trapped and together with other fluids completely filled the pore spaces in the rock. Such accumulations are called pools, from which some of the contained fluids can flow or be pumped to the surface through drill holes. Many types of geological features may act as traps to form these oil and gas pools. Those features most likely to be present in South Dakota are: anticlines and domes, which are upward folds of layers of rock; stratigraphic traps, in which porous layers of rock pass upward into nonporous layers; and fault traps, in which rocks are broken and offset so that porous layers terminate upward against nonporous layers.

Petroleum produced in South Dakota to date has contributed only a small part of the total annual production of the United States. This deficiency has resulted in part from the limited area of potentially productive rocks, and in part from limited exploration. South Dakota's petroleum potential is believed to be fairly substantial because the northwestern third of the State is occupied by the southern part of the huge Williston basin (fig. 26), a structural basin filled by productive sedimentary rocks. The part of the Williston basin in the neighboring States of North Dakota and Montana yielded about 45 million barrels of petroleum, or about 1½ percent of the total U.S. production, in 1963. The north end of the much smaller so-called Kennedy basin extends into the State along its south-central border, and margins of the Denver-Julesburg basin and of an extension of the Forest City basin, respectively, may occupy about 200 square miles each at the southwestern and southeastern corners of the State (fig. 26). Parts of South Dakota outside the Williston basin, except for areas of igneous and metamorphic rocks in the Black Hills, Sioux uplift, and near Big Stone Lake (fig. 26) where no petroleum is believed to exist, contain much smaller thicknesses of sedimentary rocks and probably have much lower petroleum producing potentials than the Williston basin.

Production of natural gas in South Dakota is at present negligible, and most of the small production obtained accompanies the production of petroleum. Natural gas probably will not be of economic significance in the near future because of a limited market and because of large producing gas fields in adjoining States.

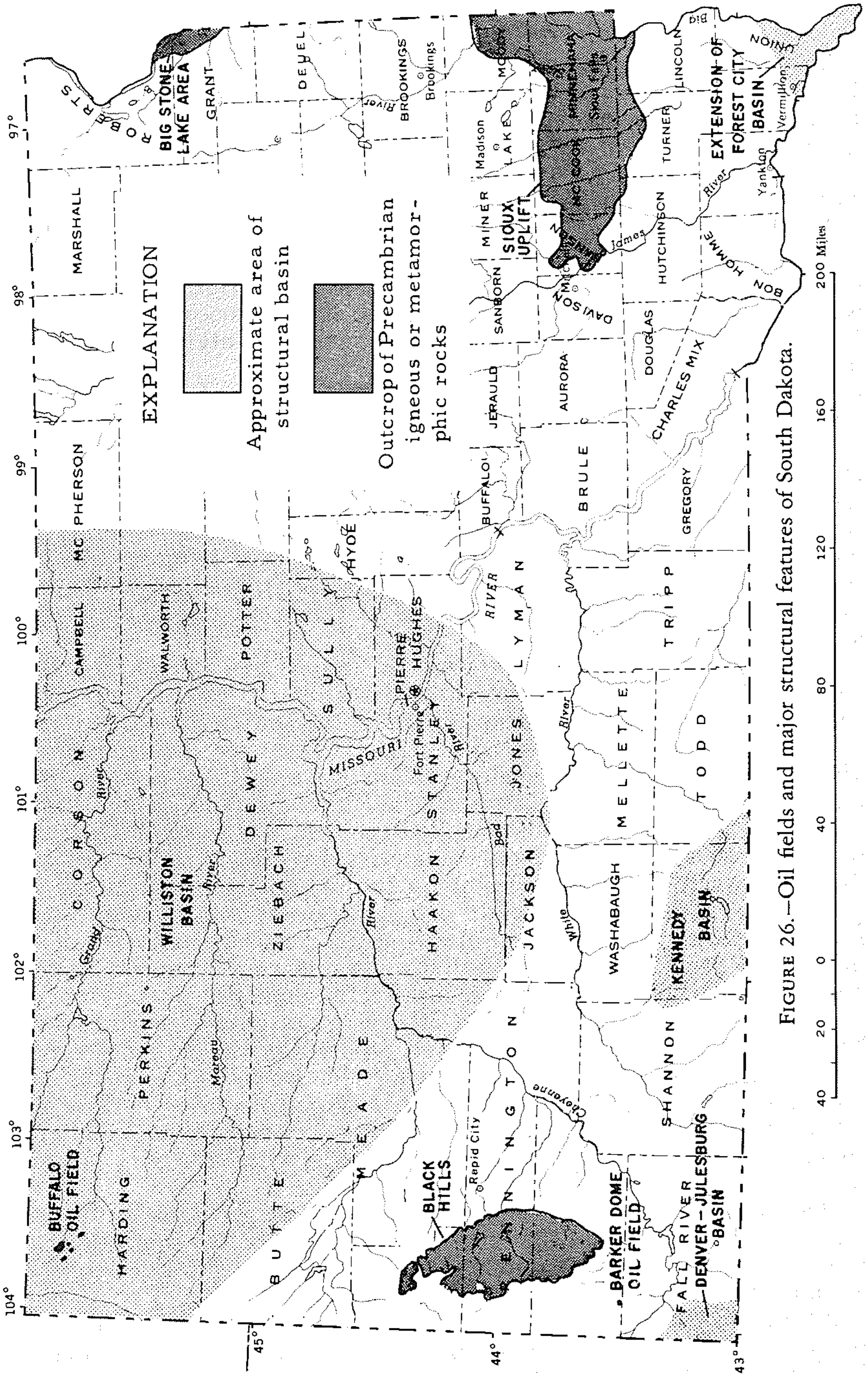


FIGURE 26.—Oil fields and major structural features of South Dakota.

HISTORY

The petroleum and natural gas industry in South Dakota is still in its infancy. Only 426 scattered test wells had been drilled in the State through the end of 1963. The important events and dates of exploitation and development are summarized largely on the basis of reports by Agnew and Lange (1961), Gries (1963, 1964), Rothrock (1944, 1955), and Wilson (1922).

Water well drilling, 1881–1906.—A 25-year period, during which many petroleum discoveries were rumored but only submarginal production of shallow natural gas for local consumption definitely was established, preceded the drilling of the first unsuccessful test well in 1906. Most discoveries in this period were incidental to the digging or drilling of water wells.

The earliest exploitation of petroleum or any of its byproducts was during the early 1880's, when a heavy grease that was found in shallow water wells along the north edge of the Black Hills was used to lubricate mill machinery (Rothrock, 1955). At about the same time, swamp gas that was discovered in hand-dug wells in the glacial drift east of the Missouri River was used locally for heat, light, and cooking (Rothrock, 1944). Both occurrences were commercially unimportant, but the presence of heavy grease in shallow wells suggested that significant accumulations of crude oil might be present at greater depth.

The first commercial exploitation of natural gas in or about 1900 followed its discovery in a water well drilled to the Dakota Sandstone of Cretaceous age, beneath glacial drift at the Indian School at Pierre in 1894. Several producing natural gas wells were drilled between 1900 and 1905 and a few development wells were drilled between 1929 and 1945 in an area that was termed the Pierre gas field (Wing, 1938). Although the flow from this so-called gas field was so small that production could not be considered commercial by present standards, production nevertheless was sufficient for limited domestic and industrial use of natural gas in Pierre and Fort Pierre for at least 45 years (Wilson, 1922; Rothrock, 1944). Following the discovery at Pierre, flows of natural gas from artesian water wells in several counties in central South Dakota were utilized locally for domestic purposes.

Sporadic test well drilling, 1906–50.—Exploration progressed slowly between 1906, when the first test well reportedly was drilled (Agnew and Lange, 1961), and 1950. During this period only about 135 scattered wells considered to be primarily petroleum or natural gas tests were drilled throughout South Dakota. Some of these wells were concentrated on the flanks of the Black Hills, where the only promising events of this period occurred.

Between 1928 and 1930, several tests drilled on geologically favorable structures mapped in the rocks at the surface on the south flank of the Black Hills recorded good oil shows but could not be completed as commercial producers (Rothrock, 1955; Gries, 1964).

Also in the area south of the Black Hills but just north of the Nebraska State line, the Ardmore gas field on the southward-plunging Chilson anticline was discovered and outlined through ten shallow test wells drilled between 1943 and 1946. Seven tests were completed as small natural gas wells, but these were later shut in and the field is now abandoned (Gries, 1963).

Intensified test well drilling, 1951–63.—Several petroleum discoveries in the Montana and North Dakota parts of the Williston basin during 1951 gave impetus to exploration in South Dakota. Between 1951 and 1963, approximately 285 test wells, or more than twice the number in the preceding half-century, were drilled in South Dakota. These tests resulted in the discovery of 2 oil fields, from which 21 wells were producing by the end of 1963. During the past 13 years, approximately 258 exploratory wells were drilled and 6 of these were successful in discovering new production. This represents a success ratio of 1:43 for the period 1951–63 in South Dakota. For comparison, the national success ratio for 1962 was about 1:5 (Carsey and Roberts, 1963).

PETROLEUM PRODUCTION

The production of petroleum in South Dakota has totaled 1,223,000 42-gallon barrels during its first 10 years, 1954–63, as an oil-producing State. This entire production came from the Buffalo oil field except for an estimated 37,904 barrels produced from the single well in the Barker Dome oil field. The following summary of annual petroleum production is prepared by the South Dakota State Geological Survey:

TABLE 25.—*Petroleum (crude oil) production in South Dakota, 1954–1963*

[In barrels—42 gallons]

	Quantity		*Quantity*
1954	37, 303	1960	281, 221
1955	30, 467	1961	233, 338
1956	36, 759	1962	168, 644
1957	55, 217	1963	214, 566
1958	60, 937		
1959	152, 359	Total, 1954–63	1, 270, 811

Buffalo oil field.—Petroleum production in South Dakota began early in 1954, with completion of the Shell Oil Co. 1 State A well in the center SW¼SE¼ sec. 9, T. 21 N., R. 4 E., Harding County. This discovery well for the Buffalo oil field (fig. 26) had an initial pumping production of 80 barrels of 31.6° API gravity oil and 200 barrels of water per day from the Red River Formation of Ordovician age at depths of 8,587 to 8,600 and 8,660 to 8,681 feet. The initial discovery was followed several months later by a successful confirmation well, the Shell Oil Co. 32–16, in the SW¼NE¼ sec. 16 of the same township. Petroleum was produced from these two wells between 1954 and 1957, with no further development of the oil field. However, between 1958 and 1960, 20 additional producing wells were completed (Cox, 1960; Agnew and Lange, 1961). Twelve of these wells served to extend and define a main pool in which the original two wells were included, and eight wells discovered and developed four small pools, which as yet have not been connected by drilling with the main pool. Two years of inactivity in 1961 and 1962 were followed by the drilling and completion of two more producing wells in the Buffalo oil field in 1963. Of the 24 producing wells completed in the field, 4 were later shut in or abandoned so that 20 wells were on production as of January 1, 1964.

The Buffalo oil field consists at present of one large and three small producing pools. The single well that formerly produced from the small southwestern pool (fig. 26) now has been shut in or abandoned.

The large pool and the two small pools alined to the southeast (fig. 26) probably are on a small fold or anticline subsidiary to and east of a large fold known as the Cedar Creek anticline. The one producing pool and the now abandoned pool on the west appear to be on the main Cedar Creek anticline near its south termination, although they may be slightly east of the crest or on another subsidiary fold. The crest of the 125-mile-long Cedar Creek anticline is highly productive. It contains at least 14 commercial oil fields and a large shallow gas field in eastern Montana and southwestern North Dakota, and two small marginal oil fields are located on its east flank or on small subsidiary folds in eastern Montana (Sandberg, 1962, fig. 3).

The economics of the presently defined Buffalo oil field are not good because the field averages only about 40 barrels of petroleum daily per well and some wells produce in addition to the petroleum as much as 200 barrels of water daily (Agnew, 1960, p. 53). However, the field has not been fully defined and future drilling may disclose other more productive pools to the west and north of the present field and closer to the crest of the productive Cedar Creek anticline.

Barker Dome oil field.—The discovery well for the second oil field in South Dakota was the Helms 1 Coffing in the SW¼NE¼NW¼ sec. 34, T. 6 S., R 2 E., Custer County. Production from this well began on August 15, 1955, and the first petroleum was marketed in September 1955. Black 30° API gravity oil from a saturated zone in the Minnelusa Formation of Pennsylvanian and Permian age between depths of 1,391 and 1,392.5 feet was produced initially by natural flow at a rate of 80 barrels per day, but after a short time pumping became necessary. The quantity of natural gas produced with the oil was very small at first, but the volume gradually increased to about 100,000 cubic feet per day after 3 months before it began to decrease (Gries, 1964). Through the end of 1963 about 10 additional wells were drilled on the structural feature known as Barker dome, from which the field was named. Production increased markedly to 26,819 barrels in 1963 (McGregor, written communication, 1964). Three new field wells are in production early in 1964. These are the first successful wells in the field since the discovery well.

The Barker dome on the Cottonwood anticline on the southwestern flank of the Black Hills was recognized by reconnaissance mapping of surface rocks early in 1929. The first well on this structural feature was the Black Hills Petroleum Co. 1 Barker, drilled by cable tools between 1929 and 1930. Oil-saturated sandstone in the Minnelusa Formation was reached at a depth of 1,327 feet, and black oil was collected from a depth of 1,344 feet. The estimated yield by bailing was reported to be 20 to 25 barrels of oil per day, but soon after the well had been fractured by an explosive charge in an attempt to increase production it produced only water (Gries, 1964). With luck or a better technique for completing this well, South Dakota might have become an oil-producing State nearly a quarter-century sooner.

NATURAL GAS PRODUCTION

The production of natural gas in South Dakota, mainly as a byproduct of petroleum production from the Buffalo and Barker dome oil fields, was negligible during the period 1954–63. The quantity produced was too small to be marketable with only 119 million cubic feet having been recorded in that period (McGregor, written communication, 1964). Most of the gas probably was flared. Consequently, the incomplete production data available are meaningless. Data on natural gas produced prior to 1954 also are of no significance because the total production for more than 50 years probably was much less than the total annual production from an average present-day gas well in the United States.

POTENTIAL RESOURCES

South Dakota was considered a future petroleum-producing province by petroleum geologists prior to the discovery of commercial production (Tulsa Geological Society, 1941, 1951; Ballard, 1942). Exploratory drilling is still so limited that this potential has been but little explored.

The ultimate resources of South Dakota are difficult to estimate in scientifically precise terms of millions of barrels of petroleum or of millions of cubic feet of natural gas because of a scarcity of usable drilling and production data. The 420 test wells drilled to date in the approximately 74,000 square miles of South Dakota underlain by sedimentary rocks represent a density of only about one well for each 175 square miles. The majority of these test wells were shallower than 1,500 feet and hence did not adequately test the total thickness of sedimentary rocks between the surface and the unproductive metamorphic and igneous rocks at depth. Furthermore, only the Red River Formation of Ordovician age and the Minnelusa Formation of Pennsylvanian and Permian age have been productive to date.

On the basis of comparisons with producing sedimentary formations in South Dakota and the adjacent States of North Dakota, Montana, Wyoming, and Nebraska, it is possible to predict roughly which formations are potentially productive in South Dakota. This analysis is presented in two parts, for the Williston basin and for all areas outside the Williston basin, with the potentially productive formations discussed according to their relative importance and in order of decreasing geologic age from Ordovician to Cretaceous. Older sedimentary rocks of Cambrian age are productive at only a few localities in the United States and hence are not regarded to be potentially productive in South Dakota. Younger sedimentary rocks of Tertiary age are predominantly nonmarine in origin in South Dakota and hence are also considered to be unproductive.

Williston basin.—The greater part of the potential for producing petroleum and natural gas in South Dakota lies in the 25,000-square-mile area of the Williston basin (fig. 26). There the thickness of Ordovician to Cretaceous rocks ranges from 2,500 feet east of the Missouri River to as much as 9,000 feet along the North Dakota State line in northern Harding and Perkins Counties. Although the potential is less than that of the Central Williston basin, a moderately productive area of about 22,000 square miles in North Dakota and eastern Montana (Sandberg, 1962, figs. 1, 3), it is roughly comparable to that of parts of southeastern Montana and north-central North Dakota outside the central basin. These areas contain many oil fields and significant reserves of petroleum and natural gas in rocks whose character, thickness, and stratigraphic relations are similar to those of rocks in the South Dakota part of the Williston basin.

The major detraction from the potential of the Williston basin in South Dakota is the presence of strong flows of fresh water in the sedimentary rocks. Some formations, which are productive elsewhere, serve as aquifers in this area. Fresh waters flow under considerable hydrostatic head through these aquifers from intake areas in the nearby Black Hills. These flows of fresh water may have flushed and dispersed many preexisting accumulations of petroleum and natural gas, as evidenced by the weak flows of natural gas and the shows of petroleum that accompany the flows of fresh water for artesian wells along the east side of the basin in central South Dakota. Some accumulations of petroleum and natural gas may have been protected from flushing because they were trapped on high structural features such as anticlines and domes, or against faults, unconformities, and relatively impermeable rocks. Except for the Cedar Creek and Camp Crook anticlines and their subsidiary folds in Harding and Butte Counties, large structural features are unknown in the South Dakota part of the Williston basin. Moreover, because of insufficient well data, many small folds, which might contain petroleum and natural gas, have been inadequately defined and stratigraphic studies have not been sufficiently detailed to indicate areas where accumulations might have been trapped against faults, unconformities, or impermeable rocks.

The greatest potential is in the Red River Formation of Ordovician age and the rocks of the Madison Group of Mississippian age (table 1), on the basis of their high productivity elsewhere. These rocks account for 80 to 90 percent of the petroleum produced in the U.S. part of the Williston basin. The Minnelusa Formation of Pennsylvanian and Permian age was regarded as highly favorable by Agnew and Gries (1960) and by Wulf and Gries (1963) because it contains many oil shows on the flanks of the Black Hills and is productive in the Powder River Basin, west of the Black Hills in northeastern Wyoming. It has not yet been productive, however, in other parts of the Williston basin.

Of secondary importance in potential production are the Winnipeg Formation of Ordovician age, rocks of Silurian age, and the Duperow and Birdbear Formations of Devonian age (table 1). All except the Winnipeg produce from scattered small oil fields in the Montana and North Dakota parts of the Williston basin. The Winnipeg Formation has yielded many promising oil shows in North Dakota, but it may have been largely flushed in South Dakota.

Other less important potential production may come from the Sundance Formation of Jurassic age and from sandstones of Cretaceous age (table 1), although these rocks are not regarded favorably by the authors. According to Agnew and Gries (1960), two tests in the Sundance on the flank of the Black Hills and in central South Dakota had an oil show and an oil stain, respectively, and beds of sandstone in the Sundance have petroleum possibilities where they rest directly on the Madison Group along the north-central border of the State. However, as shown by Sandberg (1962, fig. 6), the Minnelusa Formation generally intervenes between the Sundance and the Madison. Some sandstone beds of Cretaceous age were considered by Agnew and Gries (1960) to have locally good petroleum potentials because of stratigraphic and structural settings similar to those in the Denver-Julesburg basin of Nebraska and in the Powder River basin of Wyoming, where the same or related rocks are productive. It should be pointed out, however, that Cretaceous rocks are not yet productive anywhere in the Williston basin.

Areas outside the Williston basin.—Upper Paleozoic formations dip southwestward off the flanks of the Black Hills into the margin of the Denver-Julesburg basin, which may occupy the extreme southwest corner of the State. Although lower Paleozoic formations are largely absent there, Devonian and younger formations are present and some of these are productive nearby. Petroleum production from Barker dome oil field on the Cottonwood anticline and from many oil fields in the adjacent Powder River basin comes from the Minnelusa Formation of Pennsylvanian and Permian age. This is the most potentially productive formation in southwestern South Dakota. It is present in the Chilson anticline extending southward from the Black Hills toward the Denver-Julesburg basin and in the Cascade anticline extending southeastward toward the Chadron arch of northwestern Nebraska. All three anticlines may be favorable for the accumulation of petroleum and natural gas in the Minnelusa Formation, and none have been adequately tested. Sandstones of Cretaceous age have less potential than the Minnelusa Formation. The Cretaceous D and J sands of informal subsurface usage are productive about 80 miles to the south in northwestern Nebraska, but they apparently lie just east of the margin of the Denver-Julesburg basin in South Dakota, as shown by Wulf and Gries (1963, fig. 3). Mississippian and Devonian rocks are very thin and probably have little potential. However, they have been inadequately tested because less than 12 wells have penetrated the pre-Pennsylvanian rocks of this area.

The Kennedy basin of northern Nebraska is clearly delineated on a contour map of the Precambrian surface of that State, as shown by Carlson (1963). Its northward extent into southern South Dakota had been postulated earlier by Agnew and Gries (1960). The exact limits of the Kennedy basin (fig. 26) are unknown because of a lack of drilling, and a connection with the south end of the Williston basin may exist. The Minnelusa Formation and younger rocks are known to occupy the Kennedy basin but the presence or absence of Mississippian and older rocks is conjectural due to the absence of deep testing. The most promising petroleum potential is in sandstones of Cretaceous age, particularly the D and J sands of informal subsurface usage, which extend into south-central and central South Dakota from the Denver-Julesburg basin (Wulf and Gries, 1963). The Minnelusa Formation also is potentially productive in the Kennedy basin as well as in other parts of South Dakota, south of the Williston basin.

A small area in the extreme southeastern tip of South Dakota, where the sedimentary rocks dip southward off the south flank of the Sioux uplift has been related to an extension of the Forest City basin of Nebraska by Agnew and Gries (1960) and Carlson (1963). Rocks of Cambrian, Ordovician, and possibly Devonian age are present beneath Cretaceous rocks in this area. A few oil shows were found in test wells drilled in Union County, but the petroleum potential of this area is not great because of its small size and the thinness of the sedimentary rocks.

The large area of South Dakota north of the Sioux uplift and east of the Williston basin apparently has little petroleum or natural gas potential. Sedimentary rocks range in thickness from 0 to 2,500 feet in this area and their average thickness probably is less than 1,500 feet. The only potentially productive rocks, those of Ordovician to Pennsylvanian age, have a maximum thickness of about 700 feet along the eastern margin of the Williston basin and an average thickness that is considerably less throughout most of the area. The overlying rocks of Cretaceous age or largely nonmarine and are not regarded as sources of petroleum and natural gas. Furthermore, the Cretaceous sandstones probably have been widely flushed by fresh waters so that accumulations, which might have been derived from the underlying Paleozoic rocks, have been dispersed.

Selected References

Mineral Fuel Resources

Agnew, A. F,. 1960, Biennial report of State Geologists for fiscal years 1959 and 1960: South Dakota Geol. Survey, 71 p.

Agnew, A. F., and Gries, J. P., 1960, South Dakota oil—past, present, and future, *in* Am. Assoc. Petroleum Geologists Rocky Mtn. Sec. Geol. Rec., Feb. 1960: p. 85–95.

Agnew, A. F., and Lange, A.U., 1961, Oil tests in South Dakota: South Dakota Geol. Survey Oil and Gas Inv. Map 6, 2 sheets.

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

Ballard, Norval, 1942, Regional geology of the Dakota basin: Am. Assoc. Petroleum Geologists Bull., v. 26, no. 10 p. 1557–1584.

Brown, D. M., 1952, Lignite resources of South Dakota: U.S. Geol. Survey Circ. 159.

Carlson, M. P., 1963, Lithostratigraphy and correlation of the Mississippian System in Nebraska: Nebraska Geol. Survey Bull. 21, 46 p.

Carsey, J. B., and Roberts, M. S., 1963, Exploratory drilling in 1962: Am. Assoc. Petroleum Geologists Bull., v. 47, no. 6, p. 889–934.

Cox, E. J., 1960, Oil tests in Buffalo field and vicinity, Harding County, South Dakota: South Dakota Geol. Survey Oil and Gas Inv. Map 5 (originally published in 1959; revised to May 15, 1960).

Gries, J. P., 1963, Geology of the southern Black Hills, *in* Rocky Mountain Assoc. Geologists Guidebook 14th Field Conf., northern Denver basin and adjacent uplifts: p. 189–195.

——— 1964, Barker dome oil field, Custer County, South Dakota: The Mtn. Geologist, v. 1, no. 1, p. 43–46.

Rothrock, E. P., 1944, Mineral resources, pt. 3 *of* A geology of South Dakota: South Dakota Geol. Survey Bull. 15, 255 p.

——— 1955, South Dakota as an oil prospect, *in* North Dakota Geol. Soc. Guidebook, South Dakota Black Hills Field Conf. 3d, 1955: p. 76–80.

Sandberg, C. A., 1962, Geology of the Williston basin, North Dokata, Montana, and South Dakota, with reference to subsurface disposal of radioactive wastes: U.S. Geol. Survey Rept. TEI–809, open-file report, 148 p.

Tulsa Geological Society, 1941, Possible future oil provinces of northern Mid-Continent States, *in* Possible future oil provinces of the United States and Canada: Am. Assoc. Petroleum Geologists Bull., v. 25, no. 8, p. 1508–1526.

——— 1951, Mid-Continent region; North Dakota and South Dakota, *in* Possible future petroleum provinces of North America: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 2, p. 316–318.

U.S. Bureau of Mines, 1954, Technology of lignitic coals, pts. 1 and 2: U.S. Bur. Mines Inf. Circs. 7691 and 7692.

U.S. Bureau of Mines, 1963, Technology and use of lignite proceedings [Bureau of Mines-University of North Dakota symposium, Grand Forks, N. Dak., April 1961; compiled by J. L. Elder and W. R. Kube]: U.S. Bur. Mines Inf. Circ. 8164.

Vine, J. D., 1962, Geology of uranium in coaly carbonaceous rocks: U.S. Geol. Survey Prof. Paper 356–D, p. 113–170.

Wilson, R. A., 1922, The possibilities of oil in South Dakota: South Dakota Geol. and Nat. Hist. Survey Bull. 10, 97 p.

Wing, M. E., 1938, A structural survey of the Pierre gas field, South Dakota: South Dakota Geol. Survey Rept. Inv. 29, 20 p.

Wulf, G. R., and Gries, J. P., 1963, South Dakota—new oil frontier: Oil and Gas Jour., v. 61, no. 48, p. 192–194.

WATER RESOURCES

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INTRODUCTION

About 60 percent of South Dakota's 76,536 square miles is in the Great Plains physiographic province; the balance is in the Central Lowlands physiographic province (Fenneman, 1946). The boundary between the Great Plains and the Central Lowlands coincides roughly with the western margin of the James River basin. The Great Plains province in South Dakota includes the High Plains section along the south edge of the State, the Black Hills section near the southwestern corner of the State, and the Missouri Plateau section. The latter can be further subdivided into a large, unglaciated area west of the Missouri River, and a smaller, glaciated area east of the river.

A section known since the time of the early French fur traders as the Coteau des Prairies, or Prairie Hills country, occupies the area between the Minnesota River valley, which drains a small part of the northeastern corner of the State, and the James River valley.

The southeastern part of the Central Lowlands in South Dakota is made up largely of the drainage area of the Big Sioux River, and is in the Dissected Till Plain section of the Central Lowlands.

For the purpose of a discussion of water resources, the State may be divided generally into the glaciated section east of the Missouri River and the unglaciated section west of the Missouri River. Figure 27 shows the physiographic divisions of South Dakota as used in this report.

The average annual precipitation in South Dakota is about 18 inches; it ranges from less than 13 inches in the northwestern corner of the State to about 25 inches in the southeastern corner. Figure 28 shows the distribution of precipitation in South Dakota.

In most years, three-fourths to four-fifths of the precipitation falls during the April to September growing season. There are, however, great variations in the State from year to year. In the 30 years preceding 1959, the average annual precipitation over the entire State ranged from as much as 30 inches to as little as 12. In the eastern part of the State alone, however, precipitation has ranged from a maximum of 50 to a minimum of 10 inches annually. Periods of successive dry years, or years that are wetter than normal, are frequent.

South Dakota is near the paths of many cyclones and anti-cyclones. Because it is a great distance from any large body of water, the State has a typical continental climate, with extremes of summer heat and winter cold. Daily, monthly, and annual temperature ranges are great. Temperatures of 100 degrees Fahrenheit or higher are common in some parts of the State each summer, and below zero temperatures occur frequently in midwinter. The lowest temperature on record in the State is −58° F. observed on February 17, 1936, at McIntosh. The

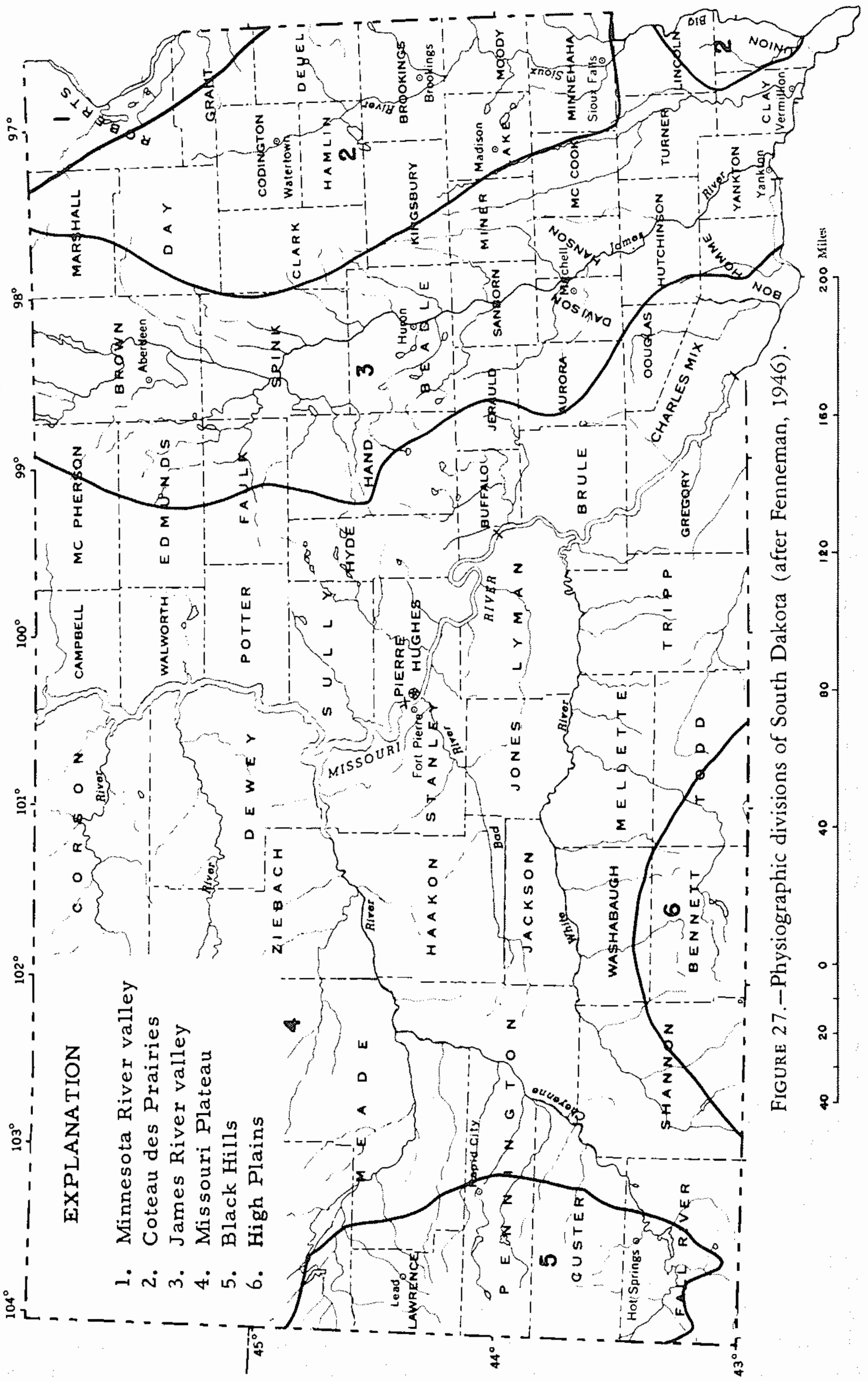

FIGURE 27.—Physiographic divisions of South Dakota (after Fenneman, 1946).

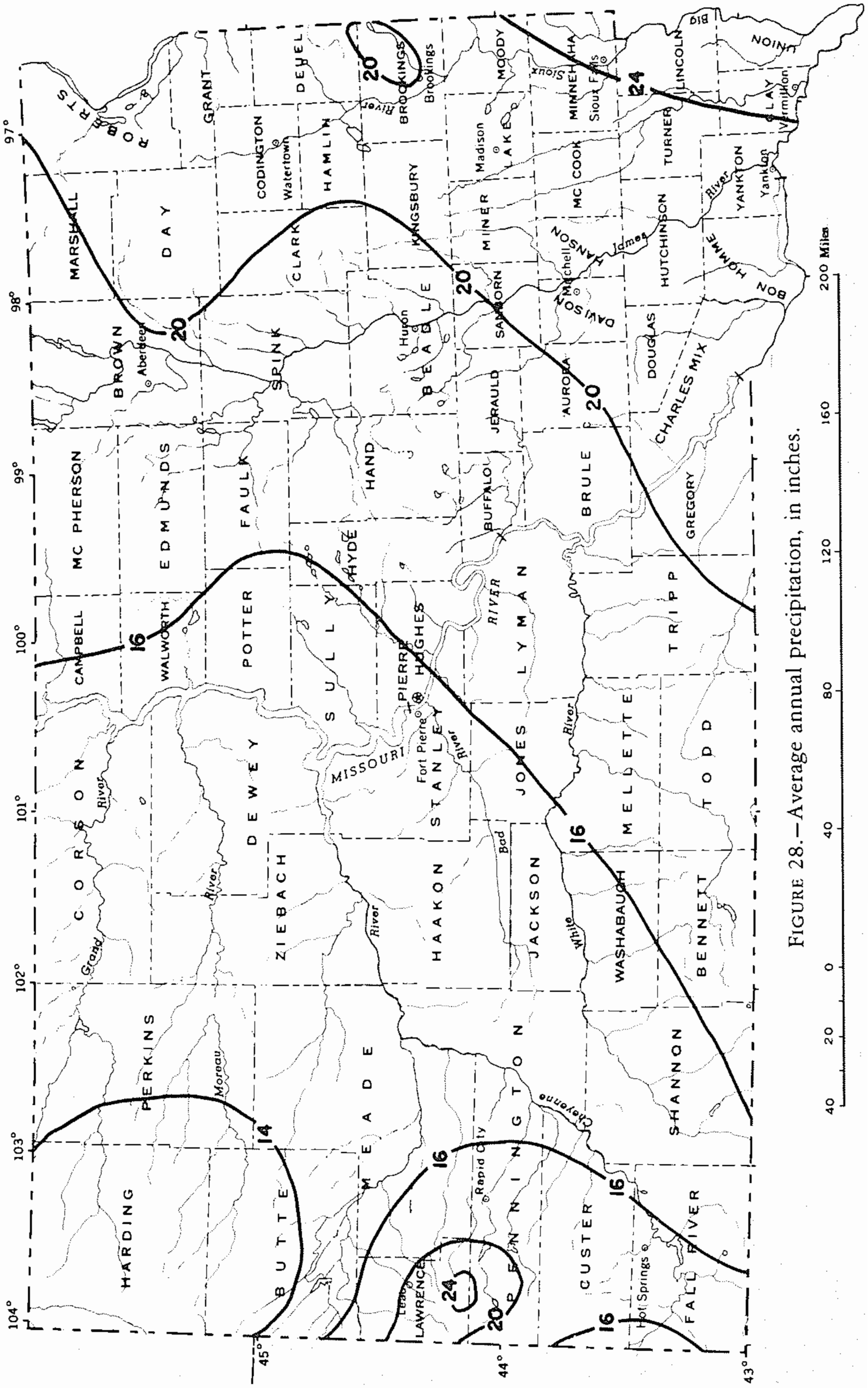

FIGURE 28.—Average annual precipitation, in inches.

highest temperature on record, 120° F., was recorded less then 5 months later at Gann Valley on July 5, 1936. The average annual temperature for the State as a whole is approximately 46 degrees.

SURFACE WATER

PRINCIPAL DRAINAGEWAYS

The Missouri River nearly bisects the State and receives drainage from all but a small area in the northeastern corner. It flows generally south from the North Dakota border to Pierre, then south-southeastward to the Nebraska border. Thence it forms the South Dakota-Nebraska border to the southeast corner of South Dakota. Its course roughly defines the boundary between the unglaciated region to the west and the glaciated region to the east.

A small area in the northeastern corner of the State around Lake Traverse is drained northward to the Hudson Bay basin through the Bois de Sioux and Red River of the North. A short distance south of Lake Traverse are the headwaters of the Minnesota River, which forms part of the Upper Mississippi drainage.

The principal drainageways and relative discharge of the main streams in South Dakota are shown schematically on figure 29. Line width of streams on the map is proportional to the mean discharge.

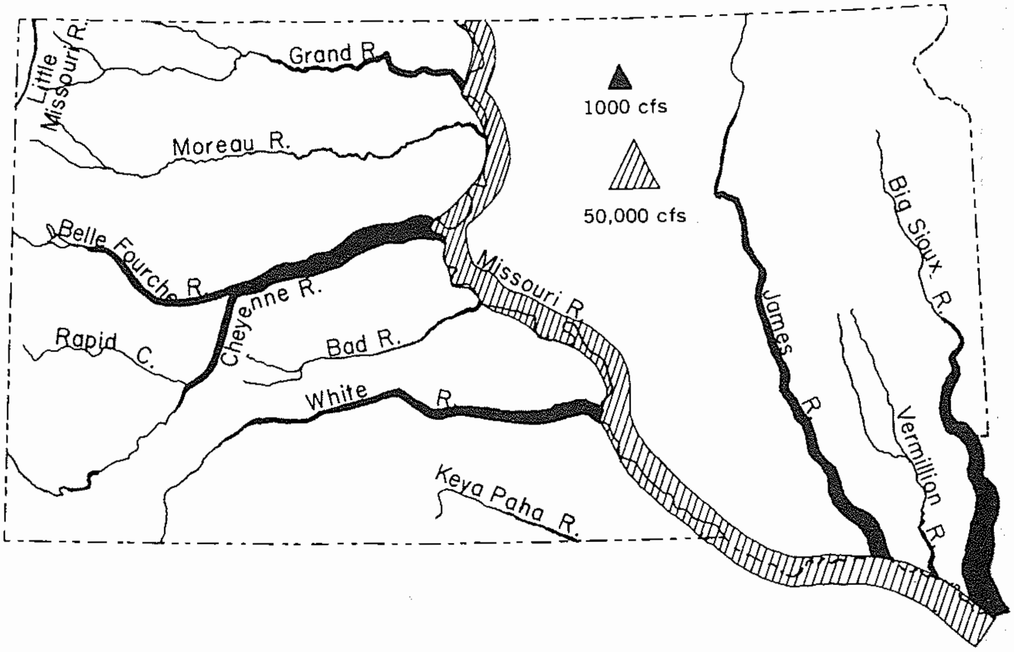

FIGURE 29.—Average discharge, in cubic feet per second, of principal rivers. (Width of river line indicates average discharge.)

Missouri River tributaries draining the eastern, glaciated region flow generally southward. The most important tributaries are the James, Big Sioux, the Vermillion Rivers, which drain that part of the State in the Central Lowlands physiographic province.

Much of the glaciated region of South Dakota does not have integrated drainage. The post-glacial land surface has low relief and was dotted with numerous, shallow, lake-filled depressions; drainage connections to established water courses have not yet developed on large areas of the State. Water falling on these areas is trapped in the lakes, sloughs, and "prairie potholes," as the smaller depressions are called, and is consumed by evaporation and transpiration or seeps into the ground. During droughts, many of the lakes and potholes become dry.

The region between the Minnesota River valley and the James River valley is known as the Coteau des Prairies or Prairie Hills. On the west the Prairie Hills are marked by a gentle slope that rises about 300 feet above the James River valley and on the east by a much steeper slope that is 600 feet above the Minnesota River valley. The topography of the Coteau is somewhat more rugged than that of the lowlands but the Coteau does have numerous lakes and ill-defined drainage. The headwaters of the Big Sioux River are in the northern part of this region.

The principal tributaries entering the Missouri from the west in South Dakota are the Grand, Moreau, Cheyenne, Bad, and White Rivers. The Keya Paha River drains a small area in south-central South Dakota and enters the Niobrara River, a tributary of the Missouri, in Nebraska. The Little Missouri drains the northwestern corner of the State and enters the Missouri in North Dakota. The Cheyenne is the largest of the western tributaries and drains the South Dakota part of the Black Hills.

The part of the State west of the Missouri River is in the Great Plains physiographic province; however, the "plains" are anything but flat. Rolling hills with a great many prominent buttes and canyons are the main topographic features. The flatness of the plains in times past, before erosion by streams and wind, is evidenced by several flat-topped buttes and a few small tablelands. Drainage patterns in the "west-river" area are generally well defined and stream gradients are considerably steeper than those in the area east of the Missouri.

RUNOFF

Runoff is the water that drains from the land into creeks and rivers. It is chiefly the residual of rainfall after Nature's take—that is, after the demands of evaporation and transpiration have been met. The mean annual runoff in South Dakota ranges from about 0.25 inch to nearly 2.5 inches and averages about 0.7 inch for the nearly 77,000 square mile area of the State. Expressed in other terms, the runoff is equivalent to a flow of 2.6 bgd (billion gallons per day) or about 3 million acre-feet per year. Areal distribution of runoff as equivalent inches of depth over the land surface is shown in figure 30.

Runoff does not necessarily increase as precipitation increases, as may be seen by comparison of figures 28 and 30. For example, the north-central part of the State, drained principally by the James River, has an average annual precipitation of 18 or 19 inches but has an average runoff of only 0.25 inch. On the other hand, northwestern South Dakota, drained principally by the Grand and the Moreau Rivers, has an average annual precipitation of about 15 inches and an average runoff of about 0.5 inch. Evaporation losses from the numerous potholes and lakes, low gradients of the tributaries and mainstream, and infiltration in the glaciated James River drainage basin are probably the main causes of low runoff in the area.

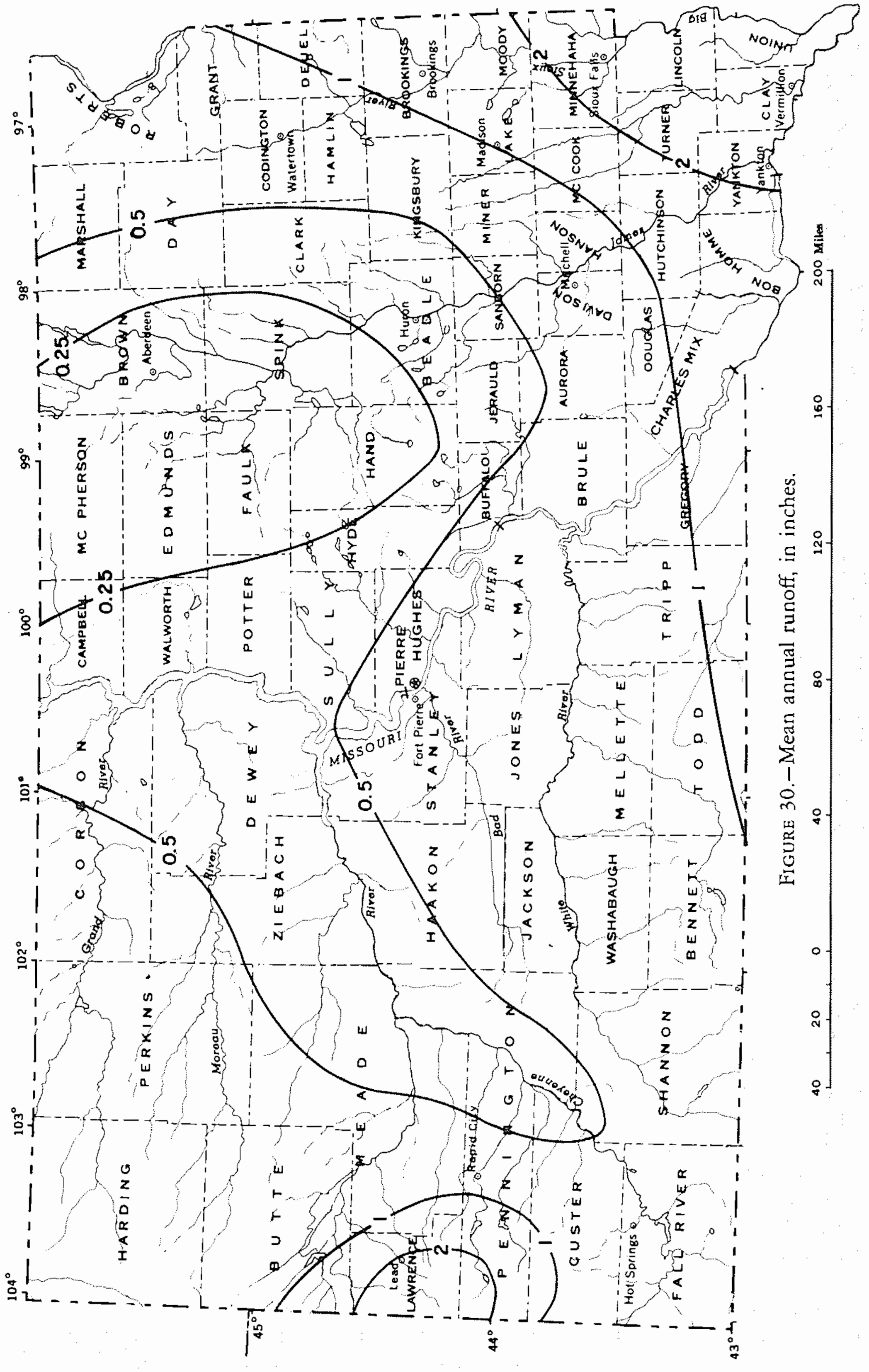

FIGURE 30.—Mean annual runoff, in inches.

Monthly distribution of runoff for South Dakota streams is extremely variable, but, on the average, most runoff takes place from March through July, with March, April, and June showing greatest amounts. The high runoff in March and April is primarily the result of snowmelt, which usually begins during the last half of March. Snowfall accumulations generally are heaviest in the east and average monthly runoff for the eastern streams is greatest in March or April. The high runoff in June is the result of rainfall; precipitation records show that June is normally the month of greatest precipitation. In streams of west-central South Dakota, June is the month of highest average runoff. In individual years, runoff may vary widely from the average; in fact, during the drought period in the late 1950's, several streams in the upper James River valley had no runoff for periods of 18 to 20 months. In some years the runoff from an individual storm may be the only runoff during the year for a particular stream.

All major tributaries of the Missouri River in South Dakota, except the White and the Big Sioux Rivers, have had one or more periods of no flow at their mouths within the last 40 years. The minimum flow of the White River at Oacoma during the period 1928–62 was 0.5 cfs (cubic feet per second). The minimum flow of the Big Sioux at Akron, Iowa, during the same period was 7 cfs. With the exception of the South Fork of the White River and some streams in the Black Hills, most of the smaller streams and a few of the larger ones have no flow for long periods each year.

The variability of annual runoff and the cycles of wet and dry years are apparent from figures 31 and 32, which show the annual runoff and average runoff of selected streams.

WATER QUALITY

The quality of surface water depends largely on the material that is dissolved and suspended in it. The concentrations and characteristics of both the dissolved solids and the sediment in the water are influenced by such factors as climate, amount and variableness of streamflow, geology, topography, and water-management practices. Because these factors differ markedly from one part of the State to another, the quality of water in most streams also differs from one part of the State to another.

Chemical quality

The dissolved-solids content of water from the streams in South Dakota varies inversely with water discharge. During floods, the water may contain less than 200 ppm (parts per million) but during periods of low flow, water from most of the major streams may contain more than 2,000 ppm. Dissolved solids in water from the Missouri River and from a few streams in south-central South Dakota seldom exceeds 500 ppm.

The prevailing dissolved-solids content of water from the major streams in South Dakota is indicated by ranges in figure 33.

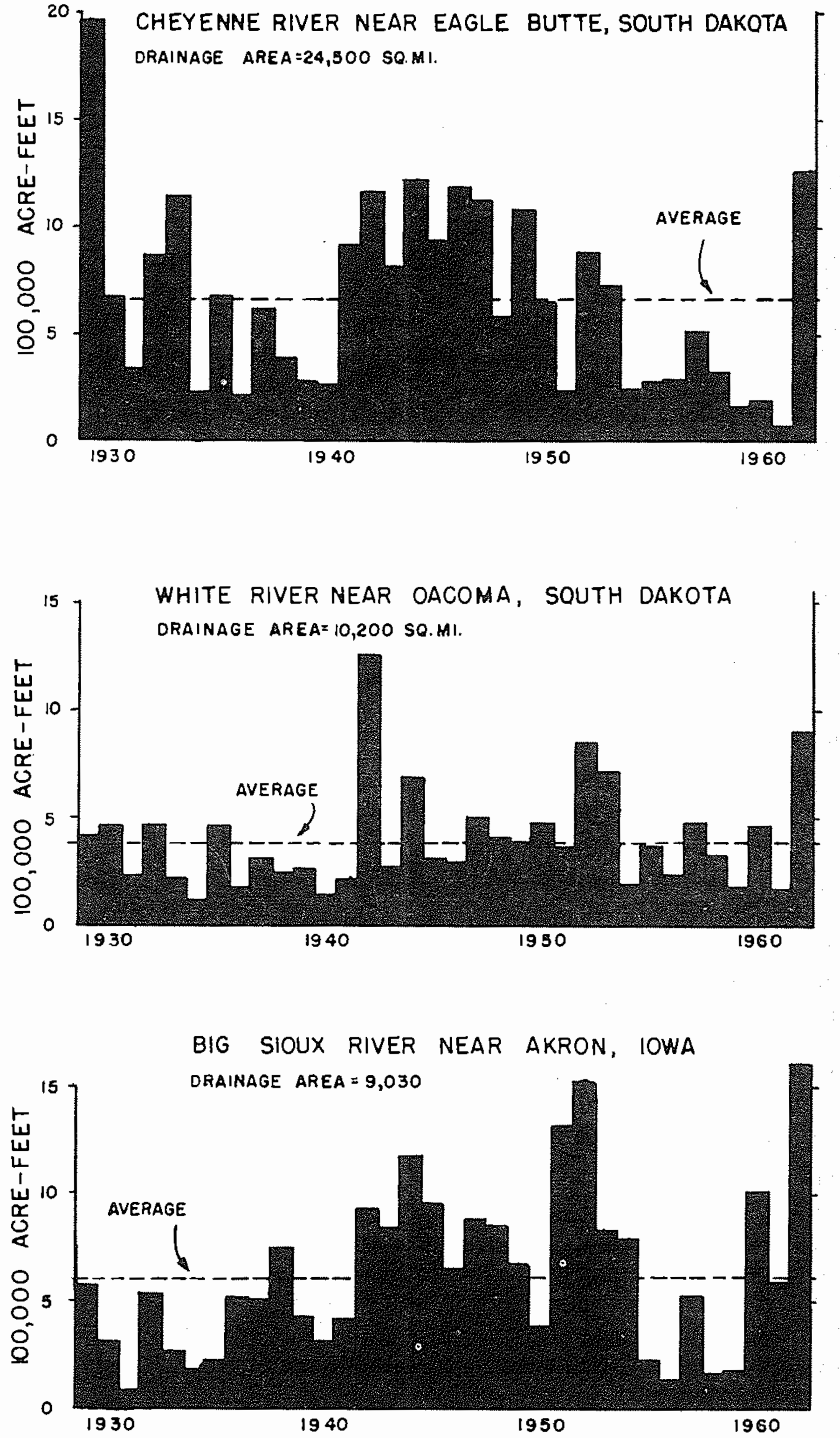

FIGURE 31.—Yearly stream flow (runoff) of selected streams. (Cheyenne, White, and Big Sioux Rivers.)

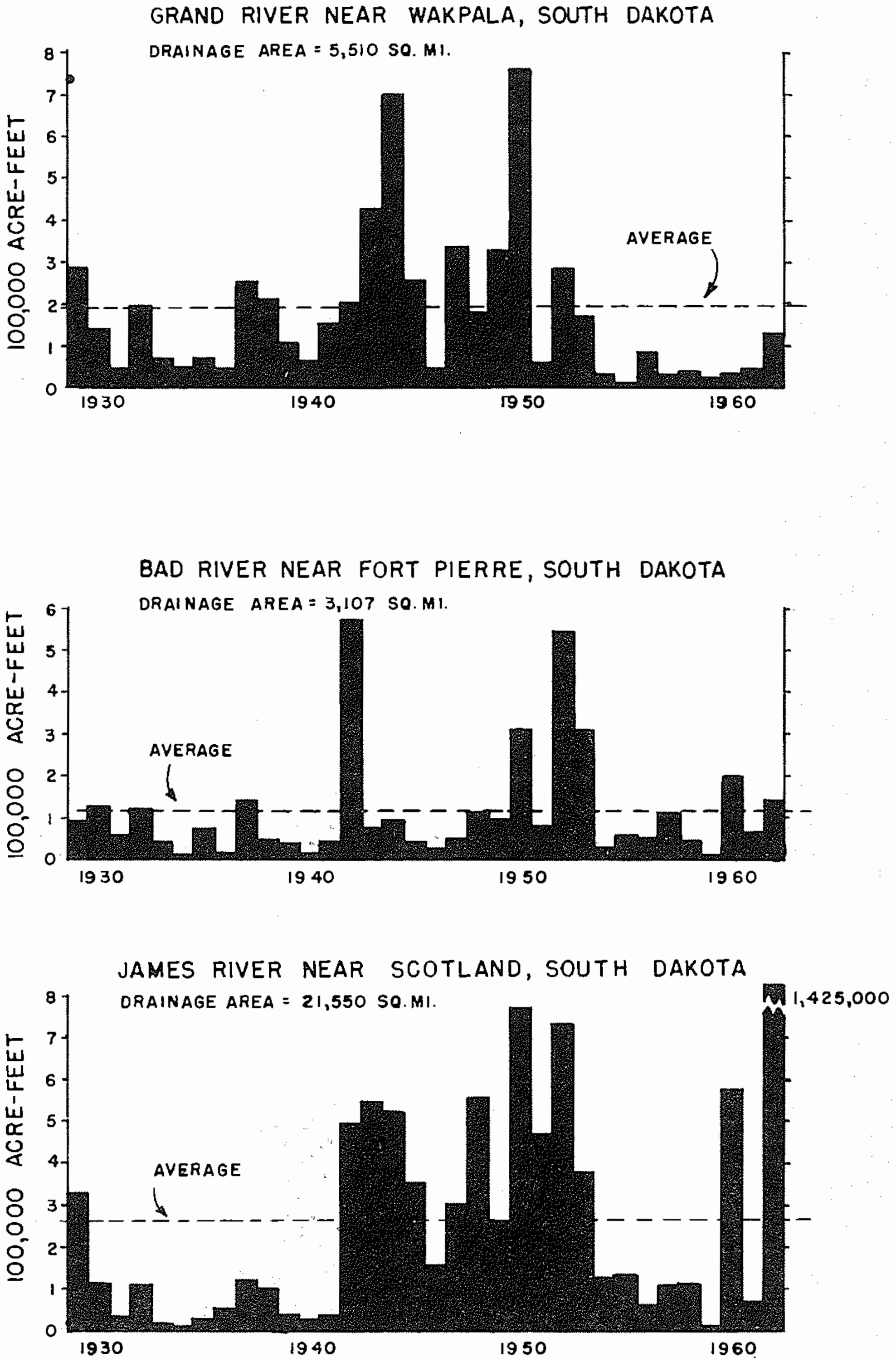

FIGURE 32.—Yearly streamflow (runoff) of selected streams. (Grand, Bad, and James Rivers.)

The dissolved solids of water from dry washes and other minor streams may differ considerably from those of water from major streams. Major streams that drain the sandhills area of south-central South Dakota and the Black Hills area usually contain lower concentrations of dissolved solids than those of other parts of South Dakota. Of the major streams, those with the most concentrated water usually drain the areas underlain directly by Pierre Shale in west-central South Dakota.

Besides differing in dissolved-solids concentration, waters from the major streams differ also in the relative proportions of the individual chemical constituents. The cations calcium, magnesium, sodium, and potassium and the anions carbonate, bicarbonate, sulfate, and chloride are present in some degree in all surface waters. During high flows, calcium and magnesium tend to be the most abundant cations in the water, and carbonate and bicarbonate tend to be the most abundant anions. During low or medium flows, however, the cation, sodium, and the anions, sulfate and chlorine, are the predominant ions.

Calcium and magnesium are the predominant cations in water from most of the State. (See fig. 34.) Even where sodium and potassium are the predominant cations, calcium and magneisum generally are present in high concentrations. A hardness (mainly calcium and magnesium hardness) as $CaCO_3$ of more than 160 ppm is normal for water from most streams, and a hardness of more than 500 ppm is not uncommon.

Concentrations of several minor, but nonetheless important, constituents are relatively low. Iron and probably maganese seldom exceed 0.3 ppm in most of the streams, and boron and fluoride seldom exceed 1 ppm. Selenium in concentrations of several hundredths of a part per million have been detected in water from several streams in the White River basin.

Generally, streamflow in South Dakota is only slightly colored. Color in excess of 30 Hazen units is rather rare in most of the State, but color of as much as 60 units is common in the eastern one-third of the State.

Fluvial sediment

Suspended-sediment concentrations and discharges range widely in the streams of South Dakota. The highest sediment concentrations are in the semi-arid western half of the State, where high erosion rates are prevalent because of locally steepened topography, shallow soils, and less resistant types of bedrocks.

Suspended-sediment concentration commonly is expressed in parts per million. It is the ratio of the weight of the dried sediment to the weight of the water-sediment mixture. Discharge-weighted concentration for a specified period is the concentration that would result if all the water and all the suspended sediment of the stream during that period were uniformly mixed. In general, discharge-weighted concentrations of streams east of the Missouri River are much lower than concentrations of streams west of the Missouri River. (See fig. 35.) Discharge-weighted concentrations are estimated to be in the 500- to 2,000-ppm range in the eastern half of the State. Discharge-weighted concentrations for major streams in the western half of the State prob-

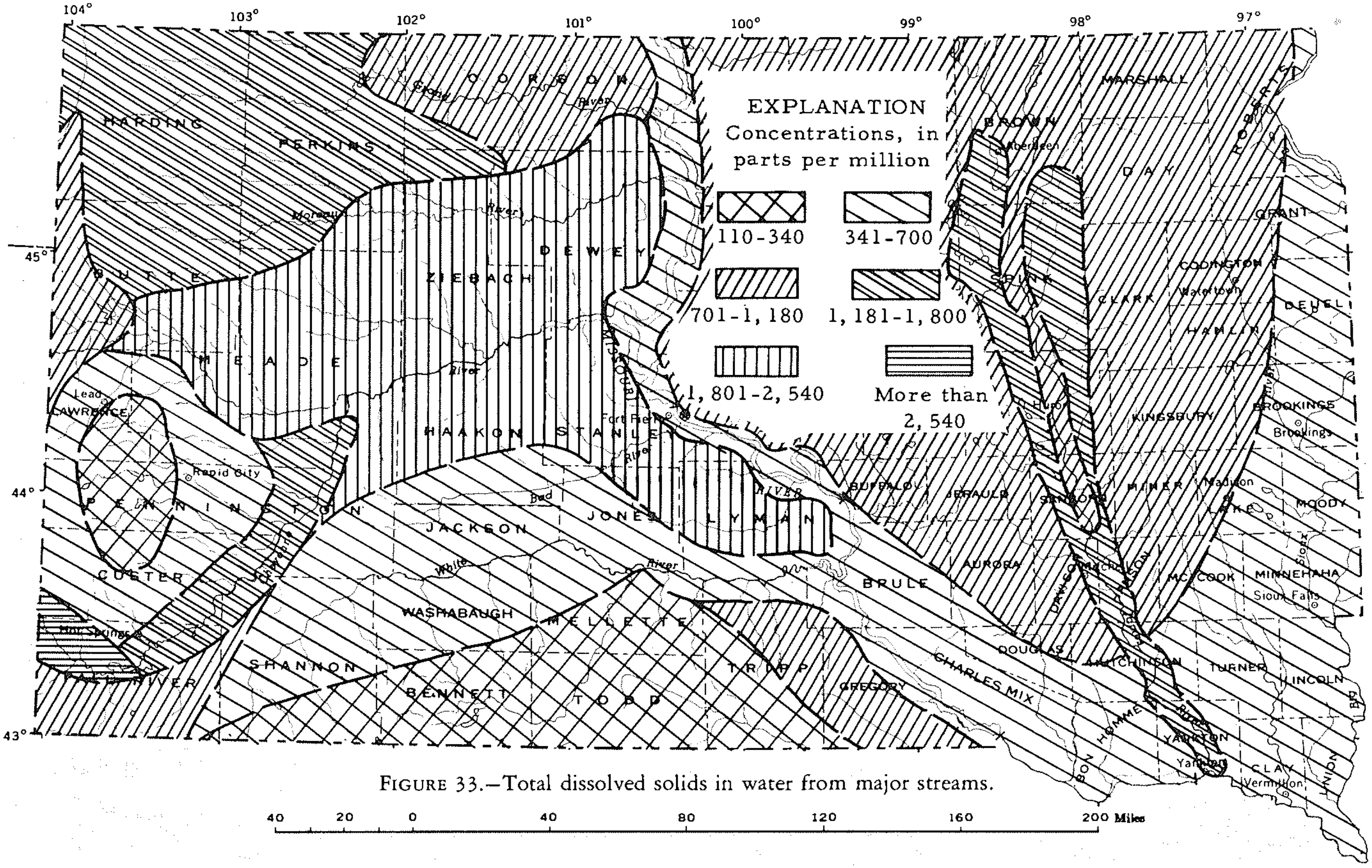

FIGURE 33.—Total dissolved solids in water from major streams.

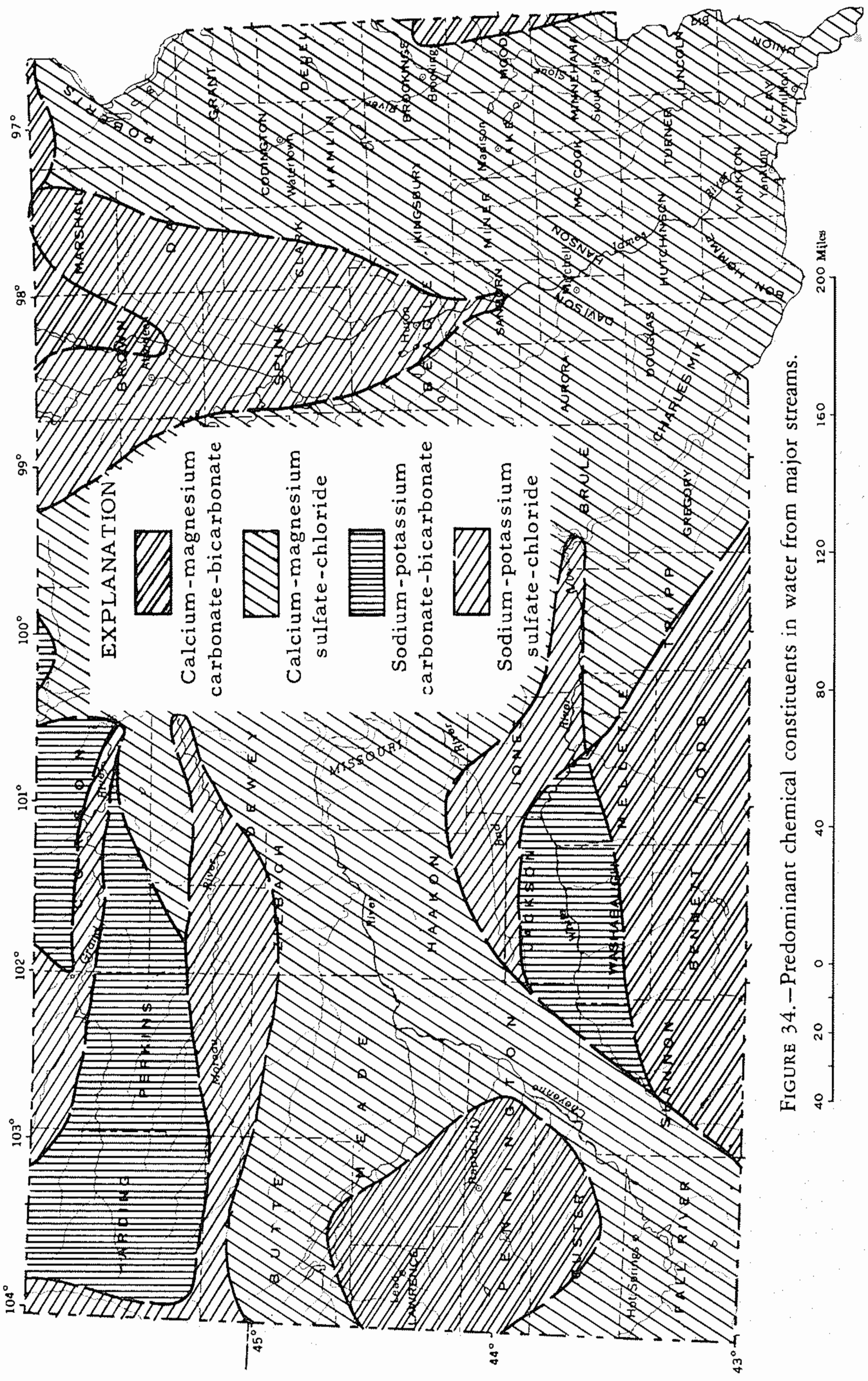

Figure 34.—Predominant chemical constituents in water from major streams.

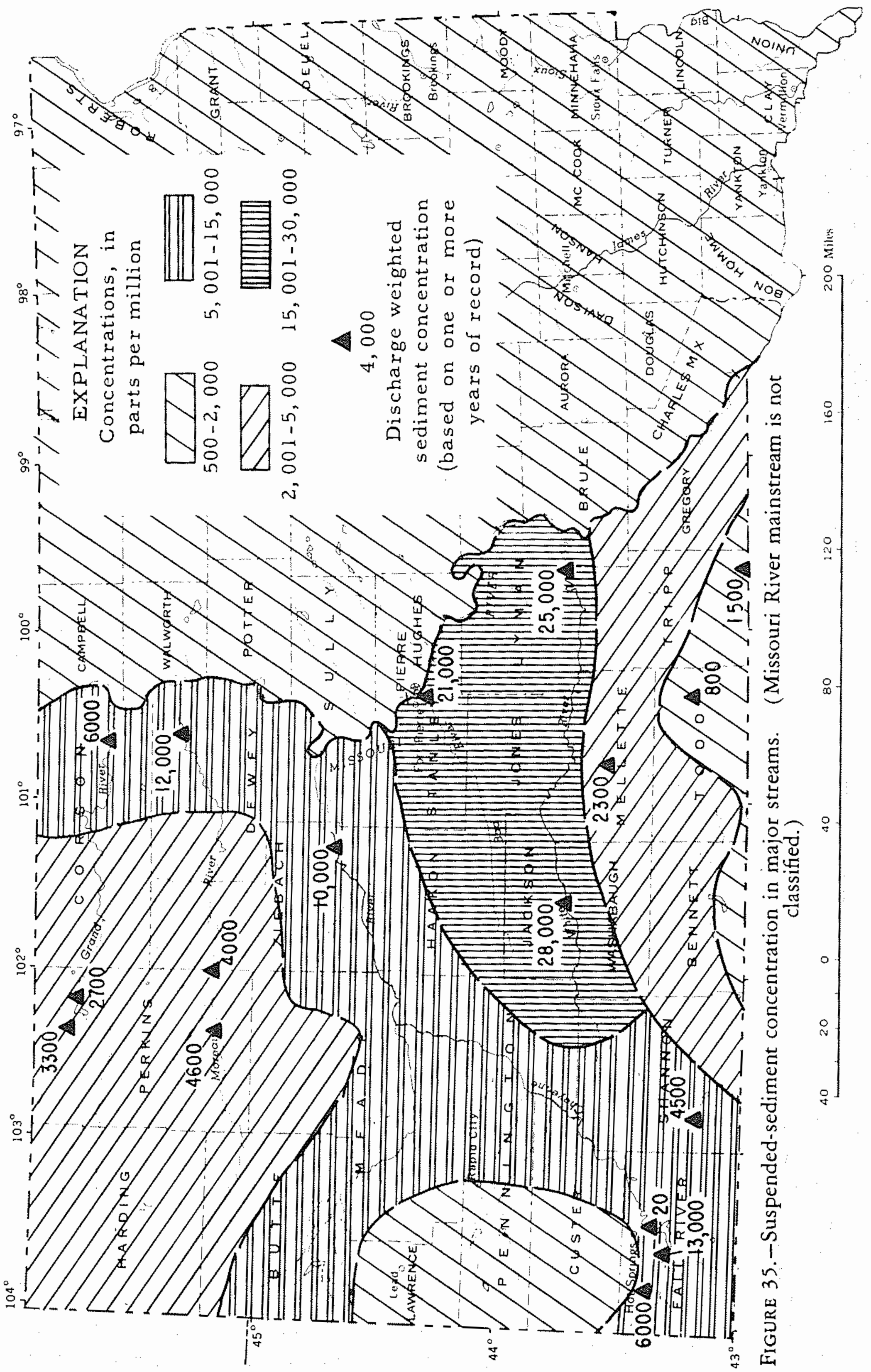

FIGURE 35.—Suspended-sediment concentration in major streams. (Missouri River mainstream is not classified.)

ably range from about 500 ppm in parts of the Black Hills and in the sandhills area along the Nebraska border to 30,000 ppm in parts of the White River and Bad River basins.

Usually sediment concentrations during short periods of rapid runoff that results from summer thunderstorms greatly exceed the long-term discharge-weighted concentrations. Maximum daily concentrations have been computed to be about 35,000 ppm in the White River, 55,000 ppm in the Cheyenne River, and 19,000 ppm in the Grand River. Much of the annual sediment discharge of such streams commonly occurs during a small part of the year; 90 percent or more of the annual sediment load may be discharged during less than 10 percent of the days. Thus, many streams that have extremely high concentrations during floods and that have high discharge-weighted concentrations have concentrations of only a few hundred parts per million during long periods of low flow each year.

Nearly all the suspended-sediment load of streams throughout the State is silt and clay; very little sand is transported in suspension.

The suspended-sediment load of a stream does not include sediment that may be moved in almost continuous contact with the streambed. Thus, the total sediment discharge of some streams may be significantly greater than the suspended-sediment discharge. For all major streams in South Dakota, however, the suspended-sediment load of the stream probably is 90 percent or more of the total sediment load.

In general, sediment concentration and sediment discharge increase as streamflow increases. During floods caused by thunderstorms the maximum sediment concentration may precede by several hours the maximum stream flow. Also, the sediment concentration during high streamflow that results from snowmelt probably is significantly less than the concentration during similarly high streamflow that results from intense summer thunderstorms.

The construction of dams and reservoirs on a stream results in marked changes in sediment concentration and discharge characteristics. Nearly all the sediment that enters a reservoir on a major stream is trapped; the water that is released from the reservoir contains very little sediment. For example, the average sediment concentration in the water that enters Angostura Reservoir on the Cheyenne River in extreme southwestern South Dakota is greater than 10,000 ppm; the average sediment concentration of the water that is released from the reservoir is less than 50 ppm. Thus a 99.5 percent decrease in average suspended-sediment concentration results as the water passes through the reservoir.

Although zones in which discharge-weighted concentrations generally are similar can be outlined as in figure 35, erosion, sediment yield, and sediment concentrations may have a wide range within any given zone. If sediment data are obtained only for the major streams, the data can lead to an erroneous conception of uniform erosion, sediment yield, and sediment concentrations throughout a basin of several hundred or thousand square miles. The data for such streams should be considered as a composite of data from inumerable small basins and parts of basins in which erosion and sediment yield characteristics differ markedly. The contribution of large percentage of the sediment load of a basin by a minor part of the basin is analogous to discharge of a large percentage of the annual sediment load during a small part of the year.

Sedimentation data on major streams are useful in defining the utility of water or in determining the amount of space that should be allocated for sediment storage in reservoirs, but data on major streams are not particularly useful for determining the source of the sediment and the effect of conservation programs within small parts of the major basin. Nearly all sediment data in South Dakota have been obtained for design purposes or for post-construction evaluation in that part of the State west of the Missouri River. The data are insufficient to determine the relative importance of sheet, gully, and channel erosion; the relation between the natural environment and the sediment yield and erosion rates in small areas; or the effect of small agricultural reservoirs and other conservation practices on the sediment yield of a basin.

DEVELOPMENT OF SURFACE WATER

Surface-water use

The major uses of surface water include irrigation, municipal, industrial, and stock water supplies, waste dilution, conservation and propagation of wildlife, recreation, and production of hydroelectric power. A complete discussion of the major surface-water uses listed above is contained in part II of this report.

Surface-water problems

South Dakota's primary surface-water problems are those related to water supply, which is variable and commonly inadequate unless storage facilities are provided. Maintenance of an adequate supply requires that water be stored in periods of considerable runoff for use during periods of little runoff. It is not merely a matter of storing spring runoff for use during the summer and fall, as it often is with mountain streams, but rather it is a matter of storing runoff for use a number of years hence. Even with the low normal runoff there is the problem of large floods.

The basic problems of evaluating the supply, and planning for its utilization and management to meet present and future demands requires solution of many complex technical problems. Adequate basic information regarding both quantity and quality of water is essential. Long-term, continuous records of flow are necessary to plan appropriate storage facilities and to design spillways to pass floods. Adequate knowledge of the quality of water is essential to determine if the water is suitable for intended use. Lack of sufficient basic data has often caused delay or abandonment of a project. Projects designed and completed without sufficient data may not fulfill the desired purpose.

In South Dakota long-term stream-gaging records are available only on the principal rivers. Additional data are needed and the stream-gaging program is being expanded to include many additional streams. Continued expansion will be necessary to provide for future needs. Quality-of-water data are insufficient and there is a definite need for expansion of this program.

Use of refined techniques for the analysis and interpretation of basic data will provide more usable data and should be intensified. For example, statistical studies can be accomplished by the use of electronic computors. Duration tables, frequency computations, and other statistical data, which formerly required tedious calculation, now can be obtained relatively easily.

GROUND WATER

GENERAL STATEMENT

South Dakota is underlain by consolidated to semiconsolidated sedimentary rocks of Paleozoic, Mesozoic, and early Tertiary age. These rocks are mantled in the High Plains by semiconsolidated to unconsolidated sediments of middle and late Tertiary age, and in virtually all the area east of the Missouri River by glacial drift of Quaternary age. The drift ranges in thickness from a thin veneer along the Missouri River to a maximum known thickness of 700 feet in the northeastern part of the State. Extensive deposits of alluvium and some glacial outwash are found in the Missouri River Valley and in most stream valleys in the glaciated area. The sedimentary rocks of Paleozoic and Mesozoic age form a shallow basin lying between the structurally high areas of the Black Hills in the west, and the nearly buried Sioux Quartzite ridge in the east. The strata dip gently except near the Black Hills where they are upturned steeply.

Precambrian basement rocks crop out in the core of the Black Hills in the western and southwestern parts of the State, in a small area near Milbank (Grant County) in the northeastern part of the State, and in small areas of Minnehaha, Turner, McCook, and Hanson Counties in southeastern South Dakota.

Ground-water reservoirs constitute a large and reliable source of water for domestic, industrial, stock, and municipal use. Most of the State is underlain by one or more aquifers that yield small to very large supplies of water of varying quality. The major undeveloped source of water in South Dakota is in ground-water aquifers.

Artesian water has been very important in the settlement of the State, and in the development of agriculture, the chief industry. Artesian aquifers from which water flows, or can be pumped from moderate depth, underlie nearly all the State. Shallow ground water is absent or scarce in much of the State, especially in the unglaciated western two-thirds. Hence, the availability of artesian water and the development of low-cost methods of drilling deep wells were of special importance in bringing about settlement, which otherwise might have been confined to river valleys where water is available from shallow deposits of alluvium. Much of the artesian water is of poor chemical quality, but it has been used nevertheless. Any large-scale utilization of the enormous quantities of saline ground water contained in the deeper aquifers underlying central and western South Dakota will depend upon development of an economic conversion process for saline water.

In recent years, the potential importance of ground water from the glacial drift in the eastern part of the State and from unconsolidated deposits in the western part has become more generally realized. Most current ground-water studies are devoted to these unconsolidated rock aquifers.

Discharge from shallow aquifers on both sides of the Missouri River is by pumping or flow from wells, by transpiration by plants, and by seepage to springs, lakes, and streams that intercept the water table.

Discharge from the deeper aquifers is mostly by flowing or pumped wells. Some water is discharged from the bedrock aquifers in isolated areas around the Black Hills where artesian springs occur. In other areas, water is discharged by the deeper aquifers to overlying aquifers through semipermeable, confining beds.

Recharge to the shallow aquifers in both the glaciated and unglaciated areas of the State is largely through infiltration of precipitation that falls upon the immediate area.

The mechanics of recharge to the deeper aquifers is not yet fully understood; however, some recharge doubtlessly occurs in the Black Hills where streams cross the exposed surfaces of the aquifers. Additional recharge possibly occurs to the west where the deeper aquifers crop out in the Rocky Mountains.

Table 26 lists, for the principal bedrock aquifers in the State, the geological age to which each belongs (in descending order as the rock strata are penetrated by the drill), and summarizes the approximate area and maximum thickness, the ground-water potential, the state of development, and the salinity of the water. The latter three items are shown by numbers from 0 through 5 to facilitate comparisons.

TABLE 26.—*Principal bedrock aquifers in South Dakota*

Aquifer and geologic age	Estimated extent (square miles)	Maximum thickness (feet)	Estimated potential as aquifer [1]	State of development [2]	Salinity of water [3]
Ogallala Formation, Pliocene	3,000	250+	3	1	1–2
Arikaree Formation, Miocene	5,000	1,000	3	1	1–2
White River Group, Oligocene	(4)	600	0–1	0–1	1–3
Fort Union Formation, Paleocene	2,700	1,000	1	2	2–4
Hell Creek Formation, Upper Cretaceous	8,700	425	1	1	3
Fox Hills Sandstone, Upper Cretaceous	11,600	250	1	3	1–3
Niobrara Formation and Codell Sandstone Member of Carlile Shale, Upper Cretaceous	50,000+	180	3	3	3–4
Greenhorn Limestone, Upper Cretaceous	50,000+	180+	1	3–4	4–5
Dakota Sandstone, Upper and Lower Cretaceous	33,000	460	5	4	3–5
Newcastle Sandstone, Lower Cretaceous	(4)	50	1	0	3–5
Inyan Kara Group, Lower Cretaceous	46,000	600	3	1–2	3–5
Sundance Formation, Upper Jurassic	40,000	450	0–1	1	5
Minnelusa Formation, Pennsylvanian and Permian	37,000	1,300	3	1	1–5
Pahasapa Limestone and Madison Group, Mississippian	39,000	1,000+	3–4	0–1	1–5
Whitewood Dolomite and Red River Formation, Upper Ordovician	35,000	550	5	0	3–5
Winnipeg Formation, Middle Ordovician	30,000	180	3	0	3–5
Deadwood Formation, Lower Ordovician and Upper Cambrian	(4)	450+	2	1	2–5

[1] 0 indicates an aquifer of almost no potential and 5 an aquifer of high potential.

[2] 0 indicates a virtually undeveloped aquifer, 1 to 3 indicate increasingly greater withdrawal, 4 indicates a withdrawal about equal to the amount of water an aquifer can supply without further decline in rate of yield, and 5 indicates withdrawal in excess of estimated current replenishment.

[3] 1 to 5 indicate the following concentrations, in parts per million of dissolved solids: 1—0 to 500; 2—500 to 1,000; 3—1,000 to 2,000; 4—2,000 to 3,000; 5—3,000 or more.

[4] Unknown.

GROUND WATER EAST OF THE MISSISSIPPI RIVER

Glacial drift

One of the major undeveloped ground-water systems in the State is the glacial drift that blankets South Dakota east of the Missouri River. Several hundred million acre-feet of water, much of it suitable for irrigation, is stored in glacial outwash and alluvium. These deposits are irregular in shape and size, and are scattered throughout the area, but they should be easy to develop once they are located and mapped. Figure 36 shows areas in the State where glacial deposits containing large amounts of shallow ground water are known to occur, and areas that are considered to have good potential for additional large, shallow, ground-water supplies.

Glacial drift constitutes the surface deposits over most of the area east of the Missouri River. It is as much as 700 feet thick near Eden in Marshall County in the northeast part of the State (U.S. Geological Survey, unpublished information) but the average thickness is much less; perhaps no more than 40 feet (Flint 1955, p. 27). The drift consists mainly of clay with admixed sand, gravel, and boulders, but contains lenses or surficial sheets of outwash sand and gravel which collectively constitute the most promising source of ground water of good quality for future development in the State.

Aquifers in the glacial drift have been extensively developed in several areas in eastern South Dakota. One area of approximately 886,000 acres, in the vicinity of the James River between Aberdeen and Woonsocket, is underlain by sand and gravel that ranges in thickness from 10 feet to more than 100 feet. This area, including parts of Sanborn, Beadle, Spink, Hand, and Brown Counties, may contain more than 11 million acre-feet of ground water in transient storage. In three parts of the area, totaling more than 80,000 acres, the thickness of the sand and gravel deposits exceeds 100 feet. An additional major source of ground-water supply, a buried outwash aquifer underlying much of Clay County, is estimated to contain 6 million acre-feet of water in transient storage. The areas where the permeable deposits are thickest bear little relation to the distribution of surficial materials; similar conditions have been observed in other areas studied and doubtless will be shown in future studies in other parts of eastern South Dakota.

Surficial deposits, especially along perennial streams, are easily recharged and are obvious and readily accessible sources for immediate ground-water development. Most of them are either supplying water or have a water-supply potential. They are usually narrow, and are along nearly all the larger streams, including most of the course of the Missouri River through the State, many of the creeks that enter the Missouri, and the James, Vermillion, and Big Sioux Rivers and their principal tributaries. The largest areas of surficial outwash occur in widened portions of some of the river valleys, such as that of the Missouri downstream from Yankton, the James River in northern Beadle County and southern Spink County, the Big Sioux and Deer Creek valleys in the vicinity of Brookings, and the Big Sioux valley in the vicinity of Sioux Falls.

Large surficial outwash deposits bearing little or no relation to present streams include one in Campbell and northern Walworth Counties crossing the Spring Creek valley and underlying Mound City, one east

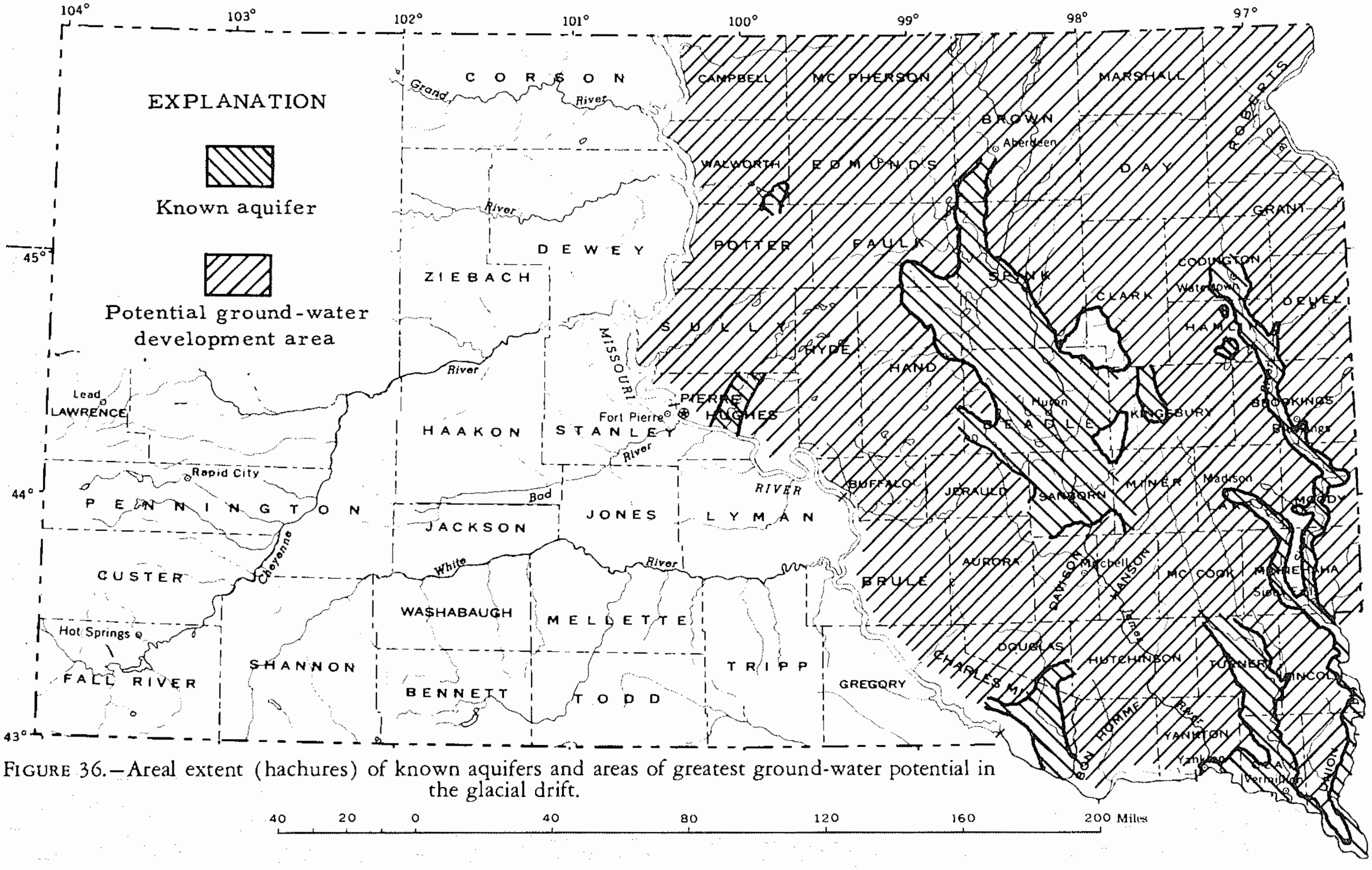

FIGURE 36.—Areal extent (hachures) of known aquifers and areas of greatest ground-water potential in the glacial drift.

of Swan Lake in southeastern Walworth and northeastern Potter Counties, one south of Redfield, one east of Woonsocket, and a long, narrow deposit extending from north of Clark in Clark County to beyond Lake Thompson in Kingsbury County, then passing down the east fork of the Vermillion River. Of the above aquifers, only that north of Huron, and the aquifer along the Vermillion River in the Parker-Centerville area have been developed substantially.

Deeper aquifers

Precambrian rocks.—The Sioux Quartzite of Precambrian age underlies most of southeastern South Dakota (fig. 5); it crops out beneath the glacial drift in a sizable area, and crops out in small areas, in Hanson, McCook, Minnehaha, and Turner Counties. It consists of massive quartzite interbedded with thin shale and a few zones of poorly cemented quartz sand. Locally, it yields small quantities of water from fractures or from porous zones.

Dakota Sandstone.—The Dakota Sandstone underlies about 33,000 square miles in eastern South Dakota. As used in this report, the Dakota Sandstone refers to those rocks in eastern South Dakota which may in part be correlative with rocks assigned to the Belle Fourche, Mowry, Newcastle, and Skull Creek Formations, and the Inyan Kara Group in the Black Hills. It consists of soft, fine- to moderately fine-grained, porous, light-gray sandstone interbedded with dark- to light-gray shale, and is as much as 460 feet thick. The depths of wells penetrating the Dakota in eastern South Dakota range from about 300 feet near the Sioux Quartzite ridge and in extreme southeastern South Dakota to about 1,400 feet near the Missouri River; in the James River valley in central South Dakota, they range from about 750 feet to 1,100 feet. In some areas in eastern South Dakota, wells finished in the Dakota flow; in other areas they must be pumped. Flows range from a maximum of about 1,500 gpm (gallons per minute) in the Missouri River valley to less than 10 gpm in the James River valley in central South Dakota, and about 10 to 15 gpm in southeastern South Dakota.

The Dakota Sandstone is a major source of ground water in eastern South Dakota. It is not uniformly permeable, but yields water in varying amounts from zones of relatively great permeability separated by zones of lesser permeability. In parts of eastern and central South Dakota there are two aquifers in the Dakota; the deeper aquifer is commonly called the second flow by residents and drillers. As many as seven separate zones are recognized in some places in the central part of the State.

The Dakota Sandstone is tapped by thousands of flowing and pumped wells in eastern South Dakota, but is developed most heavily in the James River basin where the total discharge (1960) of 16 mgd (millions of gallons per day) is probably declining slowly towards the rate of maximum sustained yield. Information in the files of the U.S. Geological Survey indicates that a total of about 40 mgd was withdrawn from the Dakota Sandstone in 1960; about 36 mgd from flowing wells and 4 mgd from pumped wells. Most of the withdrawal was in the Missouri River valley, the valleys of its tributaries, and the James River valley. Water from the Dakota is not suitable for irrigation because of its high salinity hazard.

Figure 37 shows the areal extent of the Dakota Sandstone in South Dakota where it is more than 50 feet thick.

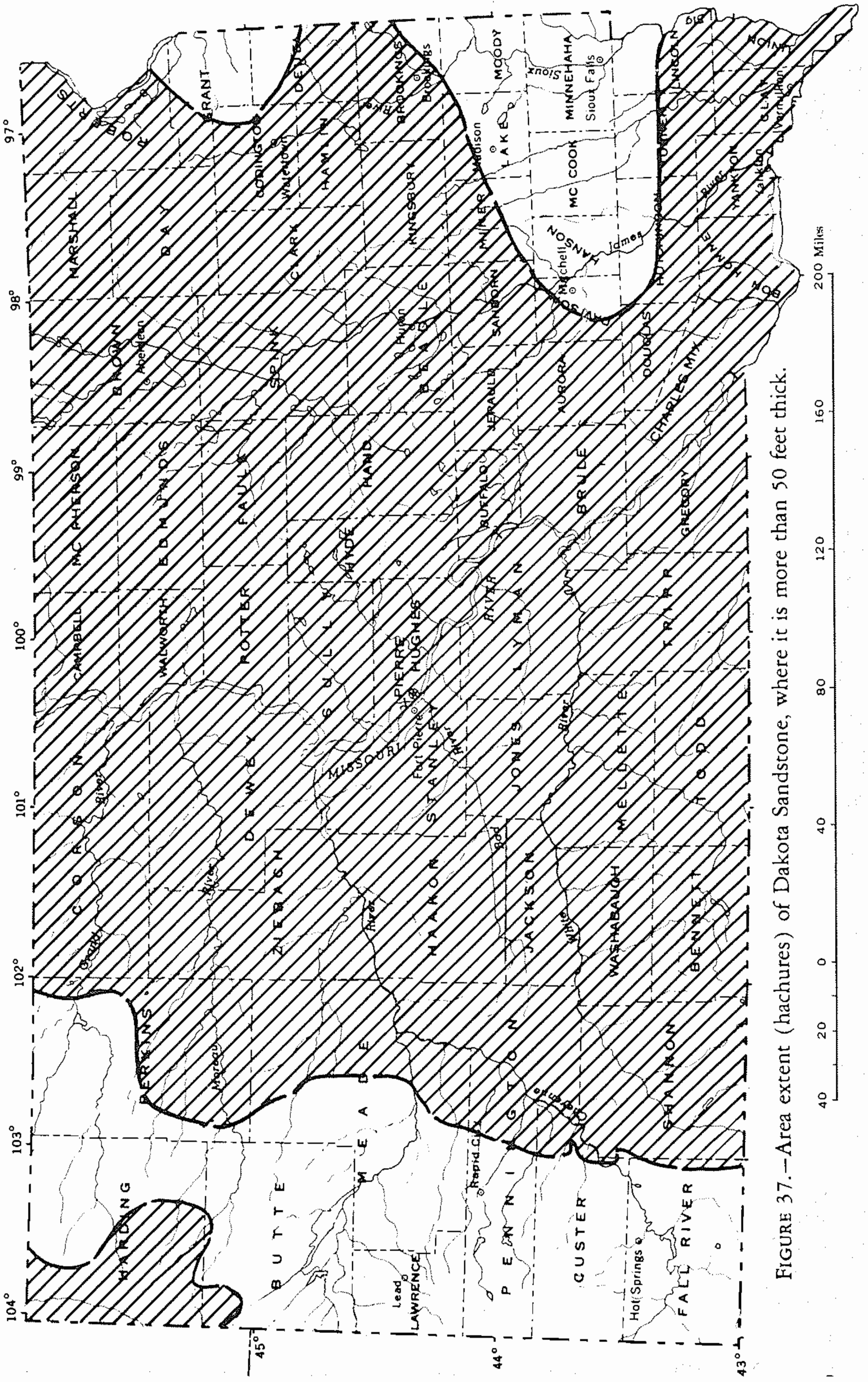

FIGURE 37.—Area extent (hachures) of Dakota Sandstone, where it is more than 50 feet thick.

Greenhorn Limestone.—The Greenhorn Limestone of Late Cretaceous age underlies virtually all the State except for the area of older rocks in the Black Hills, the area of Millbank Granite in the northeastern part of the State and the areas where the Sioux Quartzite is the bedrock in southeastern South Dakota. In the eastern part of the State, the Greenhorn is generally a dark-gray, calcareous shale and thin shaly limestone, but in the western part, where the thin Orman Lake Limestone Member is at the base there is as much as 30 feet of slabby, impure limestone at the top of the Greenhorn. The Greenhorn ranges in thickness from about 30 feet in southeastern South Dakota to about 250 feet in western South Dakota. In the eastern part of the State, the Greenhorn yields soft, saline water to some wells that are used for stock and domestic supplies. In some areas, flowing wells yield about 5 gpm, but most wells must be pumped. The Greenhorn is not widely used as an aquifer, and its potential for additional development is very small. Unpublished information in the files of the U.S. Geological Survey indicates that the artesian pressure in the aquifer is low, and that it has decreased since 1890.

Carlile Shale and Niobrara Formation.—Above the Greenhorn Limestone are the Carlile Shale and Niobrara Formation of Late Cretaceous age, which crop out around the Black Hills and underlie an area similar to that underlain by the Greenhorn. Both the Carlile and the Niobrara crop out locally in southeastern South Dakota, and the Niobrara crops out along the Missouri River at, and south of, Fort Thompson.

The Carlile Shale consists of as much as 500 feet of shale ranging from dark gray at the bottom to light gray at the top. It contains many large concretions in sandy layers. The Codell Sandstone Member, a fine-grained quartz sandstone as much as 80 feet thick, is at or near the top of the Carlile. The Niobrara Formation is a chalky marl containing shale and clay that ranges in thickness from 120 feet in the east to about 300 feet in western South Dakota.

The Codell and Niobrara appear to form a single aquifer as much as 180 feet thick in eastern South Dakota. Water from this aquifer is generally soft and saline. The aquifer is developed for stock and domestic use in central South Dakota and in the southern James River basin.

GROUND WATER WEST OF THE MISSOURI RIVER

Precambrian rocks

Precambrian basement rocks consisting of schist, quartzite, slate, marble, pegmatite, granite, and amphibolite crop out in perhaps 1,500 square miles in the core of the Black Hills uplift in Lawrence, Meade, Pennington, and Custer Counties. These rocks discharge some tens of thousands of acre-feet per year of water of good quality into streams through springs and seeps emerging from rock fractures. Small quantities of water can be obtained locally in the Black Hills area by wells penetrating these rocks.

Deadwood Formation

The Deadwood Formation of Late Cambrian and Early Ordovician age crops out around the Black Hills and underlies a large area north and east of the Hills. The Deadwood has a maximum known thickness of 450 feet in the Black Hills but is thicker in the subsurface (Sandburg, 1962). It consists of quartz sandstone, which is commonly conglomeratic, gray and green shale, and limestone. Where it is thickest, it is a soft, thin-bedded, sandstone interbedded with clay. Aquifers in the Deadwood Formation yield small to moderate amounts of good to saline water for stock and domestic supplies; locally, the aquifers can support a modest increase in withdrawal.

Winnipeg Formation

Sandstone and shale of the Winnipeg Formation of Middle Ordovician age overlie the Deadwood Formation in the northern Black Hills and in the subsurface north and northeast of the Black Hills. The formation has a maximum known thickness of 180 feet in north-central South Dakota (Sandburg, 1962). A sandstone unit of the Winnipeg is reported to yield saline water under artesian pressure, where it has been penetrated by oil testholes in northwestern South Dakota. The water in the formation has not been used and the undeveloped potential is unknown, but on the basis of reported yields it is estimated to be about average.

The areal extent of the Winnipeg Formation is shown in Figure 38.

Whitewood Dolomite and Red River Formation

The Whitewood Dolomite of Late Ordovician age crops out in a narrow band around the northern side of the Black Hills. The equivalent subsurface formation, the Red River, thickens eastward and northward from the Hills and, as shown on Figure 39, underlies about 35,000 square miles in the western, northwestern, and north-central parts of the State. It extends south to Pennington County, east to Brown County, and southeast to 20 or 30 miles northwest of Pierre. The Red River consists of massive, buff limestone and dolomite with a maximum thickness of about 550 feet in northern Perkins County. It contains an enormous volume of saline water under high artesian pressure at temperatures as high as 185°. Aquifers in the Red River are not used as a source of water in South Dakota.

Uppermost Ordovician, Silurian, and Devonian rocks

Rocks of latest Ordovician, Silurian, and Devonian age, except for the Englewood Formation of Devonian and Mississippian age, do not crop out, but are present in the subsurface in northwestern and north-central South Dakota (Sandberg, 1962). They have not been developed as sources of water, and their potential as aquifers, while thought to be small, is unknown. Water contained in the Uppermost Ordovician Silurian, and Devonian rocks is probably highly saline.

Pahasapa Limestone and Madison Group

In the Black Hills, the Pahasapa Limestone, which is equivalent to the lower part of the subsurface Madison Group of Mississippian age, is fine-grained, massive, light-gray to buff-colored limestone and dolomite containing numerous caverns, some of which are lined with calcite crystals. The outcropping Pahasapa ranges in thickness from about 250 to 600 feet; its subsurface equivalent, the Madison Group, thins to the south and east, and in the central and southern parts of the State it pinches out between the Minnelusa Formation and pre-Mississippian rocks.

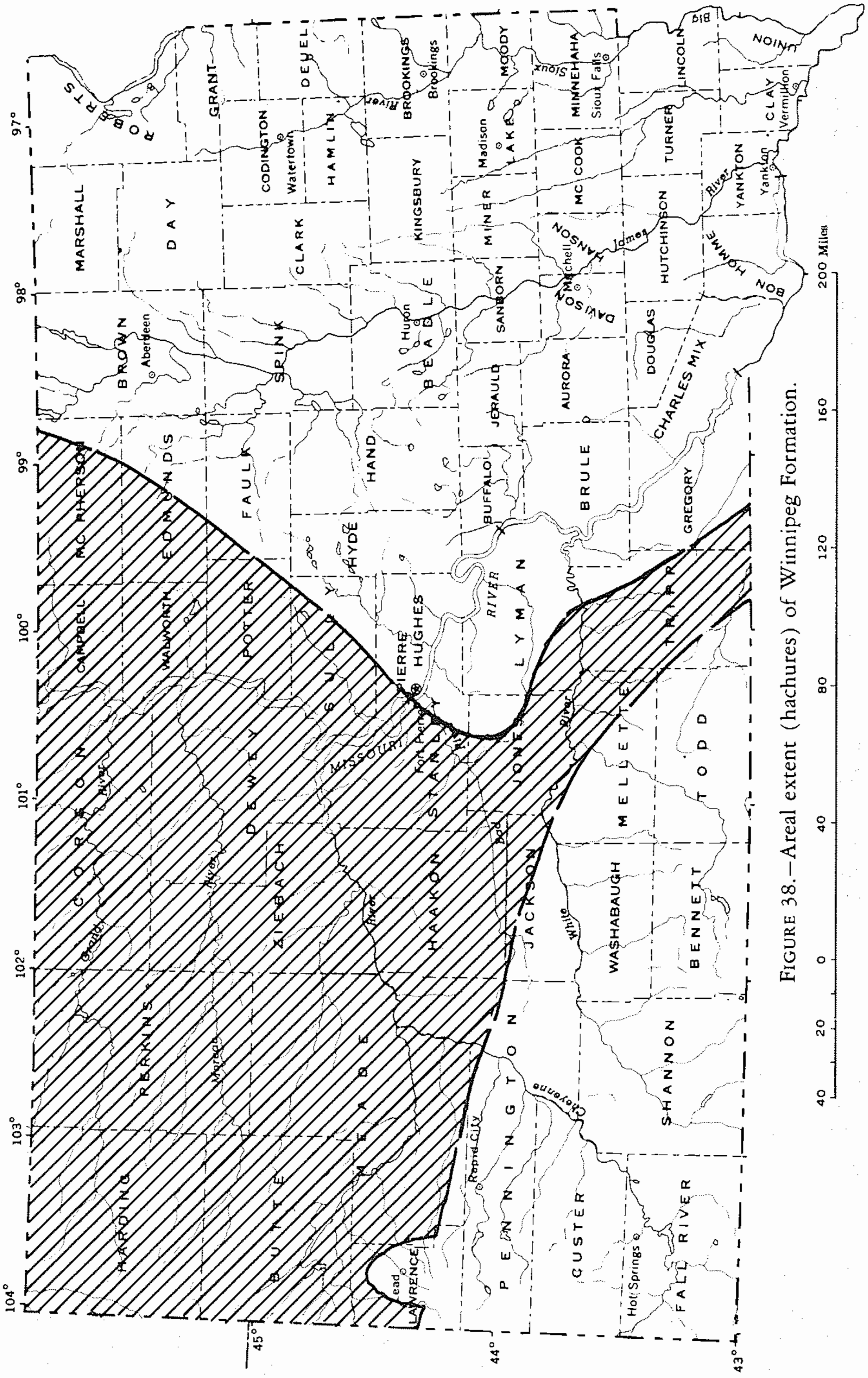

FIGURE 38.—Areal extent (hachures) of Winnipeg Formation.

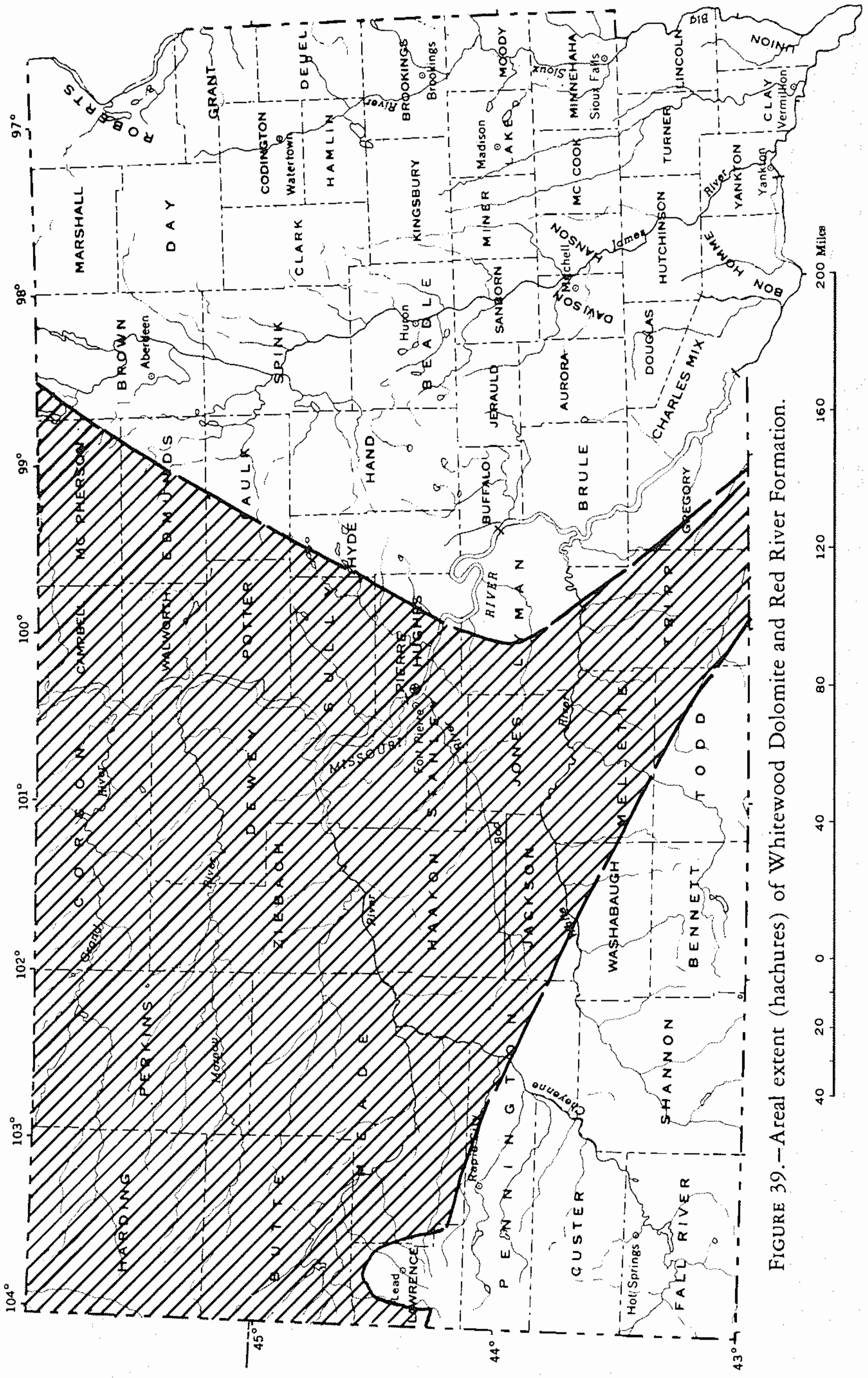

FIGURE 39.—Areal extent (hachures) of Whitewood Dolomite and Red River Formation.

The subsurface Madison Group yields large quantities of good to saline water that is under high artesian pressure. Several wells in the Madison are more than 4,000 feet deep and flow more than 100 gpm. These wells supply stock water for ranches and municipal supplies for the towns of Philip, Midland, and Eagle Butte. The Madison has a high potential for future development. The Pahasapa outcrop encircles the Black Hills, and surface streams that cross it lose all or part of their water to the formation. Much of the recharge to the Madison is accomplished in this manner.

Figure 40 shows the areal extent of the Pahasapa Limestone and Madison Group.

Minnelusa Formation

The Minnelusa Formation, the only rock unit of Pennsylvanian age reported in South Dakota, includes beds of Permian age in its upper part. At its outcrop in the Black Hills, the Minnelusa is predominantly a white and red, calcareous sandstone. Locally, it contains limestone in the middle and lower parts, and the basal part is bright red shale with thin layers of white limestone. The Minnelusa ranges from 300 to 850 feet thick at its outcrops around the Black Hills, and has a maximum thickness of 1,300 feet near the southwest corner of the State. It thins to the east and northeast, and the areal extent in these directions is not definitely known.

Several irrigation wells near the northern Black Hills obtain good quality irrigation water from the Minnelusa. A well penetrating the Minnelusa near Sturgis initially yielded 4,000 gpm at a temperature of 68° F. The flow was later reduced to about 750 gpm at a closed-in pressure of 160 psi (pounds per square inch). The Minnelusa could support a much higher yield than it does at present.

Sundance Formation

The Sundance Formation of Late Jurassic age underlies about 40,000 square miles of western South Dakota. It consists of as much as 450 feet of gray-green shale with some limestone, sandstone, and red shale. At its outcrop in the Black Hills area, the formation ranges in thickness from 200 to 300 feet. Water in the Sundance is reported to be highly mineralized, although locally near its outcrop it yields less mineralized water that is suitable for domestic use.

Inyan Kara Group

The Inyan Kara Group comprises the Lakota and Fall River Formations of Early Cretaceous age in South Dakota. The basal Chilson Member of the Lakota Formation, formerly considered a separate formation, underlies a large area in western South Dakota, but is indistinguishable from the rest of the Inyan Kara Group a short distance east of the Black Hills. The Chilson Member is a hard, coarse, locally conglomeratic sandstone, which has a maximum known thickness of 485 feet. It is a permeable and productive aquifer but, except in and near the area of outcrop in the Black Hills, it yields saline water that usually is under enough pressure to flow from wells. The supply is developed moderately and the formation could support a larger withdrawal even though the recharge is small and most of the water withdrawn would come from storage. The Chilson Member is overlain in the southeastern Black Hills by the thin and impermeable Minne-

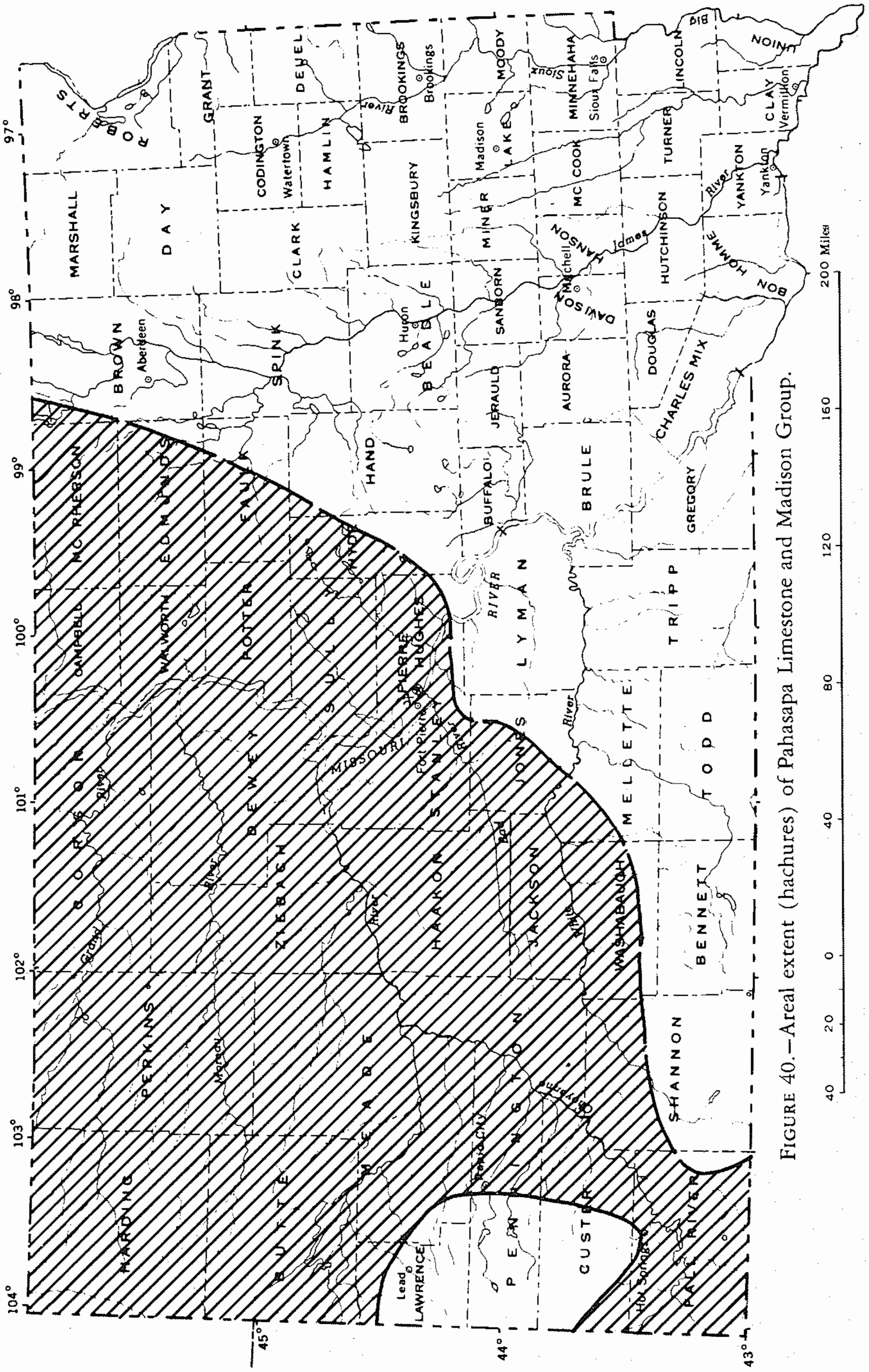

FIGURE 40.—Areal extent (hachures) of Pahasapa Limestone and Madison Group.

waste Limestone Member and the Fuson Shale Member. These were formerly recognized as separate formations. They are not considered to be aquifers.

The Fall River Formation overlies the Lakota Formation and covers a larger area, mainly in the western part of the State. It consists of as much as 200 feet of fine- to medium-grained, massive, white to buff sandstone containing thin layers of silt and clay. The Fall River is seldom differentiated in drill holes from the sandstone of the Lakota Formation below, and little is known of its water-bearing capacity; hence it is not listed in the table on properties of aquifers. The sandstone of the Fall River Formation and the Newcastle Sandstone are the "Dakota" Sandstone of older reports on western South Dakota and adjoining areas.

Figure 41 shows the areal extent of the Inyan Kara Group.

Newcastle Sandstone

The Newcastle Sandstone of Early Cretaceous age is above the Inyan Kara Group and separated from it by the intervening Skull Creek Shale. The sandstone is as much as 50 feet thick and covers an unknown area in western South Dakota and adjacent areas. It is an important producer of saline water in Wyoming, but its potential in South Dakota appears to be low.

Fox Hills Sandstone

The Fox Hills Sandstone of Late Cretaceous age crops out north, northeast, and east of the Black Hills. It consists of grayish-white to yellow sandstone and has a maximum thickness of 250 feet. The Fox Hills yields moderate quantities of water of good quality to properly constructed wells. Although it has only a modest potential as a source of water, the Fox Hills could support an increase in withdrawals. The formation supplies water for many farm and ranch wells and furnishes all or part of the municipal supplies for the cities of Dupree, Bison, Timber Lake, and Lemmon.

Figure 42 shows the areal extent of the Fox Hills sandstone.

Hell Creek Formation

The Hell Creek Formation is the youngest Cretaceous formation in South Dakota, and overlies the Fox Hills Sandstone in about 8,700 square miles of the northwestern part of the State. The Hell Creek is composed of alternating layers of somber-colored, soft, brown shale, gray sandstone, and sand, gravel, and clay layers. In its lower part, the Hell Creek is sandy and contains lignite lenses. Log-like concretions and lenses of iron carbonate are also common. The Hell Creek Formation supplies small amounts of highly mineralized water to farms and ranches west of the Missouri in Corson, Harding, Perkins, and Ziebach Counties and could support a modest increase in withdrawals.

Tertiary rocks

Fort Union Formation.—Three members make up the Paleocene Fort Union Formation in South Dakota. The basal Ludlow Member has a maximum thickness of 350 feet and is composed of gray clay and sandstone with thin beds of lignite. The Cannonball Member consists of marine green shale and yellow sandstone; it has a maximum known thickness of about 225 feet. The upper Tongue River Member consists of light-colored clay and sand, locally contains coal beds, and

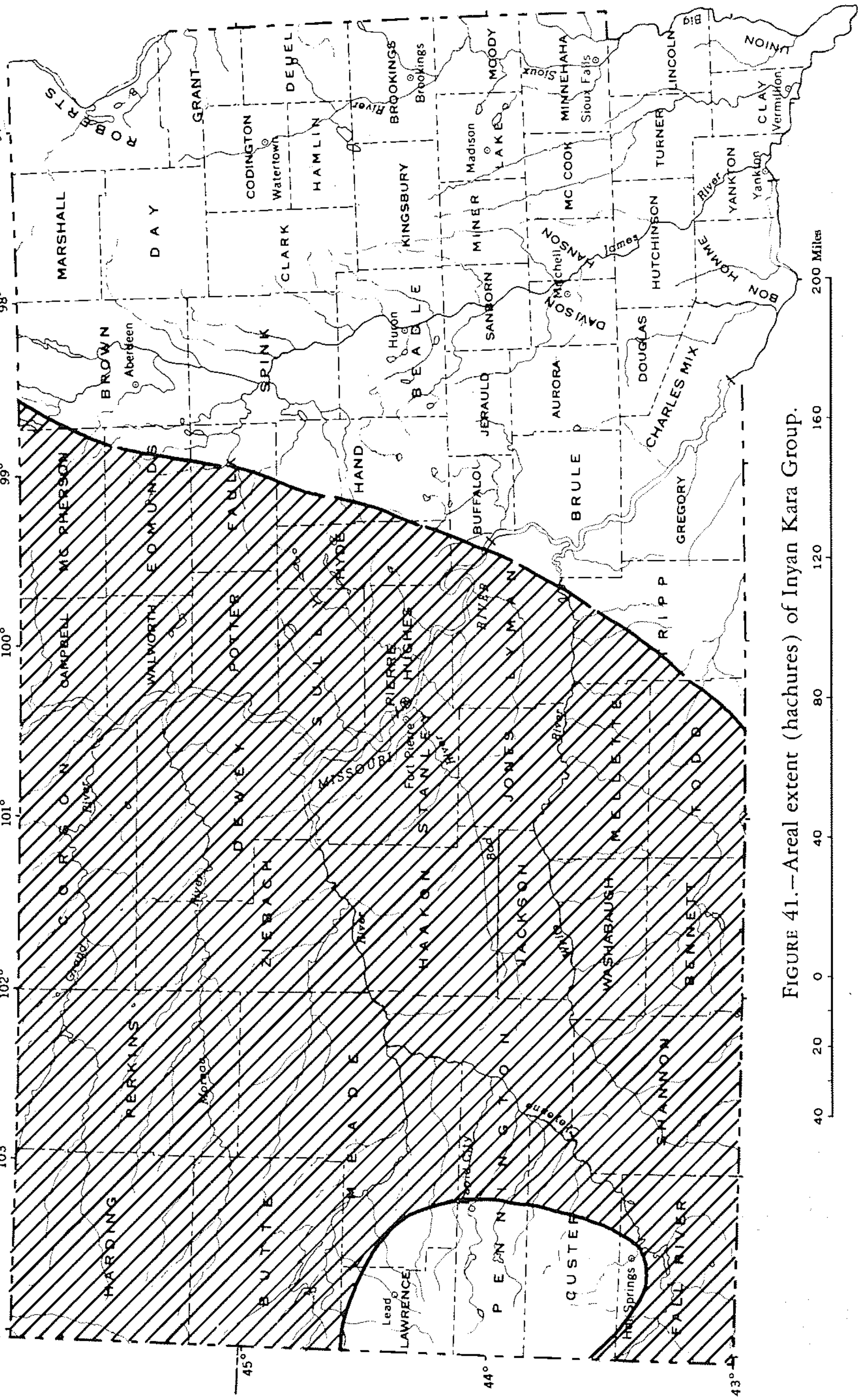

FIGURE 41.—Areal extent (hachures) of Inyan Kara Group.

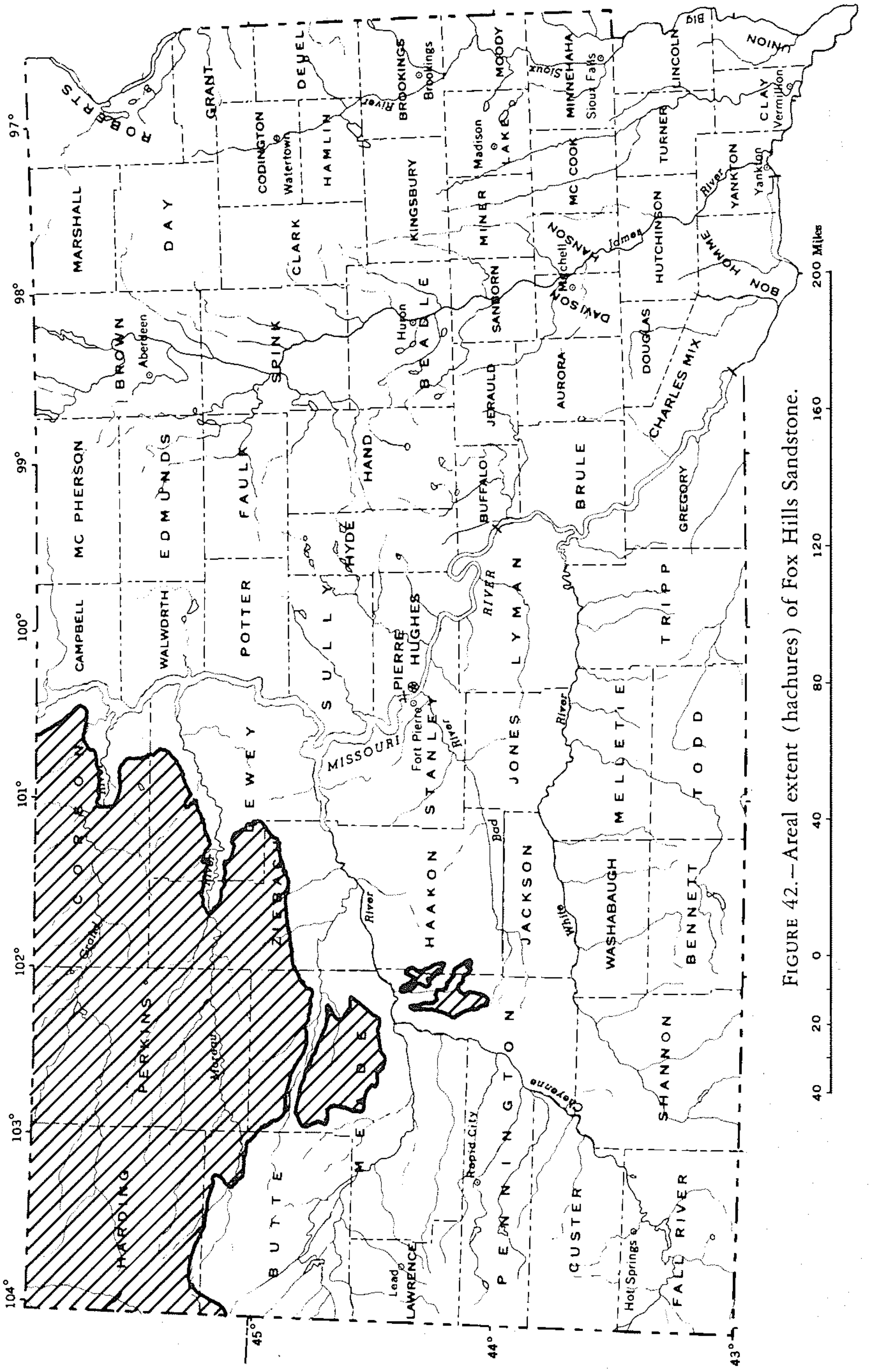

FIGURE 42.—Areal extent (hachures) of Fox Hills Sandstone.

has a maximum known thickness of about 420 feet. The Fort Union has a modest potential as a source of ground water, and is developed to a limited extent. The city of Lemmon obtains part of its water supply from two wells that tap the Fort Union. The Fort Union also supplies water to farms and ranches in parts of northern Perkins and Harding Counties; the water is saline, has a high sodium sulfate content and is barely potable.

White River Group.—The White River Group of Oligocene age consists of the basal Chadron Formation and the overlying Brule Formation. It has a maximum thickness of about 600 feet and consists of light-colored clay, channel sandstones, and limestone lenses. The Chadron is as much as 150 feet thick and the Brule as much as 450 feet thick. Both the Chadron and Brule yield small amounts of good quality water to shallow wells and a few springs in deeply incised valleys of the White River Badlands in southwestern South Dakota. As all water yielded by the Chadron and Brule is supplied by local precipitation, the amount of water available from them is limited by scant rainfall in the area of outcrop.

Arikaree and Ogallala Formations.—The Arikaree Formation of Miocene age is a soft, buff to light-gray, fine-grained, silty, sandstone. It is usually massively to poorly-bedded, but locally it contains lenticular beds of nodular concretions that consist of lime-cemented silt and sand. The Arikaree has a maximum known thickness of about 1,000 feet. The Pliocene Ogallala Formation has a maximum known thickness of more than 250 feet and consists of light-colored sand and silt. The Arikaree and Ogallala underlie about 5,000 and 3,000 square miles respectively in the High Plains area south of the outcrop of the White River Group as shown on Figure 43. The Arikaree and Ogallala are only moderately permeable, and hence, wells that are intended for irrigation use must penetrate 150 to 200 feet of saturated material to obtain sufficient water. Stock and domestic wells, on the other hand, generally obtain sufficient water if they penetrate from 15 to 30 feet of saturated material. Water from the Arikaree and Ogallala is of good quality for both irrigation and domestic use.

CHEMICAL QUALITY

Ground water is used for about 96 percent of the municipal supplies in South Dakota. Because the public supplies are widely distributed throughout the State and because they generally obtain water from the most economical aquifers in their respective areas, data on the chemical quality of the water for public supplies provide good information on the general quality of the readily available ground water throughout the State.

Chemical analyses of ground water for about 235 separate public supplies are given by the South Dakota Department of Health (South Dakota Public Water Supply Data, 1959). Data for selected chemical constituents from these analyses are given in table 27.

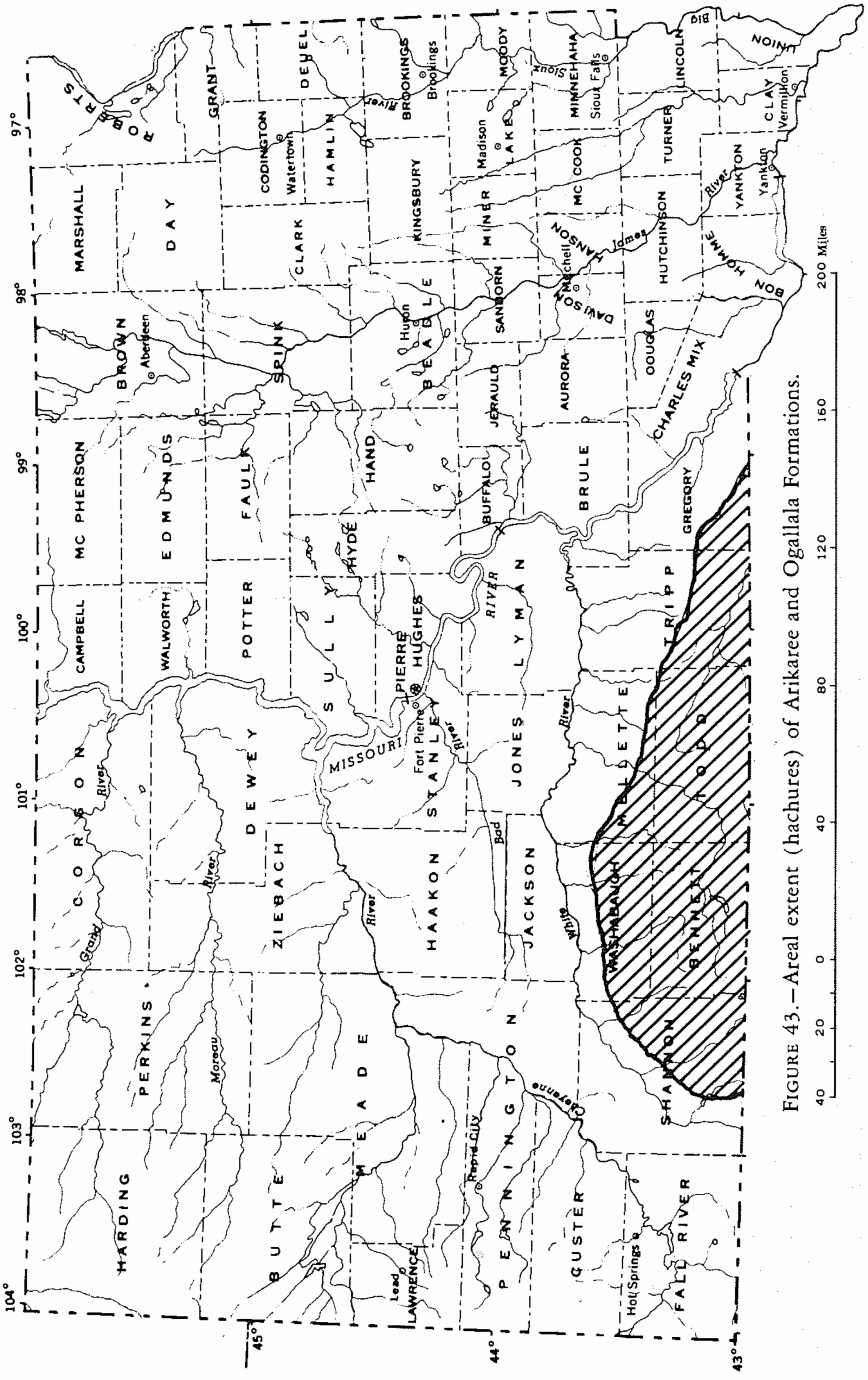

FIGURE 43.—Areal extent (hachures) of Arikaree and Ogallala Formations.

TABLE 27.—*Selected data on chemical analyses of public ground-water supplies*

Constituents	Concentration in ppm	Percentage of public ground-water supplies exceeding stated concentration
Dissolved solids	500.0	88
	1,000.0	65
	1,500.0	48
	2,000.0	32
Hardness as $CaCO_3$	60.0	87
	120.0	82
	180.0	77
	300.0	63
	600.0	34
Iron	.3	65
	1.0	39
	3.0	12
Manganese	.1	46
	.3	30
	1.0	13
	3.0	0
Fluoride	.8	68
	1.5	31
	3.0	10

Table 27 indicates that, in general, the water for public supplies has a high dissolved-solids content, which consists mainly of sulfate and either calcium or sodium. The water for most of the supplies is very hard (more than 180 ppm as $CaCO_3$). Both iron and manganese are present in troublesome concentrations (more than 0.3 ppm and 0.1 ppm, respectively) in water for about half the supplies. Concentrations of fluoride are high in water for many of the supplies.

The general chemical quality of water from most of the principal aquifers is indicated in table 28. Because the quality of water from various locations within individual aquifers may differ greatly, at least two analyses are given for each aquifers. The analyses for the Fort Union Formation are of water from southwestern North Dakota.

The range in chemical quality of water within many of the individual aquifers is greater than the range between aquifers. The water from glacial drift probably has a greater range than the water from any of the other principal aquifers. Quality ranges in individual aquifers are due to local differences in factors such as recharge, chemical and physical properties of the materials that compose the aquifer, and the nature of the overlying material through which water infiltrates to the aquifer.

TABLE 28.—*Typical analyses of water from principal aquifers*

[Constituents are in parts per million unless otherwise shown]

Temperature (° F.)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue on evaporation at 180° C.)	Hardness as $CaCO_3$
GLACIAL DRIFT															
62.0	20.0	0.10	2.0	337.0	175.0	158.0	19.0	436	1,430.0	30.0	0.3	0.1	1.2	2,570	1,560
46.0	30.0	.03	.14	83.0	36.0	15.0	5.6	323	103.0	3.2	.3	16.0	.06	465	355
49.0	28.0	4.2	----------	455.0	145.0	406.0	15.0	469	2,080.0	81.0	.5	.1	.65	3,700	1,730
DAKOTA SANDSTONE															
80.0	13.0	10.0	0.20	416.0	93.0	79.0	19.0	168	1,270.0	105.0	2.9	0	0.22	2,270	1,420
55.0	9.0	.37	.07	55.0	13.0	543.0	15.0	118	1,190.0	67.0	1.2	.1	1.5	1,990	190
INYAN KARA GROUP															
----------	10.0	1.6	0.86	230.0	71.0	132.0	10.0	132	961.0	20.0	0.4	2.6	0.08	1,550	866
119.0	27.0	.38	0	8.7	1.1	760.0	5.8	988	695.0	90.0	7.2	0	1.5	2,110	26
80.0	12.0	5.1	.25	388.0	86.0	131.0	19.0	172	1,320.0	62.0	3.1	.3	.38	2,240	1,320
GREENHORN LIMESTONE															
55.0	8.7	3.5	0.15	313.0	82.0	159.0	20.0	148	1,200.0	63.0	2.4	0	0.79	2,100	1,120
54.0	7.8	2.2	.01	14.0	3.6	688.0	8.6	248	1,220.0	83.0	3.0	.3	3.6	2,190	50
NIOBRARA FORMATION AND CODELL SANDSTONE MEMBER OF CARLILE SHALE															
51.0	8.6	0.01	0	12.0	5.4	573.0	9.7	594	632.0	110.0	1.3	5.9	4.3	1,670	52
----------	25.0	.93	0	84.0	22.0	605.0	16.0	476	1,140.0	45.0	.4	9.0	2.3	2,230	302

PRECAMBRIAN ROCKS															
41.0	19.0	0.42	0.05	23.0	7.2	5.1	2.3	54	32.0	7.7	0.3	12.0	0.02	145	87
42.0	19.0	.03	.02	36.0	18.0	10.0	4.4	207	12.0	3.4	.4	2.7	.03	219	165
DEADWOOD FORMATION															
62.0	11.0	0.08	0.03	37.0	22.0	7.6	2.0	199	31.0	0.8	0.6	1.5	0.05	209	181
48.0	11.0	.98	.09	54.0	31.0	3.2	1.4	312	5.2	1.8	.2	1.1	.03	260	261
PAHASAPA LIMESTONE															
66.0	21.0	0.03	0	40.0	13.0	9.6	2.2	193	12.0	2.0	0.3	1.0	----------	198	153
122.0	29.0	2.9	.05	383.0	106.0	75.0	28.0	171	1,280.0	70.0	4.2	0	0.33	2,210	1,390
153.0	38.0	.97	.03	232.0	58.0	21.0	6.9	158	650.0	22.0	2.2	.2	.10	1,210	819
MINNELUSA FORMATION															
51.0	9.6	2.6	0	48.0	17.0	5.1	3.2	227	11.0	2.0	0.2	0	----------	206	190
56.0	12.0	.08	0	408.0	73.0	4.9	2.2	236	1,060.0	.6	.7	.2	0.07	1,850	1,320
SUNDANCE FORMATION															
57.0	8.1	6.6	0.08	186.0	140.0	140.0	14.0	326	1,000.0	5.4	0.5	0	0.20	1,770	1,040
91.0	16.0	.35	.07	435.0	120.0	699.0	57.0	238	2,360.0	407.0	3.5	.2	1.9	4,460	1,580
FOX HILLS SANDSTONE															
49.0	12.0	0.09	0.06	33.0	6.0	230.0	7.3	400	284.0	1.1	0.4	2.5	.25	784	107
51.0	10.0	0	0	4.1	.2	422.0	1.6	652	19.0	268.0	1.9	.1	1.6	1,070	11
HELL CREEK FORMATION															
50.0	15.0	0.07	0	2.4	0	292.0	1.2	540	165.0	10.0	0.6	1.1	----------	758	6
47.0	8.8	.22	.01	5.1	1.6	465.0	2.4	720	402.0	9.6	1.4	1.4	1.2	1,270	19

TABLE 28.—*Typical analyses of water from principal aquifers*—Continued

[Constituents are in parts per million unless otherwise shown]

Temperature (° F.)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (residue on evaporation at 180° C.)	Hardness as $CaCO_3$
FORT UNION FORMATION															
----------	17.0	0.69	----------	9.6	3.3	570		645	729.0	11.0	----------	3.0	----------	1,670	38
----------	----------	.30	----------	82.0	49.0	949		875	1,660.0	9.6	0.8	----------	----------	3,200	406
WHITE RIVER GROUP															
64.0	38.0	0.02	----------	12.0	1.5	180.0	7.4	431	60.0	14.0	1.3	1.1	0.93	554	36
59.0	79.0	.04	0	124.0	15.0	66.0	20.0	345	221.0	6.3	.2	.1	.17	731	371
ARIKAREE AND OGALLALA FORMATIONS															
53.0	61.0	0.02	0	35.0	6.4	5.1	5.9	138	8.8	2.4	0.3	4.7	0.04	207	114
53.0	50.0	.08	----------	59.0	6.1	52.0	13.0	317	25.0	8.0	.2	7.0	0.7	390	172

DEVELOPMENT OF GROUND WATER

Ground-water use

Because of low rainfall, the development of ground-water supplies in South Dakota began shortly after the area was opened to settlement. More than 1,000 flowing wells had been drilled by 1900, and more than 10,000 by 1915. The present number of water wells in the State is unknown, but the rate of drilling both deep and shallow wells increased from 1915 until about 1940. During the 1940's, wartime shortages of manpower and materials forced a curtailment of well drilling. Since about 1950, however, the number of wells drilled each year has again been increased steadily.

Ground water is one of South Dakota's most important natural resources. Data collected in 1960 indicate that most of the water used in the State for municipal, domestic, stock, and industrial purposes, was obtained from wells. Of the 351 towns in the State that have municipally owned or controlled water supplies, 336 depend primarily or completely upon ground water. Ground water thus furnishes the supply for 96 percent of the municipal water system in the State. The total population served by the 351 municipal water supply sources was nearly 412,000; ground water sources supplied 79 percent of this total or about 325,000 persons. The total amount of water used by the population served by municipal water systems was 54.5 mgd, or an average of 132 gpd per person.

Irrigation is an additional major ground water use. Ground water supplied 43 percent—69 mgd or 77,000 acre-feet—of the irrigation water applied to crops in South Dakota in 1960.

Essentially all rural domestic water is obtained from wells. According to figures from the U.S. Census of 1960, the population of South Dakota was approximately 680,000 of which about 270,000 are classified as farm dwellers. In farm homes with running water, the per capita use is estimated to be about 50 gpd, and in farm homes without running water, about 10 gpd, or an average of about 30 gpd. The farm domestic ground-water use based upon these assumptions is about 8 mgd. Livestock on South Dakota farms in 1960 consumed an additional 26 mgd of ground water.

Ground-water problems

South Dakota's ground-water problems, though frequently interrelated, may be listed under the three following general categories: (1) chemical quality of water; (2) quantity of water available; (3) decline in artesian head.

Chemical quality of water.—With the exception of water from the Fox Hills Sandstone in the northwestern part of the State and the Arikaree and Ogallala Formations in the southwestern part of the State, almost all water from deep wells in South Dakota has a high dissolved mineral content. As a consequence, economic growth and development is severely hampered, especially west of the Missouri River where nonsaline ground water is very scarce. East of the Missouri River, where considerable quantities of ground water are obtained from buried glacial outwash deposits, from alluvium and glacial outwash in river valleys, and from sand and gravel lenses in the glacial till, the water is usually hard but, with proper application, it can often be used for irrigation of selected crops. Recent developments in saline water conversion hold great promise for the future utilization of the enormous amounts of water in the deeper aquifers that underlie much of South Dakota. The development and commercial application of such methods, however, will require considerably more detailed information about the physical characteristics of the aquifers and the nature of the dissolved minerals contained in the water than is now available.

Water quantity.—Supplies of water of suitable quality for domestic use are inadequate, or indeed, unavailable in large areas of South Dakota. In certain locations in the State, no ground water whatsoever is available. Elsewhere, the aquifers are deeply buried and the cost of drilling deep wells prohibits development of a ground-water supply by individual landowners. Large quantities of water are contained in the glacial drift in eastern South Dakota, but the location and extent of the water-bearing parts of the drift are largely unknown. Wells completed in the glacial deposits in certain areas have produced as much as 1,500 gpm of good quality water for irrigation. Other large areas are known to have a similiar potential supply but must be investigated further to determine if the water is suitable for irrigation.

Decrease in artesian pressure.—Studies by the U.S. Geological Survey, in cooperation with the South Dakota State Water Resources Commission, and the South Dakota State Geological Survey have shown that artesian pressures in some deep aquifers have decreased drastically since 1890. The loss of artesian head locally exceeds 350 feet, and, in some areas, artesian pressure has dropped so low that in individual aquifers wells no longer flow, but must be pumped.

The drop in pressure is due not only to widespread development of certain artesian aquifers, but also to poor well construction and wasteful practices. Many wells are wild or have uncontrolled flows; they waste water, damage farmland, and cause needless loss of artesian pressure. For example, 46 such wells along the Missouri River between Yankton and Chamberlain, flow a total of 16 mgd; most, or all of this water, is wasted.

The source, location, and mechanics of recharge to the various artesian aquifers of the State are unknown, or little understood. Hydrologic models based upon early investigations have been shown to be invalid by more recent study. The newer data are insufficient, however, to determine the correct hydrologic models. Considerable additional basic data on stratigraphy, hydrology, and quality of water are required to solve problems that will arise in connection with artesian aquifers in the State.

Suggested program to solve the ground-water problems

The following three categories of investigations, listed in order of priority, are believed to be necessary in order to provide basic information on ground-water resources in South Dakota:

(1) Studies of specific areas (preferably counties) that will provide detailed information on the quantity and quality of ground water available for agricultural, domestic, and industrial needs. The objective of such investigations should be to provide complete data on ground-water occurrence in all parts of the county. The information would be available to farmers and ranchers interested in stock or irrigation-well development, to municipalities contemplating new water systems or extension of existing systems, to industries interested in establishing water-using plants in the area, and to rural residents interested in constructing new or better domestic water systems.

Studies of counties are being made jointly by the U.S. Geological Survey and the South Dakota State Geological Survey. The program should, however, be accelerated to meet the rapidly increasing demand for ground-water information.

(2) General studies to provide information on the occurrence of ground water in deep artesian aquifers in central and western South Dakota. Evaluation of the artesian water supplies in South Dakota is particularly important in view of the new and more economical methods of treatment of saline water which are being developed. Future developments unquestionably hold great promise for an economical method of demineralizing the enormous supplies of saline water in the deeper aquifers underlying South Dakota. These studies, therefore, should determine the quantity of water that may safely be drawn from the artesian aquifers without lowering the artesian pressure, and also the chemical quality of water contained in the aquifers.

(3) Studies of the hydrology of the glacial drift in drainage basins in eastern South Dakota. Such studies would determine the general extent of glacial-drift aquifers and gather preliminary data on the quantity and quality of water contained in the aquifers. The drainage-basin studies would include the total glaciated area of South Dakota, and they would provide general information on ground water throughout the eastern part of the State. More detailed information on the feasibility of irrigation could be provided through county studies in area containing significant ground-water reservoirs.

BASIN APPRAISALS OF WATER RESOURCES

The preceding discussion has presented general information on the water resources of South Dakota. The basin appraisals that follow gives more specific information about surface water and water quality in the individual basins. Aquifers that underlie the major drainage basins are summarized in table 29. Most of the aquifers listed underlie the Missouri River main stem at one or more places in South Dakota; hence, the Missouri River main stem is not included.

TABLE 29.—*Aquifers that underlie the major drainage basins in South Dakota*

Geologic source	Age	Drainage basin								
		Grand River	Moreau River	Cheyenne River	Bad River	White River	Keya Paha River	James River	Vermillion River	Big Sioux River
Alluvium	Recent	X	X	X	X	X	X	X	X	X
Glacial outwash	Pleistocene	----	----	----	----	----	----	X	X	X
Arikaree and Ogallala Formations.	Miocene and Pliocene	----	----	----	X	X	----	----	----	----
White River Group	Oligocene	----	----	----	----	X	X	----	----	----
Fort Union Formation	Paleocene	X	----	----	----	----	----	----	----	----
Hell Creek Formation	Cretaceous	X	X	X	----	----	----	----	----	----
Fox Hills Sandstone	do	X	X	X	----	----	----	----	----	----
Niobrara Formation and Codell Sandstone Member of Carlile Shale.	do	----	----	----	----	----	----	X	X	X
Greenhorn Limestone	do	----	----	----	----	----	----	X	X	X
Dakota Sandstone	do	----	----	----	X	X	X	X	X	X
Inyan Kara Group	do	X	X	X	X	X	X	----	----	----
Sundance Formation	Jurassic	----	----	X	----	----	----	----	----	----
Minnelusa Formation	Pennsylvanian and Permian	----	----	X	----	?	?	----	----	----
Pahasapa Limestone and Madison Group.	Mississippian	X	X	X	X	?	----	----	----	----
Whitewood Dolomite and Red River Formation.	Ordovician	X	X	X	X	?	----	X	----	----
Winnipeg Formation	do	X	X	X	X	----	----	----	----	----
Deadwood Formation	Cambrian and Ordovician	X	X	X	----	----	----	----	----	----

The number of irrigation systems and the estimated number of acres irrigated with surface water in South Dakota are summarized in table 30. Regular irrigation systems that divert water from water courses or storage facilities require water rights and are regulated by the State Water Resources Commission. The number of water rights on file with the commission and the total acreage irrigated by regular irrigation systems as of July 1, 1963, are given in the column headed "Direct diversions."

TABLE 30.—*Estimated acreage irrigated with surface water*

	Direct diversions		Spreader systems	
	Number of irrigators	Acres irrigated	Number of irrigators	Acres irrigated
Bad River	4	380	9	620
Big Sioux River	25	2, 280	----	----
Belle Fourche River	55	7, 170	57	5, 460
Minor tributaries	26	2, 830	----	----
Belle Fourche Project	435	57, 050	----	----
Redwater River [1]	82	8, 730	----	----
Spearfish Creek [1]	81	4, 350	----	----
Cheyenne River	54	7, 690	134	15, 930
Minor tributaries	18	1, 570	----	----
Angostura Project	100	12, 150	----	----
Battle Creek	2	890	----	----
Beaver Creek	9	1, 670	----	----
Rapid Creek	53	7, 750	----	----
Spring Creek	4	2, 400	----	----
Grand River	20	2, 040	78	11, 500
James River	35	4, 810	----	----
Keya Paha River	15	1, 280	13	1, 270
Little Missouri River	19	3, 170	9	630
Missouri River (main stem)	43	8, 720	----	----
Moreau River	2	510	52	5, 760
White River	60	4, 880	21	1, 880
Total	1, 142	142, 320	373	43, 050

[1] Including tributaries.

Source: Compiled from records of South Dakota Water Resources Commission as of July 1, 1963.

Spreader irrigation systems spread floodwaters from small drainageways over grasslands and many of these systems do not require water rights. Water rights have been filed for some spreader systems, however, and the numbers of these rights and acreage irrigated are given in the column headed "Spreader systems." Not all the acreage irrigated by spreader systems is shown in table 30—the total acreage irrigated is estimated to be at least twice that for which water rights have been filed.

MISSOURI RIVER MAIN STEM

The Missouri River is the only stream in the State that has a large sustained flow and, therefore, is the greatest source of water for development. Some data on the flows of the Missouri River are listed below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)	
				Maximum	Minimum
Missouri River at Bismarck, N. Dak	186,400	34	20,620	500,000	1,800
Missouri River near Mobridge, S. Dak	208,700	33	21,560	443,000	[1] 2,600
Missouri River at Pierre, S. Dak	243,500	33	22,080	440,000	[2] 824
Missouri River at Yankton, S. Dak	279,500	32	24,700	480,000	2,700
Missouri River at Sioux City, Iowa	314,600	65	32,280	441,000	2,500

[1] Minimum daily discharge.
[2] Regulated minimum daily discharge.

With the completion of Big Bend Dam, the Missouri, within the State of South Dakota, will have become a chain of lakes with only a few miles of river channel remaining below the dams at Fort Randall and Gavins Point. These lakes provide for storage of many millions of acre-feet of water for flood control, power generation, recreation, navigation, irrigation, and municipal and industrial supplies. Table 31 gives pertinent information about each reservoir.

TABLE 31.—*Missouri River reservoir data*

	Oahe Reservoir		Big Bend Reservoir		Fort Randall Reservoir		Lewis & Clark Lake	
	Elevation (feet)	Storage (thousand acre-feet)	Elevation (feet)	Storage (thousand acre-feet)	Elevation (feet)	Storage (thousand acre-feet)	Elevation (feet)	Storage (thousand acre-feet)
Top of spillway gates	1,620	23,630	1,423	1,900	1,375	6,093	1,210	541
Normal maximum operating pool	1,617	22,530	1,420	1,725	1,365	5,108	1,208	477
Top of inactive storage	1,540	5,538	1,415	1,465	1,310	1,385	1,195	156
Exclusive flood control zone	1,617–1,620	1,100	1,420–1,423	175	1,365–1,375	985	1,208–1,210	64
Multiple-use zone [1]	1,540–1,617	16,992	1,415–1,420	260	1,310–1,365	3,723	1,195–1,208	321
Inactive storage zone	1,425–1,540	5,536	1,345–1,415	1,465	1,227–1,310	1,385	1,180–1,195	138
Dead storage	(2)	2	--------	0	--------	0	(3)	18
Power capacity (kilowatts)	595,000		[4] 468,000		320,000		100,000	

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[1] Flood control is included. Allocations for flood control storage varies depending on the season and conditions in the upstream drainage basin.

[2] Below 1,425 feet.

[3] Below 1,180 feet.

[4] When completed.

The chemical quality of the water in the Missouri River varies only slightly. Because the river is a series of large lakes that provide excellent opportunity for mixing of water, the variations in water quality are gradual. Most of the water in the river originates outside the State; therefore, local differences in climate, geology, and other factors do not greatly influence the quality of the river water. The water generally is good for irrigation and many industrial uses, but it requires softening for municipal use.

GRAND RIVER

The Grand River drainage basin includes an area of about 5,200 square miles in the northern part of the State west of the Missouri River. An additional 500 square miles is in the headwaters of the North Fork in southwestern North Dakota. The South Fork heads just east of the Little Missouri River and drains an area of about 1,400 square miles. The two forks join at Shadehill Reservoir south of Lemmon, South Dakota. This reservoir, which was completed in 1951, has a capacity of 409,000 acre-feet, of which 269,000 acre-feet is reserved for flood control, 81,400 acre-feet is for irrigation and conservation, and 58,600 acre-feet for sediment deposition.

Stream gradients for the two forks are nearly equal and average about 5 feet per mile. The average gradient of the main stream below Shadehill Reservoir is about 3½ feet per mile.

A large percentage of the annual runoff in the Grand River drainage basin normally occurs during the snowmelt period. This is particularly true in the upper basin where annual precipitation is at least 13 inches. From August to late March, runoff is usually small and most streams have no flow for at least part of the period. Some discharge data for the Grand River and its tributaries are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)	
				Maximum	Minimum
North Fork Grand River at Haley, N. Dak.	509	26	29.5	14,100	
North Fork Grand River near White Butte, S. Dak.	1,190	17	60.3	30,900	0
South Fork Grand River at Buffalo, S. Dak.	148	7	5.23	1,020	0
South Fork Grand River near Cash, S. Dak.	1,350	17	56.4	27,000	0
Grand River at Shadehill, S. Dak.[1]	3,120	19	128	58,000	0
Grand River near Wakpala, S. Dak.[2]	5,510	39	270	82,200	0

[1] Flow completely regulated by Shadehill Reservoir since July 1950.
[2] Flow regulated in part by Shadehill Reservoir since July 1950.

The chemical quality of water from the North and South Forks of the Grand River is similar. The dissolved-solids content of the water ranges from about 200 ppm during floods to about 2,500 ppm during low flows. Storage and mixing of water in Shadehill Reservoir improve the quality of the water downstream. The dissolved-solids content of water from the reservoir averaged about 1,000 ppm for the 1958–62 period. Even though the water generally is hard, sodium rather than calcium or magnesium is by far the most abundant cation present. A high proportion of sodium detracts from the suitability of water for irrigation.

MOREAU RIVER

The Moreau River, from its headwaters near the western border of the State to its confluence with the Missouri River, follows a course generally parallel to, and about 40 miles south of, the Grand River. The Moreau River drainage basin is very similar to that of the Grand River. Its area, about 5,400 square miles, is only slightly smaller and its shape, stream gradients, runoff characteristics, and topography are, in general, much like those of the Grand River drainage. Some discharge data for the Moreau River are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)	
				Maximum	Minimum
Moreau River at Bixby, S. Dak	1,570	14	69	15,300	0
Moreau River near Faith, S. Dak	2,660	19	146	26,000	0
Moreau River near Whitehorse, S. Dak	4,880	8	107	17,500	0
Moreau River at Promise, S. Dak	5,223	28	282	36,900	0

The chemical quality of water in the Moreau River is highly variable because water discharge of the stream is highly erratic. The dissolved-solids content of the water fluctuates widely; it is as little as 200 ppm during floods and as much as 4,000 ppm during periods of very low flow. Drainage from the areas underlain by Pierre Shale contains predominantly sodium and sulfate and contributes more dissolved solids to the river than drainage from other areas. The water is of relatively poor quality for use most of the time.

CHEYENNE RIVER

The Cheyenne River is the largest of the western tributaries of the Missouri. It drains an area of about 25,500 square miles, of which about 60 percent is in South Dakota and about 40 percent is in Wyoming. The river partially encircles the Black Hills on the south and is joined east of the Hills by its major tributary, the Belle Fourche, which flows around the northern margin of the Hills. Thence the Cheyenne flows generally eastward to the Missouri.

Some Black Hills streams have a high sustained flow and thus differ markedly from other streams in South Dakota. Most Black Hills streams, however, lose part or all their normal flow where they cross the cavernous Pahasapa Limestone outcrop near the outer edge of the Black Hills uplift area. The streams that have sustained flows provide some excellent trout fishing and have been important in making the Black Hills one of the major recreational areas in the midcontinent region.

Various facilities for utilizing the sustained flow of Black Hills streams have been developed. Small hydroelectric power plants have been installed on Fall River and Spearfish Creek. Rapid Creek provides part of the municipal water supply for Rapid City and irrigation water for almost 8,000 acres downstream from Rapid City. Because of heavy water demand in the Rapid Creek valley, two reservoirs, Deerfield and Pactola, have been constructed in the upper Rapid Creek watershed. In addition to providing storage and regulation for irrigation and municipal needs, these reservoirs afford a degree of flood protection for the lower valley and have a high recreation value.

The largest irrigation projects completed in the State are in the Cheyenne basin. The Belle Fourche project is the largest with 57,050 acres under irrigation; the Angostura project comprises 12,150 acres; and the Rapid Valley unit comprises about 7,750 acres. More information regarding these projects is contained in part II of this report. About 114,000 acres, nearly 80 percent of the State's total acreage irrigated from surface supplies, is irrigated with water from the Cheyenne and its tributaries.

Streamflow data for the Cheyenne drainage are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)	
				Maximum	Minimum
Cheyenne River at Edgemont, S. Dak	7,143	20	114	13,500	0
Hat Creek near Edgemont, S. Dak	1,044	13	21.7	9,430	0
Cheyenne River near Hot Springs, S. Dak	8,710	25	270	114,000	2.8
Fall River at Hot Springs, S. Dak	137	25	27.2	13,100	4.0
Castle Creek above Deerfield Reservoir near Hill City, S. Dak	83	14	7.97	615	1.4
Rapid Creek above Canyon Lake near Rapid City, S. Dak	371	16	31.1	2,600	0
Cheyenne River near Wasta, S. Dak	12,800	31	368	46,300	.6
Belle Fourche River at Wyoming-South Dakota State line	3,280	16	76.6	4,400	0
Redwater Creek at Wyoming-South Dakota State line	471	10	32.0	2,340	4.8
Spearfish Creek at Spearfish, S. Dak	168	16	41.6	947	3.0
Bear Butte Creek near Sturgis, S. Dak	192	17	10.9	12,700	0
Belle Fourche River near Elm Springs, S. Dak	7,210	31	354	37,900	0
Cheyenne River near Plainview, S. Dak	21,600	12	484	41,700	0
Cherry Creek near Plainview, S. Dak	1,190	17	50.7	17,500	0
Cheyenne River near Eagle Butte, S. Dak	24,500	34	913	104,000	0

In the reach from Edgemont to Wasta, the average gradient of the Cheyenne is about 7.5 feet per mile. Downstream from Wasta the average gradient is about 6 feet per mile. The Belle Fourche River, below Belle Fourche, has an average gradient of about 6 feet per mile.

Water from the Cheyenne River on the average has a higher dissolved-solids content than the water from any of the other major streams in South Dakota. A dissolved-solids content of 2,000 or 3,000 ppm is common in both the upper Cheyenne River and in the Belle Fourche River, its main tributary. Water is used extensively for irrigation both in the upper Cheyenne River basin and in the upper Belle Fourche River basin, and drainage from the irrigation projects contributes much of the dissolved solids in the river water. The Belle Fourche River drains mining areas of the Black Hills and at times carries significant amounts of such minor constituents as zinc, arsenic, and cyanide. Runoff from relatively small tributaries draining the Black Hills and from a few other small tributaries tends somewhat to improve the quality of the water in the Cheyenne River, but generally the quality is poor.

BAD RIVER

The Bad River drains an area of about 3,120 square miles between the Cheyenne drainage to the west and north, and the White River drainage to the south. Gradient of the stream in the reach from Philip to Midland averages about 8 feet per mile; from Midland to the mouth it is about 5 feet per mile.

Because of low infiltration rates in the gumbo soils of the basin, runoff from intensive rainfall is rapid and streamflow often changes from zero to flood within a single day. Such rapid fluctuations in discharge presumably suggested to the Indians the name for the river.

Streamflow data for the Bad River are as follows.

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)	
				Maximum	Minimum
Bad River near Midland, S. Dak	1,500	17	72.1	11,200	0
Bad River near Fort Pierre, S. Dak	3,107	34	161.0	34,200	0

Water from the Bad River generally is of poor chemical quality. The water contains high concentrations of sodium and sulfate, particularly during the frequent periods of low flow. The water is extremely hard, often containing more than 600 ppm. $CaCO_3$.

WHITE RIVER

The White River heads in northwestern Nebraska, flows generally northeastward, and enters South Dakota a few miles northeast of Chadron, Nebr. West of Interior, S. Dak., the stream enters a large badlands area and changes course to a generally easterly direction and empties into the Missouri southwest of Chamberlain. About 85 percent of the 10,200 square miles in the basin is within South Dakota.

In the reach from Crawford, Nebr., to Oglala, S. Dak., the White River has an average gradient of about 8 feet per mile; from Oglala to the mouth its gradient is about 4 feet per mile. The stream is seldom at zero flow above Oglala because of contribution to base flow by ground water. In the prairie and badlands below Oglala, the stream often has extended periods of no flow. Runoff from the badlands area is very rapid and carries large amounts of sediment to the stream.

The South Fork, or Little White River as it is often called, is the major tributary of the White River and is one of the few streams outside the Black Hills that has a sustained flow. It heads west of Martin, South Dakota, and flows eastward along the northern edge of the sandhills, which extend into the State from Nebraska. As it approaches the eastern edge of the sandhills, the course becomes north-northeastward to its junction with the White River. Little or no direct runoff comes from the sandhills; however, the continuous groundwater inflow from this area sustains the streamflow.

Discharge from the South Fork, although gradually diminished downstream, has been sufficient to maintain a flow at the mouth of the White River since 1928. Streamflow data on several streams in the basin are tabulated below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)	
				Maximum	Minimum
White River at Crawford, Nebr	313	27	20.7	1,270	[1] 2.7
White River near Oglala, S. Dak	2,200	19	62.4	5,200	0
White River near Kadoka, S. Dak	5,000	20	293.0	21,700	0
South Fork White River near Rosebud, S. Dak	1,020	19	115.0	4,470	10.0
South Fork White River below White River, S. Dak	1,570	13	139.0	6,050	[1] 7
White River near Oacoma, S. Dak	10,200	34	548.0	51,900	.5

[1] Minimum daily discharge.

Water from the White River and tributaries is of relatively good chemical quality. The dissolved-solids content of the water averages only about 400 ppm, although on rare occasions it is nearly double this amount. Although the White River flows mostly through areas directly underlain by Pierre Shale, little of the streamflow is from such areas. All important tributaries enter the White River from the south and derive perennial flow directly or indirectly from the sandhills. The water has the high concentrations (30 to 60 ppm) of silica typical of water from sandhill streams.

KEYA PAHA RIVER

The upper basin of the Keya Paha River includes an area of about 1,100 square miles east of the South Fork of the White River and south of the lower White River. The Keya Paha, a tributary of the Niobrara River, flows southeastward and crosses into Nebraska a few miles east of Wewela, S. Dak.

Sandy areas similiar to the sandhills contribute ground water to many of the southern tributaries of the Keya Paha. The northern tributaries drain heavy prairie soils and receive little or no ground-water inflow. Streamflow records for the mainstream at Wewela show a moderate sustained flow in most years. During the period of record, 1938–40, 1947–62, the stream had no flow only during the extremely cold period in January and February 1949. Discharge for the 17-year period of record averages 79.9 cfs.

Water from the Keya Paha River generally is of better chemical quality than water from any other major stream in South Dakota. The dissolved-solids content of the water fluctuates within the narrow limits of 150 to 300 ppm; however, the water is hard, and has the relatively high silica content typical of water derived principally from ground water of the sandhills areas.

JAMES RIVER

The James River enters South Dakota from the north about 35 miles northeast of Aberdeen. It flows generally south-southeastward across the State to just east of Yankton, where it empties into the Missouri River. About 70 percent of the 22,100 square mile drainage area is in South Dakota.

The James River meanders through the bed of a former glacial lake, from near the North Dakota border to a few miles north of Huron. The stream gradient in this reach is extremely low, averaging about 0.2 foot per mile. The gradient is so flat, in fact, that at times high inflow from a tributary stream will cause the James River to flow upstream for a few miles above the mouth of the tributary. Floodflow from Elm River in April 1952, for example, caused reverse flow of 1,860 cfs at the James River gaging station 3½ miles upstream from the mouth of Elm River. The James River gradient increases to an average of about 0.4 foot per mile in the reach downstream from Huron. Reverse flow in this reach of river is uncommon, but not unknown.

Most floods in the basin are caused by snowmelt. The flood plain of the James River is about a quarter to a half mile wide in South Dakota. The channel banks are low and the flood plain is very flat, so that moderate floods cover nearly the entire width of the flood plain. Because of the low gradient of the stream, flood crests move slowly and the flood plain is inundated for as much as a month during major floods. The towns and farmsteads along the river are generally located above the flood plain on the bordering uplands with only a few city parks and isolated homes in the lowlands. Because of this type of flood plain development, most flood damages involve rural roads, fields, and fences.

Several thousand square miles of the basin in both North Dakota and South Dakota, the prairie pothole region, do not contribute surface runoff.

The James River and its tributaries receive little or no sustained ground-water inflow; hence, most streams in the basin cease flowing for extended periods in most years. The mainstream and all tributaries except the Elm River, between the State line and the mouth of Turtle Creek, did not flow from August 1958 to March 1960. The Elm River is impounded for the Aberdeen municipal water supply and low flow was sustained by releases from upstream storage during most of this drought.

Streamflow data from representative gaging stations in the basin are given below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)	
				Maximum	Minimum
James River at Columbia, S. Dak	7,050	17	98.1	5,420	[1] 1,860
Elm River at Westport, S. Dak	1,680	17	40.5	7,520	0
James River at Ashton, S. Dak	11,000	17	136.0	5,170	[1] 1,500
Turtle Creek at Redfield, S. Dak	1,540	17	27.2	6,420	0
James River at Huron, S. Dak	16,800	23	223.0	6,250	0
Sand Creek near Alpena, S. Dak	240	12	13.3	2,240	0
James River near Scotland, S. Dak	21,550	34	376.0	15,200	0

[1] Negative figures, indicate reverse flow.

The quality of water in the James River is closely related to the amount of water discharge of the stream and is affected somewhat by regulation of Sand Lake near the North Dakota State line. When fairly large amounts of water are being released from the lake or are entering the river from tributaries downstream from the lake, the dissolved-solids content of the water varies between about 200 and 800 ppm.

Because of the large amount of channel storage of the James River, the quality of the water remains fairly constant for a few days after flow ceases entirely. However, if the period of no flow is long, the dissolved-solids content of the water in channel storage increases gradually because of evaporation, at times to more than 1,500 ppm. Hardness as $CaCO_3$ of the water also increases, at times to more than 500 ppm. The quality of the water during periods of no flow is of considerable importance to users, such as the citizens of Huron, who depend largely on the river for their water supply.

VERMILLION RIVER

About 2,180 square miles in the southern half of the State, between the James River on the west and the Big Sioux River on the east, make up the Vermillion River basin. Drainage from the relatively narrow northern half of the basin is divided between the East Fork and West Fork of the Vermillion River. The two branches head in adjacent areas south of De Smet and follow parallel courses in a generally southward direction. Near Parker, the West Fork turns east and the two forks join to become the Vermillion River.

Streamflow records collected near Wakonda (1945–62) show an average discharge of 137 cfs from the 1,680 square mile drainage area above the gaging station. The snowmelt flood in the spring of 1962 produced the maximum known discharge, 8,660 cfs. Periods of no flow, usually during the fall and winter, have occurred in five of the 17 years of record.

Because flow in the Vermillion River is unregulated and therefore erratic, the chemical quality of the water is also erratic. The dissolved-solids content of the water fluctuates between about 300 and 1,500 ppm. Scanty data suggest that the quality of the water improves downstream and that manganese concentrations of more than 0.5 ppm are not uncommon during periods of low flow.

BIG SIOUX RIVER

From its origin north of Watertown in the Coteau des Prairies of northeastern South Dakota, the Big Sioux River flows generally southward to meet the northern border of Iowa southeast of Sioux Falls, S. Dak. Thence it forms the South Dakota-Iowa border to the southeast corner of South Dakota and empties into the Missouri River at North Sioux City, Iowa. About 70 percent of the 9,570 square mile area of the basin is in South Dakota and the remainder is in Iowa and

Minnesota. Streamflow records for selected stations are summarized below:

Station	Drainage area (square miles)	Years of record	Average discharge (cubic feet per second)	Extremes of discharge (cubic feet per second)	
				Maximum	Minimum
Big Sioux at Watertown, S. Dak	1,800	17	35.7	2,220	0
Big Sioux near Brookings, S. Dak	4,420	9	127.0	10,600	0
Big Sioux near Dell Rapids, S. Dak	5,060	14	276.0	18,400	.3
Skunk Creek near Sioux Falls, S. Dak	520	14	61.2	29,400	0
Big Sioux River at Akron, Iowa	9,030	34	861.0	54,300	7.0

At Watertown, the stream normally does not flow for periods in the fall and winter; near Brookings, it has been at zero flow only a few times since 1953; and in the lower basin, flow is sustained year around as indicated by the record at Akron.

The Coteau des Prairies has numerous lakes and the drainage patterns are poorly defined. Several hundred square miles on the Coteau do not contribute surface runoff to the river. Some of the lakes are situated so that they provide natural off-stream storage for flood waters from the river, and diversion channels have been constructed to others. This off-stream storage reduces flood peaks and also runoff because, in most instances, part of the floodwater does not return as the stream recedes.

The Big Sioux River valley is more heavily populated than are other valleys in South Dakota, and flood damage is a major problem—particularly in the lower basin. Record-breaking snowmelt floods of 1960 and 1962 caused damages amounting to several million dollars. A U.S. Army Corps of Engineers flood-protection project at Sioux Falls, consisting of dikes and a bypass channel, was effective in keeping damages in and near the city to a minimum during these two great floods; smaller floods in the past have caused considerable damage. Current studies by the Corps of Engineers may result in additional projects to provide needed protection in the lower basin.

The dissolved-solids content of water in the Big Sioux River and most tributaries fluctuates between 100 and 500 ppm. The relatively good quality of the water in the Big Sioux River probably is the result of several factors. First, the basin is in the highest rainfall area of the State; second, a significant proportion of the water during low-flow periods probably is from alluvial sands and gravels that contain water of good quality; and third, storage and opportunity for mixing of water are provided by power or other type reservoirs.

Selected References

Agnew, A. F., Tipton, M. J., and Steece, F. V., 1960, South Dakota's ground-water needs and supplies, *in* Water resources activities in the United States, Views and comments of the States: Committee Print 6 of the Select Committee on National Water Resources, U.S. Senate, 86th Cong., 2d sess., p. 319–331. Reprinted as South Dakota Geol. Survey Misc. Inv. 4, 9 p., 17 figs., 1962.

Barkley, R. C., 1952, Artesian conditions in southeastern South Dakota: South Dakota Geol. Survey Rept. Inv. 71.

——— 1953, Artesian conditions in the area surrounding the Sioux Quartzite ridge: South Dakota Geol. Survey Rept. Inv. 72, 68 p., geol. map.

Colby, B. R., and others, 1953, Chemical quality of water and sedimentation in the Moreau River drainage basin, South Dakota: U.S. Geol. Survey Circ. 270, 53 p., 20 figs.

Cox, E. J., 1962, Preliminary report on the artesian water supplies from the Minnelusa and Pahasapa aquifers in the Belle Fourche-Spearfish area: South Dakota Geol. Survey Spec. Rept. 19, 17 p.

Crandell, D. R., 1958, Geology of the Pierre area, South Dakota: U.S. Geol. Survey Prof. Paper 307, 82 p., 3 pls., 33 figs.

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., 2 pls., 18 tables.

Darton, N. H., 1896, Preliminary report on artesian waters of a portion of the Dakotas: U.S. Geol. Survey 17th Ann. Rept., pt. 2–G, p. 603–694, pls. 69–107.

——— 1909. Geology and underground waters of South Dakota: U.S. Geol. Survey Water-Supply Paper 227, 156 p.

——— 1918, Artesian waters in the vicinity of the Black Hills, South Dakota: U.S. Geol. Survey Water-Supply Paper 428, 64 p.

Davis, R. W., Dyer, C. F., and Powell, J. E., 1961, Progress report on wells penetrating artesian aquifers in South Dakota: U.S. Geol. Survey Water-Supply Paper 1534, 100 p.

Dyer, C. F., 1961, Geology and occurrence of ground water at Jewel Cave National Monument, South Dakota: U.S. Geol. Survey Water-Supply Paper 1475–D, p. 139–157.

Fenneman, N. M., 1946, Physiographic divisions of United States: Map published by U.S. Geol. Survey.

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U.S. Geol. Survey Prof. Paper 262, 173 p.

Gries, J. P., 1943, Two deep water wells near Rapid City, South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 27, no. 5, p. 646–650.

——— 1958. The Dakota Formation in central South Dakota: Proc. South Dakota Acad. Sci., v. 37, p. 161–168.

Hodge, W. T., 1960, Climates of the States, South Dakota: U.S. Dept. Commerce, Weather Bureau, Climatography of the United States, no. 60–39, 16 p.

Hopkins, W. B., and Petri, L. R., 1962, Data on wells and testholes, and chemical analyses of ground water in the Lake Dakota Plain area, Brown, Marshall, and Spink Counties, South Dakota: S. Dak. Geol. Survey Water Resources Rept. 1, 269 p., 6 tables.

——— 1963, Geology and ground-water resources of the Lake Dakota Plain area, South Dakota: U.S. Geol. Survey Water-Supply Paper 1539–T, 68 p., 3 pls., 16 figs., 4 tables.

Jones, J. R., 1956, Map of east-central South Dakota showing area underlain by more than 25 feet of stratified sand and gravel: U.S. Geol. Survey open-file map, scale approx. 1 : 250,000.

Jones, J. R., and others, 1957, Appendices A to D *of* Geology and ground-water hydrology of the Oahe Unit, James River Division, South Dakota: U.S. Geol. Survey open-file repts; A, Record of wells, test holes and springs, 212 p.; B, Measurments of water levels in wells, 230 p.; C, Logs of wells and test holes, 195 p.; D, Chemical analyses of water, 81 p.

Koopman, F. C., 1957, Ground water in the Crow Creek-Sand Lake area, Brown and Marshall Counties, South Dakota: U.S. Geol. Survey Water-Supply Paper 1425, 125 p., 7 pls. incl. geol. map.

Langbein, W. B., and others, 1949, Annual runoff in the United States: U.S. Geol. Survey Circ. 52, 14 p., 2 figs., 1 pl.

Lee, K. Y., and Powell, J. E., 1961, Geology and ground-water resources of glacial deposits in the Flandreau area, Brookings, Moody, and Lake Counties, South Dakota: South Dakota Geol. Survey Rept. Inv. 87, 117 p., 3 figs., 3 pl., 9 tables.

Littleton, R. T., 1949, Geology and ground-water hydrology of the Angostura irrigation project, South Dakota, *with a section on* The mineral quality of waters, by H. A. Swenson: U.S. Geol. Survey Circ. 54, 96 p., geol. maps.

Lohr, E. W., and Love, S. K., 1954, The industrial utility of public water supplies in the United States, 1952; pt. 2, States west of the Mississippi River: U.S. Geol. Survey Water-Supply Paper 1300, 462 p., 3 figs., 5 pls., 20 tables.

Maclay, R. W., 1952, Occurrence of ground water in the Cheyenne River and Standing Rock Indian Reservations areas, North and South Dakota: U.S. Geol. Survey open-file report, 95 p., geol. map.

McGuinness, C. L., 1963, The role of ground water in the national situation: U.S. Geol. Survey Water-Supply Paper 1800, 1121 p., 2 figs., 4 pls., 4 tables.

Meinzer, O. E., 1923, The occurrence of ground water in the United States, with a discussion of principles: U.S. Geol. Survey Water-Supply Paper 489, 321 p.

——— 1929, Problems of the soft-water supply of the Dakota sandstone with special reference to the conditions at Canton, South Dakota: U.S. Geol. Survey Water-Supply Paper 597–C, p. 147–170, 4 figs., 1 pl.

Newport, T. G., 1959, Ground-water resources of the Niobrara River and Ponca Creek basins, Nebraska and South Dakota, *with a section on* Chemical quality of water, by R. A. Krieger: U.S. Geol. Survey Water-Supply Paper 1460–G, p. 273–323, 5 tables, 3 pls., 7 figs.

Oltman, R. E., and Tracy, H. J., 1951, Trends in climate and in precipitation-runoff relation in Missouri River basin: U.S. Geol. Survey Circ. 98, 113 p., 104 figs.

Riffenburg, H. B., 1925, Chemical character of ground waters of the northern Great Plains: U.S. Geol. Survey Water-Supply Paper 560–B, p. 31–52, 4 figs.

Rosier, A. J., 1951, Reconnaissance of the geology and ground-water hydrology of the Belle Fourche irrigations project, South Dakota: U.S. Geol. Survey open-file rept., 34 p., 7 figs.

——— 1953, Ground-water resources of the Rapid Valley unit, Cheyenne Division, South Dakota, *with a section on* The surface waters of Rapid Valley, by L. J. Snell: U.S. Geol. Survey Circ. 201, 32 p., geol. map.

Rothrock, E. P., 1936, Logs of some deep wells in western South Dakota: South Dakota Geol. Survey Rept. Inv. 4, 44 p., 1 pl., map (rev. 1946).

Rothrock, E. P., and Otten, E. G., 1947, Ground-water resources of the Sioux Falls area, South Dakota: South Dakota Geol. Survey Rept. Inv. 56, 111 p., geol. maps.

Rothrock, E. P., and Robinson, T. W., Jr., 1936, Artesian conditions in west-central South Dakota: South Dakota Geol. Survey Rept. Inv. 26, 2d ed., 1938, 93 p.

Sandberg, C. A., 1962, Geology of the Williston Basin, North Dakota, with reference to subsurfce disposal of radioactive wastes: U.S. Geol. Survey Rept. TEI–809, open-file rept., 148 p.

Shjeflo, J. B., and others, 1962, Current studies of the hydrology of prairie potholes: U.S. Geol. Survey Circ. 472, 11 p., 4 figs.

South Dakota State Department of Health, 1959, Public water-supply data: Div. of Sanitary Engr., 31 p.

Thomas, N. O., and Harbeck, G. E., Jr., 1956, Reservoirs in the United States: U.S. Geol. Survey Water-Supply Paper 1360–A, p. 1–99, 3 figs.

Tychsen, P. C., and Vorhis, R. C., 1955, Reconnaissance of geology and ground water in the lower Grand River valley, South Dakota, *with a section on the* Chemical quality of the ground water, by E. R. Jochens: U.S. Geol. Survey Water-Supply Paper 1298, 33 p., geol. map.

SECTION II

WATER RESOURCE DEVELOPMENT IN SOUTH DAKOTA

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INTRODUCTION

Part II of the report describes, in summary form, existing and potential water-resource development in South Dakota. Both water-resource situations are discussed with respect to their influence on irrigation, municipal and industrial water, farm and domestic use, and hydroelectric power.

Water-resource development covers a wide range of subjects, applications, and possibilities. It intricately involves engineering, economics, and population with water usage. An intelligent discusson of any one of these factors alone is difficult without recognizing the interdependency they have upon each other, especially in South Dakota.

Time limitations preclude following the many interesting facets that the subject of water-resource development contains. An attempt has been made to cover the subject very broadly, in an organized and factual manner, yet loosely enough to permit future expansion and additional exploration by readers if they so desire. Limited bibliographic and information sources have been provided at the end of part II.

HISTORY OF SOUTH DAKOTA'S ECONOMIC AND POPULATION TRENDS

South Dakota is part of the territory purchased from France in 1803, known as the Louisiana Purchase. It was under a number of different territorial governments before being admitted to the Union as a State on November 2, 1889. Settlement of South Dakota came as part of the great westward expansion of population which quickly penetrated the Great Plains area during the last half of the 19th century.

The South Dakota situation is aptly stated by the geographer, C. Warren Thornthwaite, in his description of the Great Plains:

> An area where climate conditions, unfavorable to a permanent agricultural economy, recur with irregular persistency. The unpredictable yet certain recurrence of drought has become the chief factor limiting the development of the land and the population.

South Dakota, popularly called the "Land of Infinite Variety," lives up to this descriptive phrase in many ways. Western South Dakota includes the mountainous area of the Black Hills. The geology and climatic conditions of this area vary distinctly from the rest of the State.

The fact that South Dakota was settled rather late in the Nation's westward population migration is an indication that early settlers passed it by for areas of greater rainfall. Major population settlement of South Dakota occurred late in the last half of the 19th century. The rich, fertile lands of the James, Vermillion, and Big Sioux valleys attracted homesteaders from states to the east and southeast. Gold in the Black Hills, and tall grass prairie land in the foothills lured prospectors and ranchers. Indian hostilities checked the advent of white settlers until a series of treaties stipulated reservation areas, ended uprisings, and assured a permanent peace.

The first pioneer settlements attracted not only persons of native American stock, but also a large element of foreign-born whites who came chiefly from the northern European countries. The population of the new frontier State increased by nearly 250,000 from 1880 to 1890, but the drought-ridden decade of the 1890's discouraged further immigration of settlers and induced many to leave. A new influx of people to South Dakota occurred from 1900 until the outbreak of World War I. The western plains of the State were opened to homesteaders, new railway lines or extension branches were built, and new trade centers were established in many parts of the State.

Immigration from abroad practically stopped during World War I but resumed during the 1920's. The severe difficulties which South Dakota residents experienced in the 1930's, due to depression and drought, caused the State's population to decrease. The decade from 1940 to 1950 experienced both a large net out-migration during the war years (1940–45) and a net return migration during the latter 5 years (1945–50). From 1950 to 1960, South Dakota experienced a population increase; however, people shifted from one part of the State to another.

The following tabulation shows South Dakota's population for each decade, together with the amount and percent of increase or decrease over the previous decade:

Year	Population	Increase or decrease over previous decade	Percent of increase or decrease
1870	11, 776	----------	----------
1880	98, 268	86, 492	734. 4
1890	348, 600	250, 332	254. 7
1900	401, 570	52, 970	15. 2
1910	583, 888	182, 318	45. 4
1920	636, 547	52, 659	9. 0
1930	692, 849	56, 302	8. 8
1940	642, 961	−49, 888	−7. 2
1950	652, 688	9, 727	1. 5
1960	680, 514	27, 826	4. 3

A study of the figures shown in the preceding tabulation readily indicates the effects that the previously discussed factors have had on the growth of South Dakota's population. Even in 1960, the State's population still remained 1.8 percent less than in the peak year of 1930; however, the population on July 1, 1962, was estimated at 721,000, a new high. The percentage increase of South Dakota's population exceeds the increases of only seven other continental States in the Nation; of these, North Dakota is the only State in the midwestern area. Another noteworthy consideration that can be pointed out is that of all the States bordering South Dakota, none has exceeded the national average of population percentage increase during the last decade.

Central and western South Dakota, the short grass country, was first occupied by cattle and sheep ranches and was not considered suitable for arable agriculture. However, as the frontier pushed westward, a pattern of agricultural settlement, mostly quarter- and half-section farms, was fostered by the Homestead Act. Occasional seasons of above normal rainfall encouraged oversettlement. By and large, attempts were made to superimpose an agricultural system in these areas of South Dakota which was adapted to the more humid regions of the United States.

Many new soil and moisture conserving practices had to be adopted. Social institutions such as schools, churches, and governmental services had to be adjusted to the sparsely settled plains. If agriculture was to be successful in the new environment, it would require a much larger land base. World War I stimulated demands for wheat and other agricultural products in South Dakota. Land in farms increased by 33 percent between 1910 and 1920. Values of farmlands and buildings were boosted by inflation. The postwar decade (1920–30) saw these inflated values considerably reduced. South Dakota residents during the 1930's encountered severe difficulties from economic depression, drought, and a lag in adjustment of social institutions. These influences greatly reduced the capacity of the people to tide themselves over the emergency of the drought. A further reduction of farm values took place from 1930 to 1940 so that farmlands and buildings in 1940 were worth only about half as much as in 1910. A great margin of disparity developed between what farmers paid for their necessities and what they received for their products.

The Federal Government began a series of emergency programs to alleviate hardships brought about by the drought and depression. These programs included seed and feed loans, cattle purchases, subsistence grants, and public works projects. The burden of unemployment had fallen heavily upon farm laborers and rural youth of the State. Slowly economic, social, and moisture conditions began to improve. An inflationary period followed World War II. Personal incomes increased consistently during and following the war years. Generally favorable rainfall conditions, since 1940, and mechanized farming operations have continued the trend to larger farms. While short drought periods have not generally resulted in complete crop failures, they reduce crop yields nearly every year to a fraction of what the land would be capable of producing with adequate moisture.

Economically, South Dakota is primarily an agricultural State and previous history emphasizes that its welfare pivots around the farmer's prosperity. Farm income is a source of one-third, or more, of the State's income. South Dakota ranks high in most of the major types of crops and kinds of livestock produced in the State.

The tourist industry in South Dakota is one of the larger income producers for the State. Tourism and outdoor recreation contribute to a sizable employment of people. Other important contributors to the State's income include mining, construction, transportation and retail businesses. Federal construction of military installations and of the four giant earth dams on the Missouri has stimulated the local economy in recent years.

In only one year (1948) during the last three decades, has the per capita income of South Dakota ever exceeded the national average. Per capita income in 1961 was $1,875, the highest ever recorded in the State's history; even so, this was only 83 percent of the Nation's average. Lack of opportunity for ample gainful employment among the State's younger people causes many to migrate elsewhere for brighter possibilities. Today, with a dryland farming economy, the State continues to experience a slow population growth, a widely variable annual income, low average crop yields, and a lag in major water-resource development for agricultural, industrial, and municipal use.

WATER-RESOURCE DEVELOPMENT CONCEPTS

Total water-resource development requires basin concepts of planning, especially in use of surface waters. It is not possible to establish a program of potential developments for the greatest good to the greatest number of people in an area until planning is done on a basinwide perspective. This is especially true in situations where water supply is limited, as in South Dakota, and where transbasin diversions may be feasible.

Basinwide planning usually involves multiple-purpose projects within a river basin. Multiple-purpose projects are designed to perform two or more functions which may or may not be related. This approach to planning minimizes occupation of feasible dam and storage sites within a basin by small single-purpose projects and assures receiving maximum benefits compared to the development cost involved. After a dam has been constructed, it is difficult and expensive to enlarge or modify the structure for additional storage and other benefits. Removal of an existing facility for replacement by a larger one is usually not economically justifiable. Multiple-purpose planning combines various functions into one project so as to obtain several types of benefits, such as irrigation, power, flood control, navigation, municipal and industrial water, salinity and sediment control, sanitation, recreation, and fish and wildlife. More extensive benefits result from multiple-purpose projects in which the water resources are more fully developed and utilized.

GOVERNMENT AGENCIES CONCERNED WITH WATER RESOURCES

Various governmental agencies are involved in water conservation, utilization, and resource development in South Dakota. No man or group of men, no city, county or State, no single Federal agency, working alone, could cope with the complexity of properly developing all of South Dakota's water resources. Piecemeal resource development has been going on for years, yet South Dakota has continued to lag behind other areas. It was obvious to the people in South Dakota, as well as other Missouri River basin States, that something had to be done to bring together divergent interests and needs. Comprehensive development of water resources is not a simple task.

The year 1944 was a significant milestone in South Dakota's water resource development history, as it was for the other nine Missouri River Basin States. Two Federal agency proposals, one recommended by the Corps of Engineers in the summer of 1943 and the other recommended shortly thereafter by the Bureau of Reclamation, were presented to Congress for consideration. The corps plan provided for a series of dams and reservoirs on the Missouri River and its principal tributaries primarily for flood control and navigation improvement, but with multiple-purpose storage of water for other desired purposes. The Bureau plan provided for a large number of tributary dams and reservoirs primarily for irrigation and land reclamation, but with provision also for storage and multiple use of water resources, including power generation and flood control. Congress requested that these two plans be combined into one overall program, using the best features of both proposals. The result, popularly called the "Pick-Sloan Plan," was one of the most comprehensive programs ever devised for such a large region as the Missouri River basin—an area of 529,000 square miles. The program was authorized by the Flood Control Act of December 22, 1944, 78th Congress, 2d session (58 Stat. 887). A top coordinating body, called the Missouri Basin Interagency Committee, comprising 17 members (10 State Governors and 7 representatives from Federal agencies), was established in April 1945 to keep water-resource development programs moving smoothly and efficiently within the Missouri River basin.

Today in South Dakota, State and Federal agencies are coordinating their efforts to achieve proper water-resource development. The Corps of Engineers has harnessed the main stem Missouri River in South Dakota with construction of four large dams for flood control, irrigation, power generation, navigation, and other multiple-storage purposes. The Bureau of Reclamation is developing the principal tributary streams for multiple uses, including irrigation, municipal and industrial water supply, flood control, recreation, and fish and wildlife conservation. Transmission and sale of power is also an authorized Bureau function. The U.S. Geological Survey, in addition to its mapping and mineral resource programs collects basic data about quantity, quality, and occurrence of water resources, studies areas of potential or existing water problems, and conducts research into fundamental principles of hydrology. The Soil Conservation Serivce is developing individual and small-group projects for soil and water conservation. The Weather Bureau maintains rain, snowfall, and other climatological data. The Bureau of Mines, in addition to studies of water needs of the mineral industry, investigates mineral resources in areas that may be inundated by future reservoirs. The Federal Power Commission appraises power needs. Working through the State government, the Public Health Service helps cities and industries with water supply, waste treatment, and stream pollution abatement problems. Federal agencies such as the Forest Service, National Park Service, Fish and Wildlife Service, and the newly created Bureau of Outdoor Recreation coordinate their activities with the South Dakota State Fish and Game Department to obtain optimum recreation and wildlife benefits. State agencies in South Dakota directly involved in water-resource development and planning include the State Geological Survey, Water Resources Commission, Department of Health, Committee on Water

Pollution, State College of Agriculture and Mechanical Arts, School of Mines and Technology, University of South Dakota, and others. Today, water resource development is a coordinated effort among governmental agencies in South Dakota.

The basic essence of democracy is voluntary cooperation of individuals and agencies toward a common goal. Likewise, the cooperation of governmental agencies is essential in water resource development. The personal plight of individuals living in South Dakota during periods of flood and drought, especially during the 1930's made it obvious to the people and their governmental representatives that something should be done about water-resource development within the State. Bringing together divergent interests and needs of various areas within the State is not a simple task. Education and broadened public understanding of the problems involved in water resource development is essential. State laws in South Dakota enable the people to form organizations such as irrigation districts, water conservation districts and subdistricts, drainage districts, water user associations, and other legal entities to develop and utilize water resources. The first irrigation district in South Dakota, the Belle Fourche Irrigation District, was formed in 1923. A second, the Angostura Irrigation District, was formed June 27, 1950. A third, the Pollock-Herreid Irrigation District, was voted into being on Feburary 4, 1963. The Belle Fourche and Angostura Districts are presently operating irrigation projects in the western part of the State. A proposed irrigation district, the Shadehill Irrigation District, was defeated by a narrow margin at an election on December 17, 1963. Residents of the area plan to attempt organization of the district again in 1964.

Water conservancy districts differ in purpose and legal structure from irrigation districts. They have no power to levy taxes; however, other usual corporative powers and privileges can be exercised by them, including the right to appropriate waters within the State for beneficial uses. The first conservancy district formed in South Dakota was the Rapid Valley Water Conservancy District, organized on June 18, 1943, in Pennington County. The Rapid Valley Water Conservancy District was organized from a common interest of a water shortage problem being experienced by several private ditch companies diverting water from Rapid Creek.

In order to further South Dakota's aspirations in water-resource development, especially those related to the Missouri River Basin Project, the 1959 State Legislature created a conservancy district called the "South Dakota Conservancy District," the boundaries of which coincide in all particulars with the State of South Dakota. (Reference is made to ch. 453, South Dakota Session Laws, 1959.) Subdistricts or subdivisions of the district may be formed, through a vote of the local people, to sponsor construction of water-resource projects.

The principal reason for enacting conservancy district legislation on this broad basis was to provide for the future economic welfare and prosperity of the State by conserving its water resources for beneficial uses. It is the intent of the Conservancy District Act to relate financing of water-resource projects reasonably and equitably to the degree of benefits received from such projects. To achieve this, the act provides for statewide financing for those phases of water-resources development which result in statewide benefits. The South Dakota Conservancy District has no taxing authority; however, the legislation does provide for the establishment of conservancy subdistricts which have authority to levy taxes within certain limitations. The theory back of this type of conservancy legislation is that most of the property on or near a water development will benefit in one form or another from the economic impact that occurs. Irrigation districts may be formed within the geographical boundaries of conservancy districts and conservancy subdistricts. Financial assistance supplied by the conservancy subdistricts, in addition to payments from irrigation districts, municipalities, and other beneficiaries, will be used to pay proportionate shares of the cost of water resource development projects.

Today in South Dakota there are a total of four conservancy subdistricts organized. Their formation during 1960 and 1962 reflects an increased interest in water resource development by people living in eastern South Dakota.

Table 32 lists the water conservancy and irrigation district organizations, their geographic locations, and dates of organization. Figure 44 shows the general boundary outlines of these organizations and their locations within the State of South Dakota. A study of this information indicates areas where people of the State have taken organized action toward water resources development.

TABLE 32.—*South Dakota water conservancy and irrigation districts*

Map reference No.[1]	Name	Date formed	Geographical location (by counties)
1	Belle Fourche Irrigation District	1923	Butte (part) and Meade (part).
2	Angostura Irrigation District	June 27, 1950	Fall River (part) and Custer (part).
3	Pollock-Herreid Irrigation District	Feb. 4, 1963	Campbell (part).
4	Rapid Valley Water Conservancy District.	June 18, 1943	Pennington (part).
--------	South Dakota Conservancy District.	Legislative Act, 1959.	All counties, in their entirety, within South Dakota.
5	Oahe Conservancy Subdistrict	Nov. 8, 1960	Campbell, McPherson (excluding the town of Wetonka), Brown, Marshall (part), Walworth, Edmunds, Day, Potter, Faulk, Spink, Clark, Sully, Hughes, Hyde, Hand, and Beadle.
6	Fort Randall Conservancy Subdistrict.	do	Douglas, Charles Mix, and Bon Homme.
7	East Dakota Conservancy Subdistrict.	Nov. 6, 1962	Grant (excluding towns of Big Stone City and Albee), Codington (excluding towns of Kranzburg and Wallace), Hamlin, Deuel, Kingsbury, Brookings, Miner (east half), Lake, Moody, Minnehaha, Lincoln, and Union.
8	Lower James Conservancy Subdistrict.	do	Jerauld (excluding towns of Land and Franklin), Miner (west half, excluding town of Roswell), Aurora, Davison, Hanson, and Yankton (excluding town of Utica).

[1] Reference numbers appear on map shown in fig. 44.

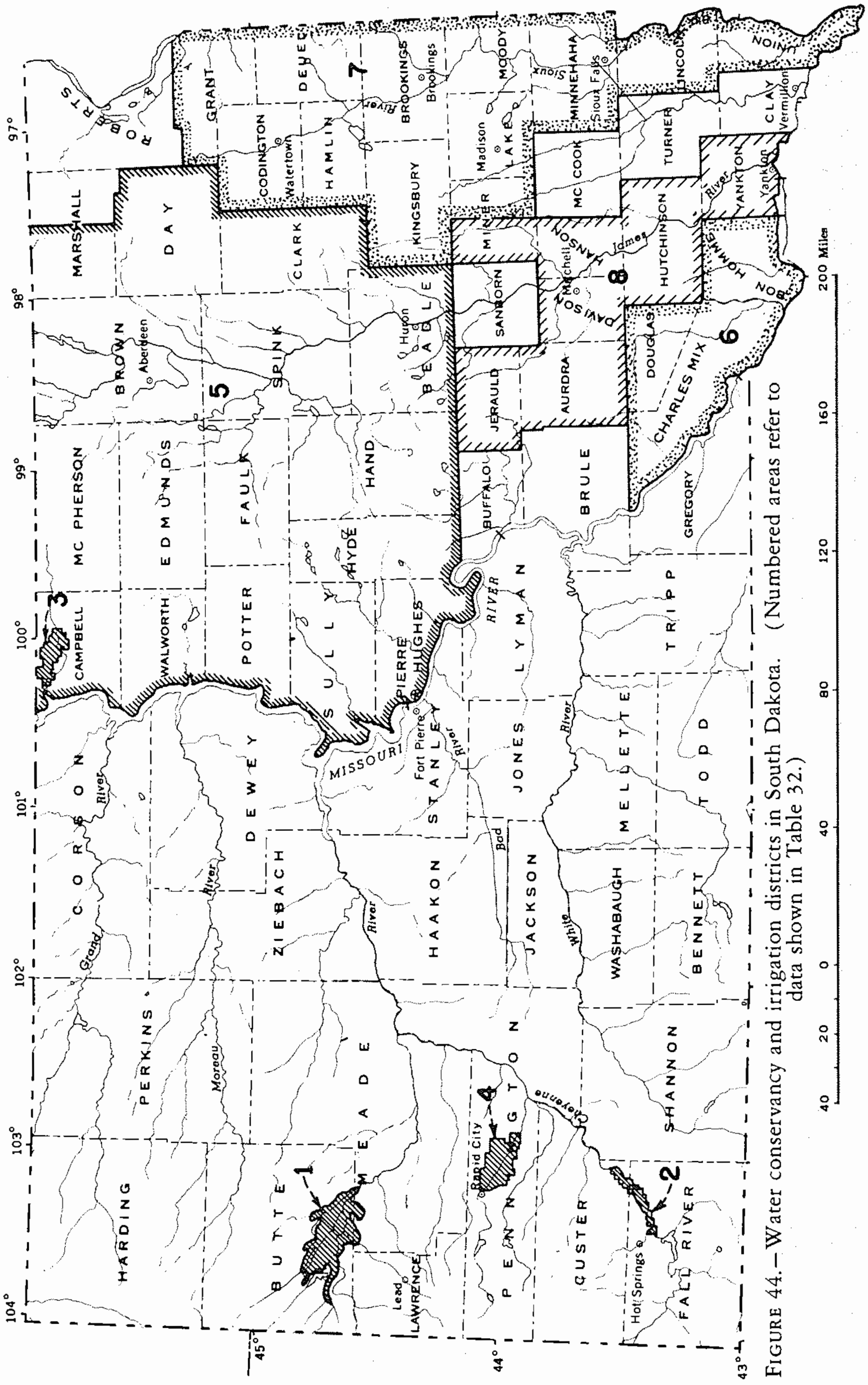

FIGURE 44.—Water conservancy and irrigation districts in South Dakota. (Numbered areas refer to data shown in Table 32.)

PRIVATE WATER-RESOURCE DEVELOPMENT

Private water-resource development in South Dakota has been primarily by individuals and small mutual groups. The interests have generally been narrow in scope and concerned with alleviating local hardships. Private water resource development is discussed under the headings of "Western South Dakota" and "Eastern South Dakota."

WESTERN SOUTH DAKOTA

A few small private hydroelectric developments exist today in the western part of the State, especially in the Black Hills region. Several mutual groups are organized in the form of irrigation ditch companies in the western areas of the State along such streams as Rapid Creek, Redwater River, Belle Fourche River, and other tributaries to the Cheyenne River originating in the Black Hills. Irrigation carried on in these areas is usually by means of simple gravity diversions or pumping from the supplying streams. A few small individually irrigated tracts exist along the western tributaries. Most private developments of surface water in the western part of the State lack adequate means of storage; consequently, they are unable to operate effectively in periods of extended drought. The inevitable result is that when water is needed most it is unavailable.

Larger municipalities and some industries in the Black Hills region rely heavily upon surface water supply from streams, springs, and infiltration galleries. The surface water is often supplemented with ground water during high demand and drought periods.

Ground water, when available by means of drilled wells, is used primarily for farm, domestic, and small municipality consumption. A few individuals irrigate from wells. Stockponds are prevalent, thus supplementing the limited ground-water supply for this primary livestock grazing area. Cloud seeding has been tried in western counties to increase and control rainfall. The results have been questionable and difficult to appraise; more research is currently in progress in this area of development.

The Missouri River was relatively inaccessible and unstable until controlled by main-stem dams. Some Missouri River water is used for municipal purposes, and at various times limited quantities are used for irrigation.

EASTERN SOUTH DAKOTA

Ground water has historically been the primary water resource in eastern South Dakota. The James, Vermillion, and Big Sioux basins appear to have extensive supplies of underground water, but the full extent of this water resource has not been determined. The acreage of land being irrigated by pumping from wells is increasing; however, high investment and operating costs, questionable water quality, and the lack of knowledge as to the extent and specific locations of available ground-water supplies are probable reasons for the limited use of ground water for irrigation at the present time.

A few municipalities have developed surface water resources, but the lack of economical and convenient surface reservoir storage sites is a limiting factor to such development.

Water for domestic use on farms in eastern South Dakota is obtained mostly from wells. Dugouts and stockpounds are numerous. Farmers and ranchers in several areas are actively participating in the Soil Conservation Service's watershed development program.

A summation of the countless small private developments within the State is difficult because of lack of records. All these endeavors at water-resource development are in a positive direction; yet local areas experience water shortages, being dependent upon the unpredictable elements of weather and location. Existing water-resource developments are discussed in more detail in subsequent sections of this report by major drainage basins and types of utilization.

PRESENT WATER RESOURCES DEVELOPMENT AND USE

An important aspect in the study of water resources is an accurate appraisal of their current utilization and degree of development. This requires accumulation and interpretation of data from many sources. South Dakota, a geographical area of 76,536 square miles, varies greatly in many characteristics, and is impractical to discuss as one entity with respect to its water resources. The Missouri River, which divides the State in a north-south direction, becomes a natural means of subdividing the State into eastern and western regions. This large system, now a chain of four man-made lakes, provides a convenient mark of delineation for geology, drainage basins, agricultural economy, population distribution, precipitation, and other factors that influence water resource development and utilization.

The U.S. Geological Survey completed a water use study of the State for the year 1960. A condensed summary of their findings is shown in the following tabulation. This information markedly illustrates current differences in water use between eastern and western South Dakota.

[In millions of gallons per day]

Method of use	West River area			East River area			All of South Dakota		
	Ground water	Surface water	Sub-total	Ground water	Surface water	Sub-total	Ground water	Surface water	Total
Irrigation	11.1	76.3	(87.4)	58.2	14.6	(72.8)	69.3	90.9	160.2
Municipal-industrial	26.4	6.1	(32.5)	35.3	9.3	(44.6)	61.7	15.4	77.1
Farm-domestic	12.8	10.0	(22.8)	19.2	6.0	(25.2)	32.0	16.0	48.0
Total	50.3	92.4	(142.7)	112.7	29.9	(142.6)	163.0	122.3	285.3

On a statewide basis of present total water withdrawn, irrigation requires 56 percent; municipalities and industry, 27 percent; and farm-domestic purposes, the remaining 17 percent. Of the 285 million gallons per day withdrawn, ground-water sources supply 57 percent and surface waters furnish the remaining 43 percent. Total water withdrawn in both areas is almost identical; however, utilization of water resources by areas differs greatly between east and west.

The West River area obtains nearly 65 percent of its total water from surface sources. Irrigation accounts for 82 percent of this surface water utilization. Municipalities and industry depend heavily upon ground water, withdrawing 52 percent of the total ground water used west of the Missouri River. Farm-domestic water utilization is more evenly divided between sources of supply: 56 percent from ground water and 44 percent from surface sources. Western South Dakota has developed a substantial portion of its surface water resources. Irrigation supplements the natural rainfall deficiency and overcomes this adverse condition by supporting agricultural production in certain local areas.

Statistics for water utilization east of the Missouri River are quite different. Ground water is by far the largest source being utilized and accounts for nearly 80 percent of all water used. Irrigation and municipal-industrial purposes use 52 percent and 31 percent, respectively, of total ground water withdrawn in the East River area. These same consumers use the largest percentages of surface waters. Ground water furnishes over 75 percent of the farm-domestic water withdrawn. The influence of relatively shallow ground-water sources, higher annual rainfall, and a lack of convenient on-stream storage sites has caused this pattern of water resource utilization in eastern South Dakota.

Natural rainfall has greatly influenced the population distribution within South Dakota. The 1960 population of South Dakota was 680,514. Of this total, 182,845 or 27 percent lived in the West River area and 497, 669 or 73 percent, in the East River area. Both areas use almost identical total quantities of water. Per capita use of water in the West River area is 780 gallons per day whereas in the East River area it is only 285 gallons per day. The West River area population uses 2.75 times as much water per person as do residents living east of the Missouri River. This is due primarily to more extensive use of water for irrigation west of the Missouri River.

The Bureau of Reclamation and Corps of Engineers activities are primarily concerned with development of surface water sources. Prior to 1944, the Bureau of Reclamation developed, under individual project authorizations, the Belle Fourche Project and the Rapid Valley Project (Deerfield Dam). The Corps of Engineers, also under small individual authorization, developed flood control projects at a few sites along tributaries to the Missouri River within the State. The Flood Control Act of 1944, authorizing joint development of the Missouri River basin by the Corps of Engineers and the Bureau of Reclamation, included numerous undeveloped potential units lying within the boundaries of South Dakota. This same authorization provided for construction of dams in the Missouri River basin upstream from South Dakota which influences development of water resources for future "in State" use. As of 1963, four Corps of Engineers main-stem Missouri River dams and four Bureau of Reclamation tributary stream dams had been completed or were under construction in South Dakota. All were authorized under the Missouri River Basin Project.

Subsequent sections of this report will discuss existing water resource developments by use, and in some instances, by major drainage basins.

EXISTING IRRIGATION DEVELOPMENTS

HISTORY OF IRRIGATION IN SOUTH DAKOTA

Early irrigation in South Dakota occurred as small developments on isolated tracts of land in western areas of the State. Deficient and untimely rainfall made farming an uncertain endeavor that required supplemental water to insure productive yields. Individual pioneer irrigators soon found it advantageous to form mutual groups known as ditch companies. At the turn of the century, several ditch companies operated in western counties along Rapid Creek, Redwater River, Belle Fourche River, and other tributaries to the Cheyenne River originating in the Black Hills. Their developments were usually simple gravity diversions to low benchlands lying along the supplying stream. These farmers experienced water shortages during years of low runoff because they had no storage or regulatory facilities. By 1906, approximately 26,000 acres were being irrigated in that portion of the Cheyenne basin lying within South Dakota. Irrigation by individuals occurred to a lesser degree within the State in other river basins west of the Missouri River early in the 20th century.

Prior to 1902, Federal legislation for irrigation had been chiefly in support of individual effort and private enterprise, and to secure participation of states. The cornerstone of modern reclamation in United States history was the passage of the Reclamation Act, approved by Theodore Roosevelt on June 17, 1902. This legislation provided the legal foundation for a Federal reclamation program in 16 western states and territories, including South Dakota. Interest in western South Dakota as a possible location for forthcoming Federal irrigation development was largely the result of four combining forces: (1) A growing population creating a demand for agricultural products; (2) the availability of funds making financing of large-scale irrigation developments possible; (3) large tracts of unsettled lands attractive and feasible in terms of the homestead provision of the Reclamation Act; and (4) the relative success demonstrated by early irrigation attempts in the area. Belle Fourche Irrigation Project, approved by the Secretary of Interior on May 10, 1904, was the first large-scale Federal irrigation project to be constructed and operated in South Dakota.

As time passed during the current century more individuals and small groups continued to develop additional irrigated acreages. The most recent Federal legislative impetus of importance to irrigation development within the State was the passage of the Flood Control Act of 1944, authorizing development of the Missouri River Basin project. Four units have been constructed under this authorization. Angostura Unit has been operating since 1953. Angostura Reservoir furnishes a full water supply to 12,135 acres and serves other purposes. The Rapid Valley Unit, which consists of Pactola Dam on Rapid Creek in the Black Hills, was completed in 1956. Pactola Reservoir furnishes municipal water for Rapid City and Ellsworth Air Force

Base and supplemental irrigation water to the Rapid Valley Water Conservancy District. Keyhole Dam and Reservoir of the Keyhole unit, situated in northeastern Wyoming on the Belle Fourche River, provides a supplemental water supply for the Belle Fourche Project in western South Dakota. Shadehill Dam of the Shadehill unit was completed in 1951. In addition to furnishing flood control and recreation, Shadehill Reservoir is providing a few farmers with water for small irrigated acreages pending construction of the irrigation system.

Some small tracts are under irrigation along the White River, primarily in the Oglala Irrigation Project on White Clay Creek in the Pine Ridge Indian Reservation. The Bureau of Indian Affairs has attempted other small projects, but due to water shortages and the past inability of the Indians to adapt readily to irrigation farming, these ventures have not been too successful. Very little land, if any, is irrigated in the Bad River and Moreau basins. A small amount of land is irrigated in the lower Cheyenne River basin.

Eastern South Dakota has recently experienced increased use of ground water, pumped from wells, for irrigating lands developed by individual farmers. The exploration, discovery, and location of aquifers, or underground water-bearing strata, at economical depths, have stimulated this resource development to a limited extent. Irrigation by this method is occurring in the James, Sioux, and Vermillion basins, and along the Missouri River bottoms.

The number of acres irrigated in South Dakota increased to a peak by the year 1919 and then decreased to a low in 1944. Census reports show an increasing trend in irrigated acreage after World War II. A considerable increase in irrigated acreage has also occurred since the last census. The following tabulation gives a brief statistical history of irrigation growth in South Dakota.

	Acres irrigated		*Acres irrigated*
1889	15, 717	1939	60, 198
1899	43, 676	1944	52, 895
1909	55, 000	1949	84, 356
1919	90, 000	1954	90, 371
1929	67, 107	1959	115, 629

A brief look at each major drainage basin within South Dakota will afford a better means of evaluating irrigation developments that exist today. Attention will be focused primarily on the larger Federal developments and organized irrigation efforts; however, numerous individual and small groups also irrigate isolated acreages. Accurate records of private irrigation developments are not readily available and estimates of their operation fluctuate annually.

Table 33 briefly summarizes pertinent facts and other important information relative to the irrigation and storage phases of existing surface-water-resource developments. Figure 45 shows the locations of these features on a base map of the State. A numbering system has been coordinated between figure 45 and table 33 to facilitate identification and location of these features for reference purposes.

TABLE 33.—*Major existing surface water irrigation developments and operating reservoir data in South Dakota*

Principal river basin	Project and/or unit [1]	Map reference No. [2]	Principal features	Stream	Gross storage capacity (acre-feet) [3]	Irrigated lands) (acres)	Responsible development agency [4]	Status
White	Oglala Project	1	Oglala Dam and Reservoir.	White Clay Creek	7,200	600	USBIA	Annual irrigated acreages fluctuate widely.
Bad	None		None					No major irrigation developments or storage reservoirs exist in the Bad River basin.
Cheyenne	Belle Fourche Project	2	Belle Fourche Dam and Reservoir.	Owl Creek	192,000	57,183	USBR	Off-stream reservoir, water supply diverted from Belle Fourche River. Initial irrigation began in 1908.
	MRBP, Keyhole unit (Wyoming).	(5)	Keyhole Dam and Reservoir.	Belle Fourche River.	200,000	(6)	USBR	Furnishes supplemental water to Belle Fourche Project. Keyhole Reservoir storage subject to provisions of the Belle Fourche River Compact.
	Rapid Valley Project	3	Deerfield Dam and Reservoir.	Castle Creek	15,700	(6)	USBR	Furnishes supplemental water for 8,900 acres of irrigable lands along Rapid Creek; also municipal water for Rapid City and Ellsworth Air Force Base. Operation coordinated with Pactola Reservoir of Rapid Valley unit, MRBP.
	MRBP, Rapid Valley unit.	4	Pactola Dam and Reservoir.	Rapid Creek	99,000	(6)	USBR	Furnishes supplemental water for 8,900 acres of irrigable lands along Rapid Creek; also municipal water for Rapid City and Ellsworth Air Force Base. Operation coordinated with Deerfield Reservoir of Rapid Valley Project.
	MRBP, Angostura unit.	5	Angostura Dam and Reservoir.	Cheyenne River	160,000	12,135	USBR	Initial irrigation began in 1953.
Moreau	None		None					No major irrigation developments or storage reservoirs exist in the Moreau River basin.
Grand	MRBP, Shadehill unit.	6	Shadehill Dam and Reservoir.	Grand River	139,700	None	USBR	Construction of dam completed in 1951. Development of irrigation facilities was postponed to evaluate water-quality problem; this has now been resolved.
Little Missouri	None		None					No major irrigation developments or storage reservoirs exist in the South Dakota portion of the Little Missouri River Basin.

Missouri (main stem)	Missouri River Basin Project.	7	Oahe Dam and Reservoir.	Missouri River	23,600,000	None	USCE	Construction essentially complete.
	do	8	Big Rend Dam and Reservoir.	do	1,900,000	None	USCE	Under construction.
	do	9	Fort Randall Dam and Reservoir.	do	6,300,000	None	USCE	Construction complete.
	do	10	Gavin's Point Dam and Reservoir.	do	540,000	None	USCE	Do.
James	MRBP, Oahe unit	11	James Diversion Dam and Reservoir.	James River	4,900	None	USBR	Construction to be completed in 1964. Supplemental municipal water supply for Huron, S. Dak.
Vermillion, Big Sioux, Red River of the North, Minnesota, Keya Paha, and Ponca Creek.			None					No major irrigation developments or storage reservoirs exist in these basins in South Dakota.

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[1] MRBP designates units of Missouri River Basin Project.
[2] Reference numbers appear on map shown in fig. 45.
[3] Total reservoir capacity to highest controlled water surface.
[4] U.S. Bureau of Indian Affairs (USBIA), U.S. Bureau of Reclamation (USBR), U.S. Corps of Engineers (USCE).
[5] Located in Wyoming; not shown on map in fig. 45.
[6] Supplemental water supply.

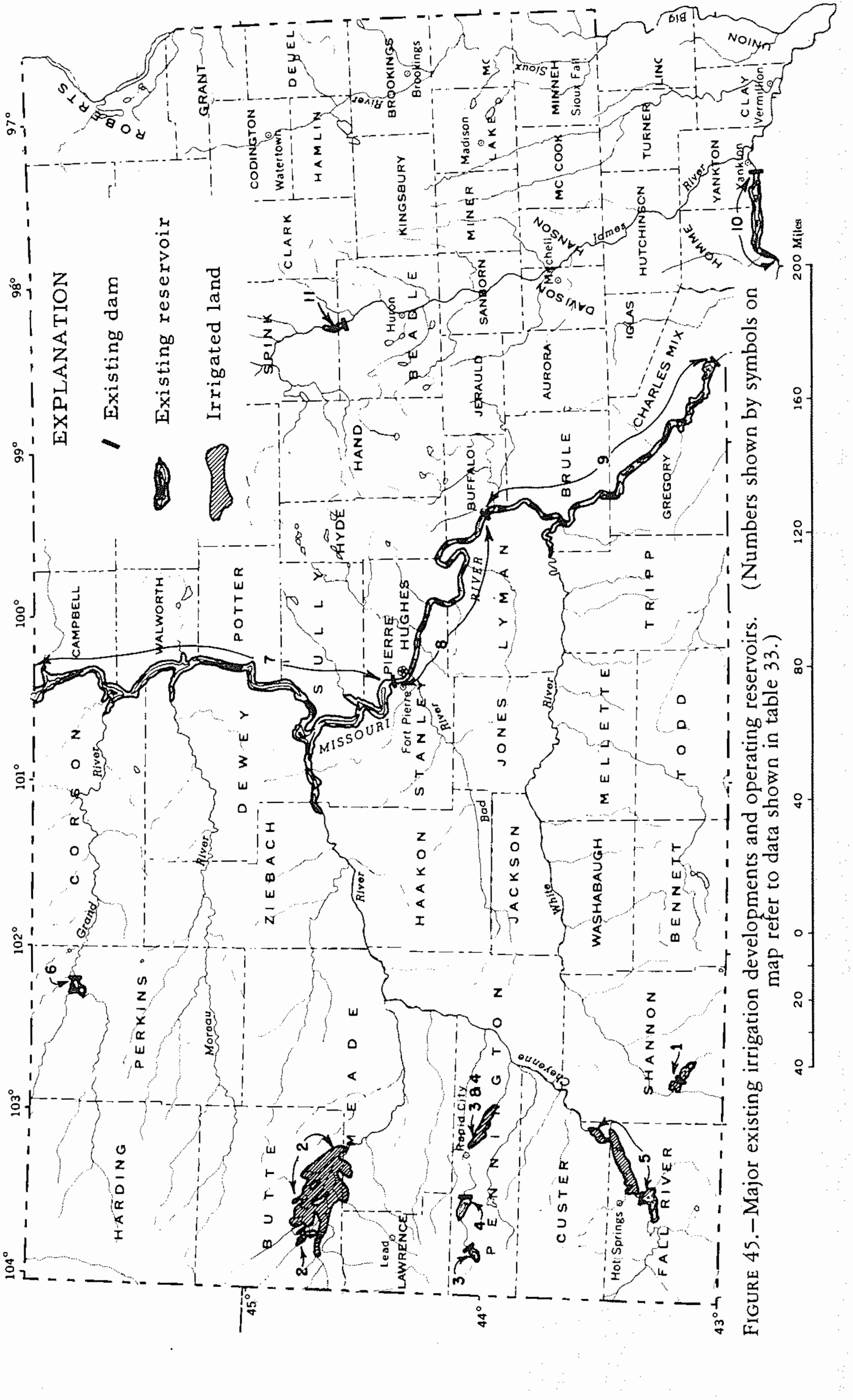

FIGURE 45.—Major existing irrigation developments and operating reservoirs. (Numbers shown by symbols on map refer to data shown in table 33.)

WHITE RIVER BASIN

The White River basin lies along the South Dakota-Nebraska State line. The White River is the principal stream of the basin and has only one major tributary, the South Fork White River, also locally known as the Little White River.

Irrigation in the White River basin has been sporadic on some of the projects. The only project which has operated continuously since its construction in 1923 is the Whitney Project in Nebraska. (Not shown in table 33 or included in fig. 45 because it is not located in South Dakota.) Attempts at irrigation in the White River basin date back to 1880, when small canals were constructed to irrigate small and limited acreages in the headwaters area. The drought years of 1910–13 in the basin area saw attempts by the Interior Colony, an organization of landholders in Jackson County and eastern Pennington County, S. Dak., to irrigate about 1,000 acres of land in scattered tracts along the White River with fair results, but the project no longer exists.

The Oglala Irrigation Project on White Clay Creek in the Pine Ridge Indian Reservation consists of a storage reservoir, just upstream from Oglala, and the necessary works to irrigate about 2,000 acres of land; however, irrigated acreages have varied up to 600 acres annually during recent years. Several other small projects, using surface water from the rivers and creeks in the Indian reservation have been operated intermittently, depending on water supply and rainfall. Refer to table 33 and figure 45 for data regarding the existing Oglala Irrigation Project.

Records of the State Water Resources Commission indicate that approximately 60 irrigators have on file rights for direct diversions from the White River to irrigate an estimated 4,880 acres. An additional 21 irrigators have on file rights for spreader-type systems on minor tributaries to irrigate about 1,880 acres. Exercising of these water rights is sporadic, as evidenced by the 1959 agricultural census which indicates that only 3,000 acres, including land on the Oglala Project, were irrigated from surface water sources during that year.

BAD RIVER BASIN

Several investigations have been made in past years to explore irrigation possibilities in the Bad River basin.

The first of these was a survey of the Bierwagen Project, made in 1913, by the State engineer of South Dakota. This project proposed irrigation of 100,000 acres of land in the western end of the basin by using a transbasin water diversion from the Cheyenne River. The State engineer found the proposal impracticable and recommended that the idea be abandoned.

A second report, covering possibilities of navigation, waterpower, flood control, and irrigation, was completed by the district engineer, Corps of Engineers, Kansas City, Mo., in 1930. This report, known as the 308 Report, "White and Bad Rivers, South Dakota and Nebraska," House Document No. 189, 73d Congress, 2d session, presented a plan for flood protection of Fort Pierre, S. Dak., by a system of levees. The flood control plan was found to be economically infeasible at that time. The same report also found irrigation to be impracticable because of inadequate low-water flows of the Bad River.

The Bureau of Reclamation began an investigation of irrigation possibilities in the Bad River basin as part of the Missouri River basin studies in 1940. The results of this investigation were summarized in Project Planning Report No. 89, dated September 1943. A plan was studied involving a storage reservoir on the North Fork of the Bad River to impound floodflows, supplemented by diversions from the South Fork Bad River. The report concluded that data concerning water supply were so scanty that definite recommendations for project development could not be made.

In 1945, the Corps of Engineers issued a flood control report on both the White and Bad Rivers. The report concluded that flood control by means of single-purpose reservoirs alone could not be economically justified. A levee system for flood protection at the town of Philip was found to have a favorable benefit-cost ratio, but local interests were unable and unwilling to provide the necessary local cooperation.

The Bureau of Reclamation completed a report on the Bad Division in January 1958. The purpose of the report was to outline what was believed to be the best plan for utilizing the available water supply for irrigation in the Bad River basin. A plan of development for the Philip unit was studied and found infeasible at that time. Details regarding the Philip unit are discussed in a subsequent section of this report regarding future irrigation development possibilities.

A recent check of the State Water Resources Commission records indicates that about four irrigators have on file rights for direct stream diversions to irrigate an estimated 380 acres; an additional nine irrigators have rights on file to irrigate approximately 620 acres by spreader-type systems from minor tributary streams. The extent of utilization today of these rights is unknown; however, little use, if any, is anticipated because of the erratic-flow characteristics of the Bad River.

Early settlers recognized the advantages of additional water on their crops, but could not find a suitable plan of storage. Irrigation has not been practiced in the basin because of the expense of developing a suitable project that will achieve storage of the limited water supply available.

CHEYENNE RIVER BASIN

The Cheyenne River basin comprises an area of about 25,500 square miles, which includes the northeastern corner of Wyoming, the southwestern corner of South Dakota, narrow area of west-central South Dakota extending from the Black Hills to the Missouri River, and minor portions of northwestern Nebraska and southeastern Montana.

Investigations and reports

A number of investigations concerning water resource development in the Cheyenne River basin have been made by the Bureau of Reclamation and by the Corps of Engineers, and others, particularly during the 1930's and early 1940's. The severe and prolonged drought in the Northern Great Plains during the 1930's focused considerable attention on plans to develop storage regulation for alleviation of water shortages on constructed irrigation projects, and on new projects to develop additional agricultural potential. The results of these investigations in the Cheyenne River basin are discussed in the following reports:

BUREAU OF RECLAMATION

"Report on Rapid Valley Project, South Dakota," 1937.
"Surveys and Estimates, Buffalo Gap Project, South Dakota," completed in 1938.
"Report on Angostura Project, South Dakota," October 1939.
"Report on Supplemental Storage, Belle Fourche Project, South Dakota," Preliminary Draft, March 1941.
"Surveys and Proposals for Supplemental Water and Extension of Rapid Valley Project," 1943.
"Survey Report on Cheyenne River Basin, Wyoming-South Dakota," October 1943.

CORPS OF ENGINEERS

"Report on Cheyenne River, South Dakota and Wyoming, Covering Navigation, Flood Control, Power Development and Irrigation," House Document 190, 1932.
"Report on Missouri River and Tributaries, Covering Navigation, Flood Control, Power Development and Irrigation," House Document 238, 1935.
"Report on Reexamination of Fall River and Beaver Creek, South Dakota," House Document 655, March 1940.

The plans of the Bureau of Reclamation for the Missouri River basin were presented in Senate Document 191, 78th Congress, 2d session. Plans of the Corps of Engineers for the Missouri River basin were presented in House Document 475, 78th Congress, 2d sesssion. Coordination of the two plans was presented in Senate Document 247, 78th Congress, 2d session. Senate Document 191 included favorable recommendations on six units or groups of units discussed herein; namely, Rapid Valley, Angostura, Keyhole, Edgemont, Cheyenne pumping, and Belle Fourche pumping. Upon authorization of the Missouri River Basin Project by the Flood Control Acts of 1944 and 1946, detailed surveys and studies were made. The Bureau of Reclamation prepared Definite Plan Reports on the Keyhole unit, 1949; Angostura unit, 1950; and Rapid Valley unit, 1951–52.

The Bureau initiated a survey in 1957 to determine further information on the origin and movement of sediment loads as effected by stockponds of the Cheyenne River basin, leading to the "Report on Sediment Control in Upper Cheyenne River Basin," June 1959.

Investigations by the Geological Survey, in cooperation with the Bureau of Reclamation, to determine the effects of stockponds on streamflows in the Cheyenne River above Angostura Dam were begun in 1950. A report on these investigations is included in "Hydrology of the Upper Cheyenne River Basin," Geological Survey Water-Supply Paper 1531, dated 1961. This report embodies, and in some instances revises, certain information and data presented in a preliminary report, "Effect of Stock Reservoirs on Runoff in the Cheyenne River Basin Above Angostura Dam," Geological Survey Circular 223, 1953.

The Geological Survey's "Progress Report-Minor Constituents in the Belle Fourche River Near Elm Springs, South Dakota," May 3, 1960, presents preliminary findings of a detailed water quality investigation initiated in 1956.

The occurrence of extremely low streamflows during the period 1959–61 resulted in severe irrigation water shortages, including the developments with storage regulation. This prompted special investigations by the Bureau in an effort to forestall future shortages. Results of these investigations are presented in two reports: "Report on Supplemental Water Supply Investigation, Angostura Unit," September 1962; and "Report on Supplemental Water Supply Investigation, Belle Fourche Project," November 1963.

The Bureau of Reclamation is currently completing a "Report on Cheyenne Division" to evaluate future development possibilities of land and water resources in the basin.. This report will be completed during 1964.

Irrigation development

First attempts at irrigation were made in the valleys of tributary streams heading in the Black Hills. The earliest application for a water right for irrigation in the South Dakota portion of the Cheyenne River basin was dated May 1876 for a tributary of Redwater Creek, which enters the Belle Fourche River near Belle Fourche. During early settlement virtually all natural flows in the Cheyenne River Basin were appropriated, and in many cases over-appropriated, precluding further development without provision of storage. The water-right filing of August 3, 1904, for the Belle Fourche Project, for example, appropriates all unregulated flows of the Belle Fourche River up to the capacity of their Inlet Canal.

In 1906 the South Dakota State engineer reported 29,000 acres under irrigation from gravity systems in the Cheyenne River basin. Except for developments of the Bureau of Reclamation, with storage regulation, no significant increases in irrigation have taken place in recent years.

Irrigation under private developments dependent upon unregulated flows generally increases during periods of normal or above-normal flows but decreases in prolonged periods of low flows. There are no known shallow ground-water aquifers in the Cheyenne River basin in South Dakota that produce water in sufficient quantities for large-scale irrigation farming. Most existing ground water is obtained from deep underlying formations, ranging at depths from 1,500 to 3,000 feet below the ground surface. Sandstone and limestone formations are generally considered good producers, yielding as much as 2,000 gallons per minute in some localities; however, the quality of water from these sources for irrigation is generally poor. The following tabulation summarizes irrigation development in the South Dakota portion of the Cheyenne River basin during the past two decades.

	Irrigated acres		
	1939	1949	1959
Drainage basin:			
Cheyenne River [1]	3,962	12,247	18,000
Belle Fourche River [1]	43,055	60,056	59,000
Rapid Creek [1]	9,170	8,468	7,000
Total	56,187	80,771	84,000
Bureau projects:			
Belle Fourche Project [2]	34,222	51,168	55,321
Angostura unit, MRBP [3]			11,382
Total	34,222	51,168	66,703
Private developments [4]	21,965	29,603	17,297

[1] From U.S. Census of Agriculture.

[2] From Annual Project Histories, Belle Fourche Project.

[3] From Annual Project History, Angostura unit, MRBP.

[4] Includes lands provided a supplemental irrigation water supply from the Rapid Valley Project and Rapid Valley unit.

Belle Fourche Project was developed during the first decade of the 20th century and is still in operation today. The prolonged drought period of the 1930's prompted investigations by the Bureau of Reclamation in search of storage possibilities for alleviation both of shortages to lands irrigated and of water supplies for new lands in the basin. These investigations led to authorization and construction of the Rapid Valley Project, and the Rapid Valley, Keyhole, and Angostura units of the Missouri River Basin Project.

Belle Fourche Project

The Belle Fourche Project has an irrigable area of 57,183 acres in the vicinity of Belle Fourche and Newell, South Dakota, northeast of the Black Hills. Construction was authorized in 1904 and first water was delivered in 1908. A diversion dam on the Belle Fourche River, about 1½ miles below Belle Fourche, diverts up to 1,635 cubic feet of water per second into the 6½ Inlet Canal, which feeds the off-channel Belle Fourche Reservoir. The Belle Fourche Reservoir is formed by the Belle Fourche Dam, which is an earthfill dam 6,262 feet in length and 122 feet high, constructed across Owl Creek, an intermittent stream tributary to the Belle Fourche River. Direct irrigation deliveries are also made from the Inlet Canal, principally to the Johnson lateral which serves about 2,500 acres. Belle Fourche Reservoir has an active storage capacity of 185,200 acre-feet, and supplies the North and South Canals. All canals, laterals, and other project features have been completed. The releases from the storage reservoir are delivered to the project lands through two main canals, each about 45 miles long. The North Canal serves about about 35,530 acres of irrigable land and the South Canal serves about 19,150 irrigable acres. The distribution and drainage systems include 410 miles of laterals and approximately 200 miles of project drains.

Alfalfa, sugarbeets, corn, small grain, hay, and irrigated pasture are the principal crops grown. The types of farming combine cash crops, livestock production, and livestock feeding. Most agricultural products are sold locally through outlets at Rapid City, Belle Fourche, and Newell. Most livestock are sold through local livestock auctions to direct buyers for Corn Belt farmers, or are shipped to one of the larger markets in eastern South Dakota or an adjacent state.

Water shortages have plagued Belle Fourche Project since the beginning, and investigations from time to time have been directed to locating sites for multiple-purpose storage to alleviate the shortages. Studies made in the late 1930's by the Bureau of Reclamation concluded that Keyhole Dam site, in Wyoming, offered the best possibility for supplemental storage of an appreciable amount of water.

Keyhole unit (*Wyoming*)

Although it is not located in South Dakota, Keyhole unit greatly influences utilization of the Belle Fourche River water resources in western South Dakota. The Keyhole unit consists of Keyhole Dam and Reservoir on the Belle Fourche River in northeastern Wyoming, 17½ miles northeast of Moorcroft and about 146 river-miles upstream from the Belle Fourche Project. It was among the units of the Missouri River Basin Project authorized for construction by the Flood Control Act of 1944 (58 Stat. 887) as amended and supplemented by the Flood Control Act of 1946 (60 Stat. 641).

Keyhole unit is a multipurpose development planned to provide a supplemental water supply for the Belle Fourche Project in South Dakota, also flood control along the Belle Fourche River valley in Wyoming and South Dakota, and supplies water for irrigating a limited acreage of bottom land along the Belle Fourche River in Wyoming. Other purposes are silt control, fish and wildlife conservation, recreational use, pollution abatement, and a possible future source of municipal water for the city of Belle Fourche.

Keyhole Dam is an earthfill structure, 3,420 feet in length, including a 2,120-foot extension of the right bank. The maximum structural height of the dam is 168 feet. Keyhole Reservoir has a capacity of 200,000 acre-feet, excluding 140,000 acre-feet of inviolate flood control space. Space reservations are 130,300 acre-feet of active conservation, 60,000 acre-feet for sediment deposition, and 9,700 acre-feet of dead storage. Storage of water began in March 1952, construction of the dam was completed in October 1952, and the first water for irrigation was available in 1953.

Since closure of Keyhole Reservoir in March 1952 and continuing through April 1962, streamflows in the Belle Fourche River basin have been extremely low and very little water has been available for storage. During this period, the Belle Fourche Irrigation District was not interested in a long-term contract for storage because of the lack of water. However, Belle Fourche Project did purchase small amounts of water on an annual basis. Above-average streamflows, beginning in May 1962, resulted in the storage of 73,900 acre-feet of water in Keyhole Reservoir. With this amount of water in storage, the Belle Fourche Irrigation District became interested and signed a contract on January 2, 1963, for 10,000 acre-feet of space in Keyhole Reservoir to store Belle Fourche Project water and for a pro rata share of the total storage. The use of Keyhole Reservoir storage will provide additional water to the project and will help provide a regulated supply to the project lands that are served directly from the Inlet Canal and the Johnson lateral.

Rapid Valley Project

The Rapid Valley Project consists of Deerfield Dam and Reservoir located on Castle Creek, a Black Hills tributary of Rapid Creek, about 25 miles west of Rapid City. The Deerfield Dam, an earthfill structure, has a structural height of 133 feet and a crest length of 825 feet. Deerfield Reservoir has a total storage capacity of 15,700 acre-feet and covers an area of 414 acres.

Irrigation has been practiced in Rapid Valley for many years. During most years up to 1930, there was, in general, sufficient flow in Rapid Creek to take care of irrigation needs. In the early 1930's it was apparent that the water supply was inadequate.

In 1937, the Bureau of Reclamation prepared a report on Rapid Valley Irrigation Project, which presented plans for storage and related facilities to satisfy the needs. Delays in negotiations and subsequent withdrawal of funds, complicated by selection of a feasible damsite, retarded progress towards construction. The Pactola damsite would have necessitated rerouting of both the main highway into Rapid City and the Western Railroad, then in existence. The estimated cost of relocations increased the water users' reimbursable obligations beyond their ability to repay. Accordingly, at a meeting on

March 10, 1941, among Bureau of Reclamation personnel, Rapid City officials, and interested farmers, the plan for Pactola Dam site was abandoned in favor of substitute storage at the Deerfield site. The new plan for construction of Deerfield Dam and Reservoir was approved by the President in 1942.

The original plan, under the Great Plains Act of 1939, required the participation of the Farm Security Administration and the Work Projects Administration Stripping of the damsite began on July 7, 1942, and the dam was completed by Government forces in 1946.

The Deerfield Dam, now operated in conjunction with Pactola Dam of the Rapid Valley unit completed during 1956 on Rapid Creek, provides a supplemental water supply for 8,900 acres of irrigable lands. Water released into the stream below the dam is diverted from Rapid Creek below Rapid City by private ditch companies into their various canals. Rapid City obtains a portion of its municipal water from Jackson Spring, a source that contributes to the natural flow of Rapid Creek. During the irrigation season, water from the city's storage in Deerfield Reservoir is released into Castle Creek to replace that consumed from Jackson Spring.

In addition to its basic water supply function, Deerfield Dam and Reservoir provide valuable recreation opportunities.

Rapid Valley unit

Interest in further development of the water resources of Rapid Creek was accentuated by the realization that an additional source of municipal water for Rapid City was required to meet summer peak demands, and the pressing need of Ellsworth Air Force Base for a more adequate and satisfactory water supply. On December 10, 1949, the city commissioners of Rapid City submitted a resolution petitioning the Bureau of Reclamation to provide storage capacity in Pactola Reservoir for the benefit of Rapid City and the airbase. Previously, in 1948, 30 Rapid Valley landowners, whose lands were not under irrigation, had petitioned that additional water storage facilities be constructed on Rapid Creek at Pactola or another suitable site.

Construction of Rapid Valley unit, Missouri River Basin Project, for supplemental water storage, was included in the Flood Control Act of 1944. Construction of Pactola Dam began November 25, 1952, and was completed August 15, 1956. This key multipurpose structure is a zoned earthfill dam 230 feet high and 1,255 feet in length. Pactola Reservoir has a total storage capacity of 99,000 acre-feet. The upper 43,000 acre-feet of usable capacity is allocated as inviolate flood-control space, leaving 55,000 acre-feet of active conservation storage capacity above the dead storage pool of 1,000 acre-feet. The unit supplies supplemental water to 8,900 acres of irrigated land in the Rapid Valley Project, in addition to furnishing municipal water to Rapid City and the nearby Ellsworth Air Force Base. The Rapid Valley unit's operation is coordinated with Deerfield Dam and Reservoir of the Rapid Valley Project.

Angostura unit

The Angostura unit, on the Cheyenne River near the city of Hot Springs, located in the southeastern slope of the Black Hills, was reauthorized as a unit of the Missouri River Basin Project by the Flood Control Act of 1944. It was constructed as a multipurpose development to provide for irrigation of 12,135 acres of new land and to supply water needed for the potential Cheyenne pumping units, generation of hydroelectric power, and incidental benefits of fish and wildlife enhancement, recreation, and sediment retention.

The principal feature is Angostura Dam, a concrete gravity structure with earth-embankment wings, having a structural height of 193 feet and a crest length of 2,030 feet, including the concrete and earth sections. Angostura Reservoir has a controlled capacity of 160,000 acre-feet, with an active conservation storage capacity above the irrigation outlet of 92,000 acre-feet. A 1,200-kilowatt hydroelectric powerplant is located approximately 500 feet downstream from the face of the dam. Near the powerplant is a 1,500-kva. switchyard that provides an interconnection with the Black Hills Power & Electric Co.

The Angostura Unit's irrigable lands consist of 12,135 acres in Fall River and Custer Counties. The unit water supply is obtained by gravity diversion from Angostura Reservoir and is delivered by a 31-mile-long main canal. In addition, there are about 60 miles of laterals, sublaterals, wasteways, and drains. The project lands in Fall River County are south of the Cheyenne River, and those in Custer County are north of the river. To reach the Custer County lands, the water is carried under the Cheyenne River bed through a 48-inch-diameter siphon 2 miles long.

Construction of Angostura Dam was started in 1946 and completed in 1949. Construction of the powerplant and switchyard followed and initial power generation began in 1951. Power generation was discontinued in 1959 because of the uncertain water supply. The years 1951–53 included the period of construction for the irrigation facilities. The first irrigation water delivery was made in 1953, with water available to all irrigable lands in 1956.

A critical 3-year period of low flow, 1959–61, required reappraisal of the dependable water supply of the Cheyenne River. It was concluded that very little water, if any, could be released from storage in Angostura Reservoir for downstream use by the potential Cheyenne pumping units or for any purpose other than irrigation of the Angostura unit.

A total of 107 irrigated farms now receive water from Angostura unit. The introduction of irrigation to lands previously dry-farmed has greatly increased crop yields. From the first irrigation, the project has produced alfalfa, barley, oats, corn, dry beans, potatoes, and livestock. The production of wheat has decreased simply due to the shift to producing feed for livestock.

Belle Fourche River compact

A Belle Fourche River compact was negotiated by a compact commission which included representatives of the States of Wyoming and South Dakota and a Federal representative. It was ratified by the State Legislatures of Wyoming and South Dakota, and confirmed by the Congress of the United States by an act approved February 26, 1944 (58 Stat. 94). Presently this compact affects the waters stored in Keyhole Reservoir and their apportionment between the two states concerned. Existing operations of the Belle Fourche Project and future developments along the Belle Fourche River in South Dakota have to remain within the limitations of the Belle Fourche River compact.

This compact provides that the unappropriated flow of the Belle Fourche River, as of the date of the compact, shall be apportioned 10 percent to Wyoming and 90 percent to South Dakota, provided that Wyoming shall have unrestricted use for domestic and stockwater purposes. To regulate their portion of the unappropriated water, Wyoming interests shall have the privilege of purchasing 10 percent of the storage capacity of Keyhole Reservoir. A further provision of the compact is that sufficient water, not to exceed 10 cubic feet per second, shall be released from this reservoir for stockwatering purposes.

Cheyenne River compact

A draft of a compact for the Cheyenne River was ratified by the State legislatures of Wyoming and South Dakota in 1949 but failed to receive the consent of Congress. It was then revised and the second version ratified by the South Dakota Legislature in 1951; however, it failed to be ratified by the Wyoming Legislature. A compact for this stream would be desirable to assure to the existing developments an equitable share of available water.

MOREAU RIVER BASIN

The Moreau River basin is a part of the unglaciated plains area of the Missouri plateau. The river heads on the Montana-South Dakota State line near Gustave. The stream's drainage area extends as a long narrow strip eastward for 180 miles to the river's confluence with the Missouri River at a point 15 miles south of Mobridge, S. Dak.

Rainfall is erratic and inadequate for reliable crop production. Drought periods of importance occurred about 1890, following 1910, and again during the 1930's. The area has experienced recurring periods of prosperity and severe hardship resulting mostly from annual variations in precipitation. Homesteaders were prevalent in the Moreau River basin during the early 1900's; however, hardships forced most of them to leave within a few years. The basin today has a sparse population, and individual land holdings are large. Residents of the basin make their livelihood by ranching and farming.

Numerous investigations have been made and reports have been prepared by several agencies. The general conclusion is that there is little potential for development of water resources. The results of the investigations in the Moreau River basin are discussed in the following reports:

"Water Resources of the Moreau River Drainage Basin," 1937, by the South Dakota State Planning Board.

A report on irrigation possibilities in the Moreau River Basin by the Bureau of Indian Affairs, 1939.

"Reconnaissance Report on Moreau River," August 1940, by the Bureau of Reclamation.

"Runoff and Waterflow Retardation and Soil Erosion Prevention for Flood Control," August 1942, by the Bureau of Agricultural Economics.

"Moreau River Basin Survey," September 1943, by the Bureau of Reclamation.

"Reconnaissance Report on Recreational Potentialities of Bixby Reservoir, Moreau River, Perkins County, South Dakota," June 1948, by the National Park Service.

Senate Document 191, 78th Congress, 2d session, included Bixby unit, Moreau division, in the plan of development for Missouri River Basin Project. The Bureau of Reclamation, during the period 1947–50, performed investigations on the potential development of the Bixby unit. A board of review, assembled in August 1950 to analyze the findings of the unit investigations concluded that existing unfavorable soil and water relationships precluded economic justification of the unit. Studies were discontinued thereafter, and no further work has been done by the Bureau of Reclamation in the Moreau River basin. A more detailed discussion of the Bixby unit is presented in a subsequent section of this report concerning future irrigation prospects of the Moreau River basin.

During the 1930's, a few garden tracts were irrigated within the Cheyenne River Indian Reservation; very few, if any, are now being served with water. Records of the State Water Resources Commission indicate that 2 irrigators have filed water rights to irrigate 510 acres by direct stream diversion; another 52 individuals have filed rights to irrigate approximately 5,760 acres by means of spreader-type systems within the Moreau River drainage basin. Data from the 1959 Agricultural Census indicate that little, if any, acreage is actually irrigated today by either organized groups or private individuals.

GRAND RIVER BASIN

The Grand River basin is within the unglaciated portion of the Missouri Plateau section of the Great Plains physiographic province. The basin extends from the uplands of southwestern North Dakota and northwestern South Dakota in a general eastward direction to the Missouri River.

The raising of agricultural products has been the principal means of subsistence for the people since white settlement began. The basin was opened for settlement during the 1890's, and a large influx of homesteaders occurred during the early 1900's. Rural and urban population trends have been materially influenced by farm prosperity. The 160-acre tracts obtained under the Homestead Act were too small to provide a family living in the rigorous climate, and the disastrous drought of the 1930's accelerated a migration from the land that began a few years earlier. As a result, today the average size of farm has become larger, the farm population has decreased, and the urban population has increased.

Rainfall is neither adequate nor timely in normal years to bring out a fully productive and diversified agriculture. With the existing dryland-farming economy, the area continues to experience a static population, a variable income, and low average crop yields.

Investigations have been made of irrigation possibilities along the Grand River since 1904, when S. B. Robbins, of the Reclamation Service, made a rough reconnaissance survey of the drainage areas of the Little Missouri, Grand, and Cannonball Rivers for the purpose of determining the feasibility of diverting water from the Little Missouri River into the Grand and Cannonball River basins for irrigation. The Bureau of Reclamation completed a reconnaissance land classification of the Grand River basin in 1940 and reported in May 1942 in the appendixes to the Basin Survey Report on Grand River. This report formed part of the supporting material for Senate Document 191, 78th Congress, 2d session.

A total of three sites was investigated. They were the Bowman-Haley site, the Shadehill site, and the Blue Horse site. The Bowman-Haley site, located in North Dakota on the North Fork of the Grand River in the vicinity of Haley, drains a relatively small area of uncertain runoff, has a high cost of development, and was considered infeasible for development of irrigation. The Shadehill site, located about 12 miles south of Lemmon, just below the confluence of the North and South Forks of the Grand River, appeared to be the most favorable site for development. The Blue Horse site, located about 17 miles south of Morristown on the main stem of the Grand River, has an excellent damsite, but the irrigable lands downstream are isolated and scattered, so as to preclude development using a gravity distribution system.

Today, Shadehill unit is the only major water resource development existing within the Grand River basin. The dam and reservoir have been completed; however, the irrigation facilities have not been constructed. The South Dakota Water Resources Commission records indicate that 20 irrigators have filed water rights to irrigate an estimated 2,040 acres by direct stream diversion, and another 78 individuals have filed water rights to irrigate an additional 11,500 acres by spreader-type systems in the drainage basin.

These rights are used to a very limited extent. Since the completion of Shadehill Dam and Reservoir, irrigation interest has increased. Currently the Bureau of Reclamation has contracts with 10 individuals using water stored in Shadehill Reservoir to irrigate an estimated 800 acres by means of pumping diversion.

The Corps of Engineers has recently been authorized to construct a dam at the Bowman-Haley site for flood control, municipal water, and other beneficial purposes.

Shadehill unit

The Shadehill unit was authorized by the Flood Control Act of 1944 (58 Stat. 887) which approved the general comprehensive plans set forth in Senate Document 191 and House Document 475, as revised and coordinated by Senate Document 247, 78th Congress, 2d session, for development of the Missouri River basin.

Construction of Shadehill Dam began April 19, 1949, and was completed August 15, 1951. Storage of water in Shadehill Reservoir began July 1, 1950. Shadehill Dam is an earthfill structure across the Grand River. The dam has a crest length of 12,843 feet and a maximum structural height of 145 feet. Other principal features of the dam are an 84-inch-diameter steel-lined circular conduit outlet works, a 13½-foot-diameter circular concrete conduit service spillway with a morning-glory-type inlet structure, and a 1,500-foot-wide unlined open cut emergency spillway channel. The multiple functions for which this structure was designed include irrigation, flood control, municipal and industrial water, fish and wildlife conservation, and recreation.

Shadehill Reservoir, at normal water surface elevation, has a total storage capacity of 139,700 acre-feet. This includes 73,800 acre-feet of active conservation storage, 7,700 acre-feet of inactive storage, and 58,200 acre-feet of dead storage. Above the normal water surface elevation, Shadehill Reservoir is designed for 218,000 acre-feet of exclusive flood control space. Unusually high runoff from an early spring snowmelt in 1952 resulted in Shadehill Dam preventing extensive flood damage in the Grand River basin. During the first 10 years of operation, Shadehill Dam and Reservoir have been credited by the Corps of Engineers with $4,121,000 worth of flood damage prevention.

After completion of Shadehill Dam and Reservoir, plans for development of irrigation were temporarily deferred until a more complete evaluation could be made of the effect that relatively poor quality of water available in Shadehill Reservoir would have on the soils proposed for irrigation development. Shadehill Reservoir water was considered as doubtful for irrigation use because of the high proportion of the sodium ions to the total cations and the high concentrations of bicarbonate anions.

A series of special studies concerning the reaction of the soils and stored water were conducted on the Shadehill Development Farm under formal agreement with the South Dakota State College's Agronomy Department. These tests involved irrigation, leaching trials, soil amendment tests, and tests to determine soil stability and permeability. An evaluation of these studies was made and the conclusion was reached that certain lands within the Shadehill unit area are suitable for sustained irrigation. A Definite Plan Report for irrigation, dated June 1963, is being revised for distribution by June 1964.

Early tentative plans included municipal water supply for the city of Lemmon, S. Dak.; however Lemmon is 400 feet higher in elevation and 14 miles northeast of the reservoir. Detailed investigations showed that alternate sources of municipal water supply were less costly and further consideration was determined to be unjustifiable.

Plans for development of Shadehill unit's irrigation facilities will be discussed in a subsequent section of this report dealing with future irrigation development possibilities.

LITTLE MISSOURI RIVER BASIN

The Little Missouri River rises in northeastern Wyoming, flows through the southeastern corner of Montana, enters the northwestern corner of South Dakota, and joins the Missouri River in North Dakota. A very small portion of its drainage basin lies within South Dakota. In 1904, S. B. Robbins, of the Reclamation Service, made a rough reconnaissance survey of the Little Missouri, Grand, and Cannonball Rivers for the purpose of determining the feasibility of diverting water from the Little Missouri River into the Grand and Cannonball River basins for irrigation. Senate Document 191 briefly mentions that previous investigations have failed to disclose desirable reservoir sites in that reach of the river from below Alzada, Mont., to the mouth of the Little Missouri. A portion of this river reach is located in South Dakota. No significant investigations have been performed by the Bureau of Reclamation on the Little Missouri River basin in South Dakota since the publishing of Senate Document 191.

South Dakota Water Resources Commission's records show that 19 individuals have filed water rights to irrigate an estimated 3,170 acres by direct stream diversion and 9 other individuals have water rights to irrigate 630 acres by spreader-type systems within the basin's drainage area. The extent to which these rights are used for irrigation today are not known but presumed to be very limited.

MISSOURI RIVER (MAIN STEM)

The channel of the Missouri River in South Dakota is about 547 miles in length. As it traverses through the State, eight principal tributaries enter the "Big Muddy." Named in order from north to south, they are the Grand, Moreau, Cheyenne, Bad, and White Rivers entering from the west, and the James, Vermillion, and Big Sioux Rivers draining the eastern part of South Dakota.

The Missouri River valley in South Dakota may be described in two parts. The upper reach, beginning at the North Dakota State line and extending south almost to Yankton, is known as the gorge of the Missouri. The lower reach of the valley begins with the mouth of the gorge, which opens about 4 miles upstream from Yankton at Gavins Point Dam, and proceeds southeastward to Sioux City, Iowa, and is characterized by a wide flood plain.

Settlement by white men, in and along the Missouri Valley, was made possible by the combination of the Homestead laws and Indian treaties. The construction of railroads to the Missouri River between 1880 and 1900 added more impetus to settlement. Many of the towns, creeks, and places are named after early traders, settlers, and prominent citizens, or are of incident and Indian origin.

The major industry throughout the entire valley is agriculture, including the raising and feeding of livestock. The bottom lands and benchlands are largely utilized for crops; and the uplands furnish hay and grazing areas. Although the soils are generally good and the growing season is adequate, precipitation limits the productivity. With irrigation, the distribution and types of crops grown would change toward an increased and stable supply of feed for livestock; production on the lands would increase and permit more efficient use of adjacent drylands. Irrigation would have a stabilizing effect on the economy of the whole area.

The first comprehensive survey of the irrigation potential of the river bottom lands was made by the Bureau of Reclamation in the late 1930's. Plans for the main-stem reservoirs, as formulated by the Corps of Engineers, showed that some of these river bottoms would be flooded. After the large main-stem reservoirs had been located, the river bottom areas which would not be inundated were included in Senate Document 191, 78th Congress, 2d session. Subsequent changes in the location of Oahe Dam and in pool elevations of the other main-stem reservoirs eliminated more of the bottom lands from the potential irrigation units.

In 1946 and 1947, investigations of higher benchlands in Campbell and Walworth Counties resulted in the establishment of additional potential irrigation units. Further study during the 1950's in Brule, Charles Mix, and Bon Homme Counties included three more potential units. A "Report on South Dakota Pumping Division—South Dakota, MRBP" was completed in April 1959. This report summarized and updated the investigations and modifications of potential irrigation units studied by the Bureau of Reclamation. It recommended that the plan of development for 12 units, including Wagner unit of the B–C–B area, be approved, and that detailed investigations proceed on those units where local interest and demand give reasonable assurance that their development will accomplished. These units are discussed in detail in a subsequent section of this report concerning future potential irrigation developments along the main-stem Missouri River.

The Flood Control Act of 1944, and subsequent legislation, authorized joint development of the Missouri River Basin by the Corps of Engineers and Bureau of Reclamation. Today, two decades later, South Dakota finds itself very fortunate to have located within its boundaries four main-stem Missouri River dams constructed by the Corps of Engineers. The "Big Muddy," a nickname derived from its tremendous silt load, has been transformed into a chain of four man-made clear-water lakes extending in a north-south direction through the entire state of South Dakota.

Oahe, Big Bend, Fort Randall, and Gavins Point dams and reservoirs

These four existing water resource developments will be discussed in this section of the report primarily from the aspect of their water storage capacities. A detailed description of their dams, powerplants, and other appurtenances is given in the hydroelectric section of this report.

All four of these facilities were designed and constructed by the Corps of Engineers. This same organization also operates and maintains them, and coordinates their functions with the Bureau of Reclamation and other governmental agencies' programs concerned with water resource utilization and development. The tremendous water storage capacity of these four large earth dams is shown in the following tabulation.

Name	Reservoir storage capacity [1]	Hydroelectric power capacity [2]	Reservoir status
	Acre-feet	*Kilowatts*	
Oahe	23,600,000	595,000	Impounding water since August 1958.
Big Bend	1,900,000	468,000	Impounding water since summer of 1963.
Fort Randall	6,300,000	320,000	Impounding water since summer of 1952.
Gavins Point	540,000	100,035	Impounding water since summer of 1955.
Total	32,340,000	1,483,035	

[1] Does not include superstorage capacity.
[2] Installed generating capacity.

Very little of the vast quantities of water stored behind these main-stem Missouri River dams is being utilized today for irrigation purposes. A total of 43 filings are recorded in the office of the State Water Resources Commission to irrigate an estimated 8,720 acres along the river. As water elevations stabilize, it is anticipated that diversion from the main-stem reservoirs by private interests will increase.

JAMES RIVER BASIN

The James River, which heads in North Dakota above Jamestown, traverses eastern South Dakota in a southerly direction, and enters the Missouri River near Yankton, S. Dak. The James River valley itself is rather flat and often not clearly distinguishable from adjacent drainage basins. The James River has a very flat gradient of only about 0.2 or 0.3 foot per mile. In parts of the basin, surface drainage channels are fairly well developed while in others, particularly that part known as the Lake Plain, surface relief is very slight. Topographically, the area is little changed from the condition existing at the close of the glacial period.

The existing dryland agricultural economy in the James River basin is in the "high risk" category because of the uncertainty of soil moisture. The income fluctuates as erratically and almost as widely as the rainfall. For a fully productive diversified cropping program, the average rainfall should be 31 inches; actually, the average rainfall is only about 19 inches over the Lake Plain area and even less in the Missouri Slope area. Hardly a summer goes by without several extended dry periods of no precipitation.

The search for a water supply to irrigate lands in the James Basin had already begun when South Dakota became a State on November 2, 1889. In his first report, dated December 1, 1890, the State Engineer of Irrigation made emphatic claims for the value of the artesian water for irrigation. After a few years of irrigation with this artesian water, it was found that the heavy concentration of salts was injurious not only to the crops but also to the soil.

As soon as the artesian water proved itself unsuitable for irrigation use, the people of the area immediately gave consideration to the Missouri River as a possible source of water. It was already known that the erratic flows in the James River would not provide a reliable supply. Early studies soon proved that, although the Missouri River was several hundred feet higher in elevation than the James River, the pump lift to cross the divide between the two basins was too high for a feasible diversion system at that time. The same would be true today if it were not for the main-stem reservoirs and the production of low cost hydroelectric power.

Irrigation within the James River basin today is scattered and very limited. Recent knowledge of the location of relatively shallow aquifers, or underground water-bearing strata, has led to the development of some irrigation by individual farmers. Some water is diverted for irrigation from the James River. The State Water Resources Commission records indicate that 35 individuals have filed for surface water diversions to irrigate an estimated 4,810 acres in the basin. The extent of use of these rights today is difficult to determine.

Oahe unit

The Oahe unit was included as a part of the Missouri River Basin Project authorized by Congress in the Flood Control Act of 1944. The Bureau of Reclamation has conducted engineering, land resource, and economic studies on the Oahe unit since the passage of the act.

During the late 1940's and early 1950's, reconnaissance engineering and soil surveys were made to delineate the general areas that would merit more detailed studies. The Bureau established two development farms, the Huron Development Farm and the Redfield Development Farm, to acquire information about crop yields and irrigation field practices that were suitable to the area. The South Dakota State College performed research on both farms in a cooperative effort.

Relatively shallow aquifers were discovered to contain suitable ground water for irrigation. In 1953 and 1954 the Bureau of Reclamation drilled eight irrigation wells on farms in the Oahe unit area. Each farmer, upon whose land a well was located, agreed to furnish the Bureau and State College data relative to water applied, crop yields, costs, and other factual information. Interest in irrigation grew among the local farmers. By 1960, approximately 60 farmers in the Oahe unit area had developed irrigation on about 7,000 acres using mostly ground water.

An Interim Information Report on Oahe Unit was completed by the Bureau and given public distribution in 1956. The Bureau prepared a draft of a feasibility report on Oahe unit in June 1960. In this report it was concluded that the proposed plan of development had engineering and economic feasibility. The report was released, unapproved, as an information report. A revised feasibility report is being completed. It will summarize recent studies and facts obtained since the 1960 report.

A plan of development for Oahe unit will be discussed in a subsequent section of this report.

James diversion dam.—In 1961, the Bureau of Reclamation began studies to determine the feasibility of constructing certain features of the Oahe unit in advance of the need for such works in the over-all Oahe unit plan of development so as to better utilize the existing flows of the James River. Several plans were studied and a report entitled "Report on James Diversion Dam of the Oahe Unit, James Division, South Dakota, MRBP" was completed in March 1962.

The aforesaid report concluded that the James diversion dam, with impoundment of natural flows of the James River, offered the best immediate opportunity of supplementing the municipal water supply for the city of Huron. Construction of this dam would also fit into future irrigation plans for Oahe unit. A water service contract was consummated and signed with the city of Huron on September 13, 1962. This contract provides for repayment over a 20-year period of that portion of the cost of James diversion dam allocated to municipal water.

A contract for construction of the dam was awarded July 18, 1963, and the contractor expects to complete construction during late summer in 1964. The reservoir capacity behind James diversion dam will be approximately 4,900 acre-feet when full.

Willow Creek Dam—Rehabilitation study.—In 1954, city officials and interested citizens of Aberdeen, S. Dak., obtained assistance from the Bureau of Reclamation in performing a study of the feasibility of rehabilitating the deteriorated Willow Creek Dam, located about 17 miles northwest of Aberdeen, in Brown County.

Willow Creek Dam was constructed as a PWA project in 1935 and operated successfully for a number of years as a source of municipal water for Aberdeen. Lack of runoff prevented complete filing of the reservoir until 1943.

Water flowed over the spillway in early summer of that year; however, after the spills ceased, leakage developed and water continued to discharge through the walls of the spillway at joints and cracks in the concrete. Reservoir pressure finally broke the spillway wall on December 24, 1943, and the entire amount of stored water discharged through the break in approximately 10 hours. The structure could not be used for water storage in that condition.

The Bureau of Reclamation completed a "Report on Rehabilitation of Willow Creek Dam, James Division, South Dakota, MRBP" in March 1955.

The Bureau's rehabilitation plans would have made it possible to store a total of 3,100 acre-feet of water in the reservoir behind Willow Creek Dam. The report concluded that no advantageous method of combining municipal water, irrigation, and flood-control benefits could be found to make rehabilitation of Willow Creek Dam economically feasible as a multipurpose Bureau project. The structure was later rehabilitated by the city of Aberdeen and is presently contributing to their supply of municipal water.

VERMILLION RIVER BASIN

The Vermillion River basin in southeastern South Dakota is approximately 100 miles in length, averages 20 miles in width, and covers an area of about 2,185 square miles. It is bounded on the east by the Big Sioux River basin and on the west by the James River basin. The Vermillion River basin covers parts of nine counties. Of these, Turner County and Clay County are almost entirely within the basin.

The climate in the basin is classified as moist subhumid. Rainfall is erratic. Precipitation in the basin averages about 23 inches a year.

The topography of the basin is typical of glaciated areas, and the stream valley is bordered by undulating uplands of glacial till.

The East Fork and the West Fork of the Vermillion River join about 3 miles southeast of Parker, S. Dak., from which point the Vermillion River flows in a southerly direction to its confluence with the Missouri River near Vermillion, S. Dak. Streamflows are derived principally from early spring snowmelt and spring rains. Heavy localized thunderstorms occur during spring and early summer, causing large runoffs during short periods of time and at unpredictable intervals.

A large aquifer, the Parker-Centerville Outwash, was investigated by the South Dakota State Geological Survey in the middle 1950's. The results of this investigation were presented in their report entitled "Report of Investigations, No. 82, Geology and Hydrology of the Parker-Centerville Outwash," dated March 1957.

Periodic flooding of agricultural land along the main stem of the Vermillion River basin has been a problem for many years. The Corps of Engineers conducted an investigation of flooding in the Vermillion River basin and prepared a report on their findings entitled "Survey Report on Flood Control for the Vermillion River and Tributaries, South Dakota," dated December 1958. The Corps recommended channel improvements and levees along the Vermillion River, Clay Creek, and on several other major tributaries. The investigation also concluded that provision of storage on the major upstream tributaries would have little or no effect on floodflows in the lower basin where the major portion of flood damage is sustained.

The Soil Conservation Service has received applications for and interest has been shown in watershed development projects under the Watershed Protection and Flood Prevention Act (68 Stat. 666), as amended, also referred to as Public Law 566, for an area of about 1,300 square miles in the Vermillion River basin. The only watershed plan that has been completed in the basin is for Turkey Ridge Creek.

An appraisal of lands in the Vermillion River basin was made by the Bureau of Reclamation from the junction of the East and West Forks to the Missouri River flood plain near Vermillion, S. Dak. It is estimated that there would be from 100,000 to 125,000 acres of potentially irrigable land in this portion of the basin.

The Bureau of Reclamation completed a "Report on Turner-Clay County Area of the Vermillion River Basin, South Dakota," dated October 31, 1963. The report concluded that development of irrigation from extensive ground-water aquifers in the area appears to be the most economical method of presently developing irrigation in the Vermillion River basin as long as these supplies are available.

A working agreement between the United States, acting through the Bureau of Reclamation, and the South Dakota State College is in effect to perform reserach on soil and water management as they pertain to irrigation in Turner and Clay Counties. The South Dakota State College, under terms of the agreement, will make available to the Bureau all information resulting from their research program.

Irrigation from ground-water sources in the general area of the Vermillion River basin, as reported in 1959 by the U.S. Census of Agriculture, is as follows:

County:	*Irrigated acres*
Clay	1,010
Turner	4,283
Union	1,656
Yankton	514
Total	7,463

The principal crops grown in 1959 on irrigated land were corn and hay. The Utah & Idaho Sugar Co. has developed interest in the raising of sugarbeets in eastern South Dakota. In 1961 there were 2,234 acres of irrigated land planted to sugarbeets in Clay and Turner Counties, and in 1962 the acreage was increased to 3,742 acres. In addition, 1,920 acres were planted to sugarbeets in Union and Yankton Counties in 1962.

A check of the State Water Resources Commission records in 1963 shows that the commission had issued 75 permits to drill wells in this area for irrigation of an estimated 10,688 acres of land. No information was obtained on surface water diversion rights for irrigation. The full extent of the use of these water rights for irrigation is not readily available.

BIG SIOUX RIVER BASIN

That portion of the Big Sioux River basin lying within South Dakota covers an area of approximately 6,420 square miles. This area includes all of Hamlin and Moody Counties, major portions of Codington, Brookings, Lake, and Minnehaha Counties, and smaller portions of Marshall, Day, Roberts, Grant, Deuel, Clark, Kingsbury, Lincoln, and Union Counties. The stream heads in northwestern Grant County and flows south along the eastern edge of the State, discharging into the Missouri River at the southeast corner of South Dakota.

The upper half of the Sioux River basin is broad and shallow; however, from Dell Rapids to the mouth, the valley becomes well defined. The basin is a prairie country for the most part. Normal annual precipitation varies between 20 and 25 inches in the upper basin and increases to more than 25 inches in the extreme lower portion of the basin. The greater part of the rural poulation within the basin is engaged in agricultural pursuits.

The Soil Conservation Service has performed some work within the Sioux River basin under the Watershed Protection and Flood Prevention Act (Public Law 566). The Corps of Engineers, under the Flood Control Act of 1954, has constructed a local protection project to alleviate the flood threat to the urban areas in Sioux Falls. Other flood control studies and plans have also been considered on the lower Big Sioux River below the mouth of the Rock River.

The Bureau of Reclamation has not conducted any water resource studies of the Big Sioux River basin for purposes of determining irrigation needs or possible developments. Census reports show a limited amount of irrigation in the basin.

RED RIVER OF THE NORTH BASIN

The extreme southern part of the Red River of the North basin is located in the northeastern corner of South Dakota. It drains the northern part of Marshall and Roberts Counties. Most of the Marshall County portion of this area drains north into the Wild Rice River in North Dakota, and the Roberts County portion of the area drains east into Lake Traverse, which forms the head of the Bois de Sioux River. Both are tributaries of the Red River of the North.

This relatively small area of approximately 670 square miles receives between 20 and 25 inches of rainfall annually. Agriculture is the basic industry of the area. Census data for 1959 indicate very little irrigation is practiced in the area.

The Bureau of Reclamation has not conducted water resource studies in the South Dakota portion of the Red River of the North basin for the purposes of determining irrigation need or potential. The Corps of Engineers has constructed flood control structures in the Lake Traverse-Bois de Sioux area. Parts of this development extend into South Dakota.

MINNESOTA RIVER BASIN

The Minnesota River has its source at the southern end of Big Stone Lake, which forms the boundary between a part of Roberts County, S. Dak., and the State of Minnesota. Although the Minnesota River does not flow through South Dakota, it derives considerable drainage from the numerous tributaries located in parts of Roberts, Grant, Deuel, and Brookings Counties. The South Dakota portion of the Minnesota River basin is triangular in shape, embracing an area of approximately 1,542 square miles.

The topography of the area is that of a subdued glacial surface exposing low ridges and relatively flat, poorly drained areas of glacial till. The average annual rainfall is between 20 and 25 inches. The area is used basically for agricultural purposes and considerable livestock is raised. Very little irrigation is practiced within the basin, according to agricultural census data. The South Dakota portion of the Minnesota River basin has not been investigated by the Bureau of Reclamation for purposes of determining irrigation need or potential.

The Corps of Engineers has performed some flood control surveys and preliminary studies in the vicinity of the Whetstone River and Big Stone Lake.

KEYA PAHA RIVER BASIN

The Keya Paha River flows southeasterly out of eastern Todd County, continues through Tripp County, and joins the Niobrara River in Nebraska about 10 miles south of the South Dakota State line. Its drainage basin includes the eastern half of Todd County, most of Tripp County, and the southwestern corner of Gregory County. The topography of the area exhibits gently rolling prairies common to the Missouri plateau.

The average annual rainfall is nearly 21 inches. Small grain and livestock raising are the main pursuits of livelihood. Years of adequate moisture and periods of drought alternately influence economic conditions within the basin. There has been no major industrial development in the Keya Paha River basin.

The Bureau of Reclamation completed a report in June 1963 of the Niobrara River basin, of which the Keya Paha River is a tributary. The report included considerations of the Keya Paha River basin. A few small scattered acreages of arable land are located along the river valley terraces; however, these tracts are so minor in extent as to preclude possibility for project-type development. Only relatively small amounts of water are available for development.

The 1959 agricultural census indicates that very minor acreages are presently being irrigated. Records of the State Water Resources Commission, as of July 1, 1963, indicate a total of 15 surface water rights to irrigate an estimated 1,280 acres by stream diversion; an additional 13 filings exist for irrigating an estimated 1,270 acres by spreader-type systems in the Keya Paha River basin. The actual use being made of these rights at the present time is undetermined.

PONCA CREEK BASIN

Ponca Creek, originating in the northeast corner of Tripp County, flows southeasterly through Gregory County and enters the Missouri River from the State of Nebraska. It parallels the Keya Paha River during its 34-mile traverse through South Dakota. The topography, annual precipitation, and economics of the area are similar to those previously described for the adjacent Keya Paha River basin.

The Ponca Creek basin is a very minor drainage area in South Dakota. The Soil Conservation Service has made some investigations in the basin. As of December 31, 1962, the Soil Conservation Service had applications pending for approval on two watershed projects, Middle Ponca Creek and upper Ponca Creek, as authorized under the Watershed Protection and Flood Prevention Act (Public Law 566).

The 1959 agricultural census indicates very little acreage under irrigation in either Gregory or Tripp Counties.

PRESENT MUNICIPAL AND INDUSTRIAL WATER DEVELOPMENT

It is estimated that South Dakota municipalities use an average of 40 million gallons of water per day to serve some 416,000 people living in over 250 urban communities. Of this total quantity used, approximately 75 percent is obtained from ground-water sources.

A brief listing of South Dakota municipalities having greater than 2,500 population, their water supply sources, type of water, and treatment used is given in the following tabulation.

Municipality	1960 population	Water source [1]	Treatment [2]
Aberdeen	23,073	SW	PHD.
Belle Fourche	4,087	SW	D.
Brookings	10,558	GW	ID.
Canton	2,511	GW	D.
Chamberlain	2,598	SW	PH.
Deadwood	3,045	SW	D.
Fort Pierre	2,649	GW	D.
Hot Springs	4,943	SW, GW	D, D.
Huron	14,180	SW, GW	D, PHD.
Lead	6,211	SW	D.
Madison	5,420	GW	D.
Milbank	3,500	SW, GW	D, D.
Mitchell	12,555	SW	PH.
Mobridge	4,391	SW	HD.
Pierre	10,088	GW	D.
Rapid City	42,399	SW, GW	PD, D.
Redfield	2,952	GW	D.
Sioux Falls	65,466	GW	HID.
Sisseton	3,218	SW, GW	I, ID.
Spearfish	3,682	SW, GW	D.
Sturgis	4,682	SW, GW	D, D.
Vermillion	6,102	GW	HD.
Watertown	14,077	SW, GW	PD, D.
Winner	3,705	GW	D.
Yankton	9,279	SW	PH.

[1] Water source designation:
GW—ground water.
SW—surface water.

[2] Water treatment designation:
P—purification.
H—softening.
I—Iron or manganese removal.
D—disinfection.

NOTE.—Where 2 sources are shown, 2 respective treatments are also indicated.

Much of the water used by municipalities within the State contains concentrations of sulfate, chloride, sodium, iron, magnesium, or other undesirable elements and generally requires treatment to make it potable and more suitable for consumptive use. Further information relative to water quality is given in the Geological Survey's section of this report.

Industry's daily self-supplied withdrawal of water within the State is estimated at 16 million gallons. Ground-water sources again furnish approximately 64 percent of this volume.

Nonconsumptive use of water means using water and returning it to streams for reuse by others. Commercial and industrial firms are estimated to have a total nonconsumptive use of 540 million gallons per day. Private hydroelectric firms are the largest group of nonconsumptive users in the State. Federal hydroelectric powerplants on the main-stem Missouri River are excluded from this estimate.

GROUND WATER UTILIZATION

Ground water is presently the principal source of municipal and industrial water in South Dakota. Economics are usually the determining factor for using this source, unless some highly objectionable characteristic, such as saline ground water, influences the selection of a surface water source. When an adequate supply of ground water is available several advantages exist. Large storage reservoirs are not needed and evaporation losses are eliminated. The source is usually close to the area of consumption and conveyance costs are therefore minimized. In the case of small municipalities and industries, when only small quantities are needed, the investment in plant and facilities is usually much less than that required to develop surface water sources. Chances of the ground-water source becoming polluted with raw sewage and industrial waste are also remote. Most municipalities of less than 2,500 population rely entirely upon ground-water sources for their water supply.

A water desalinization plant at Webster, is operated by the Office of Saline Water, U.S. Department of the Interior. This is a demonstration plant established for the purpose of determining economic feasibility of making good potable water from local sources that had highly excessive amounts of dissolved solids. The salts are removed by an electrodialysis process. Another type of an electrodialysis demineralization plant is in operation at the Gettysburg Air Force Base. Design and construction of this plant was under the direction of the Corps of Engineers.

SURFACE WATER UTILIZATION

Surface water resource development is usually more feasible for larger municipalities; however, proximity to an existing source is a primary requisite. Surface water sources are often used when large quantities of water are needed or when ground water is difficult to obtain.

Surface water supplies are used quite frequently by municipalities in the immediate area of the Black Hills in western South Dakota. The Bureau of Reclamation furnishes water from Deerfield Reservoir and Pactola Reservoir, through controlled releases in Rapid Creek, to Rapid City and Ellsworth Air Force Base. Belle Fourche, Deadwood, Lead, Hot Springs, and other municipalities rely heavily upon surface water sources.

The Missouri River is a reliable source of water for municipalities situated nearby. Mobridge, Chamberlain, and Yankton benefit from this source.

In eastern South Dakota, storage and regulatory reservoirs supply water to Aberdeen, Huron, and Mitchell. The Bureau of Reclamation is completing the James diversion dam on the James River, approximately 15 miles north of Huron, which will supply a substantial quantity of surface water for the city's future growth. The city of Watertown uses nearby Lake Kampeska for a supply source to supplement ground-water sources already developed.

Surface waters are subject to pollution from many sources, both natural and manmade. The U.S. Public Health Service, in cooperation with the South Dakota State Department of Health, and similar agencies of adjacent States, manages a pollution abatement program to maintain and control quality of surface waters.

The streams of South Dakota have been divided into two classes: class A streams, which must be protected from pollution, and class B streams, which have as their principal function the transportation and ultimate disposal of wastes.

One stream, Whitewood Creek, has been classified as a class B stream to carry away rock flour and other wastes incurred in production of gold at the Homestake mines. Pollution from raw municipal sewage and industrial wastes must be controlled to maintain suitable quality in surface water sources.

PRESENT FARM-DOMESTIC WATER DEVELOPMENT

Farm-domestic water use and development pertains to individual family facilities of the type found on the typical farm or ranch in South Dakota. The actual quantity of water consumed or used for domestic purposes within the household is relatively small. Larger quantities of water are required for livestock, and usually in the case of surface waters adequate seasonal storage must be provided.

GROUND WATER

Most farms and ranches depend upon ground-water sources, such as wells and springs, to furnish water for domestic household use. Artesian wells are prevalent throughout the State. Their quality of water is usually poor, being highly mineralized and oftentimes containing undesirable elements. Shallow wells are common in certain areas and, except during extreme prolonged periods of drought, are generally satisfactory for supplying small quantities of water. Certain areas of South Dakota, especially in the eastern portion of the State, are underlain with layers of water-bearing sands and gravels known as aquifers. Many of these aquifers have good quality water and may yield a moderate to an abundant supply of water. Rural electrification has modernized ground-water use to a real convenience in rural areas today.

Details of ground-water characteristics, their sources, and location are discussed in the Geological Survey's section of this report.

SURFACE WATER

Since the drought period of the 1930's, construction of dugouts and stockdams has become a significant factor in the storage of water for use by livestock on farms and ranches.

Dugouts are most common in the eastern part of South Dakota where the terrain is relatively flat and no definite water courses exist. They are usually small in size and are constructed in low depressions of the pastures where water may be stored by collecting spring snowmelt, early summer runoff, and ground-water seepage. Their construction is simple, being merely a wide shallow trench, usually excavated by means of a bulldozer.

Stockponds, sometimes called stock reservoirs, are similar to dugouts and used to collect and store surface water. A stockpond is formed by a dam across a natural waterway or drain. Some type of a spillway is provided to protect the structure from being washed out by severe runoff. The common practice is to use a bulldozer or carryalls for construction.

A few stockponds were constructed by the early settlers. Larger numbers of stockponds were constructed in the early 1930's, and many more were constructed in the 1940's and 1950's. These stockponds have had a very noticeable effect on surface runoff in South Dakota. The losses in runoff chargeable to these reservoirs and ponds have been estimated to average about 32 percent in some of the river basins. The effect of stockponds is greatest during years of low runoff.

SOIL CONSERVATION SERVICE DEVELOPMENT

The Soil Conservation Service cooperates and works closely with the individual farmer or rancher, or small groups of rural people, in a program that encourages desirable conservation practices for controlling soil erosion on cropland and rangeland, as well as conserving moisture. The following conservation practices have been accomplished in South Dakota since 1942:

Conservation practice		*Quantity completed*
Terraces	miles	5, 310
Pond construction	number	64, 850
Waterway development	acres	30, 821
Irrigation water management	do	30, 971
Irrigation land leveling	do	43, 987
Irrigation reservoirs	number	287
Sprinkler irrigation systems	do	260
Water spreading	acres	94, 465
Irrigation supply and field ditches	miles	1, 082
Spring development	number	2, 039

The above-listed practices have been accomplished on farms and ranches throughout the State. Many of them are relatively small in size; however, their totals amount to some impressive figures.

The terraces catch and hold runoff moisture so it enters the ground, making it available for plant life and thereby reducing downstream flooding on storms of 10-year frequency or less. Pond construction includes both earth dams and dugouts that are constructed to hold runoff for stockwatering purposes. Waterway developments serve as outlets for terraced areas. The irrigation management program helps irrigators learn and use efficient measures to apply water uniformly and reduce losses to a minimum. The program includes such irrigation practices as ditch locations, row directions, lengths of run, land leveling, drainage, location of turnouts, drop structures, and other items. The irrigation reservoirs are individual developments to catch and hold runoff for use on adjoining land. Technical assistance is provided on sprinkler irrigation systems for which the water is generally supplied from individual well developments. Water spreading is a moisture conservation practice for rangelands, utilizing a system of ditches and dikes to spread floodwaters over grassed areas. This results in increased production of forage for stock. Natural spring developments provide excellent stockwatering facilities. All of these practices are generally on individual farms and ranches; however, technical assistance is also provided on larger irrigation projects such as the Belle Fourche Project and the Angostura unit. Certain types of soil and water conservation needs cannot be adequately solved by local people except by action through local units of government such as soil and water conservation districts, watershed districts, drainage districts, irrigation districts, counties, towns, and municipalities. Aid may also be needed from State and Federal agencies. These conservation needs are primarily forms of water management such as flood prevention, agricultural water management, and nonagricultural water management.

The Watershed Protection and Flood Prevention Act (Public Law 566) makes it possible to meet many of the soil and water conservation needs that cannot be met under other programs of assistance to agriculture or through Federal public works projects on major rivers, planned and constructed by such agencies as the Corps of Engineers or the Bureau of Reclamation. The act provides a means by which local organizations can apply for and obtain assistance in the planning and installation of works and improvements for flood prevention and the conservation, development, utilization, and disposal of water in watershed areas not exceeding 250,000 acres in size.

South Dakota has numerous watershed protection projects in various stages of planning and development. The following tabulation summarizes the status of this program as of December 31, 1962.

Watershed project	Location (county)	Size (acres)	Status
Silver Creek	Minnehaha	20,661	Approved and underway.
Richland Creek	Union	6,515	Inactive, June 1960.
Pattee Creek	Lincoln	25,462	Approved and underway.
Brule Creek	Union Lincoln	142,720	Do.
Marne Creek	Yankton	20,825	Do.
Green Creek	Union	11,104	Do.
Wild Rice Creek	Marshall, S. Dak Sargent, N. Dak	233,522	Do.
Tewaukon Creek	Marshall, S. Dak Sargent, N. Dak	93,782	Do.
Upper Little Minnesota	Marshall Roberts	36,984	Being planned.
Turkey Ridge Creek	Hutchinson Turner	113,840	Do.
Upper Crow Creek	Marshall	236,000	Planning suspended February 1963.
Lower Crow Creek	Brown	160,000	Do.
Veblen	Marshall, S. Dak Roberts, S. Dak Richland, N. Dak Sargent, N. Dak	90,800	Being planned.
Upper Deer-Lake Hendricks	Brookings, Deuel, S. Dak. Lincoln, Minn	29,755	Do.
Battle Creek	Custer Pennington	182,590	Planning terminated April 1961.
North Deer Creek	Brookings Deuel	73,620	Application pending planning approval.
North Fork Whetstone	Roberts Grant	123,700	Authorized for planning April 1963.
Upper East Fork Vermillion River.	McCook Lake Miner	112,600	Application pending planning approval.
Little Vermillion River	McCook Lake Miner	89,600	Do.
Spring-Bull Creek	Charles Mix	28,000	Do.
Upper Ponca Creek	Tripp Gregory	172,545	Do.
Middle Ponca Creek	Gregory, S. Dak Boyd, Nebr	164,606	Do.
Union Creek	Union	29,216	Do.
Hurley Creek	Turner	22,000	Current interest in application.
Baptist Creek	Clay	25,000	Application received November 1963.
Mud Creek	Deuel Grant	16,580	Application received October 1963.
West Branch Vermillion River	Miner McCook Turner	196,000	Current interest in application.

There are 299 watersheds in South Dakota that are within the 250,000-acre size limitation. Many of these would be broken into smaller watersheds on the basis of local problems. Nearly 100 of these watersheds have problems that would require assistance under Public Law 566.

EXISTING HYDROELECTRIC POWER DEVELOPMENTS

INTRODUCTION

Until construction of a series of multipurpose dams on the Missouri River in South Dakota, providing storage and head for hydropower development, few hydroelectric powerplants were existent in the State and their production of electricity was very small. The generally low and irregular flows of streams in the State, except the Missouri River, combined with the lack of storage sites, have precluded any large scale hydroelectric development.

Since 1945, there has been a virtual revolution in the use of electricity within South Dakota as elsewhere in the Nation. The growth of industry and the expanded use of electric appliances have increased the demand for power. Electricity is available to most farm families who now enjoy a plane of living comparable to that of urban families.

The large-scale power development in South Dakota has come about as a result of the construction, by various agencies, under the Missouri River Basin Project. The Corps of Engineers has constructed the Oahe, Big Bend, Fort Randall, and Gavin's Point Dams on the Missouri River. The Bureau of Reclamation has constructed a network of transmission lines and substations to distribute the power generated at powerplants built by the Corps in connection with the dams. Secondary distribution of this power to the consumer is accomplished by REA cooperatives, public utilities, and municipalities. Today, about 1,484,000 kilowatts of electricity, or more than 37 times as much hydroelectric power as thought possible at the turn of the century, is being generated within the State.

PRIVATE HYDROELECTRIC DEVELOPMENTS

Table 34 presents statistical data on existing private hydroelectric powerplants in South Dakota. All but one of these plants are situated in the Black Hills. Three private firms are operating hydroelectric powerplants in South Dakota. Figure 46 shows the locations of these plants.

TABLE 34.—*Hydroelectric power resources in South Dakota*

EXISTING PRIVATE DEVELOPMENTS

Map reference No.[1]	Plant name	Stream	Agency or company [2]	Average static head (feet)	Number of generating units	Ultimate capacity (kilowatts)	Estimated average annual generation (million kilowatt-hours)	Status as of 1963	Remarks
1	Falls Hydro	Fall River	BHP&L	100	1	200	1.0	Operating	Constructed in 1890 below Hot Springs, S. Dak.
2	Redwater No. 1	Redwater River	BHP&L	120	1	1,000	2.8	do	Constructed in 1907 between Belle Fourche and Spearfish, S. Dak.
3	Redwater No. 2	do	BPH&L	60	1	346	2.0	do	Constructed in 1925 2 miles below Redwater No. 1. Also uses water diverted from Spearfish Creek.
4	Spearfish No. 1	Spearfish Creek	HM Co	666	1	4,000	16.3	do	Constructed in 1912 ½ mile south of Spearfish, S. Dak.
5	Spearfish No. 2	do	HM Co	555	1	4,000	10.2	do	Constructed in 1918 near Maurice, S. Dak.
6	Englewood	Whitewood Creek	HM Co	424	1	400	2.2	do	Constructed in 1906 1 mile northeast of Englewood, S. Dak.
7	Hydroelectric Power	Little White River	Don Jones, Sr.	16½	2	210	.5	do	Constructed in 1924 near the town of White River. Has 1 75-kilowatt and 1 135-kilowatt unit.
	(Subtotal, private)				(8)	(10,156)	(35.0)		
(EXISTING FEDERAL DEVELOPMENTS)									
8	Oahe	Missouri River	USCE	191	7	595,000	2,652.5	Operating	7 85,000-kilowatt units operating since 1963.
9	Big Bend	do	USCE	70	8	468,000	1,066.7	Under construction.	2 58,500-kilowatt units to begin in 1964. 4 58,500-kilowatt units to begin in 1965. 2 58,500-kilowatt units to begin in 1966.
10	Fort Randall	do	USCE	128	8	320,000	1,595.1	Operating	8 40,000-kilowatt units operating since 1956.
11	Gavins Point	do	USCE	41	3	100,035	616.3	do	3 33,345-kilowatt units operating since 1957. Powerplant located in Nebraska.
12	Angostura	Cheyenne River	USBR	104	1	1,200	3.3	Not operating	Located 10 miles south of Hot Springs, S. Dak. Water shortage has curtailed operation since 1960
	(Subtotal, Federal)				(27)	(1,484,235)	(5,933.9)		
	(Subtotal, existing private and Federal.)				(35)	(1,494,391)	(5,968.9)		

(POTENTIAL FUTURE FEDERAL DEVELOPMENTS)

13	Mulberry Point	Missouri River	USCE	33	(3)	188,000	(3)	Under preliminary investigation.	Near Vermillion, S. Dak.
14	Kensler's Bend	do	USCE	33	(3)	80,000	(3)	do	10 miles upstream from Sioux City, Iowa.
	(Subtotal, future)					(268,000)			

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[1] Reference numbers appear on map shown in fig. 46.

[2] Blacks Hills Power & Light Co. (BHP&L); Homestake Mining Co. (HM Co.), U.S. Corps of Engineers (USCE), and U.S. Bureau of Reclamation (USBR).

[3] Unknown.

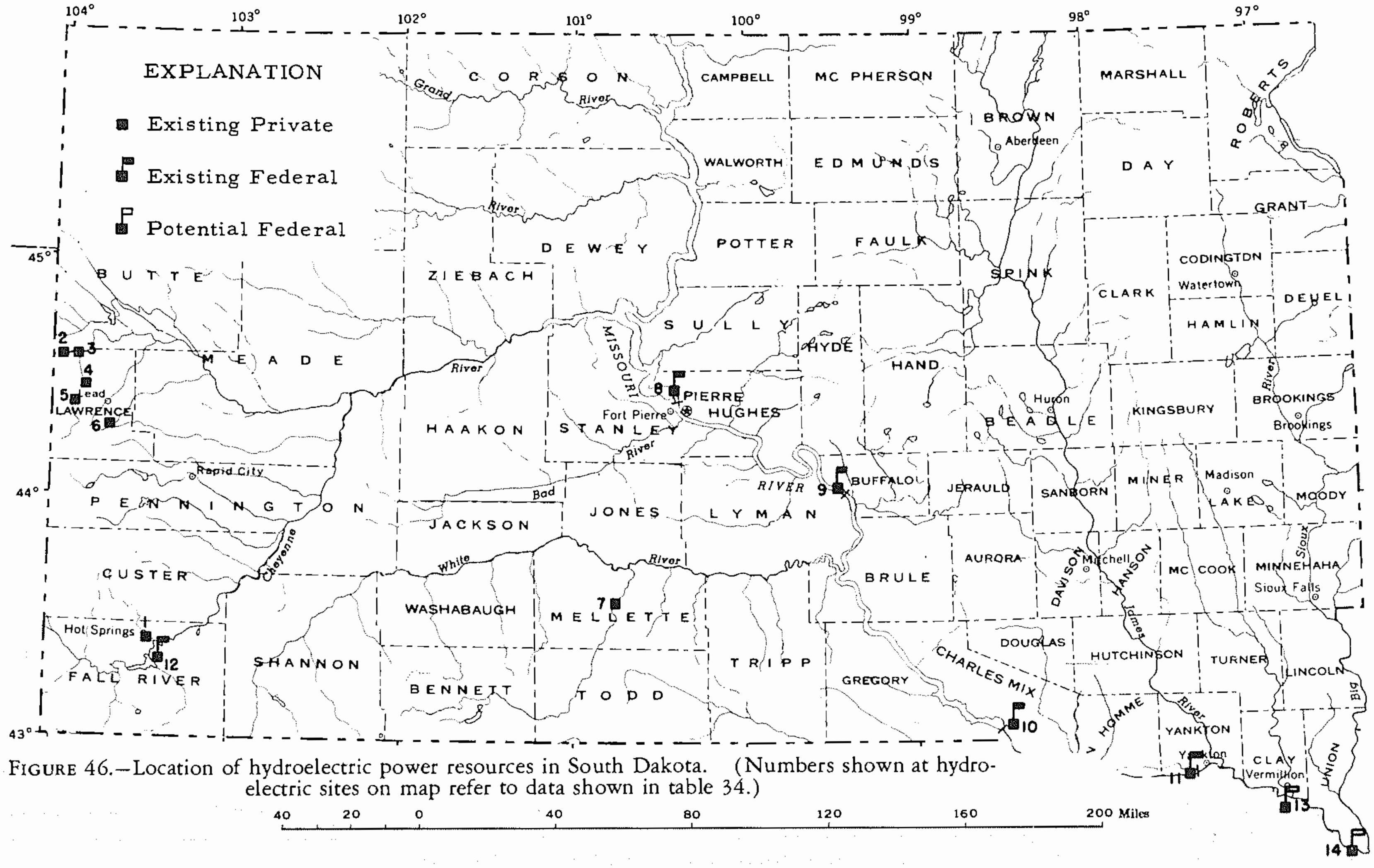

FIGURE 46.—Location of hydroelectric power resources in South Dakota. (Numbers shown at hydroelectric sites on map refer to data shown in table 34.)

The Black Hills Power & Light Co. operates three hydroelectric plants: one on the Fall River and two on Redwater River. The oldest of these is the Falls hydro plant, constructed in 1890 on Fall River immediately downstream from Hot Springs. Redwater plant No. 1 was constructed in 1907 on Redwater River between Belle Fourche and Spearfish. A second plant, Redwater plant No. 2, was completed in 1925 about 2 miles downstream from Redwater plant No. 1. The latter plant also uses water diverted from Spearfish Creek.

Homestake Mining Co. pioneering early development of hydroelectric power in the Black Hills. Today the company operates three hydroplants. The oldest is the Englewood plant, constructed in 1906 on Whitewood Creek about 1 mile northeast of Englewood. The two other plants are on Spearfish Creek. Spearfish plant No. 1 was completed in 1912 south of the city of Spearfish. Spearfish plant No. 2 was completed in 1918 near Maurice.

On the Little White River near the town of the White River, a private company called Hydro Electric Power operates a low-head plant, which was placed in operation in 1925. The plant was operated the first four years with only one generator; a second generator was added in 1929. This appears to be the smallest privately owned plant operating in South Dakota today. The entire output of the plant is sold to the Cherry-Todd Electric Cooperative of Mission, S. Dak., which serves the town of White River.

FEDERAL HYDROELECTRIC DEVELOPMENTS

South Dakota lies almost entirely within the Missouri River drainage area. The Flood Control Act of 1944 (32 Stat. 887) authorized the Missouri River Basin Project, popularly known as the Pick-Sloan Plan, for development of land and water resources of the Missouri River basin. One of the important benefits of this project is the hydroelectric power now being generated.

Table 34 shows the extent of the hydroelectric power development in South Dakota as part of the Missouri River Basin Project. About 99 percent of the hydroelectric power generated today within the State is generated at the four main-stem Missouri River powerplants constructed by the Corps of Engineers.

The first federally produced hydroelectric power in South Dakota was generated at the Angostura powerplant, which is situated on the Cheyenne River 10 miles south of Hot Springs. This plant was constructed by the Bureau of Reclamation as part of the Angostura unit. The plant was placed in operation in 1951, and all salable electric energy was marketed to the Black Hills Power & Light Co. Recent water shortages have curtailed operation of the plant, and no power has been generated since 1960. Irrigation has first priority on the stored water available in Angostura Reservoir during critical dry years.

The Corps of Engineers constructs, operates, and maintains the multipurpose dams and powerplants on the Missouri River in South Dakota. Construction of Oahe, Fort Randall, and Gavins Point Dams and Powerplants has been completed. Construction of Big Bend Dam and Reservoir is nearing completion. These large earth dams will impound water to form a chain of lakes extending in a north-south direction through the State.

Oahe Dam situated about 6 miles northwest of Pierre forms the Oahe Reservoir which, when full, will extend 250 miles upstream to within a few miles of Bismarck, N. Dak. Oahe powerplant will be the largest producer of hydroelectric power of the four main-stem plants. The powerhouse, in the left abutment of the dam, houses seven generating units rated at 85,000 kilowatts each, with a total capacity of 595,000 kilowatts. The first generating unit was placed in operation in April 1962. All units have been in operation since 1963. The water for power generation is carried to the generators by seven tunnels, each 24 feet in diameter, one of which has been designed for future connection of irrigation pumping facilities for the proposed Oahe unit. With average water supply, the powerplant is capable of generating annually more than 2.6 billion kilowatt-hours of electric energy.

The second largest hydroelectric powerplant in South Dakota in terms of installed capacity will be Big Bend powerplant. The primary function of the Big Bend Dam and Reservoir is hydroelectric power generation. The project will be operated primarily to meet peak load requirements upon the main-stem system. The powerhouse and power facilities in the right abutment of the dam will consist of eight turbine and generator units with a total installed capacity of 468,000 kilowatts. The powerhouse will be 757 feet long, 200 feet wide, and 205 feet high, of which about 90 feet will be below ground level. The first generating unit is scheduled to begin operation in 1964, and completion of all units is scheduled for 1966. Because the project will be operated mainly for power generation, discharges at the dam will normally be made through the powerhouse.

The third largest hydroelectric plant on the Missouri River in South Dakota is Fort Randall powerplant. This plant contains eight 40,000-kilowatt generators with total installed capacity of 320,000 kilowatts. With average water supply, the plant can generate nearly 1.6 billion kilowatts annually. Installation of the generating units was begun in 1953 and completed in 1956. Through 1962, the plant had generated nearly 9 billion kilowatt-hours of electric energy.

The smallest of the four main-stem hydroelectric powerplants in South Dakota is Gavins Point, situated near Yankton. The Missouri River at this point is the boundary between South Dakota and Nebraska. Gavins powerplant is actually located on the Nebraska side. The powerhouse contains three 33,345-kilowatt units with a total generating capacity of 100,035 kilowatts. Through 1962, the plant produced 2.6 billion kilowatt-hours of electric energy.

The Bureau of Reclamation constructs, operates, and maintains the electric transmission lines and substations needed to transmit the power produced at the four main-stem powerplants to load areas in South Dakota and surrounding States. The Bureau is also responsible for the sale of this power. All federally generated hydroelectric power in the Missouri River basin is marketed at wholesale, mainly to rural electric cooperatives, municipalities, public power districts, and investor-owned power companies.

Preference customers in the area, such as REA cooperatives, municipal utilities, and State and Federal agencies, have first call on power marketed by the Bureau, in accordance with criteria established by Congress. Excess power generated is sold as available to those who have generating units of their own or can economically utilize such power on a short-term basis. The hydropower generated in South Dakota is integrated and marketed with other power supplies in the Missouri basin marketing area, of which the State is a part.

Within South Dakota, since 1953, the Bureau of Reclamation has constructed a network of approximately 600 miles of 230-kilovolt steeltower and 1,150 miles of 115-kilovolt wood-pole transmission lines, and 29 substations. Table 35 lists the substations constructed and indicates their present capacities and initial dates of operation. Figure 47 shows the substation locations in South Dakota. This system transmits, controls, and coordinates power delivery to 35 different customers in various load areas throughout the State. Currently, the Bureau also has under construction within the State approximately 380 additional miles of 230-kilovolt steel-tower and 60 miles of 115-kilovolt wood-pole transmission lines, and two additional substations. Capacity is being expanded at several substations as more power becomes available from completed main-stem Missouri River hydroelectric generating units.

TABLE 35.—*Bureau of Reclamation substations in South Dakota*

Map reference No.[1]	Substation	KVA capacity (as of Dec. 31, 1963)	Date first placed in service
1	Armour	16, 250	June 11, 1954
11	Beresford	20, 000	Sept. 1, 1954
14	Bonesteel	2, 000	Mar. 18, 1954
8	Brookings	38, 750	Nov. 10, 1954
24	Eagle Butte	15, 000	Dec. 13, 1962
22	Ellsworth Air Force Base	15, 000	May 24, 1954
25	Faith	2, 500	(2)
9	Flandreau	25, 000	Nov. 15, 1954
17	Fort Thompson	20, 000	June 22, 1962
15	Gregory	3, 750	Mar. 16, 1954
5	Groton	25, 000	Aug. 19, 1954
4	Huron	137, 000	May 15, 1953
30	Martin	10, 000	Nov. 14, 1963
26	Maurine	20, 000	Nov. 19, 1962
18	Midland	7, 125	Sept. 4, 1953
29	Mission	10, 000	Oct. 11, 1963
2	Mount Vernon	18, 750	Apr. 20, 1953
27	Newell	15, 000	Dec. 13, 1962
31	New Underwood	60, 000	(2)
19	Philip	5, 000	Sept. 3, 1953
28	Pierre	15, 000	Apr. 28, 1956
23	Rapid City	20, 000	Oct. 22, 1954
10	Sioux Falls	122, 500	July 21, 1953
6	Summit	15, 500	Sept. 14, 1954
13	Tyndall	7, 500	June 16, 1953
20	Wall	7, 500	Sept. 2, 1953
7	Watertown	114, 375	May 21, 1953
21	Wicksville	2, 000	Sept. 1, 1953
16	Winner	8, 300	Mar. 17, 1954
3	Woonsocket	10, 000	May 7, 1953
12	Yankton	10, 000	Mar. 26, 1957

[1] Reference numbers appear on map shown in fig. 47.
[2] Under construction.

An extensive system of communication and automatic control devices regulates the production and distribution of this power. The Bureau of Reclamation has constructed a radio relay network and microwave system across the State to provide operation and maintenance personnel with the vital communication needed. A system dispatching office at Watertown is the nerve center for controlling system frequency

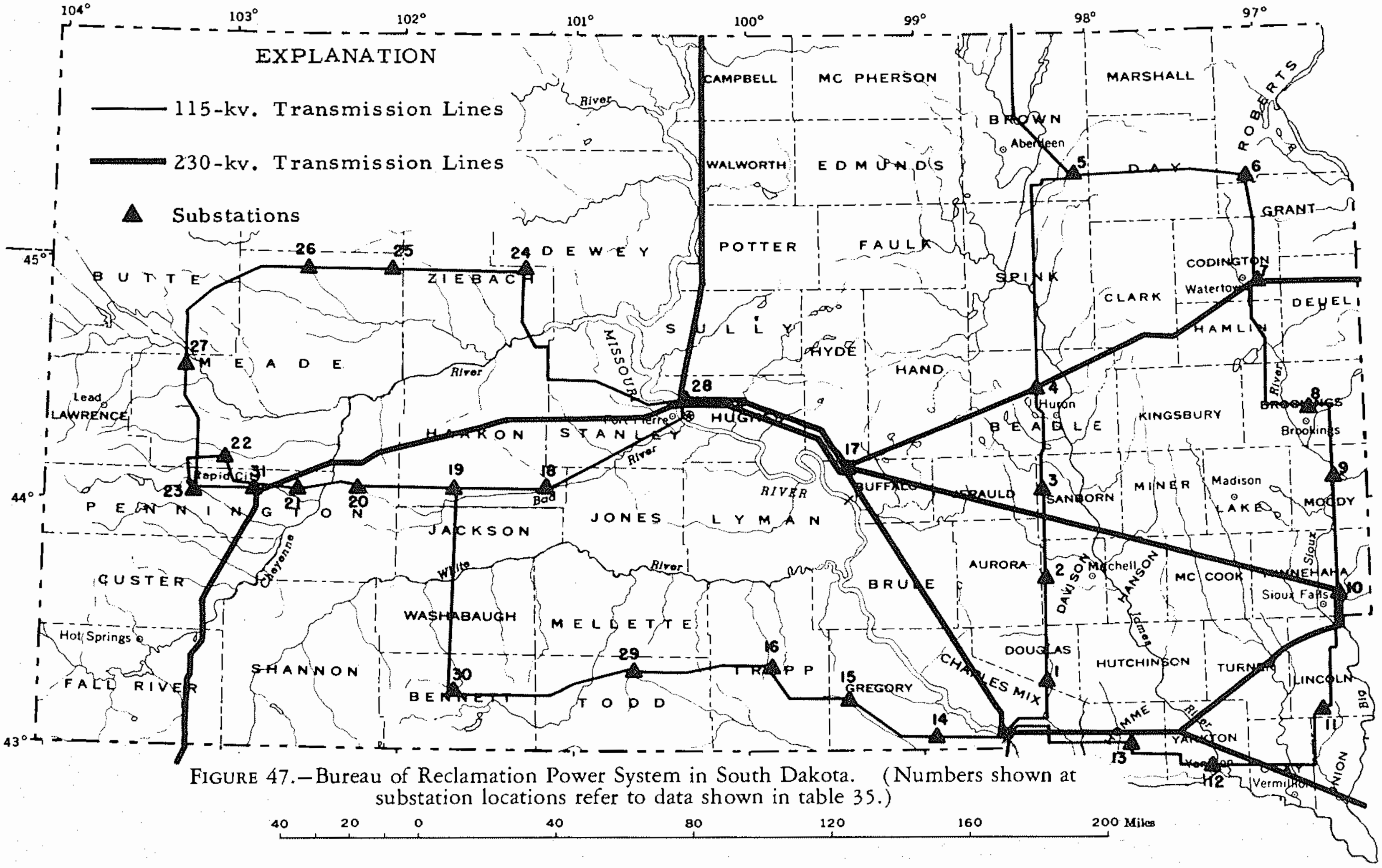

FIGURE 47.—Bureau of Reclamation Power System in South Dakota. (Numbers shown at substation locations refer to data shown in table 35.)

and voltage, coordinating planned "outages," and changing system connections. Dispatchers gather, record, and analyze a continuous stream of data that are received by automatic communications. They are in constant touch with their counterparts in adjacent power systems to coordinate joint activities and achieve efficient operations.

FUTURE WATER RESOURCE DEVELOPMENT AND USE

POPULATION TRENDS AND FORECASTS IN SOUTH DAKOTA

Past population trends for South Dakota were discussed in a previous section of this report. Forecasts of future population in South Dakota must take several factors into consideration. These factors may be briefly classified as climatic, political, economic, and technological. In the perspective of time, one may observe fairly definite influences exerted by these factors on the State's population; nevertheless, their occurrence and consequences are uncertain and unpredictable.

The following tabulation shows estimated future populations of South Dakota and the Nation, the population trends through the year 2020, and the anticipated shift of people from rural to urban areas.

South Dakota population comparison with national forecast

Year	U.S. population	South Dakota population estimate	
		Percent of United States	Number
1960	179,323,000	0.38	681,000
1980	254,000,000	.38	965,000
2000	358,000,000	.36	1,290,000
2020	502,000,000	.35	1,757,000

South Dakota population estimates by rural and urban areas

Year	Rural		Urban		Total
	Percent	Number	Percent	Number	
1960	60.7	414,000	39.3	267,000	681,000
1980	53.0	511,000	47.0	454,000	965,000
2000	43.0	555,000	57.0	735,000	1,290,000
2020	38.0	667,000	62.0	1,090,000	1,757,000

Population trend is defined as a population change which continues to occur in a given direction. It is primarily on the basis of past population trends that a forecast can be made as to what the State's future population will be. On the basis of current statistics and estimates of future population, it is forecast that South Dakota's population-increase rate will lag behind the national average.

It is anticipated that the major portion of the population increase will take place in the urban and adjacent suburban areas. This will result from the increased number of people employed in small industries in the service trades with special reference to increased tourist business in the Black Hills, the larger lakes on the Missouri River, and the smaller lakes of eastern South Dakota. The farm population has undergone a large decrease, and much of the population migration from the State each year is made up of farm people. This displacement of farm population has resulted largely from mechanization and electrification of the farms.

Many young people leave the State because of the lack of employment opportunities. A resources development program would bring about a better balance between job vacancies and job seekers. Water is one of the State's available resources. Agriculture is the basic income producer for South Dakota and would be a very compatible partner with existing water resources, especially irrigation development. Extensive development of irrigation would tend to increase the number of farms, increase productivity, and create more demand for food processing and agricultural industries, thereby providing employment for many more people and resulting in a more stable economy. This phase of water resource development, if it occurs, will have a noticeable effect upon future population trends in South Dakota. Recreation, especially those phases associated with surface waters, is also an element that can be coordinated with South Dakota's tourist industry. The extent that South Dakota's water resources are developed during the next few decades will most certainly influence the population trends within the State by the year 2000 A.D.

FUTURE IRRIGATION DEVELOPMENTS

INTRODUCTION

Future irrigation developments in South Dakota will be shaped by the economic, physical, political, and population influences upon water resources. Economic considerations such as development and construction costs, farm prices, availability of funds, and repayment abilities must be considered. Physical limitations of water supply and storage sites, existence of suitable soils, and topographical location will be encountered. Political organization of the people, either for or against irrigation, both public and private, will determine the progress that will be achieved in obtaining future irrigation projects. Population increases, both State and national, will create food demands, market potentials, and employment situations for additional development of our resources. Decisions made in the immediate future will determine the long range program that will be followed for irrigation development.

Table 36 summarizes briefly the important facts and data obtained from completed investigations. Figure 48 illustrates locations of potential developments now known and studied. Other possibilities may exist that have not been fully investigated. Table 36 and figure 48 are coordinated with a numbering system to facilitate identification and location of features for reference purposes.

TABLE 36.—*Major future irrigation and reservoir planning data in South Dakota*

Principal river basin	Project and/or unit [1]	Map ref. No. [2]	Principal features	Stream	Gross storage capacity (acre-feet) [3]	Potential irrigable lands (acres)	Responsible planning agency [4]	Status
White	MRBP, Pine Ridge unit.	1	Slim Butte Dam and Reservoir.	White River	[5] 60,000	7,400	USBR	Feasibility report to be completed.
	MRBP, Little White unit.	2	Little White Dam and Reservoir.	South Fork White River.	65,000	6,600	USBR	Under investigation.
Bad	MRBP, Philip unit	3	Philip Dam and Reservoir.	North Fork Bad River.	26,500	2,784	USBR	Economically infeasible; indefinitely deferred.
Cheyenne	MRBP, Edgemont unit.	4	Edgemont Dam and Reservoir.	Beaver Creek	27,000	2,650	USBR	Dam and reservoir in Wyoming, lands in South Dakota. Economically infeasible; indefinitely deferred.
	MRBP, Cheyenne pumping units.	5	(Individual pumping plants.)	Cheyenne River	None	3,910	USBR	Inadequate water supply. Development indefinitely deferred.
	MRBP, Belle Fourche pumping units.	6	do	Belle Fourche River.	None	4,550	USBR	Economically feasible. Quality of water questionable. Further study required.
	Belle Fourche Project	7	Indian Creek Dam and Reservoir.	Indian Creek	7,100	(6)	USBR	Supplemental water supply from Indian Creek Dam and Reservoir feasible but beyond project's ability to repay. Development indefinitely deferred.
Moreau	MRBP, Bixby unit	8	Bixby Dam and Reservoir.	Moreau River	215,000	2,059	USBR	Water-soil relationship (high exchangeable sodium) prohibits development of larger irrigable acreage. Development indefinitely deferred.
Grand	MRBP, Shadehill unit.	9	Shadehill Dam and Reservoir.	Grand River	(7)	6,700	USBR	Definite Plan Report completed June 1963; revised January 1964.
Little Missouri	None		None					No major water resource development opportunities evident. Further investigations may be needed. Interstate compact required.
Missouri (main stem)	Mulberry Point	10	Dam and reservoir	Missouri River		(8)	USCE	Only preliminary reconnaissance investigations have been accomplished.
	Kenslers Bend	11	do	do		(8)	USCE	Do.
	Pollock-Herreid unit	12	Pumping plant	Oahe Reservoir	None	10,500	USBR	Not an authorized part of MRBP. Feasibility report being completed.
	Mobridge unit	13	do	do	None	1,400	USBR	Development infeasible, indefinitely deferred. Not an authorized part of MRBP.
	Evarts unit	14	do	do	None	950	USBR	Do.
	MRBP, La Framboise unit.	15	do	Big Bend Reservoir.	None	256	USBR	Insufficient irrigable lands for feasibility. No further studies contemplated.
	MRBP, Pierre unit	16	do	do	None	132	USBR	Do.

Footnotes at end of table, p. 269.

TABLE 36.—*Major future irrigation and reservoir planning data in South Dakota*—Continued

Principal river basin	Project and/or unit [1]	Map ref. No. [2]	Principal features	Stream	Gross storage capacity (acre-feet) [3]	Potential irrigable lands (acres)	Responsible planning agency [4]	Status
Missouri (main stem)	MRBP, Rousseau unit.	17	Pumping plant	Big Ben Reservoir.	None	2,215	USBR	Preliminary investigations indicate feasibility. Future detailed studies required.
	MRBP, La Roche unit.	18	do	do	None	1,789	USBR	Do.
	MRBP, Joe Creek unit.	19	do	do	None	4,420	USBR	Do.
	MRBP, Iron Nation unit.	20	do	do	None	1,739	USBR	Do.
	MRBP, Culdesac unit.	21	do	do	None	5,444	USBR	Do.
	MRBP, Grass Rope unit.	22	do	do	None	4,340	USBR	Do.
	MRBP, Fort Thompson unit.	23	do	do	None	7,480	USBR	Do.
	MRBP, Fort Hale unit.	24	do	Fort Randall Reservoir.	None	1,136	USBR	Preliminary investigations show not feasible. No further studies contemplated.
	MRBP, Crazy Horse unit.	25	do	Missouri River	None	320	USBR	Insufficient irrigable land for feasibility. No further studies contemplated.
	MRBP, Tower unit	26	do	do	None	1,400	USBR	Definite Plan Report completed in September 1963 (revised March 1964) indicates feasibility for construction.
	MRBP, Greenwood unit.	27	do	do	None	3,550	USBR	Do.
	MRBP, Yankton unit.	28	Diversion siphon	Lewis and Clark Lake.	None	1,390	USBR	Do.
	Geddes unit	29	Pumping plant	Fort Randall Reservoir.	None	7,700	USBR	Not an authorized part of MRBP. Reconnaissance studies indicate not feasible.
	Wagner unit	30	do	Fort Randall Reservoir and Lake Andes Reservoir.	7,500	19,500	USBR	Not an authorized part of MRBP. Present studies indicate feasibility. Feasibility report being completed.
	Tyndall unit	31	do	Lewis and Clark Lake.	None	33,000	USBR	Not an authorized part of MRBP. Preliminary studies indicate marginal feasibility. Further study of unit lands in progress.
James	MRBP, Oahe unit	32	Oahe pumping plant	Oahe Reservoir	(9)	495,000	USBR	Water would be pumped from Oahe Reservoir and irrigate 50,000 acres in the Missouri Slope area; a system of supply canals and regulating reservoirs would convey water eastward into the James River valley to also irrigate 445,000 acres in the Lake Plain area.
		32A	Blunt Dam and Reservoir.	Medicine Knoll Creek.	631,000	(10)	USBR	
		32B	Cresbard Dam and Reservoir.	Cresbard Creek	31,500	(10)	USBR	
		32C	Byron Dam and Reservoir.	Foster Creek	62,100	(10)	USBR	

Vermillion	None							Surface water investigations will probably be deferred until ground-water resources are more fully developed.
Big Sioux	do							No irrigation investigations have been accomplished. Basin reconnaissance scheduled.
Red River of the North	do							No known irrigation potential of significance. No future investigations are presently contemplated.
Minnesota	do							Do.
Keya Paha	do							Reconnaissance studies indicate little potential. No future investigations are contemplated.
Ponca Creek	do							No known irrigation potential of significance. No future investigations are presently contemplated.

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[1] MRBP designates units of Missouri River Basin Project.
[2] Reference numbers appear on map shown in fig. 48.
[3] Total reservoir capacity to highest controlled water surface.
[4] U.S. Bureau of Reclamation (USBR); U.S. Corps of Engineers (USCE).
[5] Final capacity not determined.
[6] Supplemental water supply.
[7] Existing. See table 33.
[8] Unknown.
[9] See table 33.
[10] See map reference 48.

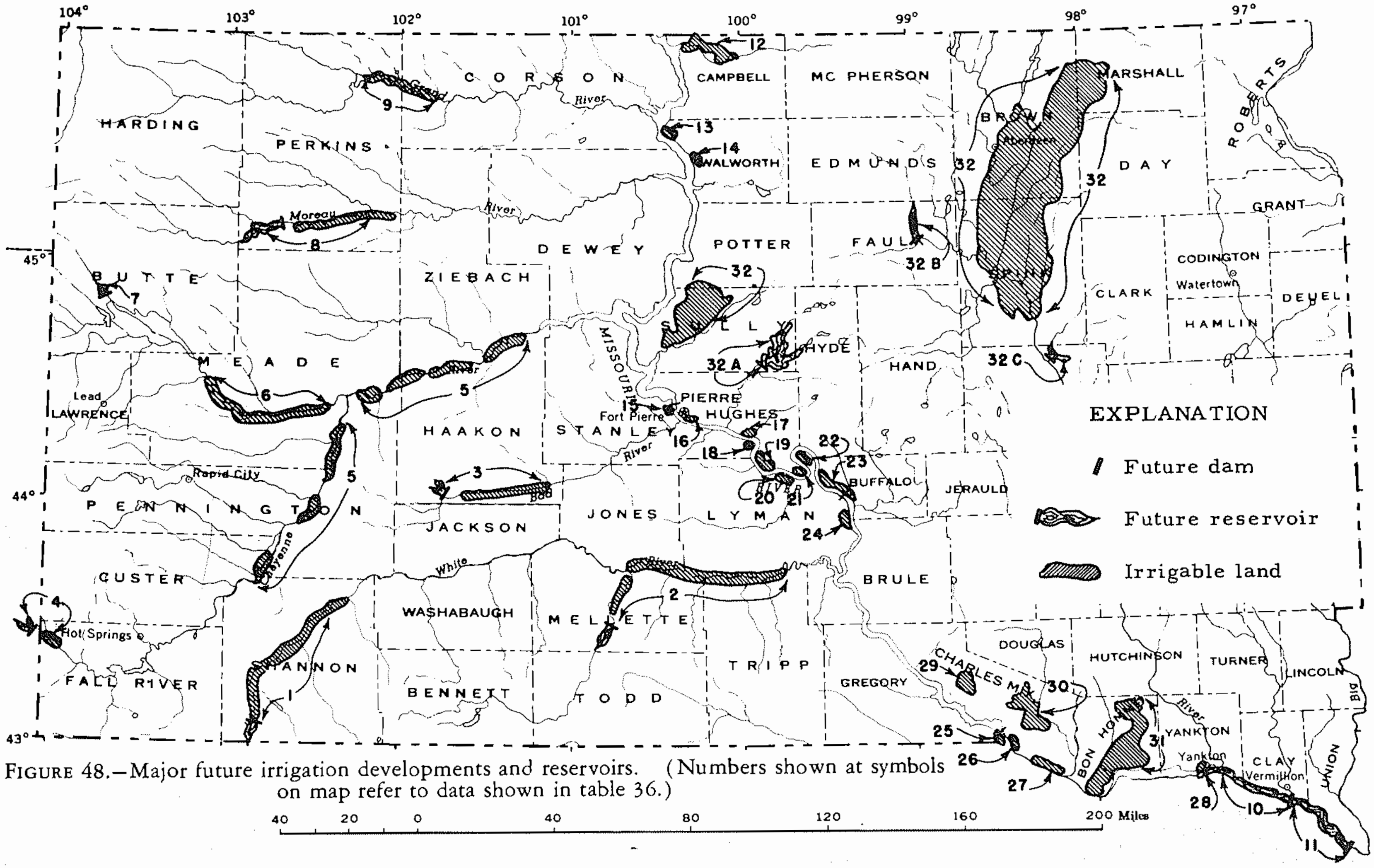

FIGURE 48.—Major future irrigation developments and reservoirs. (Numbers shown at symbols on map refer to data shown in table 36.)

WHITE RIVER BASIN

Several investigative studies have been conducted in the White River basin. Attempts to devise a satisfactory irrigation plan for the 117,000 acres of arable uplands scattered over eight counties in South Dakota and Nebraska have been unsuccessful. The quality of land susceptible of irrigation and the quality of water available for irrigation below the town of Weta, S. Dak., are such that sustained irrigation is questionable. The occurrence of selenium in the water and the high sodium content of the water are especially undesirable. Land and water qualities in the upper portion of the White River basin are suitable for a sustained irrigated agriculture. The South Fork White River (Little White River) has water of good quality, but costs of development may be high.

Pine Ridge unit

The Bureau of Reclamation completed a report on White Division in January 1959 as part of the Missouri River Basin Project investigations. A plan of development was presented therein for Pine Ridge unit. This plan was materially different from that presented in Senate Document 191, 78th Congress, 2d session; however, the plan did show engineering and economic feasibility. Location of Pine Ridge unit is shown in figure 48, and statistics for the unit are given in table 36.

The Oglala Sioux Tribal Council and the Bureau of Indian Affairs were anxious for the Bureau of Reclamation to undertake further investigations of Pine Ridge unit. A memorandum of understanding was prepared between the two Federal agencies to provide a basis for proceeding with the investigations.

The tentative plan for Pine Ridge unit is to store the water of the White River in a reservoir at the Slim Butte Dam site, about 5 miles north of the Nebraska-South Dakota State line. The stored water could then be released downstream into the river channel, and approximately 7,400 acres of land in numerous small tracts could be irrigated by pumping from the river. A feasibility report is being prepared by the Bureau of Reclamation.

Irrigation of the Pine Ridge unit would make possible a more stable farming economy for the area. The benefits would result in increased and stabilized retail, wholesale, and industrial activities extending well beyond the boundaries of the unit. The principal effects would be on the Indian Reservation economy.

Little White unit

The Little White unit would include a dam and reservoir on the South Fork White River, about 6 miles south of the town of White River in Mellette County, S. Dak., to store water for irrigation of approximately 460 acres of irrigable lands along the South Fork and 6,140 acres of irrigable lands adjacent to the main-stem White River downstream from its confluence with the South Fork White River (Little White River). There has been active local interest in the development of this potential water resource; however, this active interest has also generated some opposition.

The Little White Dam, as presently proposed, would impound 65,000 acre-feet of water which would be released downstream for sale to farmers and ranchers who would construct and operate their own pump irrigation systems. The quality of the water available in the upper reaches of the main-stem White River and in the South Fork White River is suitable for irrigation; however, the quality deteriorates as the White River passes through the South Dakota Badlands above its confluence with the South Fork. The water in the main-stem White River is still of questionable quality after mixing with the good-quality flows from the South Fork. Water-soil quality relationships need to be investigated for additional data.

The Bureau of Reclamation plans to make further soil-water relationship studies to answer questions regarding soil-water qualities and the type of irrigation facilities that would best fit the needs of the area. These problems should be resolved first, prior to initiating feasibility studies of the Little White unit as requested by the local people. Figure 48 shows the location of the Little White unit, and table 36 gives statistics for the unit.

BAD RIVER BASIN

Surveys and studies have been made in the Bad River basin to evaluate the merits of irrigation development in that basin.

Results show a total of 17,610 acres of uplands to be suitable for irrigation. These arable lands are in small widely scattered tracts. An additional 11,668 acres of bottom lands have been found suitable for irrigation also. These bottom lands are situated in small tracts lying in a narrow band along about 139 miles of the Bad River.

Philip unit

The Bad River is know for its erratic flow characteristics and contains only a limited supply of available water. Diversion of additional water from either the Cheyenne or White River basins does not appear to be practicable. The only feasible locations to develop reservoir storage sites are on the North Fork and the South Fork Bad Rivers above Philip, S. Dak.

A report by the Bureau of Reclamation on the Bad Division, dated January 1958, presents a plan of development for the Philip unit, which is based on optimum use of the Bad River basin's arable land and available water resources. Philip Reservoir, formed by the Philip Dam on the North Fork Bad River, would be used for storage. It would impound the flows of the North Fork and also the water diverted from the South Fork by means of the diversion dam, diversion pumping plant, and diversion canal. Water would be released from Philip Reservoir downstream as required for irrigation. This water would be diverted to 2,784 acres of irrigable lands situated along a 40-mile stretch of river bottom. The report concluded that the cost of developing Philip unit would exceed the benefits to be obtained and that development of the unit would, therefore, not be feasible.

The use of surface runoff for stock watering has been developed in recent years, and has probably not reached its ultimate. Since the middle 1930's, many small stockponds have been built in this cattle-grazing country. Construction of these ponds gained momentum after the close of World War II. The ponds consume a large amount of water, not so much through actual use by the animals as by evaporation. The effect of these ponds upon the surface runoff in the Bad River is the holding-back of a relatively larger proportion of water in dry years than in wet years. This use of water is in direct competition with a development such as irrigation.

Development of irrigation in the Bad River basin by the Bureau of Reclamation is not economically justified under present conditions. Further investigations are not recommended at this time.

CHEYENNE RIVER BASIN

An inventory made in 1963 of land and water resources of the Cheyenne River basin, both in Wyoming and South Dakota, together with a reexamination of all previous schemes and proposals, confirms that the remaining undeveloped land and water resources are very limited. No potential reservoir site has been found that offers a sizable capacity at reasonable cost on a stream having surplus flows. The Edgemont unit, Cheyenne pumping units, and Belle Fourche pumping units were among the potential developments presented in Senate Document 191; these units are discussed in some detail in the following pages. Of these, only the Belle Fourche pumping units appear to warrant further consideration.

Edgemont unit

As presented in Senate Document 191, the Edgemont unit would consist of a dam and reservoir on Beaver Creek in Wyoming, with a total capacity of 45,000 acre-feet, and irrigation facilities for 8,000 acres of new land in South Dakota. This land, lying along Beaver Creek and Cheyenne River from near the State line to the vicinity of the town of Edgemont, would be served by a gravity system which would divert water from Beaver Creek below the reservoir.

Further studies in 1957 to update available data for Edgemont unit, including a reconnaissance land classification study and a revised water supply study, indicated that only 4,700 acres of the 7,200 arable acres could be irrigated with the water available.

The extremely low flows experienced on Beaver Creek during the period 1959–61 imposed a further reduction in estimated acreage that might be irrigated. Revision of the reservoir operation study to include this 3-year period indicated that only 2,650 acres should be considered. These same studies also indicated that the total reservoir capacity should be reduced to about 27,000 acre-feet, of which 15,000 acre-feet would be active conservation storage and 12,000 acre-feet would be reserved for sediment deposition. Economic studies of this plan resulted in benefit-cost ratios of 0.51 for direct benefits and 0.75 for total benefits. Because of the unfavorable benefit-cost ratios and the questionable water supply in dry years, it was concluded that development of the unit should be indefinitely deferred.

Cheyenne pumping units

Senate Document 191 showed 25,300 acres of new land as being susceptible to irrigation along the Cheyenne River from immediately below Angostura unit to the mouth of the river. The new land would be located in 49 separate areas which would be supplied by pumping directly from the river. Water supplies would be dependent upon return flows and natural accretions to the river, but would be augmented by releases from Angostura Reservoir.

A semidetailed land classification survey was made in 1950–51 of lands closely adjacent to the Cheyenne River from Angostura unit to the backwater area of Oahe Reservoir. Of the 53,537 acres classified, only a total of 3,910 acres were considered irrigable. These irrigable lands were divided among 77 tracts ranging from 5 to 220 acres in size.

Another area studied included several high terraces lying along the east and south side of the Cheyenne River valley between the mouths of French and Cherry Creeks. These terraces have favorable topography and apparent good soils for irrigation. The terraces range from 250 to 470 feet in elevation above the river.

One terrace, known as the Milesville Flat, and considered representative of the group, was studied. Semidetailed land classification in 1951 indicated a total of 6,575 acres arable and suitable for irrigation; however, the costs for a long gravity canal and 470-foot pump lift for water were far in excess of economic limits.

A reconnaissance-grade reappraisal of the Cheyenne pumping units was made by the Bureau in 1958, and a conclusion was reached that further consideration was unwarranted, mainly because of the doubtful water supply. This water supply problem was confirmed as serious during the low runoff period of 1959–61. It was then concluded that no storage capacity in Angostura Reservoir should be assigned to downstream use.

The flow of the Belle Fourche River below the Belle Fourche Project should be considered for use first on the potential Belle Fourche pumping units. This leaves available only the return flows from Angostura and Rapid valley irrigation and the small flows from minor tributaries rising in eastern slopes of the Black Hills. Part of the Cheyenne River flows would necessarily be reserved for stock-water use; most, if not all, of the remainder would be lost in dry years to river bank storage and evaporation in traversing up to 155 river miles.

In view of the various adverse factors discussed above, it is again concluded that further consideration of the Cheyenne pumping units should be indefinitely deferred.

Belle Fourche pumping units

Senate Document 191 showed 5,030 acres of new land as being susceptible to irrigation in scattered pumping units along the Belle Fourche River. Earlier investigations disclosed that about 9,000 acres were suitable for irrigation but that, without storage regulation, only 5,030 acres could be assured a dependable water supply.

A search was made for reservoir sites on the river below the Belle Fourche Project and Bear Butte Creek, a tributary, in an effort to improve the water supply, but in each case the estimated costs exceeded the benefits.

Recent reconnaissance investigations indicate that there are alternate offstream storage sites on tributaries such as Four Mile Creek, and others, which may supplement natural Belle Fourche River flows and provide a water supply for approximately 4,550 irrigable acres on the low terrace lands.

A 1951 semidetailed land classification survey of both low and high terrace lands along the Belle Fourche River from the Belle Fourche Project to the mouth showed a total of 17,400 arable acres. Of this total, 7,820 acres are situated on low terraces and the remaining 9,580 acres, on high terraces.

The somewhat unusual quality of water in the Belle Fourche River below Belle Fourche Project warrants special attention. Long-time records of quality analyses for a station near Elm Springs indicates high-salinity, low-sodium water on the basis of major constituents. Use of this water for irrigation would require special management for salinity control. The water should be used only on lands with good drainage. Some of the minerals or compounds in the water are inert or harmless, and concentrations of others, considered individually, are within acceptable limits. Effects of the combination of these constituents on soils or growing crops are uncertain.

Before further consideration is given to the Belle Fourche pumping units, research should be continued to obtain a suitable plan for an adequate water supply and a determination should be made as to whether Belle Fourche River water in this area can be used for sustained irrigation.

Supplemental water supply for Angostura unit

During 1962, the Bureau of Reclamation conducted a reconnaissance investigation for the purpose of determining whether any feasible plan could be devised for supplementing the water supply for Angostura unit, and to present methods for conserving the present supply for the unit.

There are three general possibilities for reducing water shortages on Angostura unit: (1) Increase farm efficiency; (2) reduce conveyance losses; and (3) obtain additional supplies. Any one of these or any combination of them would be effective. The first possibility—increase farm efficiency—would save about 3,000 acre-feet of water annually; however, increasing farm efficiency would require the cooperation of the water users. The second possibility—reduce conveyance losses—appears very attractive, because such losses are estimated to be high on Angostura unit, approximately 13,600 acre-feet annually. The third possibility—obtain an additional water supply—appears to be the least attractive of the three methods mentioned.

Three alternatives were studied for using Fall River as a source of supplemental water for Angostura unit: (1) Gravity diversion of Fall River runoff into Angostura Reservoir; (2) diversion by pumping Fall River flows, and other available return flows of the unit, from the Cheyenne River into the existing 48-inch-diameter Cheyenne River siphon for irrigation of the lower 2,710 acres of unit land; and (3) diversion by pumping Fall River flows from the Cheyenne River to 920 acres of unit land on the low terraces adjacent to the Cheyenne River by means of three small pumping plants.

In the 1962 study, it was concluded that buried asphaltic membrane lining of the main canal and lateral system is the most feasible way to alleviate possible future shortages on Angostura unit. It was recommended that, prior to initiation of any further study of obtaining a supplemental water supply from Fall River, or pumping from the Cheyenne River, the effect of the lining on canal and lateral losses be observed for several years. Progressively greater savings in the water supply are being realized each year as new sections are lined.

Supplemental water supply for Belle Fourche Project

The Bureau of Reclamation conducted an investigation during 1963 to report on supplemental water supply possibilities for Belle Fourche Project in South Dakota. Possibilities that were investigated to alleviate the water shortages for the project were as follows: (1) Reduction of conveyance losses; (2) supplementing the project supply from deep artesian wells; (3) use of project return flows; and (4) obtaining additional supplies from surface sources.

The study resulted in several conclusions. Drought conditions and stockpond development in the Belle Fourche River basin have reduced streamflows available to the Belle Fourche Project. Over-all conveyance losses are not excessive. The high conveyance losses shown in past project histories are attributable to the lack of adequate measuring devices on the project. The development of ground-water resources to supplement surface supplies would be expensive and unpredictable. Reuse of project return flows is possible to a very limited extent on an individual farm basis. Development of a storage reservoir on Horse Creek was found to be infeasible due to the small amount of water that would be available. Development of a storage reservoir on Indian Creek for supplemental water shows a favorable benefit-cost ratio, but annual costs are believed to be beyond the project's ability to repay. An additional water supply could be provided by proper use of existing storage in Keyhole Reservoir. Keyhole Reservoir, in Wyoming, is the most practical source of additional water for project lands served directly from the Inlet Canal and Johnson lateral. The Belle Fourche Project will continue to experience water shortages during extended periods of below normal runoff.

In the "Report on Supplemental Water Supply Investigation, Belle Fourche Project," it was recommended that further investigations be postponed until the effect of use of storage in Keyhole Reservoir and of the increased usable storage in Belle Fourche Reservoir has been observed for several years. It was also recommended that additional records of streamflow and sediment yields in Horse and Indian Creeks be obtained, and that adequate measuring devices be installed on the canal and lateral system of Belle Fourche Project to assure an equitable distribution of available water and encourage efficient use of water on the farms.

Cheyenne River basin conclusions

No appreciable further development of either land or water resources may be expected in the near future in the Cheyenne River basin. The five existing Bureau of Reclamation reservoirs effectively control most of the runoff. Thousands of stockponds built during the past 25 years deplete the runoff from plains areas by more than one-third in dry years. Only carryover storage would now be effective, if reservoir sites were available, and such storage would be prohibitive in cost for the few thousand acres of irrigable land that could be served economically.

No further investigations or studies are presently contemplated by the Bureau of Reclamation in the Cheyenne River basin, with the possible exception of the potential Belle Fourche pumping units or except as may be prompted by changing conditions or by marked advances in technology. A Wyoming-South Dakota interstate compact for the Cheyenne River would be desirable to protect water rights in both states.

MOREAU RIVER BASIN

Numerous investigations and reports by several agencies have been prepared on development of water resources in the Moreau River basin. The general outlook for potential developments within the basin are rather dim. The Bureau of Reclamation has studied the possibilities of dams and reservoirs at two locations; namely, the Green Grass and Bixby sites. Studies of Bixby unit were quite comprehensive.

Bixby unit

The Bixby unit was included in the plan for development of Missouri River Basin Project, as outlined in Senate Document 191, 78th Congress, 2d session. It is located in northwestern South Dakota in Perkins and Ziebach Counties. The damsite is situated on the Moreau River, 27 miles west and 9 miles north of Faith, a short distance below the confluence of the North and South Forks of the Moreau River. The project works would extend some 40 miles downstream from the dam along the Moreau River to include irrigable lands located on the flood plains and lower terraces. The Bixby site was selected from among several sites considered because it was farthest upstream and offered the greatest opportunity for irrigation development.

The Bixby Dam would be an earthfill structure, having a crest length of 6,620 feet with a maximum structural height of 115 feet. The reservoir would have a total storage capacity of 215,000 acre-feet, exclusive of super storage. The irrigation works were to consist of numerous small pumping units complete with laterals and irrigation structures to serve the various tracts of irrigable land.

A semidetailed land classification by the Bureau of Reclamation, made in cooperation with the Bureau of Indian Affairs in 1949, showed 16,780 acres of arable land. Bixby Reservoir would provide sufficient irrigation water for only about 14,000 acres. Investigations in the Moreau River basin indicated questionable suitability of the stream's water for irrigation use. Soils were found to be high in exchangeable sodium which could lead to an alkali problem. An investigation was made to determine the probable effect of water upon the soils to be irrigated. A review board convened in August 1950 to review the available data and to make recommendations. The board concluded that the continuous deterioration of the quality of streamflow, through the effects of return flows, precluded successful irrigation development throughout most of the Moreau River's length, except in that stretch of the river from Bixby damsite to a point near Faith, an area containing 2,059 irrigable acres. Thus, with only 2,059 irrigable acres, a preliminary benefit-cost analysis showed the plan of development to be infeasible. Flood control, municipal water, recreation, and other benefits were not sufficient to justify development.

Development of Bixby unit has been postponed indefinitely. Should future studies and investigations by other agencies find construction of a dam for flood control, silt control, and other benefits, to be feasible, and when more information on water-soil adaptability is available, some irrigation features could probably be incorporated in the plans.

No other feasible water-resource development possibilities are known to exist within the Moreau River basin.

GRAND RIVER BASIN

Previous investigations in the Grand River basin show that future developments of the drainage area's potential water resources are limited primarily to the Shadehill unit and Bowman-Haley Project. The Corps of Engineers has been given authority to develop the Bowman-Haley Project in North Dakota; other than its depletion effect upon Shadehill Reservoir, South Dakota will experience little or no influence from its construction.

Completion of Shadehill unit's irrigation facilities is the remaining major feature for water resource development in the Grand River basin. A definite plan report on the unit was completed in 1963.

Shadehill unit

Shadehill Dam and Reservoir, the principal existing features of the unit, provide a means of storage and regulation for future irrigation development. The distribution of an irrigation water supply to approximately 6,700 irrigable acres of land lying on the north side of the Grand River between Shadehill Dam and Wagon Creek, a distance of 22 miles, would be accomplished essentially by a gravity system. Shadehill Canal would traverse eastward through this area, serving approximately 75 percent of the land by gravity; however, lands situated on higher benches would be served by water lifted from the canal by three relift pumping plants. A fourth pumping plant would be a relift in one of the laterals to reach a still higher area. Shadehill Canal would be 24.4 miles in length, requiring more than 120 separate and varied structures. A network of 44.2 miles of laterals would also be required. An extensive system of surface and subsurface drains would be constructed to return water into the Grand River. Power for pumping would be obtainable from the Grand Electric Cooperative, Inc., presently serving the area.

The overall plan of irrigation development has economic justification based on a comparison of benefits and costs. Economic justification of the Shadehill unit would also be improved by development of this irrigation potential.

LITTLE MISSOURI RIVER BASIN

Previous investigations of the South Dakota portion of the Little Missouri River basin have not been too fruitful. The erratic nature of the stream's flow would require large holdover storage for effective irrigation on relatively small acreages. Investigations to date have failed to find a desirable reservoir site in South Dakota.

The Little Missouri River flows through the States of Wyoming, Montana, South Dakota, and North Dakota. It is probable that a compact among the four States providing for the division of the waters of the Little Missouri River would be necessary before development in any of the States could be undertaken.

MISSOURI RIVER (MAIN-STEM), CORPS OF ENGINEERS

The Corps of Engineers main-stem dam construction program in South Dakota is nearly completed on the Missouri River above Yankton; however, the corps has been investigating several plans for improvement of the river reach between Yankton and Sioux City, Iowa. Most promising of the plans is one for open-river development of the type used downstream from Sioux City and another for two multipurpose reservoirs. The open-river development would stabilize the river banks and could extend a navigable channel upriver to Gavins Point Dam. The reservoir plan would develop hydroelectric potential, flood control, recreation, fish and wildlife conservation, and navigation, if navigation locks are provided. These plans could also be coordinated with irrigation. One of the two dams would be located at Kenslers Bend and the other at Mulberry Point.

Kenslers Bend and Mulberry Point

The Kenslers Bend damsite is about 10 miles upstream from Sioux City, Iowa, and the Mulberry Point damsite is near Vermillion. The lower reservoir pool would be the tailwater level for the upper dam. The upper pool, behind Mulberry Point, would be the tailwater level for existing Gavins Point Dam. Each reservoir would develop a nominal head of 33 feet.

MISSOURI RIVER (MAIN STEM), BUREAU OF RECLAMATION

The Bureau of Reclamation's April 1959 "Report on the South Dakota, Pumping Division—South Dakota, MRBP" presented a preliminary appraisal of the irrigation potential on the bottom lands and benchlands along both banks of the Missouri River from the North Dakota State line to the city of Yankton. Even though firm plans were not worked out, the study was adequate to determine which of the units might become successful irrigation developments.

The 1959 report considered 17 units immediately adjacent to and along the Missouri River; also included were three units on higher benchlands and uplands of the B–C–B area (Brule, Charles Mix, and Bon Homme Counties). These 20 units were grouped into four groups for study of their soils, climate, water requirements, land use, economics, and other related factors.

The units and the groupings are as follows:

Northern units:
    Pollock-Herreid[1]
    Mobridge[1]
    Evarts[1]
Southern units:
    Crazy Horse
    Tower
    Greenwood
    Yankton
B–C–B area units:
    Wagner[1]
    Geddes[1]
    Tyndall[1]
Central units:
    La Framboise
    Pierre
    Rousseau
    La Roche
    Joe Creek
    Iron Nation
    Culdesac
    Grass Rope
    Fort Thompson
    Fort Hale

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[1] Not included in S. Doc. 191 and not part of the originally authorized Missouri River Basin Project.

Pollock-Herreid unit

The Pollock-Herreid unit is in northwestern Campbell County; it extends easterly from Oahe Reservoir along Spring Creek from Pollock to about 4 miles east of Herreid. The 1959 report on South Dakota Pumping Division found this unit to be infeasible because the O.M. & R. (operation, maintenance, and replacement) costs exceeded payment capacity for the poorer lands of the unit.

Since the reconnaissance investigations were made for the 1959 report, the Corps of Engineers has constructed a subimpoundment on Spring Creek near Pollock, named Lake Pocasse, which is now being operated as part of the Pocasse National Wildlife Refuge under an interim agreement by the Bureau of Sports Fisheries and Wildlife. Construction of this subimpoundment on Spring Creek offers some possibilities for irrigation which were not considered in the 1959 report.

There is active local interest in irrigation development by landholders in the Pollock-Herreid area. The Pollock-Herreid Irrigation District was formed by an election held on February 4, 1963.

On February 18, 1963, the County Commissioners of Campbell County passed a resolution requesting the Bureau of Reclamation to make a feasibility investigation of the Pollock-Herreid unit. A reconnaissance reappraisal indicated that about 10,500 acres of irrigable land, including 1,400 acres within the proposed boundaries of the Pocasse National Wildlife Refuge, could be irrigated, utilizing Lake Pocasse as a supply and regulating reservoir. The reconnaissance reappraisal concluded that available information was inadequate for a determination of the unit's economic feasibility, using Lake Pocasse for regulation of the water supply, and that a complete feasibility study should be made.

Field investigations and surveys were begun during 1964 for a feasibility report on the Pollock-Herreid unit to be completed at the end of a 3-year study.

Mobridge unit

The Mobridge unit is in the northwest corner of Walworth County immediately adjacent to the town of Mobridge. The plan for development involves pumping water from the Oahe Reservoir and conveying it to an estimated 1,400 irrigable acres. The 1959 report on South Dakota Pumping Division found the Mobridge unit to be infeasible because the O.M. & R. costs exceeded the payment capacity for the class 3 lands. No additional investigations are contemplated.

Evarts unit

The Evarts unit is situated about 10 miles southeast of the town of Mobridge in Walworth County adjacent to Oahe Reservoir. It contains about 950 irrigable acres for which water would be pumped from Oahe Reservoir. The 1959 report on South Dakota Pumping Division also found the Evarts unit to be infeasible because O.M. & R. costs were above the payment capacity of class 3 lands. No further studies are contemplated.

La Framboise unit

The La Framboise unit, situated in the eastern extremity of Stanley County adjacent to the Missouri River immediately north of Fort Pierre, contains only 256 acres of irrigable lands. Cost estimates were not prepared for this unit and an economic analysis was not made because of the very small acreage suitable for irrigation development and the probability that some of the land would be utilized for commercial purposes. Further studies are not contemplated.

Pierre unit

The Pierre unit, situated in western Hughes County along the north bank of the Missouri River immediately downstream from Pierre, contains 517 arable acres. Of this land, only 132 acres would remain above the high pool level of the proposed Big Bend Reservoir, and subsurface drainage considerations further reduced the acreage that could be irrigated. The 1959 report on South Dakota Pumping Division eliminated the Pierre unit, because the few irrigable acres remaining made it infeasible for irrigation development. No future studies are planned.

Rousseau unit

An estimated 2,215 acres of irrigable lands are situated along the north bank of the Missouri River in Hughes County, 17 miles east of Pierre and immediately west of the village of De Grey. These lands, known as the Rousseau Unit, would be served by pumping water from the Big Bend Reservoir to the irrigable lands. The 1959 report on South Dakota Pumping Division showed the Rousseau Unit to be economically justified with payment capacity exceeding O.M. & R. costs by a sufficient margin to provide a substantial repayment of construction costs.

La Roche unit

The La Roche unit is in the extreme southeast corner of Stanley County, directly across the Missouri River from the eastern end of the Rousseau unit. It lies in the Lower Brule Indian Reservation. Water for the unit would be pumped from the Big Bend Reservoir to serve about 1,789 irrigable acres. The 1959 report on South Dakota Pumping Division showed the La Roche unit as having a favorable benefit-cost ratio and worthy of detailed study.

Joe Creek unit

The Joe Creek unit is in southeastern Hughes County, within a broad loop of the Missouri River which bounds it on three sides. The village of De Grey is 12 miles northwest of this unit, and Pierre is 33 miles northwest. Joe Creek unit lies entirely within the Crow Creek Indian Reservation. Water for the unit would be pumped from Big Bend Reservoir to serve about 4,420 irrigable acres. The 1959 report on South Dakota Pumping Division showed the Joe Creek unit as having a favorable benefit-cost ratio and to be worthy of future detailed study.

Iron Nation unit

The Iron Nation unit is in north-central Lyman County, along the right bank (facing downstream) of the Missouri River about 20 miles northeast of Kennebec, the county seat. It lies within the Lower

Brule Indian Reservation. Water for the unit would be pumped from Big Bend Reservoir to serve about 1,739 irrigable acres. The 1959 report on South Dakota Pumping Division found the benefits to exceed the costs and the Unit to be worthy of future detailed study.

Culdesac unit

The Culdesac unit lies in the extreme southeast corner of Hughes County, in a loop of the Missouri River, which bounds it on the north, east, and south. The unit lies entirely within the Crow Creek Indian Reservation. The city of Pierre is about 43 miles northwest of the unit. Water for the unit would be pumped from Big Bend Reservoir to serve about 5,444 irrigable acres. The report on South Dakota Pumping Division found the Culdesac unit to be economically justified and worthy of further detailed study.

Grass Rope unit

The Grass Rope unit is in Lyman County, within a loop of the Missouri River known as the Big Bend. The area is part of the Lower Brule Indian Reservation. The town of Reliance is 18 miles south by county road. A portion of the peninsula's 20,000 acres will be flooded out by Big Bend Reservoir. Water for the unit would be pumped from Big Bend Reservoir to serve about 4,340 acres of irrigable land. The 1959 report found the Grass Rope unit to be economically justified and worthy of further detailed study.

Fort Thompson unit

The Fort Thompson unit is situated on the left bank (facing downstream) of the Missouri River in Buffalo County near Fort Thompson. Highmore is 30 miles to the north of the unit and Chamberlain is 21 miles to the south. The unit is part of the Crow Creek Indian Reservation. Water for the unit would be pumped from Big Bend Reservoir to serve about 7,480 irrigable acres. The 1959 report on South Dakota Pumping Division showed the Fort Thompson unit to be economically justified and worthy of further detailed study.

Fort Hale unit

The Fort Hale unit is in Lyman County on the west side of the Missouri River near the upper end of Fort Randall Reservoir. It is in the Lower Brule Indian Reservation and is approximately 12 miles northwest of Chamberlain. Water for the unit would be pumped from Fort Randall Reservoir to serve about 1,136 irrigable acres. The 1959 report on South Dakota Pumping Division showed that, although benefits exceeded costs, payment capacity of the class 3 land would not meet O.M. & R. costs and financial feasibility of the unit would be doubtful. No further studies of the Fort Hale unit are presently contemplated.

Crazy Horse unit

The Crazy Horse unit is in the southeast corner of Gregory County on the right bank of the Missouri River immediately below Fort Randall Dam. The 1959 report showed that construction of Crazy Horse unit (known as Fort Randall unit in S. Doc. 191), consisting of 529 irrigable acres, was economically justified. Detailed investigations of Crazy Horse Unit was initiated in 1960. A portion of the irrigable lands had been purchased by the Corps of Engineers in their "taking area" for the Fort Randall Dam. These irrigable lands have now been leased to the South Dakota Department of Game, Fish, and Parks. No irrigation is contemplated in the long-range development of this recreation area so the Unit's irrigable acreage was decreased to 320 acres. Nearly half of this remaining acreage was accreation lands, and the abutting landowners have taken no legal steps to establish ownership. It was concluded by the Bureau of Reclamation in 1963, during preparation of a definite plan report on the other three southern units, that the Crazy Horse Unit should not be considered for Bureau irrigation development for the following reasons: (1) A very small acreage was involved; (2) there is questionable ownership regarding about one-half of the irrigable lands; and (3) the lands could be developed for irrigation by the landholders on an individual farm basis. No further studies on this unit are planned.

Tower unit

The Tower unit is in southern Charles Mix County along the east bank of the Missouri River about 16 miles southwest of Wagner. About one-third of the unit lands are under Indian trust ownership, and remaining lands are privately owned. Bureau of Reclamation studies in 1959 showed the unit to be economically justified. Detailed investigations of the Tower, Greenwood, and Yankton units were initiated in July 1960 and a definite plan report on these units was completed in 1963. Water for Tower unit would be pumped from the Missouri River into Tower Canal, 6.1 miles in length, and distributed by 1.7 miles of laterals to 1,400 irrigable acres. The Tower unit is economically justified, comparing benefits and costs. Payment capacity of the lands exceeds O.M. & R. costs by a sufficient margin to repay a substantial portion of the construction costs. Construction of the unit will be dependent upon the wishes of the local landowners and upon appropriations by Congress.

Greenwood unit

The Greenwood unit is in southern Charles Mix County about 13 miles south of the town of Wagner. It lies on the left bank of the Missouri River, beginning about 2 miles south of the Tower unit and extending in length downstream for a distance of 12 miles in a southeasterly direction. Approximately 16 percent of the irrigable lands are in Indian trust ownership. Bureau of Reclamation studies completed in 1959 found Greenwood unit to be economically feasible of development. Water for Greenwood unit would be pumped from the Missouri River into the 12-mile-long Greenwood Canal and be conveyed by 8 miles of laterals to 3,550 acres of irrigable lands. Greenwood unit is economically justified for development, comparing benefits, and costs. Payment capacity of the lands exceed O.M. & R. costs by a sufficient margin to repay a substantial portion of the construction costs. Construction of the unit will be dependent upon the wishes of local landowners and upon appropriations by Congress.

Yankton unit

The Yankton unit is in southern Yankton County, immediately west of the city of Yankton. The unit lands are situated along the left bank or north side of the Missouri River immediately downstream from Gavins Point Dam. Studies completed in 1959 by the Bureau of Reclamation found Yankton unit to be economically justified for irrigation. The water supply for the unit would be obtained direct from Lewis and Clark Lake by means of a diversion siphon through Gavins Point Dam. The diversion siphon, 620 feet in length, would deliver water into the Yankton Canal, 2.9 miles in length. The water would be distributed by 3.4 miles of laterals to 1,390 acres of irrigable land. TheYankton unit is economically feasible for development, as determined from a benefit-cost comparison. Payment capacity of the unit also exceeds O.M. & R. costs by a sufficient margin to repay a substantial portion of the construction costs. Construction of the unit will be dependent upon the wishes of local landowners and upon appropriations by Congress

Geddes unit

The Geddes unit is in central Charles Mix County, lying midway between the towns of Platte and Lake Andes. Reconnaissance investigations were undertaken in 1957 and 1958 following an indication of local interest. The results of these preliminary studies were included in the South Dakota Pumping Division report of April 1959. The reconnaissance plan for development of Geddes unit provides for diversion of water from Fort Randall Reservoir on the Missouri River to an estimated 7,700 acres of irrigable land. (More recent review indicates the irrigable acreage would be somewhat less than the 7,700 shown in the 1959 report.) In the 1959 report on South Dakota Pumping Division, it was concluded that the Geddes unit had marginal feasibility and further study under existing economic conditions would not be justified.

Wagner unit

The Wagner unit is in south-central Charles Mix County, northeast of Fort Randall Dam on the Missouri River. Reconnaissance investigations of the general area were undertaken in 1957 and 1958 following an indication of local interest. The results of these preliminary studies were included in the South Dakota Pumping Division report of April 1959. The preliminary investigations indicated that the Wagner unit warranted detailed study.

Detailed field studies were conducted on the Wagner unit in 1960 and 1961. Engineering and economic studies continued during 1962 and 1963. A feasibility report is being completed.

The plan of development for Wagner Unit provides for pumping of water from Fort Randall Reservoir on the Missouri River for irrigation of 19,500 acres of land, municipal and industrial use in two municipalities, fish and wildlife developments at three locations, and recreation uses.

Principal features of the irrigation system consist of the 195 cubic-feet-per-second Randall pumping plant, utilization of Lake Andes as a regulating reservoir, four relift pumping plants, and a system of 31.6 miles of main canals.

The Wagner unit is economically justifiable. If local interest and demand desire, construction could be accomplished after repayment negotiations and other prerequisites have been met.

Tyndall unit

The Tyndall unit is situated in Bon Homme County in southeastern South Dakota. Reconnaissance investigations were undertaken in 1957 and 1958 following an indication of local interest. The results of these preliminary studies were included in the South Dakota Pumping Division report of April 1959.

The reconnaissance studies showed Tyndall unit had an estimated 33,000 acres of irrigable land. The 1959 report on South Dakota Pumping Division concluded that Tyndall unit has only marginal feasibility. Local interests have recently requested the Bureau of Reclamation to make a detailed investigation of the area. Semi-detailed land classification is scheduled to ascertain if further study of the area is warranted.

JAMES RIVER BASIN

Most of the water resource development studies conducted by the Bureau of Reclamation in the James River basin have been concerned with the Oahe unit.

Oahe unit

The Oahe Unit is part of the Missouri River Basin Propect as authorized by the Flood Control Act of 1944, (58 Stat. 887) as amended and supplemented by the Flood Control Act of 1946 (60 Stat. 641).

The Oahe unit is in the northern part of the eastern half of South Dakota, extending east of the Missouri River to the eastern edge of the James River basin. The present plan for development comprises a total of 495,000 irrigable acres of land proposed for irrigation in the Lake Plain area in the counties of Brown, Spink, Marshall, and Day, at the northern end of the James River basin within South Dakota, and in the Missouri Slope area in northwestern Sully County and southwestern Potter County just east of the Oahe Reservoir on the Missouri River.

The plan provides for diversion of water from Oahe Reservoir on the Missouri River for irrigation of 495,000 acres of land, municipal and industrial use in 23 towns and cities, fish and wildlife developments at 28 locations, and recreational uses. Flood control, drainage of nonirrigable land, and pollution abatement are other functions of the unit.

Sources of water supply will be the Oahe Reservoir on the Missouri River, natural flows of the James River, and irrigation return flows carried by the James River. The principal supply works will consist of the 3,200-cubic-feet-per-second Oahe pumping plant which delivers water from Oahe Reservoir, a system of 155 miles of main canals, three regulating storage reservoirs, the James pumping plant, a diversion dam, and channel improvements on the James River.

For the first stage of development, it is planned to irrigate 311,000 acres, consisting of the Missouri Slope area (50,000 acres), West Lake Plain area (174,000 acres), and only as much of the East Lake Plain area as can be irrigated with return flow and natural flow in the James River (87,000 acres).

The principal features and their functions will be briefly described in the order in which they will occur as the water flows to serve the lands proposed for development.

The Oahe pumping plant, to be located at the downstream side of the left abutment of Oahe Dam, will be connected to the Oahe Reservoir by a tunnel. The pumps will take water from the tunnel and discharge it into the Pierre Canal through an average lift of 122 feet.

A maximum lift of 175 feet will be required when Oahe Reservoir is at minimum pool elevation. The Pierre Canal will convey the water eastward and discharge it into Blunt Reservoir.

Blunt Dam, located on a branch of Medicine Knoll Creek, will be an earthfill structure with a maximum height of 88 feet and a crest length of 7,300 feet. Total storage capacity of the Blunt Reservoir will be 631,000 acre-feet. The purpose of the reservoir is to provide storage which will supply varying demands for irrigation water while keeping the Oahe pumping plant and the Pierre Canal operating at a nearly constant rate.

Water for the Missouri Slope area, in Sully and Potter Counties, will be taken from Blunt Reservoir by means of Blunt pumping plant, lifted between 178 and 183 feet, and discharged into the Missouri Slope Canal for conveyance to irrigable lands.

Water for the Lake Plain areas will flow by gravity from Blunt Reservoir into the Highmore Canal that cuts through a pass in the divide between the Missouri River valley and the James River valley, and terminates at the Highmore bifurcation works.

The Faulkton Canal will extend north from the Highmore bifurcation works and discharge into Cresbard Reservoir. This reservoir will be created by Cresbard Dam, which will be an earthfill structure about 4,500 feet long at the crest and about 55 feet in maximum height. Cresbard Reservoir will have a total storage capacity of 31,500 acre-feet. The damsite is located across Cresbard Creek, a branch of Snake Creek, the lower end of which is one of the principal natural drainage courses in the West Lake Plain area. Cresbard Reservoir will regulate irrigation flows to the West Lake Plain area. Water will flow eastward by gravity from Cresbard Reservoir through Cresbard Canal for about 13 miles where a bifurcation structure will serve the Redfield and West Main Canals. The Redfield Canal will extend south to serve the southern West Lake Plain area, and the West Main Canal will extend north to serve the northern West Lake Plain area.

Water for the East Lake Plain area will enter Beadle Canal at the Highmore bifurcation works and flow by gravity for 53 miles to the James River. The Beadle Canal will cross the James River by means of a siphon in the vicinity of the James diversion dam (presently being constructed) and discharge into the James Canal.

The James diversion dam, now under construction, will form a pool for the intakes of the James pumping plant. The James pumping plant will divert irrigation return flows and floodflows from the James River into the James Canal. The James Canal will convey the combined flows received from the James pumping plant and Beadle Canal to Byron Reservoir.

The Byron Reservoir, an enlargement of the existing Lake Byron, will be formed by Byron Dam, an earthfill structure with a maximum height of 41 feet and a crest length of 7,600 feet. The total storage capacity of Byron Reservoir will be 62,100 acre-feet.

Water for the East Lake Plain area will be pumped from Byron Reservoir by means of the 4,800-c.-f.-s. Byron pumping plant, which will lift the water an average height of 71 feet, and discharge it into the East Main Canal. The East Main Canal will extend northward, having one main relift pumping plant near Conde, and continue to the northern extremity of the East Lake Plain area.

A network of main and small laterals will serve irrigable lands from the main supply canals previously described. Numerous low-lift pumping plants will also be needed.

An extensive system of surface and subsurface drains will be required to remove storm runoff and excess irrigation water. These drains will be designed to control ground water so as to protect the root zone throughout the irrigable areas, and to provide rapid and complete drainage of surface water to protect both the project works and growing crops. Channel improvements in the James River will also be required to permit irrigation return flows to pass downstream without causing flood damage.

Development of the Oahe unit can be scheduled and accomplished in harmony with State and national needs. The plan of development has engineering feasibility and economic justification, comparing benefits and costs.

Strong evidence that the people of South Dakota desire construction of Oahe unit and will make use of its facilities over an extended period of time is needed before the Federal Government will give favorable consideration to further extensive work on the project. A conservancy subdistrict has been formed. Irrigation districts must also be organized so that the repayment contracts can be executed prior to the start of any construction. Further work on the Oahe Unit depends upon the interest shown by the people in South Dakota and particulraly those landowners within the area to be developed.

VERMILLION RIVER BASIN

Investigations to date in the Vermillion River basin show that the development of irrigation from ground-water sources in Turner and Clay Counties is rapidly expanding. The most practicable and economical approach to further develoment of irrigation in this area at the present time is to extend the investigations of location and nature of the ground-water resources and to continue the soil and water management research. This can be accomplished through State and local agencies.

After ground-water sources are developed for irrigation, it is possible that development of surface water sources will be needed for additional irrigation and recharge of ground-water aquifers. Surface water sources which could be developed include the Vermillion River, James River, and Missouri River.

The surface water resources of the Vermillion River basin are limited. Importation of water to the Vermillion River basin from the James River basin is dependent upon development of the Oahe unit. The Missouri River is the most dependable potential source of surface water at the present time.

Additional study is required to determine whether a conventional Reclamation-type development is adaptable to such areas as the Vermillion River basin, where annual rainfall averages 23 inches per year and a more intensified type of farming is practiced. Similar studies have been proposed for the future in the neighboring Big Sioux River basin and Missouri River bottom lands below Yankton. Studies for these three areas could be combined into one investigation.

BIG SIOUX RIVER BASIN

The Bureau of Reclamation has scheduled a reconnaissance survey of the Big Sioux River basin. The study will review the over-all land and water resources of the Big Sioux River, and determine if potential developments exist and whether they show promise of feasibility consistent with the water supply available.

RED RIVER OF THE NORTH BASIN

The relatively small headwater area involved in the South Dakota portion of this basin does not present any known possibilities of major surface water resource development for irrigation purposes. No extensive investigations are presently programed or anticipated by the Bureau of Reclamation in the Red River of the North basin within the State.

MINNESOTA RIVER BASIN

The Bureau of Reclamation has no water resource investigations for irrigation development programed, nor does it anticipate any, in that portion of the Minnesota River basin lying within South Dakota.

KEYA PAHA RIVER BASIN

Basin studies indicate only a limited supply of water is available. The scattered nature of small tracts of arable benchlands in the main river valley preclude a project-type irrigation development. Irrigation by individual private pumps or wells appears to be the most practical method of development.

At the present time, no studies within the basin are contemplated by the Bureau of Reclamation. An indication of local interest within the basin is not evident.

PONCA CREEK BASIN

Ponca Creek drainage basin constitutes a very minor drainage basin in South Dakota. Soil Conservation Service watershed development is anticipated in the area. The Bureau of Reclamation presently has no studies programed, nor does it anticipate future investigations, in the Ponca Creek basin.

FUTURE MUNICIPAL AND INDUSTRIAL WATER DEVELOPMENT

Future use of water resources by municipalities and industries within South Dakota will depend upon many factors. Economics will be the determining factor where choices of a supply source exist for individual municipalities. It is anticipated that smaller municipalities and industries will predominantly rely upon ground water, where an adequate supply exists. Some municipalities and industries, as they increase in size and water demand, may find utilization of surface water more feasible.

The remaining portion of this municipal and industrial water topic will center around possibilities for municipal and industrial water supplies in conjunction with future Bureau of Reclamation irrigation developments. No project works are proposed specifically for municipal and industrial water users. These customers would provide and finance their own pipeline, canals, storage reservoirs, and treatment plants needed to produce a firm supply in their delivery system. They would merely buy water supplied from the "canal side" of the irrigation project works.

WESTERN SOUTH DAKOTA

Municipalities and industries in western South Dakota may experience future water supply problems sooner, and to a greater degree of severity, than some of the municipalities east of the Missouri River. Ground water in western South Dakota is available locally at shallow depths for small demands; however, water-bearing formations capable of yielding large quantities of water are generally deep-lying and expensive to develop.

Existing surface water supplies are not adequate to permit extensive future development or expansion in western South Dakota. Construction of storage reservoirs on nearly streams for local needs will increase their reliability, especially in the Black Hills. Importation of water from larger streams by transbasin diversion is possible, but high costs may prohibit this consideration under present economic conditions. Municipalities are widely separated in the western part of South Dakota. Combining group-needs into single plans is not presently feasible to overcome the hindrances of this geographical dispersion. Future economic conditions may warrant further consideration of these possibilities if water demands require it.

Some towns in the White River basin have water supply deficiencies, both quantitative and qualitative; however, future development of Pine Ridge unit will not solve their problems because of its distance from the municipalities in need. Philip and Midland are the only municipalities that might be aided by construction of the Philip unit in the Bad River basin. The Cheyenne River basin's future irrigation developments are not of sufficient size and are not conveniently located to assist municipalities in the basin that may need more water. The few small municipalities in the Moreau River basin can probably be served from ground-water sources. The Grand River basin offers little opportunity for municipal water assistance. Bureau of Reclamation studies to furnish the city of Lemmon with a municipal water supply from Shadehill Reservoir, which is 14 miles away and 400 feet lower in elevation, have shown that alternative sources are less costly under present economic conditions.

MISSOURI RIVER (MAIN STEM)

The future water supply for municipalities immediately adjacent to the Missouri River will present few problems. The existing main-stem reservoirs will provide an adequate supply for their use.

Municipalities and industries more remotely located from the river valley in upland areas will be more interested in benefits that could be derived from future irrigation developments. Development of the Wagner unit would be advantageous to the towns of Lake Andes and Wagner; the communities of Armour, Avon, Geddes, and Ravinia could also benefit if economic conditions and municipal water shortages warranted. Development of Tyndall unit would permit the municipalities of Springfield, Tyndall, Tabor, and Scotland to obtain water if needed.

EASTERN SOUTH DAKOTA

Existing municipal and industrial water supplies in eastern South Dakota are more adequate than in the western areas of the State. Population densities are also greater, and future population growth east of the Missouri River will probably continue to be greater than in the western part of the State. This will place a greater future demand on available municipal and industrial water supplies.

The most far-reaching irrigation development that would influence municipal and industrial water supplies in eastern South Dakota would be the Oahe unit. Communities that would have financial advantages over any other sources of supply by using the Oahe unit water supply for municipal purposes are:

Aberdeen
Agar
Alexandria
Ashton
Blunt
Brentford
Claremont
Columbia
Conde
Faulkton
Frankfort
Hitchcock
Huron
Mellette
Menno
Miller
Mitchell
Northville
Onida
St. Lawrence
Scotland
Stratford
Tulare

These municipalities are located in and adjacent to irrigable areas of the unit, along the canals leading to the irrigable land, and along the James River below the unit.

FUTURE FARM-DOMESTIC WATER DEVELOPMENT

Past population trends within the State of South Dakota have indicated a general rural-to-urban movement of people. This trend is still occurring but at a slower rate. Farms have generally been decreasing in number and increasing in size. Methods of farming change with advances in technology and economic trends. All these factors will influence future development of farm-domestic water resources.

GROUND WATER

It is anticipated that most domestic water for use in farm and ranch homes will still be obtained from ground-water sources. Utilization of ground water will probably increase as more knowledge of the location and extent of ground-water resources becomes available. Irrigation with water from shallow aquifers is expected to continue increasing, and water from this source should be adequate for numerous individual farm developments.

SURFACE WATER

Construction of dugouts will probably continue as the need for additional stockwater increases. Construction of new stockponds will decrease because the most feasible and economical sites have been developed. Extended periods of drought and water shortages usually stimulate farmers and ranchers to become active in surface water development for their needs.

SOIL CONSERVATION SERVICE

The Soil Conservation Service will continue to help individual ranchers and farmers and groups of rural people, with problems in soil and water management. It is expected that construction of terraces will increase significantly in future years because many thousands of acres of cropland need this type of moisture conservation. Pond construction is not expected to increase extensively because stock-water needs are fairly well satisfied and future sites will be more difficult and costly to develop. Waterway developments, serving as outlets for terraced areas, will increase as the number of terrace mileages increase. Land development practices associated with irrigation will increase as individual and project irrigation lands are developed. More sprinkler systems will be brought into operation as ground-water wells in aquifer areas increase. Water spreading areas will increase in future years. Natural spring developments in future years will be limited by the geologic and climatic conditions. Assistance to irrigators will be needed if large irrigation developments such as the Oahe unit are constructed.

Watershed development under the Watershed Protection and Flood Prevention Act (Public Law 566) will continue in accordance with the needs and desires of people living in the affected areas. Pending applications for planning will be considered for approval, and many watersheds will initiate development work. Watershed needs will be inventoried and assistance given to local organizations to evaluate their needs. The possibilities under this act will be coordinated with other future water resource development.

FUTURE HYDROELECTRIC POWER DEVELOPMENTS

The natural characteristics of South Dakota's terrain and streams have precluded large-scale development of hydroelectric power except on the Missouri River. In the future, South Dakota will have to rely on means other than waterpower for generating additional large quantities of electrical energy.

The existing four main-stem dams within South Dakota occupy the most feasible sites. Future hydroelectric power sites with sizable quantities of available water exist only along the Missouri River in the southeastern extremity of South Dakota.

No feasible opportunities for private development of important quantities of hydroelectric power in the Black Hills are known primarily because streamflows are undependable. Some streams in the eastern portion of the State may have small quantities of dependable flow; however, no feasible topographical features exist for hydroelectric power generation.

As previously mentioned, the only known sites of importance remaining in South Dakota that hold possibilities of feasible hydroelectric power development are along the Missouri River, downstream from Yankton. South Dakota, Nebraska, and Iowa would share the benefits available from these boundary waters. The Corps of Engineers has investigated two sites known as Mulberry Point and Kenslers Bend. If developed, both sites would be multiple purpose projects and would not be constructed for their hydroelectric potential alone. Kenslers Bend Dam, farthest downstream, would replace Gavins Point

Dam in its function of finally reregulating water releases from the other upstream main-stem reservoirs to serve downstream requirements. The power installation at Mulberry Point would serve as a peaking plant. Water releases at Gavins Point would be determined by power demands as well as downstream requirements. Location data and statistics on these two potential hydroelectric sites are shown in table 34 and figure 46.

The major portion of the existing system of transmission lines and substations in the areas has been constructed and is being operated by the Bureau of Reclamation. Additional facilities will have to be added as demands dictate. Power system studies and electrical power load surveys are essential for orderly planning of new facilities to meet the continuing growth in the use of electricity. Technical research indicates possibilities of power system interties that will permit economical long-distance transmission of electrical energy from areas of excess to areas of deficiency. These ties may serve as a means of overcoming unbalanced combinations of water shortages and peak power demand loads. Future demands for large quantities of electrical power, when they occur in South Dakota, will have to be satisfied from sources other than local hydropower generation, such as coal, oil, or atomic energy, or by transmission of power from other areas.

Thermoelectric generating plants normally require substantial quantities of water for cooling purposes. Adequate quantities of water are available at many locations in South Dakota. Main-stem reservoirs on the Missouri River would provide adequate water supply for thermoelectric generating plants requiring large quantities of water. Smaller thermoelectric generating plants could utilize water stored in reservoirs on tributary streams throughout the State.

SUMMARY

South Dakota is receiving benefits daily from the existing water resource developments within its boundaries. There are, however, many potential water resources that remain to be developed. Their development will require continued investigations, appraisal of needs, comparison with progress to date, and application of this information to future plans. Consumption requirements must be estimated soon enough to allow adequate time for construction of storage and conveyance systems so water will be available where and when it is needed.

Approximately 700,000 people are living in South Dakota today. The population will nearly double by the turn of the century, and increase to more than 1,750,000 by the year 2020. Per capita water consumption will also increase as irrigation and industry develop.

The tremendous water storage of the four main-stem Missouri River reservoirs represents a future resource that will have to be used to supply the difference between local water requirements and local water resources in several geographical areas within the State. Current appraisal indicates this stored water, in addition to water from other sources, will be sufficient to meet estimated future needs of South Dakota for several decades. The problem to be encountered will be one of water conveyance and distribution to areas in the State where deficiencies occur. Scheduled timing for development of potential water resources will depend upon the desires and actions of the people, and economics of feasibility.

Water shortages may occur earlier in the western areas of the State than east of the Missouri River, if extensive population or industry increases develop in the Black Hills. Limited irrigation potential exists in the White, Bad, Cheyenne, Grand, and possibly the Moreau River basins. Extensive irrigation cannot be developed due to a general water deficiency and the scattered location of arable lands. Only smaller projects of limited acreages can be developed if needed.

Numerous small arable areas along the main-stem Missouri River reservoirs can also be developed for irrigation. Additional detailed studies will be required on several units to determine their economic feasibility.

The Oahe unit is the largest irrigation development presently foreseen in eastern South Dakota. Oahe Reservoir would supply most of the water required to irrigate an estimated 495,000 acres in the Missouri Slope area east of the Missouri River and the Lake Plain area of the James River basin. Construction of Oahe unit would have far reaching economic impact upon the entire State of South Dakota. Municipalities and industries could obtain future water from several proposed irrigation developments. The Vermillion and Big Sioux River basins in the eastern part of the State require additional investigations to determine their potential resource development.

The presence of suitable ground water in several areas of eastern South Dakota offers a water resource readily available for individual irrigation development. Watershed development and other moisture conservation practices should be continued. This will alleviate local water deficiencies in minor drainage basins where large-scale water resource development is not practicable.

The hydroelectric resources in South Dakota are almost fully developed. Only two significant sites remain on the Missouri River. Insufficient water in the Black Hills precludes any additional hydropower development of importance. Adequate water is available in several locations through the State that could be used for future thermoelectric generation plants.

South Dakota must be assured of an adequate standard of living, opportunity for employment, and a stable economy. Younger citizens will migrate to other States if these essentials are unavailable. The threat of drought to agriculture, industry, and business within the State can be greatly diminished by proper development of water resources. Local, State, and Federal governmental agencies are cooperating to provide the general public with technical assistance, guidance, and information on water resources and their development. This pattern of cooperative agency action and public support has made possible existing water resource developments that South Dakota uses today. Similar efforts are needed to achieve future water resource utilization.

The people living in South Dakota today must assume the responsibility, through vigilance, support, and action, to develop the State's potential water resources for the enjoyment of future generations.

BIBLIOGRAPHY

Black Hills Power & Light Co., Rapid City, S. Dak. (correspondence).

Culler, R. C. and Peterson, H. V., U.S. Department of Interior, Geological Survey, "Effect of Stock Reservoirs on Runoff in the Cheyenne River Basin Above Angostura Dam," Geological Survey Circular 223, 1953, Government Printing Office.

Department of Agriculture, Soil Conservation Service, "South Dakota Soil and Water Conservation Needs Inventory," May 1962.

Department of Army, Corps of Engineers, Missouri River Division Office, Omaha, Nebr. Various sources such as: Correspondence; Summary of Engineering Data, January 1962; Power Generation Study, October 8, 1963; Water Resources Development in South Dakota, 1963.

Department of Commerce, "U.S. Census of Agriculture, 1959"—Final Report, Volume III.

Department of Interior, Bureau of Reclamation. Various sources such as:

- "Definite Plan Report on Rapid Valley Unit, Cheyenne Division, MRBP," September 1951, revised June 1962.
- "Definite Plan Report on Shadehill Unit, Grand Division, MRBP," June 1963.
- "Draft of Report on Tower, Greenwood, and Yankton Units, South Dakota Pumping Division, MRBP," September 1963 (unpublished).
- "Draft of Report on Cheyenne Division, MRBP," November 1963 (unpublished).
- "Draft of Report on Wagner Unit, South Dakota Pumping Division, MRBP," September 1962 (unpublished).
- "Interim Information Report on Oahe Unit, James Division, MRBP," February 1957.
- "Original Draft of Bixby Unit Report, Moreau Division, MRBP," October 1950 (unpublished).
- "Preliminary Reappraisal of Little White Reservoir, White Division, MRBP," 1963.
- "Preliminary Draft, Drainage Appendix to Division Report, James Division, MRBP," March 1953.
- "Reappraisal of Pollock-Herreid Unit, South Dakota Pumping Division, MRBP," December 6, 1963.
- "Reclamation Project Data," U.S. Government Printing Office, 1961. "Reconnaissance Report on Supplemental Water Supply for Angostura Unit, Cheyenne Division, MRBP," 1962.
- "Report on Bad Division, MRBP," January 1958.
- "Report on Oahe Unit, James Division, MRBP," June 1960.
- "Report on Rehabilitation of Willow Creek Dam, James Division, MRBP," March 1955.
- "Report on South Dakota Pumping Division, MRBP," April 1959.
- "Report on Supplemental Water Supply Investigations, Belle Fourche Project," 1963.
- "Report on Turner-Clay County Area of Vermillion River Basin, South Dakota," October 31, 1963.
- "Report on White Division, MRBP," January 1959.

Department of Interior, Geological Survey, Huron, South Dakota, 1960 Water Utilization Survey Data.

Department of Interior, Indian Irrigation Service, "Proposed White River Irrigation Project—Pine Ridge Indian Reservation, South Dakota," February 1941.

Federal Security Agency, Public Health Service:

- "Big Sioux River Drainage Basin," Water Pollution Series No. 21, October 1951.
- "Central Misouri River Drainage Basin," Water Pollution Series No. 24, June 1952.

Golzé, Alfred R., "Reclamation in the United States," McGraw-Hill Book Company, Inc., 1952.

Homestake Mining Company, Lead, South Dakota (correspondence).

Hydro Electric Power, White River, South Dakota (correspondence).

Johansen, John P., Rural Sociology Department, Agricultural Experiment Station, South Dakota State College, Brookings, South Dakota. Pamphlet, "Population Trends in Relation to Resources Development in South Dakota."

Kumlien, W. F., "Basic Trends of Social Change in South Dakota, I—Population Tendencies," Department of Rural Sociology, Agricultural Experiment Station of the South Dakota State College of Agriculture and Mechanic Arts, Brookings, South Dakota, cooperating with South Dakota Works Progress Administration.

Litterer, Oscar F., "The Missouri Basin Development Program," published by Federal Reserve Bank of Minneapolis, March 1958.

Mead, D. W., "Hydrology," McGraw-Hill Book Company, 1919.

Missouri Basin Interagency Committee's Report, "The Missouri," U.S. Government Printing Office, 1958.

Missouri Basin Survey Commission's Report, "Missouri: Land and Water," U.S. Government Printing Office, 1953.

Rural Sociology Department, "50 Years Experience on the Belle Fourche Irrigation Project," Agricultural Experiment Station, South Dakota State College, Brookings, South Dakota.

Senate Document No. 191, 78th Congress, 2d Session, "Missouri Basin Plan of the Bureau of Reclamation," 1944.

South Dakota State Department of Health, Division of Sanitary Engineering, "South Dakota Public Water Supply Data," July 1961.

South Dakota State Planning Board:

- "Water Resources of the Big Sioux River Drainage Basin," Volume I, 1937.
- "Water Resources of the Keya Paha-Ponca River Drainage Basin," Volume X, 1937.
- "Water Resources of the Minnesota Drainage Basin," Volume XII, 1937.
- "Water Resources of South Dakota," June 1, 1935.

University of South Dakota, Business Research Bureau, School of Business, Bulletin No. 79, 1963, "South Dakota Economic and Business Abstract, 1939–1962."

Water Laws of the State of South Dakota.