STATE OF SOUTH DAKOTA

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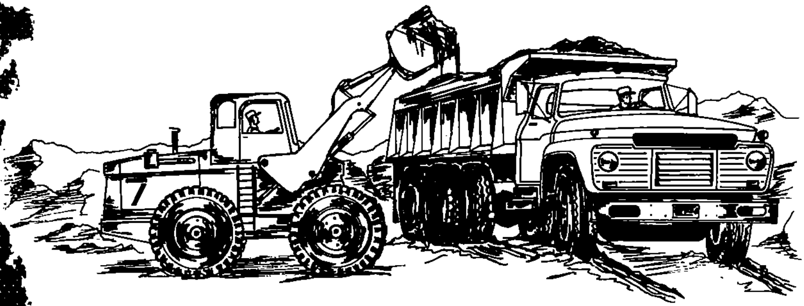
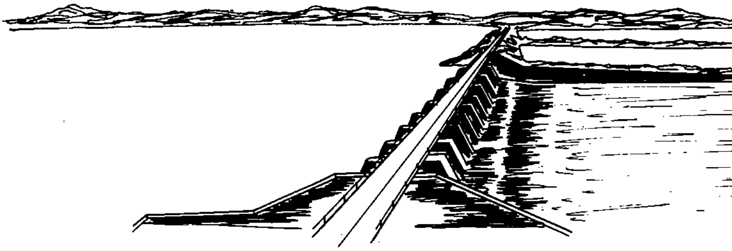


Bulletin Number 16

MINERAL AND WATER RESOURCES OF SOUTH DAKOTA



SOUTH DAKOTA STATE
GEOLOGICAL SURVEY
Duncan J. McGregor
State Geologist
Science Center, University
Vermillion, South Dakota
1964
Revised 1975

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.

Duncan J. McGregor
State Geologist

94th Congress }
1st Session }
COMMITTEE PRINT

MINERAL AND WATER RESOURCES OF SOUTH DAKOTA

REPORT

PREPARED BY THE

UNITED STATES GEOLOGICAL SURVEY

IN COOPERATION WITH THE

SOUTH DAKOTA GEOLOGICAL SURVEY, THE
SOUTH DAKOTA SCHOOL OF MINES
AND TECHNOLOGY, THE UNITED STATES
BUREAU OF RECLAMATION, AND
THE UNITED STATES
BUREAU OF MINES

PRINTED AT THE REQUEST OF

HENRY M. JACKSON, *Chairman*

COMMITTEE ON INTERIOR AND
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UNITED STATES SENATE

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MEMORANDUM OF THE CHAIRMAN

To Members of the Senate Interior and Insular Affairs Committee:

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, water, and related energy development.

HENRY M. JACKSON, *Chairman.*

FOREWORD

This report was prepared at my request by the U.S. Geological Survey and the Department of the Interior, in cooperation with the South Dakota Geological Survey and the South Dakota School of Mines and Technology.

I am confident that it will prove to be an invaluable updating of a similar report published by the Senate Interior and Insular Affairs Committee in 1964. The 1964 report was a valuable tool in assisting Federal, State, and local decisionmakers in planning ahead for the future of South Dakota. Now, after the passage of over a decade, a revised version is needed so that we may continue this effort and to take into account the great wealth of mineral and water related information which has been developed in the intervening years. As the needs and goals of our society have changed, so too has the scope of the information required to make the decisions to meet these goals. The new "Mineral and Water Resources of South Dakota" will go far toward meeting this requirement as South Dakotans look to the decades ahead.

I wish to thank the personnel of the Department of the Interior, the South Dakota Geological Survey, and the South Dakota School of Mines and Technology for their contribution to this report.

George McGovern.

LETTER OF TRANSMITTAL

U.S. Department of the Interior,
Geological Survey,
Reston, Va., April 24, 1975.

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

Dear Senator McGovern: In response to your letter of February 8, 1974, we are pleased to transmit herewith a report on the mineral and water resources of South Dakota.

The report was prepared by the U.S. Geological Survey with the help of the South Dakota Geological Survey, the South Dakota School of Mines and Technology, the U.S. Bureau of Reclamation, and the U.S. Bureau of Mines.

The report describes all the various kinds of mineral deposits known in South Dakota. It tells where they are, sums up the fundamentals of the geology, explains their importance to the State economy, and indicates how and where further deposits may be found.

The section of the report on water resources treats both the surface water and ground water. It explains the distribution and availability of water, both geographically and geologically, and discusses past and future development of supplies.

We hope that this report will be helpful to yourself and your colleagues and also to officials and residents of South Dakota.

Sincerely yours,

Henry W. Coulter,
Acting Director.

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MINERAL AND WATER RESOURCES OF SOUTH DAKOTA

INTRODUCTION

(By J. J. Norton, U.S. Geological Survey, Reston, Va.)

This report is the second, and an almost completely revised edition of a volume issued in 1964 by the Committee on Interior and Insular Affairs, U.S. Senate, and also as Bulletin 16 of the South Dakota State Geological Survey. In the intervening years there have been many changes. The State's gross economic product nearly doubled between 1964 and 1972 (Michael Keegan, written communication, May 1, 1974). The output of farm products, which is much the largest business in the State and depends heavily on knowledge and proper use of water supplies, more than doubled in value.

The price of gold in 1964 was $35 an ounce, where it had been pegged for many years. The fixed price and the increased costs, resulting from inflation and from the greater depth of mining, threatened extinction of the State's chief mining industry. Fortunately, through skillful management aided by a reduction in taxes, the Homestake mine, which has produced more than 90 percent of the gold and was the only gold mine still operating, was able to stay open. In 1974 the price of gold has generally risen to four or five times the previously fixed U.S. price. Reevaluation of old deposits and the search for new deposits in the Black Hills are resuming after a lapse of more than 30 years. Meanwhile new knowledge of the geology of the Black Hills and older knowledge now receiving much closer attention have brought optimism that sizable new deposits can be discovered.

Renewed exploration for gold may be accompanied by the discovery of other metals. Lead-silver and lead-zinc deposits, which have been mined in the past, can again become important. Discovery of deposits of other metals, such as molybdenum and copper, which have never been significant in the State, is a possibility worth attention. Iron deposits of considerable size and quality have long been known in the Black Hills, but economic influences are likely to continue to delay their development.

Second only to gold among the mineral products of the State are the construction materials, especially sand, gravel, and stone. These industries have remained vigorous, though fluctuating somewhat with economic changes. Commercial activities of every description depend so heavily on these products that a constant increase in knowledge of their availability and quality is essential to economic well-being.

Many mineral commodities of some importance in the past have experienced a decline. Some of them, such as sheet mica, which has in many years been a major industry in the southern Black Hills, may never be mined again. The market is supplied by other and cheaper sources elsewhere, or substitutes have taken their place.

Uranium, oil, and coal have all been produced in moderate quantities. An experimental coal gasification plant was built in Rapid City in 1969, and a coal boom in Wyoming and eastern Montana may extend its influence into South Dakota. In 1973 the general public was abruptly forced into awareness of the supply problem in oil and gas, and even persons long knowledgeable about the subject from the technical and trade literature were surprised at the suddenness with which it became a major concern. Increased prices and efforts to avoid environmental deterioration have heightened the effect. A result may be further exploration for oil in the Williston Basin in central South Dakota, development of coal in the northwestern part of the State, and additional search for uranium on the flanks of the Black Hills.

Similar problems lie in wait for the nation among other mineral resources, especially the metals (Pratt and Brobst, 1974). Some of these mineral products are known to be obtainable in South Dakota, and there are grounds for suspecting the existence of others. The need for increased geologic knowledge will accelerate, both to find deposits and to comprehend the environmental problems associated with their use. Geologic investigations will include not only the long standing conventional and relatively low cost field techniques of regional study and exploration but also the more sophisticated geochemical and geophysical techniques that elucidate the subsurface geology.

At the same time that the hazards of national dependence on imported mineral supplies became widely apparent, the United States assumed increased importance as an exporter of farm products. The study of soils, though dependent on the sciences of geology and mineralogy, is outside the scope of this report, as is a review of water from rainfall. But surface water (the water of streams and lakes), which is used for irrigation as well as other purposes, and ground water, which is tapped by wells, will be discussed in some detail in the final section of this report. This water, because it is in rather constant supply, is commonly used for city water systems, for industrial purposes, and on farms to meet domestic needs and for cattle. Waste water—or sewage with various degrees of treatment—is in one way or another returned to the surface and ground waters; the capability of receiving such waste without harming sources of supply elsewhere is important.

This report will place somewhat more emphasis on the future outlook than did the 1964 report. A key issue is the potential for discovering new ore deposits or for enlarging the known reserves in previously identified deposits. Similarly important is the enlargement of knowledge of water supply, of how to facilitate its further use, and of what the ultimate limits to this use may be.

The fundamentals of the geology of the State will be discussed in the detail necessary as background for the resource appraisals. The use of certain geochemical and geophysical techniques will be summarized, for they will become increasingly important. Activities of the Earth Resources Technology Satellite system (ERTS), a major facility of which has been established at Sioux Falls, will be unmentioned because they extend into many fields other than those covered by this report and their applications to mineral and water investigations are still in a developmental stage. Environmental problems arising from the use of mineral and water resources and from certain geologic processes are such a large subject that they will be described only briefly, but a guide to their basic nature has in recent years become a necessity in the understanding of mineral and water resources.

The resources themselves will then be treated in some detail. References to the thousands of pages of publications and the many maps of various kinds will be supplied for the further guidance of the interested reader. Metals will be examined first, then nonmetallic minerals, next the mineral energy sources, and finally water.

HISTORICAL BACKGROUND

(By J. J. Norton, U.S. Geological Survey, Reston, Va.)

South Dakota is, in many senses, a very youthful State. The two Dakotas entered the Union in November 1889 as the 39th and 40th states. Even the Dakota Territory was established only in 1861. Many persons living today were once personally acquainted with pioneers. As recently as 1950 a winner of the Congressional Medal of Honor at the Battle of the Little Bighorn in 1876, Charles A. Windolph, died in Lead.

The last 25 years have seen the completion of much of the State's now modern intercity highway system, the development of most of the State's important tourist business, and the construction of all the dams on the main stem of the Missouri River and many smaller dams for flood control, electric power, and irrigation, as well as recreational activities. Half a century ago it took two days to drive an automobile from Rapid City to the state capital at Pierre—and an extra night also if one missed the last ferry across the Missouri River. The great river itself, being not readily navigable, subject to flooding, and costly to bridge, was less the natural resource it really is than a cause of inconvenience or actual hazard. And the tourist industry was nonexistent.

This report is being written in the centennial year of the 1874 exploration of the Black Hills under General George A. Custer, commanding one of the last, largest, and best equipped military expeditions in the West. Publication will be in 1975, 100 years after the discovery of gold at Deadwood, which soon led to the opening of the Homestake mine and to the development of the many other gold mines of the northern Black Hills. Yet the original discovery of gold was in the southern Black Hills by the Custer expedition. This discovery is now widely regarded as its principal accomplishment, through in fact the most important result was to open the area west of the Missouri River to development.

The two decades from 1870 to 1890 were also the period of the main land rush east of the river. In 1870 the population of what is now South Dakota was about 10,000; in 1880 it was 98,268; and in 1890 was 328,808 (Schell, 1968, p. 159).

This is not to say that the region was totally unknown or untouched in earlier years. The Lewis and Clark expedition crossed South Dakota on the Missouri River between August and October of 1804 at the start of their exploration of lands acquired in the Louisiana purchase. On their return trip, after reaching the Pacific coast, they travelled down the Missouri in 1806.

Even Lewis and Clark had predecessors. French, Spanish, and British fur traders and explorers had known the area and its native inhabitants. The 1790's saw important expeditions to start a major fur trade along the Missouri River (Schell, 1968, p. 32–36). More than a century earlier, in 1679, a French expedition may have touched on the northeast corner of what is now South Dakota (Schell, 1968, p. 25).

The fur trade began in earnest not long after the Lewis and Clark expedition. Its most active years were between 1815 and 1850 (Schell, 1968, p. 50). Among the many trading posts, most of which were on the Missouri River, the chief one was Fort Pierre, established in 1832, which with a slight change in geographic position later became a city that has been continuously inhabited ever since. It was named after Pierre Chouteau, Jr., a business leader in the fur trade. The city of Pierre, on the other side of the river, was first laid out as a railroad terminus, when the Chicago and North Western Railway reached the Missouri River in 1880. Its present importance as the state capital came much later.

With the decline of the fur trade and the onset of the Civil War, the rate of development of South Dakota became negligible. When the Dakota Territory was formed in 1861, its population was exceedingly small. Schell (written communication, 1974) estimates the 1860 population of settlers in South Dakota at only 500. Yankton, the first capital, was also the first city to become incorporated, though not until 1869. Meanwhile the westward migration largely bypassed South Dakota, going to mining regions farther west and onward to the Pacific coast via the Platte River valley in Nebraska and other routes.

Development really began with the land boom and the mining rush of the 1870's and 1880's. For a long time the Black Hills was separated from the rest of South Dakota by a broad expanse of land with a sparse Indian population but otherwise crossed only by wagon trains. The first railroad to reach Rapid City came from the south in 1886. Railroads from Pierre and Chamberlain, built in 1905–1907 (Schell, 1968, p. 253), had a key role in unifying the eastern and western parts of the State.

The period of sod-busting and the beginning of crop-farming, mainly east of the Missouri River, were succeeded by the start of what became a major cattle industry, especially west of the river. For a few years in the 1890's Belle Fourche at the north fringe of the Black Hills was the largest primary cattle shipping point in the world (Schell, 1968, p. 250). Open range cattle operations had begun after the extermination of the buffalo in the mid-1880's and came virtually to an end about 25 years later as much of the public domain passed into private ownership and lands were fenced (Schell, 1968, p. 242–267). The industry then continued on privately owned ranches.

Long periods of drought have been troublesome, especially when they followed long periods of relatively prosperous agricultural activity. The 1930's were the most devastating, but a series of dry years between 1886 and 1897 (Schell, 1968, p. 343) showed the pioneers the merit of caution. Modern techniques in the use of water have alleviated but not eliminated this hazard.

Severe winters have also been damaging, especially to cattle, but much less so in recent years than in the 19th century. The increase in the number of settlements, the growth of windbreaks, improvement in weather forecasting and communication, and storage of hay for winter feeding started causing this change at an early date. Modern transportation has done much more. Even aircraft, especially military aircraft, were used in South Dakota after World War II to drop hay to stranded herds of cattle. The storms of January and February 1949, which were perhaps the worst ever experienced in the West, did much less damage than bad storms of winters during pioneer times.

A bright spot in the State economy of the 1930's was mining in the Black Hills, especially gold mining but also feldspar mining. The increase of the price of gold to $35 an ounce in 1934 was especially influential. The gold industry had never, from its very beginning, gone through a prolonged decline nor a startling increase. Yet the dollar value of the output from 1936 through 1940, which exceeded $20 million yearly, was three times that of 1926–1930, thus greatly helping a depression-ridden and drought-stricken State economy. Feldspar, though generally with an annual production of only $100,000 to $150,000, also greatly exceeded previous levels, for it too had depression resistant characteristics, especially as a constituent of glass containers used in home canning.

An event of the 1930's that had much more economic impact than could possibly have been perceived at the time was the carving of the monument at Mount Rushmore. After World War II this attracted a mass of tourist traffic to South Dakota that might otherwise have taken other routes. The focus on Mount Rushmore encouraged a great increase in visits to the Badlands and to other Black Hills attractions, especially Custer State Park, Wind Cave, and Jewell Cave.

World War II brought prosperity to crop farming and cattle raising as well as other phases of the State economy. An ordnance depot in the southern Black Hills and several Air Force training centers were established. Ellsworth Air Force Base at Rapid City became a permanent installation after the war. In the Black Hills the lumbering industry and pegmatite mining, especially for sheet mica needed for military electronic equipment, attained new levels of importance. Gold mining, however, was shut down by Goverement order to release workers for employment in more critical industries. The Homestake Mining Company continued its lumber operations and used its surface facilities at the mine for war work.

Prosperity continued after the war, though with sporadic and generally modest ups and downs. A drought in 1974 and economic deterioration of other kinds appear likely to be more serious.

Though the gross State economic product has increased greatly, the population has been almost without change, quite unlike the great increases elsewhere in a widespread movement to urban centers. The population was 652,740 in 1950 and 666,257 in 1970, and the two largest cities, Sioux Falls and Rapid City, had only 72,488 and 43,836 persons in 1970. The major urban centers serving South Dakota are outside the State, the nearest being Omaha, Minneapolis-St. Paul, and Denver. Rapid City had a very destructive flood in June 1972, from which it has made such a remarkable and well managed recovery that the net economic result may be an actual improvement; measures to protect against a similar future event should reduce the saddest result of all, the considerable loss of life.

As the 1970's unfold, the gold mining industry shows signs of going through a rejuvenation, for advances in geologic knowledge have indicated that exploration for major new deposits concealed in the subsurface has a considerable likelihood of success. Lead-silver deposits hold similar, if less dramatic, possibilities, and certain other kinds of mineral deposits also offer promise. Water resources of the State continue to present problems, especially through damage done in years of low rainfall, but technical progress will continue to effect improvements. Hazards of major floods have, however, been enormously diminished.

THE MINERAL INDUSTRY OF SOUTH DAKOTA

(By J. J. Norton, U.S. Geological Survey, Reston, Va.)

The mineral industry, which started as the key influence on the original development of western South Dakota, has continued to be important down to the present day. The total value of mineral production in 1973 was about $80,000,000.

A brief discussion of the State's mineral industry, and particularly of the overall production statistics shown in table 1, seems desirable before describing the geology and mineral resources in greater detail. Water is in a sense also a mineral resource, and the understanding of it requires at least as wide a range of geologic data. Yet the statistical treatment of water and its geologic background present such different problems that it is not ordinarily regarded as a part of the mineral industry but as a separate and very large subject. For these reasons discussion of water will be deferred to the final major section of this report.

The industry has always centered on gold, which accounted for 43 percent of the total in 1973. Nonetheless, the bulk nonmetallic materials have impressive dimensions: the value of sand and gravel was 21 percent and of stone was 14 percent of the 1973 mineral production. The remaining 22 percent consisted chiefly of cement and other commodities for which 1973 production figures have not been published.

TABLE 1.—MINERAL PRODUCTION OF SOUTH DAKOTA

[From U.S. Bureau of Mines except as noted]

	Earliest year of record	Total production through 1973		1973 production	
		Quantity	Value (thousands)	Quantity	Value (thousands)
Gold (troy ounces)	1875	35,484,483	$1,065,632	357,575	$34,974
Silver (thousands of troy ounces)	1889	13,048	10,897	184	72
Lead (short tons)	1877	508	63		
Zinc (short tons)	1942	266	57		
Iron ore (usable, long tons)	1890	91	370		
Tungsten (short tons, 60 percent WO_3)	1898	1,638	1,379		
Vanadium	1960	(1)	(1)		
Tin (pounds)	1884	[2] 379,979	[2] 110		
Manganese (short tons) [3]	1891	149	4		
Molybdenum	1964	(1)	(1)		
Copper (short tons)	1910	48	23		
Sand and gravel (thousands of short tons)	1889	397,454	278,253	13,963	16,587
Cement (thousands of 376-lb barrels)	1925	56,287	164,373	[4] 3,109	(1)
Stone (thousands of short tons)	1889	67,356	219,033	2,745	11,607
Clays, bentonite, and lightweight aggregate (thousands of short tons) [2]	1888	8,559	45,962	201	181
Feldspar (thousands of long tons)	1923	[2] 1,713	[2] 9,531	(1)	(1)
Sheet and punch mica (pounds)	1879	7,067,537	3,074		
Scrap mica (short tons)	1899	[2] 53,911	[2] 1,129		
Lithium minerals (short tons)	1898	[2] 106,700	[2] 3,930		
Beryl (short tons)	1914	5,364	1,832		
Tantalum-columbium concentrates (pounds)	1905	[2] 187,862	[2] 197		
Gypsum (thousands of short tons)	1884	[2] 701	[2] 3,070	(1)	(1)
Gem materials	1906	(5)	550	(5)	42
Petroleum (1,000 42-gal barrels)	1954	3,421	7,931	277	994
Coal (thousands of short tons)	1895	1,393	3,392		
Uranium ore (thousands of short tons)	[6] 1956	[3] 373	[2] 5,753		
Undistributed	[7] 1877		27,023		15,976
Total	1875		1,853,568		80,433

[1] Confidential figure; included in "undistributed."

[2] Some figures withheld as confidential but included in "undistributed."

[3] Excludes manganese nodules shipped for experimental work in 1940–42.

[4] From table 9. Includes some 280-lb barrels.

[5] Not available.

[6] 1956 is the date a mill began processing ore in South Dakota. Mining actually began shortly after the discovery of uranium in the southern Black Hills in 1951 but the ore was shipped to plants outside the State.

[7] Includes confidential figures and production of minor mineral commodities.

Many materials that were prominent in the past, such as the pegmatite products mica, lithium minerals, beryl, and tantalite-columbite, have little production at present. Tungsten mining, once of some importance, has no promise for revival in the short term and perhaps never in significant amounts.

Changing patterns in future mineral production are equally expectable, and increased productions of several commodities appears likely to far more than offset the contractions. For example, neither coal nor uranium was produced in 1973, but production of each is likely to be resumed. Recent increases in petroleum prices will encourage further exploration, the necessary first step for increasing production.

Improvements in understanding of Black Hills gold deposits have added to the likelihood that more deposits can be found concealed beneath the surface. The large increase in the price of gold is a still greater stimulus to exploration.

Sizable iron deposits have for some time been known to exist. The solution of technical problems and the need to preserve the environment, which is both a cost and a social problem, are likely to delay but not permanently prevent the establishment of an iron mining industry.

The lead-silver and lead-zinc deposits on the flanks of the Black Hills have never been thoroughly explored. Geologic similarities with mining regions elsewhere indicate that larger deposits can exist at depth. Exploration to test this possibility may someday be attempted.

Among the other major metals, molybdenum and copper deposits worthy of attention might be found in western South Dakota. Evidence is meager and the conclusion is partly deductive, but the implications are clear.

Sand, gravel, and stone will continue to keep pace with the regional economy, for most such material is used locally. Bentonite, which is shipped outside the State, has declined and is unlikely to increase in the near future. Production of other clays and of all other nonmetals probably will not increase significantly.

South Dakota has not been a major source of oil and gas, coal, or uranium, but it has been a significant producer and has potential for all three. The chief oil and gas area is in the Williston Basin, the south end of which occupies much of the western part of the State. Exploration and discoveries increased in recent years until the output was worth nearly $1 million in 1973 and probably very much more in 1974. This is small by the standards of the oil industry but nonetheless appreciable as a contributor to the State economy. Lignitic coal has long been mined in the northwest part of the State and resources are sizable, though there is no activity now nor likely to be much in the immediate future because deposits nearby in Wyoming and Montana are superior. Uranium, especially in the southern Black Hills, attracted attention in the 1950's and 1960's and probably will do so again as nuclear power plants become more numerous. A processing plant at Edgemont handles most of the uranium ore.

Many of the metals and also petroleum and uranium differ from most of the nonmetals in one important economic respect. Some mineral exploration and mining, as for gold, are high risk ventures, but the financial risk is justified because very rich and profitable deposits may be found. Other mineral products, such as crushed stone or sand and gravel, carry no more risk than is normal for any business and the profits are correspondingly modest. These products are, for the most part, only common rock, existing in abundance, mined by simple methods, and sold to nearby users. They cannot yield a large financial return because a company charging excessive prices can readily be undercut by competitors entering the business.

Many mineral commodities sell at virtually the same price world wide. Very rich deposits yield large returns to the ownership and generally have highly skilled, and thus highly paid, employees to mine them and to operate mills and other processing plants. The other side of the coin is that deposits of marginal quality are treated with caution if they require a large capital outlay, for unfavorable developments elsewhere can quickly cause a severe financial setback. Companies are unwilling to undertake exploration or to prepare to mine a deposit unless a profit proportionate to the risk is expectable. Conservatism is widespread among major mining companies, perhaps not by deliberate plan but because companies that act conservatively are the ones most likely to survive. To accept a large risk can, if the results are adverse, cause great damage and even bankruptcy; to refuse to accept it can at worst only prevent the company from becoming larger and more profitable.

The economics of mining is too complex to cover fully here. A key point is that mining of an effectual kind, even for precious metals, is no longer the adventurous activity, with little planning or no true planning at all, and with small capital expense, that it oftentimes has been in the past. Tales of individuals who made rich strikes were widespread as recently as the uranium boom of the 1950's, but such strikes were very rare and oftentimes not as successful as anticipated.

Mining is a far more important basic industry than its production statistics generally imply. In South Dakota, as elsewhere in the nation, the sales value of minerals is greatly overshadowed by that of farm products, which in South Dakota during 1972 had a value of $914,300,000 (Michael Keegan, written communication, 1974). Yet a comparison of the sales values of minerals and farm products, using the conventional methods of calculating them, can be misleading. Most mineral products increase far more in value as they pass through the manufacturing and marketing chain to the consumer than do farm products.

A dispassionate review of modern mining, mineral economics, and the potential of the mining industry of South Dakota fails to tell the whole story, either of the nature of mining through much of the State's history, of its contributions to the romantic accounts of fact and fiction engendered by events of the early years, or of calamitous financial experiences that diminished the reputation of Black Hills mining.

Deadwood has become a part of legend as one of the most lawless settlements ever to exist on the frontier. Even its name is picturesque. The poker hand held by Bill Hickok at the time of his murder in 1876 is still known as the dead man's hand. Many of the unsavory aspects of the time are documented by contemporary writings; some of the rest have been passed down by word of mouth, probably changed somewhat by fallible memories and a temptation to color the facts. Actual daily life undoubtedly consisted mostly of hard work and the endurance of harsh conditions.

The historical record of early mining has similar strengths and weaknesses. The exceptional tends to be emphasized by the expense of the ordinary. Prudence requires applying a discount even to written records. The physical evidence of mine workings is in many instances a more reliable indication of what was actually done, even this has its drawbacks, for extensive mine workings do not necessarily mean that a proportionate amount of ore was actually found.

Black Hills mining has seen its full share of financial adventures that were unwise, mismanaged, or worse. Certainly the region contributed to the popularity of the phrase "gold fever," which is a disease not caused solely by gold. Even today, worthless stock certificates of early mining companies occasionally are found in attics and old files. The tin exploration and mining centering on Hill City from 1884 to 1893, which yielded only about $43,000 worth of tin (Cummings and others, 1936, p. 1–4), supposedly cost at least $3,000,000, which was an enormous sum at the time. The extent of mine workings and the apparent size of the mills imply no such expenditure. Either a great amount of injudicious and fruitless prospecting was done, or the cost was less than believed, or funds were diverted to other channels. Recent mineral activities in the West, especially during the uranium rush of the 1950's, indicate that similar experiences remain possible. They indicate also, however, that important discoveries can still be made.

The first mining in South Dakota was in small plots of gold placer ground, operated by a few men or even only one man. Mining of bedrock deposits soon came into being, and with it a need for larger organizations, mechanical equipment, and capital. Nevertheless the mines were very small by modern standards. With the passage of time, most of the more productive gold deposits came to be operated by only three companies. Other mineral products began to take on importance, generally in small mines which in only a few instances ever became large. Small mines were common as late as the 1950's for such products as uranium and the various pegmatite minerals. Much of this kind of mining subsequently expired or diminished greatly as large mines elsewhere took over the market.

Profitable modern mines are, with some exceptions, very large. The first step is extensive and costly exploration; the next is a period of mine development and plant construction lasting several years; and the ultimate fruit is a large and technically intricate operation. Small and short-lived mines are a thing of the past in the metals and some other mineral fields except in such unusual instances as when a small but very high grade deposit is discovered. Small mines remain occasionally important for products such as sand and gravel that are shipped only a short distance and for specialized commodities having a widespread but small market.

Subsequent chapters of this report will indicate that South Dakota still has the potential for the discovery of important deposits and for the development of deposits already known. Exploration for such deposits and development of them are rarely suited to individuals or inadequately equipped small organizations. Instead the effort must be well supported by funds and by many kinds of expertise.

GEOLOGY

INTRODUCTION

(By J. J. Norton, U.S. Geological Survey, Reston, Va.)

The ordinary view of South Dakota, especially to those who speed across the State in an automobile, is that it consists of a broad area of flat or rolling land interrupted in the west by a small mountainous area known as the Black Hills. One also notices that the higher rainfall areas of the eastern part of the State, belonging to the long grass prairie of early times but now a prolific source of crops, change westward to the short grass prairie, where cattle raising is the main economic activity. In the Black Hills one enters pine forests and a terrain resembling, on a small scale, the Rocky Mountain ranges farther west.

The most important geographic feature is the Missouri River, which with its many tributaries drains all of the State except a small segment at the northeast corner in the Minnesota River Valley. The Missouri River enters the State near the center of its north border, then flows south to Pierre, southeast to the Nebraska border, and along the border to the southeast corner of the State. It traverses a distance of 500 miles in which its altitude drops from 1500 feet to 1100 feet. Most of the State east of the rim of the Missouri Valley is between 1200 and 2000 feet above sea level, but to the west altitudes are generally between 2000 and 3200 feet until, at the edge of the Black Hills, they begin an increase that ultimately attains 7242 feet at the summit of Harney Peak.

The only consistently large flow of water is along the main stem of the Missouri, which is generally known in the State as "the river." All the tributaries have periods of very low flow. The principal tributaries in the east half of the State are the southward flowing James and Big Sioux. To the west the main streams are the Grand, Moreau, Cheyenne, and White, all of which flow eastward. The largest of these is the Cheyenne, which circles the south and east sides of the Black Hills and is joined by its tributary, the Belle Fourche River, which comes from around the northern rim of the Black Hills. All surface drainage from the Black Hills enters one of these two rivers.

The largest physiographic subdivision of the State is the Missouri Plateau, which extends from the hogbacks around the Black Hills to the west edge of the James River basin. Along the south edge of the State, in Bennett and adjacent counties, a small area of the High Plains enters from Nebraska. The Missouri Plateau is unglaciated west of a line near the river and preserves its preglacial character. It has undulating uplands dissected by stream valleys, sizable floodplains along the larger streams, occasional bluffs and buttes, and areas of badlands. Badlands are most prominent near or along the

White River. The most spectacular display is in the Badlands National Monument of southeastern Pennington County.

East of the river the stream systems were disrupted by glacial action so that large areas lack a well-developed drainage system and have many ponds and lakes. The Missouri Plateau east of the river consists of rolling uplands cut by a few small valleys. Farther east is the lowland of the James River valley, which in large part was once a glacial lake. Beyond this, between the James and the Minnesota River valleys, is the Coteau des Prairies or Prairie Hills, with a great many ponds and lakes. The northeast side of the Prairie Hills drops down about 1000 feet within a few miles to the Minnesota River valley.

The geologic map of the State (fig. 1), which is based on King and Beikman (1974), and the generalized stratigraphic chart (fig. 2) sum up what is known about the rocks. In most of the State the bedrock is the Pierre Shale, a dark gray shale formed in the late part of Mesozoic time, which is commonly known as the age of the dinosaurs. Older rocks come to the surface in the Black Hills and in the southeast and northeast parts of the State. Younger rocks lie above the Pierre Shale west of the Missouri River in broad areas along both the Nebraska and North Dakota borders. The glacial boundary, also shown on the geologic map, marks the edge of an area, extending over the east half of the State, in which glacial deposits conceal much of the underlying rock.

Nearly all the rocks that were formed since the end of the Mesozoic (about 65 million years ago) are continental sediments; the only exceptions are deposits from one incursion of a seaway into northwestern South Dakota and a group of igneous intrusive rocks in the northern Black Hills. Older rocks, exposed at the surface or cut by drill holes, are almost entirely marine, deposited in seas that entered and withdrew from the State many times, so that deposition of sediments and intervals of erosion, marked by unconformities, alternated frequently. Some of the very oldest rocks are granites or other igneous bodies, but few of these are at the surface, even though apparently abundant in deeply buried parts of the Precambrian basement.

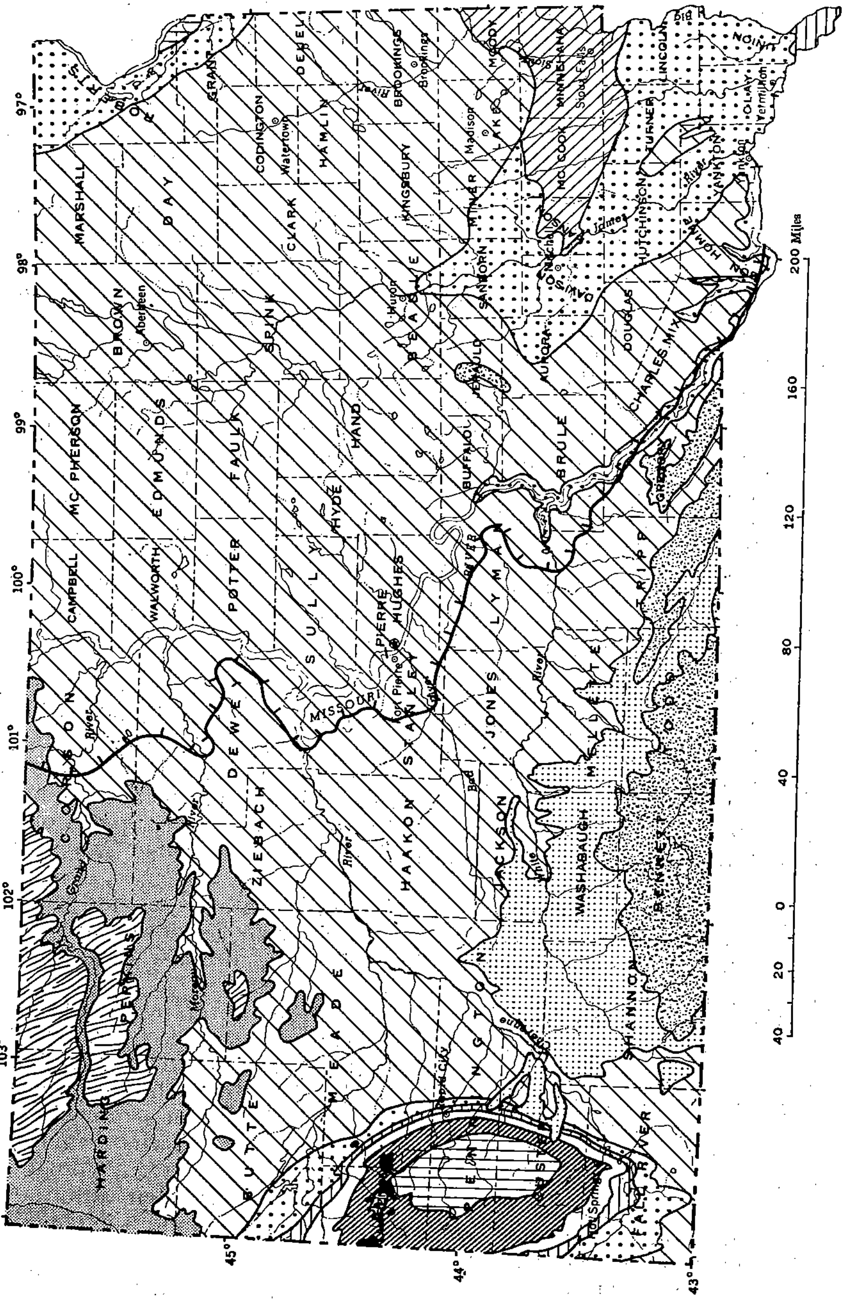
The oldest dated rocks are granites about 2500 million years old, which places them in the older part of Precambrian time. In at least one place a dated granite of approximately this age intrudes schist of still greater age. In the Black Hills a series of many tens of thousands of feet of metamorphosed and intensely folded sedimentary rocks with a few bodies of metavolcanic rocks were formed probably after the 2500 million year date and certainly before the crystallization of the Harney Peak Granite about 1700 million years ago. A few dates from subsurface samples in the southern part of the State range from 1410 to 1460 million years. Otherwise the geologic record indicates nothing but erosion until a thick quartzite was laid down in the central and southeast part of the State, probably about 1200 million years ago. This event was succeeded by another long blank in recorded events that lasted until about 500 million years ago, when the Late Cambrian Deadwood Formation was deposited.

The advance and subsequent retreat of the Deadwood sea was the first of a series of such advances and retreats that continued until the end of the Paleozoic, about 225 million years ago. Paleozoic units are exposed only around the Black Hills, where they are thinner and leave a much less complete record than obtained in the subsurface from drill holes. Paleozoic rocks underlie the western and central parts of the State but were either never deposited or have been eroded away in the east.

Mesozoic seas extended over the entire State, leaving several thousand feet of sediments that have been eroded away in only a few places. The Cretaceous is especially well-represented, widely exposed, and greatly studied.

With retreat of the sea near the end of the Cretaceous, continental sedimentation and even coal swamp conditions took over, and the uplift of the Black Hills as well as the Rocky Mountains began. By the beginning of Oligocene time the Black Hills had much the same form as today, but were then partially buried by a blanket of sediments that spread over much of western South Dakota. Most of what remains of these sediments is distributed along the White River, from which they take their name as the White River Group. Subsequent alternating sedimentation and erosion followed by glaciation and then modern conditions complete the geologic history.

The overall structure of South Dakota is very simple at the surface. It consists mainly of the oval dome forming the Black Hills and nearly flat-lying sedimentary rocks virtually everywhere else. In the subsurface the circumstances are more complex. The largest structure is the thick lens of sedimentary rocks in the Williston Basin, which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KINGSBURY
BEADLE
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MINER
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MOODY
MINNEHAHA
Sioux Falls
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BON HOMME
CHARLES MIX
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FALL RIVER
Hot Springs
SHANNON
WASHABAUGH
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TODD
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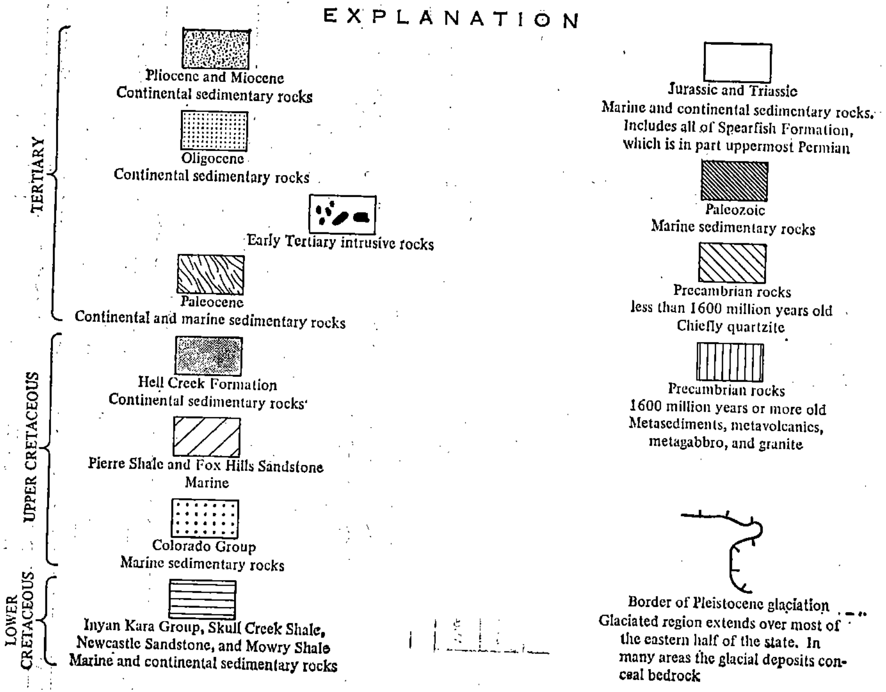
Big Sioux



From King, P. B., 1974, modified by J. J. Norton.

FIGURE 1.—Geologic map of South Dakota.

			Rock unit		Maximum thickness (feet)	Age estimates commonly used for boundaries (in million years)
CENOZOIC	Quaternary	Holocene		Stream and lake sediments		
		Pleistocene		Glacial deposits and stream and lake sediments	800	1.5-2
	Tertiary	Pliocene		Ogallala Formation	300	ca. 7
		Miocene		Batesland Formation	60	
				Rosebud Formation	250	
			Arikaree Group	Harrison Formation	600	
				Monroe Creek Formation		
				Sharps Formation		26
		Oligocene	White River Group	Brule Formation	600	(Oligocene)
				Chadron Formation	Eocene intrusive rocks	38
		Paleocene	Fort Union Group	Tongue River Formation		(Eocene)
				Cannonball Formation	1000	54
				Ludlow Formation		(Paleocene) 65
MESOZOIC	Cretaceous	Upper		Hell Creek Formation	400	
			Montana Group	Fox Hills Formation	400	
				Pierre Shale	3000	
			Colorado Group	Niobrara Formation	220	
				Carlile Shale	550	
				Greenhorn Limestone	360	
				Belle Fourche Shale	450	
		Lower		Mowry Shale	250	
				Newcastle Sandstone	100	
				Skull Creek Shale	250	
			Inyan Kara Group	Fall River Formation	150	
				Lakota Formation	550	136
	Jurassic	Upper		Morrison Formation	350	
				Sundance Formation	740	
		Middle		Piper Formation	125	
				Gypsum Spring Formation	200	190-195
	Triassic			Spearfish Formation	775	225
PALEOZOIC	Permian			Minnekahta Limestone	40	
				Opeche Shale	125	280
	Pennsylvanian			Minnelusa Formation	1400	320
	Mississippian		(Big Snowy Group)	(Kibbey Sandstone)	100	
			(Madison Group)	(Charles Formation)	550	
				(Mission Canyon Limestone) Pahasapa Limestone	1300	
				(Lodgepole Limestone)		
				Englewood Formation	70	345
	Devonian			(Three Forks Shale)	600	
				(Bird Bear Formation)		
				(Duperow Formation)		
				(Souris River Formation)		395
	Silurian			(Interlake Group)		430-440
	Ordovician		(Bighorn Group)	(Stony Mountain Formation)	600	
				(Red River Formation) or Whitewood Dolomite		
				Winnipeg Formation	180	ca. 500
	Cambrian			Deadwood Formation	600	570
PRECAMBRIAN				Sioux Quartzite	5000	
				Metasediments, metavolcanics, metagabbro, granite, and granite gneiss where exposed. Largely granite and granite gneiss in subsurface. Formation names in use apply only to small areas	At least 60,000	3000

FIGURE 2.—Generalized stratigraphic chart showing rock units of South Dakota. The nomenclature of this chart is not necessarily that accepted by the U.S. Geological Survey. Names shown in parentheses apply only in the subsurface. Compiled by E. A. Merewether after Sandberg (1962, fig. 6), Flint (1955), Harksen (this report), Mallory, ed. (1972), Gries (this report), and Geological Society of London (1964).

extends from South Dakota far into Canada. Its south end includes about one-third of the State, beginning east of the Black Hills and becoming wider and deeper to the north until the thickness from the surface to the Precambrian contact is about 10,000 feet at the North Dakota boundary. The northeast part of the State is quite different, for the top of the Precambrian basement has a gentle inclination and is at a much more shallow depth. To the south, in the region from Sioux Falls to near Pierre, the basement makes the Sioux Arch. Other subsurface arches, basins, and nearly flat areas are distributed along the south boundary of the State west of the Missouri River.

The foregoing summary of the geology will suffice for many users of this report. Others will need the greater detail in succeeding chapters, and still others will want to refer to the extensive literature, the most important parts of which are in the list of references.

For persons who need information on physiographic details, the best sources are the topographic quadrangle maps shown on figure 3. Much of the State has been mapped at a scale of 1:24,000 (2.64 inches to the mile). These maps are basic tools for many investigations in geologic, water, engineering and agricultural fields as well as in planning of many kinds. They may be purchased from the Distribution Section, U.S. Geological Survey, Federal Center, Denver, Colorado 80225, and may also be obtained from a few sources in the State that carry a small stock. An index map showing the names of all available maps is updated each year and issued free by the U.S. Geological Survey. Information on topographic work in progress can be obtained from the same source.

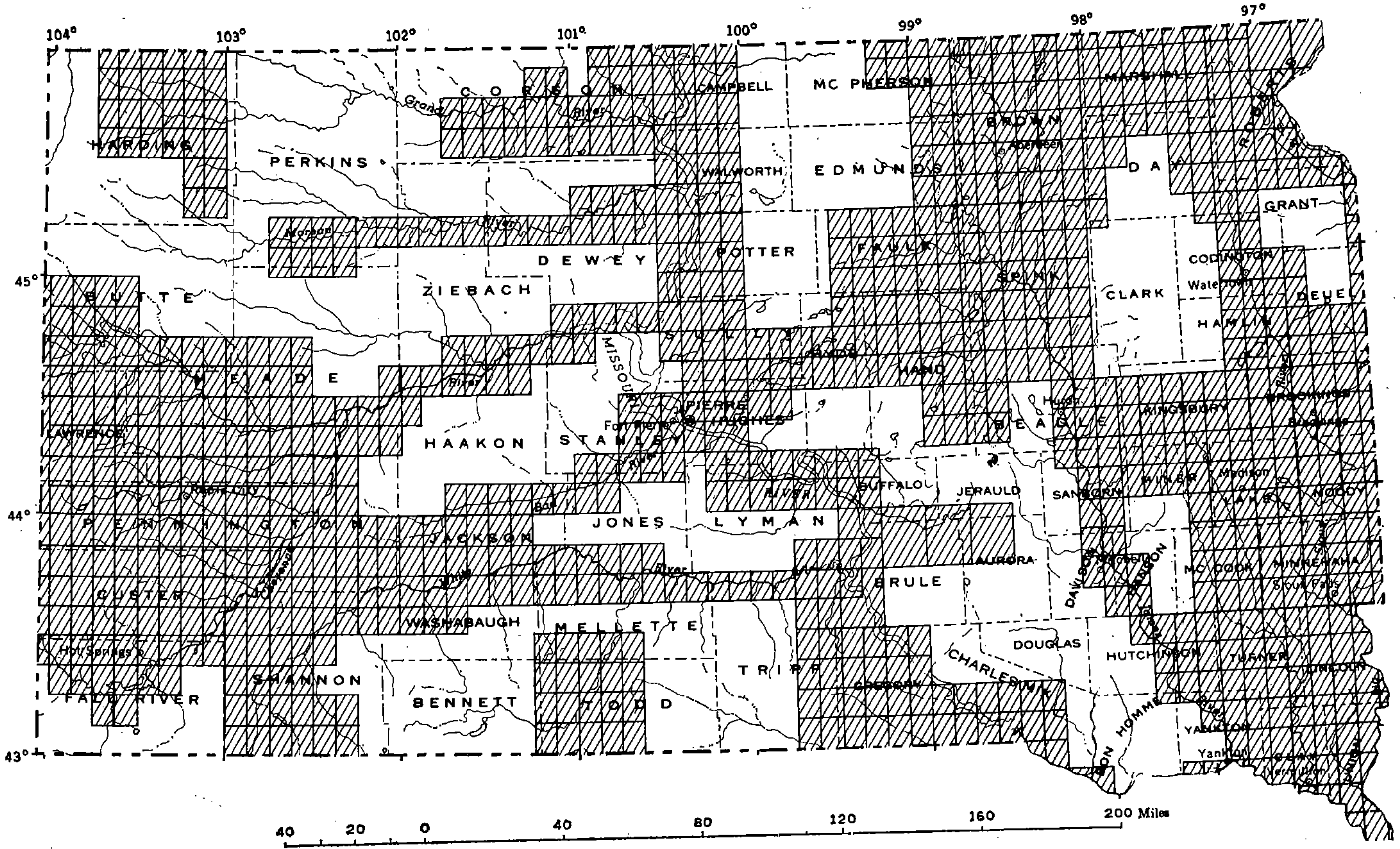


FIGURE 3.—Published topographic maps. All maps are at a scale of 1:24,000 except a few near Chamberlain and Pierre in the center of the state and some along the Wyoming border and at the northeast corner of the state. The entire state is covered by maps at a scale of 1:250,000.

Detailed geologic maps are less numerous, for they are more difficult and costly to make and thus center around localities of special interest. The outlines of areas mapped with considerable detail are shown in figure 4, and areas of somewhat more generalized coverage are recorded on figure 5. These maps are in many forms, some as single maps and some as parts of journal articles or more lengthy reports describing and interpreting the geology. They are issued by several organizations, though chiefly by the South Dakota and U.S. Geological Surveys. Most of them are available in the libraries of the University of South Dakota at Vermillion and of the South Dakota School of Mines and Technology at Rapid City. Information about how to find those that are difficult to trace down can be obtained from the same institutions or the U.S. Geological Survey, Reston, Va., or the U.S. Bureau of Mines liaison office in Rapid City.

PRECAMBRIAN GEOLOGY OF THE BLACK HILLS

(By J. A. Redden, South Dakota School of Mines and Technology and U.S. Geological Survey, Rapid City, S. Dak., and J. J. Norton, U.S. Geological Survey, Reston, Va.)

The Precambrian rocks forming the core of the Black Hills uplift consist largely of metamorphosed sedimentary rocks and lesser amounts of metabasalt and metagabbro. Two small areas of older granite have also been metamophosed, but the younger Harney Peak Granite has experienced little change. At least three and perhaps as many as six separate episodes of deformation and probably two metamorphic events have affected the rocks.

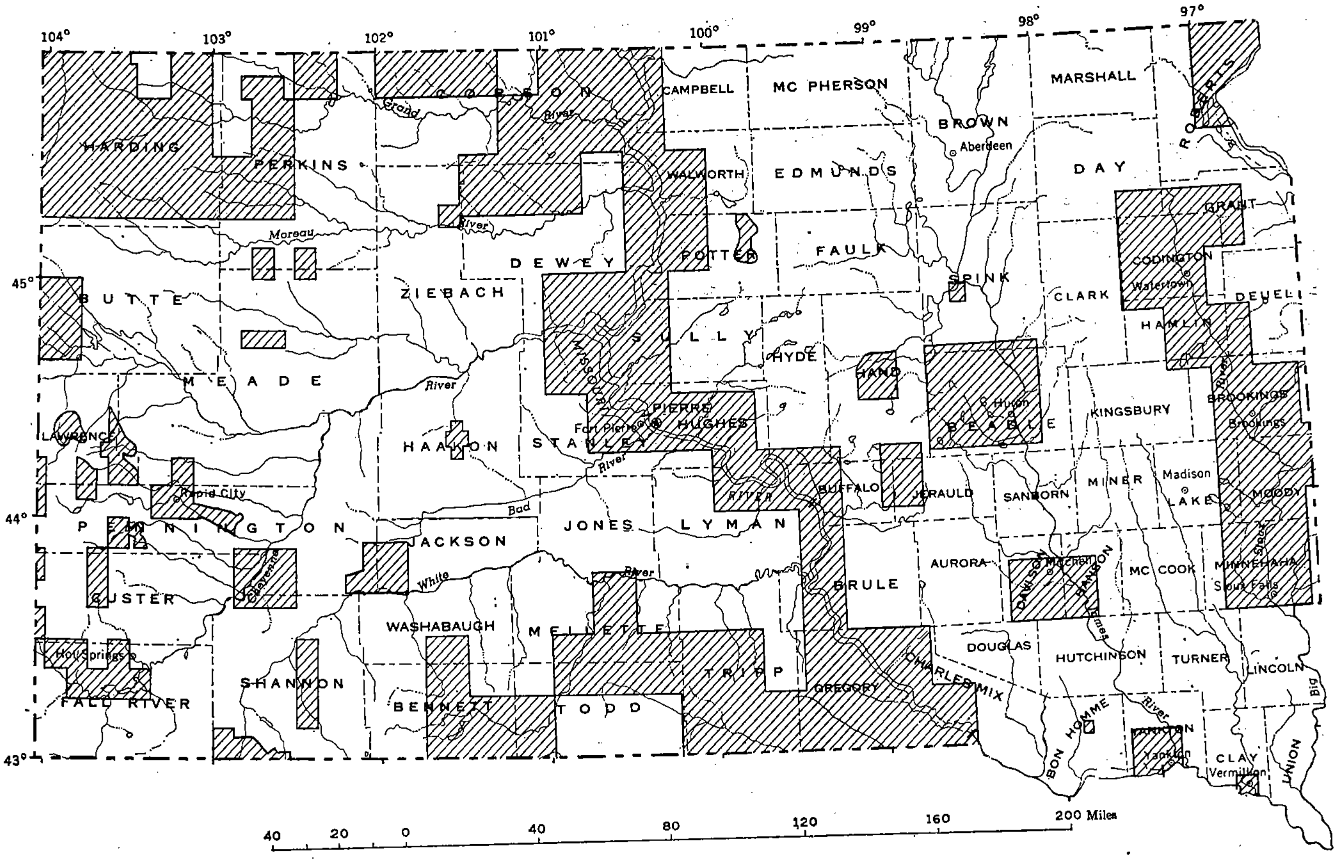


FIGURE 4.—Published geologic maps at scales larger than 1:63,360 (1 inch=1 mile).

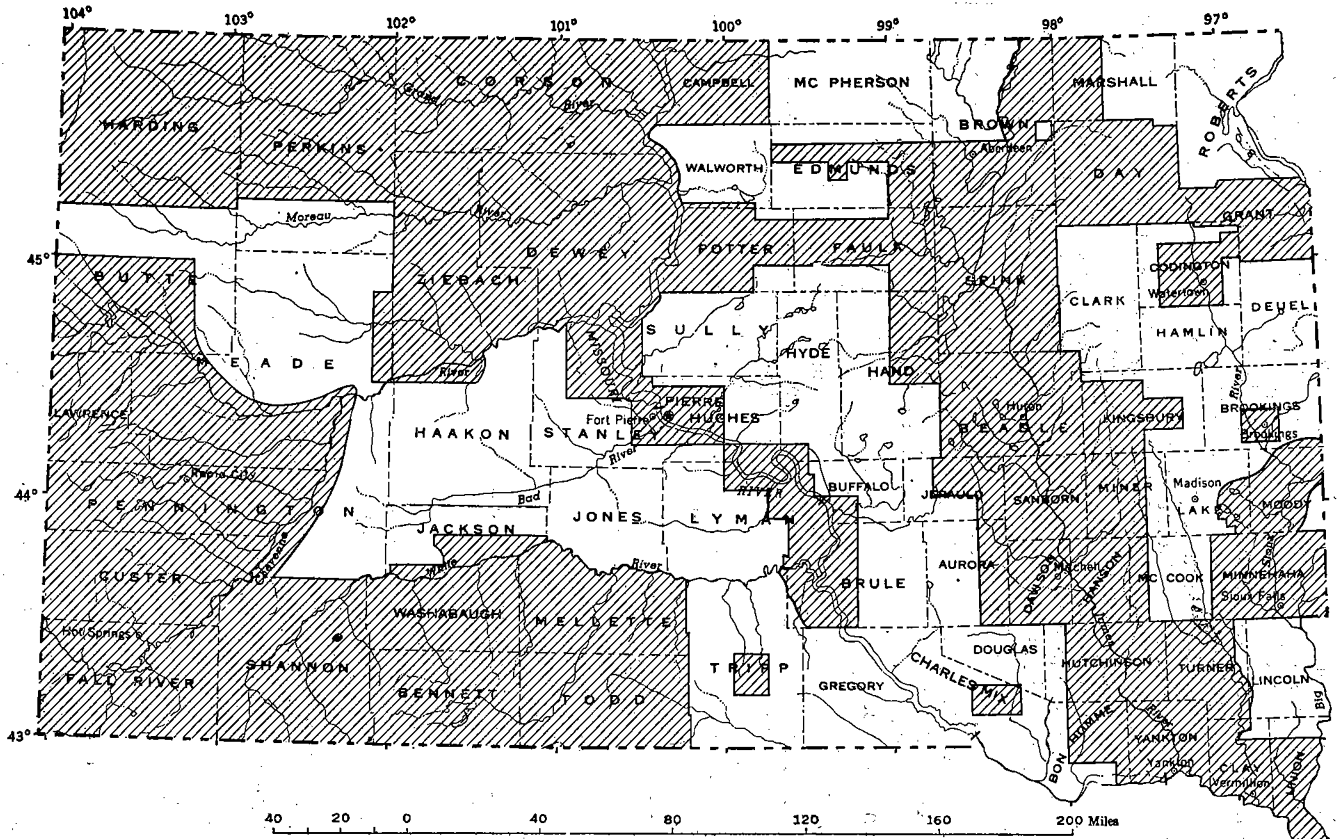


FIGURE 5.—Published geologic maps at scales of 1:63,360 to 1:250,000.

The region has been the object of a great number of investigations by many geologists over the past century. Nonetheless, critical problems remain unsolved or imperfectly understood, and whenever new detailed studies are made, new problems become recognized. The generalized geologic map of the Precambrian rocks presented in Figure 6 is the first summary compilation of its kind to have been prepared for the entire Black Hills area.

This review of the Precambrian geology is greatly compressed and generalized from the abundant information now available. The discussion and the map, although unavoidably somewhat technical, are presented to provide a framework for understanding the distribution of known mineral resources, and for use by those who are interested in searching for additional resources.

The map shows both the principal lithologic assemblages and the relative intensity of metamorphism that has affected the Precambrian rocks. Some assemblages are known to occur at more than one stratigraphic level but for others the evidence is unclear. Some metasedimentary rocks may have been deposited at the same time as rocks of a somewhat different kind, shown by a different pattern, that appear elsewhere on the map. Metamorphism causes no difficulty in identifying the rocks despite a wide range in metamorphic grade. The structure is too complex for strike and dip symbols, fold axes, and other structural symbols to be placed on a map of this scale. In short, figure 6 is not a complete stratigraphic and structural geologic map, but does show the main elements of the geology.

An open-filed map by Bayley (1972c) contains details of the entire area north of 44° latitude.[1] Other important sources of information about the northern Black Hills are Noble and Harder (1948) for the Lead-Deadwood area, Bayley (1972a) for the Rochford area, and Bayley (1972b) and Woo (1954) for the Nemo area. Published sources for the southern Black Hills are mainly Ratté and Wayland (1969) for the Hill City area and Redden (1963, 1968) for the region southwest and northwest of Custer. The principal unpublished information comes from Ratté north of Bear Mountain and from Norton and Redden throughout the region south and east of the Hill City area. In addition, Norton and Redden have at one time or another examined virtually all subdivisions of the Precambrian rocks of the Black Hills.

As the map indicates, the most common trend of metamorphic rock units and of faults is north to north-northwest. The dip is very steep or vertical through more than half of the region.

The chief exceptions to these generalizations are around bodies of granite where the surrounding metamorphic rocks dip outward to form domes. The largest dome is around the Harney Peak Granite, and smaller domes are on its flanks, generally around satellitic bodies of granite or in places where pegmatites are abundant. A second large dome, at Bear Mountain, is partially covered by Paleozoic rocks. Another dome, mostly covered by Paleozoic rocks, may exist around the granite north of Nemo.

The highest grade metamorphic rocks are in the sillimanite zone, which extends from just north and west of the Harney Peak Granite all the way to the south border of exposed Precambrian rocks. A small area south of Harney Peak has the so-called "high" or "second"

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[1] R. W. Bayley would have been a participant in writing this and the gold-silver sections of this report, but he unfortunately died November 1, 1974, after a lengthy illness.

sillimanite zone, in which the muscovite of the schists has virtually entirely changed to sillimanite. These rocks reflect the high temperatures prevailing before and during the emplacement of the Harney Peak Granite. The temperature dropped off to the north, where a staurolite zone occupies an area a few miles wide.

Farther north is a broad area belonging to the garnet zone, which extends from the Rochford region southeast to Rockerville. Probably the Tinton area is also in the garnet zone. Garnet has never been reported there, but the locality has zoned pegmatites, which the world over have rarely been found in rocks of less than garnet grade.

Northeast of the garnet isograd is a biotite zone extending from west of Lead southeast almost to Rockerville. These are the lowest grade metamorphic rocks of the Black Hills and indicate the lowest temperature. Whether they are products of the Harney Peak Granite episode or of some earlier metamorphism is as yet unknown.

Garnet reappears near Lead and can also be found elsewhere in the northern part of the region. A few localities near Deadwood have staurolite, indicating an increase in grade to the northeast beneath the Paleozoic cover.

The domes have brought the older metamorphic rocks to the surface. The very oldest, so far as now known, are biotite schists in the core of the Bear Mountain dome. These are intruded by small bodies of granite and pegmatite that have been dated at 2.5 billion years by Ratté and Zartman (1970). A probable unconformity at the top of these rocks is overlain by metamorphosed conglomerate, part of which has feldspar fragments apparently obtained from the granite. Rocks overlying the conglomerate include quartzite, mica schist, amphibole schist, and dolomitic marble. Rocks of the same kind, and presumably the same age, reappear to the east as inclusions in the very much younger Harney Peak Granite.

Another very ancient granite, of approximately the same age as that at Bear Mountain (Zartman and Stern, 1967), is the Little Elk Granite north of Nemo. This is a gneissic biotite granite with neither the pegmatitic character nor the low biotite content of the granite at Bear Mountain. The adjacent metamorphic rocks consist of quartzite and taconite, said by Bayley (1972b) to be younger than the granite despite the conclusion of Zartman and Stern (1967) that the relationships are unclear. Probably the quartzite-taconite unit has northeasterly trending folds formed before conglomerate adjacent to it was laid down, but more evidence needs to be obtained. The quartzite-taconite unit does not crop out anywhere else in the Black Hills, but magnetic surveys indicate it exists beneath Paleozoic rocks near Nemo.

The exceedingly conglomeratic unit that was the next to form contains fragments of both the quartzite and taconite but not of granite, though it has enough feldspar to be at least compatible with the supposition that it is younger than the Little Elk Granite. A very fine-grained dolomitic marble of structurally peculiar distribution (Bayley, 1972b) is associated with the conglomerate, and like the conglomerate has boulders of quartzite and taconite within it.

Probably all the rest of the metamorphic rocks of the Black Hills were formed later, either as sediments or as basalt flows or gabbroic intrusives, in the span of time between the 2.5 billion year old granites and the intrusion of the Harney Peak Granite, which Riley (1970) dated at 1.74 billion years. The geologic map separates these rocks into four lithologic assemblages. The metagraywacke and the mica schists accompanying it certainly occupy more than one stratigraphic position. The same may apply to the other three assemblages, though complex—not to say imaginative—combinations of folds, faults, and unconformities could be devised to make each of them a single stratigraphic unit. The total thickness of the four assemblages is at least 60,000 feet, even with the simplest possible interpretation of the stratigraphy (accompanied, of course, by the most complex interpretation of the structure). The largest and most common folds are tight to isoclinal structures of north-northwest trend. These are deformed by at least two sets of cross folds, nearly all of which are too small to show on the map. At Rochford, however, the peculiar pattern resembling an upside down T can at present be interpreted only as formed by an older set of folds, represented by the cap of the T, and a younger set having the regional north-northwest trend.

A very heterogeneous lithologic assemblage, extending from Lead to Rochford, is quite similar and is shown on the map as identical to an assemblage extending from Galena south to Keystone and onward past the Harney Peak Granite nearly to Pringle. The Tinton area is also tentatively placed in this unit, though on the basis of little evidence.

The predominant rock is a micaceous schist or phyllite. Amphibolite, some of it derived from basalt and some from gabbro, occurs in bodies ranging greatly in size, many of which are large enough to show separately on the map. Other rocks include clastic and cherty quartzite and iron-formation. Meteconglomerate appears in many localities near Keystone and has been found as far north as Nemo.

One of the units of iron-formation is the host rock of the gold deposits in the Homestake mine and hence is called the Homestake Formation. Below the garnet isograd it consists of iron-rich carbonate interlayered with cherty quartzite. Above the isograd the carbonate changes to cummingtonite.

Below the Homestake Formation is a carbonate-bearing phyllite called the Poorman Formation and above it is a mixture of quartzite and phyllite named the Ellison Formation. Next is phyllite and schist of the Northwestern Formation and then an unconformity on which was deposited a diverse assemblage of rocks, now called the Flag Rock Group (Bayley, 1972a), which includes phyllite or schist, metabasalt, iron-formation, and cherty quartzite. The Ellison, Northwestern, and Flag Rock are all exposed as far south as the Rochford area.

Despite uncertainty about whether these stratigraphic units are equivalent to the rocks in the belt south of Galena, the similarities are considerable. According to Bayley (1972b) a carbonate unit is the oldest, and it is followed by a quartzitic unit with iron-formation near its base, then a slate, and finally units resembling the Flag Rock Group. Farther south, at Keystone, is a mixture of schist, clastic and cherty quartzites, iron-formation, conglomerate, and amphibolite that may all belong to the Flag Rock Group, though if so there are changes along strike. Perhaps the older units of the Lead stratigraphic sequence have been wiped out at an unconformity.

Near Lead the youngest unit is the phyllitic Grizzly Formation. This extends southward to occupy a large area around Rochford. As the metamorphic grade increases, a distinctive thin-bedded biotite-garnet schist becomes prominent. It has been traced all the way to the Paleozoic contact at Pringle. The biotite-garnet schist is the most prominent phase of what Ratté and Wayland (1969) named the Oreville Formation at Hill City. Other constitutents of the Oreville Formation are muscovite-rich schists and metagraywacke, some of which are shown separately on figure 6 to outline the structure.

Southeast of Lead, near Roubaix, metagraywacke is abundant. It and mica schists and phyllites that accompany it predominate in a belt that extends south to Custer. Similar rocks spread over most of the area west of the fault that passes through Custer, where the details of the structure and stratigraphy have been worked out by Redden (1963, 1968). Metagraywacke and schist are also the most abundant rocks between the Harney Peak Granite and Rockerville, and a smaller body of metagraywacke is northwest of Rochford. Clearly, the metagraywacke is of several ages. Most, but not necessarily all, of it is younger than the rocks at Lead. Otherwise the questions and possible answers about its stratigraphic relationships are too complex and speculative to discuss here.

South of the Harney Peak Granite is a large area of clastic quartzite interbedded with sillimanite schist. The structural and stratigraphic relationships with adjoining rocks are puzzling. Because the underlying rocks change from place to place along the contact, an unconformity seems plausible, though faults may also be present. Conclusive proof is lacking to show that this is the youngest metasedimentary unit in the Black Hills, but any alternative is difficult to explain

Very similar rock is exposed along the Paleozoic contact east of Pactola Dam except that it lacks sillimanite because the metamorphic grade is too low. No surmise about why it is there or whether it is of the same age as the rocks to the south seems worth offering. Bayley (1972c) shows the same kind of rock to the northwest and labels it Ellison Formation. We agree that the northwestward exposures do have affinities to the section at Lead, and show it in this way on figure 6, but choose, at least for the present, to indicate that a part of the quartzite-rich rocks may be quite unrelated.

A long history of folding, faulting, and metamorphism preceded the emplacement of the Harney Peak Granite, which is the youngest Precambrian rock. Though shown on the map as consisting of one large and only a few small bodies, it actually includes many thousands of sills and dikes scattered throughout the southern Black Hills, as indicated in some detail on figure 21. Even the main body of granite is not a single intrusion but a cluster of a great many lesser intrusions. Most of the granite is in large sills, which follow the domal pattern, but the sills send out dikes into adjoining rock and there also are large vertical dikes with sills as offshoots. About 20 percent of the area outlined as granite actually consists of remnants of the country rock.

The principal minerals of the granite are albite, quartz, perthitic microcline, and muscovite. The chief dark accessory minerals are biotite, tourmaline, and garnet. The granite has a decided pegmatitic aspect caused mainly by large crystals of microcline, which can be several feet long. Planar bodies of coarser grained material are interspersed in finer grained albite-rich granite to give the rock a rude layering. The layers are approximately parallel to the nearest contact of the sill or dike. A less common but more easily observed planar structure results from the alternation of layers, generally less than an inch thick, of various combinations of fine grained minerals. Still a third structure, having a resemblance to layering, results where many closely spaced dikes cut a larger body of granite.

Most of the granite has primary muscovite as its only highly aluminous mineral, but some contains sillimanite as a primary mineral and some has pseudomorphs of sillimanite after muscovite. These circumstances imply that some of the granite crystallized before the peak of metamorphism, some during the peak, but most shortly thereafter.

The great thickness of the metamorphic rocks and inferences from certain aspects of the metamorphism and the geology of the pegmatites indicate that the Harney Peak Granite was formed at a great depth in the earth's crust. A good guess might be 10 miles.

No subsequent Precambrian events are recorded in the exposed rocks for the very long period between about 1.7 billion years ago, when the Harney Peak Granite formed, and about 500 million years ago in late Cambrian time, when the Deadwood Formation was deposited on the floor of an invading sea. Obviously a very great thickness of rock was removed by erosion during this period, probably for the most part at times when the country was mountainous. The erosion seemingly took place mostly before deposition of the Sioux Quartzite, which is probably about 1.2 billion years old (Steece, this report). The Sioux Quartzite is flat lying and presumably a marine deposit, thus implying that the surrounding areas were not far above sea level. The nearest Sioux Quartzite is only 110 miles from the Black Hills, but in the light of what is now known about the possibility of large movements of segments of the earth's crust, one must allow for the possibility that it was not near the Black Hills when it formed.

All of the Black Hills Precambrian rocks were weathered to a surface of low relief before the encroachment of the Deadwood sea. The climate just before Deadwood deposition was quite unlike the present environment, for chemical weathering was pronounced. Kaolinite developed from feldspar in granite and pegmatite at depths of 100 feet or more below the ancient surface, and both sulfides and iron silicates in metamorphic rocks were extensively oxidized. Areas of iron oxides occur in iron-formation several miles away from the nearest Deadwood outcrop, but they apparently were only a short distance beneath the surface in Deadwood time. Some of the higher peaks, such as Harney Peak, may never have been covered by Deadwood sediments. Except for the few places were local relief is now 1000 feet or more, not much Precambrian rock seems to have been eroded away since it was exhumed after the early Tertiary uplift that formed the Black Hills.

PRECAMBRIAN ROCKS OUTSIDE THE BLACK HILLS

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

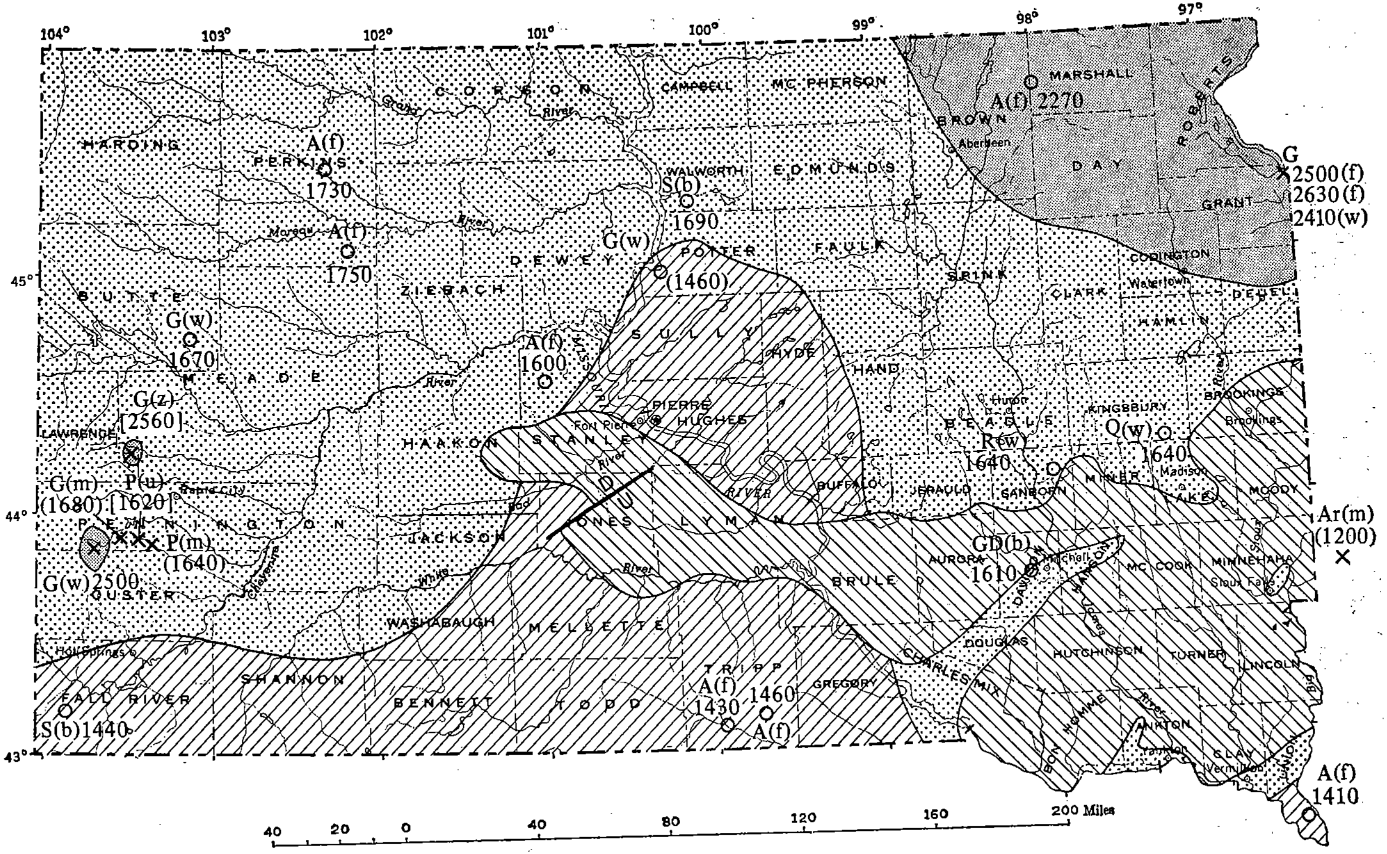
The Precambrian basement of South Dakota is undoubtedly exceedingly complex, containing a wide variety of kinds of rock with many different structures about which relatively little is known because most of the basement is concealed by younger sedimentary rocks. Precambrian rocks exposed in the Black Hills are described in the previous section of this report. Otherwise the only Precambrian exposures are of the Sioux Quartzite in the southeast part of the State and a small area with granite near Milbank, Grant County, in the northeast corner of the State.

Four major age groups of rocks are outlined on figure 7. This map, based on widely scattered data points, is undoubtedly correct in a general way even though it surely has major shortcomings in detail. The oldest rocks are at two localities in the Black Hills and in the northeast corner of the State, where granites are generally about 2,500 million years old. In the next group, ages are mostly at 1,600 to 1,700 million years, obtained from granitic rocks and schist. This period of time corresponds to an event that Goldich and others (1966) called the Black Hills orogeny. The rocks involved seem to underlie most of the western part of the State and to extend east to the Minnesota border.

Another age group, represented by only five dated rocks, falls in the remarkably narrow range of 1410 to 1460 million years. It consists of gneiss and schist collected from the extreme southwest to the extreme southeast corner of the State.

The youngest rocks of Precambrian age are in the Sioux Quartzite, which is a 5000-foot thick sequence consisting chiefly of quartzite but containing a thin basal conglomerate, argillite, and pyrophyllite. Goldich and others (1961) dated the rock at approximately 1200 million years by the K-Ar method, but suggest the date may be the time of deformation rather than of deposition. Nonetheless, the Sioux Quartzite obviously postdates all other Precambrian rocks in the State. At one time (Steece, 1964), exotic rocks occurring within the area of Sioux Quartzite were thought to be windows in the quartzite through which the other rock showed. The present interpretation (fig. 7) shows the quartzite to have a much more irregular outline than on any previous map of the State's basement rocks and it changes what earlier were regarded as windows to re-entrants or "canyons" in the quartzite. The one exception is a window exposing gabbro in Minnehaha County.

No attempt is made in this report to prepare a paleogeologic map. Several interpretations are available for the interested readers. See, for example, Steece (1964) and Lidiak (1971).


104°
103°
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HARDING
PERKINS
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CAMPBELL
MC PHERSON
BROWN
MARSHALL
ROBERTS
DAY
GRANT
CODINGTON
DEUEL
WALWORTH
EDMUNDS
POTTER
FAULK
SPINK
CLARK
HAMLIN
BUTTE
DEWEY
ZIEBACH
SULLY
HYDE
HAND
BEADLE
KINGSBURY
BROOKINGS
MEADE
LAWRENCE
PENNINGTON
HAAKON
STANLEY
HUGHES
BUFFALO
JERAULD
SANBORN
MINER
LAKE
MOODY
JACKSON
JONES
LYMAN
AURORA
DAVISON
HANSON
MC COOK
MINNEHAHA
CUSTER
WASHABAUGH
MELLETTE
BRULE
DOUGLAS
HUTCHINSON
TURNER
LINCOLN
FALL RIVER
SHANNON
BENNETT
TODD
TRIPP
GREGORY
CHARLES MIX
BON HOMME
YANKTON
CLAY
UNION
Aberdeen
Watertown
Huron
Brookings
Madison
Pierre
Fort Pierre
Rapid City
Mitchell
Sioux Falls
Hot Springs
Yankton
Vermillion
Grand River
Moreau River
Cheyenne
White River
Bad
James River
Sioux River
Big Sioux
Missouri River
A(f) 2270
G
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2410(w)
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G(m) P(u)
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1410
40 20 0 40 80 120 160 200 Miles

EXPLANATION

Age groups of dated rocks

▩ Approximately 2.5 billion years old

░ Approximately 1.7 billion years old

▨ Approximately 1.4 billion years old

▧ Approximately 1.2 billion years old

$\frac{U}{D}$ Fault; D, downthrown side; U, upthrown side

○ Well

× Outcrop

1730 Rb-Sr age of rock in millions of years

(1640) K-Ar age of rock in millions of years (omitted where Rb-Sr or U-Pb age is available)

[2560] U-Pb or Pb-Pb age of rock in millions of years

Rock types:

Ar–Argillite
R–Rhyolite porphyry
A–Adamellite
G–Gneiss
P–Pegmatite
S–Schist
Q–Quartz latite
GD–Granodiorite

Minerals dated:

(m)–Muscovite
(f)–Feldspar
(w)–Whole rock
(u)–Uraninite
(b)–Biotite
(z)–Zircon

(Dates from Aldrich and others, 1958; Eckelman and Kulp, 1957; Goldich and others, 1961; Goldich and others, 1966; Ratté and Zartman, 1970; Zartman and Stern, 1967.)

FIGURE 7.—Distribution of major age groups of Precambrian rocks.

Not only is there a wide variation of rock types and a wide range in ages of rocks in the State's Precambrian basement, but there is also a wide variation in the surface configuration shown on Figure 8. The Sioux Quartzite has a more intricately carved surface than the remainder of the basement. The appearance that this is true may be partly because more holes ending in Precambrian rocks have been drilled in the southeast quadrant of the State than elsewhere, but nonetheless the Sioux Quartzite has stood as a ridge throughout a large share of post-Precambrian time and thus has been subjected to intensive weathering and erosion. Parts of the quartzite have 1000-foot escarpments preserved above older surrounding rocks. An example might be the fault (Steece, 1961) cutting the quartzite near its terminus in Jones County (fig. 7); other faults probably also cut the quartzite.

The Precambrian surface in the southwest part of the State has an undulatory form where folds are associated with the formation of the Chadron Arch, the northern terminus of which is in this region. This structure probably is of the same age as the Black Hills uplift. Although no dates have been determined on basement rocks on this arch in South Dakota, a date of 1620 million years shown in northwest Nebraska by Goldich and others (1966, fig. 1) may date the basement under the Chadron Arch.

The remainder of the basement surface seems to have been relatively flat before the formation of the Williston Basin. From the bottom of this basin the surface gradually rises toward the Black Hills on the west, the margin of the Williston Basin on the south, and the Sioux Quartzite and the smooth terrain on the east. The maximum relief on the basement is nearly 14,000 feet between the depths of the Williston Basin and the highest peaks in the Black Hills.

PALEOZOIC ROCKS

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

The sequence of Paleozoic sedimentary rocks is most nearly complete in western South Dakota. The area of the Black Hills was near the eastern shoreline of the great Paleozoic seaway of the Rocky Mountain area, and on the southwestern flank of the Williston sedimentary basin which extends north and west from the Dakotas into Canada. Individual sedimentary units are generally much thinner near the shoreline and thicken towards the center of the basin. Several rock units present in the South Dakota part of the Williston Basin pinch out before reaching the Black Hills outcrop area. No strata of Paleozoic age are known over much of the eastern part of the State, where any rocks of this age that may have been deposited have subsequently been removed by erosion.

Cambrian

In late Cambrian time the first of the Paleozoic seas advanced over a surface of low relief developed on deeply weathered and weak schists interrupted by cliffs and ridges of quartzite and other resistant

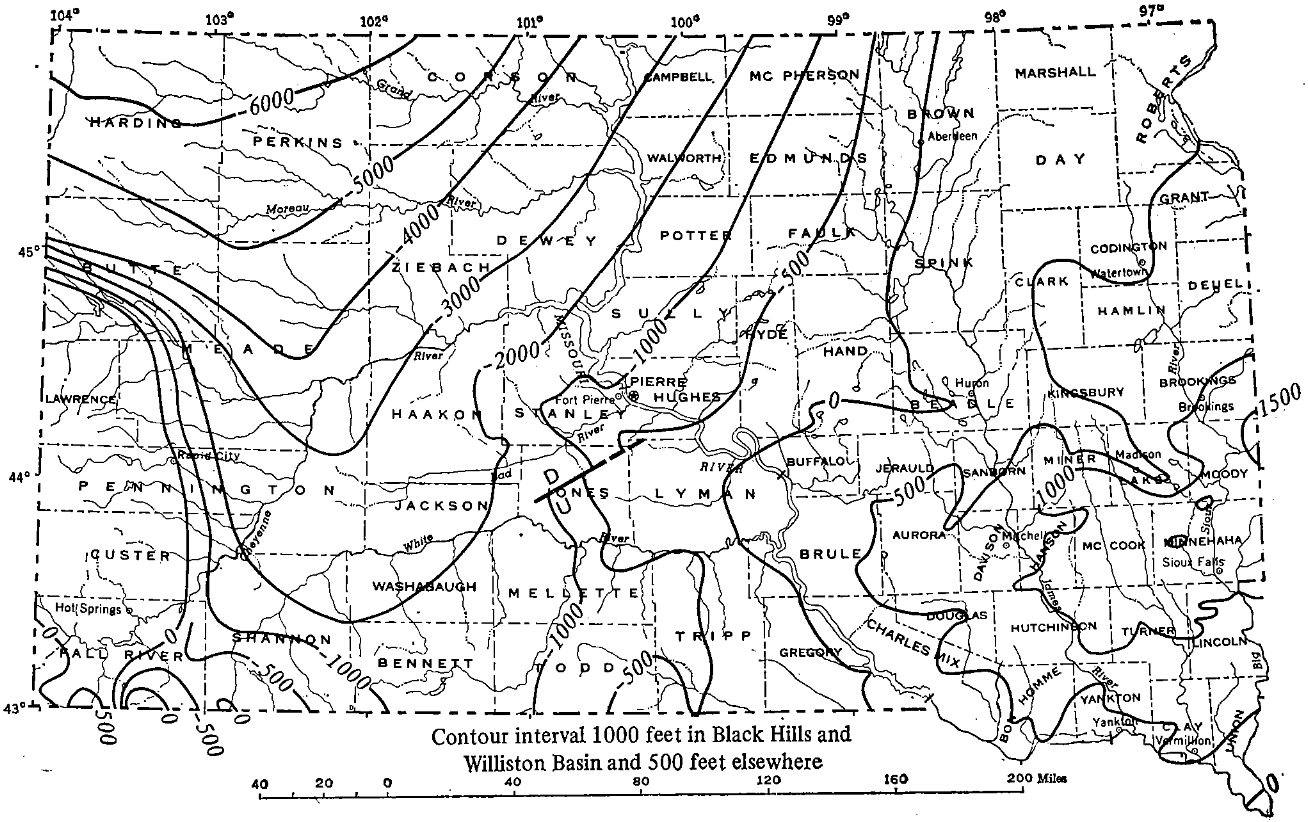
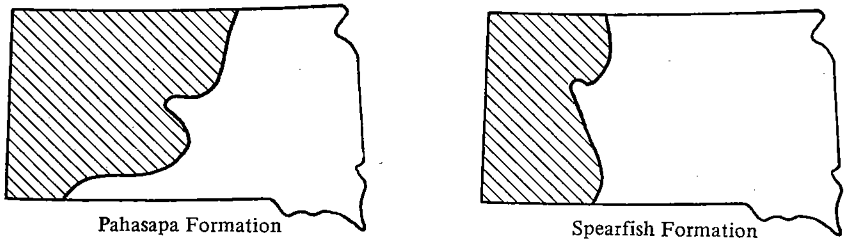


FIGURE 8.—Configuration of the top of Precambrian rocks. Datum is sea level. Fault displacing basement shown in Jones County: D, downthrown side; U, upthrown side. Modified from Steece, 1964.

rocks. The total relief of the old Precambrian erosion surface appears to have been no more than 100 feet in the Black Hills outcrop area. A relief of 600 feet or more over short distances is known from drilling around the Sioux Quartzite ridge in central South Dakota.

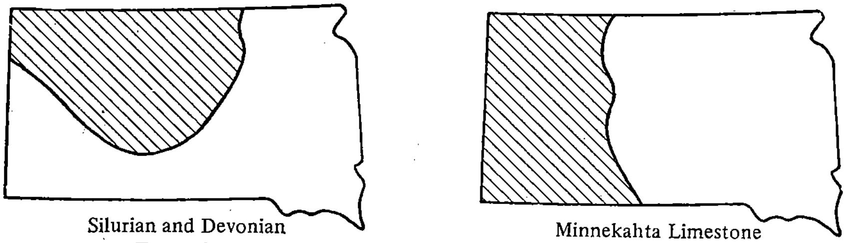
The only Cambrian unit is the Deadwood Formation, which consists of sandstone, greenish-gray shale, and carbonate rocks. A few feet of pebble conglomerate locally underlie the basal quartzitic sandstone. Limestone and dolomite intraformational conglomerates are conspicuous in the middle of the formation and glauconite and hematite are abundant accessory minerals. The Deadwood represents near-shore deposition by a generally retreating sea which covered the area in late Cambrian and very early Ordovician time. On the outcrop, the thickness ranges from as little as 5 feet in some exposures near Wind Cave to about 400 feet in the type section at Deadwood. The formation underlies the northwestern half of the state. It thins from about 600 feet in the northwestern part of Harding County to zero along a line extending southwestward from Brown to Fall River County (fig. 9).

In the northern Black Hills, a thin carbonate zone just above the basal quartzite and conglomerate was called the "lower contact" by early day miners, and the term has continued in use. A similar carbonate bed a few feet below the so-called *Scolithus* sandstone at the top of the Deadwood is called the "upper contact." Tertiary ore-bearing solutions, rising along vertical fractures, locally replaced these carbonates, resulting in the formation of gold, silver, lead, zinc, and tungsten deposits of the northern Hills. Bodies of coarse, clean sandstone, considered to be beach and bar deposits, have been mined for silica sand in the southern Hills, and are useful aquifers downdip from the outcrop.



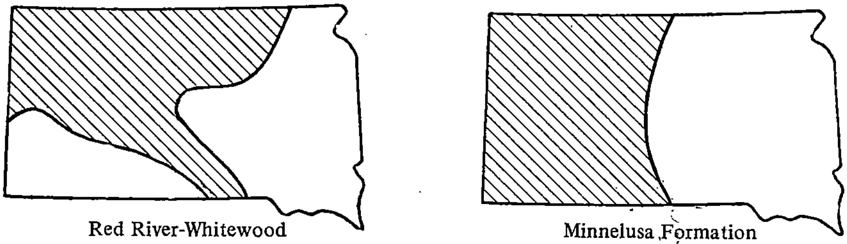
Pahasapa Formation
(Madison Group, Mississippian)

Spearfish Formation
(Permo-Triassic)



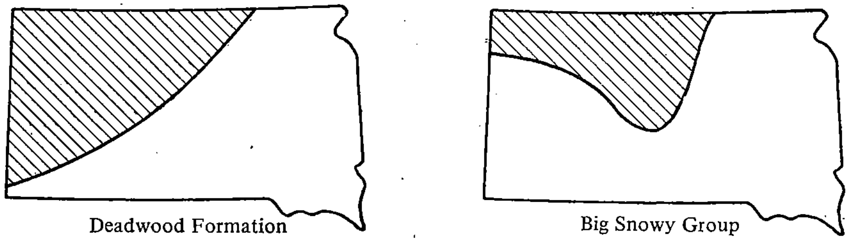
Silurian and Devonian
Formations

Minnekahta Limestone
(Permian)



Red River-Whitewood
Formation (Ordovician)

Minnelusa Formation
(Pennsylvanian and Permian)



Deadwood Formation
(Cambrian)

Big Snowy Group
(Upper Mississippian)

NOTE: Areas in Black Hills from which Paleozoic rocks have been eroded away are not shown.

FIGURE 9.—Distribution of Paleozoic rocks.

Ordovician

Winnipeg Formation. In the northern Black Hills, 40 to 60 feet of fissile green shale overlie the *Scolithus* sandstone. This shale was formerly regarded as part of the Deadwood Formation, but was separated from it when microfossils indicated a middle Ordovician age. It is now called the Icebox Shale Member and correlated with the Winnipeg Formation of the Williston Basin. The only exposures are in the northern third of the Hills outcrop area, for it has been removed to the south by pre-Mississippian erosion. It thickens northeastward and exceeds 120 feet in the north central part of the State.

Lying with very slight unconformity upon the Icebox Member, and grading upward into the overlying Whitewood Dolomite, is the Roughlock Member, which consists of 40 to 80 feet of clastic material that changes laterally from a silty clay to a siltstone, and even to a clean, fine, white sandstone. It is coextensive with the Whitewood Dolomite. Whether the Roughlock should be considered a member of the Winnipeg Formation or merely an introductory phase of Whitewood deposition is not certain.

Whitewood Dolomite.—The Whitewood Dolomite crops out only in the northern Hills, where it is at the southeastern edge of a widespread blanket of Upper Ordovician dolomite known as the Bighorn Group in Wyoming and Montana and the Red River Formation in the Williston Basin. It reaches a maximum thickness of 60 to 80 feet in outcrops in the vincinity of Deadwood and Spearfish Canyon, but thickens northeastward into the Williston Basin to about 600 feet in Corson County. The rock has a characteristic mottled appearance, and weathers to rough, pitted surfaces.

Early settlers used the Whitewood as a building stone and burned it for lime. It is a potential source of commercial dolomite. Porous zones within the upper part of the formation contain commercial accumulations of oil in Harding County.

Silurian and Devonian

Carbonate and some clastic rocks, representing the southern edge of widespread very late Ordovician (?), Silurian, and Devonian deposition in the Williston Basin, underlie counties in the northwest and north central part of South Dakota. They feather out to zero by erosion to the south and before they reach the Black Hills outcrop area to the southwest. The rocks, which are primarily middle Silurian (Interlake Group) and Upper Devonian (Souris River, Duperow, Bird Bear, and Three Forks Formations), attain a maximum thickness of at least 600 feet in Corson County.

Mississippian

Englewood Formation.—A red to lavender argillaceous dolomite, ranging in thickness from 40 to 70 feet, constitutes the Englewood Formation. Where this is thickest, as near Deadwood, the basal 20 to 30 feet are gray to faintly purple shale. Microfossils (conodonts) indicate that its age straddles the Devonian-Mississippian boundary. It rests on the Whitewood Dolomite in the northern Hills, and directly upon the Deadwood Formation in the southern Hills, where the basal few feet of the formation may be very sandy. The Englewood grades upward without discernible stratigraphic break into the overlying Pahasapa Limestone, with which it is coextensive.

Pahasapa Limestone (Madison Group).—Pahasapa Limestone is the local name for the Black Hills outcrops of the widespread Madison Group of the northern Rocky Mountain and Great Plains region. In the outcrop area it is largely dolomite, but it contains more limestone and some beds of anhydrite toward the center of the Williston Basin. The formation thins from 600 feet in Spearfish Canyon to less than 300 feet in some of the southern Hills outcrops, and it is entirely missing in the subsurface a short distance southeast of the Hills. Within the State, it reaches a maximum thickness of 1300 feet in Harding County, and thins by erosion to zero along a line extending from McPherson County in the northeast to Fall River County in the southwest.

The Pahasapa rests on rocks of all ages from Precambrian to Devonian. Following deposition of the Pahasapa, a karst topography, characterized by sinkholes, caverns, and collapse structures, was developed on its upper surface. The overlying beds are red clays and shales of Upper Mississippian and Pennsylvanian age.

The formation is mined in the Black Hills for various rock products, and is a potential source of both limestone and dolomite. Due in part to its cavernous nature, the formation is an excellent aquifer in western South Dakota and in Wyoming. It has local oil accumulations in the northern Rocky Mountain and Great Plains regions. In the Black Hills, caverns in this formation are important tourist attractions.

Big Snowy Group.—Well bedded red shales and thin carbonate rocks lie between the top of the Mississippian carbonate and the base of the detrital red shales of the Minnelusa Formation in the subsurface of northwest and north central South Dakota. These are almost certainly in the Big Snowy Group of Chesterian age, but the relation between this red section and the lower red members (Fairbank and Reclamation) of the Minnelusa Formation in Nebraska has not been established.

Pennsylvanian and Permian

Minnelusa Formation.—The Minnelusa Formation is the only unit containing Pennsylvania rocks in South Dakota. It consists of alternating beds of sandstone and dolomite, with lesser amounts of red and black shale and chert. The outcrop thickness ranges from 500 to 700 feet. Numerous beds of anhydrite, which thicken the formation in the subsurface, are missing on the outcrop except just across the Wyoming line in Crook County. The Minnelusa underlies the western half of the State, and reaches its greatest thickness of nearly 1400 feet in the extreme southwestern corner of the State.

The formation is divided into upper and lower units by a red shale marker bed, probably a weathered zone that marks an erosional break between Pennsylvanian and Permian time. The Pennsylvanian unit consists of a basal red shale overlying the karst surface of the Pahasapa and an upper sequence of dolomites, black radioactive shales, anhydrite, and thin sandstones. The sandstones yield oil in the Barker Dome field in Custer County. The Permian segment also consists of two units, a lower one of dolomite, anhydrite and sandstone, and an upper sandstone with thin dolomites near the middle and often a cap of very cherty dolomite. This sandstone is an excellent aquifer near the outcrop, and contains oil accumulations in the Powder River Basin in Wyoming.

Opeche Shale.—The Opeche Shale consists of 85 to 125 feet of red silty shale and fine red sand, commonly with thin discontinuous beds of gypsum or anhydrite. Traces of rounded quartz grains and pebbles of dolomite and chert in the basal few feet of the Opeche indicate a break in deposition between the Minnelusa and Opeche formations.

Minnekahta Limestone.—The Minnekahta Limestone is 35 to 40 feet thick, gray to purple, and thin-bedded. Because it lies between two shale units, its typical topographic expression is a low, tree-covered escarpment, cut by steep walled canyons. Four lithologic units can generally be identified. These are (a) a lower brick red shaly unit with up to 60 percent silt and clay, (b) a lower pure limestone zone with very little insoluble residue, (c) an upper shaly zone that weathers to thin slabs and contains up to 10 percent insoluble clay and silt, and (d) an upper unit of nearly pure limestone.

The Minnekahta is the principal source of crushed rock, ballast, riprap and building stone, and it is the most widely used raw material for manufacture of portland cement and lime. Selective mining of the uppermost member yields a particularly high-calcium rock.

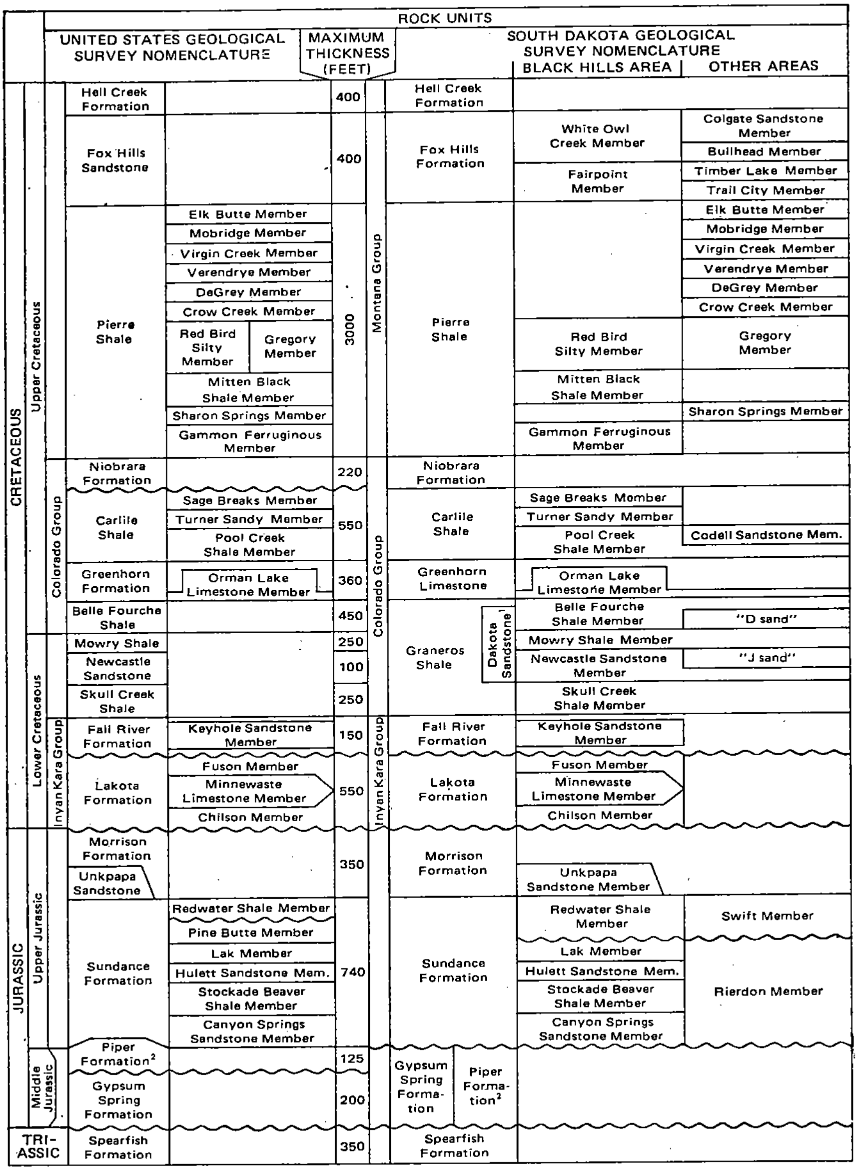
Spearfish Formation.—The Spearfish Formation extends from the Permian into the Triassic according to evidence from Wyoming, but the absence of fossils prevents pinpointing the boundary in South Dakota. Probably the dividing line is near the middle of the formation. Though the Spearfish extends over the western one-third of South Dakota, the only outcrops are at the edge of the Black Hills, where its low resistance to erosion causes it to form the prominent "Red Valley" or "Racetrack" lying within the encircling Cretaceous sandstone hogbacks. The rocks are mainly red beds of siltstone, sandstone, and shale, but also include beds of gypsum. Rock salt is prominent in the subsurface in Harding and Butte Counties. The thickness ranges from about 275 feet at outcrops in the southern Black Hills to about 700 feet on the northwest flank.

MESOZOIC ROCKS

(By E. A. Merewether, U.S. Geological Survey, Denver, Colo.)

The sedimentary rocks of Mesozoic age in South Dakota (fig. 10) consist mainly of interbedded shale, sandstone, and limestone in a sequence as much as 8,000 feet thick. They were laid down from 65 million to 225 million years ago in the Triassic, Jurassic, and Cretaceous Periods, which are commonly known as the age of dinosaurs. The most widespread and thickest formation, the Pierre shale is a dark gray shale that is at the surface over a very large share of the State (fig. 1) and is a conspicuous feature of the prairie landscape. Most of the Mesozoic rocks were deposited within or near large seas that changed in size and outline through time (Mallory, 1972). Periods of deposition, represented by the sedimentary rocks, were separated by times of erosion or nondeposition, as shown by unconformable contacts between certain formations or members.

The lowest Mesozoic beds, which are in the Spearfish Formation of Permian and Triassic age, are gradational with the underlying beds of Paleozoic age. Similarly, there is little apparent difference between the uppermost Mesozoic rocks in the Cretaceous Hell Creek



System	Series	Group	United States Geological Survey Nomenclature: Formation	United States Geological Survey Nomenclature: Member	Maximum Thickness (Feet)	Group	South Dakota Geological Survey Nomenclature: Formation	South Dakota Geological Survey Nomenclature: Black Hills Area	South Dakota Geological Survey Nomenclature: Other Areas
CRETACEOUS	Upper Cretaceous		Hell Creek Formation		400	Montana Group	Hell Creek Formation		
			Fox Hills Sandstone		400		Fox Hills Formation	White Owl Creek Member	Colgate Sandstone Member
									Bullhead Member
								Fairpoint Member	Timber Lake Member
									Trail City Member
			Pierre Shale	Elk Butte Member	3000		Pierre Shale		Elk Butte Member
				Mobridge Member					Mobridge Member
				Virgin Creek Member					Virgin Creek Member
				Verendrye Member					Verendrye Member
				DeGrey Member					DeGrey Member
				Crow Creek Member					Crow Creek Member
				Red Bird Silty Member Gregory Member				Red Bird Silty Member	Gregory Member
				Mitten Black Shale Member				Mitten Black Shale Member	
				Sharon Springs Member					Sharon Springs Member
				Gammon Ferruginous Member				Gammon Ferruginous Member	
		Colorado Group	Niobrara Formation		220	Colorado Group	Niobrara Formation		
			Carlile Shale	Sage Breaks Member	550		Carlile Shale	Sage Breaks Member	
				Turner Sandy Member				Turner Sandy Member	
				Pool Creek Shale Member				Pool Creek Shale Member	Codell Sandstone Mem.
			Greenhorn Formation	Orman Lake Limestone Member	360		Greenhorn Limestone	Orman Lake Limestone Member	
			Belle Fourche Shale		450		Graneros Shale Dakota Sandstone[1]	Belle Fourche Shale Member	"D sand"
	Lower Cretaceous		Mowry Shale		250			Mowry Shale Member	
			Newcastle Sandstone		100			Newcastle Sandstone Member	"J sand"
			Skull Creek Shale		250			Skull Creek Shale Member	
		Inyan Kara Group	Fall River Formation	Keyhole Sandstone Member	150	Inyan Kara Group	Fall River Formation	Keyhole Sandstone Member	
			Lakota Formation	Fuson Member	550		Lakota Formation	Fuson Member	
				Minnewaste Limestone Member				Minnewaste Limestone Member	
				Chilson Member				Chilson Member	
JURASSIC	Upper Jurassic		Morrison Formation		350		Morrison Formation		
			Unkpapa Sandstone					Unkpapa Sandstone Member	
			Sundance Formation	Redwater Shale Member	740		Sundance Formation	Redwater Shale Member	Swift Member
				Pine Butte Member					
				Lak Member				Lak Member	Rierdon Member
				Hulett Sandstone Mem.				Hulett Sandstone Mem.	
				Stockade Beaver Shale Member				Stockade Beaver Shale Member	
				Canyon Springs Sandstone Member				Canyon Springs Sandstone Member	
	Middle Jurassic		Piper Formation[2]		125		Gypsum Spring Formation Piper Formation[2]		
			Gypsum Spring Formation		200				
TRIASSIC			Spearfish Formation		350		Spearfish Formation		

[1] Recognized in eastern South Dakota

[2] Recognized in northwestern South Dakota

FIGURE 10.—Stratigraphic nomenclature of Mesozoic rocks.

Formation and the lowermost strata of Cenozoic age, in the Paleocene Ludlow Formation.

Triassic

Early and Middle (?) Triassic time is represented by the upper part of the Spearfish Formation, a sequence mainly of red sandstone, siltstone and shale. In wells in the northwestern part of the State the upper Spearfish is as much as 350 feet thick (McKee and others, 1959, pl. 3). Thickening of the formation from east to west indicates that it may have been deposited on a westward-slopping mud flat along the eastern shore of an inland sea. During Late Triassic time, South Dakota was probably a source area for sediments that were accumulating in Wyoming.

Jurassic

Gypsum Spring Formation.—The Early Jurassic was probably a period of erosion in South Dakota. The Middle Jurassic Gypsum Spring Formation lies unconformably over the Spearfish Formation. The Gypsum Spring occurs only in the northwestern part of the State and grows progressively thicker in a northerly direction. At outcrops on the east side of the Black Hills, the Gypsum Spring consists of interbedded gypsum, maroon siltstone, and shale, and is as much as 40 feet thick (Mapel and Bergendahl, 1956, p. 86). Where penetrated by wells in northwestern South Dakota, it includes clayey limestone and is as much as 200 feet thick (Francis, 1957, fig. 7).

Piper Formation.—The Middle Jurassic Piper Formation, which rests unconformably on the Gypsum Spring, is a sequence of interbedded shale and limestone as much as 125 feet thick in the subsurface (Francis, 1957, fig. 9). The Gypsum Spring and Piper probably accumulated in the shallows on the southeastern side of a seaway.

Sundance Formation.—Conformably overlying the Piper is the Upper Jurassic Sundance Formation, a unit of alternating sandstone and shale, which thickens from a feather-edge in central South Dakota to more than 740 feet in eastern Montana (McKee and others, 1956, pls. 5–6). Where the Sundance crops out around the Black Hills, it has been divided into six members (fig. 10); in ascending order they are the Canyon Springs Sandstone, Stockade Beaver Shale, Hulett Sandstone, Lak (maroon sandstone and siltstone), Pine Butte (sandstone and shale), and Redwater Shale Members (Imlay, 1947, p. 245–246; Pipiringos, 1968, p. D12). An unconformity separates the Pine Butte and Redwater Shale Members. Where intersected by wells in northwestern South Dakota, the lower five members and the Redwater have been called, respectively, the Rierdon and Swift Members of the Sundance. With the possible exception of the Lak Member, the Sundance was deposited in marine water near the southeastern shore of an epicontinental sea (Imlay, 1947, p. 265–266; Pipiringos, 1968, p. D18; Peterson, 1972, fig. 6).

Unkpapa Sandstone and Morrison Formation.—Lying with apparent conformity on the Sundance are the Morrison Formation, and locally the Unkpapa Sandstone, both of Late Jurassic age. In southwestern South Dakota the Unkpapa lies conformably under the Morrison and is as much as 225 feet thick (Gries, 1964, p. 26). The Morrison Formation is a sequence of interbedded varicolored shale, sandstone, and minor limestone, and where it includes the Unkpapa may be as much as

350 feet thick (McKees and other, 1956, pl. 7). In eastern South Dakota, east of the Missouri River, the formation is absent. The Morrison and Unkpapa are of nonmarine origin and were probably deposited in streams and lakes on a broad flood plain. Fossils, including dinosaur bones and small invertebrates, are abundant. Models of some of the dinosaurs are displayed at a hilltop park in Rapid City.

Cretaceous

Inyan Kara Group.—The Inyan Kara Group of Early Cretaceous age, which lies unconformably above the Morrison, includes the Lakota Formation and the younger Fall River Formation. The Lakota is composed of sandstone, shale, and locally limestone, and is as much as 550 feet thick (McGookey and others, 1972, fig. 11). From the southeast side of the Black Hills, it thins toward the southwest and east, and has not been found in eastern South Dakota. The crossbedded channel-filling sandstone of the lower Lakota commonly contains thin lenses of conglomerate and fossil wood (Gries, 1952b, p. 74). The upper Lakota, the Fuson Member, is composed of varicolored claystone and sandstone and contains abundant fossil plants. These rocks and the locally intervening Minnewaste Limestone Member accumulated in continental environments, perhaps in river valleys that sloped toward the northwest.

The Fall River Formation, which rests unconformably on the Lakota, consists of well-bedded, fine-grained sandstone and less abundant interbedded siltstone and claystone. At outcrops around the Black Hills, the formation is about 120-150 feet thick (Waage, 1959, p. 26–33). In the northern Black Hills, a cross-bedded sandstone in the middle of the Fall River is named the Keyhole Sandstone Member (Davis and Izett, 1958). These rocks were deposited in shallow waters along the eastern shore of the Skull Creek sea and represent the first marine incursion of the Cretaceous. Fluvial and deltaic sediments of the nonmarine Dakota sequence of eastern South Dakota may in part have been deposited at the same time.

Graneros Shale.—Conformably overlying the Fall River is an assemblage of Cretaceous rocks which in South Dakota is called the Graneros Shale. It consists, in ascending order, of four conformable members: the Skull Creek Shale, Newcastle Sandstone, and Mowry Shale, all of Early Cretaceous age, and the Belle Fourche Shale of Late Cretaceous age (fig. 10). The Skull Creek is about 250 feet thick and is mainly a concretion-bearing dark gray shale of marine origin (Cobban, 1952, p. 86). The Newcastle is composed of sandstone interbedded with lesser amounts of shale and bentonite and is locally as much as 100 feet thick (McGookey and others, 1972, fig. 18). Where the Newcastle crops out on the east side of the Black Hills, it consists of channel-filling, bentonitic, carbonaceous sandstone, and was probably deposited in a river or delta system. Elsewhere, it may be partly marine in origin. East and south of the Black Hills, the Newcastle is interpreted to be laterally continuous with the "J Sand". The Mowry Shale is generally composed of gray siliceous shale interbedded with less abundant bentonite; it is as much as 250 feet thick and originated in a marine environment (Gries, 1952b, p. 76). The Belle Fourche

Shale consists of soft gray concretion-bearing shale and a little bentonite, which were deposited in an inland sea. The Belle Fourche, as much as 450 feet thick in western South Dakota (Robinson, Mapel, and Bergendahl, 1964, p. 53), grades eastward into sandstone and is partly equivalent to the "D Sand" of eastern South Dakota (McGookey and others, 1972, fig. 26). The dominantly marine Graneros rocks in western South Dakota probably change laterally to fluvial sandstones generally called the Dakota Sandstone in southeastern South Dakota. Sandstones of this interval are the source of most of the artesian water in the eastern part of the State.

Colorado Group.—In the stratigraphic nomenclature of the U.S. Geological Survey, the lower Late Cretaceous rocks that overlie the Mowry Shale are termed the Colorado Group and are divided into four formations (fig. 10). The group includes, from older to younger, the Belle Fourche Shale (described above), Greenhorn Formation, Carlile Shale, and Niobrara Formation.

The Greenhorn Formation is a marine unit of interbedded calcareous shale and thin limestone as much as 360 feet thick (Cobban, 1952, p. 86). In part of western South Dakota, the basal beds of the Greenhorn are called the Orman Lake Limestone Member. The Greenhorn is concordant with the overlying Carlile Shale, a formation of marine origin which is as much as 550 feet thick (Cobban, 1951, p. 2187–2190). In western South Dakota, the Carlile is generally divided into three members—in ascending order the Pool Creek Shale, Turner Sandy Member, and Sage Breaks Member (Knechtel and Patterson, 1962, p. 921). The concretion-bearing, soft, dark gray shale of the Pool Creek grades laterally into a silty shale unit and the overlying Codell Sandstone of eastern South Dakota. The Turner, which occurs near the Black Hills, is composed of interbedded siltstone, shale, and sandstone; the Sage Breaks consists of dark gray shale with abundant light gray calcareous concretions. In eastern South Dakota neither the Turner nor the Sage Breaks is recognized as such; either or both may be represented by shale of the upper Carlile, but either or both may have been removed by pre-Niobrara erosion. The Niobrara Formation rests unconformably on the Carlile (Tourtelot and Cobban, 1968, p. L18) and ranges in thickness from about 160 feet in eastern South Dakota to about 220 feet near the Black Hills (Gries, 1952b, p. 77). It is composed of calcareous shale, limestone, and thin beds of bentonite which were deposited in a broad inland seaway.

Pierre Shale.—The Pierre Shale of Late Cretaceous age crops out or underlies Cenozoic nonmarine rocks in most of the State. It lies concordantly on and interfingers with the Niobrara in the western part of the State and lies disconformably on the Niobrara in central South Dakota (Schultz, 1965, pl. 2). The Pierre is as much as 3,000 feet thick (Gill and Cobban, 1966, p. A42) and consists mostly of concretion-bearing gray shale which has been divided into many members (fig. 10). The more distinctive members are the Sharon Springs, a sequence of interstratified bituminous shale and bentonite; the Crow Creek, a thin unit of sandstone and calcareous shale; and the Mobridge, which is largely calcareous shale. Rocks of the Pierre originated in the last Cretaceous sea that covered South Dakota.

Fox Hills Sandstone.—The Fox Hills Sandstone lies conformably above and interfingers with the Pierre in western South Dakota. It is as much as 400 feet thick (Gries, 1952b, p. 78) and is composed of sandstone and sandy shale which have been divided into several members (fig. 10). These beds were deposited in shallow water along the western edge of the Niobrara seaway.

Hell Creek Formation.—The Hell Creek Formation rests concordantly on and interfingers with the Fox Hills Sandstone and is as much as 400 feet thick in northwestern South Dakota (Gries, 1952b, p. 78). It consists mostly of sandy shale, lenticular crossbedded sandstone, and thin beds of lignite, and commonly contains the fossilized bones of dinosaurs. The formation is of nonmarine origin and probably accumulated in large river valleys. It is conformably overlain by the nonmarine Ludlow Formation of Paleocene age.

CENOZOIC ROCKS

Tertiary Sedimentary Rocks

(By J. C. Harksen, South Dakota Geological Survey, Rapid City, S. Dak.)

The boundary between the Cretaceous and Tertiary in western South Dakota was marked by no obvious change in climate or sedimentation. In the absence of a noticeable stratigraphic break between the Cretaceous Hell Creek Formation and the Paleocene Ludlow Formation, the dividing line between these two units has been placed at the base of the first major coal bed above the uppermost occurrence of dinosaur fossils. The Tertiary was a time of continental rather than marine conditions except during deposition of the Paleocene Cannonball Formation, which represents the last marine invasion of South Dakota.

At the beginning of the Oligocene, volcanic ash became a significant constituent of the accumulating sediments. Volcanic activity in the Yellowstone Park area or in Colorado furnished great volumes of ash that were incorporated into the Oligocene and Miocene units. By late Miocene time the supply of volcanic ash for the sediments had fallen to insignificant levels.

The Pliocene was characterized by an extremely flat depositional plain that stretched eastward from the Black Hills and Rocky Mountains. Sedimentary rocks formed during the Pliocene originated mainly as stream channel deposits of sand. In middle to late Pliocene time western South Dakota went into the erosional cycle that has continued unabated to the present.

Paleocene.—All of the rocks of Paleocene age currently recognized in South Dakota belong to the Fort Union Group, which is a sequence of swamp and marine deposits that contain several thick beds of lignite. The lowermost unit is the Ludlow Formation, which contains as much as 350 feet of interbedded lignite, shale, and loosely consolidated tan sandstone. Most of South Dakota's coal resources are in the Ludlow Formation.

Contemporaneous with the upper part of the Ludlow Formation is the Cannonball Formation, the youngest deposit of marine origin in the State. The Cannonball consists of as much as 170 feet of buff to gray silty sandstone and claystone with abundant randomly spaced gray to tan round calcareous concretions. The concretions resemble large stone cannonballs, which in an indirect way led to the naming of this unit.

Lying conformably on both the Ludlow and Cannonball Formations is the Tongue River Formation, which consists of as much as 285 feet of white to buff medium-grained unconsolidated sand, sandstone with calcereous cement, and some poorly developed beds of lignite. The Tongue River thickens greatly to the north and northwest, reaching a maximum of 2,000 feet near Miles City, Montana.

Oligocene.—Perhaps the most photographed and studied of all the rocks in South Dakota are those of the Oligocene White River Group. These beds are well-exposed and easily accessible in the Badlands National Monument, an area visited by many thousands of tourists each year.

The White River Group marks the return of a depositional cycle to the Great Plains after a long period of erosion which lasted virtually from the end of the Paleocene until the Oligocene, though small deposits in the northwestern part of the State may be of Eocene age. The climate was warm and moist during the period of erosion, and remnants of a lateritic paleosol (a red, iron-rich soil), known as the Interior Paleosol, are found on units directly underlying the White River Group.

The Chadron Formation, the lower of the two formations in the White River Group, is as much as 180 feet thick. Generally it consists of light green claystone that forms a popcorn-like surface where weathered. Plentiful fossilized remains of the large mammal called the titanothere led early geologists to refer to the Chadron Formation as the titanothere beds.

Little nearby volcanic activity is known during Early Tertiary time, but there was extensive volcanic activity in Colorado and in the Yellowstone Park area during the Oligocene. These eruptions furnished a large amount of wind-borne volcanic ash that was incorporated in the White River Group. This ash is abundant in the Brule Formation, the upper formation in the White River Group. The Brule is composed of as much as 450 feet of pink siltstone which weathers to a characteristic step-and-riser topography.

Vast quantities of mammalian fossils have been collected from the White River Group. These fossils have been intensively investigated and described in the scientific literature since their discovery in the nineteenth century. Published studies of the Oligocene fauna from this region are among the best documented in the world.

Miocene.—The Sharps Formation of Miocene age, the lowermost of three formations constituting the Arikaree Group, lies conformably on the Oligocene Brule Formation. The Sharps consists of 350 feet of pink silty claystone which contains many small (2- to 4-inch) randomly spaced calcareous concretions. The base of the Sharps Formation is marked by a 20- to 25-foot layer of impure white volcanic ash known as the Rockyford Ash Member.

The middle unit of the Arikaree Group is the Monroe Creek Formation, which is as much as 100 feet thick and consists of tan sandy siltstone with abundant volcanic ash.

The Monroe Creek grades upward into the Harrison Formation, a gray ash-bearing sandstone that contains many beds of fresh-water limestone. The Harrison rarely crops out and is ordinarily grass covered, markedly in contrast with the Oligocene and older Miocene beds, which are generally well exposed.

The Rosebud Formation consists of approximately 250 feet of pink ash-bearing claystone. Its age and stratigraphic relationships are not wholly known, although on the Pine Ridge Indian Reservation it lies unconformably on the Harrison Formation and is in turn unconformably overlain by both the Miocene Batesland Formation and the Pliocene Ogallala Formation. Fossils are extremely rare in the Rosebud, which is one of the reasons its time relationships are not completely understood.

The Batesland Formation is thin, attaining a maximum thickness of only 60 feet, and is restricted, so far as now known, to exposures in Bennett County. It is a green silty claystone that contains many sandstone-filled channels. The sandstone is friable but the claystone is generally extremely hard. Like the underlying Rosebud, the Batesland has unconformable upper and lower contacts. One fossil locality in the Batesland, the Flint Hill quarry, has furnished a great many vertebrate fossils.

Pliocene.—In South Dakota, the Pliocene is represented only by the Ogallala Formation, which consists of as much as 300 feet of unconsolidated tan sand and gravel in stream channels. Many geographic names, such as Bijou, Ash Hollow, Valentine, and Hisle, have been applied to parts of the Ogallala Formation in South Dakota, but the current trend is to treat the unit as a single formation not differentiated into smaller units.

Tertiary Igneous Rocks

(By J. A. Redden, South Dakota School of Mines and Technology and U.S. Geological Survey, Rapid City, S. Dak.)

Tertiary igneous rocks are restricted to a belt of intrusions approximately 10 miles wide that crosses the northern Black Hills in a N. 75° W. direction. As several geologists have noted, the trend of the belt coincides with and is an extension of the Nye-Bowler fault zone to the northwest in Montana.

There seem to be four main centers of intrusion as well as several isolated small bodies. One of the four is the Vanocker-Galena area southwest of Sturgis; another is the Lead-Deadwood dome; a third is at Tinton on the Wyoming-South Dakota boundary; and the fourth is the Bear Lodge Mountains, north of Sundance, Wyoming, or about 20 miles west-northwest of Tinton. The easternmost exposed intrusive is at Bear Butte, but according to Kleinkopf and Redden (1975) a small gravity anomaly and physiographic evidence suggest a buried intrusive about 12 miles north-northeast of Rapid City.

Anomalous geothermal gradients in wells in the south central part of South Dakota (Schoon and McGregor, 1974, fig. 1) have much the same trend and are approximately along the same line as the intrusive belt. Perhaps the intrusive belt continues as far as the Missouri River or anomalous heat from some basement structure is associated with it, though anomalous thermal gradients are not known along this belt close to the Black Hills.

The intrusions have various compositions. The most common types are quartz monzonite, monzonite, latite, and rhyolite or their porphyritic equivalents. Alkalic rocks, including phonolite, grorudite, and other less common varieties, make up about 12 percent of the total (Darton and Paige, 1925). The rocks have abundant alkalic feldspars; locally, as near the Homestake Mine, they are greatly enriched in potassium. Pyroxenite is, so far as known, limited to the Mineral Hill area near Tinton, where it is associated with various alkalic rocks. Trachytic and porphyritic textures are common. Detailed petrographic and geochemical work on the entire group of rocks has not been done. Kirchner (1971) made the most detailed study of the phonolitic rocks, but in the main he restricted his work to the Lead-Deadwood area. Welch (1974) investigated the ring complex in the Tinton-Mineral Hill region, where most of the rocks are alkalic.

The intrusions include sills, dikes, plugs, ring dikes, small stocks, and laccoliths. Generally the form reflects the planar elements of the country rock. Most of the larger masses emplaced in sedimentary rocks are probably laccoliths, although Noble (1952) questioned this interpretation chiefly on the basis of evidence from the Cutting Stock, which is in the steeply dipping Precambrian rocks just west of Lead. Certainly the larger intrusives in Paleozoic and Mesozoic host rocks produce prominent domal structures. Bayley (1972b) traced magnetic anomalies, caused by ferruginous rocks in the Precambrian basement, beneath domal Tertiary igneous rocks in the Kirk Hill area east of Galena, which implies that the intrusion has a floor. The distribution of dipole anomalies and flow structures in several of the larger intrusive areas (Anna, 1973; Rockey, 1974) indicate local conduits rather than stocklike masses. In at least six separate areas the sedimentary rocks form domes that have not yet been breached by erosion and probably conceal igneous rocks.

Paleozoic rocks from the Deadwood through the Minnelusa Formations are especially favored as sites of large and small sills. In the Bald Mountain area west of Lead, Shapiro and Gries (1970) showed that the Deadwood is commonly thickened from 300 to 600 feet by the emplacement of sills.

The only ring dike structure is at Mineral Hill, Wyoming, where nepheline syenite surrounds a pyroxenite mass which has intrusive feldspathic breccia at its center. The breccia is cut by various dikes of alkalic rocks, including pseudoleucite porphyry.

The only convincing evidence of a volcanic structure is in a small area, largely of rhyolite, which crosses U.S. 385 about 6 miles south of Deadwood where the surrounding rock is Precambrian schist. Associated with rhyolite and pitchstone are apparently pyroclastic rocks containing fossiliferous Upper Cretaceous Carlisle Shale fragments. Presumably some kind of collapse structure has caused the Carlisle fragments to be in a volcanic neck.

All authors agree that assimilation of country rock was extremely limited and that the intrusions were forcibly injected, as shown most convincingly by Noble (1952). Noble also presents substantial evidence that the entire Lead-Deadwood dome is due to an increase in volume resulting from emplacement of the igneous rocks.

Depths of cover may have varied somewhat but are unlikely to have exceeded 8,000 feet at the time of intrusion. In the Precambrian metamorphic rocks just below the Paleozoic unconformity, the steeply dipping sills and dikes made room by plastic deformation of the metamorphic rocks even at this shallow depth. In all types of country rock, contact metamorphism is very limited, and it can be assumed that most of the magmas were relatively dry, partly crystallized, and did not have excess heat.

A total of twelve age determinations on six different kinds of rock range in age from 38.8 to 60.5 million years (summarized in Shapiro, 1971b). This virtually brackets the Eocene epoch. Superimposition of the domes on the larger subsidiary folds in the Black Hills uplift (Sottek, 1959) indicates that the intrusions are younger than much of the uplift and folding of the Black Hills.

The dating is inadequate to show distinct differences in age of different kinds of rock types, but instead implies overlap in ages. Nonetheless, the rocks to the west-northwest tend to yield the younger ages. Most investigators agree that the field relationships indicate the alkalic rocks are younger than the non-alkalic varieties in any particular locality. Darton and Paige (1925) assigned a Quaternary age to the volcanic structure previously mentioned and to another small rhyolite area farther to the southeast, but later work by Drake (1967) suggests these rocks are probably also of early Tertiary age.

Most recent investigators believe there were both an alkalic and a non-alkalic magma series and that the rocks differentiated independently, despite the apparent overlap in time. In a general way, the alkalic rock types are more abundant in the western part of the belt at Tinton and in the Bear Lodge Mountains of Wyoming. The Tinton district is unique in having a ring structure, sizable intrusive breccia zones, and magnetite-rich pyroxenite. These features suggest affinities with alkalic rocks containing carbonatite. However, Welch (1974) found no evidence of carbonatite, and the contents of certain trace elements indicate dissimilarity with typical carbonatite complexes.

Obviously much more work is needed on the dating, geochemistry, and petrogeny of these two apparently different rock series which seem to be intermingled in space and time. Disseminated molybdenum in at least one intrusive west of Lead, anomalous radioactivity at a few places, the peculiar volcanic structures south of Deadwood, and the probable relationship of the igneous activity to Tertiary mineralization indicate that additions to the available information may also be important in exploring for mineral deposits.

Quaternary Glacial Deposits and Alluvium

(By M. J. Tipton, South Dakota Geological Survey, Vermillion, S. Dak.)

All of South Dakota east of the Missouri River and a small area west of the river have been glaciated. The glacial deposits are underlain principally by flat-lying marine Cretaceous strata and in a few places by Precambrian igneous and metamorphic rocks. Topographically the area consists of two plateau-like highlands, the Coteau des Prairies to the east and Coteau du Missouri to the west, separated by the James River Lowland. Elevations range from 950 feet above sea level in the extreme northeastern part of the State to a little over 2000 feet on both coteaus. The James River Lowland is generally at about 1200 feet above sea level. The region is drained mainly by the Missouri

River and two of its primary tributaries, the James and Big Sioux Rivers. Lakes, ponds, and swampy localities are common as a result of disruption of the topography by glacial processes.

A thorough knowledge of the glacial geology of South Dakota is important in understanding the distribution of ground water east of the Missouri River, where crop farming is the preeminent industry. Some glacial deposits are also sources of sand and gravel, but the products may rank low in usefulness because they are of unsuitable composition for concrete aggregate. To work out the geology, a series of county studies by the South Dakota Geological Survey in cooperation with other organizations has been underway for some years. Much of the information in this chapter comes from these investigations and from the geologists participating in them, who are too numerous to mention individually. An earlier report by Flint (1955), who synthesized the then available information and added new data and interpretations, is the principal general reference.

East of the Missouri River glacial drift is very nearly continuous. Its average thickness is more than 100 feet and thicknesses of over 800 feet have been drilled in the northern part of the Coteau des Prairies. West of the river the drift remnants consist of little more than scattered boulders lying on bedrock.

Most of the drift consists of till made up chiefly of fragments of the local Cretaceous rocks. The till is very rich in clay, reflecting the predominance of shale in the Cretaceous bedrock. Outwash deposits are very numerous in some parts of the region, especially along the edges of the drift sheets.

Layers of till are separated by layers of stratified drift and occasionally loess. The individual layers represent successive glacial stages or substages and in some places have features such as soils which record non-glacial conditions.

The tills are of both Wisconsin and pre-Wisconsin age. Early and late Wisconsin tills can be distinguished from each other, especially in the extreme eastern part of the State, by the presence of abundant shale particles in the late Wisconsin tills and a far smaller amount of Pierre Shale pebbles in the early Wisconsin tills. The three pre-Wisconsin tills that have been identified in eastern South Dakota are almost entirely devoid of Cretaceous shale pebbles, thus reflecting southwesterly movement of the pre-Wisconsin ice across the Precambrian rocks of Minnesota. The late Wisconsin ice advanced over the marine Cretaceous shales from the northwest.

The areal extent of all the pre-late Wisconsin glaciations is not well known, mainly because of burial or erosion. Evidence gathered to date indicates that only one glacial ice sheet, the late Wisconsin, advanced west of the Coteau des Prairies in the northern half of the State. Numerous radiocarbon dates show that the late Wisconsin ice reached its maximum advance probably near the Missouri River about 12,500 years ago. The scattered boulders lying west of the Missouri River must have been deposited also by the late Wisconsin ice sheet. Why till was not deposited along with the boulders remains a mystery. The early Wisconsin ice sheet must have been stopped by the Sioux Ridge on the south and also went not very far to the west, for the only known deposits are from Beadle and Sanborn Counties to the eastern border of the State north of the Sioux Ridge. The Illinoian, Kansan, and Nebraskan ice sheets crossed the Sioux Ridge, and drift from these advances has been found only in the southeastern part of the State.

During the melting of the late Wisconsin glacier, two glacial lakes existed in South Dakota. Glacial Lake Dakota occupied much of the northern James River Lowland in Spink and Brown Counties, and glacial Lake Agassiz extended into the northeastern tip of the State. Numerous beach deposits were formed around Lake Agassiz but only very sparse beach deposits can be identified around Lake Dakota, probably reflecting its short lifetime. Water flowing southward out of Lake Dakota cut the deep narrow trench in which the James River now flows. Water going southward out of the glacial Lake Agassiz passed southeastward through the glacial Warren River, cutting a deep and broad trench now occupied by the Minnesota River system, which forms part of the eastern boundary of the State along Lake Traverse and Big Stone Lake.

Although most of the rivers in South Dakota now drain to the south, prior to glaciation (and therefore prior to the existence of the Missouri River) the Grand, Moreau, Cheyenne, Bad, and White Rivers all flowed eastward from their present junctions with the Missouri River into what is now the James River Lowland. The extension of the ancient White River flowed southeastward, but the others turned north after reaching the James Lowland and were part of a major northward flowing system. With the exception of the White River, the date of the change to modern drainage conditions was almost certainly late Wisconsin, as that was the only time the ice sheet reached far enough to the west. The change of the White River was probably during the Kansan ice advance.

The Big Sioux River flows southward on the Coteau des Prairies. Throughout most of its course, it is on early Wisconsin drift. It originated as a stream in the narrow ice-free belt between the James and Des Moines lobes of the late Wisconsin ice sheet. Abundant outwash was deposited along the Big Sioux valley, reflecting its position beyond the terminus of the late Wisconsin ice. The James River valley, in contrast, has very little outwash, probably because meltwater was unable to escape the area of the James ice lobe until the draining of glacial Lake Dakota.

Deposition of alluvium along streams and erosion of uplands were the principal geologic processes operating in the western part of the State during the period of glaciation and over the whole State in modern times as well as between glacial advances. In the geologically brief time since the end of glaciation, the State has been much the same as it is today but with the gradual destruction of lakes and swamps that originated as a result of glacial interference with stream systems.

STRUCTURAL GEOLOGY

Outside of the Black Hills

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

The main structural features of the State are the Black Hills, Chadron Arch, Williston Basin, Kennedy Basin, Canadian Shield, Sioux Ridge, and Forest City Basin (fig. 11). The structure of the Black Hills will be described in the next section of this report. Contours on the top of the Precambrian rocks (fig. 8) show more detail, and are helpful in understanding the structural evolution and depositional history of the younger rocks.

Paleozoic rocks are absent outside the Williston Basin except for small areas in the Kennedy Basin, in the Forest City Basin, and in the extreme southwest corner of the State. Paleozoic rocks are very nearly flat-lying in parts of Washabaugh, Shannon, and Bennett Counties, and dip gently northward into the Williston Basin and southward into the Kennedy Basin (Schoon, 1967). Paleozoic rocks dip southeastward away from the southeast corner of South Dakota toward the depth of the Forest City Basin in Iowa, Nebraska, Missouri, and Kansas.

Mesozoic rocks overlap Paleozoic rocks and Precambrian rocks and cover the entire State except where removed by erosion from the Black Hills and from two small areas where Precambrian rocks crop out in northeastern and southeastern South Dakota. Mesozoic rocks on the Canadian Shield, extending onto and overlapping the Sioux Ridge, are nearly flat-lying to very gently dipping, though the details of their structure are masked by the widespread cover of glacial deposits. South of the Sioux Ridge these rocks have gentle southerly dips toward the Kennedy and the Forest City Basins. In the southwest corner of the State they dip into the Kennedy Basin, arch across the Chadron uplift, and then dip southwestward from the State.

Cenozoic sediments are nearly flat-lying throughout their extent in the State. They lie, for the most part unconformably, on the Mesozoic and Paleozoic rocks and mantle the upturned edges on the fringe of the Black Hills. Little or no folding or faulting has been discovered in these rocks except where local late Tertiary uplift in the Black Hills has caused some minor tilting.

The eastern half of South Dakota is largely covered by glacial drift, the distribution of which was not controlled by any of the major structural features except possibly the Sioux Ridge.

Smaller structures, not shown on the map, include the south end of the Cedar Creek anticline, extending into Harding County from Montana and North Dakota, and the White Clay fault, running nearly due west for 35 miles from Pine Ridge in Shannon County to Oelrichs in Fall River County. A Precambrian fault with as much as 650 feet of throw was first postulated by Steece (1961) in northern Jones County (fig. 8). The edge of the Black Hills uplift has the Barker dome and several anticlines and synclines shown on figure 12. There are also a large number of small unnamed anticlines, synclines, and faults scattered throughout the State.

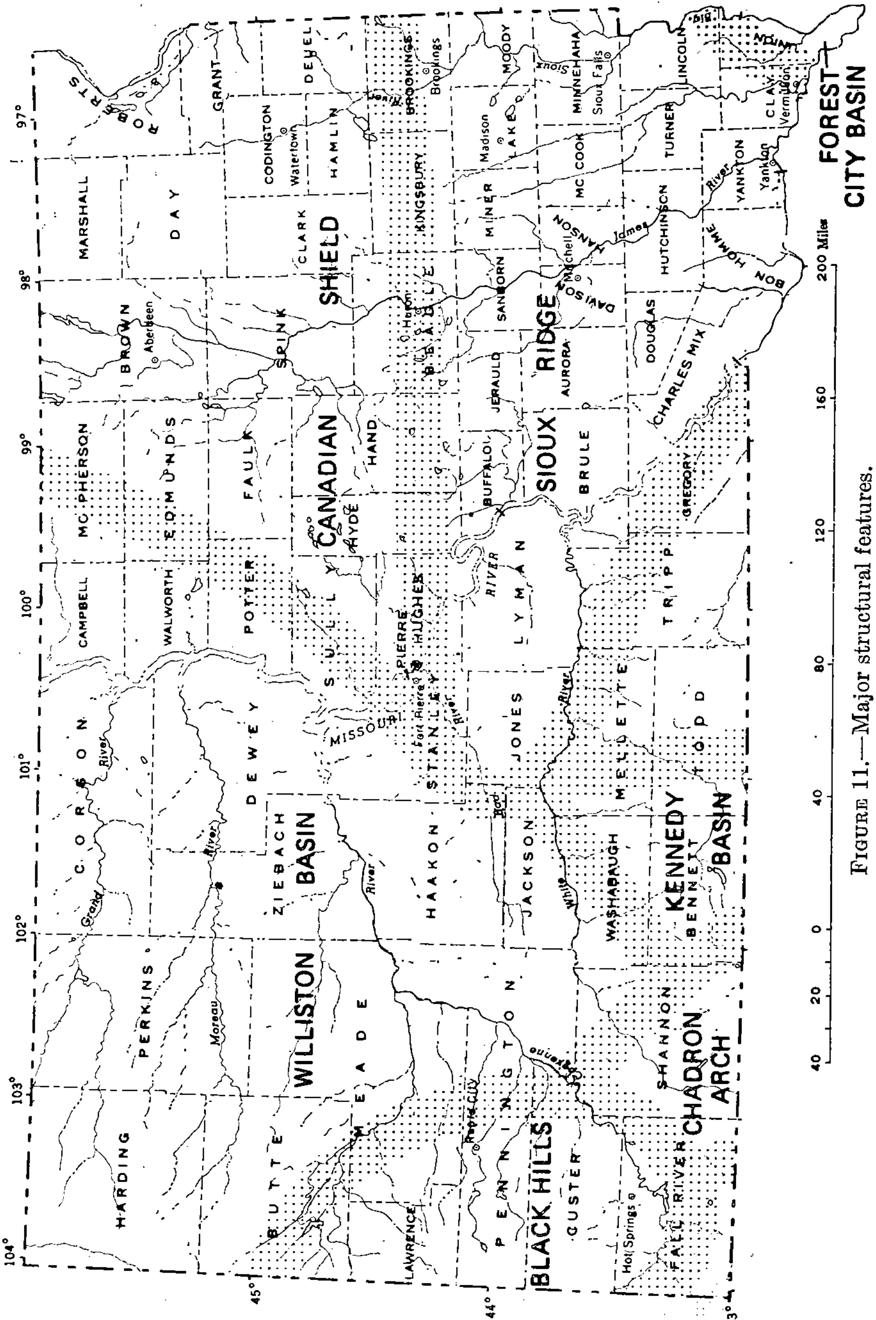
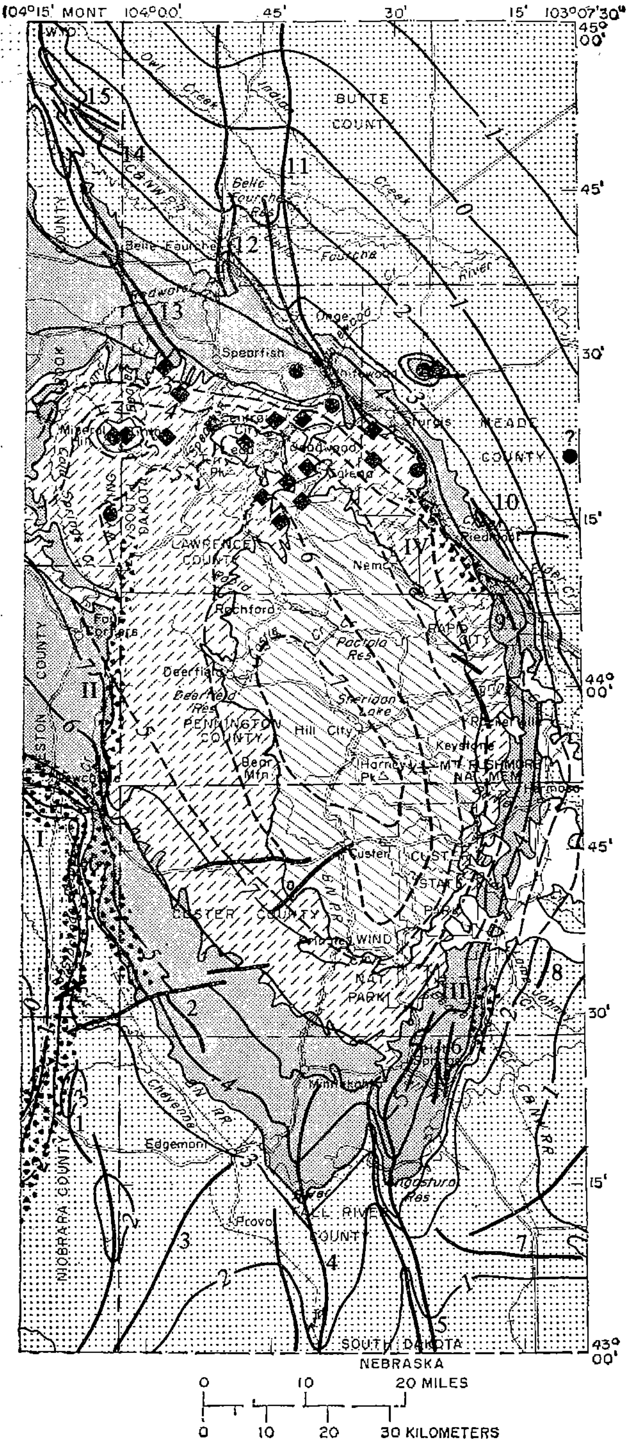


FIGURE 11.—Major structural features.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BUTTE COUNTY
Owl Creek
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Belle Fourche Res
Belle Fourche
Fourche
River
Redwater
C&NW RR
Spearfish
Whitewood
Sturgis
MEADE COUNTY
CROOK
Mineral Hill
Central City
Lead
Deadwood
Galena
Terry Pk
Spearfish
WYOMING
SOUTH DAKOTA
LAWRENCE COUNTY
Nemo
Rapid
Rochford
Four Corners
Pactola Res
RAPID CITY
Deerfield
Deerfield Res
Sheridan Lake
PENNINGTON COUNTY
Hill City
Keystone
Rockerville
Bear Mtn
Harney Pk
MT. RUSHMORE NAT. MEM.
Hermosa
WESTON COUNTY
Newcastle
Custer
CUSTER STATE PARK
CUSTER COUNTY
WIND CAVE NAT PARK
Hot Springs
Minnekahta
Cheyenne
Edgemont
Angostura Res
Provo
FALL RIVER COUNTY
NIOBRARA COUNTY
C&NW RR
Battle Cr
Elk Cr
SOUTH DAKOTA
NEBRASKA
45'
30'
15'
44° 00'
45'
30'
15'
43° 00'
I
II
III
IV
0
1
2
3
4
5
6
7
8
9
10
?
0 10 20 MILES
0 10 20 30 KILOMETERS

EXPLANATION

▨	▨	▒	░	□
Precambrian	Sequence 1	Sequence 2	Sequence 3	Sequence 4

Rock units

See table 2 for description of the units

◆

Igneous complex

●

Dome

3

Anticline

1. Mule Creek
2. Barker Dome
3. Cottonwood
4. Chilson
5. Cascade Springs
6. Dudley
7. Chadron arch
8. Fairburn
9. Rapid City
10. Piedmont
11. Whitewood
12. Belle Fourche
13. La Flamme
14. Chicago Creek
15. Colony

Syncline

II

Monocline

I. Black Hills II. Fanny Peak III. Buffalo Gap
IV. Little Elk Creek

Normal fault

– – – – 1 – – – –

Base of Deadwood Formation

———— 1 ————

Base of Fall River Formation

Structure contours
In thousands of feet above sea level

FIGURE 12.—Tectonic map of the Black Hills:

Black Hills

(**By A. L. Lisenbee, South Dakota School of Mines and Technology, Rapid City, S. Dak.**)

The Black Hills is the easternmost of the uplifts of the Wyoming Rocky Mountains. It is a kidney-shaped, relatively flat-topped dome 125 miles long by 45 miles wide. Shapiro (1971b) divided it into a western block of northwest trend in Wyoming and an eastern block of northerly trend in South Dakota. The Wyoming block is structurally lower. From Tinton on the north to Newcastle on the south the two blocks are separated by the Fanny Peak monocline (fig. 12). The monocline extends southward another 40 miles to the Hartville uplift near Lusk, Wyoming. In this region it is the pronounced structural boundary between the Black Hills and the Powder River basin. Elsewhere, the eastern block is bounded by local monoclines, folds, and homoclines.

The topographic expression of the eastern block resembles a reversed C. The periphery is marked by the "Cretaceous hogback," which for much of its length lies 5 to 15 miles inside the maximum structural extent of the uplift. On the north and south ends, however, folds plunge away from the topographic front for 10 to 25 miles, but their topographic expression is obscured in the Cretaceous shales of the prairie land.

Structural relief of the eastern segment is approximately 8500 feet, whereas that of the western block is 7000 feet. The greater uplift of the eastern block has promoted extensive erosion of its sedimentary cover and exposure of the underlying Precambrian rocks.

Pre-Laramide structure.—The Precambrian metamorphic and igneous rocks exposed in the eastern segment have a strong north- and northwest-trending fabric, as shown by the general lithologic distribution, schistosity, folds, and faults. Many folds in the surrounding sedimentary cover closely parallel this fabric which was probably a critical factor in controlling the structural character of the Laramide uplift.

Pre-Laramide sedimentary rocks are divisible into three sequences (table 2), which indicate only long wavelength warping of the crust in western South Dakota from the Cambrian through the Cretaceous. Broad sagging or arching allowed the advance and retreat of shallow seas throughout the Paleozoic. Shelf-facies clastic and carbonate rocks deposited at this time (Sequence 1) contain many disconformities, but evidence of local deformation is lacking. In general, the Paleozoic rocks thin to the southeast.

TABLE 2.—AGES OF ROCK UNITS AND STRUCTURAL DEVELOPMENT OF THE BLACK HILLS UPLIFT

Age	Rock units	Structural development
Cenozoic:		
Oligocene	Sequence 4: Continental clastic rocks	
Eocene	Near surface intrusive rocks	Laccolithic domes.
		Laramide uplift—drape folding.
Mesozoic:		
Upper Cretaceous	Sequence 3: Clastic rocks of the Rocky Mountain geosyncline.	Geosynclinal subsidence.
Uppermost Permian through Lower Cretaceous.	Sequence 2: Dominantly continental rocks; marine components in Jurassic.	Broad warping; possible local folding in Jurassic and Cretaceous.
Paleozoic:, Permian, Pennsylvaniana, Mississippian, Devonian, Ordovician, Cambrian.	Sequence 1: Marine sedimentary rocks of shelf facies.	Broad warping; several disconformities.
Precambrian	Chiefly metamorphosed eugeosynclinal sedimentary and volcanic rocks; also granite.	Strong multiple folding and faulting.

Broad warping continued in the Mesozoic with a change from marine to dominantly continental sediments. Local folding may have occurred in the Jurassic (Shapiro, 1971b) and lowermost Cretaceous (Gott, 1964), but evidence of widespread deformation is absent in the sedimentary layers that ring the uplift. Gentle downwarping allowed minor advances of the sea in the Jurassic.

In the Cretaceous, central North America subsided from the Arctic to the Gulf of Mexico to form the Rocky Mountain geosyncline, in which thick sequences of shale and sandstone were deposited. Western South Dakota lay along the eastern edge of this geosyncline.

A fourth sequence of sedimentary rocks lies with angular unconformity on the older strata. This Oligocene continental clastic material post-dates formation of the Laramide structures; most of it came from erosion of the Black Hills uplift.

Laramide structure.—The Laramide uplifts of the Wyoming province are classic examples of vertical tectonic movement in which elongate blocks of Precambrian basement were raised or lowered with piston-like motions. Initial movement was accommodated by faulting of the basement and draping of the sedimentary cover over the margin to form monoclines (Stearns, 1971). Further movement resulted in upward development and flattening of the faults in the sedimentary layers and thrusting of parts of the uplifted blocks over material in the adjoining basins.

Uplift of the Black Hills basement blocks produced monoclinal folds on the east and west, but generally did not reach the stage of strong faulting of the draped sedimentary layers. The Black Hills and Fanny Peak monoclines on the west flank of the uplift have inclined limbs dipping 30° to 90°. The east flank is bounded by a broad and gentle monoclinal flexure from the Cheyenne River on the south to at least Sturgis on the north. Abrupt local structures, the Little Elk Creek and Buffalo Gap monoclines, which are superimposed on this structure, dip as much as 90° in the inclined limb.

Asymmetric anticlines, such as the Cascade Springs and Whitewood on the southern and northeastern flanks of the uplift, have steeper dips on their west than on their east limbs. The trend of these folds parallels that of several monoclines and also that of structures in the Precambrian basement. They probably also formed by the draping of sedimentary layers over underlying structures during the doming process.

The doming was instrumental in forming smaller structures as well. Intraformational boxfolds are abundant in the thinly bedded Permian Minnekahta Limestone. The axes of these structures are parallel to the strike of the formation around the uplift. This suggests an origin by down-dip gravity sliding during uplift of the dome and tilting of the Minnekahta Limestone. Small folds are also present in the Pennsylvanian Minnelusa Formation, but the axes have locally chaotic trends, probably resulting from a combination of gravity sliding and slumping caused when the more soluble parts of the rock were carried away by ground water.

The time of the main uplift of the Black Hills block was after the Upper Cretaceous Hell Creek formation was deposited and prior to emplacement of the Eocene intrusive rocks. According to Love (1960), Paleocene clastic sediments in the Powder River basin came from the Black Hills, thus indicating a latest Cretaceous or Paleocene age for the uplift.

Post-Laramide intrusive structures.—Groups of intrusive rocks were emplaced during the Eocene in a belt of about N. 75° W. trend across the northern part of the Black Hills. They consist mainly of dikes, sills, stocks, and laccoliths, but also include a ring complex (Welch, 1974). The host rocks are almost entirely Precambrian or Paleozoic, though two intrusive centers are in Mesozoic rocks. The sedimentary cover forms a simple dome over large intrusions that are mostly or entirely beneath the surface, but where erosion has cut to deeper levels the margins have monoclines, faults, and dikes. Most of the domes are between 2 and 6 miles in diameter.

Two domes, one at Lead and the other at Tinton and Mineral Hill, are about 10 miles in diameter and have cores of Precambrian rocks. Noble (1952), in the three-dimensional exposres of the Homestake mine, showed that the Lead dome results from swelling of the basement caused by emplacement of multiple dikes and stocks subparallel to schistosity. Although the combined volume of all these dikes is sufficient to dome the basement, emplacement of individual members caused only minor deformation of adjacent country rock. Fracturing has also been attributed to the doming process (Slaughter, 1968, p. 1444), but Shapiro and Gries (1970) showed that the principal joints in Paleozoic rocks surrounding the Lead dome are older than the doming and formed during the uplift of the Black Hills or earlier.

Control of igneous emplacement appears to be twofold. The elongate trend of the entire belt of intrusive rocks suggests a major west-northwesterly trending zone of crustal weakness that provided access for magma. Local controls, such as fold structures and basement faults, further channeled the magma. For example, intrusions lie along the trend of what appears to be a basement fault separating the Whitewood anticline from the adjoining syncline.

GEOPHYSICS AND GEOCHEMISTRY

INTRODUCTION

(By J. J. Norton, U.S. Geological Survey, Reston, Va.)

It has often been said that a geologist can see no farther into the ground than anyone else. This is correct only in a strictly literal sense. An exploration geologist who cannot, figuratively, see into the ground should search for other employment.

Geologic mapping and sampling of the surface or in mine workings has been the longest standing, and to date probably the most effectual aid to finding ore bodies. Geologic maps show the location, size, and shape of the various bodies of different types of rock. They are the foundation for constructing diagrams of several kinds that are used to determine what is, or might be, beneath the surface or beyond the limits of mine workings. Geologic mapping in the Homestake mine has been critical in determining the position, shape, and size of the ore bodies and how they were formed; one can fairly say that without such maps the mine would long since have ceased operation. Most exploration drilling is based at least to some degree on geologic mapping, for obviously only in rare circumstances, oftentimes with naive financial backing, does anyone drill without facts to support his expectation of what might be found.

Prospectors and small mine operators are, in a way, doing geologic mapping, though in their heads rather than on paper, when they trace ore-bearing rock and plan their mining operations. The risk of mistakes is greater but oftentimes not enough to compensate for the lower cost.

Yet as technology has improved, other methods have been developed to predict where mineral deposits might be found. Nearly half a century ago oil exploration was revolutionized by gravity and seismographic methods used to find structures that might contain oil. Since then other geophysical techniques have come into existence. At the same time methods based on the chemistry of rocks have become widely used in what is known as geochemical exploration. Another field of geochemistry, the study of isotopes of chemical elements in rocks and ores, has recently been effective in enlarging knowledge of the origin of ores of the northern Black Hills (Rye and Rye, 1974). An earlier and better known use of isotopes and physical particles is through Geiger counters and allied devices that show the presence of uranium and other radioactive materials. Still another use is in the direct determination of the age of rocks, which can be useful in understanding the rocks and thus in determining where exploration is most likely to be fruitful.

Investigations in geophysics and geochemistry are still (with the exception of geophysics in oil exploration) more scientific than utilitarian. The body of world literature on these subjects is enormous. Only a modest amount of work has been done in South Dakota, by companies, by academic institutions, and by governmental agencies. Yet the future of these and allied fields seems so promising that the following summaries have been written to explain what has been done thus far in geophysics and geochemical exploration, and to hint at what the outlook for coming years may be. Integrated programs involving geophysics, geochemistry, geology, and drilling are most likely to be used to search for new gold deposits, especially in the gold province of the northern Black Hills, but they also can lead to the discovery of buried iron ore, perhaps lead-silver deposits, uranium concentrations, and other kinds of mineral deposits.

GEOPHYSICAL SURVEYS

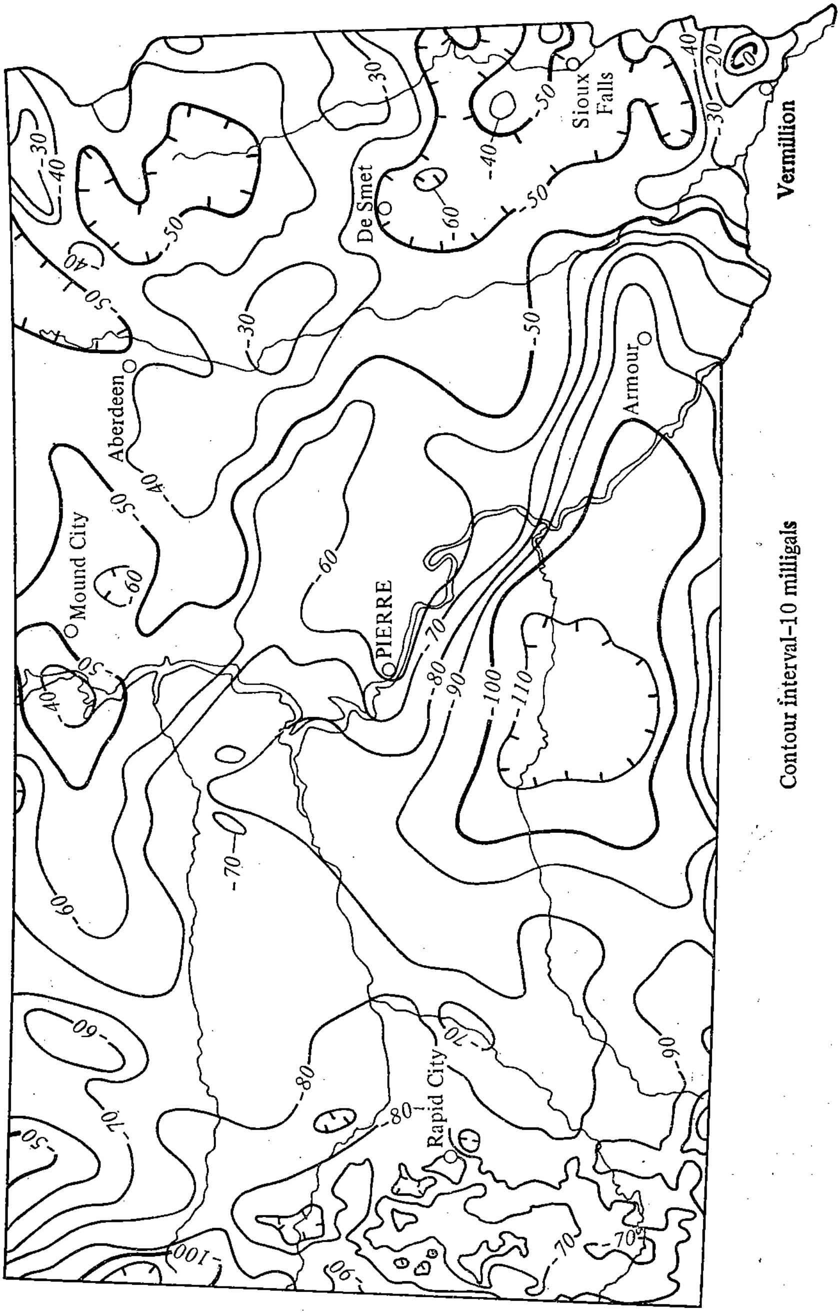
(By M. Dean Kleinkopf, U.S. Geological Survey, Denver, Colo., and J. A. Redden, South Dakota School of Mines and Technology, and U.S. Geological Survey, Rapid City, S. Dak.)

Geophysics—the application of the principles of physics to the study of the earth—has been used widely in the search for metals, oil, gas, coal, and water. In most geophysical work electronic equipment is used to detect variations in one or several of such properties as density, magnetic susceptibility, electrical conductivity, and seismic velocity. The commonly used methods rely on gravity, magnetic, electrical, seismic, and radioactivity measurements. The work may be done from aircraft, at the earth's surface, or in boreholes. Typically, regional geophysical surveys are made to identify broad anomalous areas that may hold promise for economic deposits and thus eliminate large areas not likely to contain specific types of mineral deposits. These highlighted areas then serve as prospecting targets for more expensvie techniques of higher resolution, such as electrical or seismic surveys, and ultimately drill holes.

Many kinds of mineral deposits have characteristic physical properties that can be detected directly or indirectly in geophysical prospecting. Typical examples of direct detection are location of magnetite iron deposits with magnetometer surveys and identification of sulfide minerals through electrical conductivity measurements. In the indirect techniques, the approach is to determine geologic structures, minerals, and rocks that are likely to be associated with a mineral deposit of interest. A prime example is the determination by seismic surveys of subsurface geologic features such as anticlines, faults, or buried topographic highs that may serve as traps for the accumulation of petroleum.

Regional Gravity Surveys

A regional gravity map modified from the Bouguer Gravity Map of the United States (American Geophysical Union, 1974) and the Geologic Atlas of the Rocky Mountain Region (Brinkworth and Kleinkopf, 1972) is shown for South Dakota in figure 13. The major



Contour interval-10 milligals

FIGURE 13.—Bouguer gravity map.

highs and lows on the map are in accord with some of the known and suspected regional geologic features in the State. The Bouguer values show a total relief of some 110 milligals (mgals) from the highest to lowest across the State.

A gravity high with a closed zero mgal contour in extreme southeastern South Dakota can be related to near surface mafic Precambrian crystalline rocks described by Petsch (1967) in his discussion of the Spink ground magnetic anomaly.

The large low closure of −110 mgals south of Pierre must reflect a major difference in basement rocks inasmuch as the sedimentary cover is relatively uniform. The axis of the low trends north-northwest and corresponds to the areas having high geothermal gradients shown by Schoon and McGregor (1974). The same trend fits the belt of Tertiary intrusives in the northern Black Hills and the Nye-Bowler fault farther to the northwest in Wyoming and Montana. Lum (1961a) indicates there are sizable local gravity highs within the major low. Obviously greater detail is needed for better interpretation of the anomaly. The combination of this major anomaly, the geothermal area, and the linear structural and intrusive trends suggests that the region may have potential for certain types of metal deposits.

In the north-central part of the state, Mound City lies on a regional gravity high that is elongate to the west and east for a distance of some 150 miles. On the east end this high joins a southeasterly trending high the axis of which forms a saddle between Aberdeen and DeSmet and extends to the Minnesota line. The source of these highs is almost certainly in the basement rocks but the actual cause is not known. The gravity trends seem to cross the basement trends as shown by Lidiak (1971, fig. 2), who based his interpretation largely on drill cuttings from scattered well locations and the regional magnetic map of Petsch (1967).

In the southeast part of the state in areas underlain by the Sioux Quartzite, the gravity values show considerable ranges. These differences probably reflect differences in older Precambrian rocks that underlie the Sioux Quartzite.

Black Hills Gravity Surveys

In contrast to regional data described above, gravity studies with more local objectives are undertaken where station spacing is one to two miles and data can be contoured on a one-mgal interval. A few such surveys have been made in South Dakota.

In connection with general geologic studies of mineral deposits of the Black Hills, the U.S. Geological Survey has made gravity and aeromagnetic surveys in cooperation with the U.S. Atomic Energy Commission and the South Dakota Industrial Expansion Agency. Over 2,500 gravity measurements have been made across and adjacent to the Black Hills uplift (Hazlewood, 1964; Black and Roller, 1961).

Data for the Black Hills (Kleinkopf and Redden, 1975) show that in many places individual rock types, such as the carbonates, and certain Precambrian rocks, such as amphibolite and iron formation, can be correlated directly with diagnostic gravity features. For the Black Hills uplift, the gravity data show an irregular high of about 20 mgals relief with a maximum closure of −60 mgals. The highest Bouguer gravity values were found about 10 miles southeast of Lead over outcrops of relatively iron-rich metamorphic rocks and about 8 miles northwest of Bear Mountain on a high plateau covered by Paleozoic limestones. The lowest values in the area are along the flanks of the Black Hills uplift and probably are related to the distribution of thick sections of less dense Mesozoic shales and sandstones overlying more dense Paleozoic limestone and dolomite.

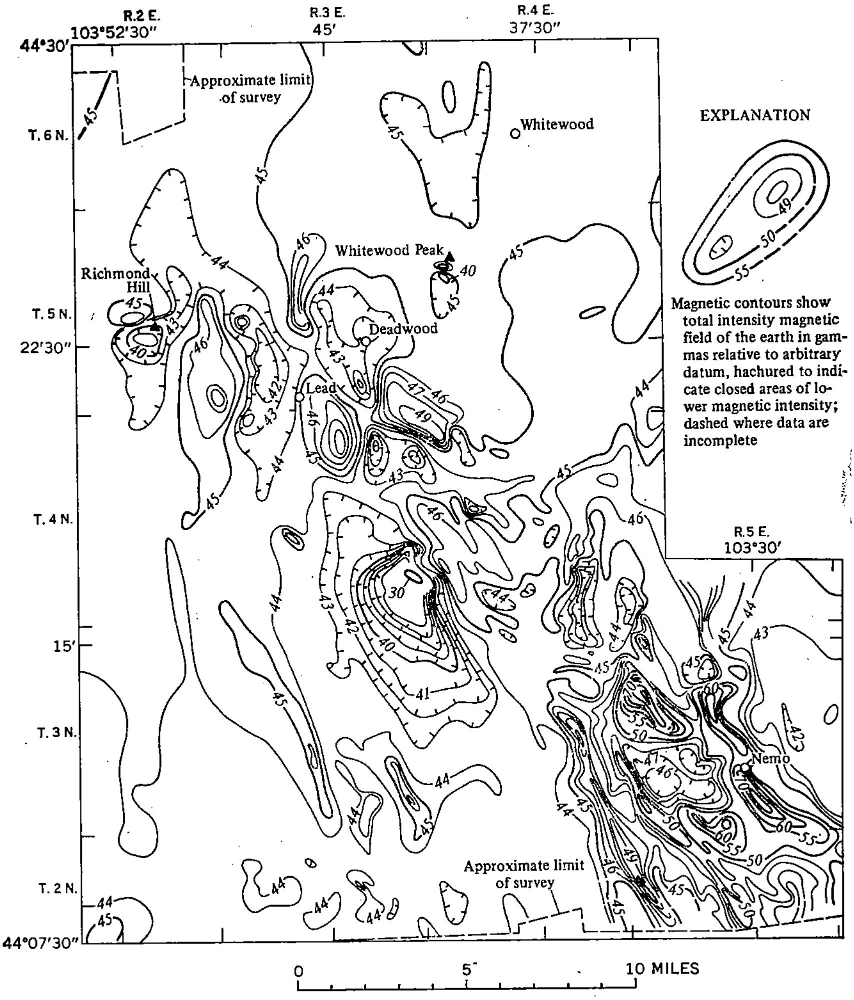
On the plains immediately surrounding the Hills, anticlinal folds in the sedimentary rocks were found in general to be marked by very slight gravity highs in areas where the carbonate rocks are at a relatively shallow depth (Kleinkopf and Redden, 1975). This is particularly evident to the south at the Cascade Springs and Chilson anticlines southwest of Hot Springs, and at the Whitewood anticline southwest of Sturgis. Other broad gravity features were noted to the north of the Hills in areas of sedimentary rock outcrop where subsurface geologic information is sparse. Kleinkopf and Redden (1975) speculated that a closed gravity low located 5 miles northwest of Newell in Butte County and a large north-northwest trending elongate high 7 miles to the northeast probably reflect structural and lithologic contrasts in the Precambrian basement.

Lum (1961a) in a regional survey covering 2,500 square miles just west of Rapid City concluded that the local gravity anomalies observed were related largely to density contrasts within Precambrian basement rocks. Tullis (1963) also made a gravity survey covering 3,400 square miles in the area just south of Lum's work.

Aeromagnetic Surveys

Aeromagnetic surveying has been meager in South Dakota. Three separate surveys of the Black Hills that totaled nearly 4,200 miles of traverse lines were made in the 1960's (U.S. Geological Survey, 1969; Meuschke and others, 1963; Meuschke and others, 1962). The interpretative report by Kleinkopf and Redden (1975) includes the aeromagnetic as well as the gravity data overprinted on a generalized geologic map.

As an example of a survey that shows prominent high and low closed anomalies and high gradients, figure 14 is a modified map covering the northern Black Hills. The original map by Meuschke and others (1962) has smaller contour spacing, flight lines, and other details omitted in figure 14. The magnetic highs with the greatest amplitudes, exceeding 4,000 gammas, cluster in the southeast near Nemo. Harrer (1966, p. 29) in a study of iron resources showed that these high amplitude anomalies are at the site of deposits of taconite or iron-formation. Kleinkopf and Redden (1975) found that local dipole anomalies, as at Whitewood Peak and Richmond Hill (figure 14), correlate well with the position of some of the Tertiary intrusive bodies. Details on the original map indicate the location of other Tertiary intrusive centers.



Magnetic contours show total intensity magnetic field of the earth in gammas relative to arbitrary datum, hachured to indicate closed areas of lower magnetic intensity; dashed where data are incomplete

Contour intervals=100, 500, and 1000 gammas expressed in hundreds of gammas

FIGURE 14.—Generalized aeromagnetic map of the northern Black Hills. Modified after Meuschke, Philbin, and Petrafeso (1962).

One of the most interesting anomalies on figure 14 is the magnetic low centered about 6 miles southeast of Lead. The large amplitude indicates the presence of a thick section of weakly magnetized rocks. This area probably is near the axis of a large syncline in which the dominant rock is metamorphosed graywacke. The lowest part of the anomaly lies just west of a small area of Tertiary rhyolite tuff and breccia and small tilted outliers of Paleozoic rocks. The tuff and breccia have been interpreted as part of a down dropped cylindrical block that was the center of an Eocene volcano (Drake, 1967). Possibly the magnetic low is related to this structure. If so, the very size of the anomaly relative to other Tertiary intrusion centers indicates unusual conditions that warrant further investigation.

Ground Magnetic Surveys

A broad reconnaissance magnetometer map of South Dakota has been prepared by Petsch (1967). The data were collected from ground readings spaced 4 to 6 miles apart and show only the general configuration of the magnetic field for South Dakota. Petsch (1967) made no attempt to draw specific conclusions based solely on the magnetic data. However, in his discussion he listed 22 anomalies with amplitudes greater than 1,000 gammas. Of these he called particular attention to seven that had amplitudes exceeding 2,500 gammas. Both Petsch (1967) and Harrer (1966) discussed some of these prominent highs in terms of drilling results obtained by the South Dakota Geological Survey. For instance, at the Spink anomaly in Union County, a drill hole penetrated basement at 792 feet and encountered Precambrian mafic crystalline rocks which were found by chemical analysis to contain 14.47 percent iron. Since Petsch's report was published, two highs of approximately 8000 gammas in Marshall and Day Counties have been drilled and taconite deposits were encountered (see iron section of this report). Petsch (1967) also called attention to the unusual magnetic low anomaly that shows so prominently in the aeromagnetic data about 6 miles southeast of Lead. However, the broad spacing of his survey failed to reveal the magnetic anomaly associated with the taconite deposits of the nearby Nemo area.

Bayley (1972 a, b, and c) used ground magnetic surveys to trace the Precambrian taconitic iron formations beneath the overlying Paleozoic rocks and also to follow the structure of various magnetic rock units in the northern Black Hills.

Private companies have made an unknown number of local ground magnetic surveys in the Black Hills during exploration for gold and other metallic deposits. The results of these surveys are not available, but it is known that sulfide-bearing Precambrian rocks give significant local anomalies even though no ore bodies seem yet to have been found by such work.

Other Types of Geophysical Surveys

Other geophysical prospecting in the state has been limited to seismic surveys by petroleum companies and airborne radiometric surveys to find uranium in the Cretaceous sandstones around the Black Hills. Some electrical surveys have been done by private companies but the results are confidential. Several radiometric anomalies detected by airborne surveys led to the discovery of minable uranium deposits in the southern Black Hills.

In the eastern part of the State, the State Geological Survey has used the resistivity method in evaluating ground water reservoirs in glacial outwash deposits. A report by Lum (1961b) summarizes some of this work and discusses the limitations of the method in these particular deposits.

Conclusions

To date, most geophysical work has been restricted to the Black Hills area and only very broad surveys have covered the remainder of the state. The inadequacy of the latter is apparent in the failure of the widely spaced regional magnetic survey to show the Nemo taconite iron deposits. On the other hand, this same survey disclosed anomalies in Day and Marshall Counties that were later shown to be underlain by taconite. Magnetic surveys are of considerable assistance in mapping and exploration of the taconite deposits in the Black Hills and in helping decipher the structure of the Precambrian rocks. Such work may ultimately lead to discoveries of additional metallic deposits. Airborne radiometric surveys resulted in discoveries of uranium deposits in the Cretaceous sandstones. Electrical surveys have helped delineate ground water reservoirs in the eastern part of the State in areas of glacial cover.

The geophysical studies, though limited, illustrate the potential for defining target areas and stimulating exploration for minerals and petroleum in the State. The greatest need is for aeromagnetic surveys over the rest of the State. Such surveys provide data at a very low cost per unit area for interpreting subsurface geologic conditions and are notably valuable in areas of forests, crops, or glacial deposits. For example, glacial deposits cover most of the bedrock in the State east of the Missouri River, and magnetic surveys would be especially valuable in interpreting subsurface conditions.

GEOCHEMICAL EXPLORATION

(By G. H. Allcott, U.S. Geological Survey, Denver, Colo.)

Geochemical exploration is the systematic measurement of the chemical composition of natural materials as a guide to finding ore deposits. This is accomplished by: 1) sampling appropriate materials; 2) analyzing the samples for chemical constituents that are likely to be associated with a mineral deposit; 3) finding the normal level of concentration for each constituent in the area; and 4) interpreting significant differences from these normal levels as potential exploration targets or as indicating trends that may point toward mineral deposits.

Geochemical techniques are most successful in the search for metallic mineral deposits. Organic geochemical techniques have potential in the search for deposits of fossil fuels.

The geochemical detection of a mineral deposit depends upon the shape and size of the deposit, the primary chemical zoning around the deposit, the secondary dispersion of elements into surrounding materials, the structures influencing the distribution of these materials, and the relation of these features to the present ground surface. So long as part of the deposit or its alteration envelope is exposed, it is theoretically detectable by geochemical means. The degree of exposure or depth of burial of an ore deposit as well as the commodity sought and its geologic, geochemical, and climatic environment affect the methods and sample media used. For exposed deposits, sediment samples are preferred for reconnaissance and rock samples for detailed exploration. If the deposit is covered by thin overburden, then soils, water, gases, and vegetation may be sampled. Where the deposit is more deeply buried, samples of fracture fillings containing products of chemical emanations are useful, but where fractures cannot be sampled, indirect techniques depending on ore-associated elements and compounds in ground water have the potential of locating a hidden deposit.

Analytical methods must be precise enough so that the errors of the method do not obscure the natural variation in the particular sample medium. As a rule, the least precise methods that will be successful are chosen, for they require less time and are less costly.

The oldest analytical procedure is the panning of stream sediments for gold. The most common analytical methods currently in use include semiquantitative emission spectography, atomic absorption spectrography, X-ray fluorescence, and colorimetry.

Interpretation of the data involves a variety of statistical methods. Oftentimes large computer facilities are required. The results of these operations are the identification and mapping of geochemical anomalies or trends in concentration to be used as guides for drilling.

Past mining was started mainly by locating exposed mineral deposits. Future mining will depend largely on the discovery of buried deposits or the utilization of previously unrecognized kinds of ore. The greatest future role of geochemical exploration will be in the search for hidden deposits.

Mineral commodities most amenable to exploration by geochemical techniques, and having substantial production or suspected resources in South Dakota, are gold, silver, uranium, tungsten, iron, lead, zinc, copper, manganese, and vanadium. Elements known to be associated with these deposits, or appearing as independent mineral occurrences, and also suitable for prospecting by geochemical methods, include molybdenum, arsenic, bismuth, cadmium, barium, strontium, thallium, thorium, mercury, sulfur, selenium, tellurium, chlorine, fluorine, and the rare earths. Deposits of lithium, beryllium, tin, niobium, and tantalum in Black Hills pegmatites can be found more easily by other methods than geochemical exploration, but nonpegmatitic deposits of some of these metals may ultimately be found by geochemical methods.

The known metallic mineral deposits of South Dakota are mainly in the Black Hills. The paucity of metallic mineral deposits in the eastern part of the State may be real; however, it may reflect the low priority accorded exploration in an area difficult to prospect because of the cover of glacial drift.

Results from Various Kinds of Samples

Historically, rock and stream sediment samples have been most used for prospecting in South Dakota, but also available are soils, glacial sediments, vegetation, water, and gases. A survey by the Association of Exploration Geochemists (H. W. Lakin, written communication, 1972) on kinds of samples used in 26 countries showed 47 percent soil samples, 19 percent stream sediments, 8 percent rocks, and 26 percent samples of other types.

Rock.—Nearly all exploration programs must at some stage involve bedrock sampling, for most mineral deposits are in bedrock and the distribution of the ore must be determined through the use of rock samples. Most of the discoveries in South Dakota have been by locating and analyzing exposed ore bodies. Probably most of the favorable outcrop in the Black Hills has been sampled, and reconnaissance surface sampling will not lead to the discovery of significant new exposed deposits unless analyses are made for associated elements and new interpretations are developed.

In the uranium programs during the 1950's in South Dakota the analysis of rocks in place for uranium was accomplished by airborne and ground radiometric detectors.

Geochemical investigations and geologic mapping of Precambrian rocks in the Galena-Roubaix district and the Rochford district utilized rock as the sample medium (Bayley, 1970, 1972). The results showed that the deposition of gold was controlled by a chert-silicate lithology and by folds. Nearly all major folds were found to be at least slightly mineralized in the surface exposure.

The distribution of copper, silver, molybdenum, gold, zinc, mercury, and arsenic in bedrock samples along Calumet Ridge, Pennington County, has been determined by Raymond and others (1975). Although there has been development for copper in the area, a large block of ground has anomalies in a number of metals and has not been sufficiently explored.

The zoning pattern of copper, lead, zinc, arsenic, and mercury with respect to high grade ore, low grade ore, and stratigraphic units at different levels of the Homestake mine seems useful as a guide to ore (Mahrholz and Slaughter, 1967). For example, near the surface, concentrations of zinc, copper, lead, arsenic, and mercury increase slightly as ore is approached and decrease near and in the ore. At the 6,800-foot level neither lead nor zinc are in the ore but are 10 to 150 feet away from it. Arsenic anomalies are in or very close to gold ore having more than 0.3 ounce of gold per ton of rock, but 50–75 feet from gold ore of 0.06 to 0.3 ounce tenor. Mercury anomalies are 25 to 150 feet from high-grade ore.

Soils.—The use of soil as a sample medium for geochemical exploration, introduced about 1935, has become common. Few soil samples have been utilized for mineral exploration in South Dakota. Large numbers of soil samples have been analyzed physically and chemically for agricultural purposes, but the data have not been applied to mineral exploration.

Minor elements in the soils of South Dakota are discussed in five publications of which four are national in scope and in which South Dakota is represented by only 8 to 18 samples (Shacklette and others, 1971, 1971a, 1973, 1974), but the results show the regional trends in distribution of many elements. The fifth publication describes the use of soil samples in mineral investigations of the Precambrian rocks in the Galena-Roubaix area, where soil samples were found to be no more effective than rock samples (Bayley, 1970).

Stream sediments.—Panning of stream sediments was directly responsible for the discovery of gold in the Black Hills and also led to the discovery of other metals within a very short time. The ore of tin, cassiterite, was first identified in gold dust from the Tinton district in 1876, and a second discovery of cassiterite was made in the southern Black Hills in 1877 (Connolly and O'Harra, 1929, p. 212). The lead-silver districts at Galena and Carbonate were identified and brought into production by 1881 and 1885 respectively. Most of the productive metal deposits of the Black Hills, except the uranium deposits, had been located by about 1900, and stream sediments or rock samples were the principal source of information used by the prospectors.

Thereafter the use of stream sediments in prospecting appears to have lagged until the 1960's, when a geochemical exploration program was undertaken by the South Dakota Industrial Development and

Expansion Agency (IDEA) (Miller, 1962, 1964a, 1964b, 1967). This program was the first attempt at a comprehensive mineral resource evaluation by geochemical techniques in the State.

IDEA conducted a stream sediment survey of the Black Hills in the watersheds of Boxelder Creek, Spring Creek, Battle Creek, Rapid Creek, Whitewood Creek, Spearfish Creek, False Bottom Creek, Miller Creek, Bear Butte Creek, and Elk Creek. Analyses were made of sediments along Boxelder and Spring Creek for copper, iron, lead, manganese, tin, zinc, and zirconium. In the Battle Creek watershed the list was expanded to include beryllium, chromium, nickel, and vanadium. In the remaining watersheds beryllium and zirconium were dropped and cobalt, molybdenum, and titanium were added. Analyses were not made for some of the rare pathfinder elements associated with known ore deposits, such as arsenic, antimony, selenium, and tellurium. These elements may be disbursed well beyond the ore deposit and thus could enlarge the exploration targets.

The raw data from the IDEA stream sediment survey is presented in geochemical maps of the individual watersheds or geochemical maps of several watersheds. The data probably should be used with caution, but nevertheless are a source of valuable information. In the Squaw Creek drainage, 4 miles west of Lead, the map shows a textbook example of a geochemical anomaly for molybdenum in an area of previously known molybdenite. This anomaly has been drilled by a private company, but the results of the drilling have not been reported (J. A. Redden, oral communication, 1974). The geochemical map that includes False Bottom Creek shows anomalous lead and zinc along the northeast flank of Spearfish Peak. Other potentially interesting areas have been defined, but follow-up work is required. Some of the more attractive include 1) copper and zinc in sections 27, 28, 33, and 34, T. 2S., R. 5 E., 2) copper, tin, and zinc in sections 23 and 24 T. 2 S., R. 4 E., 3) copper and zinc in the northeast part of T. 2 N., R. 4 E., 4) zinc in sec. 2, T. 3 N., R. 4 E., 5) lead in sec. 34, T. 3 N., R. 3 E., and secs. 3, 4, and 10, T. 2 N., R. 3 E., 6) molybdenum in T. 2 N., R. 3 E., 7) vanadium around Rochford, 8) scattered copper, molybdenum, tin, and zinc highs from the Bear Butte Creek and Elk Creek drainages, and 9) copper, molybdenum, lead, and zinc in T. 5 N., R. 2 E.

Glacial deposits.—Glacial debris is widely available as a geochemical exploration sample medium in the eastern part of South Dakota. Its use is complicated by variations in thickness within short distances and differences in the source and history of the material. Geochemical anomalies may result from transported constituents as well as from local causes.

Although geochemical exploration with glacial deposits has been successful in other parts of the world, the only recorded use of this material in South Dakota is associated with the occurrence of gold in glacial gravels of the Big Sioux Valley (Rothrock, 1944).

Vegetation.—Vegetation is used in geochemical exploration by chemical analyses of the ash of plants, by the study of the population distribution of different kinds of plants, and by remote sensing. The usefulness of these techniques depends on the responsiveness of the vegetation to the chemistry of its environment.

The most commonly used method involves the sampling of vegetation, analysis of the ash, and interpretation of the variation in the concentrations of the chemical constituents. The conceptual basis is that the roots of plants will reach covered or buried mineral deposits or water coming from such deposits, and will incorporate some chemical elements thus obtained into the system of the plant. The only such investigations in South Dakota appear to be unpublished. An example is a recent orientation study conducted by the writer in which organs of ponderosa pine were collected over different rock units in both mineralized and unmineralized areas of the Black Hills. Preliminary results are encouraging.

Study of the distribution and population densities of indicator plants can be enlightening. Indicator plants are either individual species of plants or are plants with characteristic variations in growth habits that reflect different geochemical conditions. Certain species may be restricted to areas of anomalous concentrations of a particular element, or the plants over a geochemically anomalous area may, through color variations, stunting, or sparsity of numbers, reflect the stress of growing in that environment. Helen Cannon (personal communication, 1974) in the early 1950's, found that several plants, especially the families Euphorbiaceae, Leguminosae, Cruciferae, and Compositae, seemed to be associated with uranium ore deposits in Craven Canyon, Fall River County.

Remote sensing is a technique by which differences in the surface materials are detected by photographs or images using ultraviolet, visible, infrared, or microwave radiation. Plants growing in a geochemically anomalous soil may show symptoms of physiological stress, such as the absence or deficiency of green pigment. Though the technique is in a research stage, experiments have shown (F. C. Canney, personal communication, 1974) that detection of changes in reflectance characteristics of vegetation in the infrared or the visible part of the electromagnetic spectrum offer the best chance of locating geochemical anomalies. One of the test areas is in the Black Hills.

Water.—Most substances analyzed in geochemical exploration have been transported by water and have gone through chemical reactions in the process. Water is also one of the few media available for use in the search for deeply buried mineral deposits. Waters related to mineral deposits in South Dakota might be expected to include traces of uranium, molybdenum, cadmium, zinc, copper, sulfur, and fluorine at the parts per billion level. This low level is a hindrance because of the lack of suitable analytical methods, but ways of overcoming this deficiency are being developed.

No use of water in geochemical exploration in South Dakota is recorded.

Gases.—Gases for geochemical exploration are those in or near the surface of the ground (soil gases) and those in the atmosphere. Materials include mercury, sulfur dioxide, hydrocarbons, certain metal-organic compounds, rare gases, and airborne particulate matter. The use of gases in geochemical exploration have been investigated mainly since about 1960, and much of the work is in an experimental stage. Aside from some work with mercury, gases have not been used in South Dakota.

Future Geochemical Exploration in South Dakota

The future of geochemical exploration in South Dakota appears bright. From what is known about the mineral deposits and geology of the State, it is reasonable to expect that buried deposits remain to be discovered and that geochemical techniques will be helpful in finding them.

Long range mineral evaluation.—Two alternatives are available for the broad evaluation of the mineral resource potential of an area. The historically most important is commodity oriented: as demand develops for a mineral commodity an intensive effort is made to find reserves of it, to the neglect of other mineral resources. The other method is to gather basic data for as many kinds of mineral resources as may be economically and technically feasible at the time. Both approaches are useful, but with more of the second there should be less need of the first.

The geochemical part of a long range program for evaluating the mineral resource potential of a State should begin with a reconnaissance survey of the entire State. Stream sediments are a good reconnaissance sample medium, for they represent an averaging of the geologic materials in the drainage basin. Such sampling would be most applicable in the nonglaciated areas of South Dakota, though useful also in glaciated areas if most of the drift has come from within a few miles of its present position. Soil and rock samples, though also helpful, represent smaller geographic areas and tend to show greater variations in composition, thus requiring a detailed knowledge of the geology for proper interpretation. Vegetation, particularly deep rooted species, may provide a means for geochemical exploration through the glacial drift of eastern South Dakota.

Ground water is a geochemical sample medium which has not been exploited in South Dakota. The thousands of wells scattered over the State represent a great untapped source of data to use in exploring for buried mineral deposits. A program to collect and analyze water from these wells for trace elements, as well as the normal constituents sought in testing for the quality of water, would provide information about patterns of circulation and potential sites of mineral deposits.

Among the gases, hydrocarbons and rare gases, particularly the helium reported in South Dakota gas wells, may indicate petroleum and gas resources. Metal-organic compounds, sulfur gases, and mercury can direct the way to sulfide deposits. The rare gases helium and radon may indicate deposits of radioactive minerals.

Regional and detailed investigations.—More detailed geochemical information would be particularly useful in and near the known mineralized areas of the Black Hills, not only to identify exploration targets but also to enhance the planning capability of government and business organizations concerned with mineral resources.

Two recent studies have suggested areas and methods for further exploration. Norton (1974) proposed that Precambrian gold deposits similar to the Homestake ores may exist under cover of younger rocks, and that they may be detected by investigation of these younger rocks. Shapiro and Gries (1970), from an investigation of the ore deposits in Paleozoic and Tertiary rocks of the northern Black Hills, recommended further work in several localities.

The observations in the literature may be variously interpreted, and some interpretations raise questions regarding former evaluation of the mineral potential in the State. Additional systematic geochemical exploration could answer some of these questions or help lead to answers. The literature shows:

1. The Black Hills is obviously a gold province, but a thorough geochemical evaluation has not been made of the distribution of gold and related elements.
2. Several unusual commodities have been produced in this area—tungsten and tin are the best examples—but results of systematic heavy mineral surveys are not recorded.
3. Sporadic occurrences of molybdenum are found in the Cretaceous and Tertiary sedimentary rocks outside the Black Hills and in Precambrian rocks and Tertiary intrusions within the Black Hills. What is their full distribution, and are they minable?
4. Fluorite is associated with Tertiary deposits of gold, silver, and other metals in the Bald Mountain area, with gold in the Ragged Top district, and alone in the Bear Lodge area of Wyoming. Does this reflect a vertical zoning pattern that would serve as a guide to buried deposits?
5. Vanadium is associated with the lead-silver ores at Carbonate and Galena. Fluorite is commonly reported in the Tertiary deposits west of Lead, but no mention is found of fluorite to the east. If a regional zoning pattern exists, it can be of importance to future exploration.
6. Tellurium is associated with Tertiary gold deposits. This element should be used as a pathfinder, because a method for analysis at low levels of concentration is available.
7. The Homestake lode contains abundant arsenopyrite, closely associated with gold. Arsenic may have been volatilized by Tertiary instrusives. If so, it may be found around and in these intrusives and used as a guide to buried ore.

Geochemical techniques are available to begin to provide evidence bearing on these and other problems, and may well lead to the discovery of new ore deposits.

ENVIRONMENTAL EFFECTS OF MINERAL AND WATER DEVELOPMENT IN SOUTH DAKOTA

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

The development of mineral and water resources inevitably has effects, either good or bad, on the environment. The effects may be caused directly by man's activity, as is true of mine subsidence, or may be the result of unwise use of terrain that is subject to natural geologic hazards, as with the flooding of urbanized flood plains. Many of these effects fall in the general field of study variously called engineering geology, urban geology, or environmental geology.

The purpose of this section is to discuss the aspects of environmental geology in South Dakota related to development of water resources and mineral industries. Subjects such as earthquakes, volcanic hazards, and landslides, normally considered part of environmental geology, are treated only to the slight extent that they are pertinent in South Dakota.

WATER RESOURCES DEVELOPMENT

One of the major uses of water resources is for the development of urban areas, and it is not by chance that most of our cities are built along rivers or lakes. Flood plains in particular seem desirable for residential construction because of their level surface; but they are level because they occasionally become flooded—a fact learned by early settlers but too often ignored in today's rush to house a growing population. Indifference to a recognized natural hazard potential can have disastrous results.

On June 9, 1972, as much as 14 inches of rain fell within 6 hours on the eastern flank of the Black Hills, and the resulting floods killed 236 people and caused well over $100 million in damage. Rapid City was especially hard hit, for the discharge reached a peak of 50,000 cubic feet per second (cfs) on Rapid Creek and Canyon Lake dam was washed out. Though a flood of this magnitude is rare, geologists and hydrologists recognize floods as inevitable. A stream overflows its banks and inundates the flood plain every few years. All the death and destruction in Rapid City was limited to the flood plain of Rapid Creek. A comparison of the area flooded (Larimer, 1973) and limits of the flood plain, as mapped and published on conventional geologic maps (Cattermole, 1969, 1971), shows an almost exact correlation. Thus the flood plain was well-known, and outlined on published maps, prior to the flood. The problem was that construction of homes on the flood plain was not prohibited.

Rapid City learned the hard way and has now invested $64 million in its floodway, mostly through federal urban renewal funds, and is converting the Rapid Creek flood plain into a park, which includes some commercial establishments but no residential areas. The next flood of this size on Rapid Creek will not be a disaster in Rapid City. However, in other areas in the eastern Black Hills the lesson has been neglected. Some of the communities devastated by the June 9 flood have been reconstructed. In Keystone, more buildings than ever are jammed into the narrow flood plain of Grizzly and Battle Creeks. On the flood plain of Rapid Creek just southeast of the city limits of Rapid City, scores of trailer homes have been located since the flood—on land that was inundated on June 9. Floods are inevitable; but with proper planning, flood damage can be averted.

Flood-controlled dams are an alternative to flood plain zoning. The Missouri River dams and large dams in the Black Hills afford excellent flood control as well as making water available for recreation, hydroelectric power, and irrigation. The construction of more dams does not, however, meet all needs for flood control. Dams may afford flood protection for only a short distance downstream; for instance, the new Pactola Reservoir is only 10 air miles upstream from Rapid City but did little to reduce the flood of June 9, 1972. Poorly constructed dams can fail and add to flood discharge, as with the failures of Canyon Lake, Dalton Lake, and others on June 9, 1972. Some dams have been poorly located geologically in the Black Hills and do not serve the multiple functions for which they were designed. Cottonwood Springs Canyon Reservoir near Hot Springs, completed in 1971, was built on the permeable Minnelusa Formation and Pahasapa Limestone and therefore does not hold water; the reservoir has been dry since it was built. Other Black Hills dams—such as Cedar Canyon, Fort Meade, and Cold Brook—are also built on permeable rocks and have similar histories.

The construction of dams may cause unexpected adverse environmental effects. The Missouri River is severely eroding its banks below the large main stem dams. This is because the clear water flowing over the dam contains no bedload and little suspended load, and is trying to establish equilibrium between its load and other hydraulic conditions. The rapid erosion affects both river banks and bridge foundations. Elsewhere in the world, earthquakes have been triggered by the increased load and hydrostatic head caused by the construction of large dams, but there is probably little chance that this would happen in South Dakota because of the absence of active faults and very high dams. The great size of Oahe Reservoir raises the possibility that earthquakes could be triggered near Pierre, although Agnew and Tullis (1962) concluded that the Pierre earthquake of 1961, having a depth of 10 miles, was not caused by Oahe Reservoir.

The possible adverse environmental effects of the proposed Oahe irrigation project in the upper James River valley present an incompletely resolved problem. The project calls for the diversion of at least 1,200 cfs from the Missouri River near Pierre to irrigate initially 190,000 acres and ultimately 495,000 acres in the Dakota Plain north of Redfield. About 200 miles of main supply canals are required, as well as three major regulating reservoirs and about 1,000 miles of small canals and laterals. Because of the flatness and low permeability of the glacial terrain that is to be irrigated, the construction of 935 miles of surface drains and almost 3,000 miles of subsurface collector drains is required. The U.S. Bureau of Reclamation estimates the project will cost more than $300 million (this report).

Major environmental concerns associated with the Oahe irrigation project were presented by the Environmental Protection Agency and others in the Environmental Impact Statement (U.S. Bureau of Reclamation, 1973). They include (1) the degradation of water quality downstream caused by saline irrigation return flows to the James River, (2) increased flooding caused by channelization of 120 miles of the James River, and (3) waterlogging and salinization of the irrigated areas. Construction of the pumping plant near Pierre began in 1974.

The development of ground-water resources in South Dakota has had little direct impact on the surface environment. A more indirect environmental effect has been the drain on the artesian water resource itself. Many flowing wells waste water as their casings are eroded. Some flowing wells discharge water under the Missouri River reservoirs; small circles of open water mark their location when the reservoirs are frozen over in the winter. The mixing of brackish waters from deep wells, where uncased, may lead to the pollution of overlying fresh-water surficial aquifers. Because the aquifers are deep and consolidated, land subsidence due to ground-water withdrawals from artesian aquifers has not been observed in South Dakota as it has elsewhere in the world.

METALLIC MINERALS

The mining of gold placers in the Black Hills in the late 1870's caused disruption and pollution of the streams. Discharge of mine wastes into streams continued with the development of bedrock mines. Virtually all of these mining activities and related pollution have now ceased. The single exception is the Homestake gold mine at Lead, which has been operated almost continuously for nearly 100 years, and is now the most productive gold mine in the United States. During this time, an estimated total of 65 million tons of tailings have gone into Whitewood Creek, a tributary of the Belle Fourche and Cheyenne Rivers.

Whitewood Creek at Whitewood has an average discharge of about 25 cfs and carries about 2,700 tons per day of silt, mostly crushed quartzite. Mercury was formerly used in the amalgamation of gold, and an estimated 12 to 40 pounds of mercury was lost each day into Whitewood Creek (U.S. Environmental Protection Agency, 1971). A preliminary check on the mercury level in the flesh of fish in the Cheyenne River arm of the Oahe Reservoir showed that the levels were in excess of the Food and Drug Administration's guideline of 0.5 parts per million (ppm). Other toxic effluents discharged by Homestake are average daily loads of 312 pounds of cyanide, 240 pounds of zinc, and 9.5 tons of arsenopyrite. The arsenopyrite is oxidized, resulting in arsenic concentrations in the Cheyenne River that are four times greater than the U.S. Public Health Service water-supply criterion.

Untreated municipal waste from Lead and Deadwood also contributes to the pollution of Whitewood Creek, and would constitute a health hazard were it not for the fact that virtually all organisms are killed by the mining wastes. Homestake discontinued using the mercury amalgamation process in December 1970. However, the large quantities of mercury as well as arsenic and cyanide contained in the alluvial deposits along Whitewood Creek and the Belle Fourche and Cheyenne Rivers may be an environmental hazard for years to come. The mercury content in shallow ground water in these deposits is higher than the recommended limit of 0.5 ppm for drinking water (U.S. Environmental Protection Agency, 1971)

Plans are now being made for the complete renovation of Whitewood Creek. The initial plan by an engineering company for the construction of a large tailings and sewage lagoon in Centennial Valley met with strong opposition by a group of local citizens who feared the toxic waters would pollute ground water. During the public hearings in Deadwood in December 1973, the Lead-Deadwood Sanitary District proposed an alternative plan by another company for a tailings lagoon in Grizzly Gulch on Homestake property. This plan is being studied.

The uranium mines northwest of Edgemont produce no significant water or air pollution. Areas disturbed by underground or strip mining are small. Some operations present minor hazards for livestock and man, but these can be remedied by appropriate fencing. The radioactive ore dumps along the banks of the Cheyenne River may constitute a local hazard below Edgemont, but these are monitored by various Federal agencies.

In plans for development of the large taconite iron deposits near Nemo, some environmental problems must be faced. A major concern is the source, use, and disposal of the water required for processing the ore. The creeks near the deposits have little discharge. Withdrawal of large amounts of ground-water from the Pahasapa Limestone several miles to the east could effect water supply elsewhere. However, modern technology, through recycling of water, precipitation of dust, and other means, can keep water and air pollution to a minimum during mining and concentrating of ore. No large area will be strip mined, for the surface area underlain by taconite totals only about 160 acres (Bayley, 1972b). The iron mining will probably result in a few large open cuts similar to the taconite mine at Atlantic City, Wyoming. The ore is largely composed of iron oxides; it contains little soluble matter that could pollute surface or ground waters, and lacks iron silicates of the kind that in Minnesota have caused concern for public health.

Iron-rich waters drain from areas where bog iron was mined in Quaternary deposits along the flood plains of tributaries of Rapid Creek near Rochford (Luza, 1970). Degradation of the streams, in the form of rusty-colored acidic water and lack of aquatic life, generally persists for as much as a mile downstream from the mined areas. However, the bog iron deposits are not likely to be mined in the future, at least partly because of the resulting stream pollution Similar iron-rich waters and sterile environments seem to be present in many tributary canyons of Castle and Rapid Creek where there has been no bog mining. This iron results from the natural oxidation of sulfide-rich slates and phyllites, and is transported into the valley alluvium by ground-water (Rice, 1972).

Old abandoned metal mines in the Black Hills have little current environmental impact, although numerous unmarked prospect holes and shafts constitute a hazard for hikers. Gries (1971, 1974) measured discharge, acidity (pH), and conductance of waters draining old bedrock mines in the Black Hills, and found that in the northern Black Hills the total discharge of water from abandoned metal mines was less than 500 gallons per minute (gpm), and the mineral content and acidity of the drainage waters was generally highest where the discharge is very low. The most acidic mine drainage observed was in Strawberry Creek below the Gilt Edge mine near Galena, where the average pH was 3.0 and the average discharge was 1 gpm. Strawberry Creek empties into Bear Butte Creek, which contains no fish from the mouth of Strawberry Creek to where it disappears in limestone sinkholes 4 miles downstream. Mines having larger discharges have better quality water. Drainage from the Cutting (Gladiator) Mine near Lead is potable and serves as a source of water for the town of Deadwood.

Nonmetallic Minerals

Sand and gravel pits are scattered throughout the State and contribute much to the mineral segment of the economy. Even the largest pits—near Oral, Wasta, and Brookings—cause little ground to be disturbed. Indeed, it may be argued that the land 3 miles south of Brookings along I–90 is now more valuable for man and wildlife than before the gravel was quarried, as the area now contains fresh-water recreational ponds that occupy abandoned gravel pits.

Rapid City has the greatest air pollution in the State. A significant contributor to this pollution, in spite of stack precipitators and scrubbers, is the State-owned cement plant, the only cement plant in the State. Plans are being made to double the plant's current production. One means of avoiding an increase in the pollution of Rapid City's air would be to build a new plant elsewhere, for the Minnekahta Limestone, source rock for the cement, is present at the surface entirely around the Black Hills.

Large quarries for the mining of road aggregate or dimension stone are in the Sioux Quartzite at Sioux Falls and Dell Rapids, in the Minnekahta Limestone at Rapid City, and in the Milbank granite at Milbank. Little environmental damage is associated with these operations except for the creation of dust and the aesthetic impact of a large quarry. Quarries in the Sioux Quartzite are reclaimed by allowing them to fill with water to become recreational lakes; those in the Minnekahta Limestone in Rapid City could be used for urban construction after quarrying ceases.

Old bentonite strip mines west of Belle Fourche and south of Buffalo Gap are marked by unsightly waste heaps and disturbed ground where little reclamation work was done in the first half of this century. Improved reclamation techniques at the pits near Belle Fourche may improve the duck habitat by creating artificial ponds.

Pegmatite mining has left many open holes and quarries in the Black Hills, but most of them are very small. Their adverse effect on the scenery is at least partly offset by their recreational value to rockhounds. Perhaps best viewed as a mixed blessing is the fact that some quarries are used as dumps for local refuse that might otherwise be scattered throughout the Black Hills.

Organic Fuels

Oil and gas development in South Dakota has been minimal, and has led to virtually no environmental damage. Plugging of abandoned exploratory drill holes has prevented mixing of good and bad water from different aquifers.

South Dakota has vast lignite resources, but at present they are not competitive with the exceptionally thick sub-bituminous coal and lignite in Wyoming, Montana, and North Dakota. However, massive coal developments that are anticipated in these adjacent states may affect South Dakota's environment. Mine-mouth electric plants could pollute South Dakota's air. Demands for surface and ground water in the adjacent states may cause problems associated with interstate streams and aquifers. A proposed coal slurry pipeline would take 9,000 gpm from wells in the Madison Limestone at a location in Wyoming near the State border west of Edgemont. Although details of the permeability, porosity, and recharge to the Madison are not known, the cone of depression seems likely to cross the State boundary and influence the water pressure in this aquifer in southwestern South Dakota. In October 1974, South Dakota filed suit against Wyoming in order to allow for a more detailed assessment of this environmental impact.

SUMMARY

Past development of water and mineral resources has had varying degrees of impact on South Dakota's environment. Appropriate planning is necessary to keep the effects of future developments within acceptable limits. The Rapid City flood of 1972 indicates the need for flood plain planning and zoning. Dam construction will continue to serve valuable functions for flood control and low flow augmentation of streams. The location of dams requires careful consideration of geology in order to avoid permeable rocks that allow leakage of reservoir water. Continued studies of ground water withdrawals, safe yields, and long-term future needs are required. South Dakota's role in future ground- and surface-water diversions arising from the development of coal in adjacent states should be studied.

Tailings from the Homestake mine have considerably degraded the environment of the Whitewood-Belle Fourche River system, but appropriate remedies for control of tailings discharge and milling techniques should reduce this effect. Otherwise, past mining operations in the Black Hills have had relatively little adverse effect on today's environment. Taconite iron mining is likely to be a major future activity in the Black Hills, and appropriate planning is required to keep potential environmental problems to a minimum.

A major need in the development of all mineral and water resources is interdisciplinary planning to utilize these resources before some other land use permanently preëmpts them. Planning would avoid such problems as that of the Brookings dump, which is in Brookings County's best aquifer (Lee, 1958). Sand and gravel or rock quarries near urban areas should be developed before the land is used for home or residential areas. Once urbanized, the resource will be lost.

MINERAL RESOURCES

INTRODUCTION

(By J. J. Norton, U.S. Geological Survey, Reston, Va.)

In the following pages the mineral deposits of the State are discussed in three categories: 1) metallic minerals, 2) nonmetallic minerals, which also are commonly referred to as industrial minerals and rocks, and 3) the mineral energy sources. Most sections treat a single commodity, but where two or more mineral products ordinarily occur together in one kind of deposit they are discussed as a group. The most important products based on past production and future outlook are generally discussed first and the least important last.

For each commodity the history of mining and exploration is summarized and available production figures tabulated, generally for the entire period from the earliest year of recorded mining to the end of 1973. The standing of South Dakota's output relative to other sources is mentioned where pertinent, but is omitted for commodities such as sand and gravel that are ordinarily shipped only a short distance. The uses of many mineral products are too well-known to merit discussion; for others the uses are less widely known and are described in some detail.

The geographic distribution and geologic environment of the various kinds of deposits are described extensively, as is their mineralogy, structure, and other traits that influence their value. Mining, processing, and marketing problems are summarized where they are out of the ordinary.

A key question in discussing a mineral commodity is how much material suitable for use remains in the ground. The question, more exactly stated, is what is known to be present and what is the expectation for future discoveries or for development of known deposits that have not yet been mined. The words "reserves" and "resources" are the customary labels for estimates of the amounts likely to be available. Oftentimes such estimates are subdivided according to the completeness of the data on which they are based and the economic feasibility of extraction. The words sum up a group of complex concepts involving geologic, engineering, and marketing considerations.

"Reserves" applies only to material that can be obtained at a profit commensurate with the business risks and for which there is considerable evidence of its existence and location. The word is almost invariably misused by laymen, and oftentimes carelessly used by professionals. Undiscovered ore, even if of great value, is not a reserve until its existence and location become known and its nature can at least be inferred from geologic evidence. Then as tests of various kinds increase knowledge of the quality of the ore bodies, their size and shape, the amenability to milling or other processing, and the marketability of the product, quantitative estimates proceed through a series of categories until they become what is known as a "measured" or "proved" reserve when the ore is ready for mining. Because such work is costly, the proved reserves of a mine tend to be maintained at a level only large enough to plan the mining properly and to justify any capital expenditures required, though there is also a necessity to obtain enough information about additional ore to predict how operations will proceed in the long-term future. Yet there is little reason to spend money to prove reserves that will not yield a return until many years later. For some commodities there is even a risk that what are considered reserves now will cease to be reserves in the future as a result of the discovery of better deposits elsewhere or technological changes that alter the market.

"Resources" includes both reserves and material that gives promise of being mined in the future. It includes undiscovered deposits that would, if found, be minable immediately. It also includes material, discovered as well as undiscovered, that cannot now be profitably used but may be mined when better deposits are depleted or technological and market conditions change. Investigations of such resources, which are important in gaging the future, tend to be in the province of governmental organizations, whereas the search for reserves to be more promptly used is mainly by industry, though there are exceptions on both sides. The example of resource studies that is of greatest current interest is the many decades of work on coal and oil shale, the results of which have made the energy crisis less intimidating than it would otherwise be.

In estimates of reserves and resources, the quality and quantity of the data and their probable meaning are more important than mere numerical summaries. Most of the discussions of the various commodities on the following pages will treat resources not primarily in terms of arithmetic calculations but instead will emphasize the meaning and the shortcomings or strengths of the available information.

METALLIC MINERALS

Gold and Gold-Silver Deposits

(By J. J. Norton, U.S. Geological Survey, Reston, Va., and J. A. Redden, South Dakota School of Mines and Technology and U.S. Geological Survey, Rapid City, S. Dak.)

Production and history

South Dakota has a recorded gold production through 1973 of 35,484,483 troy ounces, of which 32,212,129 ounces or 91 percent came from the famous Homestake mine at Lead (table 3). This amounts to slightly more than 1 percent of all the gold that man has ever mined. The gross value of the Black Hills production somewhat exceeds the billion dollar mark, which generally is taken as the lower limit in defining what constitutes a major mining area. At the approximately $180 per ounce price widely quoted in December 1974, this quantity of gold would be worth $6.4 billion.

TABLE 3.—GOLD AND SILVER PRODUCTION FROM SOUTH DAKOTA AND THE HOMESTAKE MINE, 1875-1973

[From U.S. Bureau of Mines except as noted]

Year	Gold			Silver		
	South Dakota		Homestake mine (troy ounces)[1]	South Dakota[2]		Homestake mine (thousands of troy ounces)[1]
	Troy ounces	Value (thousands)		Troy ounces (thousands)	Value (thousands)	
1875	70	$1	-----	-----	-----	-----
1876	[3] 60,000	[3] 1,200	-----	4	$4	-----
1877	100,606	2,080	-----	6	7	-----
1878	157,356	3,253	3,636,340	8	9	3,604
1879	117,067	2,420		8	9	
1880	174,150	3,600		55	63	
1881	193,500	4,000		54	61	
1882	159,637	3,300		135	154	
1883	154,800	3,200		115	129	
1884	159,638	3,300		115	129	
1885	154,800	3,200		78	83	
1886	130,612	2,700		325	325	
1887	116,110	2,400		422	409	
1888	125,775	2,600		77	73	
1889	140,287	2,900		105	99	
1890	154,800	3,200		100	105	
1891	171,731	3,550		100	99	
1892	178,987	3,700		58	51	
1893	193,809	4,006		140	109	
1894	159,594	3,299		59	37	
1895	187,187	3,870		159	104	
1896	240,414	4,970		230	155	
1897	275,491	5,695		148	89	
1898	275,723	5,700		152	90	
1899	312,962	6,470		146	88	
1900	298,842	6,178		536	332	
1901	313,446	6,480		78	47	
1902	336,952	6,965		340	180	
1903	330,243	6,827		221	119	
1904	356,264	7,364	1,676,769	162	93	
1905	334,460	6,914		179	109	
1906	319,512	6,605		155	105	
1907	200,185	4,138		107	70	
1908	374,529	7,742		197	106	
1909	317,998	6,574		196	102	
1910	260,267	5,380		121	65	
1911	359,904	7,440	2,838,803	204	108	
1912	381,745	7,891		206	127	
1913	354,071	7,319		173	104	
1914	354,758	7,334		177	98	
1915	358,280	7,406		200	101	
1916	360,909	7,461		215	142	
1917	356,245	7,364		187	154	
1918	317,598	6,565		159	159	
1919	235,250	4,863		116	130	
1920	226,224	4,676		91	99	
1921	319,525	6,605	3,125,607	112	112	
1922	315,298	6,518		119	119	
1923	309,905	6,406		96	79	
1924	295,930	6,117		87	58	
1925	289,747	5,990		96	67	
1926	279,529	5,778		82	51	
1927	322,032	6,657		96	55	
1928	317,379	6,561		91	53	
1929	316,837	6,550		85	45	
1930	407,221	8,418		105	41	
1931	432,075	8,932	5,205,669	114	33	
1932	480,338	9,929		126	36	
1933	512,404	13,097		125	44	
1934	486,119	16,990		100	64	
1935	567,230	19,853		151	109	
1936	586,353	20,523		144	112	597
1937	581,544	20,354		140	108	
1938	594,847	20,820		162	105	
1939	618,536	21,649		168	114	
1940	586,662	20,533		176	125	
1941	600,637	21,022	556,963	171	121	118
1942	522,098	18,273	486,696	187	133	109
1943	106,444	3,726	103,675	36	26	21
1944	11,621	407	11,495	5	4	3
1945	55,948	1,958	53,498	27	19	13
1946	312,247	10,929	298,470	87	70	54
1947	407,194	14,252	393,174	112	101	78
1948	377,850	13,225	360,716	95	86	72
1949	464,650	16,263	447,070	109	99	84

See footnotes at end of table.

TABLE 3.—GOLD AND SILVER PRODUCTION FROM SOUTH DAKOTA AND THE HOMESTAKE MINE, 1875–1973—Cont.

	Gold			Silver		
	South Dakota			South Dakota[2]		
Year	Troy ounces	Value (thousands)	Homestake mine (troy ounces)[1]	Troy ounces (thousands)	Value (thousands)	Homestake mine (thousands of troy ounces)[1]
1950	567, 996	19, 880	548, 927	142	129	111
1951	458, 101	16, 034	441, 108	140	126	96
1952	482, 534	16, 889	466, 809	132	120	92
1953	534, 987	18, 725	520, 072	139	125	106
1954	541, 445	18, 951	524, 358	151	137	116
1955	529, 865	18, 545	514, 510	154	139	104
1956	568, 523	19, 898	551, 577	136	123	109
1957	568, 130	19, 885	554, 912	135	122	117
1958	570, 830	19, 979	558, 943	153	138	111
1959	577, 730	20, 221	573, 384	124	113	114
1960	554, 771	19, 417	554, 770	108	98	108
1961	557, 855	19, 525	557, 838	127	118	127
1962	577, 232	20, 203	577, 231	113	123	112
1963	576, 726	20, 185	576, 723	117	150	116
1964	616, 913	21, 592	616, 910	133	172	133
1965	628, 259	21, 989	628, 259	129	167	129
1966	606, 467	21, 226	606, 467	110	142	110
1967	601, 785	21, 062	601, 783	121	188	121
1968	593, 052	23, 283	592, 333	138	295	137
1969	593, 146	24, 621	593, 101	124	223	124
1970	578, 716	21, 059	578, 644	120	212	117
1971	513, 427	21, 179	513, 494	107	165	106
1972	407, 430	23, 875	407, 397	100	168	99
1973	357, 575	34, 974	357, 634	72	184	72
Total	35, 484, 483	1, 065, 632	32, 212, 129	13, 048	10, 897	7, 440

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[1] From Slaughter, 1968, p. 1438 for 1878–1965. From Homestake Mining Co. annual reports thereafter except that silver production for 1973 is assumed to be the total State production.

[2] Dollar values are from Allsman, 1940, p. 8 for 1876–88. Ounces are calculated using prices quoted by U.S. Mint.

[3] Allsman, 1940, p. 8, is the source of the value $1,200,000. Ounces estimated by dividing by 20.

Most of the more than 3 million ounces from mines other than the Homestake also came from the northern Black Hills. Table 4, which identifies the sources of the gold to the extent possible, shows that two properties near Lead each approached a million ounces in output from Tertiary replacement deposits in the Deadwood Formation. The same table indicates that about 99 percent of all the gold came from within 5 miles of Lead. The principal district elsewhere is at Keystone, which probably has yielded somewhat more than 100,000 ounces. The Black Hills Mineral Atlas of the U.S. Bureau of Mines (1954a, 1955) summarizes data on 225 gold properties, and even it does not treat all the places that have drawn more or less serious attention. The most important localities are shown in figure 15.

Silver production has amounted to 13,048,000 ounces selling for $10,897,000. Of this total, 7,440,000 ounces or 57 percent was a by-product at the Homestake mine. Approximately 1,500,000 ounces came from lead-silver deposits, to be described in the succeeding section. The slightly more than 4 million ounces remaining came from the smaller gold mines, especially the deposits in the Deadwood Formation.

The original discovery was of placer gold at an encampment of the Custer expedition of 1874 on French Creek, 3 miles east of what is now the city of Custer. The far richer placers of Deadwood Gulch were discovered in November 1875, and the first lode claims on what became a part of the Homestake property were located in December. The original Homestake claim was located in April 1876.

TABLE 4.—SOURCES OF GOLD MINED FROM THE BLACK HILLS, 1875-1973[1]

Mine or locality	Location	Principal source of ore[2]	Gold produced (in troy ounces)
Principal mines:			
Homestake	At Lead, Lawrence County	pCif	32,212,129
Golden Reward group of mines	2 mi southwest of Lead	Cdd	950,000
Bald Mountain group of mines	3 mi west of Lead	Cdd	836,000
Mogul	3 mi southwest of Lead	Cdd	350,000
Placers of Deadwood region	Near Deadwood	QTp	200,000
Maitland (Penobscot)	3 mi north-northwest of Lead	Cdd	147,000
Wasp No.2	2 mi south of Lead	Cdd	120,000
Keystone and Holy Terror	At Keystone, Pennington County	pCq	86,000
Gilt Edge	5 mi east-southeast of Lead	Ti	56,000
Spearfish Gold	7 mi west of Lead	Mp	45,464
Clover Leaf (or Uncle Sam)	At Roubaix, 7 mi southeast of Lead	pCq	43,885
Lundberg, Dorr, and Wilson	2 mi west-southwest of Lead	Cdd	43,617
Hoodoo—Union Hill	5 mi east-southeast of Lead	Ti	30,000
Reliance	5 mi west of Lead	Cdd	27,003
Rockerville placers	Just east of Rockerville, Pennington County.	QTp and Cdc	20,000
Ragged Top	6 mi west of Lead	Mp	15,800
Deadwood, Standard	7 mi west of Lead	Mp	11,983
J.R	3 mi N. 60° east of Hill City, Pennington County.	pCq	11,500
Hidden Fortune	Just north of Lead	Cdd	10,997
Other deposits:[3]			
Lawrence County (especially Alder Creek— Cleopatra, Bismarck, Golden Crest, Monarch, and Kicking Horse).[4]		Cdd	50,000
Pennington County (especially Empire, Bullion, Standby, and Sunnyside.)[4]		pCif and pCq	30,000
Custer County		pCq	4,000
Total production from identified sources.			35,301,378
Production from unidentified sources			183,105
Total recorded production			35,484,483

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[1] Modified from Norton, 1974, table 1. Footnotes to the original table give details of how the data was obtained.

[2] pCif, Precambrian iron-formation; pCq, quartz veins in Precambrian metamorphic rocks; Cdc, conglomerate at the base of the Deadwood Formation; Cdd, replacement bodies and veins in dolomite and other rocks of the Deadwood Formation; Mp, Pahasapa Limestone; Ti, Tertiary igneous rocks; QTp, Quaternary and Tertiary placer deposits.

[3] None of the hundreds of small placer deposits mined after the gold rush years are included.

[4] Mines specifically named are those that have a recorded or estimated production of between 3,000 and 10,000 ounces.

Ore was also soon found in the basal conglomerate of the Deadwood Formation, and not long thereafter the many replacement deposits in the Deadwood began to be discovered. Many mines in the replacement deposits were developed before 1900, and production continued from some of them until 1959.

Small placer deposits were worked on most of the creeks elsewhere in the Black Hills during the first few years of prospecting. Claims were also staked on many other lode deposits. Except for the localities identified in table 4 and figure 15, few of these have been profitable. Occasional efforts to work placer ground by dredges or other mechanical equipment have had little success.

As table 3 indicates, gold production increased continuously, with generally modest ups and downs, for several decades. The increase accelerated in the 1930's after the price of gold was raised to $35 per ounce. A peak was reached in 1939 at 618,536 ounces. The closing of gold mines in World War II caused a sharp decline, from which recovery was gradual. The combination of inflating costs of mining and the fixed price of gold caused virtually all mining except at Homestake to come to an end at the termination of the 1950's.

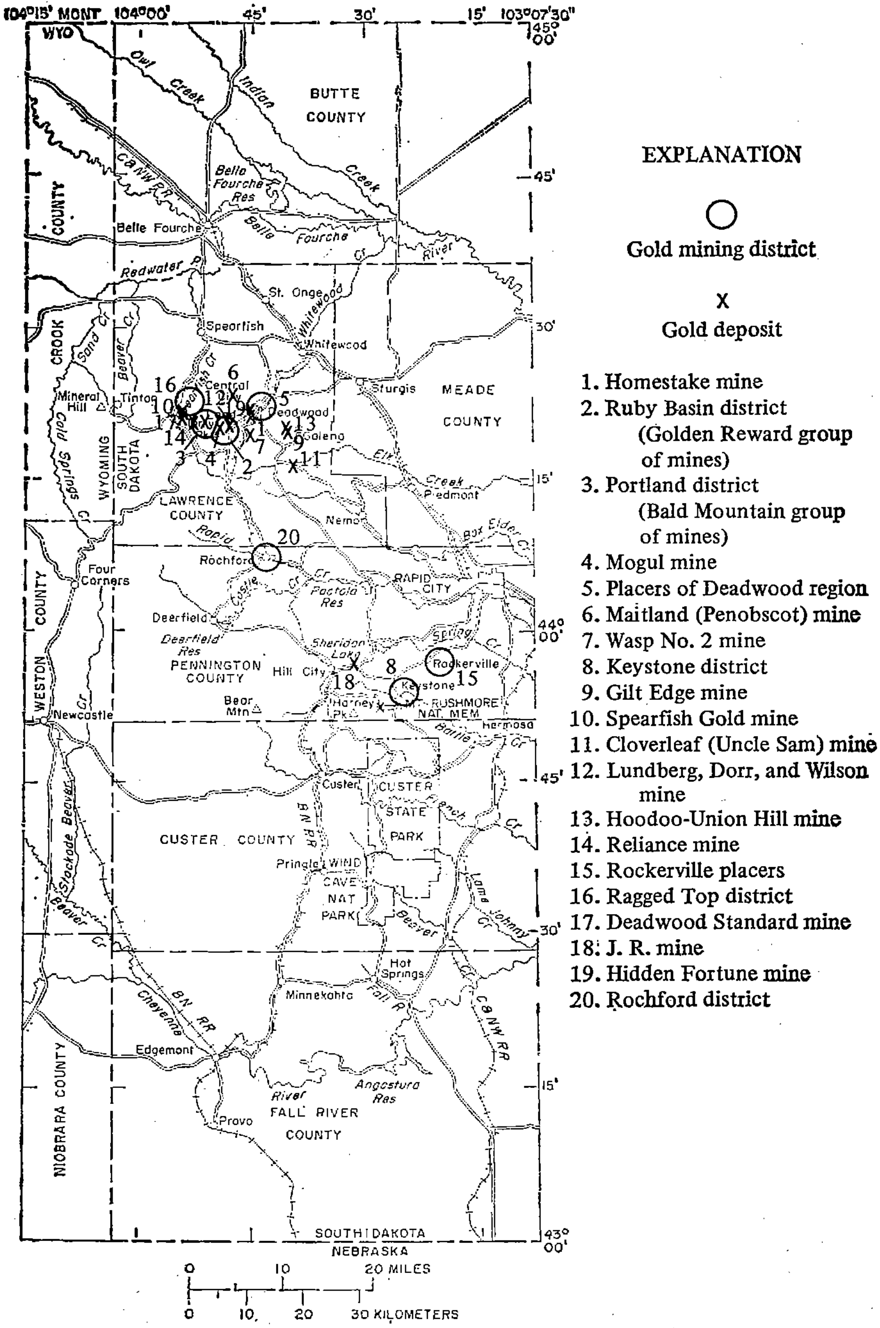

FIGURE 15.—Principal gold districts and deposits of the Black Hills.

Homestake met the problems by intensive efforts to improve mining methods and to enlarge the operation so as to reduce unit costs. The year of largest production was 1965, when 628,259 ounces were mined, all of it at Homestake.

Fortunately skillful management enabled mining to continue, for the release of the price restriction in the late 1960's and the very great price increases of the 1970's have drastically changed the outlook. The quantity of gold produced has diminished, probably from such causes as the great depth of mining, the opportunity to use lower grade ore, a shortage of skilled labor, and the difficulty of adjusting to the changed economic environment after a long period of marginal operation in which exploration and development were necessarily minimal. Nonetheless, the money value of the gold obtained has increased dramatically, though not necessarily permanently, for the price of gold can now go down as well as up. At the end of 1974 no additional mine has opened nor is there promise that one soon will. Exploration has increased somewhat, but has yet to accelerate to the rate expectable.

Geology of the deposits

The gold and gold-silver deposits may be divided into four different categories involving four different ages of mineralization: (1) lode deposits, either of replaced iron-formation and associated rocks or of quartz veins, in Precambrian terrane in which most of the mineralization probably was Precambrian; (2) deposits in the basal conglomerate of the Deadwood Formation that appear to be fossil placers; (3) Tertiary replacement deposits and veins, mainly in the Deadwood Formation but also in the Pahasapa Limestone and Tertiary igneous rocks; and (4) Tertiary and Quaternary placers.

Homestake deposits and similar deposits.—The Homestake mine is in what is known as a strata-bound deposit—that is, a deposit for the most part confined to a single stratigraphic unit. In this instance the rock containing the ore bodies is a metamorphosed iron-formation, which appropriately is named the Homestake Formation. The most important reports on Homestake geology are by Noble (1950), Noble and Harder (1948), Noble, Harder, and Slaughter (1949), and Slaughter (1968).

The Homestake Formation is a metamorphosed banded unit of cherty quartzite and sideroplesite (magnesium-iron carbonate) below the garnet isograd but changes to quartzite and cummingtonite just above the garnet isograd. The main ore bodies are in the zone of this change.

The rocks are in a set of large isoclinal folds, of southeasterly plunge, that have been refolded by two sets of smaller folds. The older of the smaller folds have a right-hand movement pattern (that is, they have the shape of the letter N in plan) and the younger folds have an opposite shape. Configurations can be of such extreme complexity that axes of the major folds may take on an exceedingly sinuous pattern, plunges may change greatly and even turn to the north, and a few fold noses have become detached from the limbs. Some warping results from emplacement of Tertiary igneous rocks and from the dome formed around the Cutting stock, exposed west of Lead.

The ore bodies are irregular pipelike structures located in the younger set of cross folds. They are a somewhat chloritized version of the Homestake Formation impregnated with pyrrhotite, pyrite, arsenopyrite, and free gold. Quartz veins are common but generally not rich in gold. Veinlets of carbonate minerals, pyrite, and other minerals are insignificant as sources of gold, but because they cut Tertiary dikes they provide one of the arguments that the ore formed in Tertiary rather than Precambrian time.

Whether the gold was an original constituent of the sediments and whether the ore bodies formed mainly in Precambrian or mainly in Tertiary time are questions of considerable economic importance because they influence exploration for additional deposits of the same kind. The Homestake mine is in an isolated area of Precambrian rocks surrounded by a cover of Paleozoic rocks. The attractiveness of exploring for concealed deposits and how to do the exploration depend on the premises one accepts. Norton (1974), in a review of the geology urging such exploration, pointed out that without the removal by erosion of the Paleozoic rocks the Homestake deposit itself probably would not yet have been discovered. The very existence of a Homestake mine is thus something of an accident.

The age of the ore forming process has been the subject of considerable debate. Noble (1950, pp. 245–247), who has contributed more than any one else to the knowledge and interpretation of Homestake geology, called the age of mineralization an unsolved problem, but communications from him through the years indicate he favors a Tertiary age. The chief reasons are that veins cut Tertiary rhyolite dikes in the mine, gold deposits in nearby younger rocks are Tertiary, the cross folds controlling the localization of the ore bodies may also be Tertiary, and the ore of the Deadwood conglomerate shows evidence of hydrothermal origin.

Arguments to the contrary are: 1) the Tertiary ores are of different mineralogy and have different gold-silver ratios than the Homestake ores, 2) none of the Tertiary vertical gold veins have ever been traced downward into ore in Precambrian rocks, 3) the chief deposits of gold in Deadwood conglomerate are near the Homestake outcrop and thus probably are fossil placers, 4) the ore bodies are in the zone where sideroplesite gives way to cummingtonite, implying that metamorphism influenced their origin, and 5) cross folds have now been found to be so abundant in Black Hills Precambrian rocks as to allow virtually no reason to believe they are of Tertiary age. Furthermore, geologic studies throughout the world since the time of Noble's work have shown that many strata-bound ore deposits carry metals originally deposited in the sediments. Iron-formation throughout the Black Hills contains gold, as chemical analyses and the great abundance of prospect pits and small mines attest, and this wide distribution of gold implies a Precambrian age.

The persuasiveness of these points was neglected until isotopic data and interpretations of Rye and Rye (1974) and Rye and others (1974) were published. They showed that the oxygen certainly and the sulfur almost as certainly were original constituents of the Homestake sediment. The lead isotope data indicate the lead came from a 2.5 billion year old source and went through metamorphism and remobilization at 1.6 billion years. In isotopic compositions the Homestake ores are quite different from the ores in the Deadwood Formation.

Thus it appears the sulfur, oxygen, and other major constituents of the Homestake deposit were part of the original sediments and were redistributed to form ore bodies by fluids produced during metamorphism. Whether the gold and also arsenic, with which the gold commonly has a close association, went through the same history or were introduced from an outside source is not so certain, for neither of them is common in the world's iron-formation (James, H. L., written communication, 1974). Nonetheless, Noble (1950, p. 231–232) found arsenopyrite to be one of the first ore minerals formed. Thus, regardless of whether the arsenic was original or was introduced during the mineralizing process, it almost surely was deposited in the ore bodies during the metamorphic episode. The possibility that the gold was not Precambrian is equally remote, especially as it is a constituent of iron-formation in many places in the Black Hills.

From this evidence it may be concluded that the principal period of mineralization was Precambrian and that the location of the ore bodies was controlled by 1) a sufide-bearing phase of the Homestake Formation, 2) the cross folds, and 3) proximity to the garnet isograd. Any place where these three conditions come together should be promising for exploration.

Unfortunately the Homestake Formation is not known to crop out anywhere except in the Lead area, nor is it even certain that the stratigraphic level at which it should appear is at the surface anywhere else in the Black Hills. It may pinch out or be cut off by an unconformity at some concealed locality. Yet many other places have iron formation, several with gold mines of modest productivity. There is no reason to suppose that these cannot somewhere have the same geologic history as at Lead, if not at the surface then beneath younger Precambrian rocks or beneath the Paleozoic cover.

The Rochford district, 15 miles south of Lead, has been the site of extensive exploration, both in early years and again recently after a study of the area by Bayley (1972a), who obtained many encouraging gold analyses. According to Bayley, the area has three separate banded quartz-grunerite units in an anticlinorial structure that has a trend somewhat west of north. The rock units go beneath the Paleozoic cover and probably pass beneath the Portland and Ruby Basin districts, which contain the largest Tertiary gold deposits. The Homestake Formation, if it exists in the area, is concealed beneath the surface according to Bayley, for the iron-formations described by him are higher in the stratigraphic section. An attempt to find the Homestake Formation by drilling near Rochford was unsuccessful.

The Keystone region has three quartzite-grunerite units that reach thicknesses of several hundreds of feet, largely through duplication by isoclinal folding. The principal gold mines, which are at or very near Keystone, are in or near one of these units. At least three other layers of iron-formation exist nearby but are generally less than 20 feet thick. The lithologies of the iron-formations and the associated rocks sufficiently resemble those at Rochford to suggest that they are stratigraphically equivalent. Regardless of whether they are equivalent, they were certainly some tens of miles removed from the Rochford rocks at the time of original sedimentation.

Units of iron-formation have also been prospected for gold, with only slight success, in the Custer and Nemo regions.

Gold quartz veins.—Small quartz veins, some of which have gold, are common in the Precambrian rocks. Some gold-bearing veins are cut by pegmatites in the southern Black Hills (Redden, 1963, pp.

217–218) and are clearly Precambrian but formed after the climax of the main metamorphism, thus dating them rather closely as nearly contemporaneous with the Harney Peak Granite.

One of the largest deposits is the Clover Leaf mine at Roubaix, which is described by Irving (1904) as a saddle reet in an anticlinal fold that plunges about 40° southeast. The quartz has some chlorite and mica; ore minerals include gold, galena, sphalerite, and pyrite. Adjacent schist contains gold, pyrite, pyrrhotite, and arsenopyrite. The mine has been developed to the 750-foot level. Its low silver content implies the deposit is not Tertiary, though it is near areas of known Tertiary mineralization. The low gold content and restriction of ore to the one anticlinal structure offer little encouragement that the deposit can become a major mine.

The Holy Terror mine at Keystone is also a gold quartz deposit. The vein was thin and only about 100 feet long at the surface but thickened to a length of more than 1000 feet on the 500-foot level. Total development extended to a depth of 1200 feet. Apparently the grade of ore decreased as the vein thickened. The rich upper part of the vein was bounded by a thin plaster largely of muscovite, and free gold was abundantly sprinkled through the quartz near the contact. Sulfide minerals consisted chiefly of sparse arsenopyrite and pyrite.

Other gold quartz deposits worthy of mention are at the J. R. and the Empire mines, the former 3 miles N. 60° E. and the latter 4 miles N. 75° E. of Hill City. Little is known about the geology of either of them.

There are hundreds of other prospects and dozens of small mines on quartz veins. They have no known stratigraphic control nor even convincing structural reasons for their localization. They are probably all Precambrian, though Norton (1974, pp. 13–14) notes that several are near freshly brecciated zones. Some of these veins have graphitic and tourmalinized wall rock but others have minimal alteration.

Deposits in basal conglomerate of the Deadwood Formation.—The Deadwood basal conglomerate has gold of probable placer origin at a few localities. Known deposits are restricted to conglomerates that developed in topographic lows on the Precambrian surface and were generally only a few feet or a few tens of feet thick. The richest ore was near the base of the conglomerate and in the upper few inches of underlying weathered schists. Not all such conglomerates are gold-bearing, for a source of gold in the Precambrian rocks was necessary.

The presence of pyrite in the ore and evidence from the shapes of gold particles indicate that later processes affected the deposits. Noble (1950, p. 246) doubted that they even have a placer origin, but early geologists (Devereux, 1882, and Irving, 1904), who surely had a thorough familiarity with placer gold, were convinced that most of the gold was detrital. The fact that the largest deposits are near the outcrop of the Homestake deposit and the variety of evidence that the Homestake ore is Precambrian are the most persuasive reasons now available for believing in a placer origin, for the main deposits have been mined out.

Large deposits formed at Lead because the outcrop of the Homestake deposit was an island that supplied gold to surrounding gravels in the Deadwood sea. The ores were termed "cement ores" by the early miners. Their decomposition and weathering contributed to the rich stream placers that caused the original Deadwood gold rush.

Deposits of apparently similar nature are near Rockerville, where the Deadwood basal conglomerate is much better developed than is ordinary in the southern Black Hills. Conglomerate a few miles to the south near Hayward is also gold bearing. No pyrite is reported and the area is far removed from known Tertiary mineralization. The Precambrian source of the gold is not known but is presumably within a few miles. Most of the gold workings in the Rockerville region are not in the Deadwood but in Quaternary gravels that were supplied with gold by the Deadwood and by decomposed schist nearby.

Replacement deposits in Paleozoic and Tertiary rocks.—A broad area of the northern Black Hills contains Tertiary gold-silver deposits, largely in the Deadwood Formation but also in the Pahasapa Limestone and Tertiary igneous rocks. Most of the mining has been in the Portland and Ruby Basin area on the south flank of the Lead dome, but several important mines and many prospects are distributed elsewhere around the dome. Total production is between 2.5 and 3 million ounces of gold (table 4), which is a sizable amount but so greatly overshadowed by the Homestake output that even the existence of these mines is not widely known. Shapiro and Gries (1970) have issued a comprehensive report on these deposits.

Most of the ore bodies are where vertical mineralized fractures pass through beds of dolomite, which are replaced outward from the fractures. The largest deposits are where fracturing is most intense. Ore is chiefly at two stratigraphic levels within the Deadwood—the so-called "lower contact" and "upper contact" zones, a terminology which Shapiro and Gries (1970, p. 29) suggest may have originated by being used to designate ores at the top and bottom of a large sill in the Ruby Basin district. In the locally conventional usage, however, the lower contact zone is a 6- to 30-foot thick interval of interbedded sandy dolomite and shale that lies immediately above the unit of quartzite at or near the base of the Deadwood. The upper contact ore zone has similar lithology but is about 15 feet below the upper massive *Scolithus* sandstone of the Deadwood. Minor ore zones occur in other dolomite beds as well as below a glauconitic quartzite immediately beneath the upper contact ores and in quartzite at the bottom of the formation. Contacts of sills and dikes can also be ore-bearing.

The ore bodies are long and narrow. Lengths range from only a few tens of feet to 5,000 feet. Widths are generally small but may be as much as 300 feet where fractures are closely spaced. The larger ore bodies follow fractures of northeasterly or northerly trend, but northwesterly and westerly trending ore shoots are also common.

Radial fracturing caused by intrusion of the Cutting Stock may be an important control of the directions taken by the ore bodies (Slaughter, 1968, p. 1444, fig. 1). On the other hand, Shapiro and Gries (1970, p. 45–48, pl. 8) found evidence that some of the fractures belong to regional systems of probably greater age.

Another possibility, previously overlooked, comes to notice from the observation that many mines in the lower contact zone are in places where the Deadwood basal units of conglomerate and quartzite are absent. Such localities presumably were topographic highs on the Cambrian surface. The edges of these highs would, during compaction of the Deadwood sediments and any subsequent deformation, be favored localities for the closely spaced fracturing necessary to allow a large ore body to be formed.

The ore in the Deadwood consists of the primary so-called blue ore, which is siliceous, hard, and blue to blue gray, and the secondary red or brown ore, which is oxidized primary ore. In the blue ore, pyrite is abundant and is locally accompanied by fluorite, arsenopyrite, calcite, or gypsum. Other sulfide and carbonate minerals are sparse. Some primary ore consists of pyrite in dolomite without any silicification. The gold of all primary ore is finely disseminated in pyrite and also forms rich pockets of telluride minerals. In the secondary ores pyrite has been destroyed, thus freeing the contained gold and making its recovery easier.

The Pahasapa Limestone contains gold-silver replacement deposits in the Ragged Top district and the nearby Carbonate lead-silver district. The ore follows joints, small faults, and breccia zones, but differs from Deadwood ores in the absence of a noticeable regularity in the selection of beds to be replaced and in the scarcity of pyrite or other iron sulfides. Some limonitic fissure fillings were exceptionally rich. Mineralized limestone is silicified and locally contains fluorite, but elsewhere the rock is not strikingly different from normal limestone.

Among the Tertiary igneous rocks, mineralization was common in and along the contracts of sills in the Deadwood Formation in the Lead area and districts to the west, but the most significant mineralization was near Galena at the Gilt Edge mine and apparently the Hoodoo-Union Hill mine. The Gilt Edge deposit is in a series of extensively altered and mineralized rhyolite dikes. Pyrite is abundant and intimately associated with ore. The wide extent of the alteration (Mukherjee, 1968) suggests that the deposit could be much larger than past production implies. The Hoodoo-Union Hill mine is geologically similar but otherwise little known, for the mine has been inaccessible since the early 1900's (Allmans, 1940, p. 63).

Tertiary and Quaternary placer deposits.—All stream valleys and many gravels on terraces above the valley bottoms were prospected during the first few years after the discovery of gold. Many were worked extensively, especially along major streams, where water needed in mining was plentiful. Much of the physical evidence of what was done has been destroyed because the placer localities are also the places best adapted to farming and for town sites. Gold production from placer ground is the most inaccurately known, for nearly all the operations were conducted by individuals rather than by companies. Probably many of the placer workings were profitless, and some that yielded an adequate return in the 19th century would not do so today because, being small and ill-adapted to mechanical mining, they required a great amount of hand labor.

The largest and richest deposits certainly were those distributed along the narrow gulches of the Lead-Deadwood region. These received their gold by erosion of the Homestake lode, the Deadwood cement ores, and the Deadwood replacement deposits.

The Rockerville-Hayward region almost certainly ranked second, but a distant second. Most of its gold seems to have been reconcentrated from Deadwood fossil placer deposits.

Localities along French, Castle, Rapid, and other creeks were worked from time to time as recently as the 1930's, and in a small way are occasionally worked even today. Gravels on terraces along valley walls or on divides between valleys are generally too small to be of interest now and were too far from water to be worked earlier, but some of them may be attractive as sources of gold. A few of these may be of Tertiary age, dating as far back as the Oligocene. Larger bodies of Oligocene sediments distributed along the east flank of the Black Hills seem not to have been searched for gold and do not necessarily lack commercial concentrations.

Outlook for exploration

The current high gold price is causing renewed interest in the Black Hills. The now persuasive evidence that the Homestake is a Precambrian deposit implies that other deposits of the same kind may lie beneath Paleozoic cover. The remark by Norton (1974, p. 1–2) that even the presence of outcrops of the Homestake deposit was an erosional accident, without which the ore might still remain undiscovered, has not escaped notice.

Exploration for concealed plunging ore shoots of the kind in the Homestake mine is somewhat like looking for a needle in a haystack without even knowing the needle exists. The key difference is that geologic evidence shows which parts of the haystack are the best places to search.

The distribution of exposed units of iron-formation in the Black Hills is now well known, and the probable positions of many of them beneath Paleozoic rocks can be guessed. Deciding where a sulfide facies might be found is not possible from currently available information, but merely knowing or suspecting that such a facies may be required to form ore is helpful in deciding how exploration should proceed as new data accumulate. The garnet isograd, if one believes it marks the site of ore-forming processes, becomes useful now that its approximate position has been identified by Redden and shown on figure 6. Interestingly enough, the Black Hills Mineral Atlas (U.S. Bureau of Mines, 1954a) records very few metal deposits in the region below the garnet isograd.

The distribution of Tertiary ore bodies may be a sign useful in searching for Precambrian ore, because the gold of the Tertiary deposits must have come from Precambrian sources. Whether the source or sources are rich enough to be mined, whether they are shallow or of excessive depth, and whether they are beneath the Tertiary deposits or laterally far removed from them are all important questions. The Homestake deposits lack evidence that any gold was carried away from them during Tertiary activity (Shaddrick, D.R., oral communication, 1974). Nonetheless, an exploration plan that is keyed to the distribution of mineralization in the Deadwood and younger rocks has a chance of locating additional Tertiary ore bodies even if no Precambrian deposit is found.

Helpful information could be obtained by making a contour map of the Precambrian-Cambrian contact, acquiring detailed data about the subsurface stratigraphy of the Deadwood Formation, and undertaking a geochemical study to make maps showing the distribution of some of the metals in basal units of the Deadwood. To acquire the information, drilling as well as work along outcrops would be necessary. Discovery of an ancient hill with gold-bearing conglomerate on its flanks, as at the Homestake outcrop, is a possible result that would be too attractive to need explanation to anyone. A more likely outcome, however, is to find circumstances of much greater complexity, the meaning and use of which cannot now be anticipated. Only two of the several Homestake ore bodies cropped out at the Precambrian-Cambrian contact. The tops of all the others were at lower levels. Even with the most comprehensive geologic information and the most careful interpretation, a large measure of luck would be needed to find such ore bodies.

Yet the rewards of finding one or more major gold deposits would be large, to the company making the discovery, to the economy of the State, and to the nation's position in the world gold market. Exploration seems likely to become vigorous, especially if indications of success become known and a follow-the-leader attitude develops.

Norton (1974, p. 19–21) suggested four places as worthy of attention: 1) north of Lead, 2) the Portland and Ruby Basin region, 3) the Deadwood-Galena area, and 4) the vicinity of Rockerville. No new data and no new interpretations have given reason to alter these suggestions. The most important of the new information—the delineation of the garnet isograd—has reinforced the evidence that these are the most attractive localities.

Exploration of the kind needed will be costly and time consuming, and the development of a mine will be even more so. Yet the effort seems worthwhile and may be undertaken.

Lead-Silver and Lead-Zinc Deposits

(By J. A. Redden, South Dakota School of Mines and Technology and U.S. Geological Survey, Rapid City, S. Dak.)

Lead-silver ores were produced largely during early mining of the Black Hills and were mainly from the Carbonate and Galena districts in the northern Black Hills (fig. 16). U.S. Bureau of Mines data indicate the total lead production from the Black Hills was 508 tons from 1877 to 1973. According to Lincoln and others (1937, p. 36), the tonnage could have been 8 to 10 times greater than this. Most of the lead was produced between 1885 and 1902. Incomplete production records show that the Carbonate and Galena districts produced approximately 500,000 and 1,000,000 ounces of silver respectively. Clearly the lead was a by-product of silver production. Total zinc production recorded by the U.S. Bureau of Mines is only 266 tons, virtually all of which came from the Belle Eldridge mine southeast of Deadwood in the period 1942–48.

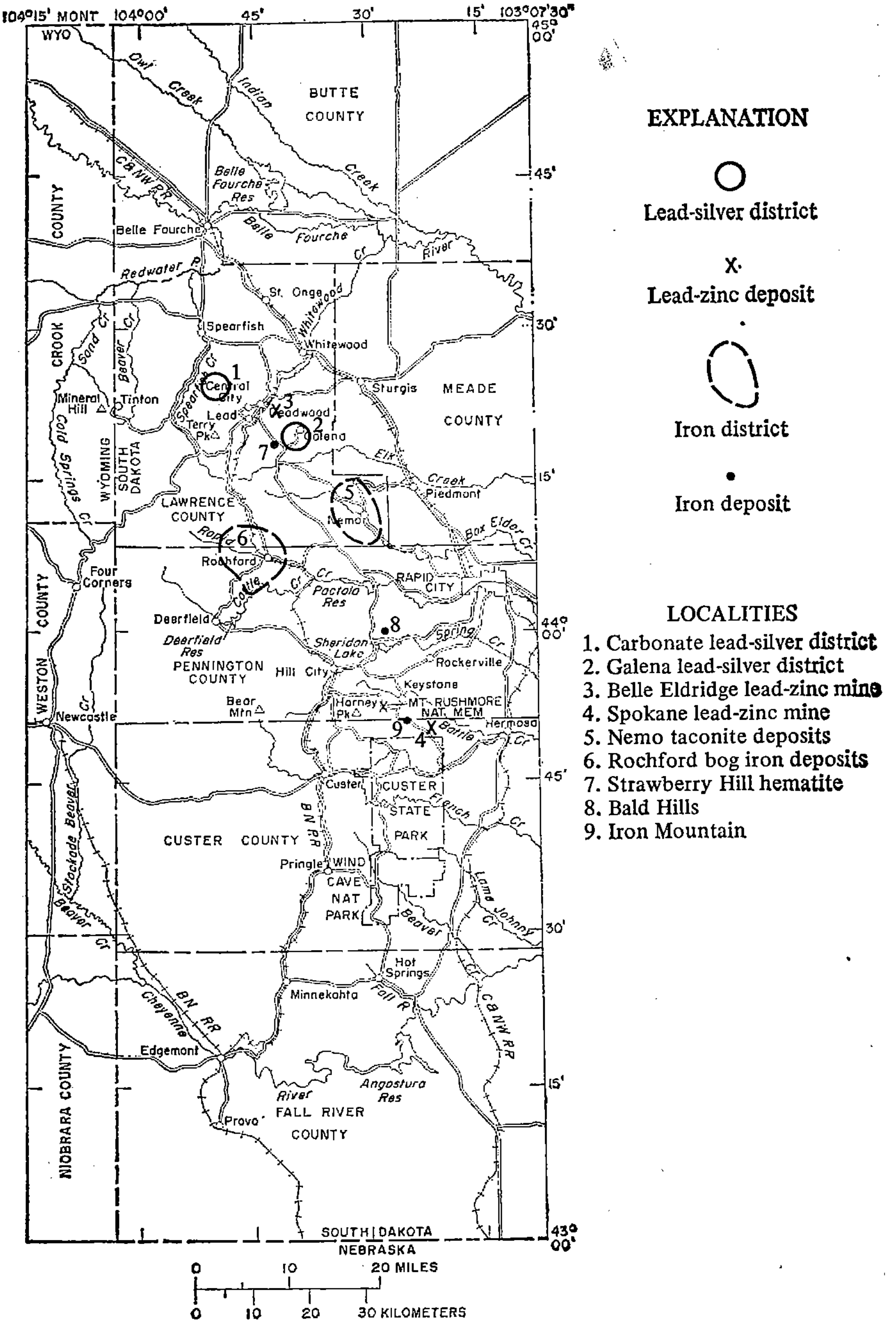

FIGURE 16.—Lead-silver, lead-zinc, and iron deposits of the Black Hills.

Carbonate district

The deposits of the Carbonate District are irregular replacement bodies along jasperized vertical fissures cutting the Pahasapa Limestone and along contacts between the limestone and porphyry intrusions (Irving, 1904, p. 177). Most of the ore at the Iron Hill mine, which was by far the largest deposit, was associated with porphyry, but a vertical seam goes downward from the main ore body. The ore was mainly secondary silver and lead minerals, although galena occurred in unoxidized areas. The minerals included cerargyrite, cerussite, pyromorphite, wulfenite, matlockite, plattnerite, and atacamite (Irving, 1904, p. 178). Shapiro and Gries (1970) indicate that the ore was followed to a maximum depth of 460 feet, which must have been near the base of the Pahasapa Limestone. Crevices along the vertical fissures commonly were filled with ferruginous gouge-like material from which considerable gold was obtained.

Galena district

Lead-silver ores of the Galena district are similar to the Tertiary gold-silver ores in that relatively small lenticular deposits adjacent to vertical fissures are ordinarily in two sandy dolomite zones in the Deadwood Formation. One zone is above the massive quartzite near the base of the Deadwood and the other is above an upper quartzite unit near the top of the formation. The ore either replaces the carbonate or occupies pocket-like cavities apparently caused by differential solution along the fissures. The vertical fissures follow major fracture sets, which strike northwest, northeast, and east-west. Apparently fracturing was largely restricted to the quartzite, but mineralization affected overlying rocks as far up as the Pahasapa Limestone. Tertiary sills and dikes are common in areas of mineralization but most of them are older than the ore.

Ore bodies are commonly only a few feet thick and rarely more than 20 feet wide. Some can be traced along the strike of the vertical fissures for several hundreds of feet. The ore in many of the mines was completely oxidized to mixtures of cerussite, pyromorphite, jarosite, and corkite. The primary ore was largely argentiferous galena, sphalerite, freibergite, arsenopyrite, chalcopyrite, siderite, and quartz.

The district has many small mines. The largest was the Richmond-Sitting Bull, the workings of which extend over an area about 1400 by 1000 feet. The ore was chiefly in the upper mineralized zone of the Deadwood, although the basal quartizite also has ore in what is known as the Double Rainbow mine.

The value of the ore produced was at least $1,200,000 and one source estimates $2,500,000. Probably at least 80 percent of the value was from silver. Since World War II there has been considerable exploration from old workings. Mineralization was found to be relatively widespread but the ore bodies tend to be small and difficult to locate by drilling.

Other localities

The Belle Eldridge zinc deposits (fig. 16) are similar to the other Teritiary metals deposits for the ore is in replacement deposits along vertical fissures cutting the Deadwood formation. Most of the ore is a replacement of dolomite beds overlying a 240-foot thick quartz monzonite sill, which was emplaced a few feet above the basal Deadwood quartzite (Shapiro and Gries, 1970). The ore is unusual because of the richness in sphalerite and arsenopyrite. It also contains pyrite, chalcopyrite, galena, and pyrrhotite. Samples of sulfide ore taken by Schwartz (1937) contain an average of 4.7 ounces of silver and a little gold. Mining was chiefly during a short period in World War II.

There are many other occurrences of lead, zinc, and silver in the northern Black Hills, but none have had much production nor does the available evidence indicate any significant potential.

The only lead-zinc-silver deposit in the southern Black Hills is the Spokane mine southeast of Keystone (fig. 16). The silver content is apparently much lower than in the other districts, probably about 0.5 ounce for each 1 percent of lead (Connolly and O'Harra, 1929, p. 185). This deposit is a quartz vein, probably localized along a small fault, in high grade metamorphic rocks and pegmatites. The ore consists largely of galena, iron-rich sphalerite, pyrite, and arsenopyrite. The deposit has been explored to a depth of 300 feet and for several hundreds of feet along strike. Production of lead was minor and the deposit is of interest mainly because it seems to be the most southerly occurrence of mineralization of probable Tertiary age. Kulp and others (1956) obtained a lead isotope age of 400 m.y. but commented that the results were not inconsistent with a Tertiary age. Another center of Tertiary mineralization might exist in the area, but Paleozoic rocks crop out just east of the mine and are not known to be mineralized.

Exploration potential

In the Black Hills.—Both galena and sphalerite are minor constituents in some of the Tertiary gold-silver deposits. A zonal arrangement of the Teritary mineralization was recognized by Emmons (1926) and Connolly and O'Harra (1929). A central area of gold-tungsten deposits near Lead is surrounded by gold-silver deposits followed by lead-silver deposits of the Carbonate and Galena districts at the periphery of the area of mineralization.

Additional lead-silver deposits undoubtedly exist in the Galena area, especially to the east of the Richmond-Sitting Bull mine. However, these deposits surely are primary and can be expected to have less silver than the deposits mined to date. Because the Double Rainbow portion of the Richmond-Sitting Bull mine has been partially developed by recent exploration openings, deposits there may be mined if high metal prices continue.

The size and shape of all known ore bodies cause exploration by drilling to be difficult and make the ore bodies not conducive to large-scale mining methods. The Deadwood carbonate units favorable for replacement are not known to be thicker anywhere than in places already explored. Careful mapping of the structural complexities adjacent to the Vanocker laccolith, northeast of Galena, may reveal some fault or other structures that would permit extensive mineralization in the thicker carbonate units above the Deadwood Formation. Unless evidence can be obtained of an area of extensive fracturing or potential channeling of solutions to form a large manto deposit, the outlook for future mining is not favorable.

Additional deposits similar to those at Carbonate should exist but are surely concealed, for surface prospecting has been extensive. Exploration of the Deadwood Formation below the known Carbonate deposits may also be worthwhile, especially as ores richer in gold than silver might be found. Nonetheless, the problems of exploration and mining are the same as in the Galena district.

Outside of the Black Hills.—Much of South Dakota is underlain by Paleozoic sedimentary rocks concealed by younger sedimentary rocks. Lead-zinc deposits of what is known as the Mississippi Valley type are commonly in carbonate rocks that have enough open space for deposition of ore. Modern theory suggests that these deposits were formed by up dip movement of metal-bearing connate fluids from basins to structural and chemical traps or by migration of metal-bearing fluids associated with thermal highs in deep rocks to similar traps.

South Dakota contains the southern part of the Williston basin, and such structural features as basement highs, faults, and reefs on the flanks of the basin could be sites for deposits. Of course many similar basins in the United States have no known deposits of the Mississippi Valley type. Yet if special thermal conditions are necessary for the movement of metal-bearing waters, then the problem takes on a different color. The basic questions for South Dakota would be whether or not it has thermal anomalies that may have produced appropriate metal transport and whether there are suitable structural or stratigraphic traps.

The Williston basin has thick lower and middle Paleozoic carbonate rocks. Ordinarily these rocks change from limestone in the center of the basin to dolomite on the edges. Furthermore, there is a change to shallow reef conditions. Reefs are known to be favorable sites for many lead-zinc deposits of the Mississippi Valley type. The large Pine Point lead-zinc deposits occur in Devonian reefs at the extreme north end of the basin in the Northwest Territories, Canada. Unfortunately, the amount of deep exploratory drilling by oil companies on the southern edge of the basin in South Dakota has been small. Yet drill cuttings from one well in Walworth County has small amounts of galena and sphalerite in Devonian carbonate rocks.

The chapter on geothermal energy in this report shows that deep groundwater in western South Dakota is commonly 38° C (100° F) or hotter. Schoon and McGregor (1974, fig. 1) show that the highest geothermal gradients are generally on the flanks of the Williston Basin. Their data show high geothermal gradients have east-southeast trends in the south central part of the state and one of the highs is in line with the area of Teritiary intrusions in the Black Hills. Possibly this is only coincidence but it may have significance. Groundwaters in part of the area of high geothermal gradient have abnormal radioactivity.

Swanson (1968) postulated that water from the Madison aquifer moves eastward from outcrop areas in the Black Hills to the vicinity of the Missouri River and there rises and recharges Cretaceous aquifers. If so, a result would be mixing of hot chloride-rich Madison waters with sulfate-rich waters of the Cretaceous. Because chloride waters probably are a common medium of transport for metals, the mixing zone might be the site of deposition of metal sulfides. Study of the metal contents of water from wells in this area would test this possibility and perhaps indicate areas worthy of exploration, even though deposits would be deep and extremely difficult to find and evaluate. However speculative this suggestion may seem, samples from oil exploration holes and anomalies in geophysical logs should routinely be examined for indications of the presence of metals, and any data obtained on hydrology, water chemistry, structural geology, thermal properties, and sedimentary facies changes should also be viewed with same end in mind.

Iron

(By J. A. Redden, South Dakota School of Mines and Technology and U.S. Geological Survey, Rapid City, South Dakota)

South Dakota has produced only a moderate quantity of iron ore but has the potential for much greater production as economic conditions change and reserves are depleted in states closer to industrial areas. The deposits will require beneficiation but this is so for virtually all of the domestic iron deposits now being mined. Special considerations controlling development of South Dakota deposits will be transportation cost and environmental factors.

The total production since the beginning of mining, in about 1890, is at least 220,000 tons, though according to U.S. Bureau of Mines records (table 1) only 91,000 long tons were usable as a source of iron. Approximately 150,000 tons have been used as an additive in cement produced at Rapid City. Most of the material used in cement has been high grade limonitic or hematitic ore; the relatively higher grades of taconite[1] can also be used but bring a lower price. Recent production of iron ore has been about 10,000 tons per year; all of this has been used by the State Cement Plant at Rapid City. Expansion of this plant is expected to require 22,000 tons per year after 1977. Small amounts of iron ore were also mined for use as a paint pigment and as nonferrous smelter flux prior to 1948.

The deposits that have been mined are in the Black Hills. They include taconite, small bog iron deposits, and secondary iron deposits associated with basal Cambrian rocks. Of these, only taconite has the potential for significant future development. Details of the different deposits have been described by Harrer (1966) in the most comprehensive existing report on iron deposits in the State.

Taconite deposits

The taconite deposits are restricted to the Nemo area (figure 16), mostly in a relatively narrow belt of Precambrian metamorphic rocks about 2 miles wide by 5 miles long (Harrer, 1966; Bayley, 1972b). The taconite is steeply dipping and generally about 125 feet thick, but it has been greatly thickened locally by intense folding to as much as 1000 feet. These folded bodies plunge steeply. In the same area lower grade iron deposits consist of taconite clasts and iron-rich matrix in Precambrian conglomerate.

The taconite ore consists largely of mixtures of the iron-bearing minerals specularite, martite, and magnetite accompanied by quartz.

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[1] Taconite is a term used in Minnesota and adjacent states for an unleached iron-formation containing magnetite, hematite, siderite, hydrous iron silicates, and ferruginous chert or quartz.

The deposits have not been fully evaluated, although some exploration by diamond drilling has been done. A small open cut yielded a few thousand tons used in cement.

Harrer (1966) estimated that the deposits contain about 500 million tons of ore that has an average grade of 29 percent iron. The extent of the area mapped as taconite by Bayley (1972b) implies the deposits would contain substantially more ore—probably more than 700,000 tons per foot of depth. This estimate, however, may be about 25 percent too great because infolds of country rock and other structural complexities could cause the deposits to be diluted by country rock. One of the larger single bodies of taconite is exposed along Estes Creek about 600 feet above the valley floor and presumably could readily be mined to the floor of the valley. Tests by the U.S. Bureau of Mines showed that Nemo taconite can be upgraded readily by either flotation or magnetic separation: the tests indicate that beneficiation is easier and recoveries are higher than for some of the taconite deposits currently being mined in Minnesota.

Magnetic anomalies extend north and eastward from the exposed deposits across an area covered by Paleozoic rocks (Meuschke and others, 1962; Bayley, 1972b). The anomalies presumably result from concealed taconite deposits similar to the exposed deposits. Some of these possible deposits are covered by only a few hundred feet of Paleozoic rocks and probably could be mined by open-cut methods.

Major environmental factors that would affect the development of the taconite deposits are the difficulty of obtaining an adequate supply of water and of disposing of wastes. Sufficient water possibly could be obtained from surface waters and from underground sources, but recycling of the water would be necessary. Harrer (1966, p. 97) stated that a one million ton per year taconite pellet plant having the 95 percent water recovery of the Erie plant of Pickands Mather Company in northeastern Minnesota would require between 250 and 500 gallons per minute. Waste disposal systems would need careful planning and sizable capital outlays because the potential taconite mining district lies along the scenic Boxelder Creek drainage. Construction of some type of transportation system for ore concentrates to railroad connections in Rapid City would also be necessary.

Other deposits in the Black Hills

Low grade Precambrian deposits of iron carbonate-quartz or iron silicate-quartz iron-formation are widely distributed through the Black Hills. These occur as thin units in the Lead-Deadwood area, where some of the iron-formation is the host for the Homestake gold deposit. Similar iron formations are known in the Rochford area, and others extend south from Roubaix past the west side of the Nemo district to Keystone. Iron-formation reappears on the south side of the Harney Geak Granite and extends, with interruptions, south toward Pringle. All localities have been extensively prospected, but mainly in the search for gold rather than iron.

The iron-carbonate variety is restricted to the northern and east-central parts of the Black Hills, where the metamorphic grade is relatively low; the iron-silicate variety, on the other hand, occurs in areas that contain higher grade metamorphic rocks. Cummingtonite-grunerite is abundant in the iron-silicate variety; an iron-rich pyroxene is also present in the south. Hematite, derived by weathering of magnetite and the iron-carbonate and iron-silicate minerals, is the common iron oxide near the surface. Weathering of the rocks to yield local near-surface concentrations of hematite and hydrous iron oxides is accelerated where iron-sulfide minerals occur in the iron-formation. Magnetite is present but rarely exceeds more than a few percent of the rock. In general, the total iron content of these rocks is 20 to 25 percent, but because the iron is chiefly in iron-silicate minerals, from which it cannot be extracted under current technology, the deposits are not presently of commercial interest. Furthermore, most of them are small and perhaps none are large enough for mining.

Bog iron deposits are most numerous along the tributaries of upper Rapid Creek in the Rochford region, but a few exist in the Castle Creek drainage and elsewhere. These deposits consist of bedded iron-rich material and of porous replacements of organic material in swampy areas. The bog iron deposits are less than 10 feet thick, and individual deposits cover at most a few tens of acres. The iron minerals are mainly the hydrous iron oxides limonite and goethite. The iron content typically ranges from 25 to 55 percent. The iron was derived mostly from the weathering of either sulfide-rich schists or iron-formation and was transported in surface and spring waters to the bogs, where it was precipitated largely by organic material. Transport and deposition of iron still is going on in many places. Several bog iron deposits along tributaries of Rapid Creek have been mined for local use. Harrer (1966, p. 11) estimated that these deposits contain about 0.5 million tons of iron-bearing material. Yet because mining, though small in scale, has had adverse effects on the streams, public reaction probably will prevent further excavations, even though appropriate techniques could insure minimum sedimentation and minimal degradation of the streams. Ironically, most of the iron content of the stream waters resulted from natural processes rather than past mining activity.

Additional small iron deposits in the Black Hills were apparently formed mainly by extensive weathering that preceded deposition of the Deadwood Formation. Several deposits of hematite occur along the basal contact at Strawberry Ridge, in Lawrence County, and north of Bear Mountain in Pennington County. The deposits are clastic beds, a few feet thick, derived from weathering of the underlying and nearby ferruginous Precambrian rocks. Another hematite deposit of moderate size is at Iron Mountain, south of Keystone on the Pennington-Custer County line. The deposit is believed to have formed by deep weathering of sulfide-rich iron-formation. The weathering preceded deposition of the Cambrian rocks, which subsequently were removed in this region by erosion. Inasmuch as the deposit straddles the scenic south approach to Mount Rushmore, mining is prohibited. The Bald Hills area, 3 miles south of Pactola Dam, also contains small deposits of apparently similar origin, for they also are not far beneath the probable level of the Cambrian-Precambrian contact. At this locality a little hematite has been mined above sulfide-rich slates and phyllites. Other small deposits near the Cambrian-Precambrian contact appear along the outer edge of the exposed Precambrian rocks, but these are thin and restricted in area by the topography, type of bedrock, and Paleozoic cover.

Deposits outside the Black Hills

Low-grade concentrations of iron of little economic significance occur in concretions in terrace gravels derived form iron-manganese concretion zones of the Cretaceous Hell Creek Formation in the Grand, Moreau, and Cheyenne River basins of western South Dakota (Harrer, 1966, p. 71). Although extending over a broad area, there is little likelihood that these deposits will be of economic interest during this century. Any future development would depend on the production of the coexisting manganese as well as the iron.

Large amounts of iron and manganese also occur in carbonate concretions in the DeGrey Member of the Pierre Shale where it crops out along the Missouri River (Gries, this report). Although there are many millions of tons of the concretions, their average iron content is only about 9 percent (Zinner and Grosh, 1949, p. 13); any possible future development would depend mainly on production of manganese.

Exploration for additional deposits

Deposits of magnetic taconite of potential commercial significance have been delineated locally by aeromagnetic and ground magnetic surveys in the State. As noted previously, the Nemo taconite deposits have been shown by magnetic survey to extend beneath the Paleozoic rocks, but no available information indicates that any of these magnetic anomalies have been penetrated and tested by drilling.

A reconnaissance ground magnetic survey of South Dakota, done with approximately 6-mile station spacing (Petsch, 1967), failed to show the anomalies of the Nemo deposits but did disclose other anomalies outside of the Black Hills. Two of these anomalies in the southeastern part of the state have amplitudes of approximately 3000 gammas and have been drilled; diabase and gabbro of Precambrian age were found at depths of 750 to 800 feet (Harrer, 1966, p. 72–73). Three other anomalies of approximately 8000 gammas, in Marshall and Day Counties, imply the existence of extremely magnetic deposits, and drilling on two of them has confirmed this supposition (M. H. Bergendahl, personal communication, 1974). A vertical hole near Langford, in Marshall County, reached Precambrian rocks at a depth of 924 feet and after penetrating 108 feet of metavolcanic rocks encountered at least 27 feet of hematite-magnetite-quartz iron-formation. Another hole near Bristol in Day County entered the Precambrian basement at 1,485 feet and was entirely in magnetite-quartz iron-formation to a total depth of 1,746 feet. Two composite samples contained 34.7 and 35.61 percent Fe, 0.079 and 0.084 percent P, 0.11 and 0.03 percent Mn, 0.002 and 0.005 percent S, 2.10 and 3.76 percent Al_2O_3, and 45.38 and 40.62 percent SiO_2. A second hole at Bristol was entirely in well-bedded staurolite schist. The bedding in the rocks is nearly vertical at both localities and thus the true thickness of the iron-formation was not determined. Although these occurrences are not yet of economic interest, they indicate that iron-formations in Minnesota extend southwestward in the subsurface into South Dakota.

Tungsten

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

Tungsten has been of modest importance in the Black Hills in the past and some small scale future mining may be anticipated under favorable economic conditions. It was first discovered in the early 1880's but no production is recorded before 1898, and only about 300 tons of concentrates and high grade ore valued at $25,000 was produced prior to 1915. The "boom days" were from 1915 to 1918 when about 57,000 units [2] (950 short tons—60 percent WO_3 basis) valued at $1,132,500 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 resumed after 1940. Total production through 1973 has amounted to less than 100,000 short ton units valued at approximately $1,379,000. This is about 0.6 percent of the total U.S. production. Table 5 shows the detailed production record.

TABLE 5.—TUNGSTEN ORE AND CONCENTRATES PRODUCTION, 1898–1973

[From U.S. Bureau of Mines]

Year	Quantity (short tons, 60 percent WO_3 basis)	Value	Year	Quantity (short tons, 60 percent WO_3 basis)	Value
1898–1914	[1] 300	$25,000	1941	(2)	(2)
1915	240	181,000	1942–43		
1916	239	404,775	1944	7	(2)
1917	270	299,644	1945	4	(2)
1918	201	247,100	1946	1	(2)
1919–23			1947–51		
1924	(2)	(2)	1952	(3)	$335
1925			1953	2	(2)
1926	90	41,900	1954	(3)	500
1927	141	(2)	1955–73		
1928	(2)	(2)	Total (1898–1973)	[4] 1,638	[4] 1,378,694
1929	5	(2)			
1930–40					

[1] Reported as concentrates and high-grade ore. Probably not converted to 60 percent WO_3 basis.
[2] Confidential figure; included in total.
[3] Less than 1 ton.
[4] Includes figures indicated by footnotes 2 and 3.

Tungsten is critical to modern industry chiefly because its alloys and carbides are notable for their extreme hardness and wear resistance and particularly for retaining hardness at high temperatures. More than 70 percent of recent consumption has been in alloy tool steel and in tungsten carbide for cutting edges, dies, drill bits, wear-resistant machine parts, tire studs, and other uses in which extreme hardness is desirable.

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 75 years, the rate of production has ranged widely due to various economic factors, particularly Government stockpiling programs. Only a few domestic producers have been able to compete consistently on the open market with foreign producers (Holliday, 1960, p. 914).

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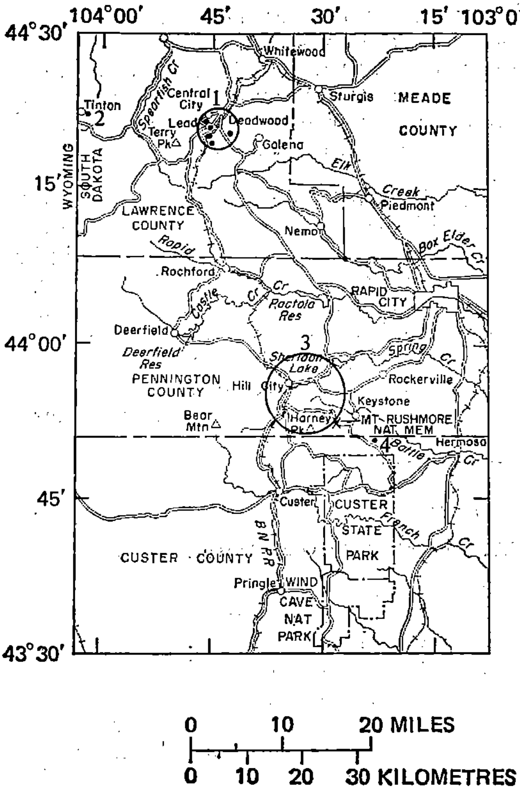
[2] One unit equals 1 percent WO_3 per ton or 20 pounds WO_3.

However, a large domestic productive capacity was demonstrated twice in recent 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 a Government stockpiling program started during the Korean crisis. In 1955 production reached an all-time peak that was nearly four times the average annual production of the immediate post-war period 1946–50. After the end of Government stockpile purchases in December 1956, the price fell drastically and production from many mines was stopped or radically reduced. In 1956 nearly 600 operations 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 kinds of rocks, 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 deposits occur principally as quartz veins that contain minerals of the wolframite group, scheelite, or both, as contact metamorphic deposits (tactite), containing scheelite, and as hydrothermal replacement bodies of wolframite and scheelite in igneous, sedimentary, or metamorphic rocks.

In South Dakota tungsten is restricted entirely to the Black Hills, within or very near its Precambrian core. Historical details of the tungsten mining industry in South Dakota as well as descriptions of the deposits are contained in publications of the South Dakota School of Mines by Runner and Hartman (1918), Connolly and O'Harra (1929), Lincoln, Miser and Cummings (1937), and Roberts and Rapp (1965). These papers as well as reports by Irving (1904), Hess (1908) and the U.S. Bureau of Mines (1954a, 1955) have supplied much information for this brief description. The tungsten deposits have been divided into two major types based on the age and mode of occurrence: (1) Tertiary replacement bodies in dolomitic rocks or quartzite of the Deadwood Formation, and (2) quartz veins and pegmatities of Precambrian age. Figure 17 shows the principal localities.



EXPLANATION

●

Tungsten deposit or group of deposits

○

Mining district containing tungsten deposits

Principal tungsten mines and prospects

1. Lead-Deadwood area – Includes the Hidden Fortune, Harrison, Durango, Etta, Wasp No. 2, Alder Creek, Mary Group, and S. R. Smith Group (U.S. Bur. Mines, 1954)
2. Tinton area
3. Hill City area – 23 small deposits are recorded by the U.S. Bur. Mines (1955)
4. Fern Cliff Prospect

FIGURE 17.—Tungsten in the Black Hills.

Wolframite is the chief mineral in both modes of occurrence, although some huebnerite is found; scheelite is usually associated with all the deposits, and in a few places either huebnerite or scheelite is the dominant mineral.

The major tungsten production from the Black Hills has come from replacement deposits with wolframite and some scheelite in Cambrian dolomite and quartzite near Lead, Lawrence County (no. 1 on fig. 17). Two operations, one of them north of Lead and west of the Homestake gold mine open pit, and the other, the Wasp No. 2 mine, 2 miles south of Lead, were the principal producers of this type of ore. Both localities were also important sources of gold and silver. Other tungsten occurrences are known in the Lead-Deadwood area.

The ore consists of small grains of wolframite in a siliceous matrix accompanied by gold, a little scheelite, and barite. The occurrence of these tungsten deposits in Cambrian rocks and their close association with Tertiary rhyolite porphyry dikes and sills clearly relate their origin to a Tertiary period of mineralization. The deposits are thus distinctly separate from the Homestake gold ore in the metamorphic rocks on which the Deadwood Formation rests.

Pegmatites and quartz veins occur widely in the Precambrian rocks of the southern Black Hills, but tungsten-bearing bodies are largely restricted to two areas, the Hill City district (no. 3 on fig. 17) and a few miles southeast of Keystone (no. 4, fig. 17). The amount of tungsten is small. Tungsten-bearing quartz veins, which have been the main source of interest, range in width from a fraction of an inch to about 4 feet or more and exhibit a strong tendency to pinch and swell or branch. Usually no single vein or group of veins can be traced for more than a few hundred feet, and the occurrence of tungsten minerals within them is erratic.

The sizable output of tungsten in World War I was from small, relatively high-grade deposits. 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 1915–1918 period. 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 outlook for a revival of substantial production is not bright. A small amount will undoubtedly continue to be recovered at times of high prices or as a byproduct of operations for other mineral commodities.

Vanadium

(By **R. W. Schnabel, U.S. Geological Survey, Denver, Colo.**)

Most of the domestic supply of vanadium, and about half of the world's supply, has come from deposits of uranium-vanadium minerals in sandstones of the Colorado Plateau in southwestern Colorado and adjacent parts of New Mexico, Arizona, and Utah. Similar deposits in the Black Hills of South Dakota and Wyoming have yielded a small amount of vanadium as a byproduct of uranium. Otherwise the world's vanadium has come from a deposit of vanadium-bearing asphalt in Peru and as a byproduct of base-metal deposits in Africa and of iron deposits in Europe and Africa. The iron deposits, and similar ones elsewhere in the world, contain very large resources of vanadium; they will probably become increasingly important sources in the future.

Vanadium is used chiefly as an alloy with iron in making special tool, engineering, and structural steels. It is used to control grain size, impart toughness, and inhibit fatigue. Other domestic uses have been in nonferrous alloys and in chemicals (U.S. Bureau of Mines, 1960, and Busch, 1961).

South Dakota's production figures for vanadium are not available, but the amount is very small in comparison with the U.S. annual consumption of about 5,000 short tons (Fischer, 1973, fig. 74). Most of the vanadium has come from deposits of uranium-vanadium minerals in sandstones of Cretaceous age in Fall River and Custer Counties; a small amount has come from uranium-vanadium deposits in and associated with Tertiary lignites in Harding, Perkins, and Butte Counties. The section on uranium in this report gives information on the geology and mineralogy of these deposits as well as the locations of some of them. A vanadium circuit was added to the mill at Edgemont in 1960, and vanadium was produced from the uranium ores until 1972. Other materials have been processed for their vanadium content at the mill since uranium production stopped.

The vanadium content of the South Dakota uranium ores averages about 0.15 percent V_2O_5, which is a little more than enough to form carnotite and tyuyamunite, the principal vanadium-bearing minerals.

Additional vanadium is apparently in clay minerals. Ores of the Colorado Plateau contain about 1.5 percent V_2O_5.

As the uranium section of this report indicates, reserves total about 600,000 tons of ore. If the vanadium content is consistently about 0.15 percent, these ores contain about 900 tons of V_2O_5. Additional resources in the sandstone deposits and in lignites may amount to between 5,000 and 9,000 tons of V_2O_5. Although the vanadium contained in ores of South Dakota is of small quantity in comparison with the world's needs and cannot be recovered from the ore economically as a primary product, it should nonetheless be extracted during processing for uranium.

Tin

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

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 $99,000 was produced from placers, veins, and pegmatites. Since then, approximately 10 tons of tin has been added (table 6). Some tin was produced as recently as 1969.

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 6.—TIN PRODUCTION, 1884–1973

[From the U.S. Bureau of Mines]

Year	Quantity (pounds)	Value
1884–1912 [1]	314,000	$76,500
1913	2,000	660
1914–16		
1917	20,000	12,300
1918	240	200
1919		
1920	12,000	6,000
1921–26		
1927	325	200
1928	4,000	2,000
1929	500	200
1930–36 [2]	3,045	1,100
1937	2,000	1,000
1938	2,000	900
1939	(3)	608
1940	4,000	$1,710
1941	3,210	(3)
1942	4,000	1,560
1943	2,000	750
1944	(3)	(3)
1945–47		
1948	(3)	(3)
1949–1965		
1966	(4)	(4)
1967–68		
1969	(4)	(4)
1970–73		
Total (1884–1973)	[5] 379,979	[5] 110,276

[1] Estimated.

[2] Data shown for the period of years to avoid disclosure of confidential figures.

[3] Confidential figure; included in total.

[4] Confidential figure; not included in total.

[5] Includes confidential figures indicated by footnote

The U.S. Bureau of Mines (1954a, 1955) records 51 prospects and mines in which tin was of interest. Seven of these are near Tinton in the northern Black Hills near the Wyoming border. The remaining 44 are in the southern Black Hills, about half of them within 3 miles of Hill City.

The Tinton district has 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 small placer deposits.

Most of the rest of the production has been from the Hill City district, chiefly from quartz veins that contain muscovite, beryl, and cassiterite. The Cowboy mine has generated perhaps the most interest. In it the vein is 1 foot wide over most of its length but 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 pegmatites of the southern Black Hills. Its main habitat is mica-rich environments, 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. Worldwide, productive tin pegmatites are restricted largely to areas where deep tropical weathering promotes residual and alluvial concentrations of cassiterite (Sainsbury and Reed, 1973, p. 643).

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 for the Hill City district, based largely on examination of the deposits in 1941–43 by geologists of the U.S. Geological Survey, suggest measured and indicated reserves of 60 tons of tin and inferred reserves of the same magnitude. Cassiterite-bearing pegmatites of the southern Black Hills have several hundred tons of tin, but at a grade that in no known deposit exceeds 1 percent.

In short, tin has been found in many places as a minor constituent of rocks in the Black Hills, as in geologically similar localities throughout the world. The possibility of discovering larger and richer deposits, suitable for full-scale mining, should not be wholly disregarded, but the history of the extensive and largely unsuccessful search for such deposits can be viewed only as discouraging.

Manganese

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

Manganese is obtained mostly from deposits of black oxide minerals pyrolusite and psilomelane and a mixture of oxides called wad; a small quantity is derived from the carbonate rhodochrosite.

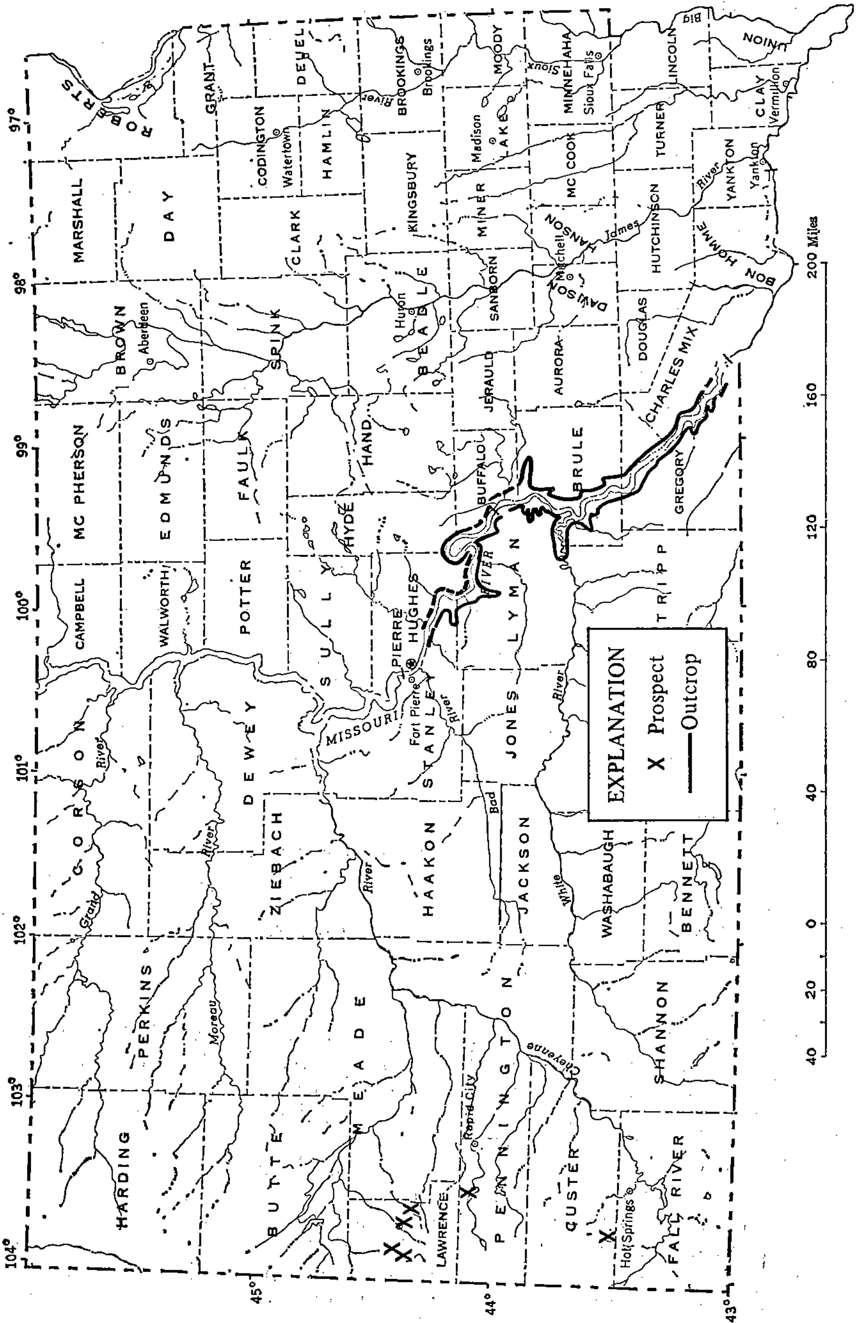


FIGURE 18.—Manganese.

Manganese-rich nodules from deep ocean deposits are a promising future resource that has been much investigated by industry and governments.

The manganese content of commercial ore normally is at least 25 percent before beneficiation. Annual world production totals approximately 23 million tons of ores and concentrates containing 30 percent or more Mn. Most of the 2 million tons consumed annually in the United States is used in the manufacture of iron and steel, in which it is indispensable; the remainder is divided between the manufacture of storage batteries, the chemical industry, and a host of minor uses. The United States has generally produced only a few percent of its own needs but now produces none at all, thus depending entirely upon imports. Two-thirds of the U.S. imports come from Brazil, Gabon, and South Africa.

The Black Hills has produced small quantities of manganese, but no large commercial reserves are known. Vast resources of low-grade material along the Missouri River (fig. 18) are not competitive with conventional ores.

Shipments of South Dakota manganese-bearing material, as recorded in South Dakota State Mine Inspector's reports, are listed below. The large shipments of Chamberlain nodules were for experimental work conducted by laboratories outside of the state.

Date	Nature of material shipped	Source	Amount
1892	Oxide ore from Minnelusa Formation	Custer County	19 tons.
1918	Ore of manganese, gold and silver, 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.

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) showed 46.05 percent manganese.

Thin layers of manganese oxides are found in stratified fillings within caves in the Pahasapa limestone. J. A. Redden (oral communication, 1974) reports that 10 feet of high quality manganese ore was encountered at 340 feet in an unsuccessful water well in sec. 18, T. 5 S., R. 4 E., Custer County.

Small concentrations of manganese minerals are associated with Tertiary mineralization in the northern Black Hills. Manganese oxides occur in Cambrian rocks at Galena as well as east and southeast of Deadwood at Spruce Gulch, Two Bit Creek, and Strawberry Hill, and in Pahasapa Limestone ores in the Carbonate district and at Ragged Top Mountain. Lincoln and others (1937, p. 163) also report one manganese prospect in Precambrian rocks 1 mile north of Pactola Lake. 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 (South Dakota State Mine Inspector's Report for 1942). This ore was produced under a government buying program established to permit mining of material that would normally be noncommercial either because of small volume or low grade.

Missouri River deposits

History of exploration.—Concretions that weather out of the DeGrey Member of the Pierre Shale form a continuous black band along the Missouri River breaks in central South Dakota (fig. 18). 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 the 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. D. F. Hewett of the U.S. Geological Survey analyzed this test pit data and concluded that the manganese concretions underlying 9 townships near Chamberlain contained an estimated 102,000,000 tons of metallic manganese (Hewett, 1930).

Stratigraphic studies in 1934–35 indicated that the manganese-bearing zone formed a laterally continuous member of the Pierre Shale 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 (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, (2) gravel, and (3) waste substances.

Description of the deposits.—The DeGrey Member 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 potato. Nodules may be widely separated or so closely spaced as to form a nearly continuous pavement. 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, which 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) still softer nodules that grade into shale and are as likely to have fractures going through a concretion as around it. Types 1 and 2 easily break free of the enclosing shale.

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 ordinarily 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.

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. The concretion zone ranged in thickness from 12 feet at Wheeler Bridge, Charles Mix County, to 72 feet near the Big Bend of the Missouri River. The average thickness used in tonnage estimates was 40 feet. Samples from bucket drill holes were dried and hand sorted to separate the concretions from the shale. Concretions range from 2.45 percent by weight near Big Bend to 6.11 percent near Oacoma, Lyman County; the average, over all areas drilled, is 4.85 percent of the dry material in the zone. If minus one-half inch material is excluded, the percentage drops to 3.19.

The average composition of concretions in 9 of the 10 areas drilled is 15.68 percent manganese and 8.7 percent iron. For the plus one-half inch concentrate, the percentages increase to 16.09 and 10.26 respectively.

Experimental mining indicated that the concretion zone could be mined in a single bench, using a 3-yard or larger shovel. Mining and hauling would be difficult in periods of continued wet weather.

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 yielded 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 it would be desirable to devise a metallurgical process that could handle a concentrate with no less than 10 percent shale.

Resources. In calculating resources, all material has been included that is under overburden less than one-half the thickness of the concretion zone. Pesonen and others (1949a, p. 87) state "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." There is, however, no known practical method of recovering the manganese disseminated in the shale.

Outlook 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.

Molybdenum and Rhenium

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

Only small amounts of molybdenum have been mined in South Dakota, but recent explorations and new geologic interpretations may alter the picture. Molybdenum is known in the crystalline rocks of the central Black Hills; it accompanies uranium in bedded deposits in sandstone and lignite along the southern margin of the Hills and near the northwestern corner of the State and it is in sandstone in the Badlands region. Because of their apparently small size or low average molybdenum content, the deposits have not been commercially exploited. Trace amounts of rhenium have been found in the molybdenum-uranium deposit in sandstone along the southern flank of the Black Hills.

The economic importance of molybdenum and rhenium is due chiefly to their versatilities as alloying metals in the ferrous metal and specialty metals industries and as catalysts in the petroleum industry. About 80 percent of the molybdenum consumed in the United States is used in the manufacture of high temperature alloy steels, stainless steels, and castings (Bieniewski, 1970). The demand for molybdenum, therefore, is to a large degree dependent on the demand for steel. The remainder of domestic consumption goes into special alloys, metal products, refractories, chemicals, pigments, catalysts, lubricants, and agricultural products. New uses are continually being developed. Molybdenum imparts hardness, toughness, and resistance to wear and erosion when alloyed with steel.

The major uses of rhenium are in the manufacture of petroleum reforming bimetallic catalysts (85 percent), and in the fabrication of devices for electrical contacts, thermal controls, and X-ray tubes (Shimamoto, 1973). It provides a stable catalyst when used in combination with platinum that increases the yield and octane rating of gasoline. It can be expected that the demand for rhenium will expand as the use of unleaded gasoline grows.

Molybdenum is widely distributed over the surface of the earth; its abundance in rocks of the earth's crust is estimated to be from 1 to 2.5 parts per million (.0001 to .00025 percent). 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 ferrimolybdite (iron-molybdenum oxide), wulfenite (lead molybdate), powellite (calcium molybdate, commonly with tungsten), jordisite (amorphous molybdenum disulfide), and ilsemannite (a water-soluble molybdenum oxide). A number of rare minerals of doubtful economic significance have been identified.

Rhenium, in contrast to molybdenum, is truly a rare metal, its abundance in the earth's crust being estimated at between .5 and 10 parts per billion. It has been intensively studied in the short time since its discovery in 1925. Except for the one rare mineral dzhezkazganite, a rhenium-copper sulfide recently found in sandstone ores in Russia, rhenium minerals have not yet been identified; molybdenite seems to be almost the sole host for significant amounts of rhenium. Its range in molybdenite is from a trace to a few tenths of 1 percent, and it is of economic importance where present in amounts greater than 50 parts per million (.005 percent). Rhenium has been produced in the United States during the past 30 years, attaining a current production of about 7,000 lbs annually.

Not until the early part of the present century was the potential value of molybdenum to the metals industry recognized and wide applications for it developed. Intensive search for the metal followed, which resulted in the discovery of high-grade vein deposits of wulfenite in Arizona and Nevada, of molybdenite in New Mexico, and of the large low-grade molybdenite deposit at Climax, Colorado. Within the past 50 years molybdenum production in the United States has grown from about 1 million lbs to slightly over 100 million lbs annually, the United States contributing about 90 percent of the world's molybdenum supply.

Molybdenum is marketed either as concentrates (95 percent MoS_2), nominally priced at about $2 per pound of contained molybdenum, or as molybdenum oxide (MoO_3) produced by roasting molybdenite concentrates. Rhenium is marketed as salts of the metal or as rhenium metal powder valued at about $675 per pound.

Molybdenum deposits are of five types: porphyry deposits in which metallic sulfides are concentrated in large volumes of altered and fractured rocks; contact metamorphic zones and bodies of silicated limestone adjacent to granitic rocks; quartz veins; pegmatites; and bedded deposits in sedimentary rocks.

Small but significant amounts of molybdenum are present in many of the uranium-bearing lignites and coaly rocks in the North Cave Hills, Flint Butte, and Slim Buttes areas in the northwestern part of South Dakota. The uraniferous lignites and carbonaceous shales contain important reserves of uranium. The more uraniferous rocks contain more than 0.2 percent molybdenum; the deposits therefore constitute a significant potential resource of byproduct molybdenum. Some molybdenum has in fact been recovered in recent years during the processing of lignite for uranium.

A potential source of molybdenum is the Indian Creek deposits in the Badlands southwest of the town of Scenic in the southwestern part of the State. The deposits consist of lenticular beds of sandstone in the basal unit of the Chadron Formation, which are impregnated with molybdenum oxides. The mineralized beds are from a few inches to several feet thick and the molybdenum content ranges from a few hundredths of one percent to as much as 10 percent. A yellow molybdenum oxide and a blue efflorescence (ilsemannite) occur at surface exposures; below the surface jordisite and pyrite become prominent.

Small quantities of molybdenum in the minerals jordisite and ilsemannite and trace amounts of rhenium are associated with the uranium-vanadium ores in the Runge and East Runge mines, north of Edgemont. However, unless a considerable tonnage is involved, molybdenum and rhenium serve only as nuisance contaminants rather than adding value as byproducts to the uranium-vanadium ore.

Anomalous concentrations of molybdenum and other base, metals have been found by geochemical surveys within the decade in several areas in the northern Black Hills in a belt trending west-northwest from the Galena district to Tinton. Recent exploration has revealed that molybdenite is considerably more widespread than previously believed. The complex intrusive systems of Tertiary porphyries in the northern Black Hills have yielded evidence that some of these may contain porphyry (disseminated) molybdenum, perhaps with copper at depth. Specimen molybdenite occurrences associated with pegmatites and a single molybdenite quartz vein deposit are also known in the northern Black Hills.

Anomalous concentrations of Mo, Cu, Ag, As, Hg, Zn, and Co have been discovered recently by a geochemical survey in the southern Black Hills in an area north of Keystone (Raymond and others, 1975). The anomalies are in complexly folded and faulted iron-formation. Physical exploration would be needed to evaluate the economic significance of these metal concentrations.

Perhaps, contrary to previous supposition, the Black Hills is enough of a molybdenum province to warrant further investigation.

Copper

(By J. J. Norton, U.S. Geological Survey, Reston, Va.)

The Black Hills Mineral Atlas of the U.S. Bureau of Mines (1954a, 1955) lists nine prospects and small mines in which copper is an important constituent. Though several of these have some hundreds of feet of workings, recorded production has a value of only $23,000.

Most of the deposits are in phyllite or schist, generally graphitic and associated with iron-formation and cherty quartzite. The deposits have a remarkably limited distribution: the northernmost is 6 miles north of Rochford and the southernmost is 8 miles west of Hill City at Copper Mountain. A new locality, 3 miles southeast of Copper Mountain, has recently been the object of claim-staking and diamond drilling, reputedly with some success. The molybdenum section mentions geochemical anomalies both in iron-formation and in Tertiary intrusions; such anomalies encourage hope for copper because the two metals are commonly associated.

Now that Rye and Rye (1974) have shown that the gold and sulfides of the Homestake mine were probably deposited as part of a sediment of iron-formation, the tendency to regard copper as virtually absent from the Black Hills merits reexamination. Yet, after a century of prospecting, no one should expect to find a copper deposit either at the surface or buried at a shallow depth. If any deposit exists, it is well concealed.

The copper in many of the world's largest and richest deposits is now known to have been an original constituent of the sediments with which it is associated. The Black Hills may well contain a buried copper sulfide facies of metasedimentary rock. Furthermore, the Tertiary plutonism of the northern Black Hills can have redistributed deeply buried copper to form shallower vein or porphyry deposits.

Another possibility worth keeping in mind is that South Dakota rocks of Paleozoic and Mesozoic age, which thus far are known only to contain uranium deposits in Cretaceous sandstones around the Black Hills, can also carry copper or other metals. As J. A. Redden has pointed out (oral communication, 1974), black shale in the upper part of the Minnelusa Formation has resemblances to shales mined for copper elsewhere. Some logs of samples from oil drill holes in South Dakota mention copper minerals, but chemical tests of a few examples collected by Redden (oral communication, 1974) do not confirm the identification.

The known circumstances are not sufficiently encouraging to warrant exploration for copper, especially when known copper provinces elsewhere in the world are incompletely explored. The only expectable possibility for discovery in the near future is by accident in the course of searching for other minerals more attractive for exploration.

Thorium and Rare Earths

(By **J. W. Adams and M. H. Staatz, U.S. Geological Survey, Denver, Colo.**)

Thorium and the rare-earth metals are treated together in this report because they are commonly associated in nature and are closely interrelated economically. Minable deposits of ores of these elements have not been found in South Dakota, but the possibility of their future discovery should not be discounted.

Thorium is a heavy silver-gray metal that, like uranium, is the parent of a series of radioactive decay products ending in a stable isotope of lead. Unlike uranium, however, it tends to be dispersed in rocks rather than concentrated in sizable deposits.

The chief non-nuclear uses of thorium are in magnesium alloys and the manufacture of gas mantles. Thorium is also used as an atomic fuel for reactors. Several reactors using thorium are currently in operation in the United States.

The rare-earth group of metals consists of the 15 lanthanide elements having atomic numbers 57 to 71, including lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). Yttrium (Y), with atomic number 39, is also classed with the rare earths because of its chemical similarities and geochemical affinities. One of the lanthanides, promethium, is best known as an artifically produced element, although its occurrence as minute traces in natural materials has been reported.

The rare earths are divided into two subgroups. Elements from lanthanum to europium make up the cerium subgroup or "light" rare earths. Yttrium and the elements from gadolinium to lutetium constitute the yttrium subgroup or "heavy" rare earths. Cerium subgroup elements, especially cerium, lanthanum, and neodymium, are the most abundant in most rare earth ores.

The rare earths are used in a variety of ways (Parker and Baroch, 1971), notably in the catalysts used in petroleum refining, in the metallurgy of iron and steel, in the manufacture of glass and ceramics, and in phosphors for high-intensity lighting and color television. Domestic consumption now exceeds 10,000 tons of rare-earth oxides per year.

Thorium and rare earths are constituents of many minerals, but only a few of these occur in sufficient quantities to be considered ores or potential ores. Monazite, a phosphate of the cerium subgroup, has been the most important source of both thorium and the rare earths. This mineral commonly contains from 3–10 percent ThO_2 and from 55 to 60 percent total rare earths. Bastnaesite, rare-earth fluocarbonate, is an important source of cerium subgroup rare earths. This is the chief ore mineral in the large carbonatite being mined at Mountain Pass, California, which is the world's largest known rare-earth deposit. Thorite, which commonly occurs in veins related to alkalic complexes, is moderately abundant in Idaho, Montana, Colorado, and New Mexico. Other minerals that are potential sources of thorium and rare earths are thorianite, xenotime, and multiple oxide minerals such as euxenite. The rare earths in most of these minerals are chiefly cerium subgroup elements, but in xenotime and euxenite the yttrium subgroup predominates.

Thorium and rare-earth minerals are found in several geologic environments. Some of the world's production comes from beach placers formed from the weathering of high grade metamorphic rocks in subtropical and tropical climates or from reworking similarly formed sedimentary rocks. Monazite is recovered from beach sands as a relatively minor byproduct in the recovery of other heavy minerals, such as ilmenite, rutile, cassiterite, and zircon. Stream placers have been a source of thorium in the United States, principally from the Carolinas, where monazite was recovered prior to World War I, and in Idaho, where euxenite and monazite were obtained in the 1950's. Low grade deposits are also present in some sandstones and conglomerates. One of the largest thorium and rare-earth sources is in quartz-pebble conglomerates of Precambrian age with large uranium deposits in the Elliot Lake area of Ontario (Griffith and Roscoe, 1964). Small amounts of monazite also occur in the basal conglomerate of the Deadwood Formation of Cambrian age in the Big Horn Mountains, Wyoming (Eilertsen and Lamb, 1956), and the Goodrich Conglomerate of Precambrian age in Marquette County, Michigan (Vickers, 1956). Thorium and rare earths are also commonly associated with alkalic rocks such as syenites, phonolites, and shonkonites. In the vicinity of these intrusives they are in carbonatites or veins. The carbonatites are generally intruded in or near the alkalic rocks, and are potentially a source of rare earths. Veins may occur in the same region, but are generally farther from the alkalic rocks. Veins may have sizable resources of both thorium and rare earths.

Very few localities of minerals containing thorium or the rare earths have been reported in South Dakota. An early description of the mineralogy of the Black Hills (Scott, 1897) saying that monazite occurs "throughout the tin region around Harney Peak" appears to have been in error, for no monazite has since been found in the Harney Peak Granite, pegmatites, or tin veins. Monazite is reported, however, as a minor constituent of the conglomerate in the Deadwood Formation north of Lead (Roberts and Rapp, 1965, p. 143). It was also listed as occurring to the extent of 6 pounds per ton in black sand concentrate from the vicinity of Tinton in Lawrence County (Day and Richards, 1960).

Thorium-bearing limonitic quartzite is found in the basal 15 feet of the Deadwood Formation 8 miles west-northwest of Rochford in secs. 2 and 11, T. 2 N., R. 2 E. Appreciable amounts of thorium are erratically scattered through the limonitic part of these quartzites; the rare-earth content is low. The thorium is not in placer minerals, such as monazite, and evidently was introduced into the limonite after the deposition of the Deadwood Formation.

Several radioactive occurrences, some of which are due largely to thorium, are 2 to 4 miles west of Lead near Bald Mountain (Vickers, 1954). These are generally mineralized fractures in Lower Paleozoic sedimentary rocks or Tertiary intrusives, part of which are of alkalic rocks. Some contain as much as 0.1 to 0.2 percent thorium. Other constitutents include uranium, rare earths, and gold. Neither thorium nor rare earths appear to be present in sufficient amounts to be of economic interest at the present time.

NONMETALLIC OR INDUSTRIAL MINERALS AND ROCKS

Sand and Gravel

(By C. M. Christensen, South Dakota Geological Survey, Vermillion, S. Dak.)

Sand and gravel are produced in larger volume than any other mineral product and consistently rank among the top five mineral commodities nationally in total value. In South Dakota, production of sand and gravel is the major nonmetallic mineral industry, and is second only to gold in total value. Records indicate that since 1889 nearly 400 million short tons have been produced, with a value of $278 million (table 7). If the present trend of ever increasing use continues, many additional deposits of sand and gravel will have to be developed.

Economic deposits of sand and gravel exist in all counties in South Dakota, and in 1973 some sand and gravel were produced in nearly every county. Production varies markedly, for it is primarily dependent upon demand for the product as a road metal.

TABLE 7.—SAND AND GRAVEL PRODUCTION, 1889–1973

[From U.S. Bureau of Mines]

Year	Quantity (short tons)	Value
1889–1908[1]	4, 500, 000	$900, 000
1909	1, 526, 714	271, 260
1910	849, 800	157, 738
1911[1]	600, 000	90, 000
1912	545, 622	69, 348
1913	1, 068, 833	89, 306
1914	232, 395	40, 215
1915	256, 270	45, 717
1916	1, 095, 594	133, 755
1917	194, 520	49, 654
1918	229, 787	48, 362
1919	648, 939	231, 390
1920	572, 259	253, 614
1921	185, 639	136, 152
1922	200, 408	121, 690
1923	304, 768	156, 914
1924	323, 303	113, 602
1925	1, 769, 922	576, 248
1926	2, 013, 350	286, 591
1927	1, 162, 823	231, 218
1928	2, 461, 963	1, 301, 075
1929	2, 729, 271	578, 204
1930	2, 419, 441	931, 814
1931	2, 369, 279	931, 137
1932	2, 065, 282	248, 173
1933	3, 233, 940	624, 428
1934	3, 863, 410	773, 559
1935	4, 178, 035	794, 276
1936	3, 325, 490	746, 711
1937	3, 845, 423	612, 552
1938	4, 677, 593	627, 344
1939	2, 539, 417	722, 046
1940	2, 910, 331	524, 842
1941	2, 627, 059	559, 766
1942	3, 577, 983	$1, 443, 908
1943	2, 291, 450	701, 034
1944	2, 501, 431	956, 178
1945	2, 642, 494	1, 106, 983
1946	3, 215, 608	1, 537, 822
1947	3, 122, 409	1, 672, 253
1948	4, 687, 055	3, 247, 428
1949	5, 456, 742	2, 315, 430
1950	5, 392, 247	2, 750, 847
1951	5, 037, 384	2, 502, 340
1952	5, 846, 140	2, 478, 314
1953	5, 402, 378	2, 817, 726
1954	14, 819, 228	7, 840, 393
1955	13, 537, 801	10, 096, 828
1956	12, 539, 000	8, 423, 050
1957	14, 758, 000	8, 001, 000
1958	14, 705, 000	9, 179, 000
1959	17, 775, 000	11, 058, 000
1960	13, 548, 000	9, 359, 000
1961	11, 324, 000	7, 336, 000
1962	15, 371, 000	9, 207, 000
1963	20, 806, 000	16, 313, 000
1964	13, 770, 000	13, 641, 000
1965	13, 998, 000	14, 155, 000
1966	13, 630, 000	13, 585, 000
1967	13, 463, 000	13, 737, 000
1968	11, 558, 000	11, 578, 000
1969	11, 158, 000	10, 807, 000
1970	16, 556, 000	16, 656, 000
1971	16, 727, 000	18, 392, 000
1972	12, 748, 000	14, 793, 000
1973	13, 963, 000	16, 587, 000
Total (1889–1973)	397, 454, 239	278, 253, 235

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[1] Estimated.

Most of the sand and gravel deposits east of the Missouri River are directly related to glacial activity and are in recognizable glacial landforms. Most of the sand and gravel pits in this part of the State are in glacial outwash occurring as outwash plains, valley trains, or terrace remnants. Other useful deposits are in kames, kame terraces, eskers, beaches, and as isolated bodies within moraines.

In the unglaciated western half of the State most sand and gravel sources are confined to the terraces of the major streams and their larger tributaries. Near the Black Hills, mountain outwash provides a valuable source of concrete aggregate.

Uses of sand and gravel are exceedingly diverse. A vast array of construction practices require large amounts of sand and gravel to impart durability, strength, and bulk at low unit cost. By far the largest amounts are used in all phases of road construction. At the present time over 90 percent of the sand and gravel produced in the State is used in highway fill, base course, and final surfacing. In addition, all major construction projects, such as airports, dams, public and private buildings, and the maintenance of ballast in railroads, require sand and gravel. High purity silica sand, which amounts to only a small share of the production but has been mined from the Deadwood Formation in western Pennington County, finds special uses in abrasive blasting, in molding, and in the hydrafrac process in the oil industry.

Many factors, including quantity, quality, demand, and transportation cost, greatly affect the value of sand and gravel. Because they are low cost commodities, the distance between the source of supply and the market is of primary importance. Higher grade supplies can, of course, be hauled over longer distances than lower grade supplies. As the demand continues to expand, and construction specifications become more rigid, high quality deposits will be depleted at an increasing rate. Eventually lower quality sand and gravel will be processed for use in products requiring high quality materials.

Information on specific localities of known sand and gravel deposits throughout the State is available from the South Dakota Geological Survey in Vermillion.

Limestone

(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. It is the principal raw material for the very successful State-owned cement plant in Rapid City. Commercial limestone-bearing formations crop out only in the Black Hills area. The marketing area extends over a radius of 250 to 300 miles from the outcrop for prepared rock, and as much as 500 to 600 miles from Rapid City for lime and cement.

Limestone in massive pieces has been used in South Dakota as building stone and riprap. In crushed and sized 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 calcium-rich rock, magnesian or dolomitic limestones and dolomite, argillaceous carbonate rock, and metamorphosed siliceous dolomitic marbles.

Geology

The formations that may serve as sources of limestone are considered below in order from oldest to youngest in 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 use a metamorphosed magnesian limestone south of Harney Peak (Connolly and O'Harra, 1929, p. 295). No market developed for a cut and polished finished product and the project was abandoned. Other carbonate deposits within the Precambrian have not been used for either ornamental value or 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 becomes thinner or absent 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 rock. No record shows that this material has ever been utilized.

Whitewood Dolomite.—The Whitewood Dolomite crops out in the northern part of the Black Hills. It thins from about 60 feet in the most northerly exposures near Deadwood to a feather edge at its southern limits near Nemo on the east and Cheyenne Crossing on the west. The formation is a mottled, irregularly dolomitized rock 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.

Prior to World War I, it 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 (Madison) Limestone.—The Pahasapa Limestone is a white to very light gray carbonate rock ranging in thickness from less than 300 feet to over 600 feet in the northernmost exposures. 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 range from 5 to 10 degrees, and is as much as 10 miles wide on the western side of the Hills. The formation is ordinarily dolomitic and should more properly be called a dolomite in the outcrop area. 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). No bed of pure limestone more than 5 feet thick is known in the 600-foot Spearfish Canyon section.

Quarries in the Pahasapa have generally been located along the railroads. Quarries along the Burlington Northern Railway route through the central Hills have been operated at Loring Siding, Pringle, and Dumont. At Loring Siding, 4 miles southwest of Pringle, two quarries, no longer in operation, supplied burned lime and limestone

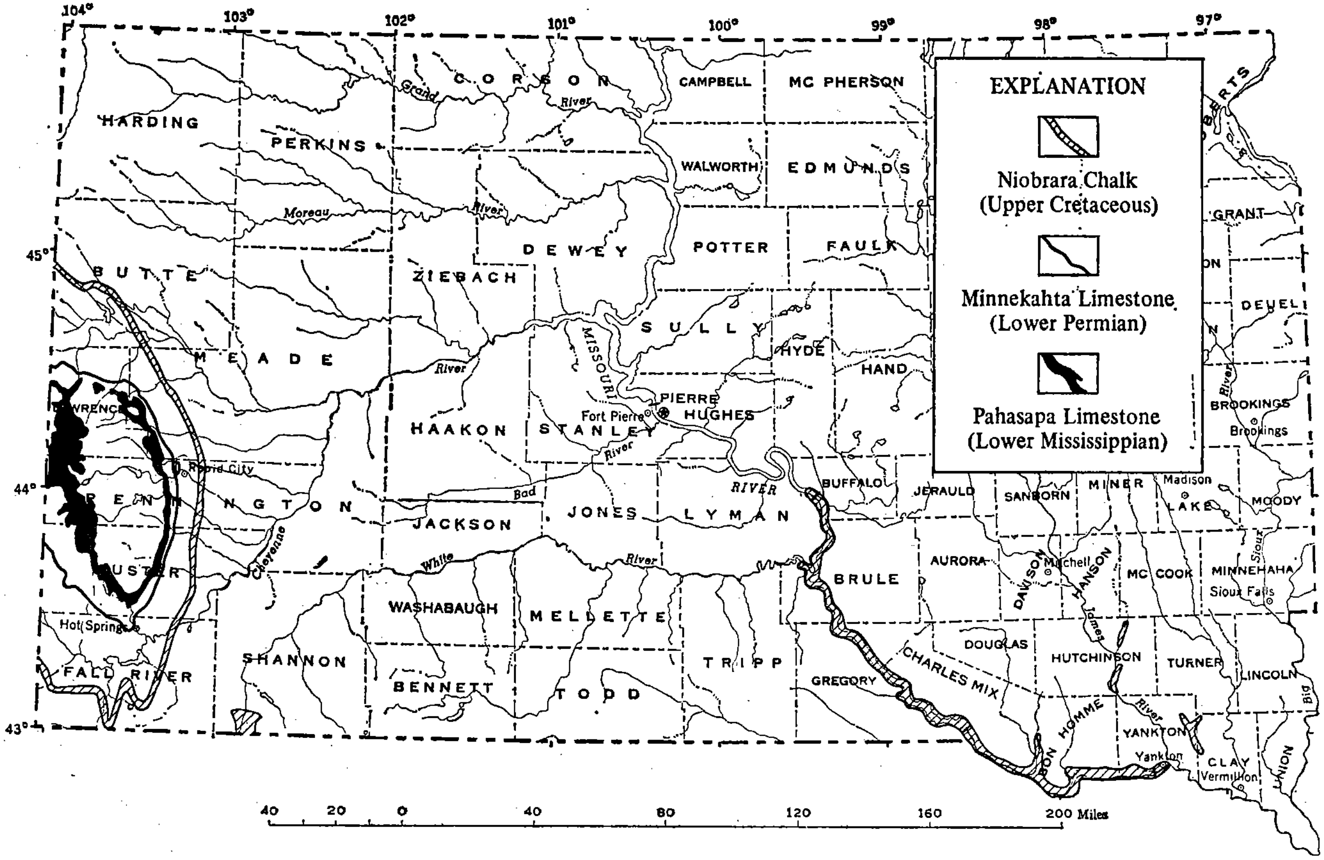


FIGURE 19.—Limestone and chalk.

for sugar beet plants in Nebraska and Wyoming. A quarry and plant at Pringle produces lime and various rock products. At Dumont, 8 miles south of Lead, Pahasapa limestone was quarried for flux for the Deadwood smelter.

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

Limestone and dolomitic limestone resources in the Pahasapa are virtually limitless at any conceivable 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 calcium-rich layers are present in places 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 ranges from 0.2 to 2.0 miles, and the dip slope is usually studded with pine trees.

The following fourfold subdivision of the Minnekahta Limestone in the Black Hills (Gries, 1952) is based on the lithologic appearance of outcrops and on 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 slabs and plates.
3. Lower pure zone: Resembles zone 1.
4. Lower shaly zone: Limestone, very argillaceous, brick red, residue abundant and largely of 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 and composition
Upper pure zone	14	1½, clay and silt.
Upper shaly zone	14	4, clay.
Lower pure zone	7	Less than 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 unusual. Quarry owners report layers of very calcium-rich rock, which they may save for shipment to sugar beet processors.

The Minnekahta Limestone has been burned for lime since the 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 lime was shipped 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 modern lime plant using Minnekahta Limestone was started at Rapid City in 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 in 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, and generally above the water table, are sufficient to last many thousands of 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 at Bear Butte. No attempt has been made to mine 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 southeast of Hot Springs for nearby use, 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 220 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 the Big Bend dam. Although an extensive portion of the outcrop has been submerged by waters behind the Gavins Point and Fort Randall dams, huge reserves remain above water level. The Niobrara also occurs at the surface 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 used as a building stone in the southeastern part of the State prior to about 1880, and occasional use of the stone persisted through the depression years of the 1930's. 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 the reasons given 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.

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 project was abandoned.

No use of the Niobrara chalk in western South Dakota is anticipated in the foreseeable future.

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 (S. Dak. State Cement Comm., p. 68–80) to determine if calcium carbonate was abundant enough for cement manufacture. 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 of the White River Group in the Big Badlands and in the Black Hills. A fresh-water limestone of this age

TABLE 8.—TYPICAL ANALYSES OF SOUTH DAKOTA CARBONATE ROCK.

[In percent]

Formation, location, and source of data	CaO	MgO	Ingition 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	.42	.40		--------
Pahasapa Limestone, B. H. Lime Co., Pringle, sec. 22 or 23, T. 5 S., R. 4 E. (Connolly and O'Harra, 1929, p. 286)	53.98	1.64	43.77	.56	.20	.06	tr.
Pahasapa Limestone, B. H. Marble Quarries, sec. 13, T. 1 N., R. 6 E. (Lincoln, 1930, p. 43)	38.00	14.10	45.32	2.10	.36		tr.
Pahasapa limestone (lithographic stone) sec. 16, T. 4 S., R. 3 E. (Connolly and O'Harra, 1929, p. 341)	56.08	.16	43.73	tr.	.12		--------
Minnekahta Limestone, quarry face at Calcite; sec. 30, T. 4 N., R. 6 E. (Connolly and O'Harra, 1929, p. 288)	53.91	.39	42.74	2.12	.42	.60	.08
Minnekahta Limestone, grab sample at Spearfish quarry (Connolly and O'Harra, 1929, p. 288)	54.96	.71	43.00	1.92	.28		tr.
Minnekahta Limestone, Cement Plant Quarry, sec. 33, T. 2 N., R. 7 E. (South Dakota State Plan. Board, no date, p. 31)	54.46	.48	42.95	1.22	.44	.34	.03
Niobrara Formation, Antelope Creek, Meade County (O'Harra and others, 1908, p. 20)	38.85	1.08	36.67	15.51	5.80		tr.
Niobrara Formation, white chalk near Chamberlain, sec. 36, T. 105 N., R. 71 W. (South Dakota State Cement Comm., no date, p. 12)	44.88	.77	31.20	10.72	1.86	9.20	.43
Mobridge Member, Pierre Shale, Carson County, sec. 19, T. 18 N., R. 30 E. (South Dakota State Comm., no date, p. 75)	5.98	2.60	7.02	52.56	4.27	18.36	2.78
White River Group, NE¼ SE¼ sec. 21, T. 1 S., R. 7 E., Pennington County	52.3	1.2	41.7	.50	.30	.60	.10

in the Rockerville quadrangle, on the east flank of the Black Hills, is of large areal extent and high calcium content (P. H. Rahn, personal communication, 1974); an analysis is shown in table 8. Another freshwater limestone occurs in the Miocene Monroe Creek Formation of Arikaree age on the Rosebud and Pine Ridge Indian Reservations. These slabby limestones have been used locally for culverts and as riprap for stock dams. The thicker beds reputedly 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, except for the deposit 3½ miles east of Rockerville, Pennington County.

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. A cement plant, operated at Yankton from 1891 through 1909, produced a total of 1,913,738 barrels of Portland cement. A small lime plant at Pringle, with a daily capacity of 16 tons of lime, has been in operation since 1899.

The State of South Dakota operates a cement plant at Rapid City. Started in 1925 with a coal-fired kiln capable of producing about 700,000 barrels of Portland cement per year, it now has a capacity of 3 million barrels a year and uses natural gas as a fuel. The plant is currently being enlarged and modernized. By 1977 it will have a capacity of 6 million barrels per year, and will be converted to use Wyoming low-sulfur subbituminous coal in the kilns.

The plant is located at the limestone quarry west of the city. Pierre Shale is quarried 8 miles east of Rapid City, and trucked to the plant. Gypsum is mined from Spearfish redbeds north of the plant, and silica sand from the Sundance Foundation about a mile east of the plant. Iron ores are bought on contract from sources in the central Black Hills. In 1971 the plant used 419,000 tons of limestone, 101,000 tons of shale, 28,000 tons of sand, 15,000 tons of gypsum, and 6,000 tons of iron ore to produce 2.2 million barrels of cement. The plant produces five types of portland cement (I, IA, II, III, V) as well as DACOTAH brand masonry cement. Total production 1925–1973 was 56.6 million barrels.

Acceptance of the technique of using lime to stabilize heaving soils under highway and airport pavements justified the construction of a modern lime plant at Rapid City in 1964. The plant started with one standard rotary kiln with a daily capacity of 90–100 tons of finished lime (CaO). By expanding the capacity of the first kiln, and adding a vertical kiln of advanced design, the plant now has a rated capacity of 340 tons per day. It takes roughly two tons of quarry rock to produce one ton of finished product.

Prior to 1920, only the dollar value of lime and limestones was reported. Subsequently, total tonnage of limestone produced by all operators has been published in the Minerals Yearbook. A critical analysis of early production figures is given by Lincoln (1930, p. 43–44). Lime production figures are generally withheld to avoid disclosing individual company confidential data. Production of cement is indicated by a yearly statement of barrels shipped by the State Cement Commission.

TABLE 9.—LIMESTONE AND CEMENT PRODUCTION, 1964–73

	Limestone		Cement—Barrels shipped[1]
	Thousands of short tons	Value (thousands)	
1964	1,180	$1,735	2,058,217
1965	863	1,403	1,629,855
1966	1,095	1,785	2,024,438
1967	882	1,399	1,457,837
1968	1,082	1,694	1,879,894
1969	989	1,207	1,604,559
1970	1,043	1,052	1,583,887
1971	1,426	1,621	2,201,863
1972	1,685	1,845	2,668,278
1973	(2)	(2)	3,109,333

[1] Includes both 376 and 280 pound barrels.
[2] Not available.

Source: U.S. Bureau Mines Minerals Yearbooks and South Dakota State Cement Commission.

Stone

(By D. J. McGregor, South Dakota Geological Survey, Vermillion, S. Dak., and J. J. Norton, U.S. Geological Survey, Reston, Va.)

The term stone includes both dimension stone and all crushed or broken natural rock. The term "dimension stone" is restricted to stone that is quarried in blocks and cut or shaped for use in monuments, as a construction material, or for decorative purpose. Crushed or broken stone is used in road building, cement manufacture, other construction activities, agriculture, chemical and metallurgical processes, and roofing material. Much of the crushed stone of South Dakota is limestone, described in the preceding chapter, but it also includes considerable amounts of sandstone, quartz, and quartzite. Production of all stone is shown in table 10. Production figures for the different major categories, in table 11, indicate that in South Dakota dimension stone is of greatest economic significance.

TABLE 10.—STONE PRODUCTION, 1889–1973

[From U.S. Bureau of Mines]

Year	Quantity (short tons)	Value	Year	Quantity (short tons)	Value
1889–99[1]	750,000	$1,500,000	1922[3]	133,920	$272,152
1900	(2)	174,552	1923[3]	250,730	479,288
1901	(2)	171,368	1924[3,4]	166,970	362,508
1902	(2)	197,394	1925[3,5]	211,880	456,342
1903	(2)	202,333	1926[3,5]	211,340	472,032
1904	(2)	367,784	1927[3,5]	264,500	535,232
1905[3]	(2)	200,061	1928[3,5]	172,360	451,869
1906[3]	(2)	156,360	1929[3,5]	250,440	635,890
1907[3]	(2)	155,875	1930[3,5]	166,020	666,201
1908[3]	(2)	131,994	1931[3,5]	222,510	636,841
1909[3]	(2)	167,357	1932[3,5]	196,100	442,507
1910[3]	(2)	173,726	1933[3,5]	133,520	376,078
1911[3]	(2)	148,190	1934[3,5]	237,510	497,200
1912[3]	(2)	162,295	1935[3,5]	229,420	585,434
1913[3]	(2)	172,736	1936[3,5]	259,130	693,496
1914[3,4]	(2)	156,907	1937[3,4,5]	407,270	982,906
1915[3]	(2)	159,089	1938[3,5]	320,740	899,190
1916[3]	(2)	205,497	1939[3,5]	408,730	998,444
1917[3]	(2)	182,907	1940[3,5]	255,600	878,866
1918[3]	(2)	97,894	1941[3,4,5]	401,550	1,189,564
1919[3]	140,400	222,490	1942[3,5]	714,750	1,763,790
1920[3]	196,880	489,753	1943[3,4,5]	269,410	1,304,370
1921[3]	181,600	386,906	1944[3,4,5]	255,530	1,412,141

See footnotes at end of table.

TABLE 10.—STONE PRODUCTION, 1889–1973—Continued

[From U.S. Bureau of Mines]

Year	Quantity (short tons)	Value	Year	Quantity (short tons)	Value
1945[3,4,5]	303,500	$1,605,904	1961	2,806,000	$6,642,000
1946[3,4,5]	379,880	2,385,543	1962	2,852,000	6,533,000
1947[3,4,5]	885,650	3,554,096	1963	2,794,000	7,339,000
1948[3,4,5]	763,000	3,911,000	1964	2,118,000	6,245,000
1949[3,4,5]	1,024,000	4,473,000	1965	1,554,000	5,387,000
1950[3,4,5]	1,206,000	4,861,000	1966	2,186,000	7,995,000
1951[3,5]	1,263,322	4,660,074	1967	1,866,000	9,694,000
1952[3,5]	1,671,187	4,806,882	1968	1,860,000	9,687,000
1953[3,5]	1,189,444	4,997,497	1969	2,092,000	10,839,000
1954	1,614,818	4,928,855	1970	1,979,000	13,375,000
1955	2,262,246	5,679,444	1971	2,199,000	8,874,000
1956	2,200,000	5,725,000	1972	2,665,000	10,864,000
1957	1,718,000	5,068,000	1973	2,745,000	11,607,000
1958	1,395,000	4,095,000	Undistributed[6]	6,484,973	5,072,416
1959	2,721,000	7,243,000			
1960	3,149,000	7,909,000	Total, 1889–1973	67,355,830	219,032,520

[1] Estimated.

[2] Not reported; estimate included in undistributed.

[3] Excludes stone used to make lime; included in undistributed.

[4] Excludes some stone that must be concealed to avoid disclosure of confidential figures: ncluded in undistributed.

[5] Excludes stone used to make cement; included in undistributed.

[6] Includes estimated 2,000,000 tons for period 1900–18 as indicated by footnote 2; 214,973 tons valued at $317,666 for confidential figures indicated by footnote 4; estimated 385,000 tons valued at $481,250 used to make lime during the period 1905–53 as indicated by footnote 3; and estimated 3,885,000 tons valued at $4,273,500 used to make cement during the period 1925–53 as indicated by footnote 5.

TABLE 11.—PRODUCTION OF MAJOR CATEGORIES OF STONE, 1963-72

[Quantity of granite expressed in short tons; all other figures are in thousands of short tons or thousands of dollars]

Year	Granite (dimension stone)		Limestone and dolomite (crushed and broken)		Sandstone, quartz, and quartzite (crushed and broken)	
	Quantity	Value	Quantity	Value	Quantity	Value
1963	18,930	$2,753	1,646	$2,395	1,034	$2,071
1964	17,803	2,808	1,180	1,735	920	1,702
1965	20,129	2,945	863	1,403	651	1,007
1966	23,506	4,066	1,095	1,785	984	1,991
1967	26,349	6,117	882	1,399	780	1,622
1968	38,422	6,519	1,082	1,694	676	1,402
1969	44,121	7,620	989	1,207	1,055	2,001
1970	63,167	10,409	1,043	1,052	844	1,804
1971	35,643	5,654	1,426	1,621	716	1,540
1972	36,673	7,014	1,685	1,945	941	1,897
Total	324,743	55,905	11,891	16,236	8,601	17,037

Source: U.S. Bureau of Mines Minerals Yearbooks.

The world's crushed stone industry became important only about 150 years ago, but dimension stone has been in wide use for thousands of years, going back to very early civilizations in the Middle East. The colossal statues, temples, and pyramids of ancient Egypt, stone structures of the Phoenicians, and Persepolis in Persia are all famous, as are the buildings and statuary of ancient Greece and Rome and the castles, forts, and cathedrals of the Middle Ages. A structure as massive and remarkable as many of these is the Mount Rushmore Memorial, which is the key attraction of the large tourist industry of South Dakota.

Stone for dimension use must be strong, durable, free of flaws or substances causing stain, and for many purposes hard and capable of taking a polish. Granite and limestone or marble are the most commonly used; but sandstone or quartzite, slate, soapstone, verd antique (serpentine), and many other rocks have a market. In South Dakota, granite and limestone are the only important kinds of dimension stone. Though other rocks are in use, such as those that can serve as flagstone or as decorative material for fireplaces and the like, they are generally collected by individuals and rarely pass through commercial channels.

The Milbank Granite stands foremost. It has been produced continuously since 1907 from as many as seven different quarries, all in the northeast part of Grant County. The granite is an attractive dark to medium red stone that takes a high polish and is used extensively for monuments. It is composed of plainly visible mineral grains or crystals, of which 60–70 percent are feldspars that impart the red color to the rock, about 25 percent is clear quartz, and the remainder is chiefly biotite. Differences in the color of the granite are due chiefly to differences in the color of the feldspar.

The granite is Early Precambrian in age and in large part covered by glacial deposits or by Cretaceous sedimentary rocks. It crops out as small bosses in shallow stream valleys. Local relief on the granite surface is about 100 feet. Quarrying has extended outward from outcrops to where the thickness of overburden is too great for profitable operation. The thickness of the granite is not known, but the depth of quarrying has exceeded 200 feet with no indication that the total thickness has been reached.

About 90 percent of the production is for monuments and commands a premium price. For example, data from the U.S. Bureau of Mines Minerals Yearbook for 1972 indicate that the State produced about 6 percent of the total United States granite dimension stone by tonnage, but the value was about 15 percent of the total production. The market is nationwide. Dealers generally do not stockpile such stone, and thus sales are almost exclusively on a made-to-order basis. Most of the sales are in Ohio and in the western states. The nearest competitors for the South Dakota granite industry are plants in Minnesota and in Wisconsin. The annual value of granite dimension stone over the period 1963–72 averaged about \$5.6 million, ranging from a low in 1963 of about \$2.8 million to a high of about \$10.4 million in 1970.

Six companies operate quarries. Two of them fabricate the finished product within the State, but the other four do their fabricating in mills elsewhere. The total number of employees involved in quarrying granite and in fabricating products in South Dakota is about 225.

In 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, attractiveness, and ability to take a polish. Favorable surface examination should be supplemented by core drilling to determine the thickness and nature of the rock underground and to provide samples for further appraisal.

The Harney Peak Granite in the Black Hills has rarely been quarried for dimension stone. Although the composition of the granite is similar to that in Grant County, its texture is unsuitable. Many of the mineral crystals are several inches or even several feet long, the rock chips easily when carved, and much of the granite contains small veins that diminish its attractiveness. Such parts of the granite as are sufficiently uniform and fine grained to be quarried would yield a white or gray stone that probably would not have enough sales appeal to ship the long distance to the principal markets.

Most other Precambrian rocks of the Black Hills also have aesthetic or physical shortcomings or are too difficult to quarry for the small market they would attract. Rock that approaches slate in its physical properties is used on patio surfaces and in other ways near the Black Hills, but markets in distant population centers were never developed even when slate was much more used than now.

The Minnekahta Limestone, however, has become popular. It is durable and breaks readily into blocks along its excellent bedding. It has been used for retaining walls, culverts, patios, and rustic buildings in public parks, and it has come into vogue as a facing stone by placing large slabs on edge in random pattern. Notable examples are several buildings in Rapid City.

The Sioux Quartzite once was used extensively for similar purposes. Many buildings in the state attest to its durability and beauty. Because quartzite is an extremely hard rock, fabricating it is expensive and it is no longer quarried.

In recent decades dimension stone has lost much of its former importance in construction as cheaper materials have taken its place and lightweight building products have come into wide use. Among the buildings in downtown Rapid City in which stone is prominent, about half of those built since 1960 have some type of artificial stone, whereas all of the older buildings used only natural material (P. H. Rahn, oral communication, 1974). With high costs in the construction industry, this trend is unlikely to be reversed.

The value of crushed and broken stone production has averaged about $3.3 million over the period 1963–1972 and is nearly equally divided between the limestone-dolomite and sandstone-quartz-quartzite categories (table 11). Much of the limestone described in the previous chapter is used for cement manufacture. Most of the other crushed stone is Sioux Quartzite quarried in the southeastern part of the state, where four producers are responsible for most of the output. Resources of quartzite and similar rocks are very large and will continue to be widely used for crushed stone.

Clays, Bentonite, and Lightweight Aggregate

(By S. H. Patterson, U.S. Geological Survey, Reston, Va., and J. C. Harksen, South Dakota Geological Survey, Rapid City, S. Dak.)

Common clay and shale used in making brick, tile, lightweight aggregate, and portland cement are the principal clay materials mined in South Dakota. The State was formerly among the leaders in the production of high swelling bentonite. Now the only plant processing this type of clay in South Dakota is the one operated by the American Colloid Co. at Belle Fourche and most of the raw bentonite currently used is mined in Wyoming. The common clay and shale mined is used by the Black Hills Clay Products Co., Belle Fourche, Butte County, the South Dakota State Cement Plant, Rapid City, Pennington County, and Lightweight Aggregates, Inc., Rapid City. Clays mined in the State in the past but no longer produced include fire clay for low- and moderate-grade refractory products, and fuller's earth for declorizing and purifying fats and oils.

From 1888 through 1973, 8.6 million tons of clay valued at nearly $46 million was produced in South Dakota (table 12). The sharp drop in annual value after 1970 indicated in the table is because bentonite is excluded in succeeding years. Bentonite has lost its high rank in the mineral industry of the State because of depletion of reserves in deposits that can be strip-mined.

TABLE 12.—CLAY PRODUCTION, 1888–1973[1]

Period [2]	Total Quantity (short tons)	Value
1888–1920 [3]	465,000	$584,000
1921–35	230,000	523,000
1936–40	136,622	947,289
1941–45	646,876	4,224,232
1946–50	1,207,120	9,127,068
1951–55	1,481,229	11,150,096
1956–61	1,890,914	10,090,357
1962	249,000	690,000
1963	240,000	960,000
1964	245,000	1,076,000
1965	223,000	1,220,000
1966	231,000	$870,000
1967	199,000	799,000
1968	226,000	1,119,000
1969	187,000	1,171,000
1970	165,000	946,000
1971	150,000	128,000
1972	185,000	156,000
1973	201,000	181,000
Total, 1888–1973	8,558,761	45,962,042

[1] Includes bentonite except for years 1971–73.

[2] Data in part shown for periods of years to avoid disclosure of confidential data.

[3] Estimated from record of brick and miscellaneous clay production.

Source: U.S. Bureau of Mines.

The suitability of clays 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 elements. The clay minerals that are common in South Dakota include montmorillonite, illite, kaolinite, 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 that affect their suitability for different uses include plasticity, bonding strength, color, vitrification range, deformation during drying and firing, resistance to high temperatures, gelation, wall-building properties, viscosity of slurries, swelling capacity, ion-exchange capacity, and adsorbent properties. Books by Grim (1962, 1968) contain detailed information on the composition, mineral structure, and methods of identification of various clays. An article by Patterson and Murray (1975) summarizes the economic geology of all clays, and its lengthy bibliography will be useful to the reader who needs further information.

Bentonite

Bentonite is a clay that has altered from volcanic ash or tuff, and it is ordinarily composed chiefly of montmorillonite. It is divisible into two varieties, both of which have been mined in South Dakota. One known as "Wyoming type" or "sodium type" has a high swelling capacity, extremely fine particle size, and other properties that make it of value in drilling mud, as a bonding material for foundry sands and pelletizing fine-grained iron ores, which require high dry strengths, as a relatively impervious lining for reservoirs, irrigation ditches, and stock tanks, and for many other purposes. A second type, called "calcium bentonite," "southern type," or "nonswelling bentonite," is mineralogically similar to "Wyoming" bentonite but has different physical properties. Bentonite of this kind was formerly mined in South Dakota for use in making water softeners, and a small tonnage has been mined in Butte County in recent years and sold for use in foundry sand bonding where high green strengths are required. Both kinds of bentonite have high ion-exchange capacities. The kind and abundance of exchangeable ion is thought to be important in controlling the physical properties.

Bentonite mining in South Dakota began 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 were 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 1972 only one company mined a small tonnage of bentonite in South Dakota.

The 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. Thickness of bentonite in this bed ranges 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, but the quality is not as good as in the Clay Spur bed and only a small tonnage has been mined for experimental purposes.

The low-swelling Ardmore bentonite bed of Spivey (1940, p. 3), which was mined for water softener in Fall River County, is at the bottom of the Sharon Springs Member of the Pierre Shale (Connor, 1963, p. 115) some 60 to 70 feet above the base of the formation. The average thickness is about 3 feet. 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 near Rapid City, and thus must contain a very large tonnage of bentonite. The

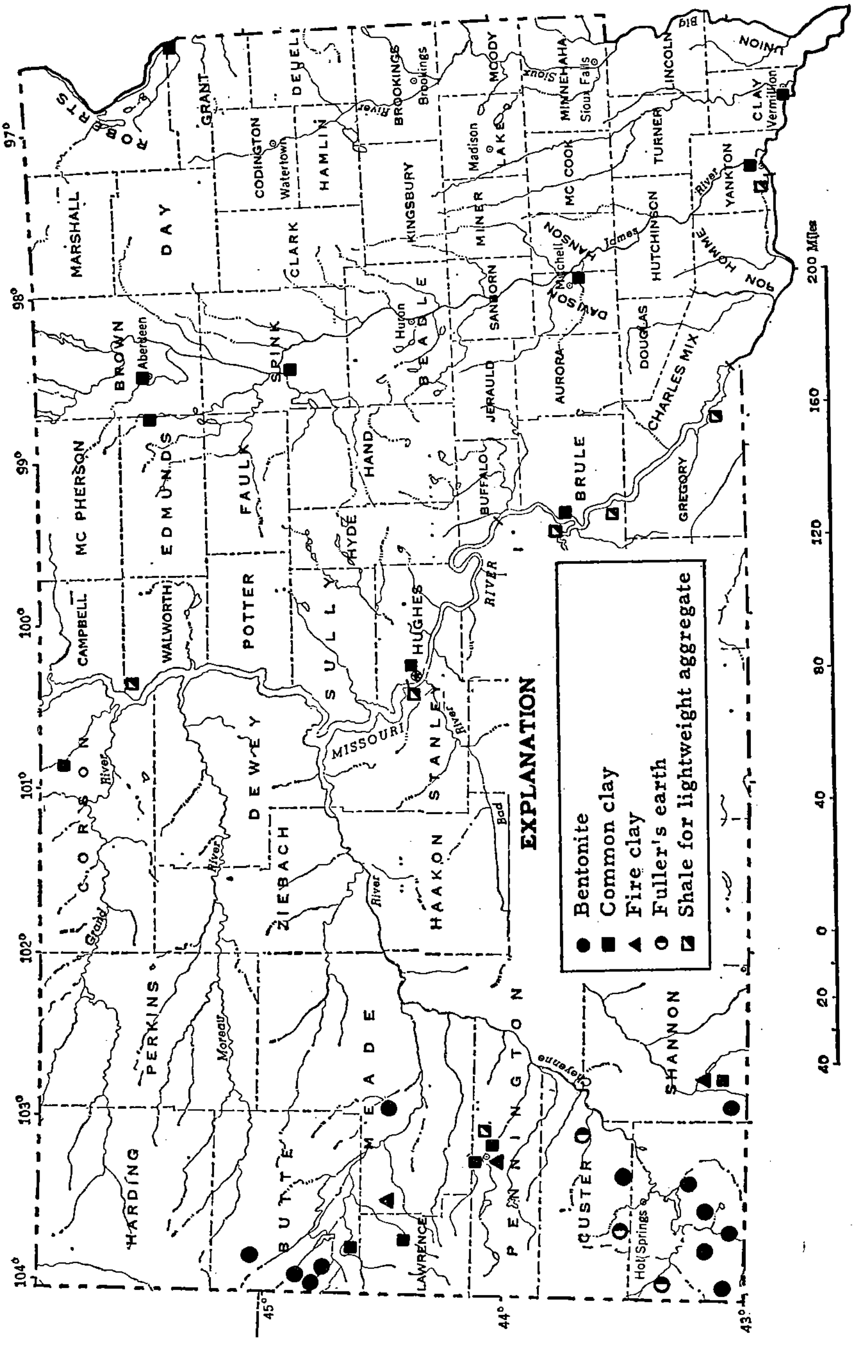


FIGURE 20.—Clays.

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 had very high green-bonding strengths but had no value as drilling mud (Knechtel and Patterson, 1962, table 4). Some of this bentonite has been used in recent years for foundry sand bond materials.

Beds of low-swelling bentonite have been found in the upper part of the Pierre Formation in both Meade and Shannon Counties. Beds along South Dakota Highway 34 in sec. 3, T. 6 N., R. 10 E., Meade County, were mined on a small scale during the late 1930's. Evidence of mining is still observable, but it is not known what the bentonite was used for or even if any of it was actually sold.

Common clay

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; 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 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 1974 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).

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 layer of light clay fires yellowish tan. This clay is probably in the same stratigraphic position and of much the same composition as 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, and every center of population in the State is near resources that could be used for these purposes. The Pierre Shale crops out over much of the central and western parts of the State and has been used for bricks at several 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 several formations. Not all of these materials can be made into brick that would be accepted by the present-day consumer.

Common clay weathered from the Pierre Shale is used in making cement at Rapid City, Pennington County. Some grades of cement have as much as 22 percent shale from this source.

A small tonnage of low-grade pottery clay is dug and used in making art pottery, chiefly for sale to tourists. These clays have come from the Fuson Member of the 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 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), though seemingly never tested or used for this purpose.

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. Al_2O_3 contents range from 6.56 to 18.30 percent in clays from south of Rapid City and in a pit south of Belle Fourche (Connolly and O'Harra, 1929, p. 307–308). Clays having Al_2O_3 contents in this range are rarely suitable for more than moderate-heat-duty refractory products; 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 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 local demand for refractory products.

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 was mined from a deposit 5 miles southwest of Fairburn and another 2 miles west of Argyle, Custer County. Other deposits of fuller's earth are reportedly located 2 miles south of Buffalo Gap, Custer County, 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 as 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 as efficient for bleaching and purifying cottonseed oil as fuller's earth now in use. Though resources in the southern Black Hills are probably very large, they are of a grade that cannot compete in distant markets with more efficient materials, and no local demands for these clays exist; hence they have little value at present.

Nonswelling bentonite in the southern Black Hills is efficient for use in filtering and purifying mineral and vegetable oils (Miller, 1959, p. 11–12). These bentonites, therefore, can be called 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, 1964). There are large resources of nonswelling and low-swelling bentonite in the southern Black Hills and elsewhere in the State, but how much of it is suitable for decolorizing oils and as bleaching agents has not been determined.

Lightweight aggregate

The only lightweight aggregate plant in South Dakota has been in operation at Rapid City since 1952. The raw material is mined from the Pierre Shale (Cole and Zetterstrom, 1954, p. 15) approximately 8 miles east of Rapid City, where reserves are very large.

Shales suitable for making lightweight aggregate occur in many places in South Dakota and the establishment of plants at localities other than Rapid City has been considered. Shale 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 suitable material are 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 in the Pierre Shale in South Dakota are very larger and other formations probably also contain suitable shales and clays.

Outlook

Common clay suitable for making brick, tile, and structural clay products is in ample supply in the State, and shale resources for lightweight aggregate and cement are virtually inexhaustible. Most products made from common clay and shale are heavy or inexpensive and can be shipped only to nearby markets.

The principal demand for bentonite from South Dakota and adjacent States is for the high-swelling type of the Clay Spur Bed. This bentonite is consumed in most states in the United States and is shipped to many foreign countries. Nonetheless, the outlook for mining in South Dakota is not bright, because reserves in the Clay Spur Bed under slight overburden are largely exhausted. The bentonite plant 2 miles northwest of Belle Fourche operated by the American Colloid Co. is 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 a long time, 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 demand were to develop for the nonswelling type, a possibility that has been suggested (Miller, 1959, p. 12; Lee and others, 1961). In addition, if taconite mining begins in the Nemo area, Lawrence County, local nonswelling bentonites may be used as a bonding agent for the concentrate.

The possibility of extracting aluminum from the Pierre Shale has been considered a number of times (Gries, 1942, p. 64–66; Rothrock, 1944, p. 65–66), and several research projects by chemical engineering students of the South Dakota School of Mines and Technology were on this subject (Miller, 1959, p. 26). Interest in the Pierre Shale for this purpose may develop again, because of the nationwide concern over domestic shortages of bauxite and increasing costs of imports. Yet the Pierre Shale is unpromising, for it contains only 12 to 18 percent Al_2O_3 (Tourtelot, 1962, table 7) and several potential nonbauxite sources of alumina in the United States are considerably richer (National Materials Advisory Board, 1970).

Pegmatite Minerals

(By J. J. Norton, U.S. Geological Survey, Reston, Va.)

The chief mineral products of the southern Black Hills, in 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, has been a source of lithium, tantalite-columbite, and feldspar. Total production of these minerals has had a value of about $20,000,000. The heyday of mining activity was between the mid 1930's and early 1960's.

"Pegmatite" is the name of an unusual form of granitic rock. It consists, as does granite, mainly of the minerals 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 of 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 more stable parts of the economy of the southern Black Hills for several 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. 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. Scrap mica is mica that is reduced by grinding to a finely divided form in which it is used in roofing materials, paint, rubber, and other ways.

Lithium minerals—spodumene, ambylgonite, and lepidolite—rank next in total value of production, but in recent years lithium mining has been virtually nil in the Black Hills. Lithium products are used in grease, airconditioning systems, alkaline storage batteries, fluxes for welding and brazing, glass and ceramics, and other purposes. Expansion in the need for batteries and in nuclear power plants may cause a great increase in lithium consumption in the next few decades.

Beryl, which contains the metal beryllium, was produced at the rate of a few hundred tons per year for many years. Production was 144 tons in 1962, when a U.S. Government purchase program came to an end, but the rate of output has been lower since then. For a long time most beryllium went into beryllium-copper alloys used in electronic equipment. More recently the light weight, rigidity, and electrical, nuclear, and thermal properties of beryllium have led to a diversity of uses and experimentation with new uses, especially in the nuclear field and in aircraft and space equipment. The light weight may encourage a considerable expansion in the sale of beryllium alloys, especially alloys of magnesium and aluminum.

Other products of Black Hills pegmatites include tantalum and columbium (niobium), a small quantity of tin, white quartz, rose quartz, and mineral specimens.

The 1964 edition of this report showed that pegmatite mining had severely declined and that this decline was unlikely to be reversed. The prediction was all too correct. Feldspar mining has continued at a not greatly diminished volume, but the other previously important minerals have lost their attraction. A new product—crushed white quartz—began to be produced in at least moderate amounts in the 1960's. One ambitious attempt in the 1960's to produce beryl, feldspar, quartz, and scrap mica in a single operation culminated in bankruptcy.

The reasons for the decline are various. Depletion of easily discovered high-grade deposits is only a minor cause. The chief reason, paradoxical as it may seem, arises from a great increase during the past 25 years in the market for most of the products. As a result, new and large deposits have been searched for and found elsewhere, large mechanized operations have come into existence, and the several industries have developed beyond the point at which the generally small, even though commonly high-grade, deposits of the Black Hills can compete effectively.

The problem becomes more understandable when one examines the trends of consumption and production figures in the U.S. Bureau of Mines Minerals Yearbooks and compares them with South Dakota production.

Feldspar used in the United States in 1940, including small imports, amounted to 303,285 long tons, virtually all of which was hand sorted. The same year imports of nepheline syenite from Canada, also in an only slightly processed form, were 27,894 long tons. In 1971 the United States consumed 663,343 tons of feldspar and imported about 370,088 tons of nepheline syenite. Most of this came from large milling operations, especially flotation plants, which were first operated in North Carolina in 1946. Not only pegmatitic materials but also feldspar-quartz sands were used as feldspar sources. Meanwhile, South Dakota production has ranged from a high of 70,913 long tons in 1943 to a low of 17,211 in 1970 followed by an increase to 25,000 in 1972 (table 13) and probably larger amounts in 1973 and 1974. South Dakota feldspar, which is hand sorted and further processed only by being passed through a grinding plant, has not only failed to obtain a share of the greatly increased market but seems to have lost some of what market it had, probably in large part because the product must be shipped a long way.

Yet compared with the other South Dakota pegmatite minerals, feldspar has been a great success.

Lithium is the most instructive example of what can happen to a mineral product from small mines during great expansion of the industry. Lithium minerals used by the United States in 1940 probably contained no more than 70 tons of lithium, of which well over half was from hand sorted products of Black Hills mines. Increase in demand in World War II and a much greater increase in the 1950's, when the U.S. Atomic Energy Commission became the chief purchaser, led to the development of large mines and processing plants. The chief sources were three pegmatite mines, one in North Carolina, another in Quebec, and the third in Rhodesia. Maximum world production, in 1957 or soon thereafter, was probably between 5,000 and 6,000 tons of lithium (Norton, 1973, p 371–372), most of which came to the United States. Production from South Dakota at that time, though unpublished, was almost certainly no greater than in 1940. The end of Atomic Energy Commission purchases brought a sharp drop in world production. Subsequently consumption again increased, largely as the result of the development of lithium mining from a brine deposit in Nevada. In 1970 the United States used about 1,900 tons of lithium and the whole world about 3,000 tons (Luckenbach, 1972, p. 115). The Black Hills had no production at all in that year.

Events in the beryllium industry have been similar but less dramatic. Domestic consumption of beryl in 1940 was 1,200 tons, of which 74 tons came from the Black Hills. The consumption was 9,511 tons in 1970 (part of which was bertrandite recalculated to its equivalent in beryl). The Black Hills production in 1970 and the years shortly before and after seems to have been no more than it was in 1940. Virtually all of the beryllium used in the United States was from beryl of pegmatites, chiefly in South America and southern Africa, until in 1969 a nonpegmatitic bertrandite mine in Utah began operating. From now on about half of the domestic requirements will be met by bertrandite ores (Griffitts, 1973, p. 87).

The sheet mica industry has quite different problems. Sheet mica requires such a large amount of hand labor that nations with high living standards can produce it in sizable amount only in times of high prices, usually under subsidy. Sheet mica mining in the United States ended in 1970 and is unlikely to be resumed at a significant level except under unusual circumstances. Consumption by the United States of sheet mica—including block, film, splittings, and punch—was 8,093,174 pounds in 1940. It peaked at 17,296,196 pounds in 1943 to meet wartime needs. In subsequent years it was generally between 8 and 15 million pounds, most of which came from India and Brazil. By 1971 consumption had dropped to 5,478,000 pounds. In short, this industry has not shared in the industrial expansion of recent decades. The reason is that the costliness of sheet mica encourages dependence on substitutes or other means of avoiding its use.

Scrap mica has never been important in South Dakota, though production in the United States has gone from 22,386 tons in 1940 to a high of 133,000 tons in 1969 and to 127,000 tons in 1971. Production is mainly from deeply weathered deposits, chiefly of pegmatite but also of mica schist, that can be mined at a large scale and washed and screened to recover the mica. Because the Black Hills lacks the required weathering characteristics, most of its scrap mica production has been incidental to the production of other minerals. In no year has as much as 3,000 tons been obtained.

Tantalum and columbium (niobium) have been only minor byproducts of South Dakota pegmatites except at a few deposits in a very few years (table 18). Total production is less than 200,000 pound of concentrates. In contrast, the United States imported for consumption 6,765,000 pounds of concentrates in 1970 alone.

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. 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.

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, and Beecher No. 2 mines. Amblygonite was mined from many deposits. Lepidolite was obtained chiefly from the Bob Ingersoll No. 1 mine. When the world's lithium industry expanded in the 1950's, the several lithium mines and mills of the Black Hills held a place for a while, but ultimately they proved to be too small to compete. Since the closing of the Etta mine in 1960, lithium mining in the Black Hills has been nearly dormant.

Potash feldspar was first extracted 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. 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 feldspar produced since then.

Beryl was the last of the pegmatite minerals to come into prominence. Though mined sporadically as a byproduct 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 was generally between 150 and 400 tons.

Production figures for all the pegmatite minerals are presented in tables 13 to 18, provided by the U.S. Bureau of Mines. Some figures for early years, when production records were less exact than now, are estimates based on published statements and other source materials, 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 and mining 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 well suited for mining. These 200 are known as zoned pegmatites.

The interior of such a pegmatite is divided into a series of more or less concentric zones, each of which has a somewhat different suite of minerals. The zonal structure is of critical economic importance, for the commercially valuable minerals are concentrated in single parts of the deposit from which they can be selectively mined. Unzoned pegmatites are of more uniform composition, and the entire body, including a disproportionate amount of waste, would have to be mined. Furthermore, zoned pegmatites tend to be coarser grained and thus more amenable to the hand-sorting methods generally used than are the unzoned pegmatites.

The unzoned pegmatites are little more than varieties of Harney Peak Granite, which is pegmatitic in many respects, for not only its minerals (chiefly feldspar, quartz, and muscovite) but also its wide range in grain size, the presence of large crystals, and the sparsity of dark minerals are such that all of it could as well be called pegmatite as granite. They 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 important characteristics of such 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.

Many of the zoned pegmatites are approximately ellipsoidal in shape, but generally have a rounded top, a keel-like bottom, and irregularities or "rolls" along the contact with the enclosing schist. More complex forms are common, especially among the larger deposits, as shown by the many maps and sections in such publications as those by Page and others (1953), Sheridan and others (1952), and Norton and others (1962 and 1964).

The outermost or wall zone almost invariably consists of quartz, albite (soda feldspar), and muscovite. Generally this is followed by a zone of quartz, albite, and perthite. Strictly speaking, perthite is not a mineral but a combination of two minerals: the predominant member is microcline (potash feldspar), but it contains within it many small streaks and patches of albite (soda feldspar). Perthite tends to be most abundant near the top of the pegmatite and to give way to albite at depth. Further inward a pegmatite may contain zones with various combinations of lithium minerals non-perthitic microcline, albite, and quartz. The innermost zone or "core" commonly is entirely quartz.

Selective small-scale mining confined to a single zone, to take fullest advantage of the enrichment of that zone, 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.

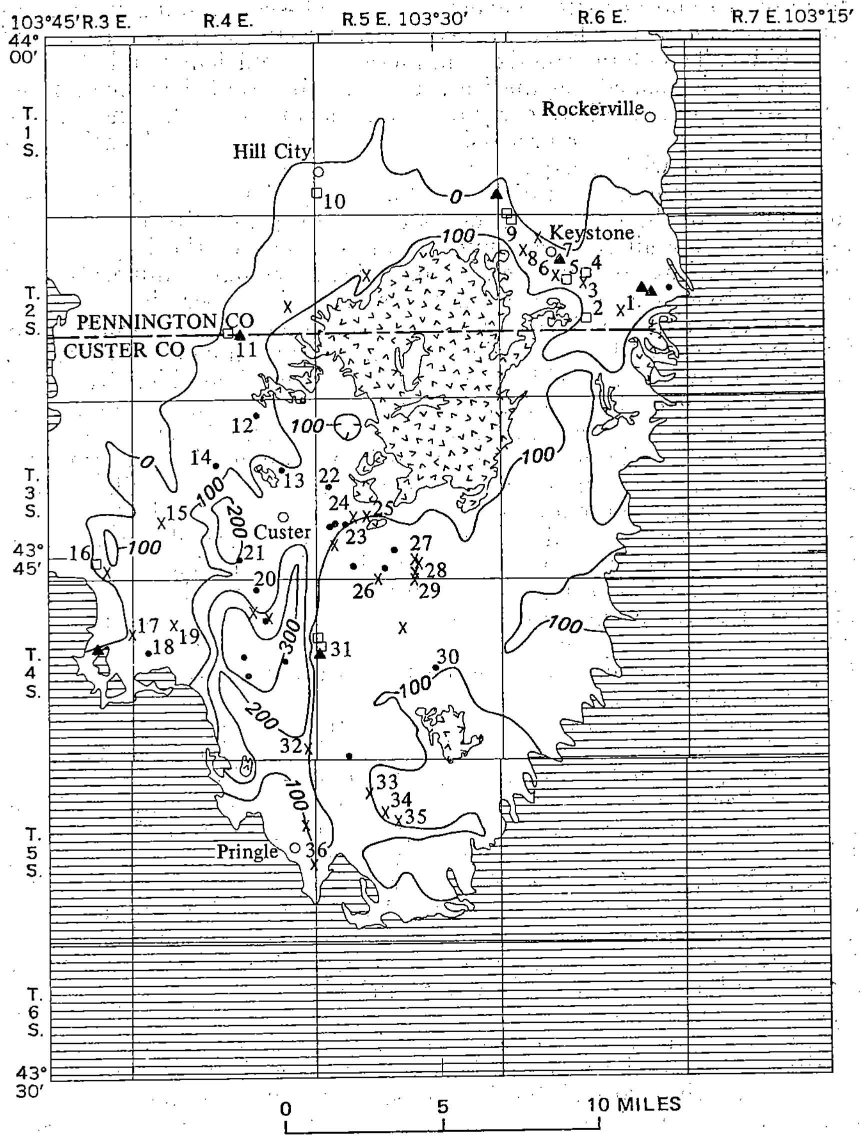
Mine operators generally direct their efforts toward a single mineral at a time when its market is most advantageous. With a change in market conditions, they change to another mineral, perhaps in a different zone of the same pegmatite or perhaps in an entirely different pegmatite. Or if a deposit becomes exhausted, they have the flexibility to move to another site. Nevertheless, small-scale mining in pegmatites has had, as its least wanted characteristic, a large measure of instability. To enlarge the size and increase 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, as has been done with feldspar for several decades.

Another method, often discussed but rarely if ever applied successfully for more than a short time, is to mine a pegmatite or group of pegmatities for all the economic products. Some of the larger Black Hills pegmatites contain many economically valuable minerals, and there is obvious appeal to a mining and milling operation 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. The chief drawback probably is the difficulty of marketing numerous products that go into widely diverse trade channels. The market demand for the various minerals has no direct relation to their abundance in a pegmatite. 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.

The locations of 65 of the more important deposits are shown on figure 21. This same figure also shows the distribution of all types of pegmatites, unzoned as well as zoned, by means of isograms signifying the number of pegmatities 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. The pegmatite-bearing area 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 65 zoned pegmatites that have been mined intensively are widely distributed. 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 6 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. Only a scattering of zoned pegmatites is along the north and west sides of the Harney Peak Granite. The absence of zoned pegmatites in the southeast segment of the map is because this area is in Custer State Park, where prospecting and mining have been prohibited for many decades and thus the location and abundance of deposits is unknown.

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.


103°45′
R.3 E.
R.4 E.
R.5 E.
103°30′
R.6 E.
R.7 E.
103°15′
44° 00′
T. 1 S.
T. 2 S.
T. 3 S.
43° 45′
T. 4 S.
T. 5 S.
T. 6 S.
43° 30′
Rockerville
Hill City
Keystone
PENNINGTON CO
CUSTER CO
Custer
Pringle
0
100
200
300
1
2
3
4
5
6
7
8
9
10
11
12
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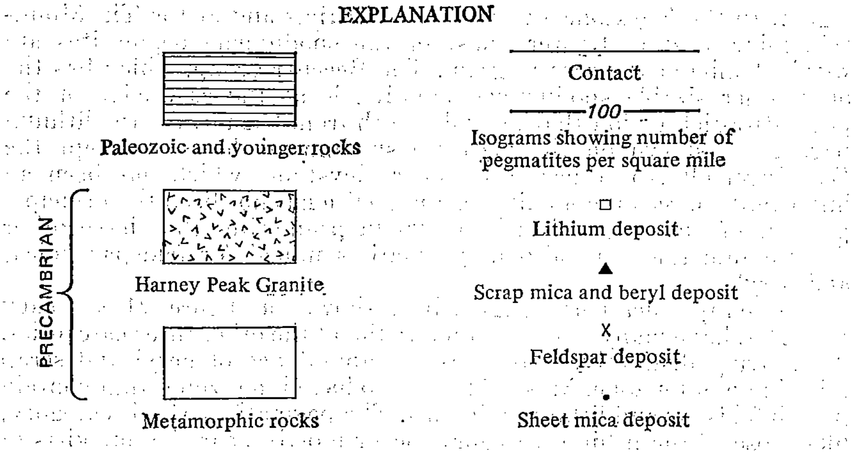
35
36
0
5
10 MILES



PRINCIPAL MINES

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

FIGURE 21.—Pegmatites of the southern Black Hills.

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. Nearly 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.

Zoned pegmatites with potash feldspar as the dominant industrial mineral are more abundant than any other variety. The potash feldspar occurs either with both quartz and plagioclase or with quartz alone in inner zones. Figure 21 shows the location of 27 of the more important deposits. 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.

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 principal deposits contain large spodumene-rich inner zones with feldspar and quartz and smaller zones of other kinds. Such pegmatites tend to be on the fringes of the 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 scrap mica-beryl pegmatites, shown on figure 21 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 40 years. Nearly all feldspar is mined in open pits, and the only processing at the mine consists of hand sorting. It is then trucked to the grinding plant, and from there shipped to market.

The only grinding plant now operating was built at Custer in 1959, replacing an earlier plant that existed from 1936 until 1958. A grinding plant was 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 13) 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 generally been between 20,000 and 40,000 long tons.

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

Potash feldspar is obtained chiefly from perthite-rich units in the upper parts of pegmatites. 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 of 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.

TABLE 13.—FELDSPAR PRODUCTION, 1923–1973[1]

[From U.S. Bureau of Mines]

Year	Quantity (long tons)	Value	Year	Quantity (long tons)	Value
1923[2]	150	$600	1953	50,601	$321,026
1924–30[3]	27,913	153,887	1954	44,498	281,810
1931	11,062	39,013	1955	42,164	267,286
1932	6,067	22,256	1956	45,000	289,000
1933	3,220	12,058	1957	41,316	267,000
1934	9,190	30,892	1958	23,229	145,000
1935	22,099	62,498	1959	30,825	196,000
1936	32,144	103,671	1960	45,588	292,000
1937	41,392	158,976	1961	29,354	186,000
1938	42,297	122,467	1962	29,697	191,000
1939	45,328	133,893	1963	25,590	157,000
1940	54,692	157,323	1964	26,980	180,000
1941	59,015	170,723	1965	51,560	346,000
1942	64,842	225,410	1966	53,810	369,000
1943	70,913	342,643	1967	61,411	420,000
1944	64,806	288,188	1968	39,077	264,000
1945	68,374	314,787	1969	29,434	194,000
1946	74,540	299,852	1970	17,211	114,000
1947	58,959	284,378	1971	22,000	539,000
1948	54,037	271,000	1972	25,000	400,000
1949	32,272	157,000	1973	(4)	(4)
1950	43,875	249,000			
1951	48,559	290,520	Total (1923–73)	1,713,254	9,531,111
1952	40,163	220,954			

[1] No production prior to 1923.

[2] Estimated.

[3] Data shown for a period of years to avoid disclosure of confidential figures.

[4] Confidential figure; not included in total.

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 "sheet mica," which is any mica that is cut into sheets of approximately 1 square inch or larger, and "scrap mica," which is reduced by grinding to various sizes for different uses.

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 has been a regular and continuous source of scrap mica.

TABLE 14.—PRODUCTION OF SHEET AND PUNCH MICA, 1879–1973

[From U.S. Bureau of Mines]

Year	Quantity (pounds)	Value	Year	Quantity (pounds)	Value
1879–1912[1]	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	(2)	(2)	1951		
1919–23			1952	4,308	32,034
1924	(2)	(2)	1953	11,174	77,352
1925	1,555	207	1954	16,299	65,222
1926	(2)	(2)	1955	4,854	21,383
1927–29			1956	12,000	67,000
1930	(2)	(2)	1957	9,093	46,000
1931	(2)	(2)	1958	16,772	68,000
1932	852	149	1959	38,775	158,000
1933–38			1960	30,887	145,000
1939	(2)	(2)	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	1964–73		
1943	333,424	447,209			
1944	146,383	472,026	Total (1879–1973)	[3] 7,067,537	[3] 3,074,160

[1] Estimated.

[2] Confidential figure.

[3] Includes confidential figures indicated by footnote 2

TABLE 15.—SCRAP MICA PRODUCTION, 1899–1973

[From U.S. Bureau of Mines]

Year	Quantity (short tons)	Value
1899–1912 [1]	800	$12,000
1913	591	10,403
1914	515	6,138
1915	179	2,684
1916	527	10,472
1917	272	5,033
1918–20 [2]	519	10,138
1921	92	2,290
1922	(3)	(3)
1923	324	6,480
1924	458	9,267
1925	996	19,220
1926	835	15,907
1927–31 [2]	2,208	41,589
1932		
1933	(3)	(3)
1934	515	6,665
1935–39 [2]	7,691	96,872
1940	2,240	32,074
1941	1,611	27,616
1942	2,545	44,579
1943	2,234	42,764
1944	2,558	51,405
1945	1,192	21,534
1946	2,806	63,692
1947	1,499	$37,225
1948	988	29,000
1949	1,125	31,000
1950	1,902	25,000
1951	2,292	42,714
1952	915	24,148
1953	1,687	27,388
1954	1,510	26,943
1955	1,322	26,853
1956	1,000	31,000
1957	1,626	43,000
1958	1,003	24,000
1959	158	5,000
1960	205	10,000
1961	1,054	32,000
1962	210	6,000
1963	(3)	(3)
1964	996	32,000
1965–68	(4)	(4)
1969	423	20,000
1970	443	34,000
1971–72	(4)	(4)
1973		
Total, 1899–1973	53,911	1,128,619

[1] Estimated.
[2] Data shown for the period of years to avoid disclosure of confidential figures.
[3] Confidential figure; included in total.
[4] Confidential figure; not included in total.

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 India, which has supplied most of the world's mica. More recent references written in the United States are by Skow (1962) and Montague (1960). A fully satisfactory description that applies particularly to the Black Hills deposits was written by L. R. Page and others (1953, p. 27–33).

The process of preparing sheet mica for market consists, in brief, of four steps: (1) extracting the mica crystals or "books" from the rock and cobbing away any adhering waste matter; (2) splitting or "rifting" the mica into sheets one-eight 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 physical imperfections such 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 14.

The selling price ranges 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. Prices also have been affected greatly by market conditions and by U.S. Government subsidies to meet wartime and stockpiling needs. In 1970 prices ranged from $0.85 a pound for sheet 1½ inches across to $8.00 a pound for sheets 8 inches or larger (Lesure, 1973, p. 418). In 1958 the price schedule under a 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. Prices in 1958 for India mica of similar quality ranged from $2.50 to $37 per pound (Montague, 1960, 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 from red through light brown to white. 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 or gas inclusions, known as "air stain," are a prominent defect in the mica of many deposits, but other kinds of stain are uncommon.

Most of the sheet mica of the Black Hills has been obtained from quartz-albite-muscovite wall zones. 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.

Production of sheet mica has been mostly 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. The next notable period was in World War II, when 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 moderate level. No production was recorded for 1964 through 1973. As elsewhere in the United States, revival of sheet mica mining seems unlikely.

Lithium minerals

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.

The Etta spodumene mine at Keystone was mined from 1898 until 1960, and was the world's chief source of lithium during much of this time, especially prior to World War II. 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 ore at the Edison mine near Keystone.

TABLE 16.—LITHIUM MINERALS PRODUCTION, 1898–1973 [1]

Year	Quantity (short tons)	Value
1898–1904 [2]	1,250	$50,000
1905		
1906–09	980	15,600
1910–14	2,153	41,080
1915–19	5,679	134,770
1920–24	5,545	115,115
1925–29	4,510	136,750
1930–39	9,034	248,031
1940–49	29,585	$942,707
1950–63	47,811	2,240,642
1964	(3)	(3)
1965	150	[2] 5,000
1966–69	(3)	(3)
1970–73		
Total, 1898–1973	106,700	3,929,800

[1] No production prior to 1898. Data shown for groups of years to avoid disclosure of confidential figures.
[2] Estimated.
[3] Confidential figure; not included in total.

Source: U.S. Bureau of Mines.

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

Somewhat more than 5,000 tons of beryl has been produced from Black Hills pegmatites (table 17). This is a sizable total by the standards of the past, for few pegmatite districts in the world have done better. Now, however, it amounts to barely more than half the U.S. consumption in a single year.

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, Bob Ingersoll, and Beecher No. 3 mines, which together have been the source of nearly one-third of the Black Hills beryl.

Much of the beryl comes from the so-called scrap mica-beryl pegmatites of figure 21. 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 1 percent beryl is generally confined to small shoots.

TABLE 17.—BERYL PRODUCTION, 1914–73[1]

[From U.S. Bureau of Mines]

Year	Quantity (short tons)	Value
1914–38[2]	520	$23,600
1939	84	2,390
1940	74	2,064
1941	151	7,067
1942	205	18,148
1943	238	28,843
1944	305	44,565
1945	38	5,776
1946	95	17,422
1947	70	11,762
1948	43	8,000
1949	139	40,000
1950	96	30,000
1951	138	46,007
1952	334	166,251
1953	392	157,656
1954	337	139,663
1955	294	$157,046
1956	195	95,000
1957	268	145,000
1958	240	129,000
1959	156	84,000
1960	167	88,000
1961	238	130,000
1962	144	77,000
1963–65	(3)	(3)
1966	124	40,000
1967	(3)	(3)
1968	75	35,000
1969	46	23,000
1970–72	(3)	(3)
1973		
Total, 1914–73	[4] 5,364	[4] 1,832,260

[1] No production prior to 1914.

[2] Estimated.

[3] Confidential figure

[4] Includes confidential figures indicated by footnote 3.

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

Beryl is commonly 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 become 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. Probably no 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 a few 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 concentrates was of tantalite-columbite from Tinton, and the rest, including a little microlite and tapiolite, was from the southern Black Hills (table 18). Crushed white quartz from the Hugo, Peerless, and other mines, in quartz veins as well as pegmatites, has been of some importance since the mid 1960's; production figures are probably included with stone (table 10) and cannot be readily separated; an estimate for 1973 is in table 23. Rose quartz, which is valued for decorative purposes, is obtained from the Rose Quartz mine southeast of Custer and from several other pegmatites. Much of its production is probably incorporated with that of gem materials (tables 22 and 23), but some is recorded as stone (table 10). 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. Professional mineralogists have sought rare phosphate minerals for scientific investigation.

TABLE 18.—PRODUCTION OF TANTALUM-COLUMBIUM CONCENTRATES, 1905–73

[From U.S. Bureau of Mines]

Year	Quantity (pounds)	Value	Year	Quantity (pounds)	Value
1905–9[1]	2,000	$1,000	1940–41		
1910–17			1942	200	$175
1918	4,500	2,250	1943	872	1,354
1919	300	90	1944	(2)	(2)
1920	4,000	1,450	1945	85	(2)
1921	3,400	1,150	1946	1,702	3,246
1922	600	240	1947		
1923	1,350	540	1948	500	(2)
1924	1,197	598	1949–50		
1925			1951	(2)	(2)
1926	2,100	650	1952	(2)	(2)
1927	1,100	378	1953	4,431	9,022
1928	34,899	26,332	1954	25,447	43,260
1929	22,117	17,261	1955	5,638	9,584
1930	4,100	(2)	1956	237	403
1931	(2)	(2)	1957	2,311	6,000
1932–33			1958	4,294	10,000
1934	425	168	1959–66		
1935	7,681	4,521	1967	(3)	(3)
1936			1968		
1937	13,376	11,307	1969	(3)	(3)
1938	33,922	33,406	1970–73		
1939	(2)	(2)	Totals, 1905–73	[4] 187,862	[4] 196,853

[1] Estimated.

[2] Confidential figure; included in total.

[3] Confidential figure; not included in total.

[4] Includes confidential figures indicated by footnote 2.

Reserves and resources

The existing data from Black Hills pegmatites leaves no real doubt that the resources are adequate to yield at least as much production in the future as in the past. Deposits as rich and easily accessible as the well-exposed deposits opened up in the early years of mining are, of course, now difficult to find. Yet the great abundance of zoned pegmatites in the southern Black Hills indicates that others can be discovered.

Nevertheless, with the decline in demand for the products of South Dakota pegmatites, estimates of reserves and resources have lost much of their relevance. If even the best sheet mica deposit cannot be mined profitably in the United States, and if lithium deposits of the kind found in the Black Hills are no longer competitive, then it makes so little difference what they contain that such estimates become misleading. Estimates similar to those made in the past can again become important only under changed economic circumstances, and then new estimates would have to be made to fit the new conditions. For these reasons the tables of resources figures in the 1964 edition of this report and in other publications are not repeated here, nor have they been updated. Their usefulness had been outrun by recent events. Such estimates, however, have been useful when feldspar or lithium companies made plans to draw raw material from several deposits or when the Federal Government sets up purchase programs for strategic minerals.

Potash feldspar, the mining of which has been the most stable and viable among the pegmatite minerals, is the commodity that seemingly most warrants reserve estimates. Yet so many elements besides the quality of a deposit influence whether it can be mined that reserve estimates are best stated in inexact terms. Changes in the market or in the industry's processing techniques can change a good deposit to a bad one or a bad one to a good one in a very short time. If the one grinding mill in the Black Hills were to close, there would, for practical purposes, be no market and thus no reserves in the Black Hills. Yet if a flotation mill ever becomes practical and is built, the market and the reserves will be greatly enlarged.

Potash feldspar deposits range from those with 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 not only yield more product per ton of rock mined, but they also tend to have large crystals that are relatively free of impurities, and thus are better adapted to hand-cobbing. Many of the lower grade deposits are of large size, which is an advantage because large-scale mining brings lower costs. Another important point 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 allow underground mining.

Sheet mica resources are difficult to ascertain because 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. In 1943–45, which was the most active period of mica mining in World War II, 189,733 pounds of sheet mica was produced and about 70 deposits were active enough to be called mines; yet 116,352 pounds, or 61 percent of the total, came from only three deposits, the Victory, White Spar, and Buster (Page and others, 1953, p. 88, 209, 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 thus 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 decades 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 continued to be found whenever the market encouraged a search for them. 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 are at least as great as past production.

The production of scrap mica depends so much on the mining for other minerals that a quantitative evaluation of the 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. The richest deposits 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 sizable share of the scrap mica from the Black Hills, the mica is a coproduct with beryl.

The lithium resources of the Black Hills were studied in detail 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 Corporation of America and other companies were especially active in this region. Most of the exploration and mining was for spodumene, obtainable mainly from a few large deposits. Amblygonite is more widely distributed but is abundant in only a few pegmatites. If any sizable lepidolite resources remain, they have not been discovered. Known lithium deposits comparable to those mined in the past—that is, those having more than 1.0 percent Li_2O or capable of yielding a lithium byproduct—contain at least 250,000 tons of lithium minerals.

Beryl resources were the object of close study in the late 1940's because of the importance of beryllium in atomic energy, and the data were reexamined in the late 1950's when beryllium became attractive for use in structural components of aircraft. Black Hills deposits in which the beryl content exceeds 100 tons and is 1.0 percent or more of the rock probably carry a total of about 3500 tons of beryl. Deposits of smaller size or lower grade, but from which beryl is occasionally obtained as a byproduct, may have an additional 15,000 tons.

The Black Hills has at least the possibility of containing undetected nonpegmatitic deposits of lithium and beryllium in the Precambrian metamorphic rocks and perhaps even columbium associated with the alkalic Tertiary intrusions, which are similar to some rocks with columbium deposits elsewhere. All these possibilities are at best remote but worth keeping in mind. Evidence has long been available to show that pegmatites are formed by differentiation of granite magma or are in some other way closely related. Such rare elements as lithium and beryllium are supposedly concentrated during granitic differentiation. This conclusion avoids the question of how the granite acquired lithium and beryllium, and it does not account for the fact that most pegmatites are virtually devoid of lithium and beryllium. The details of the problem are beyond the scope of this report. The interesting point is that some clays with volcanic affinities are enriched in lithium, and the principal known nonpegmatitic beryllium deposit, at Spor Mountain, Utah, is an altered volcanic ash which, according to Shawe and others (1964), is also enriched in lithium. If similar deposits were formed in the Black Hills in what now are metamorphic rocks, they not only could be economically important but also would simplify questions about how the lithium and beryllium became concentrated in a few pegmatites. They could easily be overlooked, for they would not be noticeably different in appearance from surrounding metamorphic rocks.

Gypsum

(By **C. G. Bowles, U.S. Geological Survey, Denver Colo., and J. A. Redden, South Dakota School of Mines and Technology and U.S. Geological Survey, Rapid City, S. Dak.**)

The gypsum resources of South Dakota are large but mostly undeveloped because of high transportation costs to major population centers and competition from other deposits. Current gypsum mining is entirely at Rapid City, where the gypsum is used for the manufacture of portland cement. Resources of gypsum elsewhere in the United States are so large that further development of South Dakota deposits will be slow.

Gypsum mining dates back to the early 1880's and there has been a small but moderately consistent production since that time (table 19). In 1972 production was 24,000 tons, which amounted to only 0.2 percent of the total U.S. production in that year of 12,328,000 tons (Reed, 1974). The only producer was the South Dakota State Cement Plant, which requires approximately 10 pounds of raw gypsum per barrel of cement. The output of processing plants operated in early years was used mainly in plaster, though some was sold as a soil conditioner. The more important of these plants for which records are available are the six listed below:

Early gypsum plants in the Black Hills

Location and operator	*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

TABLE 19.—GYPSUM PRODUCTION, 1884–1972

Year	Quantity (short tons)	Value
1884–1955	410,000	$1,941,000
1956	16,000	63,000
1957	13,000	53,000
1958	12,000	49,000
1959	19,000	78,000
1960	20,000	89,000
1961	22,000	89,000
1962	23,000	93,000
1963	24,000	97,000
1964	19,000	76,000
1965	7,000	27,000
1966	17,000	$68,000
1967	12,000	49,000
1968	16,000	65,000
1969	11,000	46,000
1970	15,000	61,000
1971	21,000	83,000
1972	24,000	43,000
1973	(1)	(1)
Total, 1884–1972	701,000	3,070,000

[1] Confidential figure.

Source: U.S. Bureau of Mines.

The mineral gypsum ($CaSO_4.2H_2O$) occurs largely as bedded deposits that were formed during the evaporation of sea water. Consequently it can be associated with other evaporite minerals such as halite (common salt) and the potash salts. Probably most gypsum is altered from the mineral anhydrite ($CaSO_4$) as a result of hydration by near surface waters. Bedded deposits that are mined down dip generally contain more and more anhydrite at greater depths, and bedded gypsum does not occur at depths greater than about 2000 feet.

The ease of hydration or dehydration results in the main uses of gypsum. If it is crushed and calcined to a moderate temperature of about 170 to 175°C (338 to 347°F), part of the water is driven off and it is converted to the hemihydrate ($CaSO_4.1/2H_2O$) or plaster. When water is again added, the mixture upon "setting" crystallizes into a rigid interlocking network of needle-like gypsum crystals. It can be used directly as plaster when mixed with sand or it can be processed by sandwiching the mixture between paper to produce plasterboard or the common "dry wall" of the construction industry. About 95 percent of the gypsum used in the United States is calcined and used for plaster or plaster products. The remainder is used in portland cement to retard the setting time or as fertilizer and a soil conditioner. When used in agriculture the gypsum provides sulfur and reacts with the excess sodium carbonate typical of irrigated soils. Anhydrite can have some of the same uses as gypsum, but if it is to be calcined, it must first be ground and hydrated. This increases the cost, and hence only about 2 percent of the total production in the United States originates as anhydrite.

Bedded gypsum deposits of possible commercial significance are limited to the Black Hills in outcrops of rocks of Pennsylvanian to Jurassic age. The deposits that have been mined and that have the most potential are almost entirely restricted to the Spearfish Formation and the overlying Gypsum Spring Formation. The outcrop areas of these formations are shown in figure 22. The gypsum beds of the Spearfish have an aggregate thickness of 50 to 80 feet and are intercalculated in a 350 to 700 foot thick section of shale and siltstone exposed all the way around the Black Hills except where covered by younger deposits. Dips are generally so low that the outcrop width of the Spearfish is as much as 3 miles across. Most of the gypsum is restricted to rocks of Permian age in the lower 200 to 250 feet of the formation. Two persistent beds have been the source of most of the production. The lowermost of these 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), and about 40 feet in an area 7 miles northeast of Hot Springs, but it is commonly 6 feet thick along the eastern flank of the Black Hills (Kulik, J. W., written communication, 1961). A second bed 170 feet above the base of the formation (Gott and Schnabel, 1963) is present throughout the southern Black Hills. This is 30 to 50 feet thick and marks the top of the Permian System in the Black Hills. Approximately 25 to 50 feet higher in the section is a 5- to 10-foot thick bed in rocks of Triassic age. In the northern Black Hills Darton (1901, p. 518) described an "upper gypsum" bed near the top of the Spearfish Formation, but this is now considered to be in the Gypsum Spring Formation of Jurassic age (Imlay, 1947).

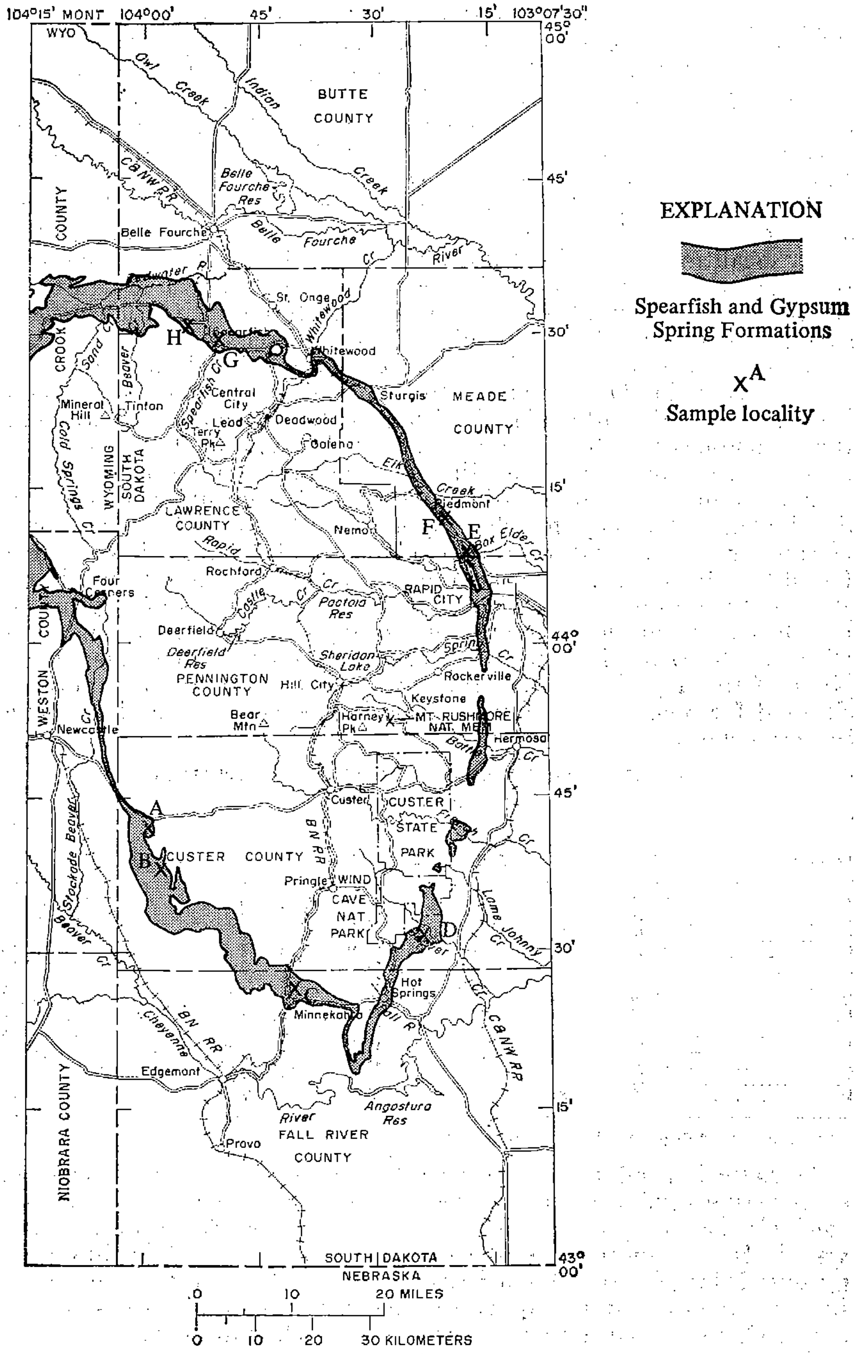


FIGURE 22.—Outcrop of the Spearfish and Gypsum Spring Formations.

The Gypsum Spring Formation contains a massive 25- to 30-foot thick bed of white gypsum 1 mile northeast of Spearfish (Mapel and Bergendahl, 1956). This bed, which was described by Darton and Paige (1925) in sections in the northern Black Hills, thins and wedges out southward and is not recognized south of Rapid City. Gypsum may have been mined from the Gypsum Spring Formation before 1900, but no record of production exists.

The Spearfish and Gypsum Spring Formations contain large reserves of gypsum that are readily adapted to open pit mining in the many localities of low dip. Table 20 contains the available analyses of the gypsum from these formations at the locations shown in figure 22. All the analyses except at Locality A indicate more than 90 percent gypsum, which is generally required for commercial use.

Gypsum also occurs in the outcrops of the Minnelusa Formation and the overlying Opeche Shale. In these units, however, the gypsum beds are generally intercalated with sandstones, and ground water in the sandstones has dissolved so much of the gypsum that it is rarely present at the outcrop. The Minnelusa contains an aggregate thickness of as much as 250 feet of anhydrite in the subsurface of western South Dakota but only in Hell Canyon in southwestern Custer County (Braddock, 1963) and in the Sundance-Beulah area of Wyoming (Brady, 1958) do gypsum beds crop out. Most of the gypsum is restricted to the upper one-third of the formation. Beds of gypsum in the Opeche Formation also crop out locally in Hell Canyon and elsewhere in the Black Hills but they are rarely more than 10 feet thick. None of the deposits in the Minnelusa and Opeche are as favorably situated for open cut mining as those in the Spearfish and Gypsum Spring formations.

TABLE 20.—ANALYSES OF GYPSUM FROM THE SPEARFISH FORMATION

[In percent]

Location	H_2O	SiO_3	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	30.00		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

Source: Darton and Paige, 1925; Ehle, 1911: Connolly and O'Harra, 1929.

Gypsum is a relatively low priced commodity and transportation costs play a significant role in the development of deposits. Although the United States produces about one-fifth of the world's total gypsum, we still import more than 30 percent of our supply. The imported gypsum is largely from Nova Scotia, from which it can be transported by ship at low cost to supply the heavily industrialized east coast. South Dakota must use expensive rail or truck transportation.

A South Dakota gypsum industry would depend largely on local markets. If a processing plant were established in the Black Hills, it would meet strong competition from existing plants at Heath, Montana; Cody, Wyoming; Florence, Colorado; Fort Collins, Colorado; Blue Rapids, Kansas; Medicine Lodge, Kansas; and Fort Dodge, Iowa.

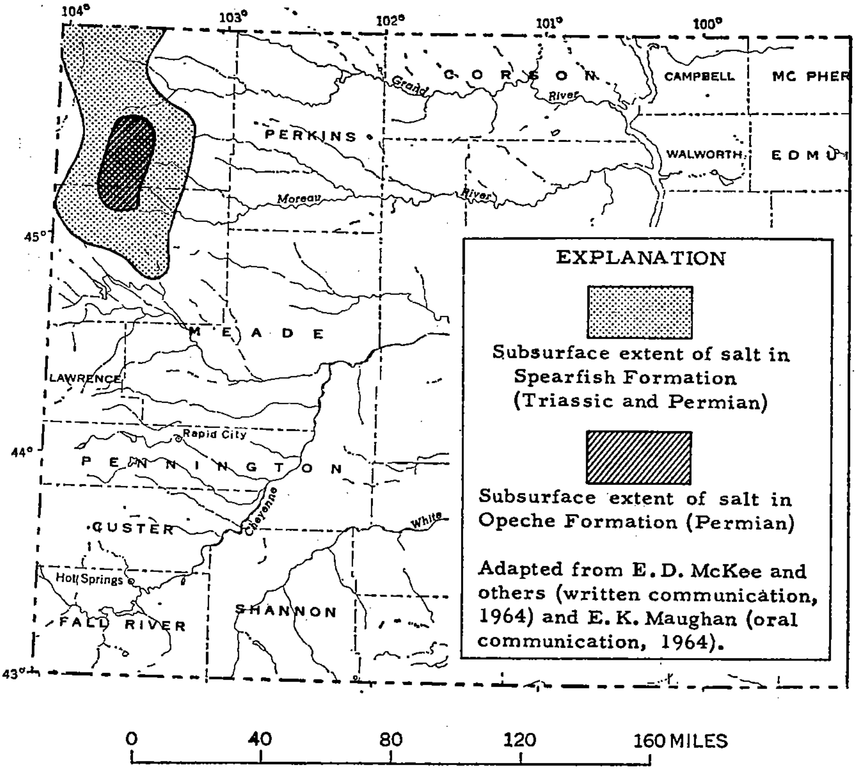
According to a study by the Business Research Bureau, University of South Dakota, a Black Hills processing plant could competitively deliver prefabricated gypsum products to a population market of 900,000. If only calcined material were produced and no prefabrication were involved, the material could be competitively supplied to only two-thirds of this population (Director, Business Research Bureau, University of South Dakota, 1961, written communication). The potential market for finished products would require about 35,000 tons of gypsum per year.

Because the Black Hills deposits are large and can be mined by relatively inexpensive methods, it seems only a matter of time before they will be put to use, but the time may be lengthy. Meanwhile, operations will be restricted to supplying the State Cement Plant at Rapid City.

Salt

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

Salt (sodium chloride) is an abundantly used industrial raw material, but it has not been produced in South Dakota except, presumably, during pioneer times in a small way from surficial deposits. Salt beds underlie much of Harding and Butte Counties in the northwest corner of the state (fig. 23). In this region salt may at some future



Adapted from E.D. McKee and others (written communication, 1964) and E.K. Maughan (oral communication, 1964).

FIGURE 23.—Salt deposits.

time be extracted by solution mining techniques from thick beds in the Spearfish Formation at depths ranging from 4,000 to 6,000 feet.

More than one-fourth of the world production of salt is from the United States, which is both the world's leading producer and consumer. In 1972, the U.S. salt production from 17 states amounted to 44,010,000 tons (MacMillan, 1974). About 54 percent of this salt was produced as brine, 33 percent as rock salt, and 13 percent was evaporated from saline water. The large consumption of salt in the U.S. is closely linked to industrial development. The greatest consumer is the domestic chemical industry, which uses 60 percent of the output, chiefly to manufacture chlorine and soda ash (sodium carbonate). Use on highways, to melt snow and ice, accounts for 18 percent of U.S. production. Only 6.6 percent was used by the food industry (MacMillian, 1974). The average value per ton of salt produced in the United States in 1972 was $21.26 for evaporated salt, $6.31 for rock salt, and $3.29 for brine.

The Spearfish Formation contains a thick unit called the Pine Salt by Zieglar (1955). Salt beds comprise as much as 330 feet of the uppermost Permian part of the formation and also a salt bed in the lower Triassic part has a thickness of as much as 25 feet. Thick silt and clay separate the Permian and Triassic salt. The upper part of the Permian salt contains fewer impurities than the lower part, which has interlayered anhydrite beds as well as sand, silt, and clay impurities (McKee and others, 1967, pl. 14). These impurities increase in abundance towards the margin of the basin, where solution at the top of the salt prior to deposition of the Jurassic sediments has caused much variation in thickness of the salt. The greatest thicknesses of salt were deposited at the southwest margin of the salt basin and in line with the Cedar Creek anticline (Maughan, 1966, 1967).

The Opeche Formation contains salt beds in south central Harding and north central Butte Counties. These beds were deposited in the shallow, southern edge of the Williston Basin. The salt beds are thin and are of little or no economic value.

The salt of northwestern South Dakota is too deeply buried to be extracted by any method except solution mining. Salt produced in South Dakota would compete for markets with existing output from Kansas, Michigan, North Dakota, and Colorado. Solution mining of salt might be stimulated by a demand for underground chambers for the storage of petroleum products or for the disposal of waste materials.

Sulfur and Arsenic

(By J. J. Norton, U.S. Geological Survey, Reston, Va.)

Both sulfur and arsenic have been and probably will continue to be so unimportant in South Dakota that they merit merely brief mention in this report. The only production of either of them has been from metallic mineral deposits of the Black Hills. This association of the two is the reason they are treated together here. Unlike sulfur, arsenic is sometimes classified as a metal, and some of its uses are in alloys, though most are in nonmetallic compounds used as poisons in agriculture.

Sulfur, through its use in making sulfuric acid, is one of the most fundamental industrial raw materials. Concentrations of native sulfur associated with salt, especially in salt domes, are the principal commercial source. One of the landmarks of chemical engineering was the development about 1900 of the Frasch process whereby steam heated to a temperature above the 113° C melting point of sulfur was driven down wells to liquefy sulfur and bring it to the surface. A much smaller quantity of sulfur is obtained from oil and gas and from deposits of iron sulfides.

All arsenic is a by-product of smelters operating on arsenic-bearing ores. In comparison with sulfur, it is of small commercial importance.

South Dakota production amounts to only $130,000 worth of sulfur produced as pyrite, all prior to 1929, and $7,167 worth of arsenic obtained in 1924 and 1925 (U.S. Bur. Mines, 1954a, p. 4). Most of the pyrite (probably with other iron sulfides) was produced when smelters were operated in the northern Black Hills on either lead-silver ores or refractory gold-silver ores. Much of the arsenic came from arsenopyrite in the Bullion gold mine at Keystone, and perhaps all of it came from there, though published records are unclear on this issue.

Sulfur and arsenic cannot be expected to become important in South Dakota. Neither the saline deposits of the State nor the coal and oil are likely sources of sulfur, and massive sulfides suitable for sulfur production are not characteristic of known Black Hills metals deposits. As for arsenic, its main mineral, arsenopyrite, is common in some gold ores of the Black Hills, especially the Homestake, but processing methods in use or likely to be used do not permit its recovery at a reasonable cost.

Zeolites

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

Zeolites are important rock-forming constituents in some sedimentary rocks and are potentially valuable industrial minerals. They are crystalline hydrated aluminosilicates of the alkali and alkaline earth elements with a framework structure that encloses interconnected cavities occupied by the relatively large cations and water molecules (Smith, 1963). The cations—chiefly sodium, potassium, and calcium—and water have considerable freedom of movement within the structure and give the zeolites cation exchange and reversible dehydration properties. Because of their porous character, zeolites can act as molecular sieves for the separation of compounds according to the size and shape of the molecules or for the selective adsorption of gases and liquids.

These unique properties of the zeolites suggest diverse applications in industrial processes, agriculture, and animal husbandry. Most of the commercial zeolites are synthetic. They are used principally as catalyst supports, selective sorbents, and desiccants (Breck, 1974); they are now utilized in about 90 percent of the petroleum catalytic cracking installations and have greatly increased the recovery of gasoline.

Natural zeolites have found only limited use in the United States. The utilization and potential utilization of natural zeolites have recently been discussed by Mumpton (1973) and Munson and

Sheppard (1974), and will be only briefly summarized here. Clinoptilolite is used to remove cesium and strontium from radioactive wastes (Brown, 1962), and chabazite is used to desiccate mildy acidic natural gas. Laboratory and pilot-plant studies indicate that clinoptilolite is effective in the removal of ammonia from waste water (Mercer and others, 1970). Zeolitic tuff is also used as dimension stone and as a pozzolan in cement. The potential uses of zeolites can be considerably increased by effecting chemical and structural modifications of the natural material.

Clinoptilolite and mordenite are extensively mined and utilized in Japan. Minato and Utada (1969) described the following uses: desiccant for gases, separator of oxygen from air, adsorbent of obnoxious odors in farmyards, dietary supplement for pigs and chickens, filler and whitening agent for paper, and soil conditioner to increase the effectiveness of chemical fertilizers.

Zeolites occur chiefly as authigenic rock-forming minerals in sedimentary and low-grade metamorphic rocks (Hay, 1966) and as fracture- and vesicle-fillings in igneous rocks. Most of the large, attractive zeolite specimens in museum collections were obtained from igneous rocks. The zeolites in sedimentary rocks are so very finely crystalline as not to appeal to mineral collectors, but deposits of them are voluminous and have economic potential. Although phillipsite was identified in sediments as early as 1891, extensive and abundant zeolite deposits were not recognized in sedimentary rocks until the late 1950's. Zeolites have formed in sedimentary rocks of diverse lithology, age, and depositional environment, but they are especially common in Cenozoic rocks that originally contained abundant silicic vitric material of volcanic origin (Sheppard, 1971a). The zeolites formed after deposition of the rocks, mainly by reaction of the volcanic glass with interstitial water, which may have originated as either meteoric water or connate water of a saline, alkaline lake. Of the more than 30 naturally occurring zeolites, only about eight are sufficiently abundant in bedded deposits to be considered potentially valuable. These are analcime, chabazite, clinoptilolite (including heulandite), erionite, ferrierite, laumontite, mordenite, and phillipsite. The zeolites occur in nearly monomineralic beds, or, more commonly, are associated with other zeolites, clay minerals, silica minerals, or feldspars.

Only scant occurrences of zeolites have been reported in the sedimentary rocks of South Dakota (table 21). Except for minor amounts of clinoptilolite and phillipsite in the Pierre Shale and of analcime in lignites of the Fort Union Group, the zeolites are chiefly in fluviatile and lacustrine tuffaceous rocks of the Arikaree Group. As of 1974, none of the zeolite deposits in South Dakota has been mined. Although the size and purity of the deposits are not adequately known, large volumes of vitric tuffs have obviously been altered to zeolites. A careful examination of tuffaceous rocks of Cenozoic age may reveal zeolite deposits comparable to those having economic potential in other western states (Sheppard, 1971b). The most favorable targets for exploration are probably the originally vitric ashes in Tertiary units younger than the Fort Union Group. The bedded zeolites are a future potential resource of South Dakota, but studies to determine their size and value await further industrial development and the establishment of suitable markets.

TABLE 21.—BEDDED ZEOLITE DEPOSITS

Locality	Zeolites	Description	References
Badlands National Monument, Pennington and Jackson Counties.	Clinoptilolite	Tuff in the Arikaree Group of Miocene age.	R. A. Sheppard and A. J. Gude, 3d, unpublished.
Sheep Mountain Table, Shannon County.	Clinoptilolite, erionite.	Tuff in the lower part of the Arikaree Group of Miocene age.	Deffeyes (1950); Schultz (1961).
Pass Creek Basin, Washabaugh County.	Clinoptilolite	do	R. A. Sheppard and A. J. Gude, 3d, unpublished data.
Cedar Butte (T. 43 N., R. 44 W.) and Cedar Butte (T. 41 N., R. 44 W.), Shannon County.	do	Tuff in the upper part of the White River Group of Oligocene age and in the lower part of the Arikaree Group of Miocene age.	Do.
Horseshoe Butte, Mellette County	do	Tuffaceous sandstone in the upper part of the White River Group of Oligocene age.	Do.
Near Ludlow, Harding County	Analcime	Lignite in the upper member of the Tongue River Formation of Paleocene age.	Rozendal (1956).
South Cave Hills, Harding County	do	Lignite in the Ludlow Formation of Paleocene age.	Denson and others (1959).
In Buffalo County, 11 miles north of Chamberlain.	Clinoptilolite	Bentonite in the Sharon Springs Member of the Pierre Shale of Cretaceous age.	Schultz (1963); Sheppard and Starkey (1964).
Near Mud Buttes, Butte County	Phillipsite	Bentonite in the Gammon Ferruginous Member of the Pierre Shale of Cretaceous age.	Schultz (1963).

Decorative Stone, Mineral Specimens, Gems, Fossils, and Meteorite

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

The economic importance of decorative stone, mineral specimens, gem stones, and fossils in South Dakota is rising rapidly as our society becomes more affluent in time and money, and an increasing number of dealers, hobbyists, and earth science students journey to western South Dakota in search of specimens for collections or raw material for lapidary work. Collections made for museums, for research, and for instructional use in academic institutions are of lesser direct economic importance but of considerable cultural significance.

Although separate data for South Dakota are not available, market analyses indicate that over two million persons purchase specimens and engage in earth science collecting in the United States. In 1973 over thirty full-time or seasonal minerals stores and rock shops were in business within the State, supplying specimens and bulk material to research laboratories, schools, public and private museums, collectors (including members of sixteen South Dakota gem and mineral clubs), tourists, interior decorators, and garden and landscape shops. Because the production of mineral specimens, fossils, and semi-precious stones is due not only to the efforts of dealers but also to hobbyists and other part-time collectors, it is difficult to obtain adequate figures on the amount of raw material produced or even the variety of minerals and fossils sought for the trade. Table 22 gives U.S. Bureau of Mines production values for gem and semi-precious stones from South Dakota from 1906 through 1972. Table 23, containing estimates compiled by the author, indicates that the value of decorative stone, mineral and fossil specimens, and gem and semi-precious stones for 1973 totaled about $468,350. This large amount greatly exceeds the annual rate of production implied by the preceding table mainly because it includes products, especially quartz from pegmatites, that are recorded by the Bureau of Mines under other categories but also because it includes fossils, which are not ordinarily treated as mineral products at all. Nonetheless, the larger figure, now approaching half a million dollars annually, probably is a somewhat more accurate reflection of the impact of this somewhat unusual industry on the State economy.

TABLE 22.—GEM AND SEMIPRECIOUS STONE PRODUCTION, 1906–73

[From the U.S. Bureau of Mines]

	Value		*Value*
1906–52 [1]	$75, 000	1964	$20, 000
1953	5, 000	1965	20, 000
1954	5, 000	1966	20, 000
1955	7, 400	1967	30, 000
1956	10, 000	1968	34, 000
1957	15, 000	1969	36, 000
1958	16, 000	1970	35, 000
1959	20, 000	1971	40, 000
1960	20, 000	1972	42, 000
1961	18, 000	1973	42, 000
1962	20, 000		
1963	20, 000	Total, 1906–73	550, 400

[1] Estimated.

TABLE 23.—PRODUCTION OF DECORATIVE STONE, MINERAL AND FOSSIL SPECIMENS, AND GEMS AND SEMIPRECIOUS STONES IN 1973[1]

Source and commodity	Value
Pegmatites:	
Rose quartz (420 tons)	$84, 000
White quartz (11,000 tons)	330, 000
Microcline (206 tons)	7, 200
Albite (2 tons)	400
Muscovite (7 tons)	4, 200
Lepidolite (6 tons)	3, 600
Biotite (1 ton)	600
Tourmaline (2 tons)	1, 000
Spodumene (1 ton)	500
Arsenopyrite-loellingite (1,500 lb)	750
Beryl (1,000 lb)	400
Cassiterite in matrix (1,200 lb)	1, 200
Columbite-tantalite, phosphates, chrysoberyl, uraninite, autunite, microlite, and pollucite	1, 500
Metamorphic rocks: Andalusite, sillimanite, actinolite, tremolite, almandine garnet, staurolite	2, 100
Sedimentary rocks:	
Siliceous calcite	1, 500
Barite	3, 000
Gypsum (700 lb)	200
Carnotite (1,000 lb)	500
Quartz:	
Agate	7, 000
Petrified cycads	1, 000
Other petrified wood (8 tons)	6, 000
Invertebrate fossils (ammonites, belemnites, coral, etc.)	8, 500
Vertebrate fossils (titanotheres, oreodonts, turtles, etc.)	2, 000
Veins and other deposits: Wolframite, pyrite, sphalerite, galena, gold, meta-uranocircite, etc	1, 200
Total	468, 350

[1] Estimated.

Mineral specimens and gem material occur in a wide variety of geological environments in South Dakota. The most important mode of occurrence is in the pegmatite deposits of the Black Hills. A second type is in sedimentary rocks where circulating ground water has deposited or recrystallized many mineral species such as barite, gypsum, carnotite, and secondary silica in various forms. Other occurrences are in metamorphic rocks, veins, alluvial deposits, gossans, and so on.

"Mineralogy of the Black Hills", Bulletin Number 18 of the South Dakota School of Mines and Technology, by Roberts and Rapp (1965), describes all mineral species found in western South Dakota, lists all mines and mineral localities, and provides a complete bibliography. Nearly all decorative stone, mineral specimens, and gem materials come from Custer, Fall River, Lawrence, Meade, and Pennington counties and the adjacent area to the east of the Black Hills. Isolated occurrences are known of petrified wood and cycads near Lemmon and of agate along the Missouri Valley, but these do not constitute a significant part of the known resources.

Many pegmatite minerals are recovered in the Custer-Pringle and Keystone-Hill City areas for their value as mineral specimens, semiprecious stones, or for various decorative purposes. Rose quartz is mined at the Bull Moose mine, which is the largest producer, and also has been recovered from the Scott, White Elephant, Sutherland (Wiley), and Big Chief mines. Most of it is marketed for architectural or landscaping purposes. White quartz is mined at the Hugo mine near Keystone; 60 percent is used for architectural purposes and 40 percent for landscaping. A salmon-red variety of microcline is mined in the Custer-Pringle area for architectural use, specimens, and tumbling into baroques for jewelry. Albite, muscovite, biotite, tourmaline, arsenopyrite, beryl, chrysoberyl, and a wide variety of rare primary and secondary phosphate minerals are obtained from numerous pegmatite mines. The Tin Mountain and Bob Ingersoll mines are the major sources of lepidolite, loellingite, cassiterite, uraninite, autunite, microlite, and pollucite; columbite-tantalite of specimen quality is obtained chiefly from the Etta mine.

Virtually all andalusite, sillimanite, almandine garnet, and staurolite are recovered from Precambrian schists near Keystone and west of Harney Peak. Actinolite and tremolite are obtained at or adjacent to marble deposits northeast of Custer.

The principal specimen and gem material in sedimentary rocks and alluvial deposits is some form of silica. Chief among these are varieties of agate. Four varieties are well known: 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. Blue chalcedony and "plume" chalcedony are recovered from Tertiary sediments. Jasper is found in Pleistocene deposits that probably originated by erosion of the Minnelusa Formation.

Amber barite has gained in popularity since it was first marketed internationally in 1951. It is found at several localities north, east, and southeast of the Black Hills. Production has been sporadic but has reached $14,000 per year. For several decades siliceous calcite crystals have been recovered in large quantities from a Miocene deposit in Washabaugh County. As with barite, production has been sporadic, but has reached $10,000–12,000 per year. Pine Ridge Reservation officials no longer permit collecting, so all recent sales are from preexisting stocks. Carnotite specimens from the Cretaceous sandstone uranium deposits are obtained from the Edgemont district for distribution to private collectors, museums, and schools. Various types of gypsum are collected from the Spearfish Formation and Pierre shale for sale mainly to tourists.

Minerals marketed from veins and replacement deposits are obtained exclusively from Precambrian and Tertiary deposits in the northern Black Hills at or near Galena and Lead.

Invertebrate fossils are collected chiefly from valleys cut in the Pierre Shale, from the Fox Hills Sandstone, and from outcrops of the Jurassic Sundance Formation. Vertebrate fossils marketed are obtained exclusively from Oligocene deposits in the vicinity of the Badlands National Monument. The fossil market embraces museums, primary and secondary schools, private collectors, and even tourists and interior decorators.

Meteorites, although of little economic significance, are of very great scientific interest. Since the discovery of the Fort Pierre meteorite in 1856, only seven additional falls have been recovered within the State. However, with the increase in number, mobility, and awareness of mineral, gem, and fossil collectors, additional falls undoubtedly will be recognized and brought to the attention of research institutions.

MINERAL ENERGY SOURCES

Oil And Gas

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

History

The earliest use of local petroleum products in South Dakota was in the early 1880's when a naturally occurring heavy grease was used by residents as lubricant (Rothrock, 1955). The search for natural gas began in South Dakota as early as 1894, when wells were drilled in the Pierre area. During the next decade several wells were drilled to meet local demands for natural gas for heating and cooking (Rothrock, 1944). Some gas discoveries were incidental to the drilling of water wells. Many wells with recorded gas and oil shows and a few with small gas production had been drilled by the mid 1940's (Rothrock, 1944). Details of early exploration are in reports by Wilson (1922), Wing (1938), and Gries (1947).

The first oil test in the State was the No. 1 Fox well in Potter County drilled in 1910. The hole penetrated to a depth of 2,260 feet without success. Tests were drilled sporadically for the next decade, and drilling has been more or less continuous ever since. The history is summed up by table 24, showing the yearly test drilling record, which reached a total of 734 holes by 1973, and by table 25, which shows when the 41 producing oil wells were completed. Figure 24 has the locations of all test wells, and figure 25 contains the details of the Harding County oil fields, which have been the most prolific producers.

The first major surge in drilling was in the middle 1950's, and the first discovery was of the Buffalo Field, Harding County, in 1954. This discovery led to more intensive drilling and to some success in the latter part of the decade. Drilling declined in the early 1960's, but it hit the highest peak in the State's history in 1969 and 1970 when 148 test holes were drilled, which was more than one-fifth of all holes drilled to that time. The years 1971 to 1973 have witnessed a steady decline in the number of test holes, but seven discoveries were made.

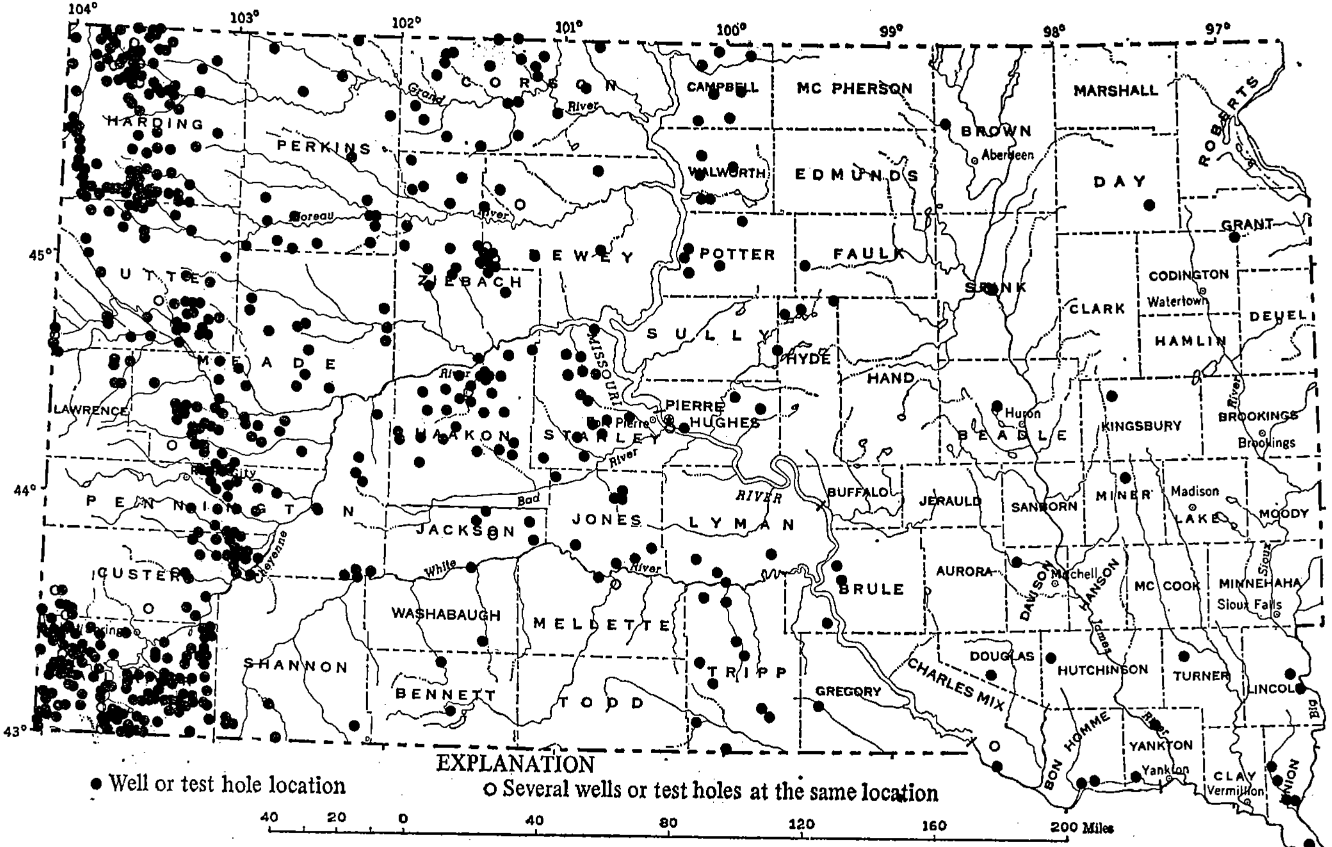


FIGURE 24.—Oil and gas wells and test holes drilled, 1900–1973.

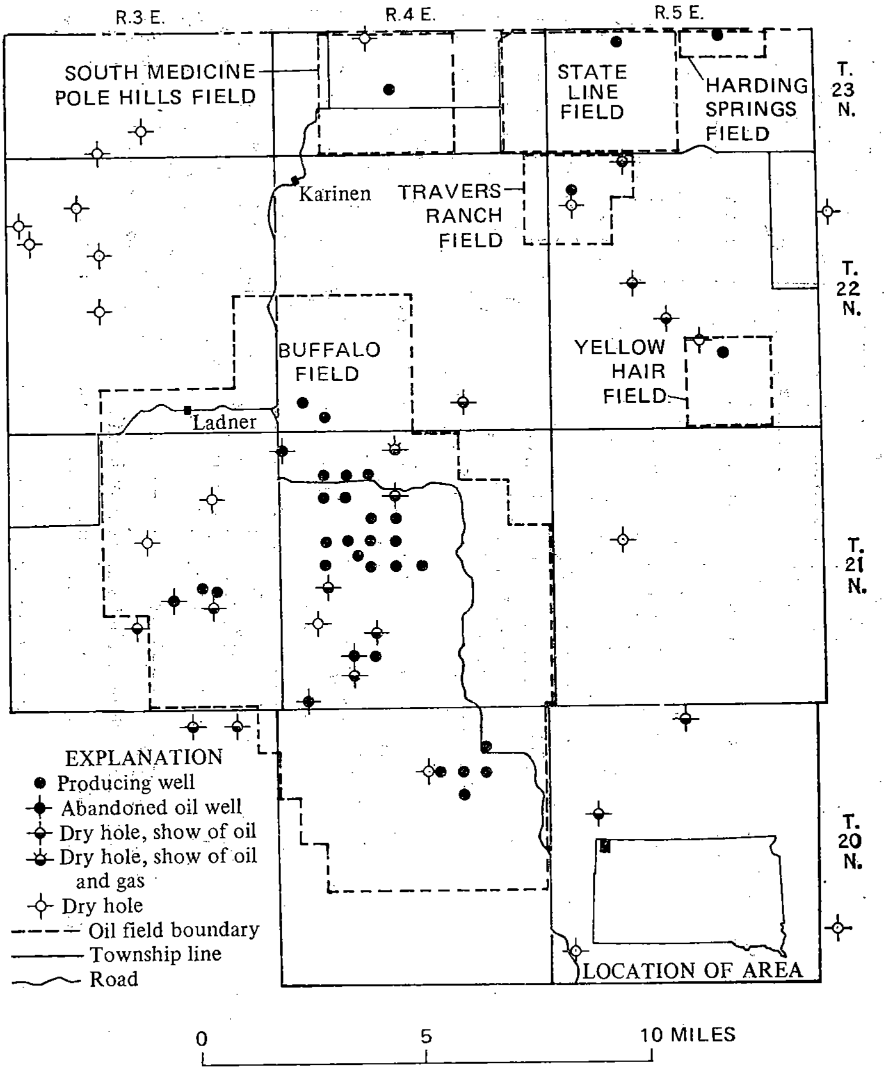


FIGURE 25.—Map of Harding County oil fields, showing producing wells, abandoned wells, and dry holes.

These discoveries resulted in the establishment of five new oil fields in Harding County.

TABLE 24.—OIL AND GAS TESTS DRILLED, 1900–1973

[Data from files of South Dakota Geological Survey

	Number of test drilled		Number of test drilled
1900	1	1944	5
1901–1903	0	1945	6
1904	1	1946	13
1905–09	0	1947	2
1910	1	1948	6
1911–15	0	1949	6
1916	1	1950	13
1917	1	1951	10
1918–20	0	1952	16
1921	3	1953	25
1922	9	1954	20
1923	0	1955	40
1924	3	1956	43
1925	4	1957	44
1926	4	1958	12
1927	2	1959	24
1928	3	1960	20
1929	2	1961	5
1930	6	1962	13
1931	5	1963	19
1932	4	1964	20
1933	3	1965	35
1934	2	1966	12
1935	2	1967	10
1936	0	1968	26
1937	1	1969	75
1938	2	1970	73
1939	1	1971	28
1940	5	1972	20
1941	3	1973	15
1942	6		
1943	3	Total	734

TABLE 25.—PRODUCING OIL WELLS COMPLETED, BY YEAR

Year:	*Number producing wells completed*
1954	2
1955	1
1957	1
1958	2
1959	9
1960	9
1963	5
1965	4
1966	1
1971	1
1972	2
1973	4
Total producing wells	41

Of the 734 wells and test holes drilled for which official records are available, only 233 or about one-third have been deep enough to test the Red River Formation, which is the source of 95 percent of all oil pumped in South Dakota. The 734 holes totaled about 457 miles or slightly more than 2.4 million feet in length. The average depth of these holes is 3290 feet.

The total production during the State's 20 years as an oil producer, from 1954 to 1973, was 3,421,392 barrels of oil worth nearly $8,000,000 and 238,994,000 cubic feet of gas. Table 26 shows the oil and gas production figures from the various fields, and table 27 gives the State oil production by years. Virtually all of the gas was used either as fuel on the production site or was flared, because there was not enough of it to transport elsewhere.

As this report goes to press, the record for 1974 has become available. Oil production increased to 493,766 barrels, or nearly 80 percent greater than in 1973. The output of gas was 47.8 million cubic feet, in contrast to 17.6 million cu. ft. in 1973. Among the 17 new holes completed, two were successful, one as a field well and the other as a discovery in sec. 24, T. 22 N., R. 4 E., which is near the Travers Ranch field (fig. 25). The average depth of the 17 holes was 5061 feet. Because seismic exploration has intensified, it is likely that drilling will increase in the next few years.

TABLE 26.—OIL AND GAS PRODUCTION BY FIELDS, 1954–73

Year discovered	Field	Number of producing wells, Dec. 31, 1973	Cumulative oil (bbls)	Production gas (Mcf)
1954	Buffalo	[1]23	2,928,773	228,440
1955	Barker Dome	[2]3	198,041	
1970	Unnamed[3]	(4)	5,453	
1971	Yellow Hair	1	207,504	
1972	South Medicine Pole Hills	1	12,682	
1973	State Line	1	43,094	9,724
1973	Harding Springs	1	18,990	
1973	Travers Ranch	1	6,855	830
	Total	31	3,421,392	238,994

[1] Excludes 4 wells shut in and 3 wells plugged and abandoned.
[2] Excludes 2 wells shut in.
[3] Unnamed, unspaced field in Dewey County.
[4] Four wells have shown some production; no production during 1973.

Note: Bbls=barrels of 42 U.S. gallons; Mcf=1,000 cubic feet.

TABLE 27.—OIL PRODUCTION BY YEARS, 1954–73

[From U.S. Bureau of Mines and South Dakota Geological survey]

Year	Quantity (42-gallon barrels)	Value (thousands)	Year	Quantity (42-gallon barrels)	Value (thousands)
1954	37,303	(1)	1965	218,876	$438
1955	30,467	(1)	1966	239,337	479
1956	36,759	(1)	1967	210,887	502
1957	55,217	(1)	1968	186,655	401
1958	60,937	(1)	1969	158,188	362
1959	152,359	(1)	1970	159,765	374
1960	281,221	(1)	1971	233,167	604
1961	233,338	(1)	1972	219,274	574
1962	168,644	(1)	1973	277,010	994
1963	214,566	$428			
1964	247,422	495	Total, 1954–73	3,421,392	7,931

[1] Confidential figures included in total.

Oil fields

Buffalo Field.—Commercial oil was first produced in South Dakota in January 1954 when the Shell No. 1 (34–9) State "A" well in the SW¼SE¼ sec. 9, T. 21 N., R. 4 E., Harding County, was brought in with an initial production pumping (IPP) of 80 barrels (bbls) of 31.6° API gravity oil and 200 bbls of water. The well was completed from 8587 to 8600 feet and from 8660 to 8681 feet in the "A" zone of the Red River Formation of Ordovicain age; total depth of the well was 9529 feet. This discovery well was followed by the Shell No. 32–16 State in SW¼NE¼ sec. 16, T. 21 N., R. 4 E. These two wells produced from 1954 to 1957; no further development work was done during these three years. During 1958, 1959, and 1960 a total of twenty producing wells were completed in the then newly established Buffalo Field. The field order established 160-acre spacing to allow the most beneficial rate of withdrawal of oil and gas from the reservoir. Subsequent drilling proved this spacing to be adequate to outline the large main pool and four small peripheral pools. During 1961 and 1962 no field wells were brought in, and 1963 saw only one successful completion. Again there was a lag in 1964, but three wells were completed in 1965 and one in 1966. No development work was done in the field again until 1972 and 1973 when Phillips Petroleum Company successfully completed one well each year in the north end of the field, which had been respaced at 320 acres by the Oil and Gas Board after a special hearing.

At the end of 1973 there were 23 wells producing in the Buffalo Field, four wells had been plugged and abandoned, and three wells were shut in.

Barker Dome Field.—The Barker Dome Field was discovered in 1955 by the Helms No. 1 Coffing well located in the SW¼NE¼ sec. 34, T. 6 S., R. 2 E., Custer County. This discovery culminated a search in the Barker Dome that began in 1930, when Black Hills Petroleum No. 1 Barker was drilled to a depth of 1,510 feet. This early well revealed oil in the Leo sands of the Minnelusa Formation, but the oil could not be extracted profitably, though it did encourage the drilling of about 20 test holes in the next 25 years. The first production from the discovery well came in August 1955. The initial potential flowing (IPF) of the well was 80 barrels of oil per day (BPOD) of black 30° API gravity oil. After a short time the well was placed on pump. The official records of the South Dakota Geological Survey contain no mention of gas, but Gries (1964) reported gas production that was at first meager and then increased to a maximum of about 100,000 cubic feet per day (100 MCFPD) before a decrease began.

The Barker Dome Field was established by the Oil and Gas Board in September 1955. The field spacing was set at 10-acre units.

Ten test holes were drilled in the field after the discovery well but none was successful until 1963, when four additional field wells were successfully completed. The discovery well had produced only 10,549 barrels of oil through 1962, but with the additional 4 wells producing late in 1963, the field production increased to 18,199 barrels in 1963 and then to the peak production for the field of 50,397 barrels in 1964. The production has steadily declined since that time. The total production is slightly less than 200,000 barrels of oil (table 26). At the end of 1973 only 3 of the 5 wells were producing.

Yellow Hair Field.—In January 1971 oil was recovered from a drill stem test that indicated a discovery in the "C" zone of the Red River Formation at the Depco. Inc. No. 42–27 Federal well in SE1/4NE1/4 sec. 27, T. 22 N., R. 5 E., Harding County (figure 25). The well was initially swab-tested at 40 BOPD. The well was shut in for several months during the most severe winter weather. When put on pump in March 1971, the calculated initial potential pumping (IPP) rate was 480 BOPD, but official records of the State Geological Survey show that the well was producing an average of 308 BOPD during March and that the peak production was 422 BOPD during April.

Production has declined steadily until at the end of 1973 the well was producing 133 BOPD. Cumulative production through December 31, 1973 was 207,504 bbls.

The Yellow Hair Field was established by order of the Board of Natural Resource Development in November 1973 with 320-acre spacing. The well has not been offset to date and may never be, for it was drilled on an apparently small structure.

South Medicine Pole Hills Field.—Oil was discovered in the Quadrant Oil Company No. 1 Buckley well in NE1/4SE1/4 sec. 28, T. 23 N., R. 4 E., Harding County, in December 1972, when 1,300 feet of 34° API gravity oil was recovered in a drill stem test in the Red River "A" zone, between 9,100 and 9,150 feet. The well was placed on pump January 22, 1973, with a projected IPP of 97 BOPD and an equal amount of water. The peak production from this well was 79 BOPD during March 1973. Since that time production has decreased steadily until at year end the well was producing 30 BOPD. Cumulative production through December 31, 1973 was 12,682 bbls.

The South Medicine Pole Hills Field was established by order of the Board of Natural Resource Development in November 1973 with 320-acre spacing. At the end of 1973 only the one well had been drilled in the field.

State Line Field.—A drill stem test in the "C" zone of the Red River Formation indicated an oil discovery from 9,053 to 9,141 feet in the Depco, Inc. No. 1 Ferkingstad well in the NW1/4SE1/4 sec. 20, T. 23 N., R. 5 E., Harding County. The discovery was made on July 10, 1973, when 3,470 feet of 35.6° API gravity oil was recovered from the well. The IPF was 264 BOPD and 60 MCFPD of gas with 5 barrels (2 percent) of water per day. The well was perforated from 9,118 to 9,132 feet; production began on July 21, 1973. The well began flowing at a rate of 278 BOPD and 63 MCFPD of gas; this rate dropped off until the well was placed on pump. Production then increased to a maximum of 350 BOPD and 122 MCFPD in November and has steadily declined from that date. At the end of 1973 the well was producing 307 BOPD and 74 MCFPD. The cumulative production through December 31, 1973, was 43,094 bbls. oil and 9,724 MCF gas (table 26).

The State Line Field was established by order of the Board of Natural Resource Development in August 1973 with 320-acre spacing. No offset wells had been drilled at the end of 1973.

Harding Springs Field.—Depco, Inc., discovered oil in June 1973 in their No. 41–22 Otterness well in the SE1/4NE1/4 sec. 22, T. 23 N., R. 5 E., Harding County. The well was completed in all three zones ("A", "B", "C") of the Red River Formation from 9,150 to 9,970 feet. The IPP was 210 BOPD and a volume of gas too small to measure, along with 4 barrels (2 percent) of water. The first production, in August, resulted in 196 BOPD and no gas. The rate of production has declined steadily, and at the end of December was 111 BOPD. Cumulative production through December 31, 1973 was 18,990 bbls.

The field was designated with 320-acre spacing by the Board of Natural Resource Development in December 1973. No offset wells had been drilled at year end.

Travers Ranch Field.—A total of 3,638 feet of 34.5° API gravity oil was recovered in September 1973 from a drill stem test in the Red River Formation in the Kenneth D. Luff, Inc., No. 1–6 Travers well in the SW1/4SE1/4 sec. 6, T. 22 N., R. 5 E., Harding County. The test was in the "C" zone of the formation from 8,939 to 9,022 feet. The well flowed 269 BOPD, 32 MCFPD gas, and ½ barrel of water, and was placed in production November 12, 1973. The first official production recorded for November was 154 BOPD and 19 MCFPD gas. This rate had declined to 102 BOPD and 12 MCFPD gas in December 1973. Cumulative production through December 31, 1973, was 6,855 bbls oil and 830 MCF gas.

The field was designated by the Board of Natural Resource Development in December 1973 with 320-acre spacing. No offset wells have been drilled.

Resources

The possibilities of discovering additional commercial oil and gas in South Dakota have been discussed by Ballard (1942), Agnew and Gries (1960), Sandberg (1962), Wulf and Gries (1963), and Sandberg and Prichard (1964). As of December 31, 1974, the recorded primary recoverable reserves were 2.6 million barrels of oil and 145 million cubic feet of gas.

Though the production record has been modest, a large number of geologic structures throughout the western part of South Dakota remain to be tested with the drill. A listing of all these structures and a description of each would be too lengthy for this article. It is sufficient to point out that the increased demand for petroleum and petroleum products along with higher wellhead prices for "new" oil and gas, brought about by the energy crisis of 1973, will undoubtedly stimulate activity in the region. More oil production can also be expected when secondary techniques are applied to some of the older wells in the State. Evidence that gas will become important is negligible.

The fact should be re-emphasized that through 1973 only 734 oil tests have been drilled in South Dakota. In contrast, 895 oil tests were drilled in Wyoming and 856 in Colorado during the single year 1973. South Dakota cannot become significant as an oil producing State until many more exploratory holes are drilled in intensified efforts to discover new oil fields and to further develop existing fields.

Coal

(By E. R. Landis, U.S. Geological Survey, Denver, Colo., and M. J. Tipton, South Dakota Geological Survey, Vermillion, S. Dak.)

A large area in northwestern South Dakota is underlain by rocks that contain lignite (fig. 26). The southwestern part of the State has small quantities of bituminous coal. Both the lignite and the bituminous coal have been mined to a small extent in the past and used almost solely for domestic heating nearby. Though the amount of bituminous coal is small, the lignite of the State constitutes a resource of considerable magnitude and potential value.

Geology

The coal-bearing rocks of South Dakota are of Cretaceous and Tertiary age. Bituminous coal is in the Lakota Formation of Early Cretaceous age at scattered places in the southwestern part of the

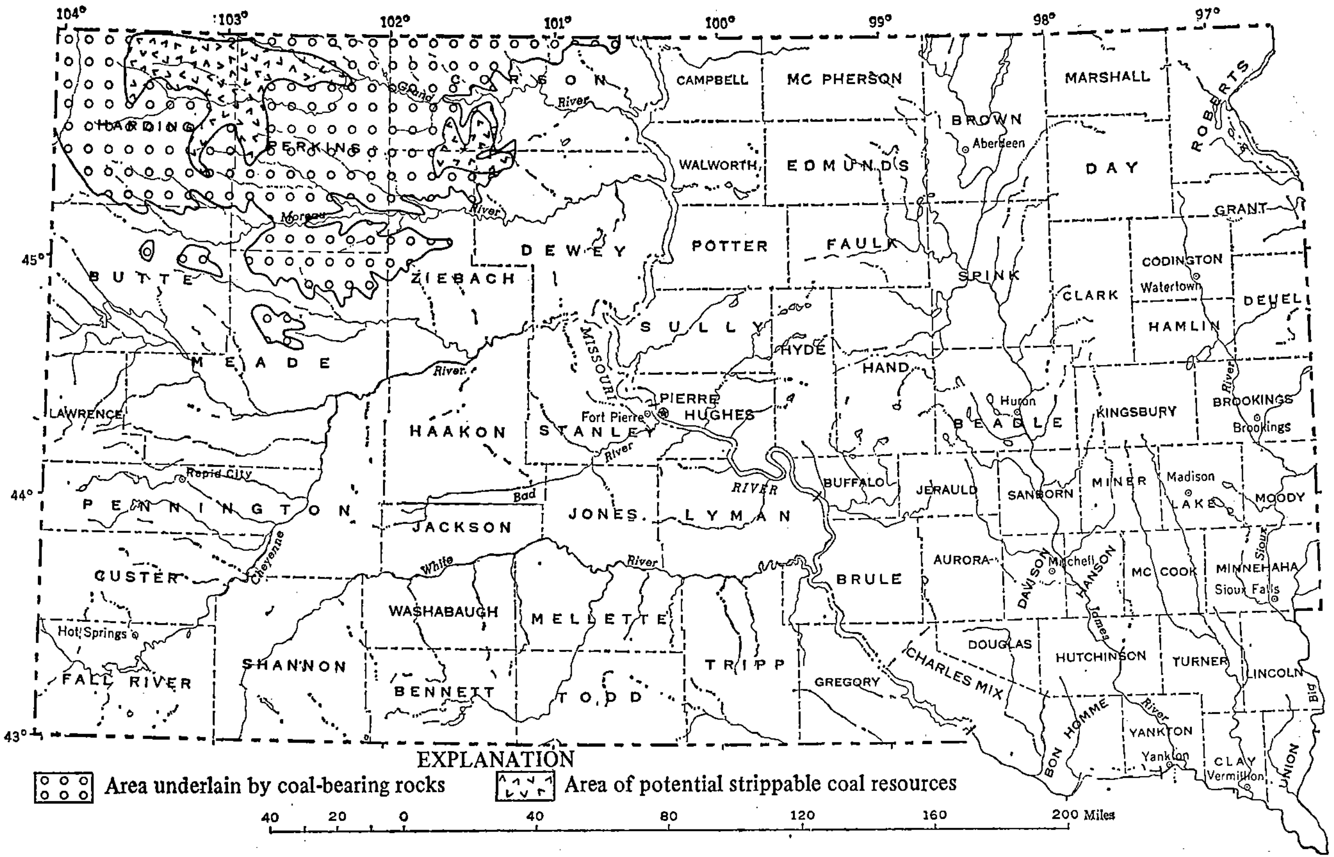


FIGURE 26.—Coal.

State, but known resources have been delineated only in Fall River County, where the coal was mined. A total of about 11,000 tons of bituminous coal is estimated to have been present before mining began. The bituminous coal is not discussed further in this report because its quantity is insignificant. The main resources consist of lignite in the northwestern part of the State in the Hell Creek Formation of latest Cretaceous age and in the Fort Union Group of earliest Tertiary age.

The Hell Creek Formation underlies a large part of the northwestern quarter of the State and contains lignite through much of this area. Lignite from the Hell Creek has been mined until recently 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 Group in South Dakota has the Ludlow Formation at its base followed by the Cannonball and Tongue River Formations. The Ludlow and Tongue River are nonmarine and coal-bearing. The Cannonball, which is marine, does not contain coal and is present only in the northern parts of Harding, Perkins, and Corson Counties. The Ludlow Formation "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. The Tongue River Formation is only in the northern parts of Harding and Perkins Counties. It contains coal beds as much as 9 feet thick in northern Perkins County. Nevertheless, 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 the areal extent of the Tongue River is small. Uranium associated with some of the Fort Union lignite is discussed in the uranium section of this report.

Production and utilization

The 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 production is about 1,393,147 tons, which had a total value of about $3,391,846 (table 28). The peak year was 1941, when about 70,000 tons were mined. No production has been reported since 1967.

Most of the lignite has come from strip mines. Strip mining is more economical and more productive than underground mining in places like South Dakota where the coal beds are overlain by a relatively thin overburden composed of soft rocks. All recent recorded production has been from strip mines in Dewey and Corson counties. Though small underground mines may be active periodically, the amount of coal obtained from them is usually too small to be reported.

The lignite mined has in the main been used locally for domestic heating. In other northern Great Plains States lignite is extensively used to generate electric power. Lignite lends itself to processes such as carbonization and gasification, and can furnish a great variety of organic chemical substances (U.S. Bureau of Mines, 1954b and 1963).

TABLE 28.—COAL PRODUCTION, 1895–1973

[From U.S. Bureau of Mines and South Dakota Geological Survey]

Year	Quantity (short tons)	Value
1895–1912	[1]95,200	[1]$192,400
1913	10,540	20,648
1914	11,850	20,456
1915	10,593	16,384
1916	8,886	18,021
1917	8,042	23,346
1918	7,942	22,230
1919	14,417	45,707
1920	12,777	46,000
1921	7,553	21,200
1922	7,752	22,000
1923	10,379	25,000
1924	12,043	36,000
1925	14,447	42,000
1926	14,428	42,000
1927	12,507	38,000
1928	13,929	39,000
1929	12,854	38,000
1930	12,810	31,000
1931	27,485	64,000
1932	49,074	87,000
1933	59,375	104,000
1934	42,407	76,000
1935	13,243	21,000
1936	41,331	55,000
1937	46,979	63,000
1938	48,058	65,000
1939	49,495	69,000
1940	66,085	88,000
1941	70,825	108,000
1942	53,538	$104,000
1943	40,664	78,000
1944	26,827	55,000
1945	24,445	53,000
1946	16,946	36,362
1947	14,618	35,727
1948	29,000	86,000
1949	26,000	92,000
1950	[1]27,000	[1]95,000
1951	28,350	99,008
1952	[1]25,000	[1]60,000
1953	23,671	82,117
1954	[1]20,000	[1]70,000
1955	25,782	90,240
1956	25,000	90,000
1957	21,000	79,000
1958	20,000	78,000
1959	22,000	88,000
1960	20,000	83,000
1961	18,000	75,000
1962	18,000	77,000
1963	16,000	62,000
1964	13,000	63,000
1965	10,000	49,000
1966	10,000	45,000
1967	5,000	27,000
1968–73	0	0
Total, 1895–1967	1,393,147	3,391,846

[1] Estimated.

Resources

As the map (fig. 26) indicates, about 7,700 square miles of South Dakota is underlain by rocks that ordinarily contain lignite. In such a large area, in which the amount of mining has been modest and the search for deposits cannot have been intensive, the known resources may be substantially less than the actual resources. Yet lignite may be very thin or absent in much of the area outlined on the map. For this reason, resource estimates are commonly limited to localities that have been investigated with enough care to provide data from which, following certain standardized procedures, reasonably reliable calculations can be made. Such estimates are of what is known as identified resources, which is the only kind that can be discussed in detail for South Dakota.

Identified coal resources are those for which the location, quality, and quantity are known from geologic evidence supported by engineering measurements. The total was estimated by Brown (1952) at 2,032.91 million short tons in six counties. Reexamination of Brown's results in the light of new data has changed the total only slightly, to the 2,185 million tons shown in table 29.

The estimates were made by the standard methods of the U.S. Geological Survey (Averitt, 1961, p. 14–22). These methods call for dividing the resources into measured, indicated, and inferred cate-

TABLE 29.—IDENTIFIED LIGNITE RESOURCES[1]

[In millions of short tons; overburden 0–1,000 ft]

County	Original resource [2]	Inferred resources and resources in beds less than 5 ft thick	Total
Corson	40	10	50
Dewey	200	50	250
Harding	700	1,000	1,700
Meade		1	1
Perkins	80	100	180
Ziebach	1	5	6
Total	1,021	1,166	2,187
Commulative production and losses to Jan. 1, 1972 [3]			2
Resources remaining in the ground, Jan. 1, 1972			2,185

[1] From Brown (1952), with modifications to accord with new data on stripping coal resources.
[2] Measured and indicated resources in beds 5 ft or more thick plus lignite in thinner beds suitable for strip mining.
[3] Past losses in mining are assumed to equal past production.

gories according to the reliability of the data, and also for using thickness categories, which for lignite and subbituminous coal are 2.5 to 5 feet, 5 to 10 feet, and more than 10 feet. The thickness of overburden, which is commonly used in classifying coal resources, has been disregarded in South Dakota because all of the known coal is less than 1,000 feet below the surface (Brown, 1952, p. 7).

Because the lignite of the State normally occurs in very lenticular beds and because information points were widely spaced and largely confined to outcrops, less than 10 percent is classed as measured, more than 80 percent is indicated, and about 10 percent is inferred (Brown, 1952, p. 1). Only 3 percent of the lignite is more than 10 feet thick, and 63 percent is between 2.5 and 5 feet thick.

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 because it is too close to other mines, wells, or man-made structures. The ratio of the coal produced to the total amount of coal actually present 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). If the 50 percent is in fact correct, the recoverable known lignite resources of South Dakota are about 1,092 million tons. A larger recoverability factor possibly should be used, for as much as 80 percent of the State's known resources may be under less than 500 feet of overburden (Brown, 1952, p. 1) and a large share can be strip mined (table 30). A recoverability factor of 80 percent is commonly used for strip mining and actual recovery is 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 next few decades probably will be obtained in the same way.

TABLE 30.—AVAILABILITY OF IDENTIFIED LIGNITE RESOURCES BY MINING METHODS

[In millions of short tons]

County	Original identified resources, 0–1,000 ft overburden[1]	Mining methods				
		Surface mining			Underground mining	
		Resource[2]	Potentially recoverable[3]	Economically recoverable[4]	Resource[2]	Potentially recoverable[5]
	(1)	(2)	(3)	(4)	(5)	(6)
Corson	40	30	24		10	5
Dewey	200	130	104		70	35
Harding	700	227	182		473	237
Meade						
Perkins	80	40	32		40	20
Ziebach	1	1	1		0	0
Total	1,021	428	343	206	593	297

[1] Cumulative production and losses are so small that original identified resources are virtually unchanged.

[2] Col. 2 plus col. 5 equals col. 1.

[3] 80 percent of figures in col. 2.

[4] 60 percent of total in col. 3. Not classified by county.

[5] 50 percent of figures in col. 5.

Uranium

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

Uranium deposits of economic significance were discovered in 1951 in the Craven Canyon area of Fall River County, South Dakota, in what became known as the Edgemont mining district (Page and Redden, 1952). Prospecting quickly intensified and by 1953 production of uranium ore had increased to a point such that the U.S. Atomic Energy Commission established a buying station in Edgemont. In 1956 a mill for processing the ore was completed in Edgemont.

Commercial uranium deposits were discovered in lignite beds of Harding County in 1954, but occurrences of uranium minerals had been reported as early as 1948 (Wyant and Beroni, 1950).

The locations of the principal deposits are shown on figure 27. Exploration and development increased rapidly and production of ore reached a peak in 1964. Production declined greatly in the late 1960's, partly because the U.S. Government support price was eliminated and partly because the supply of uranium exceeded demand. The mill at Edgemont stopped producing uranium concentrates in 1972. However, with the energy crisis of 1973 and 1974, and the consequent increase in proposals for the construction of nuclear power generating stations, the prospects for another uranium boom appear bright. Uranium mining in South Dakota probably will be reactivated, and exploration for new deposits will accelerate.

Production, reserves, and resources

Data compiled by the U.S. Atomic Energy Commission show that by the end of 1973, nearly one million tons of uranium ore containing about 3,200,000 pounds of U_3O_8 have been produced from deposits in South Dakota (table 31). This amounts to only about 0.5 percent of the uranium produced in the United States, but at an average price of perhaps $8 per pound, total value has been about $25,000,000.

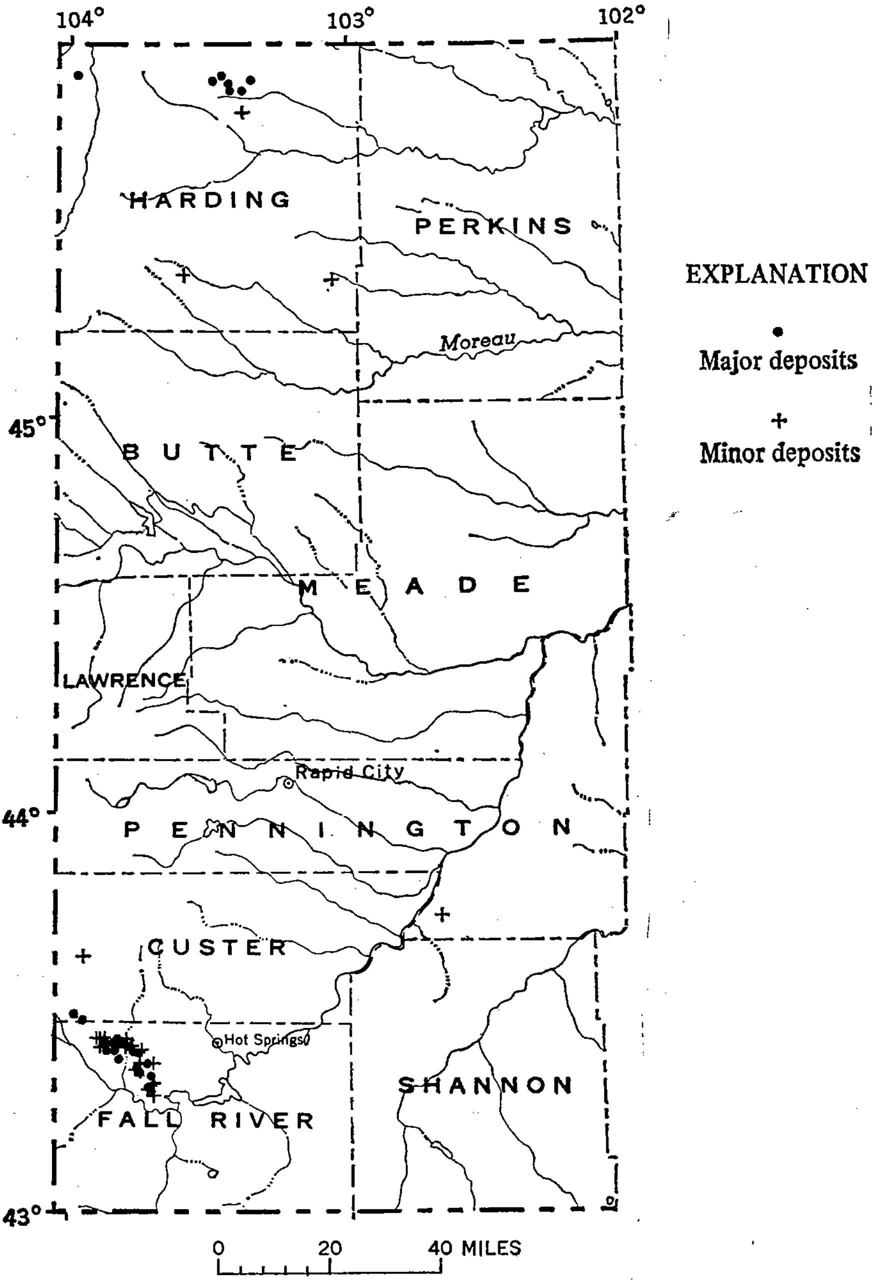


FIGURE 27.—Uranium deposits.

TABLE 31.—URANIUM PRODUCTION BY COUNTIES, THROUGH 1973

[From Grand Junction Office, U.S. Atomic Energy Commission]

County	Short tons ore	Grade[1]	Pounds U_3O_8
Butte	2,050	0.148	6,066
Custer	166,675	.151	502,583
Fall River	740,243	.130	1,922,560
Harding	89,746	.412	738,638
Lawrence	52	.063	65
Pennington	388	.167	1,298
Total	999,154	----------	3,171,210

[1] In percent U_3O_8.

Reserve estimates for South Dakota compiled by the U.S. Atomic Energy Commission (Carl Applin, oral communication, 1974) indicate about 200,000 tons of ore that can be produced at a price of $8 per pound of contained U_3O_8 and about 400,000 tons of ore that can be produced at a price of $10 per pound of contained U_3O_8.

Resources in coal and lignite may be between 2,500,000 and 5,000,000 tons of ore-grade material. Undiscovered resources in sandstones of the Inyan Kara Group may be about 1,000,000 tons of ore-grade material. Resources of ore-grade material in other rocks known to contain uranium deposits probably do not exceed a few thousand tons.

In addition to material minable under today's economic conditions, very large tonnages of rocks containing about 0.007 percent uranium occur in, and associated with, the Tertiary lignite beds of northwest South Dakota. Extraction of the uranium contained in these rocks awaits technological advances in both mining and metallurgy.

Precambrian rocks of the Black Hills have been intensively prospected with virtually no success, but the possibility that deposits exist beneath Paleozoic cover cannot be wholly discounted.

Deposits in sandstone

The principal deposits are in sandstones of the Inyan Kara Group of Cretaceous age. These deposits are of the uranium-vanadium type that is common in sandstones throughout the western United States Most of them are lens-shaped and, depending upon their mineralogy, are classified as follows: yellow oxidized; purplish-black, partly oxidized; or black unoxidized deposits. The ore minerals are listed in table 32 according to these categories.

TABLE 32.—ORE MINERALS IN BLACK HILLS URANIUM-VANADIUM DEPOSITS IN SANDSTONE

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

Uranium deposits in the Edgemont mining district are mostly in the so-called No. 1 and No. 4 sandstones of the Lakota Formation and in the No. 5 sandstone of the Fall River Formation (Gott and Schnabel, 1963). Thin sandstone and siltstone beds adjacent to these thicker sandstone beds have accounted for nearly all other production. The No. 1, 4, and 5 sandstones are wide, sinuous units that probably were deposited in ancient river valleys. The thin sandstones and siltstones, which are interbedded with carbonaceous shales, probably formed on flood plains adjacent to the river valleys. The large channel sandstones presumably were major pathways along which the uranium-bearing solutions migrated laterally, but undoubtedly there was some vertical movement of the solutions along fractures caused by faulting, jointing, or collapse structures.

Recent studies have indicated that uranium is precipitated from solution in a reducing environment and remobilized in an oxidizing environment unless sufficient vanadium is present to form insoluble uranyl vanadates.

The near-surface uranium deposits in the Edgemont district are mostly of the oxidized type. They seem to have been localized mainly by an abundance of carbonaceous material or pyrite, and they have been preserved in their present position in the oxidizing zone either by a high percentage of vanadium or by a local reducing environment caused by accumulations of carbonaceous material or pyrite. The deposits that formed at the erosional contact between the No. 4 and No. 5 sandstones (Gott and Schnabel, 1963, p. 180–181) apparently resulted from mixing of uraniferous carbonate solutions carried by the No. 4 sandstone and solutions rich in organic acids and hydrogen sulfide carried by the No. 5 sandstone.

Uranium with lignite

A modest amount of uranium has been obtained from deposits in and associated with lignite and coaly rocks in the Fort Union Group of Paleocene age in the northwest part of the State. Nearly all of the production has been from the Slim Buttes and Cave Hills areas in Harding County.

Most of the uranium in the lignites is in the form of organo-uranium compounds and thus can be detected only by instruments that measure radioactivity or by chemical analyses, though green and yellow uranium minerals locally coat joint surfaces in the lignite. Some of the minerals that have been identified are listed in table 33.

TABLE 33.—URANIUM AND VANADIUM MINERALS IN LIGNITE AND COALY ROCKS OF NORTHWEST SOUTH DAKOTA[1]

Abernathyite—$K_2(UO_2)_2(AsO_4)_2.8H_2O$
Metazeunerite—$Cu(UO_2)_2(AsO_4)_2.8H_2O$
Metanovacekite—$Mg(UO_2)_2(AsO_4)_2.8-10H_2O$
Meta-autunite—$Ca(UO_2)_2(PO_4)_2.2\frac{1}{2}-6\frac{1}{2}H_2O$
Metatorbernite—$Cu(UO_2)_2(PO_4)_2.8H_2O$
Metauranocircite—$Ba(UO_2)_2(PO_4)_2.8H_2O$
Saleeite—$Mg(UO_2)_2(PO_4)_2.8H_2O$
Sodium-autunite—$Na_2(UO_2)_2(PO_4)_2.8H_2O$
Uranophane—$Ca(UO_2)_2Si_2O_7.6H_2O$
Carnotite—$K_2(UO_2)_2(VO_4).1-3H_2O$
Metatyuyamunite—$Ca(UO_2)_2(VO_4)_2.3-5H_2O$
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 is concentrated in the reducing environment produced by the organic material in the lignites in much the same manner as in the carbonaceous environments in sandstone deposits. Lignite or coaly beds occur at various stratigraphic horizons in the Fort Union Group but at any single locality only the uppermost bed is uraniferous. Different lignite beds are the uppermost in different places, because subsequent erosion removed differing amounts of the Fort Union. The occurrence of uranium in only the uppermost lignite bed among several lignite beds led Denson, Bachman, and Zeller (1959) to conclude that the uranium had been leached from White River volcanic debris, carried downward by water, and then concentrated in the reducing environment of lignite.

Minor occurrences of uranium

Uranium minerals have been found in the Deadwood Formation, Minnelusa Formation, Spearfish Formation, Newcastle Sandstone, and Pierre Shale, as well as in several of the Tertiary formations in western South Dakota. Except for one small deposit in the Chadron Formation, none of these units has yet produced any uranium ore. Whether they may contain more important undiscovered deposits is uncertain.

Small quantities of uranium minerals have been obtained from the Precambrian zoned pegmatites of the Black Hills, especially the Bob Ingersoll No. 1 at Keystone, but they have been used mainly as specimens and for research. In the mid-1950's prospectors were attracted to the Harney Peak Granite, chiefly its northeast quarter, and also to nearby schists; sizable bulldozer trenches and pits were made, apparently with slight results.

Future development

Recently the uranium mining industry of South Dakota has been virtually dormant. Supplies of uranium have exceed demand and the price has been depressed to the point beyond which only very high-grade ores or very large deposits can be mined profitably. Circumstances are now changing with the construction of increasing numbers of nuclear reactors for the production of electrical energy. These reactors will require a very large amount of uranium for fuel, and thus the demand and the price for uranium are expected to increase. A consequence will be further search for uranium deposits in South Dakota as well as elsewhere.

The intense prospecting activity of the late 1950's and early 1960's probably resulted in the discovery of nearly all of the large, easily found near-surface deposits of uranium in South Dakota. Future exploration will require new strategies. Drilling to explore promising areas of geologic formations known to be productive, as well as formations not yet adequately tested, will probably be most frequently used. Because drilling is very expensive, much effort will be needed to improve geologic and geophysical methods for outlining target areas.

Geothermal Resources

(By Lewis Howells, U.S. Geological Survey, Huron, S. Dak.)

Ground-water temperatures measured in South Dakota show that the State may have geothermal resources of greater potential value than generally supposed. Several major aquifers, underlying about

40,000 square miles, yield hot water at temperatures above 38° C (100° F). In some municipal supply wells, Midland and Phillip having good examples, the water is as hot as 67° C (153° F), and must be cooled before distributed for domestic consumption. The Midland supply also has been used to heat the public school. Water from a private well (59° C or 138° F) at Eagle Butte has been used to heat a store. A scattering of ranchers in the western part of the State heat their homes and barns with hot water from their wells. Many oil-test holes have penetrated hot-water aquifers; bottom-hole temperatures as high as 121° C (250° F) have been recorded. Warm springs are present in several places in the southern Black Hills but have too low a temperature to be attractive as sources of geothermal energy. The area was prominent at one time as a spa locality and the city of Hot Springs was founded and named for these features.

Figure 28 shows the approximate extent of the area underlain by aquifers yielding water at 38° C (100° F) or warmer; also shown are a few temperatures reported for oil-test wells.

At least eight major geologic units contain hot-water aquifers. These units range from the Inyan Kara Group of Cretaceous age, through the Sundance and Minnelusa Formations, Madison Group, Devonian and Silurian rocks, and Red River Dolomite, to the Deadwood Formation of Cambrian age. The aggregate thickness of these units ranges from less than 1,000 feet to more than 5,000 feet. The total volume of water stored in "hot-water" aquifers is more than 1.5 billion acre-feet. The amount of energy stored in these rocks at a temperature greater than 38° C (100° F) is more than 6×10^{18} BTU or 16×10^{14} KWH. This is equivalent to more than 900 years production of electric power in the United States at the 1971 generation rate.

The geochemistry of the hot water may be important, not only because of possible engineering problems that might arise in developing any geothermal potential, but also because the dissolved constituents might be a source of byproducts. Total dissolved-solids contents reported range from less than 2,000 mg/l (milligrams per liter) to as much as 190,000 mg/l. Good data are scanty, but if the reports are correct, the hypersaline brine may represent a doubly valuable resource by providing both energy and a source of raw materials.

Although studies of geothermal energy usually focus on the relatively small areas where temperatures are high enough to produce wet or dry steam (generally, above 180° C or 356° F), hot-water geothermal resources actually are far more widely distributed and are several orders of magnitude larger. Commercial production of electricity from the hot-water aquifers described here may not be economically feasible today, but as energy becomes more highly valued economically, and as research finds cheaper or more efficient methods of recovery, the situation could reverse. Othmer and Roels (1973) believe that utilizing temperature differences of 15° to 25° C to generate electricity is competitive today in some places.

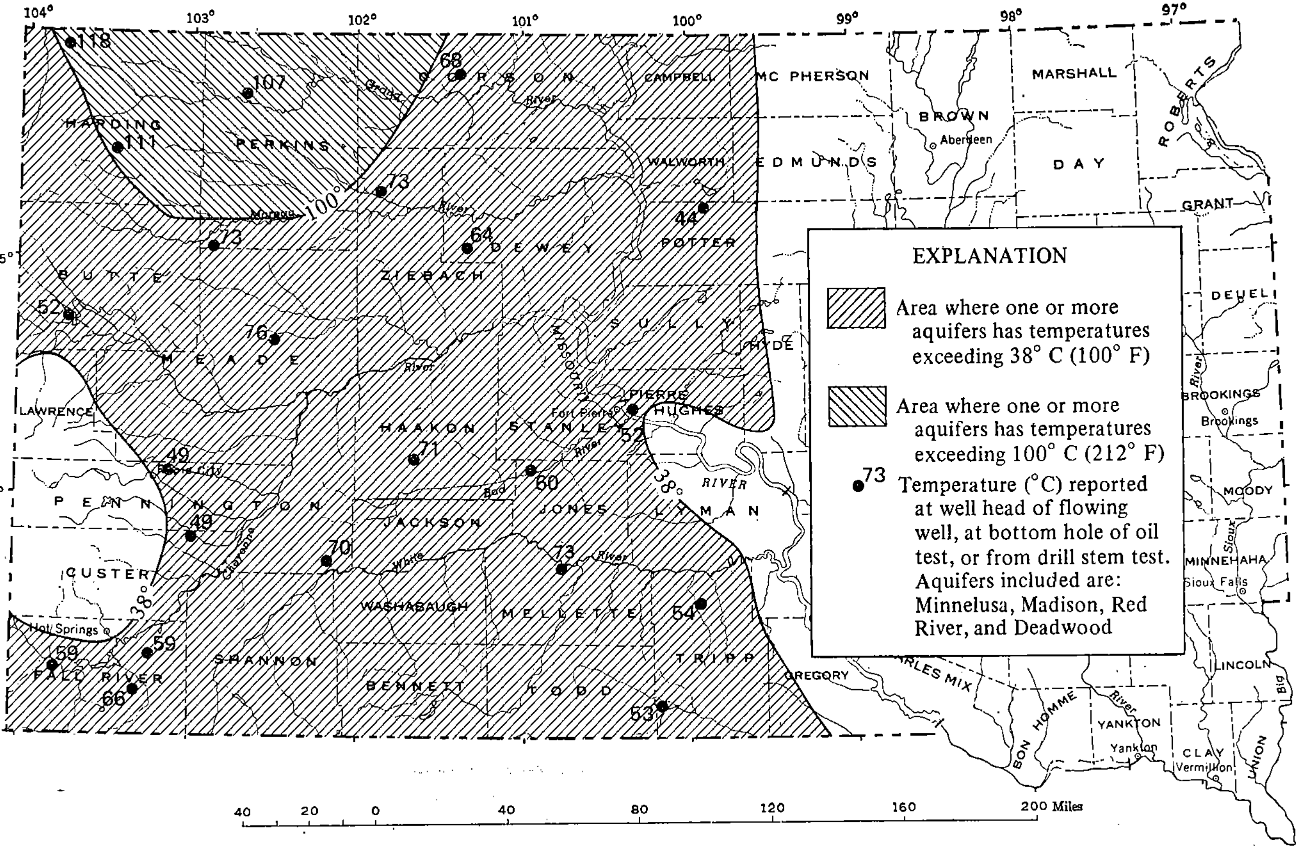


FIGURE 28.—Approximate area within which acquifers contain water at 38° C (100° F) or hotter.

WATER RESOURCES

(By the U.S. Geological Survey, Huron, S. Dak., and the U.S. Bureau of Reclamation, Huron, S. Dak.)

INTRODUCTION

About 60 percent of South Dakota is in the Great Plains physiographic province; the balance is in the Central Lowlands physiographic province. All but a small section in the northeastern part of the State is drained by the Missouri River. 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. Most of the eastern part of the State is drained by the southward-flowing James, Vermillion, and Big Sioux Rivers. Two small areas in the northeastern corner of the State are part of the Hudson Bay or Upper Mississippi drainage.

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 29 shows the distribution of precipitation in the State.

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 45 years preceding 1974, the annual precipitation over the State ranged from as much as 50 inches to as little as 7.5. Periods of successive dry years, or years that are wetter than normal, are frequent.

The major undeveloped source of water in South Dakota is underground in water-bearing beds of rock or sediment called aquifers. Where present, these aquifers may provide a large and reliable source of water for all uses. The aquifers are of two types—those in glacial drift and those in bedrock. Glacial drift makes up the surface deposits over most of the area east of the Missouri River; it consists mainly of clay with admixed sand, gravel, and boulders, but contains lenses or surficial sheets of sand and gravel. The bedrock aquifers are mostly sedimentary rocks. Ground water is absent or scarce in near-surface materials in much of the State, especially in the unglaciated area west of the Missouri River.

The bedrock aquifers underlie almost all of the State. Because water flows from these aquifers or can be pumped from a moderate depth, they have been an important factor in the development of agriculture in parts of South Dakota, primarily in connection with livestock production.

An important aspect in the understanding of the water resources of a State is an accurate appraisal of their utilization and degree of development. A water use study by the U.S. Geological Survey for the year 1970 reveals a marked difference in water use practices between the glaciated area east of the Missouri River and the unglaciated area west of the river.

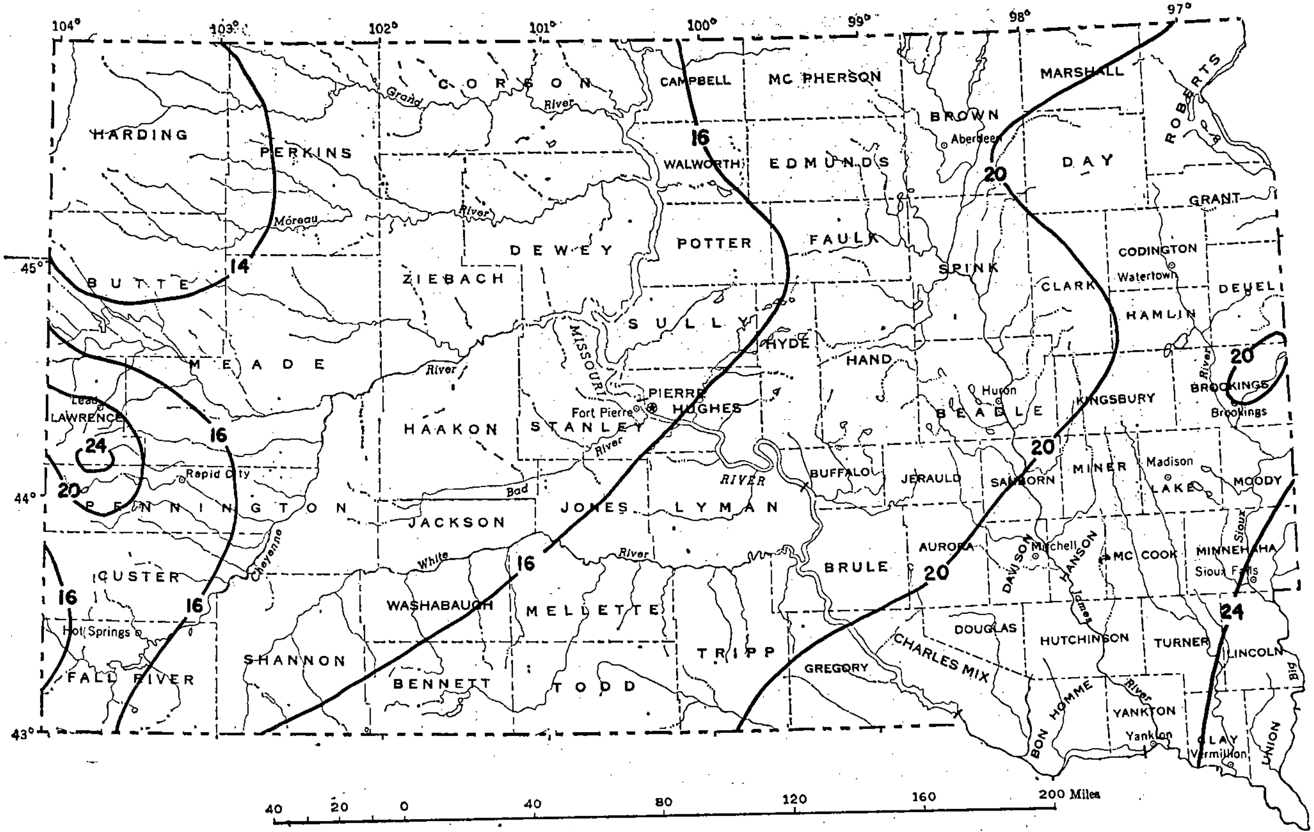


FIGURE 29.—Average annual precipitation, in inches (Data from National Weather Service).

On a statewide basis, of the total water withdrawn, irrigation requires 51 percent; farm-domestic purposes, 27 percent; and municipalities and industry, the remaining 22 percent. Of the 453 million gallons per day withdrawn, surface waters supply 55 percent and ground-water sources furnish the remaining 45 percent.

West of the Missouri River 73 percent of the water used is from surface sources and irrigation accounts for 89 percent of this use. In contrast, municipalities and industry in this area depend heavily upon ground water for nearly 80 percent of their supplies. Farm-domestic supplies are estimated to be 71 percent from ground water and 29 percent from surface sources. Western South Dakota has developed a substantial portion of its surface water resources. Supplemental irrigation is necessary in some local areas in order to support agricultural production.

Water utilization east of the Missouri River is quite different. Ground water is by far the largest source being utilized and accounts for nearly 76 percent of all water used. Of the total ground water withdrawn, irrigation uses 19 percent and municipalities and industry use 33 percent. Ground water also furnishes over 81 percent of the farm-domestic water withdrawn. The influence of relatively shallow ground-water sources, greater annual rainfall, and a lack of convenient on-stream storage sites has caused this pattern of water utilization in eastern South Dakota.

Water Resource Development

Planning concepts

Modern water-resource development requires comprehensive planning with a view to fulfilling more than one objective, especially in the use of surface water. "Multiobjective" planning, as this is called, has been established as national policy by the Water Resources Council in planning the development of water and land resources. By encouraging a wide range of agencies, interest groups, and individuals to state their priorities and preferences, this policy should lead to plans that reflect compromise solutions of the often conflicting desires of different interests. Multiobjective planning provides various alternative plans that may be selected so as to reflect the prevailing set of values and priorities at any given time.

Basinwide planning involves use of multiobjective procedures within a river basin to assess development potential. The result can be a single project with several types of benefits such as irrigation, hydroelectric power, flood control, navigation, municipal and industrial water supply, water quality control, fish and wildlife enhancement, and recreation development. On the other hand, multiobjective planning can result in a decision that national economic development and environmental quality are best served by selection of an alternative specifying a single purpose project, or even an alternative that calls for no development at all. In any case, proposed plans are supported by an environmental impact statement, which is thoroughly reviewed by agencies of all levels of government and by concerned organizations and citizens through a series of public hearings prior to consideration for construction authorization.

Agencies and organizations

Many governmental agencies are involved in water conservation, utilization, and resource development in South Dakota. No single State or Federal agency could cope with the complexity of properly developing South Dakota's water resources. Piecemeal development occurred in the past. South Dakota continued to lag behind other areas in water development. The people in South Dakota, as well as other Missouri River Basin States, recognized that something had to be done to bring together divergent interests and needs in comprehensive basinwide planning and development.

The year 1944 was a significant milestone in South Dakota water-resource development, as it was for the other nine Missouri River Basin States, when the Missouri River Basin Project was authorized by the Flood Control Act of December 22, 1944, 78th Congress, 2d Session (58 Stat. 887).

Executive Order 11658 of March 22, 1972, established the Missouri River Basin Commission to carry out basinwide water and related land resource development planning as specified in the Water Resources Planning Act (79 Stat. 244; 42 U.S.C. 1962 et seq.). The Commission consists of 21 or more members (a chairman, representatives of 10 Federal agencies, representatives of 10 states, and representatives of interstate compact agencies in the basin recognized by Congress).

The original Missouri River Basin Project is now known as the Pick-Sloan Missouri Basin Program, the name being changed by Congress to honor the originators of the project plan.

Present-day planning for water-resource development in South Dakota shows continued close cooperation and coordination between State and Federal agencies. The U.S. Army Corps of Engineers continues its work in the primary areas of flood control, hydroelectric power generation, bank stabilization, public recreation, conservation of fish and wildlife, and improvement to navigation while also contributing to water supplies for irrigation, municipal and industrial water, and water quality control. The U.S. Bureau of Reclamation is the lead agency in developmental planning for irrigation, municipal and industrial water supply, and transmission and sale of power, plus flood control, recreation, fish and wildlife, and water-quality control associated with its project developments. The U.S. Geological Survey, in addition to its topographic and geologic mapping and its mineral resource programs, collects basic data on quantity, quality, and occurrence of water resources; studies areas of potential or existing water problems; and conducts research into fundamental principles of hydrology. The U.S. Soil Conversation Service plans individual and small watershed projects for soil and water conservation. The National Weather Service maintains rain, snowfall, and climatological data. The U.S. Bureau of Mines, in addition to studying water needs for 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 U.S. Environmental Protection Agency helps cities and industries with water supply, quality, waste treatment, and stream pollution abatement problems. Federal agencies, such as the Forest Service, National Park Service, Bureau of Sport Fisheries and Wildlife, and the

Bureau of Outdoor Recreation coordinate their activities with State and other Federal agencies to obtain optimum recreation and wildlife benefits from water-resource development.

State agencies in South Dakota directly involved in water-resource planning and development include the Department of Agriculture, Department of Environmental Protection, Department of Game, Fish and Parks, State Planning Bureau, Department of Natural Resources Development, South Dakota State University, South Dakota School of Mines and Technology, and the University of South Dakota. Water-resource development in South Dakota is truly a coordinated effort among governmental agencies.

State laws of South Dakota enable the people to form organizations such as water conservancy districts and subdistricts, irrigation districts, drainage districts, county conservation districts, watershed districts, water users associations, and other legal entities to develop and utilize water resources.

Water conservancy districts differ in purpose and legal structure from irrigation districts. They have no power to levy taxes; however other usual corporate 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. This organization was formed 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 aspiration in water-resource development, especially those related to the Pick-Sloan Missouri Basin Program, 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. 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 provided 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 six conservancy subdistricts and nine irrigation districts organized. Their formation reflects an increased interest in water-resource development by people living in South Dakota.

Table 34 lists the water conservancy and irrigation district organizations, their geographic locations, and dates of organization. Figure 30 shows the general boundary outlines of these organizations and their locations within the State.

TABLE 34.—WATER CONSERVANCY AND IRRIGATION DISTRICTS

[Date formed: Dates are of original formation; dates of subsequent additions, deletions, etc., not shown]

Reference number on figure 30	Name	Date formed	Geographical location (by counties)
—	South Dakota Conservancy District	Legislative Act, 1959	All counties in their entirety, within South Dakota.
I	Black Hills Conservancy Subdistrict	November 1964	Lawrence, Meade, Pennington, and Custer (excludes towns of Pringle and Quinn).
II	West River Conservancy Subdistrict.	November 1968	Perkins, Corson, Ziebach, Dewey, Haakon, Jackson, Jones, Lyman, Mellette, Tripp, and Gregory (excludes towns of Oacoma, Presho, and Reliance).
III	Oahe Conservancy Subdistrict	November 8, 1960	Campbell, McPherson (excludes town of Wetonka), Brown, Marshall (part), Walworth, Edmunds, Day, Potter, Faulk, Spink, Clark, Sully, Hughes, Hyde, Hand, and Beadle.
IV	Lower James Conservancy Subdistrict.	November 6, 1962	Jerauld, Miner (part), Aurora, Davison, Hanson, Hutchinson, and Yankton (excludes towns of Lane, Roswell, Utica, and T. 107 N., R. 63 W.).
V.	Fort Randall Conservancy Subdistrict.	November 8, 1960	Douglas, Charles Mix, Buffalo, Bon Homme, and Brule.
VI	East Dakota Conservancy Subdistrict.	November 6, 1960	Grant, Codington, Hamlin, Deuel, Kingsbury, Brookings, Miner (east half), Lake, Moody, Minnehaha, Lincoln, and Union (excludes towns of Albee, Big Stone City, Kranzburg, and Wallace).
1.	Belle Fourche Irrigation District	Mar. 12, 1923	Butte (part) and Meade (part).
2.	Rapid Valley Water Conservancy District (irrigation).	June 18, 1943	Pennington (part).
3.	Angostura Irrigation District	June 27, 1950	Fall River (part) and Custer (part).
4.	Pollock-Herreid Irrigation District	Feb. 4, 1963	Campbell (part).
5.	Missouri Slope Irrigation District	May 26, 1970	Sully (part).
6.	Northwest Irrigation District	Jan. 4, 1972	Buffalo (part).
7.	Lake Andes-Wagner Irrigation District.	March 1969	Charles Mix (part).
8.	West Brown Irrigation District	Jan. 5, 1965	Brown (part).
9.	Spink County Irrigation District	do	Spink (part).

The Watershed Protection and Flood Prevention Act (Public Law 83–566), administered by the U.S. Soil Conservation Service, 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 for local installation of works and improvements for watershed protection and 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. Figure 31 illustrates and table 35 summarizes the status of this program as of January 1, 1974.

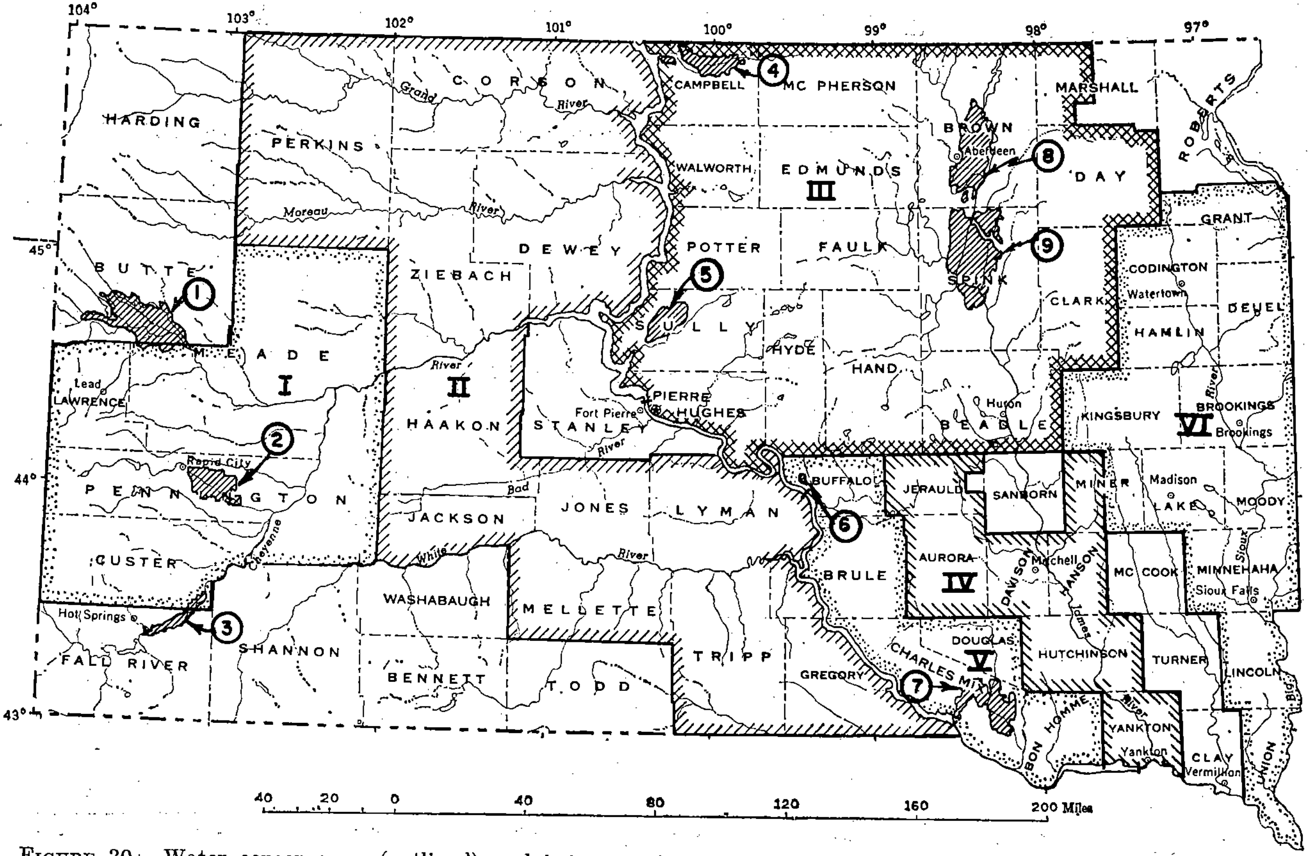


FIGURE 30.—Water conservancy (outlined) and irrigation (hachured) districts (Numbered areas identified in table 34).

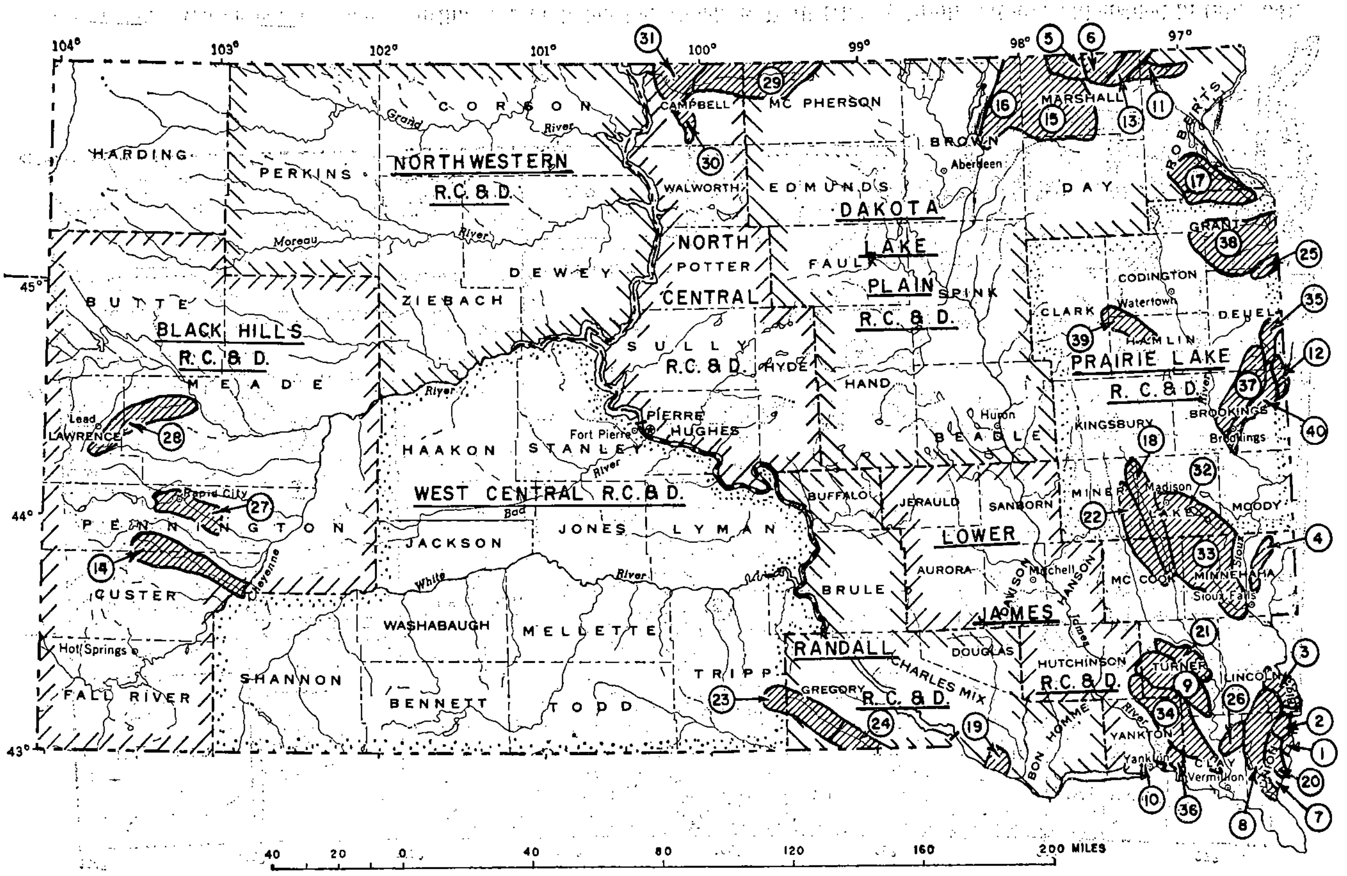


FIGURE 31.—Watershed protection projects (hachured) and resource conservation and development projects (outlined) (Numbered areas identified in table 35).

TABLE 35.—WATERSHED PROTECTION (PUBLIC LAW 83-566) AND RESOURCE CONSERVATION AND DEVELOPMENT PROGRAM (PUBLIC LAW 87-703) PROJECTS

Reference number on fig. 31 and project	Location (county)	Size (acres)	Status
WATERSHED PROJECTS			
1 Scott Creek (pilot)	Union	2,900	Completed.
2 Green Creek	do	11,104	Do.
3 Pattee Creek	Lincoln	25,462	Approved and underway.
4 Silver Creek	Minnehaha	20,661	Completed.
5 Wild Rice Creek	Marshall, S.D., Sargent, N.D	233,522	Do.
6 Tewaukon Creek	Marshall, S.D., Sargent, N.D	93,782	Do.
7 Richland Creek	Union	6,515	Inactive, June 1960.
8 Brule Creek	Union, Lincoln	142,720	Approved and underway.
9 Turkey Ridge Creek	Hutchinson, Turner	113,840	Inactive.
10 Marne Creek	Yankton	20,825	Do.
11 Upper Little Minnesota	Marshall, Roberts	36,984	Do.
12 Upper Deer Creek-Lake Hendricks.	Brookings, Deuel, S.D.; Lincoln, Minn.	29,755	Approved and underway.
13 Veblen	Marshall, Roberts, S.D.; Richland, Sargent, N.D.	90,800	Planning suspend.
14 Battle Creek	Custer, Pennington	182,590	Planning terminated April 1961.
15 Upper Crow Creek	Marshall	241,050	Being planned.
16 Lower Crow Creek	Brown	123,098	Do.
17 North Fork Whetstone	Roberts, Grant	123,700	Planning suspended.
18 Upper East Fork	McCook, Lake, Miner	112,600	Application pending planning approval.
19 Spring—Bull Creek	Charles Mix	27,000	Approved and underway.
20 Union Creek	Union	29,216	Do.
21 Hurley Creek	Turner	27,000	Do.
22 Little Vermillion River	McCook, Lake, Miner	89,600	Application pending planning. approval.
23 Upper Ponca Creek	Tripp, Gregory	172,545	Application pending.
24 Middle Ponca Creek	Gregory, S.D.; Boyd, Nebr	164,606	Do.
25 Mud Creek	Deuel, Grant	16,580	Approved and underway.
26 Baptist Creek	Clay	25,000	Application received November 1963.
27 Rapid Creek	Pennington	153,460	Application pending.
28 Bear Butte Creek	Lawrence, Meade	144,000	Do.
29 Upper Spring Creek	Campbell, McPherson, S.D.; McIntosh, N.D.	242,000	Do.
30 South Branch Spring Creek	Campbell, S.D	130,000	Do.
31 Lower North Branch, Spring Creek.	Campbell, S.D.; McIntosh, Emmons, N.D.	132,000	Do.
32 Upper Skunk Creek	Lake, Minnehaha, McCook, Moody	200,000	Do.
33 Lower Skunk Creek	Minnehaha	207,000	Do.
34 Turkey-Clay Creek	Hutchinson, Clay, Turner, Yankton	162,700	Do.
35 Cobb-Florida	Deuel, S.D., Yellow Medicine, Lac Qui Parle, Minn.	92,320	Do.
36 Mission Hill	Yankton	7,020	Being planned.
37 North Deer Creek	Brookings, Deuel	73,620	Application pending planning approval.
38 Yellowbank River	Deuel, Grant, S.D.; Lac Qui Parle, Minn.	249,000	Application pending.
39 Marsh Lake	Hamlin Clark, Codington	38,400	Do.
40 Six Mile Creek	Brookings, Deuel	48,740	Do.
RESOURCE CONSERVATION AND DEVELOPMENT PROJECTS			
Randall	Buffalo, Brule, Gregory, Charles Mix, Douglas, Bon Homme.	2,920,320	Authorized for operations and underway.
Black Hills area	6 South Dakota counties; 3 Wyoming Counties.	12,066,650	Do.
	(South Dakota Counties: Butte, Meade, Lawrence, Pennington, Custer, Fall River).	(8,077,440)	Do.
Lower James area	Jerauld, Sanborn, Aurora, Davison, Hanson, Hutchinson, Yankton.	2,576,640	Authorized for planning, December 1973. Being planned.
Northwestern area	Corson, Dewey, Perkins, Ziebach	6,286,080	Application made November 1970.
North central area	Campbell, Walworth, Potter, Sully, Hughes, Hyde.	3,294,080	Application made December 1970.
West central area	Bennett, Haakon, Stanley, Jackson, Jones, Lyman, Mellette, Todd, Tripp, Shannon, Washabaugh.	9,914,240	Application made February 1971.
Dakota Lake Plain area	McPherson, Edmunds, Faulk, Hand, Brown, Spink, Beadle, Marshall, Day, Roberts.	7,886,720	Application made May 1971.
Prairie Lakes area	Grant, Clark, Codington, Hamlin, Deuel, Kingsbury, Brookings, Miner, Lake, Moody.	4,421,120	Application made June 1973.

A total of 449 watersheds have been evaluated in South Dakota. Over 1,232,764 acres with flooding problems, and over 301,000 acres damaged by erosion, need project action to solve the problem. Projects in 205 watersheds were determined feasible in the 1970 USDA Conservation Needs Inventory.

The Resource Conservation and Development Program (RC&D) is authorized by the Food and Agriculture Act of 1967 (P.L. 87–703). It expands opportunities for conservation districts, local units of government, and individuals to improve their communities in multi-county areas.

Nearly all counties in South Dakota are included in RC&D projects (Table 35). An RC&D applicant area may receive assistance from going programs of USDA and other agencies prior to authorization for planning. After receiving authorization for planning, then authorization for operations, the RC&D council and sponsors may receive additional technical and financial assistance for resource conservation and development measures to be carried out by eligible sponsors (conservation districts, counties, cities, Indian tribes, and other public bodies). Measures eligible for RC&D financial and technical assistance include critical area treatment (erosion and sediment control), flood prevention, public water-based fish and wildlife, and recreation developments, farm irrigation, land drainage and soil and water management for agricultural-related pollutant control. The RC&D Project Plan is an "open-ended" overall plan for resource conservation and development.

GROUND WATER

General Statement

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—that is, ground water under enough pressure to rise above the level at which it is first encountered in a well, though it does not necessarily rise to or above the ground surface—has been very important in the settlement of the State, and in the development of its chief industry, agriculture. 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 part. 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

Ground Water in Glacial Drift and Alluvium

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 32 shows areas in the State where glacial deposits containing large amounts of ground water are known to occur. Table 36 lists the major glacial drift aquifers that have been mapped as a result of water-resources studies. Most of these studies are cooperative Federal-State-County water-resources studies that have been made within the last ten years.

Glacial drift makes up the surface deposits over most of the State east of the Missouri River. It is as much as 800 feet thick on the Prairie Coteau in the northeast part of the State, but the average thickness is much less—perhaps about 150 feet. 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.

Alluvial deposits, especially those along perennial streams, are easily recharged and are obvious and readily accessible sources for immediate ground-water development. Most of them either are supplying water or have a water-supply potential. These deposits are usually narrow, and are along nearly all the larger western streams, the Missouri River, 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.

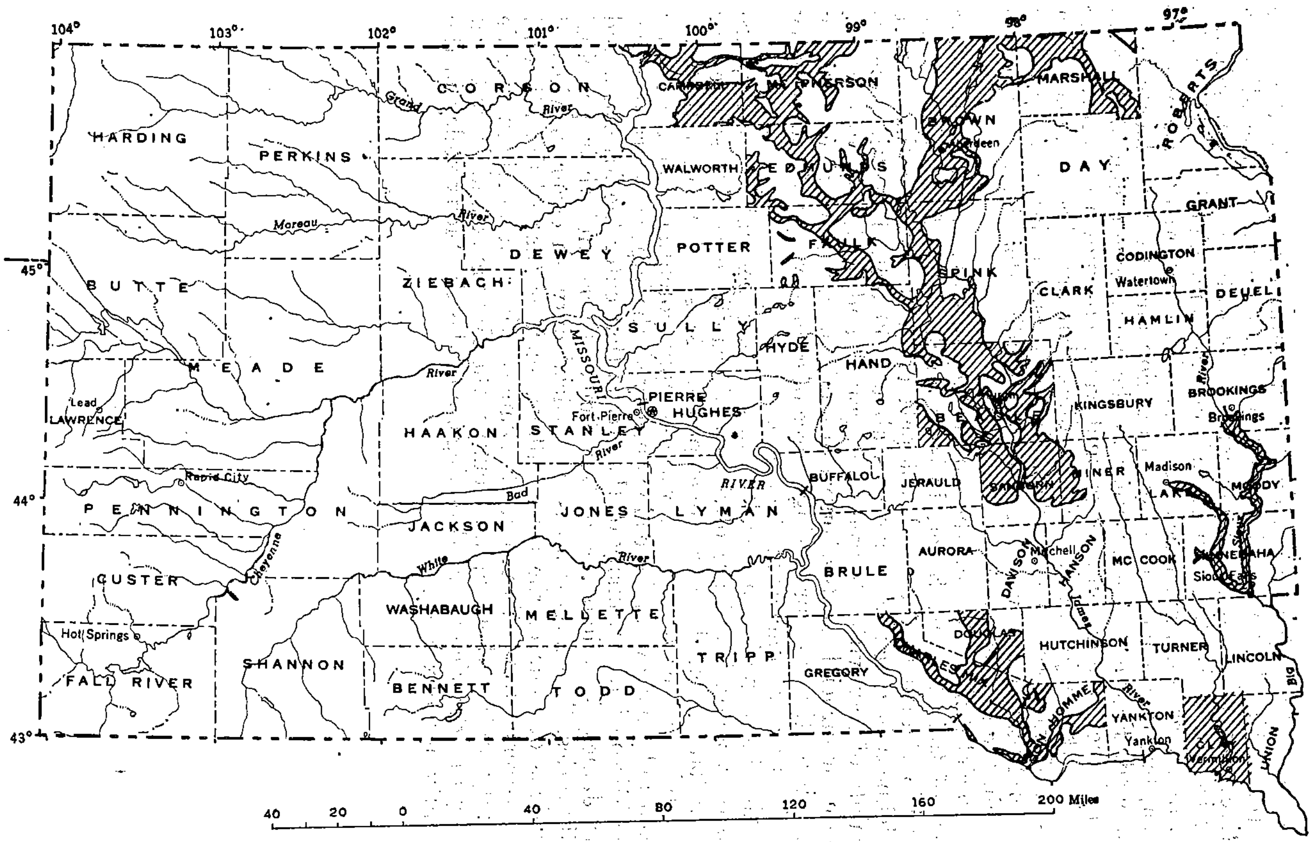


FIGURE 32.—Major glacial drift aquifers that have been mapped as the result of water-resources studies.

TABLE 36.—MAJOR GLACIAL DRIFT AQUIFERS[1]

County and aquifer	Estimated areal extent (square miles)	Maximum thickness (feet)	Water storage (acre-feet)	Estimated maximum well yield (gallons per minute)	Salinity of water index
Beadle:					
Warren	240	90	1,400,000		
Floyd	265	100	1,800,000		4
Tulare	260	200	1,800,000		
Brown:					
Deep James	250	160	1,000,000	1,000	3–5
Middle James	530	70	1,400,000	1,000	2–4
Elm	390	112	1,200,000	1,000	1–5
Bon Homme:					
Choteau	32	170	120,000	500	3
Hubonmix	36	53	90,000	150	3
Tyndall-Scotland	90		440,000	900	2–4
Campbell:					
Spring Creek	100	145	320,000	500	2–3
Selby	200	120	640,000	700	1–5
Deep glacial	160	225	2,500,000	1,000	3–4
Clay:					
Lower Vermillion-Missouri	300	170	5,000,000	2,000	1–5
Wakonda	70	190		2,000	3–5
Charles Mix, Douglas:					
Choteau	327	90	2,200,000	1,500	3–5
Corsica, Geddes, Greenwood, Delmont, and Tower	216	145	1,300,000	1,000	1–4
Edmunds:					
Grand	170	116	1,100,000	500	3–4
Bowdle	59	50	200,000	200	1–3
Elm	63	70	160,000	300	2–5
Faulk:					
Grand	120	138	800,000	1,000	3–4
Onake	30	95	100,000	500	4
Elm	40	77	240,000	300	2–5
Marshall:					
James	220	129	1,500,000	1,000	2–3
Veblen	24	69	154,000	1,000	2–4
Coteau-lakes	50	77	160,000	1,000	1–4
McPherson:					
Grand	70	175	500,000	1,000	3
Hillsview	80	40	300,000	200	3
Twin Lakes	30	40	100,000	200	3
Spring Creek	160	85	500,000	50	2–3
Selby	47	30	200,000	100	2–3
Minnehaha: Big Sioux	33	50	194,000	1,500	2–3
Minnehaha, Lake: Skunk Creek-Lake Madison	71	114	167,000	500	1–4
Sanborn:					
Warren	190	85	1,200,000	1,500	1–5
Floyd	180	83	1,000,000	1,500	3–5

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[1] Estimated maximum well yield: Maximum expected yield of a properly constructed well. Salinity of water index—1 to 5 indicate the following values of specific conductance in micromhos per centimeter at 25° C: 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. Salinity hazard, often expressed in terms of specific conductance, is an important consideration for irrigation water. The U.S. Salinity Laboratory staff (1954) classifies the salinity hazard of irrigation waters, in terms of specific conductance, as follows: less than 250 micromhos, low; 250 to 750 micromhos, medium; 750 to 2,250 micromhos, high; and greater than 2,250 micromhos, very high. However, the satisfactory use of a particular water for irrigation depends on many factors other than water quality, such as soil characteristics, drainage, irrigation practices, and crops grown.

Ground Water In Bedrock Aquifers

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 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 rocks crop out in the core of the Black Hills in the western and southwestern parts of the State, in small areas in the northeastern and southeastern parts of the State.

Table 37 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 37.—PRINCIPAL BEDROCK AQUIFERS[1]

Aquifer	Geologic age	Estimated extent (square miles)	Maximum thickness (feet)	Estimated potential as aquifer	State of development	Salinity of water index
TERTIARY						
Ogallala Formation	Pliocene	3,000	300	3	1	1–2
Arikaree Group	Miocene	5,000	600	3	1	1–2
White River Group	Oligocene	(2)	600	0–1	0–1	1–3
Fort Union Group	Paleocene	3,000	1,000	2	2	2–5
MESOZOIC						
Hell Creek Formation	Late Cretaceous	9,000	400	3	3	2–5
Fox Hills Formation	do	13,000	400	3	3	1–5
Niobrara Formation and Codell Sandstone Member of Carlile Shale.	do	50,000+	180	3	4	3–5
Greenhorn Limestone	do	50,000+	360	1	3–4	4–5
Dakota Sandstone	Late and Early Cretaceous	50,000+	460	5	4	3–5
Inyan Kara Group	Early Cretaceous	50,000	700	3	1–2	3–5
Sundance Formation	Late Jurassic	49,000	740	3	1	3–5
PALEOZOIC						
Minnelusa Formation	Permian and Pennsylvanian	48,000	1,400	4	1	1–5
Madison Group	Mississippian	39,000	1,850	5	0–1	1–5
Red River Formation	Late Ordovician	36,000	580	5	0	3–5
Winnipeg Formation	Middle Ordovician	(2)	180	0–1	0	3–5
Deadwood Formation	Early Ordovician and Late Cambrian.	30,000	600	4	0–1	2–5

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[1] Estimated potential as aquifer: 0—almost no potential; 5—high potential. State of development: 0—virtually undeveloped aquifer; 1 to 3—increasingly greater withdrawal; 4—withdrawal about equal to the amount of water an aquifer can supply without further decline in rate of yield; 5—withdrawal in excess of estimated current replenishment.

Salinity of water index—1 to 5 indicate the following concentrations of dissolved solids in milligrams per litre: 1 equals 0 to 500; 2 equals 500 to 1,000; 3 equals 1,000 to 2,000; 4 equals 2,000 to 3,000; 5 equals 3,000 or more. Industrial tolerances for dissolved solids differ widely, but few industrial processes will permit more than 1,000 mg/1. Much natural water contains dissolved solids in concentrations exceeding 1,000 mg/1. Such water is classed as saline. The Geological Survey classifies the degree of salinity of these more mineralized bodies of water as follows (Swenson and Baldwin, 1965): less than 1,000 mg/1, nonsaline; 1,000 to 3,000 mg/1, slightly saline; 3,000 to 10,000 mg/1, moderately saline; 10,000 to 35,000 mg/1, very saline; more than 35,000, brine.

[2] Unknown.

Tertiary rocks

Ogallala Formation and Arikaree Group

The Pliocene Ogallala Formation has a maximum thickness of 300 feet and consists of light-colored silt, sand, and gravel. The Arikaree Group of Miocene age is composed of claystone, siltstone, and soft, buff to light-gray, fine-grained sandstone which is generally poorly-bedded, but locally contains lenticular beds of nodular sandy concretions. The Arikaree has a maximum thickness of about 600 feet. The Ogallala and Arikaree underlie about 3,000 and 5,000 square miles, respectively, in the High Plains area south of the White River shown on figure 1 as the area of Pliocene and Miocene rocks. The Ogallala and Arikaree are only moderately permeable, and hence, wells that are intended for irrigation use must penetrate 150 to 200 feet of saturated rocks to obtain enough water. Stock and domestic wells, on the other hand, generally contain an adequate amount of water where they penetrate 15 to 30 feet of saturated beds. Water from the Ogallala and Arikaree is of good enough quality for both irrigation and domestic use.

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 claystone, channel-filling sandstone, and lenses of limestone. The Chadron is as much as 150 feet thick and the Brule is as much as 450 feet thick. Both the Chadron and Brule yield small amounts of good water to shallow wells and at a few springs in deeply incised valleys of the White River Badlands, in southwestern South Dakota. Because all of the water obtained from the Chadron and Brule originates as local precipitation, the amount of water available in the formations is limited by the scanty amount of rainfall in the outcrop area. The areas in which these Oligocene rocks are at or near the surface is shown on Figure 1, and they also are present beneath the Pliocene and Miocene strata.

Fort Union Group

Three formations make up the Paleocene Fort Union Group in South Dakota. The basal Ludlow Formation has a maximum thickness of 350 feet and is composed of gray claystone, sandstone, and thin beds of lignite. Overlying the Ludlow is the Cannonball Formation, which consists of marine green shale and yellow sandstone; it has a maximum thickness of about 225 feet. The topmost or Tongue River Formation consists of light-colored clay, sand, and sandstone; locally it contains coal beds, and has a maximum thickness of about 420 feet. The Fort Union has moderate potential as a source of ground water, and is only partially developed. The city of Lemmon obtains part of its water suppply from two wells that tap the Fort Union. The Fort Union also supplies water for farms and ranches in parts of northern Perkins, Harding, and Corson Counties; the water is saline, has a high sodium sulfate content, and is barely potable.

The areal extent of these Paleocene rocks is shown on figure 1.

Mesozoic rocks

Hell Creek Formation

The Hell Creek Formation is the youngest Cretaceous formation in South Dakota, and overlies the Fox Hills Formation in about 8,700 square miles of the northwestern part of the State. The Hell Creek is composed of as much as 400 feet of alternating layers of somber-colored, soft, brown shale, gray sandstone, and sand, gravel, and clay layers. The lower part of 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 to moderate amounts of good quality to highly mineralized water to farms and ranches, west of the Missouri River in Corson, Harding, Perkins, and Ziebach Counties, and could support a small increase in withdrawals.

The areal extent of the Hell Creek Formation is shown on figure 33.

Fox Hills Formation

The Fox Hills Formation of Late Cretaceous age crops out north, northeast, and east of the Black Hills. It consists of grayish-white to yellow sandstone and sandy shale and has a maximum thickness of about 400 feet. The Fox Hills yields small to moderate quantities of fresh to saline water to properly constructed wells. Although it has small potential as a source of water, the Fox Hills could support an increase in withdrawals. The formation is the source of water for many farm and ranch wells and furnishes all or part of the municipal supplies for the cities of Bison, Timber Lake, and Lemmon.

Figure 33 shows the areal extent of the Fox Hills Formation.

Niobrara Formation and Carlile Shale

The Niobrara Formation and the underlying Carlile Shale of Late Cretaceous age crop out around the Black Hills and locally in southeastern South Dakota. The Niobrara also crops out along the Missouri River near Fort Thompson.

The Niobrara Formation is a chalky shale ranging in thickness from 160 feet in eastern South Dakota to about 220 feet in the western part of the State. The Carlile Shale consists of as much as 550 feet of shale which ranges from dark-gray at the bottom to light-gray at the top. It contains many large concretions in sandy layers. In the eastern part of South Dakota, 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 and Codell probably form a single aquifer as much as 180 feet thick, in eastern South Dakota. Water from this aquifer generally is soft and saline. The aquifer is exploited for livestock and domestic uses in central South Dakota and in the southern James River basin.

Greenhorn Limestone

The Greenhorn Limestone of Late Cretaceous age underlies all of South Dakota, except where older rocks crop out in the Black Hills and in the northeastern and southeastern parts of the State. In eastern South Dakota, the Greenhorn generally is 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

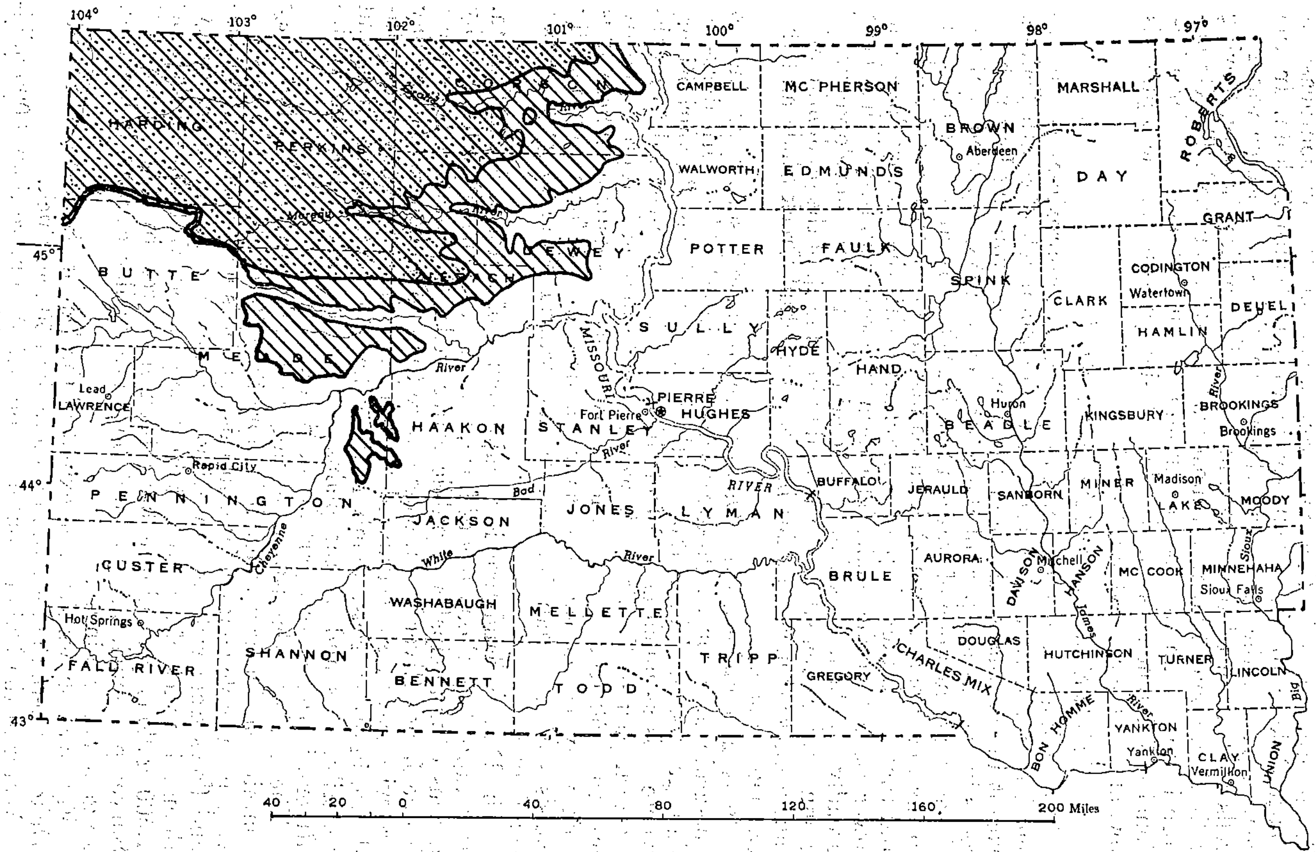

Figure 33.—Areal extent of the Hell Creek Formation (dots) and of the Fox Hills Formation (hachures).

feet of slabby, impure limestone at the top of the formation. The Greenhorn ranges in thickness from about 30 feet in southeastern South Dakota to about 360 feet in western South Dakota. In the eastern part of the State, the Greenhorn yields soft, saline water to wells that are used for stock and domestic supplies. Locally, flowing wells yield about 5 gpm, but most wells must be pumped. The Greenhorn is not commonly used as an aquifer, and its potential for additional development is small. The artesian pressure in the aquifer is low, and has decreased since 1890.

Dakota Sandstone and Newcastle Sandstone

The Dakota Sandstone and sandy strata of approximately equivalent Early and Late Cretaceous age underlie much of South Dakota except in the Black Hills and the areas of outcropping Precambrian rocks in the eastern part of the State. Gries (1958) reported that the Newcastle Sandstone of western South Dakota is laterally equivalent to the lower part of the Dakota Sandstone of eastern South Dakota and that the Dakota is partly correlative with the Mowry Shale and lower Belle Fourche Shale. The term "Dakota Sandstone" has been broadly applied, especially in conjunction with development of ground water where it has been used to include all of the predominantly sandstone sequence that lies between the Skull Creek Shale and the Graneros Shale.

Beds that make up the Dakota are commonly soft, very fine- to fine-grained, porous, light-gray sandstone interbedded with dark- to light-gray shale. The Dakota is thickest east of the Missouri River, where it is as much as 460 feet thick. In the north-central to northwestern part of the State, however, the formation is represented by less than 50 feet of silty and sandy shale or siltstone. Where it is commonly called the Newcastle Sandstone, the formation usually consists of less than 100 feet of fine-grained white to gray or tan sandstone.

The Dakota Sandstone is a major source of water in South Dakota. It is tapped by thousands of farm, ranch, and domestic wells, and by dozens of municipal and public water wells. Exploitation is greatest in the James River basin, where more than 16 million gallons per day are withdrawn. An estimated 24 million gallons per day are withdrawn in other areas, mainly in the valleys of the Missouri River and its tributaries and on the plains between the Cheyenne and White Rivers, in the central part of the State.

The Dakota Sandstone is not uniformly permeable, but may contain, particularly where it is more than 50 feet thick, two to seven very permeable zones. Water in this aquifer is under artesian pressure and flows from wells in the Missouri valley and in the James valley, though in much of the State it must be pumped. Well flows as large as 1,500 gallons per minute have been measured by U.S. Geological Survey personnel, but most well flows are smaller, commonly less than 15 gallons per minute.

Figure 34 shows the areal extent of the Dakota Sandstone in South Dakota, where the formation is more than 50 feet thick.

Water in the Dakota contains from 1,700 to more than 8,000 milligrams per litre (mg/l) dissolved solids, and laterally and vertically in the formation, the water varies in the composition of the predominant

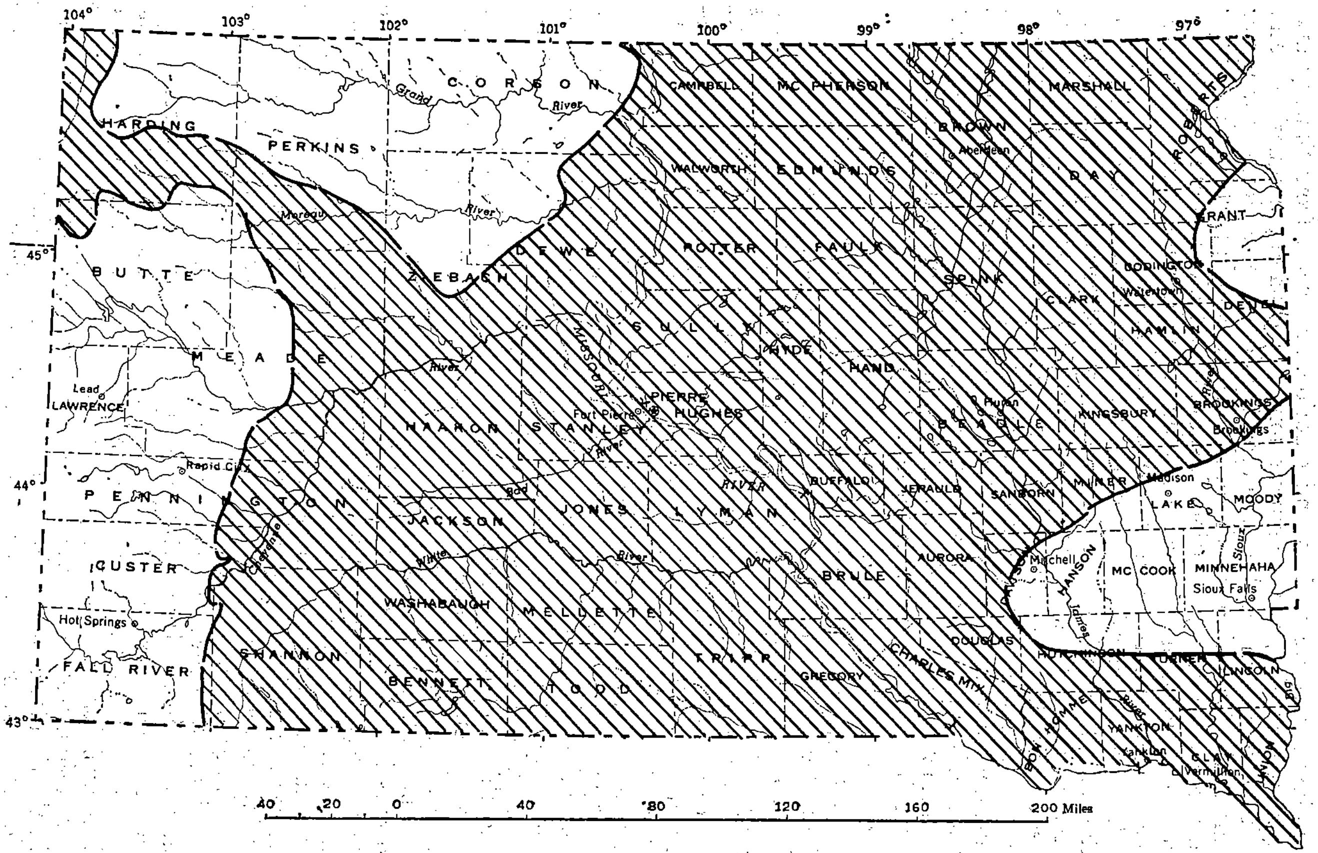

FIGURE 34.—Areal extent (hachures) of Dakota sandstone where it is more than 50 feet thick and is an aquifer.

ions. Within the Williston Basin, where the salinity is highest, the dominant ions are sodium and chloride. Eastward from Stanley and Lyman Counties, the dominant ions are calcium, magnesium, and sulfate, though in much of the area the dominant cation in the upper part of the formation is sodium. Elsewhere, and in parts of the aquifer in the areas already mentioned, sodium and bicarbonate may be the dominant ions, or mixtures of sodium, magnesium, and calcium, or bicarbonate, chloride and sulfate are dominant.

Though the artesian head in the Dakota has dropped drastically in the last 80 years (resulting in a more than 60 percent reduction of the area where wells will flow) the formation can continue to support heavy withdrawals. Unpublished information of the U.S. Geological Survey indicates that the rate of withdrawal may be decreasing to a sustainable long-term yield. Because much of the well flow from the Dakota is unused, and therefore wasted, controlled reduction of natural well flows to the needed amounts could easily more than double the quantity of water available for use.

Inyan Kara Group

In South Dakota, the Inyan Kara Group comprises the Lakota and Fall River Formations of Early Cretaceous age. 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-grained, locally conglomeratic sandstone, which has a maximum thickness of 485 feet. It is a permeable, productive aquifer and yields saline water, except in and near the outcrop area of the Black Hills, that generally flows from wells. The source is moderately used and the formation could sustain more withdrawal, 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 Minnewaste Limestone Member and the Fuson Member. These were formerly recognized as separate formations. They are not aquifers.

The Fall River Formation overlies the Lakota Formation and occurs in a larger area. It consists of as much as 150 feet of fine- to medium-grained, massive, white to buff sandstone containing thin layers of silt and clay. The Fall River seldom is differentiated from the Lakota Formation in logs of drill holes. The sandstone of the Fall River Formation and the Newcastle Sandstone are referred to as the "Dakota Sandstone" in older reports on western South Dakota and adjoining areas.

Figure 35 shows the areal extent of the Inyan Kara Group. The aquifer(s) in the Inyan Kara are commonly tapped for livestock and domestic supplies near the Black Hills, across the central part of the State between the Cheyenne and White Rivers, and east of the Missouri River. Commonly, particularly in the eastern part of the formation, wells are screened not only in the Inyan Kara, but also in the Sundance and Minnelusa. The Inyan Kara Group is an underdeveloped source of water for stock and domestic use. Water quality ranges from good (less than 1,000 mg/l dissolved solids) near the Black Hills, to saline (1,000 to 3,000 mg/l) in the central and eastern part of the State, to very saline (more than 10,000 mg/l) in the northern part of the State.

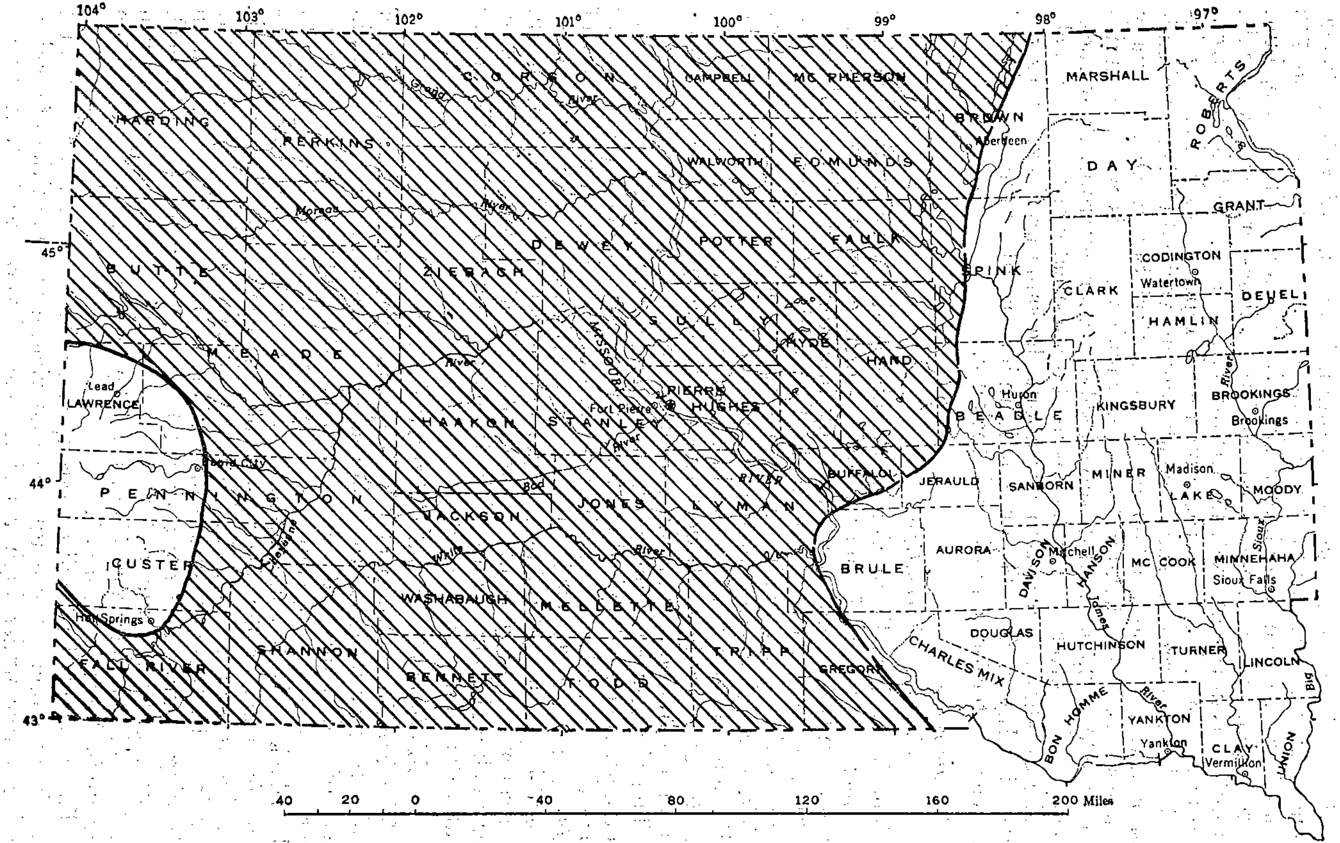

FIGURE 35.—Areal extent (hachures) of Inyan Kara Group.

Sundance Formation

The Sundance Formation of Late Jurassic age underlies about 43,000 square miles in western South Dakota. It consists of as much as 740 feet of gray, green, and brown shale interbedded with white, buff, or red, glauconitic, fine-grained sandstone, limestone, and red shale. At outcrops in the Black Hills, the formation ranges in thickness from 200 to 300 feet. Water in the Sundance is reported to be highly mineralized. The largest dissolved-solids content verified (1974) by chemical analysis is about 6,000 mg/l. In central South Dakota many ranches obtain stockwater from the Sundance; this water contains from 2,000 to 3,500 mg/l dissolved solids. Near outcrops, these rocks locally yield better water which is used domestically and for livestock.

The Sundance Formation has about the same areal extent as the overlying Inyan Kara Group, and is an important and underexploited source of water for domestic and stock use.

Paleozoic rocks

Minnelusa Formation

The Minnelusa Formation of Permian and Pennsylvanian age is a complex sequence of marine rocks which commonly contains five major sandstone units separated by limestone, dolomite, shale, and anhydrite beds. At outcrops in the Black Hills, the formation is predominantly red and white calcareous sandstone and is 300 to 850 feet thick. Throughout the northern and central part of South Dakota the Minnelusa is 400 to 800 feet thick; the maximum thickness is about 1,400 feet, near the southwestern corner of the State. Figure 36 shows the areal extent of the Minnelusa Formation.

The Minnelusa is a major water-bearing unit. Several wells near the northern Black Hills yield more than 1,000 gpm of good quality water for irrigation. A well near Sturgis, for example, had an initial flow of 4,000 gpm at 20°C (68°F); the flow was reduced to about 750 gpm at closed-in pressure of 160 pounds per square inch (psi). Many ranches in central and western South Dakota obtain water from the Minnelusa for stock and domestic uses. The formation could produce much more water than it does at present.

Madison Group and Pahasapa Limestone

The Madison Group of Mississippian age is a thick sequence of white to gray to light brown limestones and dolomites which contain beds of halite, anhydrite, and shale. The Pahasapa, which is the lower part of the Madison, contains many caverns and solution cavities. In the Black Hills, the outcropping Madison (Pahasapa) ranges in thickness from 250 to 600 feet; south of the Black Hills, it thins and is missing in southeastern Fall River County. North and east of the Black Hills, these rocks are more than 1,300 feet thick in northern Harding County and more than 800 feet thick in northern Ziebach County. They are thinner further east and pinch out between Brown and Stanley or Gregory Counties. The areal extent of the Madison Group is shown in figure 37.

The rocks of the Madison Group comprise a major hydrologic unit and include one or more aquifers that yield large quantities of good to saline water under high artesian head. Several wells tapping the

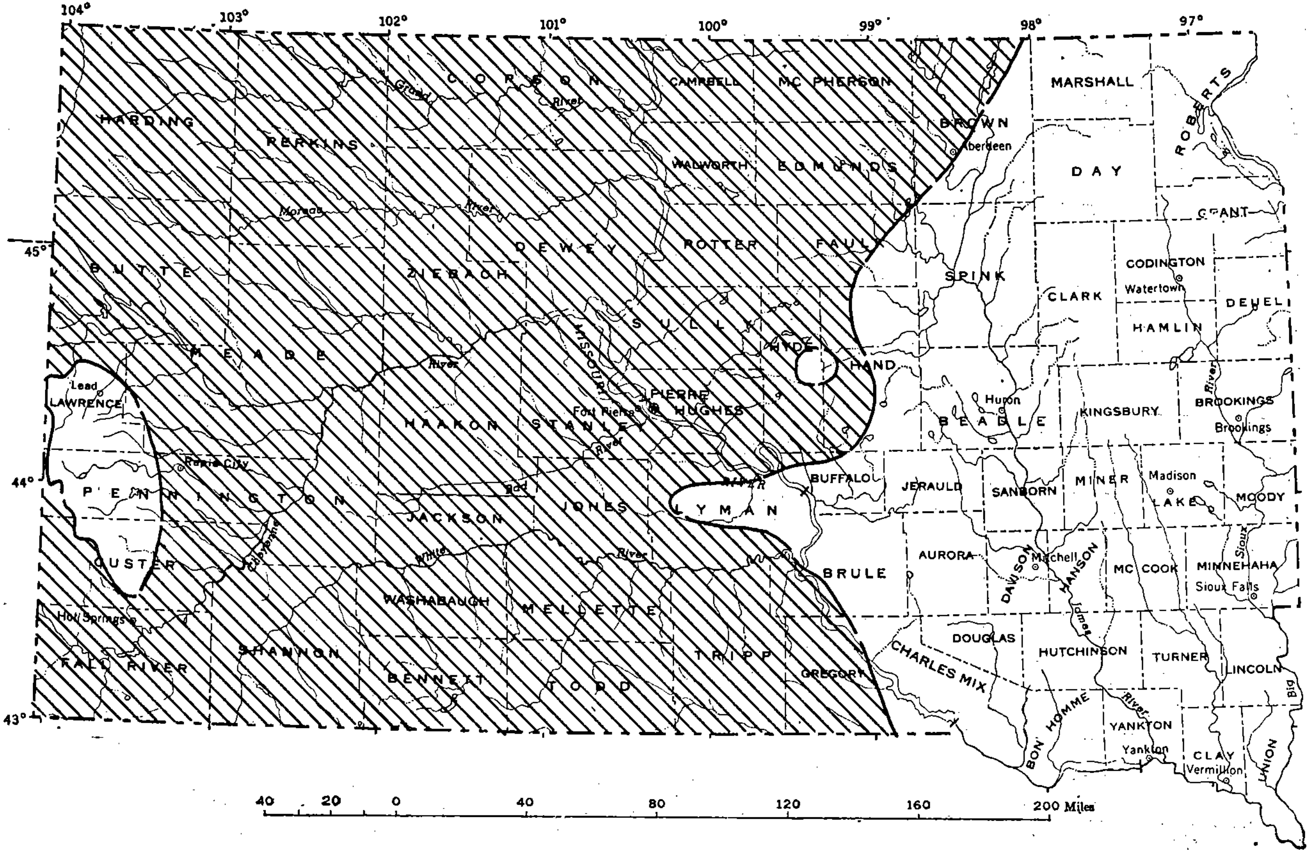

FIGURE 36.—Areal extent (hachures) of the Minnelusa Formation.

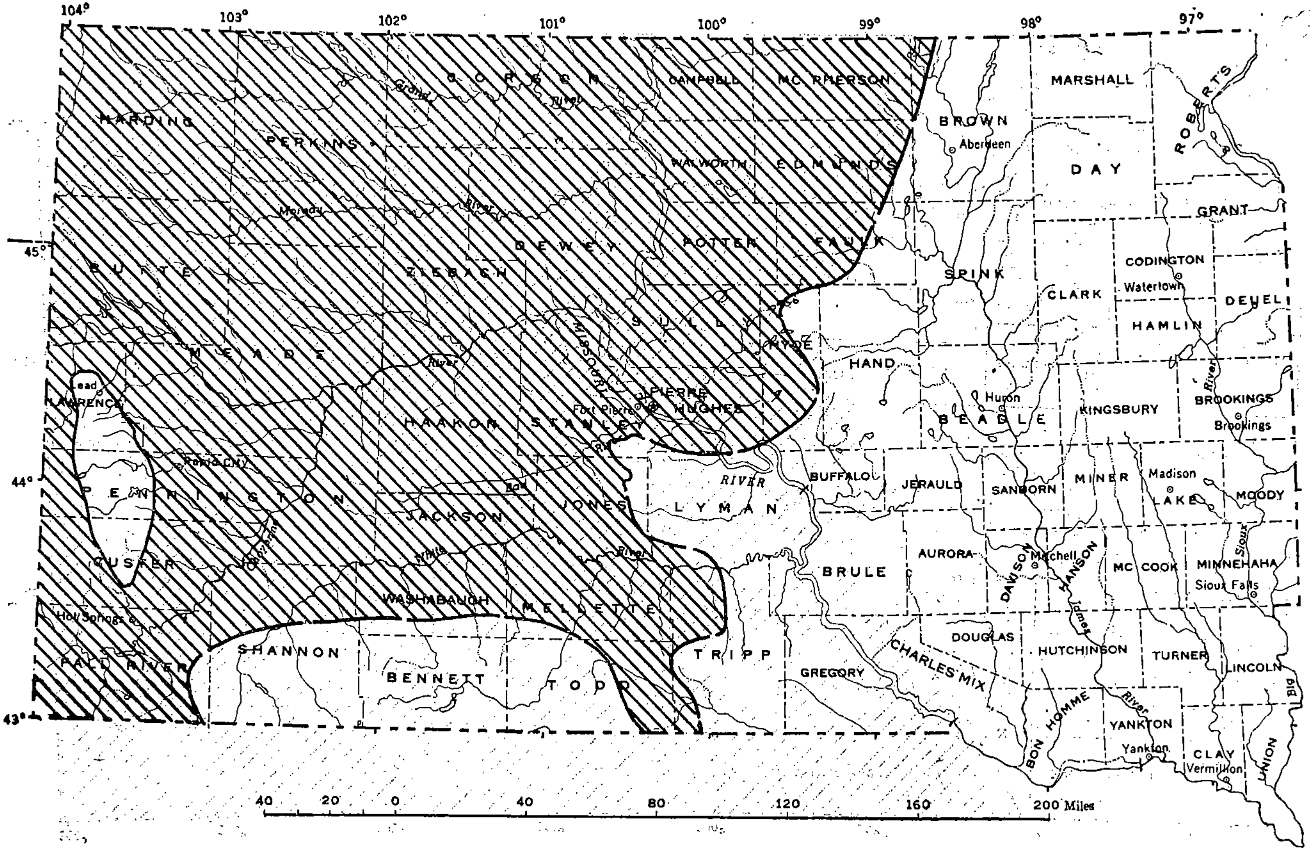

FIGURE 37.—A real extent (hachures) of the Madison Group.

Madison are more than 4,000 feet deep and flow more than 100 gallons per minute. Such wells produce water for ranches and the municipalities of Philip, Midland, Eagle Butte, and Dupree. Water temperatures as high as 71° C (160° F) have been measured in municipal wells and temperatures as high as 83° C (181° F) have been reported from oil wells.

The Madison Group has great potential for development. Estimated water storage is about 200 million acre-feet and may be larger. The dissolved-solids content of the water ranges from less than 500 mg/l to more than 120,000 mg/l.

The aquifer(s) in the Madison Group seem to be the major source of the water that recharges the overlying bedrock aquifers in eastern South Dakota. The water migrates by leakage upward into the Minnelusa Formation and along the Precambrian surface near the Madison pinchout. Most of the recharge is probably within 50 miles of the eastern limit of the Madison.

Rocks of Post-Red River Ordovician Age and of Silurian and Devonian Age

Strata of Devonian and Silurian age and latest Ordovician age underlie northwestern and north-central South Dakota. Beds of Devonian age have the greatest extent, as they have been recognized in Brown, Stanley, and Tripp Counties on the east and may extend as far south as Nebraska. Of these strata only the youngest formation, the Englewood Formation of Devonian (?) and Mississippian age, crops out (in the Black Hills).

These beds are predominantly limestone and dolomite, but include sandstone, red, green, and black shale, and evaporite (rock salt, gypsum, and anhydrite). The limestone, dolomite, and sandstone beds are water-bearing but their potential for development may be low. Water from these formations is reported from oil exploration tests to contain from 2,500 to more than 100,000 mg/l of dissolved solids. Water temperatures as high as 106° C (223° F) have been reported.

Red River Formation and Whitewood Dolomite

The Late Ordovician Red River Formation underlies about 35,000 square miles in the western, northwestern, and north-central parts of the State (figure 38). Where these rocks crop out, in a narrow band around the northern end of the Black Hills, they are called the Whitewood Dolomite. The Red River thickens eastward and northward from the Black Hills to a maximum thickness of more than 550 feet in northern Perkins and Corson Counties. The formation consists mostly of pink to buff, light-brown, and light-gray dolomite and dolomitic limestone. It probably contains more than 70 million acre-feet of water under high artesian pressure. Water temperatures as high as 121° C (250° F) have been reported. The Red River Formation is apparently not being used at present as a source of water in South Dakota.

Winnipeg Formation

Shale and sandstone of the Winnipeg Formation of Middle Ordovician age overlie the Deadwood Formation in the northern Black Hills and north and east of the Black Hills. The formation has a maximum thickness of about 180 feet in South Dakota (Sandberg, 1962). Near the North Dakota border, the sandstone in the Winnipeg

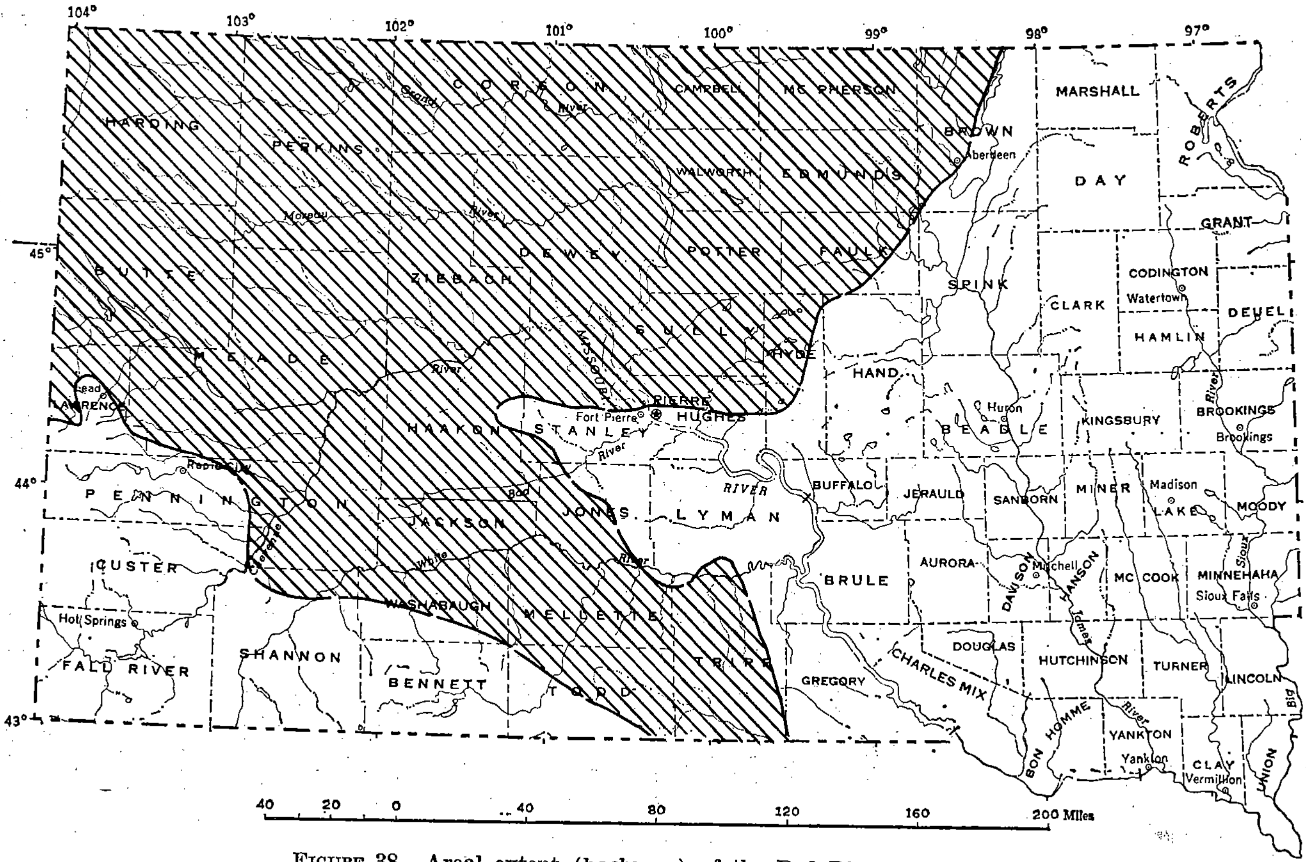

FIGURE 38.—Areal extent (hachures) of the Red River Formation.

reportedly yields saline water under artesian pressure. The water in the formation is not used and the potential for development is unknown.

Deadwood Formation

The Deadwood Formation of Early Ordovician and Late Cambrian age is soft, thin-bedded, quartz sandstone, siltstone, and flaggy limestone. Commonly conglomeratic, the formation also contains beds and partings of glauconitic shale. At outcrops around the Black Hills the Deadwood is as much as 450 feet thick; in the subsurface north and east of the Hills, the formation is as much as 600 feet thick. The Deadwood Formation probably extends as far south as northern Washabaugh County and it also underlies the area north of a line extending from north-central Haakon County to northwestern Brown County. In the Black Hills area, an aquifer(s) in the Deadwood yields small to moderate amounts of fresh to saline water for stock and domestic supplies; this aquifer(s) can support a modest increase in withdrawal. Elsewhere in the State, the Deadwood is untapped and its potential for development is unknown; the formation probably will produce moderate amounts of saline to very saline water. Total storage of water in the Deadwood Formation probably exceeds 50 million acre-feet. Water temperatures higher than 100°C (212°F) have been reported.

Precambrian rocks

The Sioux Quartzite underlies most of southeastern South Dakota; it is covered by glacial drift in a large area and crops out in smaller areas in Hanson, McCook, Minnehaha, and Turner Counties. The formation, which is as much as 5,000 feet thick, is a massive orthoquartzite interbedded with thin shale and a few units of poorly cemented quartz sand. Locally it yields small quantities of water from fractures or from porous zones.

Precambrian rocks consisting of schist, quartzite, slate, marble, pegmatite, granite, and amphibolite crop out in an area of about 1,500 square miles in the Black Hills, in Lawrence, Meade, Pennington, and Custer Counties. Each year, these rocks discharge tens of thousands of acre-feet of good quality water to streams, through springs and seeps emerging from rock fractures. Small quantities of water can be obtained locally in the Black Hills from wells penetrating these rocks.

Elsewhere in the State, the Precambrian rocks are covered by sedimentary strata as much as 10,000 feet thick. The basement rocks include a variety of igneous and metamorphic types and are non-water-bearing except where fractured.

Conglomeratic beds—locally containing cobbles—reportedly overlie the Precambrian rocks. Commonly known as "quartzite wash", "granite wash", or "wash", probably few of these beds are really Precambrian in age but resulted from the erosion of Precambrian rocks during Paleozoic time. This "basal wash" is generally very permeable and where sufficiently thick, can be a major source of water. Maximum known thickness is about 50 feet. Recharge of these rocks is by leakage from other aquifers where they are in hydraulic contact—commonly where the other aquifers pinch out; thus, the "wash" acts as a conduit for water moving along the Precambrian surface.

Chemical quality

Ground water is used for about 94 percent of the municipal supplies in South Dakota. Because public supplies are widely distributed throughout the State and because they generally obtain water from the most easily developed aquifers in their respective areas, data on the chemical quality of the water for public supplies provide good information on the general quality of readily available ground water throughout the State.

Chemical analyses of ground water for about 262 separate municipal supplies were published recently by the South Dakota Department of Health (1971). Data for selected chemical constituents from these analyses are given in table 38.

TABLE 38.—SELECTED DATA ON CHEMICAL ANALYSES OF MUNICIPAL GROUND-WATER SUPPLIES

[Data from South Dakota Department of Health, 1971]

Constituents	Concentration	Percentage of supplies exceeding stated concentration	Constituents	Concentration	Percentage of supplies exceeding stated concentration
	mg/l		Fluoride	0.8	69
Dissolved solids	500	87		1.5	32
	1,000	67		3.0	11
	1,500	49		µg/l	
	2,000	29	Iron	300	66
Hardness as $CaCO_3$	60	88		1,000	40
	120	83		3,000	10
	180	78	Manganese	100	49
	300	64		300	31
	600	33		1,000	10
				3,000	2

Table 38 shows that, in general, the water for municipal supplies has a high dissolved-solids content (consisting mainly of sulfate and either calcium or sodium). The water of most of the supplies is very hard—more than 180 mg/l as $CaCO_3$. Both iron and manganese are present in troublesome concentrations, more than 300 micrograms per litre (µg/l) and 100 µg/l, respectively, in about half of the supplies. Concentrations of fluoride are high in many of the supplies.

The general chemical quality of water from most of the major aquifers is shown in table 39. Because of the great areal variation of water quality in individual aquifers at least two analyses are given for each aquifer.

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 in quality than the water from any of the other major aquifers. Quality variations in individual aquifers are caused by local differences in factors such as rate of recharge, chemical and physical properties of the materials that compose the aquifer, and the nature of the material through which water infiltrates to the aquifer.

TABLE 39.—TYPICAL ANALYSES OF WATER FROM PRINCIPAL AQUIFERS

Location (Twp./Ra./Sec.)	County	Silica (SiO_2) mg/l	Iron (Fe) µg/l	Manganese (Mn) µg/l	Calcium (Ca) mg/l	Magnesium (Mg) mg/l	Sodium (Na) mg/l	Potassium (K) mg/l	Bicarbonate (HCO_3) mg/l	Sulfate (SO_4) mg/l	Chloride (Cl) mg/l
GLACIAL DRIFT											
94N52W 4AABA	Clay		60	2,000	100.0	39.0	13.0	5.0	280	190.0	10.0
110N59W26CDCD1	Beadle	29.0	10	10	63.0	39.0	45.0	2.7	381	93.0	4.2
110N63W 6ADDC	do	31.0	80	150	86.0	27.0	428.0	14.0	440	665.0	160.0
113N59W35BDDC	do	29.0	30	10	488.0	202.0	344.0	23.0	644	1,640.0	208.0
OGALLALA FORMATION AND ARIKAREE GROUP											
35N41W 4BCC	Shannon	61.0	120	0	124.0	58.0	17.0	12.0	205	201.0	109.0
36N43W32A	do	61.0	200	0	35.0	6.4	5.1	5.9	138	8.8	2.4
38N35W31DD	Bennett			0	50.0	13.0	30.0			26.0	7.0
WHITE RIVER GROUP											
41N45W18DD	Shannon	59.0	10	10	20.0	9.2	63.0	8.8	242	19.0	6.3
41N34W18DC	Washabaugh	47.0	60	10	7.5	.1	158.0	5.9	378	26.0	20.0
FORT UNION GROUP											
Lemmon, S. Dak	Perkins		500	0	17.0	5.0	874.0	7.8	802	1,223.0	9.0
21N17E14BBDB	Corson	11.0	50	80	120.0	44.0	790.0	7.6	677	1,400.0	98.0
21N19E 6DAAA	do	14.0	2,500		72.0	38.0	120.0	6.2	403	250.0	4.7
HELL CREEK FORMATION											
18N17E13DA	Corson	11.0	30		8.2	1.5	380.0	2.5	826	200.0	4.9
21N19E18DDDA	do	14.0	100		4.9	1.7	94.0	1.4	211	42.0	1.0
23N22E28AD	do	13.0	960	0	14.0	2.9	668.0	1.6	588	988.0	4.2
17N19E29CDDD	Ziebach	9.9	50	20	8.4	.5	490.0	1.7	603	630.0	15.0
FOX HILLS FORMATION											
10N16E 3DB	Meade	9.6	740	470	130.0	27.0	1,100.0	8.0	610	2,000.0	180.0
15N18E 4CCBB	Ziebach	13.0	30		62.0	6.8	34.0	1.7	267	26.0	11.0
15N20E30CBDD	do	9.4	40		13.0	1.3	730.0	2.0	523	83.0	750.0
NIOBRARA FORMATION AND CODELL SANDSTONE (member of Carlile Shale)											
105N59W23BCBB2	Sanborn	26.0	1,300	1,700	202.0	56.0	315.0	21.0	212	1,100.0	122.0
106N62W15ADB1	do	9.3	50	20	11.0	2.6	565.0	8.1	723	374.0	219.0
112N60W30CCBB	Beadle	7.3	3,800	60	23.0	5.5	816.0	7.4	482	1.8	1,060.0

TABLE 39.—TYPICAL ANALYSES OF WATER FROM PRINCIPAL AQUIFERS—Continued

Location (Twp./Ra./Sec.)	County	Silica (SiO_2) mg/l	Iron (Fe) µg/l	Manganese (Mn) µg/l	Calcium (Ca) mg/l	Magnesium (Mg) mg/l	Sodium (Na) mg/l	Potassium (K) mg/l	Bicarbonate (HCO_3) mg/l	Sulfate (SO_4) mg/l	Chloride (Cl) mg/l
GREENHORN LIMESTONE											
107N61W28CDC2	Sanborn	7.7	940	0	9.3	1.2	699.0	6.3	713	817.0	104.0
110N62W 9BBAD3	Beadle	3.7	20	120	20.0	14.0	805.0	18.0	364	1,120.0	288.0
DAKOTA SANDSTONE											
6N18E31ABDC1	Haakon	24.0	70	0	2.6	.4	820.0	3.2	1,730	7.3	250.0
8N22E32CCBB	Ziebach	19.0	30	10	8.0	2.7	1,800.0	7.5	1,500	19.0	1,900.0
94N64E26DBA	Charles Mix	9.6	3,200	180	210.0	43.0	90.0	22.0	190	660.0	51.0
109N64E33ACC1	Beadle	13.0	990	30	290.0	72.0	242.0	21.0	166	1,240.0	76.0
123N61E33BBBD1	Brown	8.2	680	60	14.0	3.3	660.0	10.0	233	1,060.0	170.0
INYAN KARA GROUP											
6N 5E21DABA1	Meade	11.0	10	20	172.0	38.0	5.8	2.6	247	374.0	.1
2S22E28ABD1	Jackson	25.0	60	150	57.0	11.0	500.0	12.0	220	990.0	68.0
10N19E13DDB	Ziebach	24.0	280	20	7.3	1.6	1,400.0	5.8	1,430	1,100.0	570.0
127N73W35DCBB2	McPherson	12.0	2,800	120	340.0	100.0	140.0	25.0	184	1,300.0	63.0
SUNDANCE FORMATION											
12N24E27BCCB	Ziebach	22.0	6,800	100	700.0	130.0	1,700.0	6.6	268	2,600.0	2,300.0
7N28E18AC	Stanley	16.0	280	2,570	178.0	46.0	330.0	37.0	222	1,120.0	70.0
108N71W15DABB	Buffalo	14.0	1,000	100	408.0	102.0	69.0	19.0	244	1,220.0	89.0
126N67W17DAAD	McPherson	12.0	1,720	170	342.0	85.0	144.0	24.0	180	1,300.0	48.0

MINNELUSA FORMATION											
7N 1E32BBB1	Lawrence	11.0	50		80.0	31.0	2.5	2.1	250	119.0	.6
3S22E31BB	Jackson	23.0	1,300	20	11.0	1.1	660.0	10.0	838	638.0	73.0
14N29E36DBDD	Dewey	16.0	50	130	430.0	110.0	750.0	65.0	247	2,400.0	410.0
123N68W27BDBB1	Edmunds	11.0	2,100	130	340.0	88.0	120.0	23.0	177	1,200.0	48.0
MADISON GROUP											
2N 9E 7	Meade	20.0	120		97.0	31.0	[3] 7.4		205	205.0	2.0
42N26W34A	Mellette		350		268.0	24.0	35.0	10.0	168	630.0	2.5
12N24E17CBBD	Dewey	30.0	590	20	380.0	110.0	64.0	31.0	168	1,300.0	67.0
118N68W19BAAA	Faulk		20		345.0	87.0	155.0	23.0	156	1,350.0	550
RED RIVER FORMATION											
12N22E 8DB	Dewey				445.0	96.0	106.0		185	1,346.0	125.0
22N19E11CB	Corson				6,510 0	1,160.0	[3] 42,400.0		220	950.0	79,500.0
DEADWOOD FORMATION											
4S 2E 2	Custer		550	0	54.0	32.0	4.1	1.3	320	6.9	2.0
22N19E11CB	Corson				1,370.0	156.0	[3] 13,630.0		260	1,950.0	22,300.0
PRECAMBRIAN ROCKS											
3S 4E	Custer		840	300	49.0	18.0	[3] 19.0			63.0	18.0
1S 5E30	Pennington		0	100	48.0	15.0	20.0	5.0	184	58.0	19.0
106N56W 2	Miner		200	0	187.0	50.0	[3] 410.0		234	1,110.0	130.0

TABLE 39.—TYPICAL ANALYSES OF WATER FROM PRINCIPAL AQUIFERS—Continued

Location (Twp./Ra./Sec.)	County	Fluoride (F) mg/l	Nitrate (NO3) mg/l	Boron (B) µg/l	Dissolved solids (residue at 180° C) mg/l	Hardness as CaCO3 (Ca, Mg) mg/l	Noncarbonate hardness mg/l	Sodium absorption ratio (SAR)	Specific conductance (micromhos /cm at 25° C)	pH (units)	Temperature (° C)
GLACIAL DRIFT											
94N52W 4AABA	Clay	0.2	0.0		[1] 880	410			850		12.0
110N59W26CDCD1	Beadle	.4	4.0	170	452	319	7	1.1	741	7.7	
110N63W 6ADDC	do	.3	11	140	1,650	326	0	10.0	2,420	7.8	
113N59W35BDDC	do	.3	319	1,500	3,780	2,050	1,520	3.3	4,220	7.6	7.0
OGALLALA FORMATION AND ARIKAREE GROUP											
35N41W 4BCC	Shannon	.3	76	600	934	550	382	.3	1,140	7.3	13.0
36N43W32A	do	.3	4.7	40	207	114	1	.2	256	7.2	12.0
38N35V31DD	Bennett	.2	.1		[1] 340	172					
WHITE RIVER GROUP											
41N45W18DD	Shannon	.3	8.2	180	324	88	0	.3	444	7.6	
41N34W18DC	Wahsabaugh	.4	20	140	481	19	0	16.0	707	8.0	
FORT UNION GROUP											
Lemmon, S. Dak	Perkins	1.3	.0		2,561	62		48.0	3,571	8.2	
21N17E14BBDB	Corson	1.0	[2] 4.4	910	3,330	480	0	16.0	3,930	7.5	9.2
21N19E 6DAAA	do	1.1	[2] .0	300	803	340	6	2.8	1,100	7.1	9.0
HELL CREEK FORMATION											
18N17E13DA	Corson	1.3	[2] .15	1,500	1,070	27	0	32.0	1,610	8.1	9.5
21N19E18DDDA	do	1.0	[2] 2.6	160	314	19	0	9.3	453	7.5	9.0
23N22E28AD	do	.8	3.8	1,300	2,000	47	0	42.0	2,870	7.9	9.0
17N19E29CDDD	Ziebach	1.5	[2] .05	1,800	1,510	23	0	44.0	2,170	8.3	9.5
FOX HILLS FORMATION											
10N16E 3DB	Meade	0.2	[2] .02	1,800	3,700	440	0	23.0	4,760	7.6	
15N18E 4CCBB	Ziebach	.3	[2] .91	130	296	180	0	1.1	484	7.5	10.0
15N20E30CBDD	do	.7	[4] .04	3,000	1,930	38	0	52.0	3,130	7.8	

NIOBRARA FORMATION AND CODELL SANDSTONE MEMBER OF CARLILE SHALE											
105N59W23BCBB2	Sanborn	.5	.0	1,100	2,060	734	560	5.1	2,570	7.5	12.0
106N62W15ADB1	do	1.0	.0	3,800	1,560	38	0	40.0	2,450	7.9	10.0
112N60W30CCBB	Beadle	.8	.3	4,200	2,210	80	0	40.0	4,000	8.0	9.0
GREEN HORN LIMESTONE											
107N61W28CDC2	Sanborn	3.4	.3	6,200	2,060	28	0	57.0	3,000	7.8	12.0
110N62W 9BBAD3	Beadle	2.3	.1	4,720	2,440	105	0	34.0	3,480	8.2	----------
DAKOTA SANDSTONE											
6N18E31ABDC1	Haakon	6.0	[2].01	4,600	1,980	8	0	125.0	3,170	8.1	41.0
8N22E32CCBB	Ziebach	2.4	[2].05	6,600	[1]4,510	31	0	140.0	7,930	7.8	40.0
94N64E26DBA	Charles Mix	2.9	[2].00	710	1,260	710	550	1.5	1,650	7.4	19.0
109N64E33ACC1	Beadle	2.7	.5	510	2,140	1,020	880	3.3	2,510	8.0	17.8
123N61E33BBBD1	Brown	2.7	16.	2,250	2,120	48	0	42.0	3,060	7.4	----------
INYAN KARA GROUP											
6N 5E21DABA1	Meade	.3	.5	50	783	586	383	.1	1,020	7.1	11.0
2S22E28ABD1	Jackson	1.2	[2].01	490	1,780	190	9	16.0	2,480	7.6	50.0
10N19E13DDB	Ziebach	5.2	[2].87	31,000	[1]3,860	25	0	122.0	5,670	8.0	40.0
127N73W35DCBB2	McPherson	3.4	[2].00	330	2,800	1,300	1,100	1.7	2,510	6.7	27.0
SUNDANCE FORMATION											
12N24E27BCCB	Ziebach	3.4	[2].04	2,100	[1]7,620	2,300	2,100	15.0	10,500.0	6.8	40.0
7N28E18AC	Stanley	3.1	.1	630	2,020	630	448	5.7	2,590.0	7.8	36.0
108N71W15DABB	Buffalo	3.4	.0	160	2,240	1,440	1,240	.8	2,400.0	7.4	29.0
126N67W17DAAD	McPherson	3.3	.1	300	2,200	1,200	1,060	1.8	2,340.0	7.8	26.0
MINNELUSA FORMATION											
7N 1E32BBBB1	Lawrence	.4	.8	20	410	328	123	.1	605.0	7.4	14.0
3S22E31BB	Jackson	4.7	.1	780	1,870	32	0	51.0	2,730.0	8.0	----------
14N29E36DBDD	Dewey	3.2	[2].40	2,100	[1]4,320	1,500	1,300	8.4	5,310.0	6.7	31.5
123N68W27BDBB1	Edmunds	3.6	[2].00	380	[1]1,920	1,200	1,100	1.5	2,320.0	7.8	26.0
MADISON GROUP											
2N 9E/	Meade	.4	.6	----------	490	370	202	----------	684.0	7.0	49.0
42N26W34A	Mellette	----------	.0	----------	1,185	770	----------	.5	1,330.0	7.8	61.0
12N24E17CBBD	Dewey	3.8	[2].07	340	2,080	1,400	1,300	.7	2,440.0	7.2	55.5
118N68W19BAAA	Faulk	----------	.0	----------	[1]2,092	1,220	----------	----------	2,390.0	----------	----------

See footnotes at end of table.

TABLE 39.—TYPICAL ANALYSES OF WATER FROM PRINCIPAL AQUIFERS—Continued

Location (Twp./Ra./Sec.)	County	Fluoride (F) mg/l	Nitrate (NO_3) mg/l	Boron (B) μg/l	Dissolved solids (residue at 180° C) mg/l	Hardness as $CaCO_3$ (Ca, Mg) mg/l	Noncarbonate hardness mg/l	Sodium absorption ratio (SAR)	Specific conductance (micromhos /cm at 25° C)	pH (units)	Temperature (° C)
RED RIVER FORMATION											
12N22E 8DB	Dewey	3.0	.3	0	2,510	1,500			7.9		
22N19E11CB	Corson				130,740	21,000				6.8	
DEADWOOD FORMATION											
4S 2E 2	Custer	.1	.4		278	267			476.0	7.7	
22N19E11CB	Corson				39,670	4,050				6.6	
PRECAMBRIAN ROCKS											
3S 4E	Custer	.6	.0		205	196				6.8	
1S 5E30	Pennington	.3	1.5		295	182				7.2	
106N56W 2	Miner	3.0	2.0		[1]2,120	672				7.2	

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[1] Sum of dissolved constituents.

[2] Nitrate plus nitrite as nitrogen (NO_3+NO_2 as N).

[3] Sodium plus potassium (Na+K).

Development of ground water

Ground-Water Use

Because low rainfall supplied inadequate amounts of surface water for use, 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 number of water wells in the State today (1974) is unknown, but the rate of drilling of 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 increased steadily.

Ground water is one of South Dakota's most important natural resources. Data collected in 1970 indicate that most of the water used in the State for municipal, domestic, livestock, and industrial purposes, was obtained from wells. Of the 362 communities in the State that have public water supply systems, 342 depend primarily or completely upon ground water. Ground water thus furnishes the supply for 94 percent of the public water systems in the State. The total population served by the 362 community supply systems was nearly 410,000; ground water sources supplied 60 percent of this total or about 283,000 persons. The total amount of water used by the population served by municipal water systems was 59.5 million gallons per day (mgd), or an average of 145 gallons per day (gpd) per person.

Irrigation is an additional major ground-water use. Ground water supplied 14 percent—40 mgd or 45,000 acre-feet—of the irrigation water applied to crops in South Dakota in 1973.

More than 90 percent of rural domestic water is obtained from wells. According to figures from the U.S. Census of 1970, the population of South Dakota was approximately 666,000 of which about 240,000 are classified as rural dwellers. In rural homes with running water, the per capita use is estimated to be about 70 gpd, and in farm homes without running water, about 30 gpd, or an average of about 67 gpd. The farm domestic ground-water use based upon these assumptions is about 15 mgd. Livestock on South Dakota farms in 1970 consumed an additional 81 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; and (3) decline in artesian head.

Chemical Quality of Water

With the exception of water from the Fox Hills Formation in the northwestern part of the State and the Arikaree Group and Ogallala Formation 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 some 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 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 inhibits development of ground-water supplies 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 unknown for much of the area. 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 similar 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 550 feet, and in large areas, artesian pressure has dropped so low in some aquifers that 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 to 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 by more recent study to be invalid. 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 Support Ground-Water Development

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 and quality 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 three recent developments. The first is the imminence of new and more economical methods for desalinization of saline water; future developments hold great promise for an economical method of demineralizing the enormous supplies of saline water in the deeper aquifers underlying South Dakota. The second recent development is the rapid expansion in the exploitation of the extensive lignite deposits of Wyoming, Montana, and the Dakotas, and the accompanying construction of power, fuel conversion, and chemical plants to utilize the lignite. Mining and industrial facilities already planned (1974) will require an enormous quantity of water—far beyond the surface water supply available. Developers expect to tap major aquifers to supply much of the needed water. The third recent development, like the second, has gained attention recently because of the generally growing awareness of the importance of domestic energy sources. Water in some of the deeper aquifers is hot. Temperatures as high as 121°C (250°F) have been reported in northwestern South Dakota. The amount of energy stored in hot-water aquifers in the State, at temperatures above 38°C (100°F), has been estimated to exceed 6×10^{18} British thermal units (16×10^{14} kilowatt hours). Economic recovery of this energy probably is not possible now (1974); but as research develops cheaper and more efficient recovery processes, these hot water aquifers may become an important resource for their energy content as well as for their water content. (See section on geothermal energy).

Thus, to make possible the orderly and safe development of the deep aquifers, it is imperative that studies be made to determine the quantity of water that may be safely withdrawn from these aquifers and also to determine the chemical quality and other characteristics of the water and of 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 would be provided through county studies in areas containing significant ground-water reservoirs.

SURFACE WATER

Lakes

The thousands of natural lakes scattered throughout eastern South Dakota are an important part of the water resources of the State. They range in area from less than an acre to several square miles. Lake Poinsett, the largest natural lake in the State, has a surface area of more than 12 square miles. Most of the lakes occupy shallow depressions in an area sometimes called "the lake region." Many are temporary—drying completely, or nearly so, within a few months following spring runoff. Some are semipermanent, drying only in years of severe drought. A few are permanent.

The lakes are important chiefly because of the wildlife habitat and water-based recreation they provide. Some of the permanent and semipermanent lakes are excellent for fishing, boating, and other water sports. Many of the small temporary lakes are important as breeding grounds for native waterfowl and as resting areas for migratory waterfowl. A few of the lakes provide water for large municipalities such as Watertown, Mitchell, and Aberdeen; and a few others are potential sources of water for other municipalities.

The importance of the lakes will increase as the population grows and the need to provide more recreational facilities and additional water supplies is felt. Whether a particular lake will help to satisfy this need will depend to a large extent on the quality of its water. In a study of 26 lakes in 1965, Petri and Larson found that water from all the lakes was very hard. However, if softened and treated to remove iron and manganese, water from many of the lakes would be of such quality that it could be used for municipal supply. Water from all but four of the lakes is suitable for irrigation on well-drained land but is probably too limited in quantity to be used extensively for this purpose.

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 is drained northward to the Hudson Bay basin. A short distance to the south is 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 in figure 39. Line width of streams on the map is proportional to the mean discharge.

Missouri River tributaries draining the eastern, glaciated region flow generally southward. The most important tributaries are the James, the Big Sioux, and the Vermillion Rivers, which drain that part of the State in the Central Lowlands physiographic province.

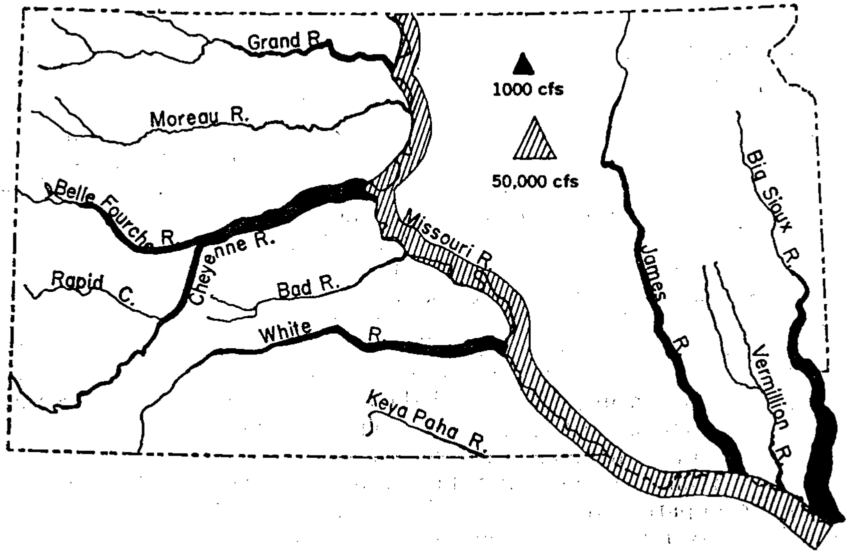

FIGURE 39.—Average discharge, in cubic feet per second, of principal rivers.

Much of the glaciated region of South Dakota does not have integrated drainage. The post-glacial land surface has low relief and is dotted with numerous shallow depressions. Precipitation 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. 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 Cheyenne River is the largest of the western tributaries and drains the South Dakota part of the Black Hills. 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 River drains a small area in the northwestern corner of the State and enters the Missouri in North Dakota.

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. 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 77,000 square mile area of the State. Expressed in other terms, the runoff is equivalent to a flow of 2.6 billion gallons per day (bgd) 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 40.

All major tributaries of the Missouri River in South Dakota, except the Big Sioux River, have had one or more periods of no flow at their mouths within the last 45 years. The minimum flow of the Big Sioux at Akron, Iowa, during the same period was 7 cubic feet per second (cfs). With the exception of the Little 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 41 and 42, 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 variability 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 mg/l, but during periods of low flow, water from most of the major streams may contain more than 2,000 mg/l. Dissolved solids in water from the Missouri River and from a few streams in south-central South Dakota seldom exceed 500 mg/l. The prevailing ranges of dissolved-solids content of water from the major streams in South Dakota is indicated in figure 43.

Calcium and magnesium are the predominant cations in surface water over much of the State. (See fig. 44.) Even where sodium and potassium are the predominant cations, calcium and magnesium generally are present in high concentrations. A hardness (mainly calcium and magnesium hardness) as $CaCO_3$ of more than 160 mg/l is normal for water from most streams, and a hardness of more than 500 mg/l is not uncommon.

Concentrations of several minor but important constituents are relatively low. Iron, and probably manganese, seldom exceed 300 μg/l in most of the streams, and boron seldom exceeds 1,000 μg/l. Fluoride is usually present in concentrations less than 1 mg/l. Selenium in concentrations of several hundredths of a milligram per litre has been detected in water from several streams in the White River basin.

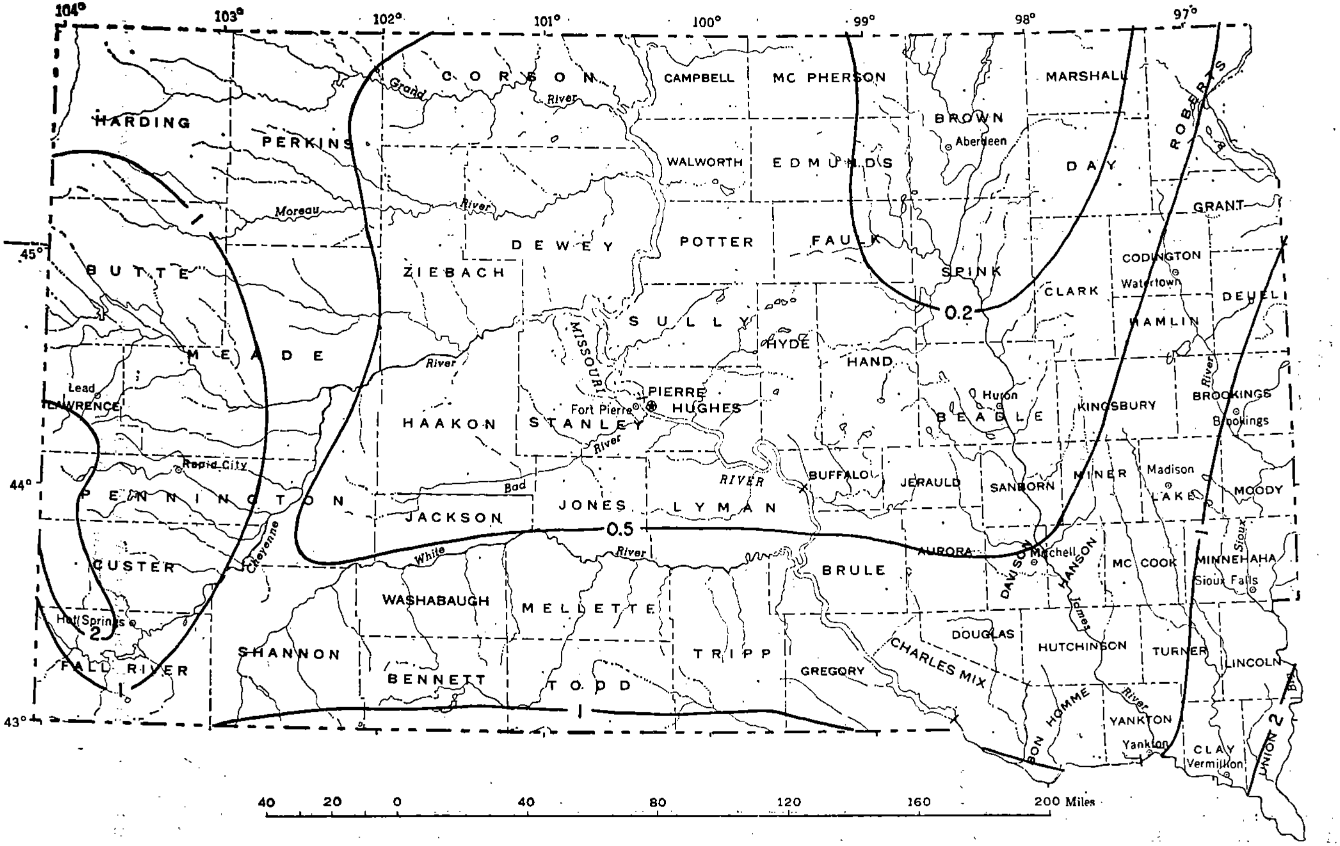

FIGURE 40.—Mean annual runoff, in inches.

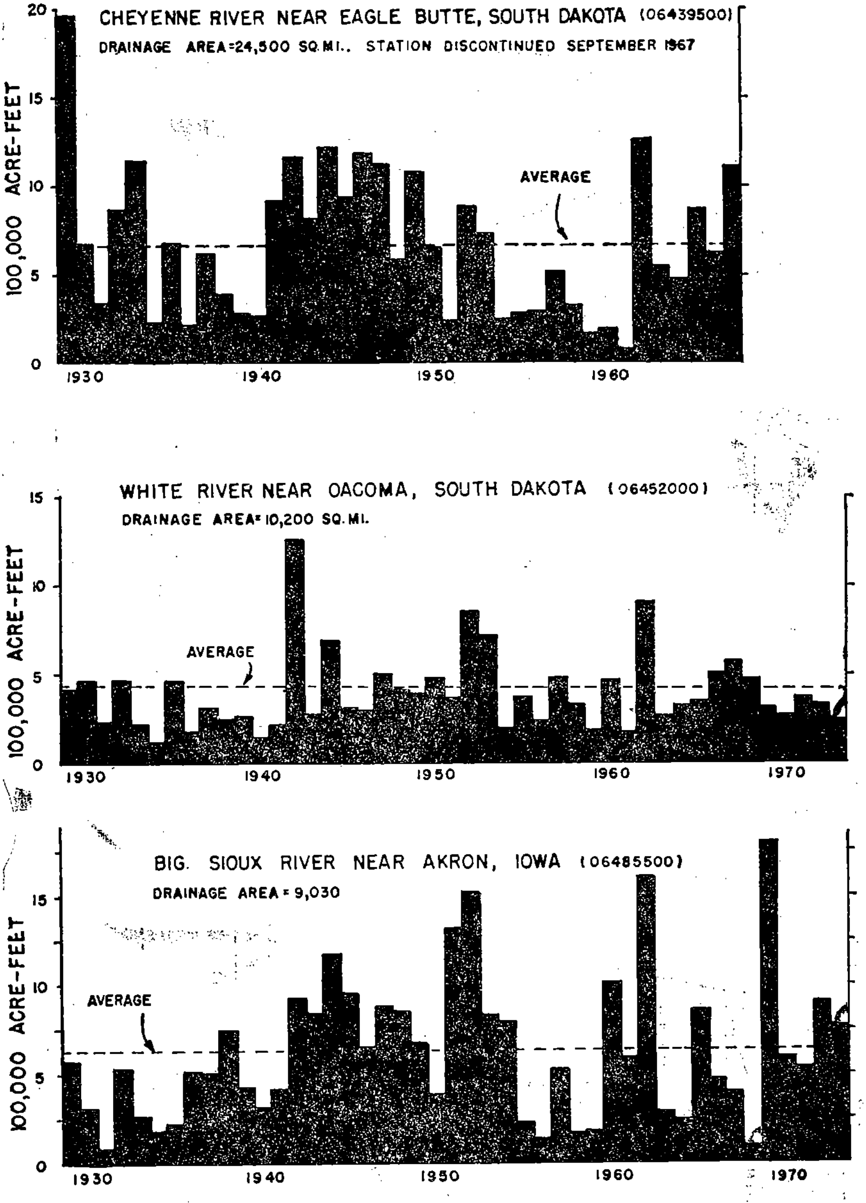

FIGURE 41.—Yearly streamflow (runoff) of selected streams (Cheyenne, White, and Big Sioux Rivers).

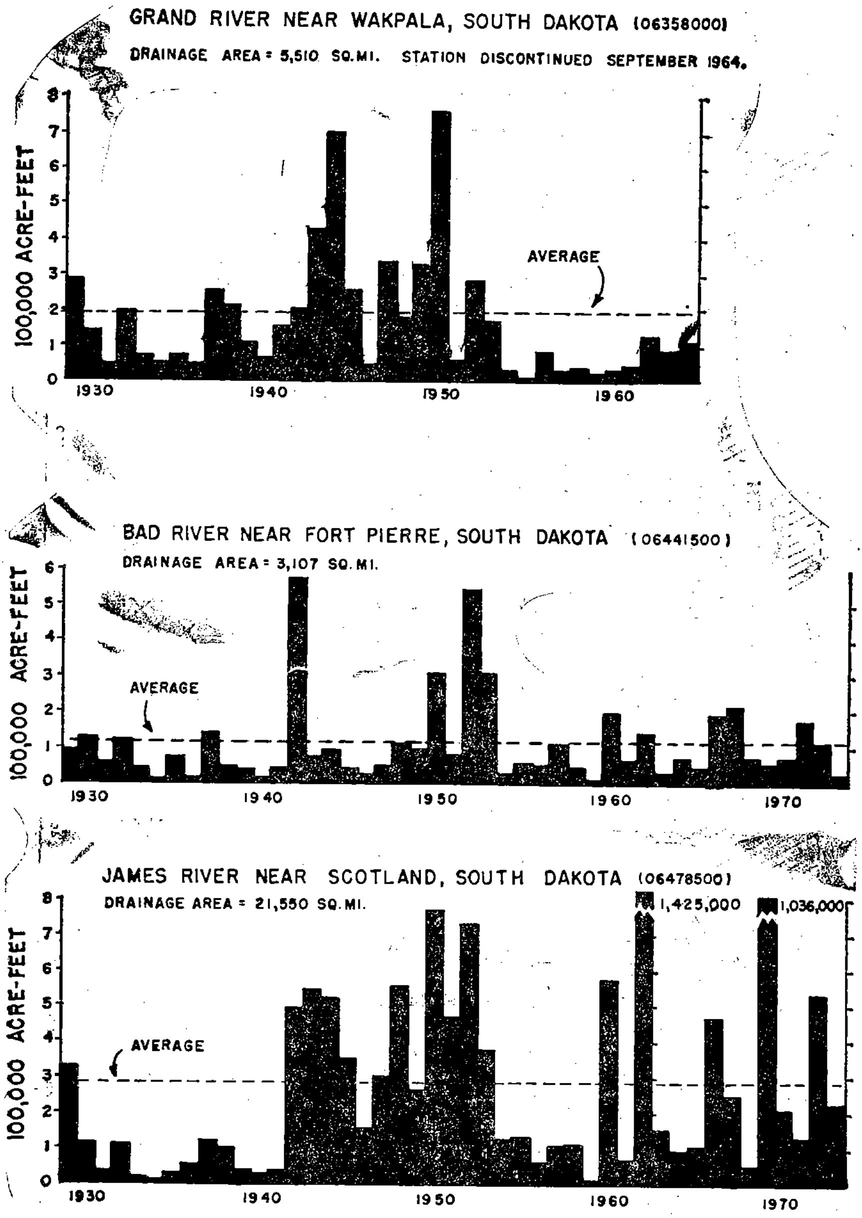

FIGURE 42.—Yearly streamflow (runoff) of selected streams (Grand, Bad, and James Rivers).

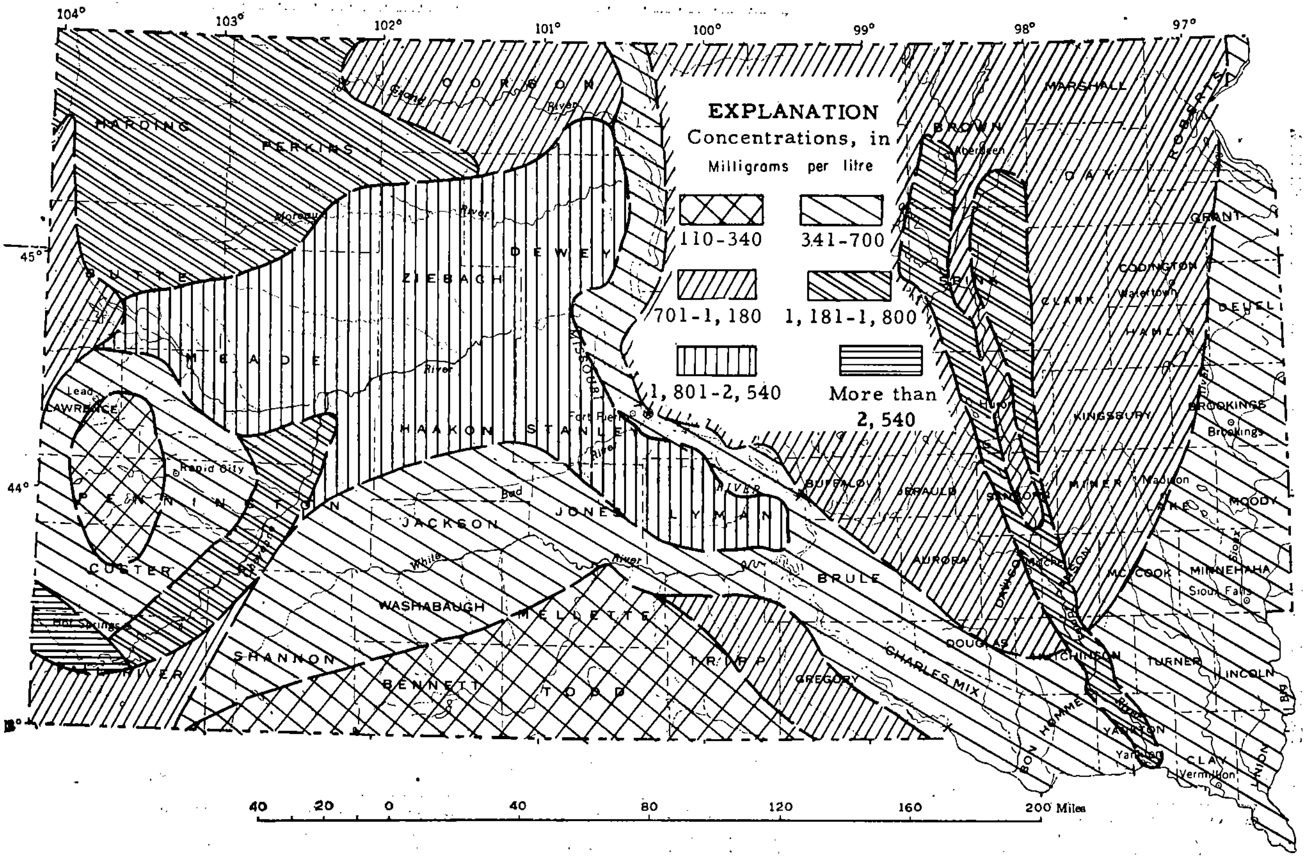

FIGURE 43.—Total dissolved solids in water from major streams.

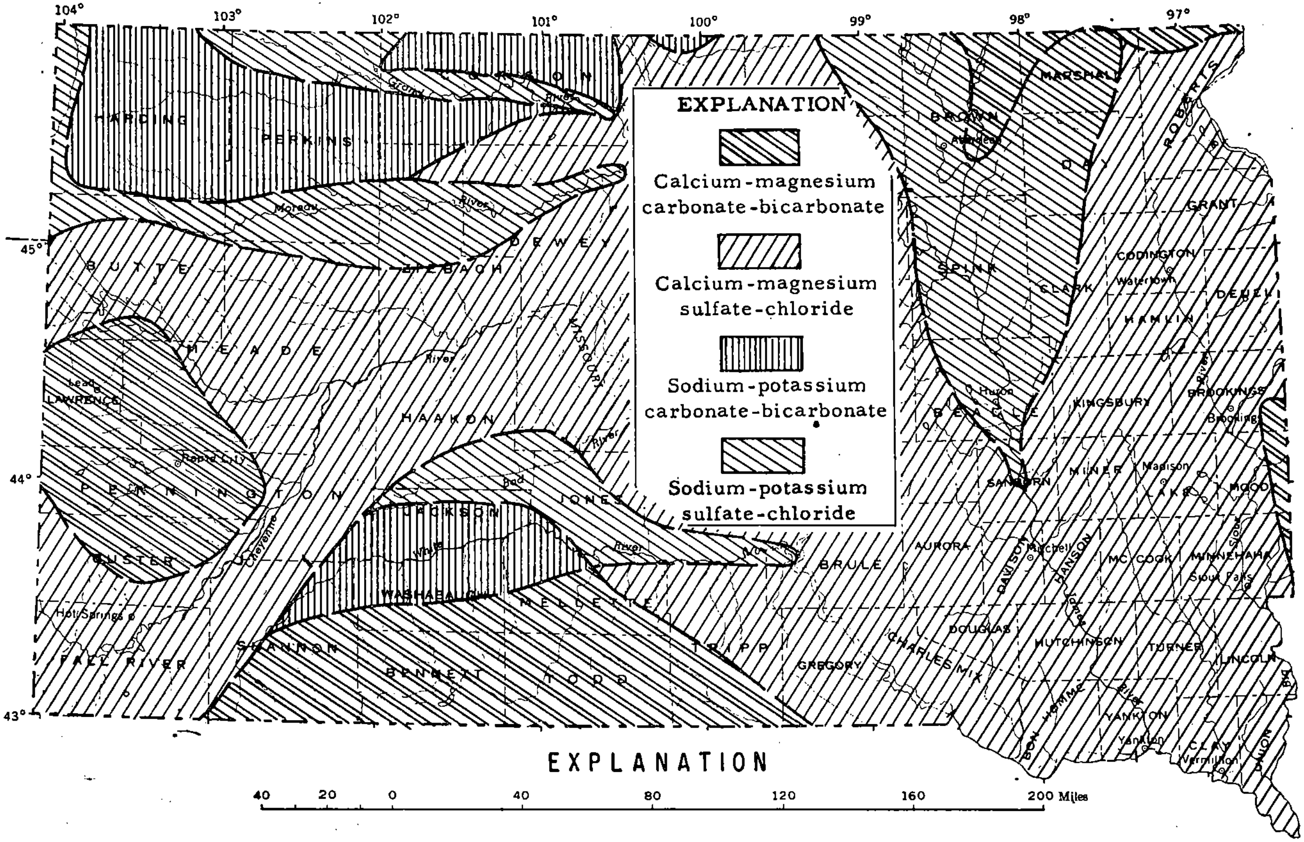

FIGURE 44.—Predominant chemical constituents in water from major streams.

Generally, stream water 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.

Sanitary quality

The sanitary quality of many surface water sources in South Dakota is unsatisfactory for use without treatment. Coliform bacteria, indicative of the presence of organic matter having an animal origin, are found in many lakes and streams. Runoff from cattle feed lots and pasture lands along the rivers, combined with sewage effluent from municipalities using the same rivers for discharge has resulted in coliform concentrations ranging from 1,000 to more than 100,000 colonies per 100 ml in many streams.

Despite the presence of much organic waste matter, dissolved oxygen (DO) concentrations have been reported at levels ranging from about 5.0 mg/l to more than 10 mg/l. A few DO concentrations as low as 3.0 to 5.0 mg/1 have been reported for streams in the eastern half of the State, but even these low concentrations should support aquatic life. The lower DO values occur mainly in the winter time when the rivers have an ice cover.

Because of lack of oxygen, winter fish kills are quite common in South Dakota. Organic wastes are decomposed by bacteria which require oxygen for this process. Thus, there may be a steady depletion of oxygen in the water underneath the ice during the winter months. The ice cover prevents re-aeration of the water and eventually a fish kill may occur, especially if the winter is a long one. In very sluggish and slow moving rivers the problem is compounded by enormous summer algal blooms feeding on nutrients released by the decomposition of animal wastes and probably by fertilizers used in agriculture. As the water temperatures drop and reach the freezing point sometime in November, the algae that have died before the freeze sink to the bottom and are not carried away as in faster moving rivers. Thus, the summer algal bloom contributes significant amounts of organic matter to the existing organic waste load.

The biochemical oxygen demand (BOD) is a measure of the oxygen-consuming potential of organic materials in water. It is the amount of oxygen required by bacteria to stabilize decomposable organic matter under aerobic conditions. In South Dakota, most of these values are low, usually less than 8.0 mg/l.

Nutrients, another factor in the sanitary quality of water, are the various inorganic and organic nitrogen and phosphorous compounds that exist in some degree in all surface water. Nitrogen and phosphorous are essential nutrients for plant growth. In general, dissolved nitrogen and phosphorous are quite low, less than 1.0 mg/l, in most surface waters in South Dakota. However, in the eastern half of the State the amount contained in suspended matter is relatively high. Total nitrogen concentrations ranging from 5 to nearly 30 mg/l and total phosphorous concentrations of around 20 mg/l have been reported. The suspended matter includes living algae and other microorganisms as well as sewage and cattle wastes. The decomposition of this organic matter by bacteria releases nitrogen and phosphorous which then becomes available to the aquatic plant community. The dense, rapidly multiplying algal blooms mentioned above are probably influenced by the extra amount of nitrogen and phosphorous added to the water from the decomposition of organic wastes.

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 bedrock.

Suspended-sediment concentration commonly is expressed in milligrams of dried sediment per litre of a 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. 45.) Discharge-weighted concentrations are estimated to be in the 500- to 2,000-mg/l range in the eastern half of the State. Discharge-weighted concentrations for major streams in the western half of the State probably range from about 500 mg/l in parts of the Black Hills and in the sandhills area along the Nebraska border to 70,000 mg/l 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 70,000 mg/l in the White River, 65,000 mg/l in the Cheyenne River, and 20,000 mg/l in the Moreau and Grand Rivers. 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 high discharge-weighted concentrations, have concentrations of only a few hundred milligrams per litre during the 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.

In general, sediment concentration and sediment discharge increase as streamflow increases. 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. 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 mg/l; the average sediment concentration of the water that is released from the reservoir is less than 50 mg/l.

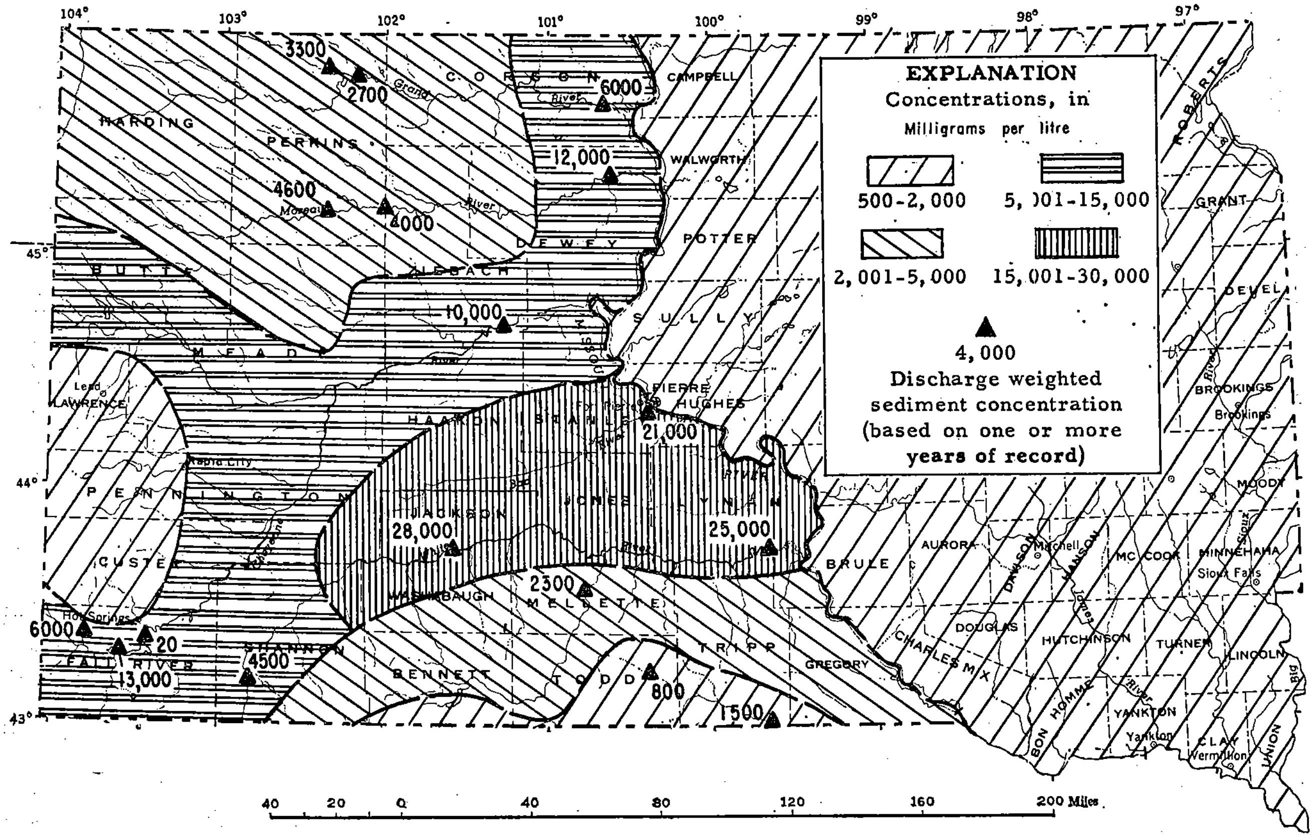

FIGURE 45.—Suspended-sediment concentration in major streams.

Surface Water Problems

South Dakota's surface-water problems are those related to a generally inadequate supply. Low-flow periods of most streams are rarely able to support withdrawals for both extensive irrigation and municipal use. Storage requirements are such that capacities adequate to contain both spring floods and reservoir releases to augment low-flow periods need to be provided.

Planning for utilization and management of the surface-water supply requires the solution of many complex problems. Long-term records of runoff are necessary to properly assess the potential and actual runoff from a basin. Lack of sufficient basic data can cause delay or even abandonment of a project. Long-term streamflow records are available at only a few locations on the principal rivers of the State. Continuing maintenance and expansion of the stream-gaging is necessary to provide data for future users.

Adequate knowledge of the quality of surface water is also essential to meet present and future needs of project planners. There is a definite need for an expanded water-quality sampling program to provide base-line information in this field.

Interpretive reports using basic data currently being collected should be greatly increased. Studies involving duration tables, high-and/or low-flow frequency, basin modeling, and other statistical data can now be easily accomplished using modern high-speed electronic computers.

BASIN APPRAISAL OF SURFACE WATER RESOURCES DEVELOPMENT

Introduction

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, an area of 77,047 square miles, varies greatly in so many characteristics that it is impractical to discuss the State 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 manmáde lakes, provides a convenient mark of delineation for surficial geology, drainage basins, agricultural economy, population distribution, precipitation, and other factors that influence water-resource development, as shown in figure 46.

Subsequent sections of this report will discuss existing water-resource developments by use and by major drainage basins. A brief look at each major drainage basin within South Dakota will afford a better means of evaluating water-resource developments that exist today.

Table 40 briefly summarizes pertinent facts and other information relative to major existing surface-water developments. Figure 47 shows the locations of these features; features on the map are keyed to Table 40 by number.

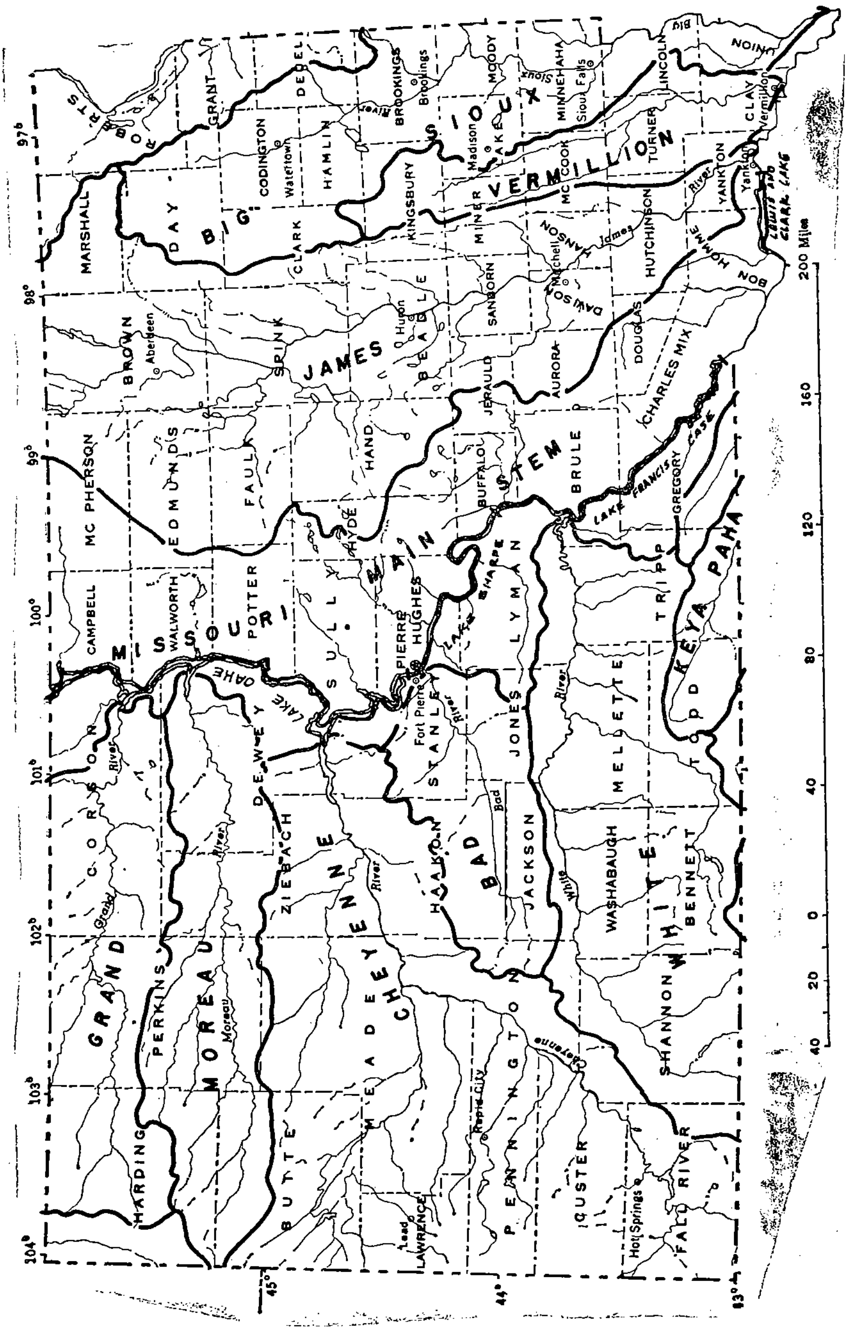

FIGURE 46.—Principal drainage basins.

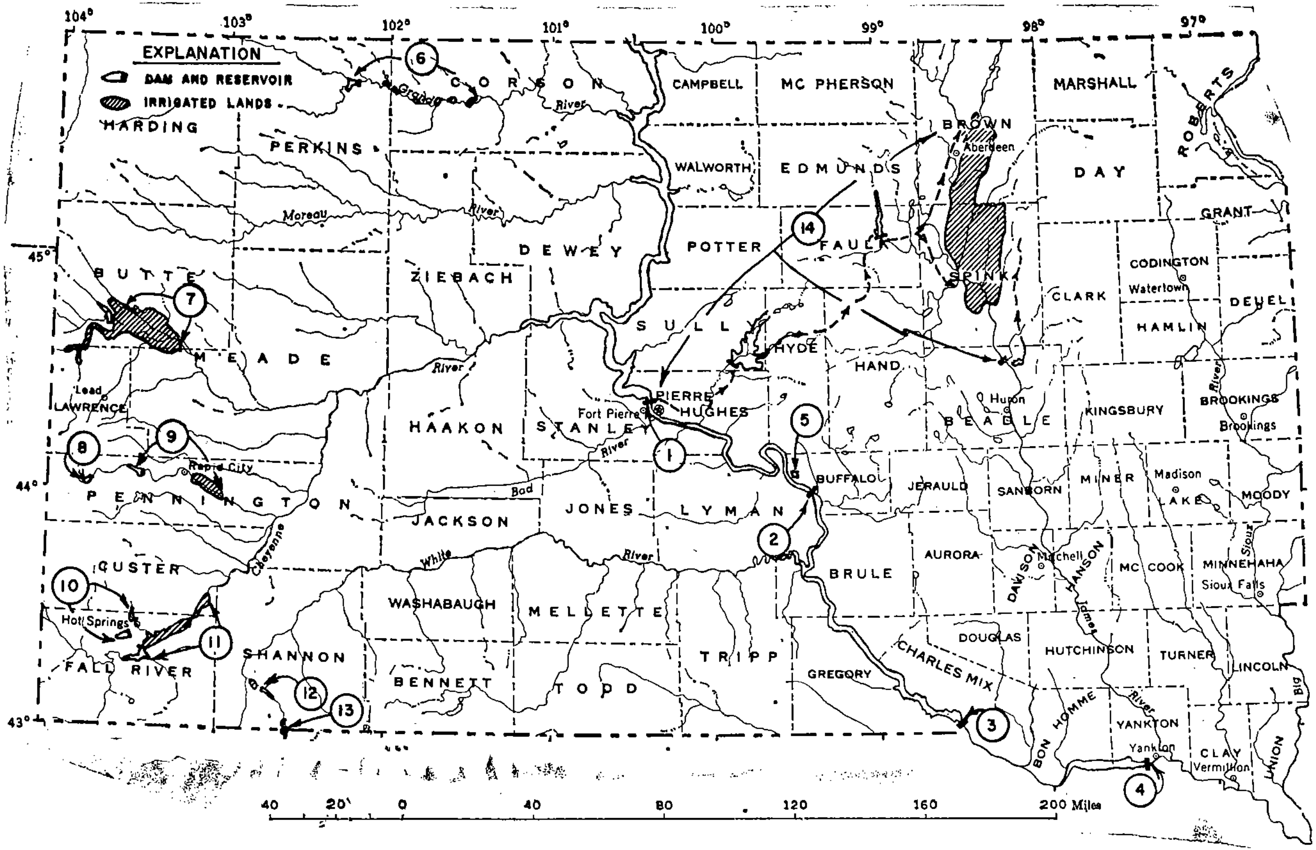

FIGURE 47.—Major existing surface-water developments and operating reservoirs.

TABLE 40.—MAJOR EXISTING SURFACE WATER RESOURCE DEVELOPMENTS AND OPERATING RESERVOIRS[1]

Principal river basins and project and/or unit	Reference number on fig. 47	Principal features	Source of water	Gross storage capacity (A.F.)	Irrigated lands (acres)	Responsible development agency	Status
Missouri (main stem):							
P–S MBP	1	Oahe Dam and Lake Oahe	Missouri River	23, 630, 000	(2)	USCE	Construction complete; serves multipurpose objectives of flood control, irrigation, hydroelectric power, municipal and industrial water, recreation, conservation of fish and wildlife, water quality control, and improvement of navigation.
Do	2	Big Bend Dam and Lake Sharpe	do	1, 900, 000	(2)	USCE	Do.
Do	3	Fort Randall Dam and Lake Francis Case.	do	5, 816, 000	(2)	USCE	Do.
Do	4	Gavins Point Dam and Lewis and Clark Lake.	do	541, 000	(2)	USCE	Do.
Private development	5	Northwest Irrigation project	do		2, 385	(3)	Authorized by State legislature February 1974. Has 4 pumping plants (total of 6 units) which will supply 13,800 gal/min to project from Lake Sharpe. Construction will be completed July 1975.
Grand: P–S MBP, Shadehill Unit	6	Shadehill Dam and Reservoir	Grand River	139, 700	(4)	USBR	Construction of dam completed in 1951; no irrigation facilities were constructed. Shadehill Reservoir, with controlled downstream releases, presently provides water supply to private irrigators.
Moreau: None		None					No major irrigation developments or storage reservoirs exist in the Moreau River Basin.
Cheyenne:							
P–S MBP, Keyhole Unit (Wyoming)	(5)	Keyhole Dam and Reservoir	Belle Fourche River	200, 000	(4)	USBR	Furnishes supplemental water to Belle Fourche project. Keyhole Reservoir storage subject to provisions of the Belle Fourche River compact.
Belle Fourche project	7	Belle Fourche Dam and Reservoir.	Owl Creek	192, 000	57, 068	USBR	Offstream reservoir, water supply diverted from Belle Fourche River. Initial irrigation began in 1908.

Rapid Valley project	8	Deerfield Dam and Reservoir	Castle Creek	15,700	(4)	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, P–S MBP.
P–S MBP, Rapid Valley unit	9	Pactola Dam and Reservoir	Rapid Creek	99,000	(4)	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 of Rapid Valley Project.
Fall River flood control project	10	Cold Brook Dam Cottonwood Springs Dam and Reservoir.	Cold Brook Cottonwood Springs Creek.	6,260 8,340	(2) (2)	USCE USCE	Project completed in 1969 for flood control and recreation.
P–S MBP, Angostura unit	11	Angostura Dam and Reservoir	Cheyenne River	160,000	12,218	USBR	Initial irrigation began in 1953.
Bad: None		None					No major irrigation developments or storage reservoirs exist in the Bad River basin.
White:							
Oglala project	12	Oglala Dam and Reservoir	White Clay Creek	7,200	600	USBIA	Irrigated acreages operated privately by the Oglala Sioux Farm & Ranch Enterprise. Annual irrigated acreages fluctuate widely.
White Clay project	13	White Clay Dam and Reservoir	do	1,500	400	USBIA	Furnishes supplemental water to 200–400 sprinkler irrigated acres operated by the Oglala Sioux Tribe.
James: P–S MBP, Oahe unit	14	Initial stage	Missouri River, James River.		190,000	USBR	For details see fig. 51 and table 47, under James River basin.
Vermillion, Big Sioux, and Keya Paha		None					No major irrigation developments or storage reservoirs exist in these basins in South Dakota.

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[1] Project and/or unit: P–S, MBP=units of Pick-Sloan Missouri basin program (formally Missouri River basin project). Gross storage capacity: total reservoir capacity to highest controlled water surface. Responsible development agency: USBIA=U.S. Bureau of Indian Affairs; USBR=U.S. Bureau of Reclamation; USCE=U.S. Corps of Engineers.

[2] None.

[3] Northwest Irrigation District (private).

[4] Supplemental water supply.

[5] Located in Wyoming; not shown in fig. 47.

Although irrigation in South Dakota is still in the stage of early development, more than half the water withdrawn for use in the State is for irrigation. There are a number of Federal and other large organized irrigation efforts, and the number of individual and small groups irrigating is increasing rapidly. Accurate records of private irrigation development are not readily available and the number of acres irrigated fluctuates annually. Table 41 based on the South Dakota Water Resources Commission Annual Report, June 30, 1971—July 1, 1972, lists by county the acreage covered by irrigation water right permits as of July 1, 1972. The table does not show the actual number of acres irrigated in any given year but it is an indication of the growing interest in irrigation throughout the State.

TABLE 41.—IRRIGATION WATER RIGHT PERMITS GRANTED AS OF JULY 1, 1972

	Acres under permit (number of irrigators)			
		Surface water		
County	Ground water	Direct diversion	Spreader system	Total
Aurora	289 (1)			289 (1)
Beadle	14,289 (64)	4,695 (27)		18,984 (91)
Bennett	3,321 (15)	434 (4)	424 (1)	4,179 (20)
Bon Homme	205 (2)	1,744 (8)		1,949 (10)
Brookings	2,675 (18)	286 (5)		2,961 (23)
Brown	2,936 (12)	657 (6)		3,593 (18)
Brule	572 (2)	653 (8)		1,225 (10)
Buffalo	1,421 (5)	7,558 (7)		8,979 (12)
Butte	1,320 (8)	21,148 (97)	3,227 (26)	25,695 (131)
Campbell	290 (2)	1,656 (7)		1,946 (9)
Charles Mix	3,285 (19)	9,717 (41)		13,002 (60)
Clark	2,343 (10)	320 (2)		2,663 (12)
Clay	4,636 (26)	686 (3)		5,322 (29)
Codington				
Corson		6,686 (23)	1,320 (11)	8,006 (34)
Custer	91 (2)	3,771 (17)	2,719 (15)	6,581 (34)
Davison	3,374 (16)	2,970 (20)		6,344 (36)
Day	411 (2)			411 (2)
Deuel	1,025 (4)	64 (1)		1,089 (5)
Dewey		60 (1)	780 (7)	840 (8)
Douglas	972 (5)	157 (1)		1,129 (6)
McCook	140 (1)			140 (1)
McPherson	848 (3)	930 (5)		1,778 (8)
Marshall				
Meade	773 (7)	18,894 (65)	11,164 (59)	30,813 (131)
Mellette		3,107 (19)	598 (5)	3,705 (24)
Miner	1,377 (5)	896 (4)		2,273 (9)
Minnehaha	2,299 (18)	1,440 (15)		3,739 (33)
Moody	1,842 (10)	2,058 (13)		3,900 (23)
Pennington	18 (2)	8,744 (41)	4,648 (25)	13,410 (68)
Perkins		16,900 (55)	2,834 (17)	19,734 (72)
Potter	1,547 (9)	6,020 (8)		7,567 (17)
Roberts	547 (3)	223 (2)		770 (5)
Sanborn	2,165 (8)	2,306 (9)		4,471 (17)
Shannon		1,148 (9)	664 (2)	1,812 (11)
Spink	14,065 (67)	5,079 (27)		19,144 (94)
Stanley	284 (2)	6,619 (18)	79 (1)	6,982 (21)
Sully	6,757 (15)	21,268 (12)		28,025 (27)
Todd	2,391 (15)	3,441 (14)		5,832 (29)
Tripp	1,399 (11)	3,488 (25)		4,887 (36)

See footnote at end of table.

TABLE 41.—IRRIGATION WATER RIGHT PERMITS GRANTED AS OF JULY 1, 1972—Continued

County	Acres under permit (number of irrigators)			
		Surface water		
	Ground water	Direct diversion	Spreader system	Total
Turner	12,418(78)			12,418 (78)
Union	11,904(72)	1,271(12)		13,175 (84)
Edmunds	128 (1)	30 (1)		158 (2)
Fall River	699 (7)	8,397(47)	5,577(28)	14,673 (82)
Faulk		37 (1)		37 (1)
Grant	87 (1)	200 (2)		287 (3)
Gregory	250 (1)	707 (6)		957 (7)
Haakon	319 (2)	6,219(23)	2,793(20)	9,331 (45)
Hamlin	1,526 (8)	368 (2)		1,894 (10)
Hand	1,567(10)	3,260(13)		4,827 (23)
Hanson	320 (1)	3,803(13)		4,123 (14)
Harding		9,492(31)	8,316(35)	17,808 (66)
Hughes	2,471(13)	53,681(47)		56,152 (60)
Hutchinson	1,579 (6)	2,593(10)		4,172 (16)
Hyde	1,837 (4)	3,982 (4)		5,819 (8)
Jackson		5,066(27)	2,196(19)	7,262 (46)
Jerauld	1,510 (6)	160 (1)		1,670 (7)
Jones	31 (1)	3,252(15)	168 (3)	3,451 (19)
Kingsbury	2,296(12)	118 (1)		2,414 (13)
Lake	523 (4)	475 (2)		998 (6)
Lawrence	3,912(30)	835 (9)	46 (2)	4,793 (41)
Lincoln	10 (1)	446 (3)		456 (4)
Lyman		4,990(24)	782 (7)	5,772 (31)
Walworth	1,143 (6)	1,836 (9)		2,979 (15)
Washabaugh		1,425 (7)	301 (3)	1,726 (10)
Yankton	3,808(24)	1,907(14)		5,715 (38)
Ziebach		1,380 (8)	2,059(16)	3,439 (24)
Total	128,245	281,753	50,677	460,675

Source: South Dakota Water Resources Commission Annual Report, June 30, 1971–July 1, 1972.

Future surface-water developments in the State will be shaped by economic, physical, political, and population influences. 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 topographic locations will also affect planning. Political organization of the people, either for or against various proposals, both public and private, will select which water resource development programs are implemented. Population increases, both State and national, will create food demands, market potentials, energy needs, recreation needs, 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.

Table 42 summarizes the important facts and data obtained from completed investigations of suggested future water resource developments. Figure 48, keyed by number to the table, locates the sites studied. Other possibilities may exist that have not been fully investigated.

TABLE 42.—MAJOR FUTURE SURFACE WATER RESOURCE DEVELOPMENTS INVESTIGATED IN SOUTH DAKOTA[1]

Principal river basin and project and/or unit[2]	Reference number on fig. 48	Principal features	Source of water	Gross storage capacity (A.F.)	Irrigated lands (acres)	Responsible development agency	Status
Missouri (main stem):							
Pollock-Herreid unit	1	Pumping plant	Lake Oahe	None	15,000	USBR	Feasibility report completed 1968 showing economic feasibility. Joint Federal, State, and local financing being studies.
Mobridge unit	2	do	do	None	1,400	USBR	Development not economically feasible. No further studies contemplated.
Evarts unit	3	do	do	None	950	USBR	Do.
LaFramboise unit	4	do	Lake Sharpe	None	256	USBR	Insufficient irrigable lands for feasibility. No further studies contemplated.
Pierre unit	5	do	do	None	132	USBR	Do.
Rousseau unit	6	do	do	None	2,215	USBR	Preliminary investigations indicate feasibility. Future detailed studies required if sufficient landowner interest develops.
La Roche unit	7	do	do	None	1,789	USBR	Do.
Joe Creek unit	8	do	do	None	4,420	USBR	Do.
Iron Nation unit	9	do	do	None	1,739	USBR	Do.
Culdesac unit	10	do	do	None	5,444	USBR	Do.
Grass Rope unit	11	do	do	None	4,100	USBR	Draft feasibility study completed in 1970. Final report not released pending additional cooperative studies with the Bureau of Indian Affairs and the Lower Brule Sioux Tribe.
Fott Hale unit	12	do	Lake Francis Case	None	1,136	USBR	Preliminary investigations show not economically feasible. No further studies contemplated.
Crazy Horse unit	13	do	Missouri River	None	320	USBR	Insufficient irrigable land for feasibility. No further studies contemplated.
Geddes unit	14	do	do	None	7,700	USBR	Reconnaissance studies indicate not economically feasible.
Tower unit	15	do	do	None	1,400	USBR	Definite plan report completed in September 1963 (revised March 1964) indicates feasibility for construction. Development depends on landowner interest.
Greenwood unit	16	do	do	None	3,550	USBR	Do.
Wagner unit	17	do	Lake Francis Case and Lake Andes Reservoir	7,500	19,500	USBR	Draft feasibility report completed in 1966, but final report not released. Concluding report to be finalized in 1975. Local landowner interest very high. They are presently exploring non-Federal alternatives for irrigation development.
Tyndall unit	18	do	Lewis and Clark Lake	None	78,000	USBR	Preliminary studies indicate marginal feasibility. Further study of unit lands for sprinkler irrigation completed in 1965 showed unit not economically feasible. No further studies contemplated.
Yankton unit	19	Diversion siphon	do	None	1,390	USBR	Definite plan report completed in September 1963 (revised March 1964) indicates feasibility for construction. Development depends on landowner interest.
P-S MBP-Missouri Terrace Area	20	Pumping plant	Missouri River	None	45,000	USBR	Preliminary studies by USBR and South Dakota State University show development potential exists. More detailed study needed on alternatives for developing irrigation if landowners become interested.
Mulberry Point	21	Dam and reservoir	do	440,000	(2)	USCE	Only preliminary reconnaissance investigations have been accomplished.
Kenslers Bend	22	do	do	410,000	(2)	USCE	Do.

Grand: None							No major future surface water developments planned due to shortage of available surface water runoff in the drainage basin.
Moreau: Bixby unit	23	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.
Cheyenne:							
Belle Fourche project	24	Indian Creek Dam and Reservoir.	Indian Creek	7, 100	(2)	USBR	Supplemental water supply from Indian Creek Dam and Reservoir feasible but beyond project's ability to repay. Development indefinitely deferred.
Belle Fourche pumping units	25	Individual pumping plants.	Belle Fourche River	None	4, 550	USBR	Economically feasible. Quality of water questionable. Further study required.
Cheyenne pumping units	26	do	Cheyenne River	None	3, 910	USBR	Inadequate water supply. Development indefinitely deferred.
Edgemont unit	27	Edgemont Dam and Reservoir.	Beaver Creek	27, 000	2, 650	USBR	Dam and reservoir in Wyoming; lands in South Dakota. Economically infeasible; indefinitely deferred.
Bad: Philip unit	28	Philip Dam and Reservoir	North Fork, Bad River.	26, 500	2, 784	USBR	Economically infeasible; indefinitely deferred.
White:							
Pine Ridge unit	29	Slim Butte Dam and Reservoir.	White River	94, 000	6, 940	USBR	Feasibility report completed 1968. Preparation of companion report being considered by Bureau of Indian Affairs.
Little White unit	30	Little White Dam and Reservoir.	South Fork, White River.	65, 000	6, 600	USBR	Investigation completed 1965. Not economically justified.
Rosebud site	31	Rosebud Dam and Reservoir.	do	140, 000		USCE	Reported as not economically justified by Corps of Engineers. Because of need for economic development on the Rosebud Indian Reservation, bills for authorizing construction are pending.
James:							
Oahe unit (potential ultimate development).	32	Beadle Canal, East Main Canal (north half), Conde pumping plant, Blunt pumping plant, Missouri Slope Canal.	Missouri River, James River.		305, 000	USBR	Additional future detailed studies needed; indefinitely deferred until landowner interest develops.
Mitchell unit	33	Mitchell diversion pumping plant, Mitchell diversion pipeline.	James River	(3)		USBR	Final feasibility report completed 1968.
Vermillion: None							Surface water investigations will probably be deferred until ground water resources are more fully developed.
Big Sioux:							
Flandreau	34	Flandreau Dam and Reservoir.	Big Sioux River	410, 300		USCE	Project purposes are for flood control, water supply storage, and recreation. Complete initial study presently undergoing revision. Report due in 1974.
Skunk Creek	35	Skunk Creek Dam and Reservoir.	Skunk Creek	110, 500		USCE	Do.
Sioux Falls unit	36	Big Sioux Pumping Plant, Sioux Diversion Pipeline, Slip Up Creek Dam and Reservoir, Slip Up Creek Pumping Plant, Sioux Falls Pipeline.	Big Sioux River	36, 745		USBR	Data provided from feasibility study currently underway. Report due in 1975. Multiobjective plan calls for provision of water for supplemental municipal and industrial uses, water-based recreation, plus fish and wildlife development.

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[1] Project and/or unit: All units refer to Pick-Sloan Missouri basin program (P-S MBP). Gross storage capacity: total reservoir capacity to highest controlled water surface. Responsible development agency: USBR equals U.S. Bureau of Reclamation; USCE equals U.S. Corps of Engineers.

[2] Unknown.

[3] Uses existing Lake Mitchell.

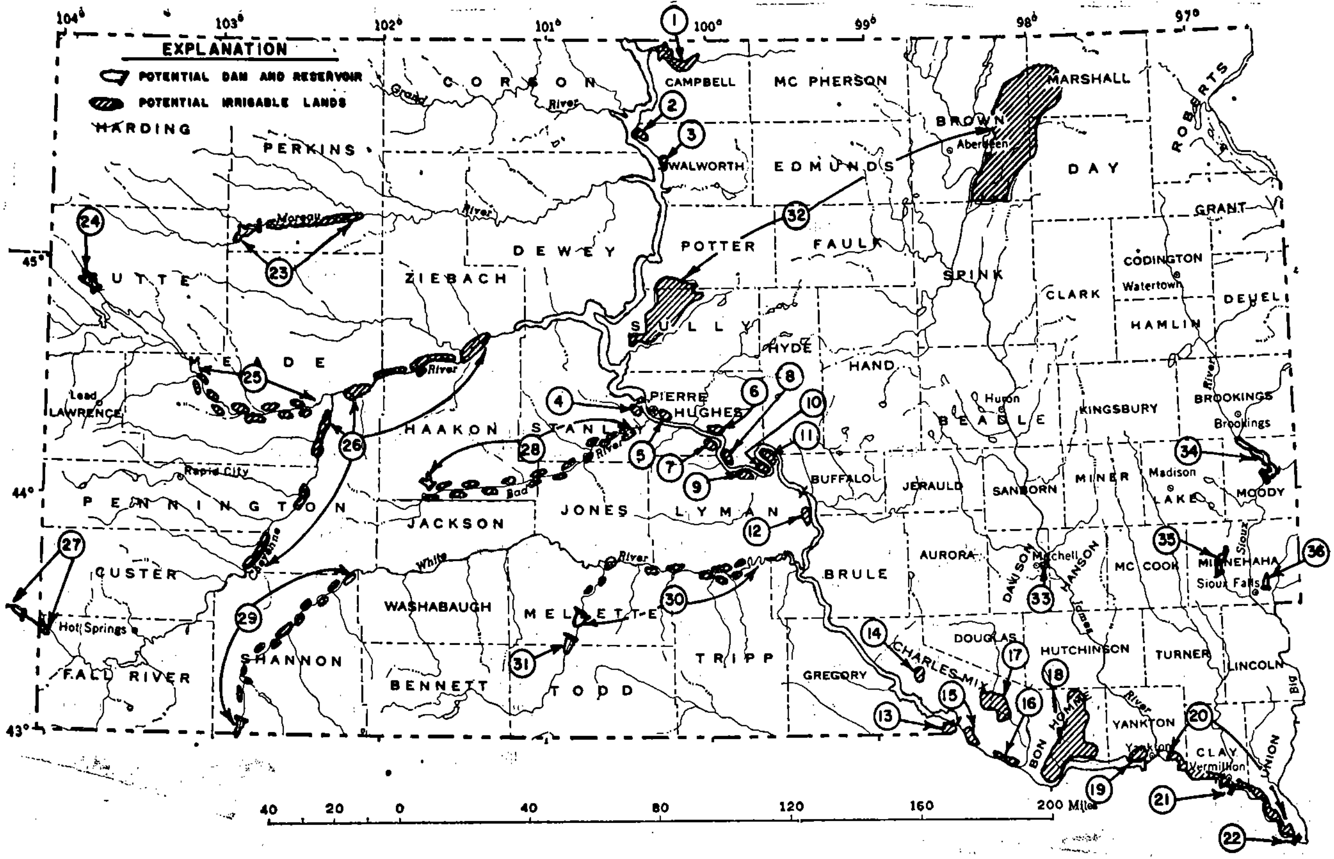

FIGURE 48.—Major surface-water developments investigated.

Multibasin Aspects

Some water-resource uses transcend development of particular river basins. These multibasin aspects will be discussed prior to treatment of developments in each basin. They are farm-domestic water, municipal and industrial water, and hydroelectric power.

Farm-domestic water

Farm-domestic water use and development pertain 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, particularly in the semiarid area west of the Missouri River where adequate ground-water supplies are difficult to develop.

Existing Development

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 common throughout the State. Their water is usually of poor quality, being highly mineralized and oftentimes containing high concentrations of dissolved 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 Ground-water 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 small water courses are poorly defined. They are usually small and are constructed in low depressions of the pastures where snowmelt, runoff, and ground-water seepage may be stored. 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 building 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 other earth-moving equipment for their construction.

These stockponds and dugouts have had a very noticeable effect on surface runoff in western South Dakota. The decrease in runoff chargeable to these reservoirs and ponds has 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 Assistance.—The Soil Conservation Service (SCS), a technical agency of the U.S. Department of Agriculture, works through local Conservation Districts to assist individuals, groups, and units of government in the conservation, development, and productive use of soil, water, and related resources. SCS technicians help landowners and land users apply practices that require special skills or knowledge, such as engineering design and layout for construction jobs, and guidance in planting and managing grassland, woodland, recreation and wildlife areas, and critical erosion areas.

Following are some of the conservation practices that have been carried out in South Dakota since 1942:

Pond construction (number)	92, 992
Grassed waterways (acres)	50, 686
Terraces (miles)	8, 401
Diversion terraces (miles)	925
Grade stabilization structures (number)	628
Irrigation systems (number)	1, 261
Irrigation water management (acres)	130, 762
Irrigation reservoirs (miles)	281
Irrigation ditch lining and pipelines (miles)	230
Water spreading (acres)	107, 018
Livestock pipelines (miles)	1, 100
Wells (number)	20, 644
Windbreaks (acres)	218, 045
Wildlife area management (acres)	626, 927

Pond construction includes both earth dams and dugouts that are constructed to hold runoff for stock water. Grassed waterways convey runoff water from terraces and diversions. Terraces catch and hold rainfall runoff so that it enters the ground, making more moisture available for plants, as well as reducing total runoff, and thereby reducing downstream flooding. Diversion terraces intercept runoff water and carry it to points of safe discharge, usually a waterway or grade stabilization structure. A grade stabilization structure serves as a "ladder" in which water is dropped from a higher to a lower level to prevent gullying and overfalls. Irrigation systems include sprinkler and row watering methods.

Irrigation water management involves working with the irrigator to help him determine the amount of water needed per application, and then applying it in controlled amounts to meet the needs of crops and soils. This includes such practices as row direction, row grade, leveling, lengths of run, and location of ditches or pipelines for water conveyance.

Irrigation reservoirs hold water for use of the irrigator. They may intercept runoff or may hold water from another source, such as water received by canal from an irrigation district. Unless water is conveyed in pipelines or lined ditches, much of it is lost through percolation. The figures in the preceding table do not include portable pipelines. Water spreading is a moisture conservation practice for rangeland, utilizing a system of ditches and dikes to spread floodwater over vegetated areas. This results in increased production of forage for stock.

Livestock pipelines convey water from wells or springs to tanks located to achieve distribution of grazing. These wells are used only for livestock watering purposes.

Windbreaks include plantings around farmsteads to protect buildings and livestock from wind and snow, thereby saving fuel costs; and field windbreaks, which reduce wind erosion.

Another 29,700 acres of trees have been planted for other purposes, generally as a component of wildlife habitat or timber production.

All of these measures are generally done on individual farms and ranches; however, technical assistance is also provided on larger irrigation projects such as the Belle Fourche Project, the Angostura unit, the Northwest Irrigation Project, and Pollock-Herreid Irrigation Project. Certain types of soil and water conservation needs cannot be adequately solved by individuals except by action through local units of government such as conservation districts, watershed districts, drainage districts, irrigation districts, counties, towns, and municipalities. Aid may also be needed from State and Federal agencies for such measures as flood plain zoning and control of pollution by sediment.

Future Development

Past population trends within the State have consisted of a general rural-to-urban movement of people. This movement is still occurring but at a slower rate. Farms have generally been decreasing in number and increasing in size. Methods of farming change with advance 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 limited 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.

The SCS will continue to provide assistance in solving problems relating to soil and water. Pond construction is not expected to increase significantly in future years as more livestock wells are developed and pipelines are installed. Grassed waterways will increase to serve as outlets for an expected increase in miles of terraces to be installed. Diversions are also expected to increase as a means of protecting lands to be irrigated from being damaged by runoff from adjacent lands. A big increase is foreseen in irrigation activities. More land will be brought under irrigation; some will require leveling. Use of sprinklers, in conjunction with pipelines to convey water, will increase dramatically. Proper amounts of water to be applied will become even more important; consequently irrigation water management will increase.

Watershed development under the Watershed Protection and Flood Prevention Act (Public Law 83:566) and under the Resource Conservation and Development Program (Public Law 87:703) will continue in accordance with the needs and desires of people living in the affected areas.

Municipal and industrial water

Existing Development

The U.S. Bureau of Census reported over 300 incorporated places in South Dakota in 1970. It is estimated that these incorporated centers use an average of 40 million gallons of water per day to serve over 411,000 people. Of this total quantity used, approximately 75 percent is obtained from ground-water sources. Industry's daily self-supplied withdrawal of water within the State is estimated at 16 million gallons. Ground-water sources furnish approximately 64 percent of this volume.

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 Table 43.

TABLE 43.—WATER SUPPLY OF MUNICIPALITIES OF MORE THAN 2,500 POPULATION

Municipality	1970 population	Water source [1]	Water treatment [2]
Aberdeen	26,476	SW	PHD
Belle Fourche	4,236	SW	D
Brookings	13,717	GW	ID
Canton	2,665	GW	D
Chamberlain	2,626	SW	PH
Deadwood	2,409	SW	D
Hot Springs	4,434	SW, GW	D, D
Huron	14,299	SW, GW	D, PHD
Lead	5,420	SW	D
Madison	6,315	GW	D
Milbank	3,727	SW, GW	D, D
Mitchell	13,425	SW	PH
Mobridge	4,545	SW	HD
Pierre	9,699	GW	D
Rapid City	43,836	SW, GW	PD, D
Redfield	2,943	GW	D
Sioux Falls	72,488	GW	HID
Sisseton	3,094	SW, GW	I, ID
Spearfish	4,661	SW, GW	D, D
Sturgis	4,536	SW, GW	D, D
Vermillion	9,128	GW	HD
Watertown	13,388	SW, GW	PD, D
Winner	3,789	GW	D
Yankton	11,919	SW	PH

Source: South Dakota Public Water Supply Data, 1971.

[1] Water source: GW-ground water; SW-surface water.

[2] Water treatment: P-purification, H-softening, I-iron or manganese removal, D-disinfection. Where 2 sources of water are shown, 2 treatments also are shown.

Much of the water used by municipalities within the State contains high concentrations of sulfate, chloride, sodium, iron, magnesium, or other elements and generally requires treatment to make it potable and more suitable for consumptive use. Further information relative to water quality is given in previous sections of this report.

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 make up 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 at present 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 of the ground water, such as salinity, requires the selection of a surface water source. Availability of an adequate supply of ground water has several advantages. 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. When only small quantities of water are needed, as is true of small municipalities and industries, the investment in plant and facilities is usually much less than that required to develop surface-water sources. Chances of a 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.

Surface-Water Utilization.—Surface-water resource development is usually more feasible for larger municipalities; however, nearness 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 or is of undesirable quality.

Surface-water supplies are used commonly by municipalities in the immediate area of the Black Hills. Water from Deerfield Reservoir and Pactola Reservoir is furnished, 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 near it. Mobridge, Gettysburg, Pierre, Chamberlain, Lake Andes, Springfield, and Yankton benefit from this source.

In eastern South Dakota, storage and regulatory reservoirs supply surface water to Aberdeen, Huron, and Mitchell. The James Diversion Dam on the James River, approximately 15 miles north of Huron, stores a substantial quantity of surface water for that city. The city of Watertown uses nearby Lake Kampeska for a supply source to supplement ground-water sources already developed.

Surface waters may be contaminated by pollution from many sources, both natural and manmade. As a result of recent Federal legislation, the latest being the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92–500), efforts are underway to achieve the desired improvement in the quality of the surface waters of the State.

The State Department of Environmental Protection has instituted Water Quality Standards relating to the control of pollutants in the surface waters in the State in accordance with the regulations promulgated by the United States Environmental Protection Agency and in conformance with Chapter 46–25 of the South Dakota Compiled Laws. In addition, the State Board of Environmental Protection has promulgated "Regulations Establishing Procedures for Construction of Water Pollution Control Facilities or Projects" in conformance with one of the sections of P.L. 92–500 concerning the National Pollution Discharge Elimination System (NPDES). These actions by the State have established standards and the criteria applicable thereto for various beneficial uses on all the surface waters of the State, as well as effluent standards that must be met within the surface waters under the discharge permit system that will ultimately be administered by the State following approval by the U.S. Environmental Protection Agency.

Future Development

Development of additional water supplies for municipalities and industries to provide for existing and projected needs is a significant concern within South Dakota. Many factors have to be considered in evaluating possible alternate sources and the economic factors associated with them. Smaller municipalities and industries probably will continue to rely predominantly on ground water wherever adequate supplies exist. As water needs increase, however, use of surface water resources may be more economical, especially in areas near existing or planned water development projects. For example, the Bureau of Reclamation, in association with irrigation development and with multipurpose projects, is working with several municipalities to develop specific plans.

Irrigation investigations mentioned as "Units" in this section are discussed more fully under each basin section.

The Bureau of Reclamation could design and construct the necessary conveyance facilities (open channels or pipelines with pumping plants) and storage reservoirs (for carryover winter storage when irrigation supply systems are inoperative) needed to obtain an increased and firm water supply to meet future growth needs. Potential municipal customers are particularly interested in the long-term repayment provisions (up to 50 years) that could be obtained under this type of Federal participation with the Bureau of Reclamation because their private financing opportunities have usually been already committed to water treatment, distribution, and treated water storage works within their existing municipal water system.

Alternative possibilities that could also be considered are monetary grant programs available from the Department of Housing and Urban Development (HUD), Economic Development Administration (EDA), Farmers Home Administration (FHA), and other agencies in financing both raw water supply projects and treatment, distribution, and storage works within municipalities.

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 those 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 nearby streams for local needs may increase their reliability, especially in the Black Hills. Importation of water from larger streams by transbasin diversion by pipeline is possible, but high costs may prohibit this consideration under present economic conditions. This would be particularly true of conveying Missouri main-stem reservoir water to western areas of South Dakota. Municipalities are widely separated in western South Dakota. Combining group needs into single plans is not always feasible to overcome the hindrances of 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 neither of sufficient size nor conveniently located to assist municipalities in that basin that may need more water. The few small municipalities in the Moreau River Basin can probably be served from ground-water sources or, in some instances, additional surface-water impoundments. The Grand River Basin offers little opportunity for municipal water assistance except from Shadehill Reservoir storage. 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 close 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 or jointly used pipeline schemes. Development of the Wagner Unit would be advantageous to the towns of that area 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 nearly 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 greater future demands on available municipal and industrial water supplies, particularly in the southeastern part of the State for cities such as Sioux Falls.

A far-reaching development that would influence municipal and industrial water supplies in eastern South Dakota would be the Oahe Unit. Communities that might find financial advantages by using the Oahe Unit water supply for municipal purposes are shown below (those municipalities marked with an asterisk have already requested the Bureau of Reclamation to accomplish feasibility studies for municipal and industrial water-supply purposes).

*Aberdeen
Agar
Alexandria
Ashton
Blunt
Brentford
Claremont
Columbia
Conde
*Cresbard
Faulkton
Frankfort
*Harrold
Hitchcock
Huron
Mellette
Menno
*Miller
Mitchell
Northville
*Onida
*Redfield
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.

The city of Sioux Falls will need additional sources of water to provide for future growth. Its needs to the year 2030 can probably be satisfied from surface and groundwater resources of the Big Sioux Basin. Other municipalities in the southeastern part of the State may find if feasible to rely on pipeline diversions from the Missouri River reservoirs, provided future water needs can justify construction costs of these types of facilities.

Hydroelectric power

Few hydroelectric powerplants existed in the State, and their production of electricity was very small, until construction of a series of multipurpose dams on the Missouri River in South Dakota provided storage and head for major hydropower development. The generally low and irregular flows of streams in the State other than theMissouri 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, and they now enjoy a quality of living comparable to that of many urban families.

The large-scale power development in South Dakota has come about as a result of the construction of dams and power distribution systems, by various agencies, under the Pick-Sloan Missouri Basin Program. The Corps of Engineers has constructed the Oahe, Big Bend, Fort Randall, and Gavins 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 centrury, is being generated within the State.

Existing Development

Private.—Table 44 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 49 shows the locations of these plants.

Federal.—South Dakota lies almost entirely within the Missouri River basin drainage area. One of the important benefits of the Pick-Sloan Missouri Basin Program is the hydroelectric power generated.

The extent of the Federal hydroelectric power development in South Dakota is summarized in table 44. 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.

TABLE 44.—EXISTING AND POTENTIAL HYDROELECTRIC POWER DEVELOPMENTS

[Agency or Company: B.H.P.&L.—Black Hills Power and Light Co.; HM Co.—Homestake Mining Co.; USCE—U.S. Corps of Engineers]

Reference number figure 49 and plant name	Stream	Agency or company	Average static head (feet)	Number of generating units	Ultimate capacity (kilowatts)	Estimated average annual generation (million kilowatt-hours)	Status as of 1974	Remarks
EXISTING PLANTS (PRIVATE)								
1. Falls Hydro	Fall River	BHP&L	100	1	200	1.0	Operating	Constructed in 1890 below Hot Springs, S.D.
2. Redwater No. 2	Redwater River	BHP&L	60	1	346	1.0	do	Constructed in 1925 2 miles below Redwater No. 1. Also uses water diverted from Spearfish Creek.
3. Spearfish No. 1	Spearfish Creek	HM Co	666	2	4,000	16.3	do	Constructed in 1912 ½ mile south of Spearfish, S. D.
4. Spearfish No. 2	do	HM Co	555	2	4,000	10.2	do	Constructed in 1918 near Maurice, S.D.
5. Englewood	Whitewood Creek	HM Co	424	1	400	2.2	do	Constfucted in 1906 1 mile northeast of Englewood, S.D.
6. 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.
Total				9	10,156	35.0		
EXISTING PLANTS (FEDERAL)								
7. Oahe	Missouri River	USCE	191	7	595,000	2,590	Operating	7 85,000-kilowatt units operating since 1963.
8. Big Bend	do	USCE	70	8	468,000	990	do	8 58,500-kilowatt units operating since 1966.
9. Fort Randall	do	USCE	128	8	320,000	1,715	do	8 40,000-kilowatt units operating since 1956.
10. Gavins Point	do	USCE	41	3	100,035	695	do	3 33,345-kilowatt units operating since 1957. Powerplant located in Nebraska.
Total				26	1,483,035	5,990		
POTENTIAL PLANTS (FEDERAL)								
11. Mulberry Point	Missouri River	USCE	33	(1)	188,000	(1)	Inactive	Near Vermillion, S.D.
12. Kenslers Bend	do	USCE	33	(1)	80,000	(1)	do	10 miles upstream from Sioux City, Iowa.
7,8,9 Additional generator units for peaking power.	do	USCE	(1)	(1)	(1)	(1)	Report due July 1975	Addition of units being studied for Oahe, Big Bend, and Fort Randall Dams.
Total					268,000			

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[1] Unknown.

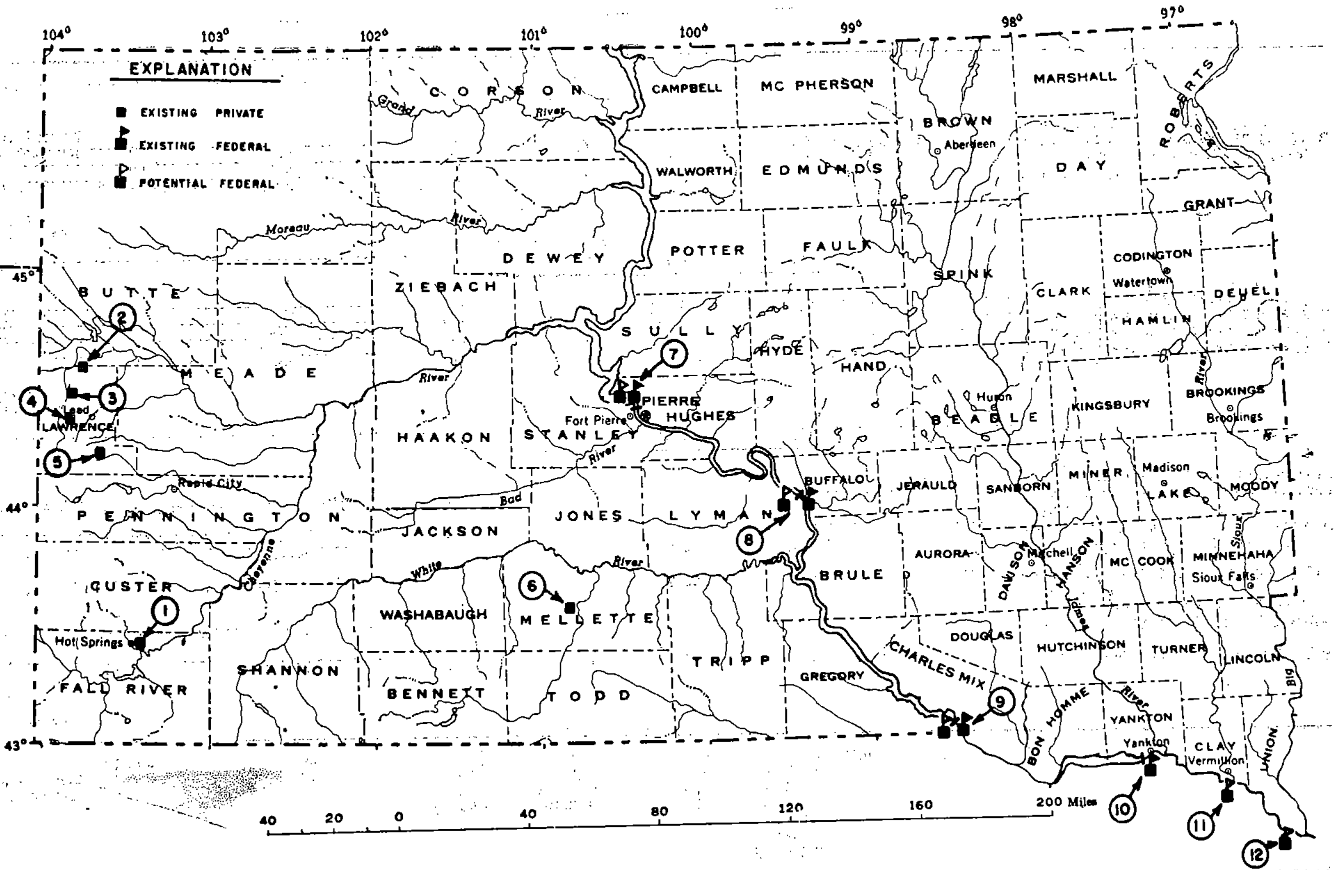

FIGURE 49.—Hydroelectric power resources (Numbered areas identified in table 44).

The Corps of Engineers operates and maintains the four existing multipurpose dams and powerplants. These large earth dams impound water to form a chain of lakes extending in a north-south direction through the State. Oahe Powerplant is the largest producer of hydroelectric power of the four main-stem plants. The second largest hydroelectric powerplant in terms of installed capacity is Big Bend Powerplant, which is operated primarily to meet peak load requirements upon the main-stem system. The third largest hydroelectric plant is Fort Randall Powerplant, and the smallest of the four powerplants is Gavins Point, situated near Yankton. The Missouri River at this point is the boundary between South Dakota and Nebraska, with Gavins Powerplant actually located on the Nebraska side.

Within South Dakota, since 1953, the Bureau of Reclamation has constructed a network of approximately 104 miles of 345-kv, and 1,000 miles of 230-kv steel-tower, plus 1,280 miles of 115-kv wood pole transmission lines. Currently under construction are 178 miles of 345-kv and 44 miles of 115-kv transmission lines. Table 45 lists the 31 substations constructed and indicates their 1974 capacities and initial dates of operation. Figure 50 shows the transmission lines and substation locations in South Dakota. This system transmits, controls, and coordinates power delivery to 43 different customers in various load areas throughout the State. Capacity is being expanded at several substations as more power becomes available.

TABLE 45.—BUREAU OF RECLAMATION POWER SYSTEM IN SOUTH DAKOTA

Ref. number on fig. 50	Substation	KVA capacity (as of Dec. 31 1973)	Date first placed in service
1	Armour	37,500	June 1954.
11	Beresford	50,000	September 1954.
14	Bonesteel	4,687	March 1954.
8	Brookings	38,750	November 1954.
24	Eagle Butte	15,000	December 1962.
22	Ellsworth Air Force Base	15,000	May 1954.
25	Faith	2,500	February 1954.
9	Flandreau	25,000	November 1954.
17	Fort Thompson	270,000	June 1962.
15	Gregory	[1] 16,250	March 1954.
5	Groton	56,667	August 1954.
4	Huron	[1] 241,667	May 1953.
30	Martin	10,000	November 1963.
26	Maurine	20,000	November 1962.
18	Midland	7,125	September 1953.
29	Mission	10,000	October 1963.
2	Mount Vernon	41,667	April 1953.
27	Newell	15,000	December 1962.
31	New Underwood	100,000	July 1966.
19	Philip	15,000	September 1953.
28	Pierre	32,500	April 1956.
23	Rapid City	20,000	October 1954.
10	Sioux Falls	218,750	July 1953.
6	Summit	23,000	September 1954.
13	Tyndall	18,750	June 1953.
20	Wall	7,500	September 1953.
7	Watertown	[1] 546,667	May 1953.
21	Wicksville	2,000	September 1953.
16	Winner	[1] 20,000	March 1954.
3	Woonsocket	12,500	May 1953.
12	Yankton	12,500	March 1957.

[1] Some transformers are company owned but operated by the Bureau of Reclamation.

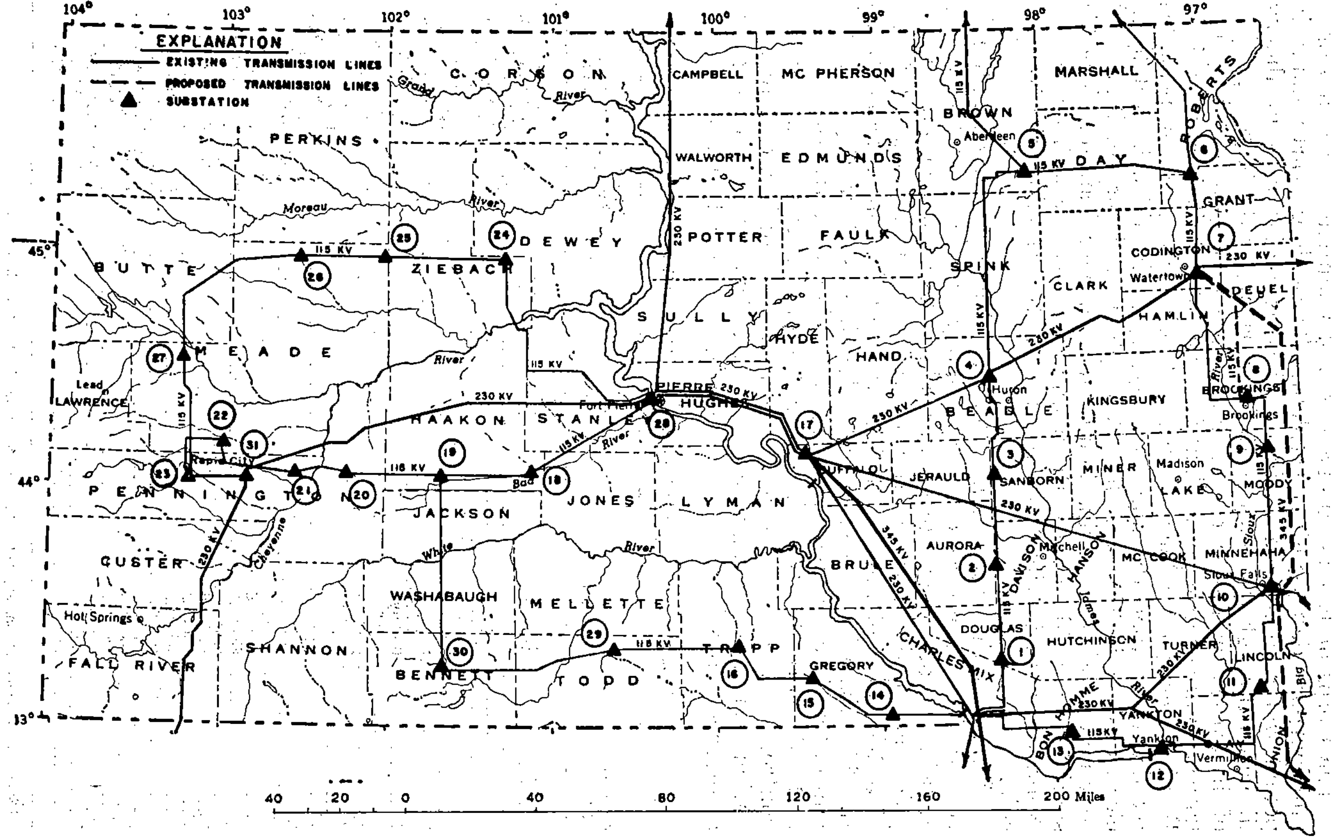

FIGURE 50.—Bureau of Reclamation power system in South Dakota.

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 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 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 Development

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 hydropower 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 the State.

No feasible opportunities for additional development of important quantities of hydroelectric power in the Black Hills are anticipated because streamflows are undependable. Some streams in the eastern portion of the State may have small quantities of dependable flow; however, no feasible topographic features exist for hydroelectric power generation.

Changing Concepts for Future Utilization.—The last decade has witnessed changing concepts in the planning and use of hydroelectric power generated at Missouri River main-stem dams within the Missouri River Basin, particularly those in South Dakota. Initially, this hydropower was utilized to fulfill base power needs over extended periods of time.

Private power companies and cooperatives have progressed tremendously during the past decade in planning and constructing large thermoelectric plants to add to the base load electric power generating capacity within the region. Because of this developing situation, the Federal Power Commission is now exploring the possibility of planning additional future main-stem hydroelectric power installations and using them to meet peak power demands that are anticipated to occur during short intermittent periods of a day, week, or season.

Conventional hydropower plants with large storage reservoirs, such as exist on the main-stem Missouri River in South Dakota, offer more flexibility in meeting peak power demands because they can be operated to meet a specified load curve. They also have the unique advantage and capability of being quickly brought into or taken out of service in an efficient manner. This is not easily or efficiently accomplished with large thermoelectric generation facilities.

To this end, the Corps of Engineers is studying the feasibility of constructing additional hydroelectric generation capacity for peaking purposes at Oahe, Big Bend, and Fort Randall Dams in South Dakota in order to provide additional capability and flexibility to the overall power system within the region. The proposed addition of more generators at the main-stem dams will not produce more energy, but will permit a greater peak production at any one time.

As previously mentioned, the only known sites of importance remaining in South Dakota that hold possibilities for 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 Mulbery 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 powerplant. 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 44 and figure 49.

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 elctrical 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, 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. Diversion of water from the Missouri River main-stem reservoirs could be vital to future thermoelectric power generation at coalfields in western North Dakota, eastern Montana, and northeastern Wyoming to satisfy the Nation's energy needs.

Missouri River main stem

Introduction

The channel of the Missouri River in South Dakota—or the "Big Muddy," as it is nicknamed because of its tremendous silt load—is about 547 miles in length. Eight principal tributaries enter the Missouri as it traverses the State. 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. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within basin.)

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; it is characterized by a wide flood plain.

The Missouri River is the only stream in the State that has a large sustained flow, and it is therefore 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	45	21,720	500,000	1,800
Missouri River near Mobridge, S. Dak.[1]	208,700	33	21,560	443,000	2,600
Missouri River at Pierre, S. Dak.[1]	243,500	36	21,860	440,000	[2] 589
Missouri River at Yankton, S. Dak	279,500	43	25,520	480,000	2,700
Missouri River at Sioux City, Iowa	314,600	75	31,900	441,000	2,500

[1] Discontinued station.

[2] Regulated minimum daily discharge.

Source: U.S. Geological Survey, Water Resources Data for South Dakota, Pt. 1, Surface-water records.

With the completion of Big Bend Dam, the Missouri River within the State of South Dakota has 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 46 gives pertinent information about each reservoir.

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. The water generally is good for irrigation and many industrial uses, but it requires softening for municipal use.

Below Oahe Dam and below Gavins Point Dam the water has been found to contain coliform bacteria in fairly low concentrations indicating water of fair to good sanitary quality. The river below these two dams also has a very insignificant Biochemical Oxygen Demand (BOD).

Existing Development

Private.—Very little of the vast quantities of water stored behind the main-stem Missouri River dams is being utilized. It is anticipated that diversion from the main-stem reservoirs by private and municipal interests will continue to increase.

TABLE 46.—MISSOURI RIVER RESERVOIR DATA

	Lake Oahe		Lake Sharpe		Lake Francis Case		Lewis and 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	5,816	1,210	541
Normal maximum operating pool	1,617	22,530	1,420	1,725	1,365	4,834	1,208	477
Top of inactive storage	1,540	5,538	1,415	1,465	1,310	1,336	1,195	156
Exclusive flood control zone	1,617–1,620	1,100	1,420–1,423	175	1,365–1,375	982	1,208–1,210	64
Multiple-use zone [1]	1,540–1,617	16,992	1,415–1,420	260	1,310–1,365	3,498	1,195–1,208	321
Inactive storage zone	1,425–1,540	5,536	1,345–1,415	1,465	1,227–1,310	1,336	1,180–1,195	138
Dead storage	(2)	2		0		0	(3)	18
Power capacity (kilowatts)	595,000		468,000		320,000		100,035	
Storage began	(4)		(5)		(6)		(7)	

[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] August 1958.

[5] November 1963.

[6] December 1952.

[7] July 1955.

The South Dakota Department of Natural Resource Development reports Missouri River main-stem diversions as of January 1974 as follows:

Number of permits and source	Purpose	Rate (cfs)	Irrigable acres	Comment
141 Main-stem reservoirs	Irrigation	1,290.00	89,590	Primarily private individual developments.
5 Missouri River	do	14.50	1,061	Primarily private individual developments between Oahe Dam and Lake Sharpe, Fort Randall Dam, and Lewis and Clark Lake, and downstream from Gavins Point Dam.
2 Main-stem reservoirs	Rural water supply systems.	4.71		
5 Main-stem reservoirs	Municipal and industrial water supply.	10.70		Mobridge, Gettysburg, Chamberlain, Lake Andes, and Springfield.
2 Missouri River	do	25.00		Both permits held by city of Yankton.

The Northwest Irrigation Project, Buffalo County, is an example of main-stem diversion for irrigation. A group of private farm owners formed the Northwest Irrigation District containing 3,250 acres. The District plans called for four pumping plants that provide 30.7 cfs of water for 2,385 acres. One pumping plant is completed and in operation with the remainder to be completed by July 1975.

Federal.—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. The four main-stem Missouri River dams constructed by the Corps of Engineers are the Oahe, Big Bend, Fort Randall, and Gavins Point dams. The Corps also operates and maintains the dams and their reservoirs, and coordinates their functions with the Bureau of Reclamation and other governmental programs concerned with water-resource utilization and development.

Future Development

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 multi-purpose reservoirs. The open-river development would stabilize the riverbanks 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. In addition, the Corps is studying the feasibility of adding generating units to the existing facilities at Oahe, Big Bend, and Fort Randall Dams for producing "peaking power." (For additional discussion of peaking power, see previous section of this report titled "Hydroelectric Power".)

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.

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 diversion 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 groupings are shown below (those marked with asterisk were not included in Senate Document 191 and were not part of the originally authorized Missouri River Basin Project).

Northern units:
- *Pollock-Herreid
- *Mobridge
- *Evarts

Southern units:
- Crazy Horse
- Tower
- Greenwood
- Yankton

B–C–B area units:
- *Wagner
- *Geddes
- *Tyndall

Central units:
- La Framboise
- Pierre
- Rousseau
- La Roche
- Joe Creek
- Iron Nation
- Culdesac
- Grass Rope
- Fort Thompson
- Fort Hale

The Bureau of Reclamation has since completed a number of more detailed investigations on some of the above irrigation units and has done preliminary study concerning the broad Missouri River bottom lands from below Yankton to approximately 10 miles upstream from Sioux City, Iowa. These bottom lands are called the Missouri Terrace Area.

UNITS NOT FEASIBLE

Nine of the above irrigation schemes investigated have been found not feasible for further investigation or development by the Bureau of Reclamation. They are:

Name	Reason
Mobridge unit	Not economically feasible.
Evarts unit	Do.
La Framboise unit	Small acreage—insufficient irrigable land.
Pierre unit	Small acreage and land has drainage problem.

Name	Reason
Fort Thompson unit	Half of irrigable land developed privately (Northwest Irrigation Project). Remainder has private development potential. No further unit development planned.
Fort Hale unit	Not economically feasible.
Crazy Horse unit	Small acreage that can be privately developed by individuals.
Geddes unit	Not economically feasible.
Tyndall unit	Do.

UNITS FEASIBLE FOR FURTHER STUDY

Rousseau, La Roche, Joe Creek, Iron Nation, and Culdesac Units were found to be economically justified and worthy of further study should sufficient local interest develop.

Pollock-Herreid Unit.—The Pollock-Herreid Unit lies on the east side of Lake Oahe in northwestern Campbell County along Spring Creek. 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 by the U.S. Fish and Wildlife Service.

A feasibility report on the Unit was completed in January 1968, which showed engineering feasibility and economic justification.

The plan of development provides for pumping water from Lake Oahe to Lake Pocasse, which would serve as a regulatory reservoir, and then being distributed to supply sprinkler irrigation for 15,000 acres. The plan also provides for a municipal and industrial water supply for the towns of Pollock and Herreid, and for fish and wildlife enhancement.

Authorizing legislation was introduced in the 91st Congress, 1st session; however, the Department of the Interior was unable to recommend enactment until re-evaluation using new interest rates and current criteria was completed. The re-evaluation was completed in 1971 and showed that the unit still had economic feasibility; however, new irrigation projects currently have a low national priority for development.

Local interest remains keen and the Bureau of Reclamation has been requested to determine if Federal-State-Local joint financing arrangement is a plausible alternative.

Grass Rope Unit.—The Grass Rope Unit is in Lyman County, within a loop of the former Missouri River known as Big Bend. The area is part of the Lower Brule Indian Reservation and is 18 miles north of the town of Reliance. Diversion water for the unit would be pumped from Lake Sharpe to serve about 4,100 acres of irrigable land. A draft of a feasibility report was completed in fiscal year 1970; however, completion of the final report has been delayed so additional future studies may be made in cooperation with the Bureau of Indian Affairs. The Lower Brule Sioux Tribe would also be involved in multiobjective planning procedures for evaluating social and economic benefits that would accrue to the Tribe.

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.

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 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 for 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 cost.

Wagner Unit.—The Wagner Unit lies east and northeast of Lake Francis Case, formed by Fort Randall Dam on the Missouri River in south-central Charles Mix County. The Unit is located in an area of "high risk" dryland farming where agricultural economy fluctuates as erratically and widely as rainfall.

The original development plan for Wagner Unit provided for pumping water from Lake Francis Case for irrigation of 19,500 acres of irrigable land, municipal and industrial water for the towns of Lake Andes and Wagner, fish and wildlife enhancement, and recreation development.

Principal features of the plan included the following: the Randall Pumping Plant at Lake Francis Case; the Andes Canal which would convey water to Lake Andes, a natural lake to be used as a regulating reservoir; four relift pumping plants; a network of laterals for delivering water; and a system of open and closed drains.

Reconnaissance investigations of the Wagner Unit were completed in April 1959. A detailed feasibility study was initiated in 1960 and a report draft completed in 1966; however, release was withheld pending further study of high drainage costs.

The Lake Andes-Wagner Irrigation District was formed by an election of area landowners on March 11, 1969, and was enlarged by two subsequent elections. The present district encompasses essentially all of the lands (19,500 acres) in the Bureau's original proposed plan for the Wagner Unit and an additional area equal in size to the east and north of the original unit area.

A re-analysis and re-formulation of the project was initiated in fiscal year 1972. Drainage and land classification fieldwork were completed; however, further study funds were withheld because of the administration's decision to assign low national priority to study of new irrigation projects. A "wrap-up" concluding report on Wagner Unit will be completed in fiscal year 1975.

Local interest in the Lake Andes-Wagner Irrigation District among landowners remains high. They are presently exploring alternative non-Federal methods which might be used to develop irrigation in the project area.

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. The Yankton Unit is economically feasible for development, as determined from a benefit-cost comparison.

Missouri Terrace Area.—Studies by the Bureau of Reclamation and South Dakota State University show that irrigation development of the Missouri Terrace Area has potential. About 45,000 acres could be served by diversion pumping of Missouri River water. Ground-water potential in the area could also be used as a source of water supply in some instances. More detailed studies in the area for selection of a plan would depend on the local interest shown in development of irrigation.

Diversion Potential

Today, South Dakota has within its boundaries four main-stem reservoirs on the Missouri River with very large water storage capacity. Recognizing the importance of this, the 1968 South Dakota Legislature passed a concurrent resolution urging Congress to consider development and use of water of the upper Missouri Basin in upper Great Plains states before authorizing diversion of this water to other states.

Individuals and groups of landowners located conveniently adjacent to these main-stem reservoirs have developed isolated small tracts of irrigable lands by diversion of water from the impoundments. A few nearby municipalities have also used the reservoirs as a dependable water supply source. Most of these developments have occurred east of the Missouri River.

Agricultural land and the abundant, dependable water supply in the Missouri River reservoirs are significant underdeveloped resources in South Dakota, and interest in use and diversion of this stored water has continued to increase through the years. It is anticipated that the future will see considerable multiobjective water resource planning involving diversion of stored Missouri River water to meet anticipated future needs of various areas in South Dakota for irrigation, municipal and industrial water supplies, fish and wildlife enhancement, streamflow augmentation, lake restoration, and recreation.

Grand River basin

Introduction

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. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within basin.)

The drainage basin includes an area of about 5,200 square miles. An additional 500 square miles is in the headwaters of the North Fork in 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.

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. 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.[1]	509	37	29.9	14,100	0
North Fork Grand River near White Butte, S. Dak.[1]	1,190	28	58.4	30,900	0
South Fork Grand River at Buffalo, S. Dak.	148	18	8.10	2,780	0
South Fork Grand River near Cash, S. Dak	1,350	28	56.2	27,000	0
Grand River at Shadehill, S. Dak.[2]	3,120	30	122	58,000	0
Grand River near Wakpala, S. Dak.[3]	5,510	39	263	82,200	0

[1] Flow regulated by Bowman-Haley Lake beginning August 1966.
[2] Flow completely regulated by Shadehill Reservoir since July 1950.
[3] Discontinued station; flow regulated in part by Shadehill Reservoir since July 1950.

Source: U.S. Geological Survey, Water Resource Data for South Dakota, Pt. 1, Surface-water records.

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 mg/l during floods to about 2,500 mg/l during low flows. Storage and mixing of water in Shadehill Reservoir improve the quality of the water downstream. Ths dissolved-solids content of water from the reservoir averaged about 900 mg/1 for the 1954–58, 1959–68 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.

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. A rough reconnaissance survey was made 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.

Three sites were investigated. They were the Bowman-Haley site, located in North Dakota on the North Fork of the Grand River, in the vicinity of Haley, which drains a relatively small area of uncertain runoff; the Shadehill site, located about 12 miles south of Lemmon, just below the confluence of the North and South Forks of the Grand River; and the Blue Horse site, located about 17 miles south of Morristown, on the main stem of the Grand River.

Existing Development

PRIVATE

As of 1973, irrigators had filed 49 water rights to irrigate 15,867 acres by diversion. These rights are used to a very limited extent due to the lack of surface water runoff during dry periods when irrigation is needed.

FEDERAL

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 was completed August 15, 1951. Shadehill Dam is an earthfill structure across the Grand River. 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.

Shadehill Dam and related facilities are operated and maintained by the Bureau of Reclamation.

Recreation plus fish and wildlife conservation areas around Shadehill Reservoir are administered by the South Dakota Department of Game, Fish and Parks. There were an estimated 87,700 visitations to the reservoir area in 1973.

The Corps of Engineers estimates the reservoir has reduced flood damages by a total of $6,260,600 since construction.

The Definite Plan Report on the Shadehill Unit dated June 1963 (Revised January 1964) identified 6,700 acres of land as being suitable for irrigation with the supply of water available from Shadehill Reservoir. These lands are located along the north side of the Grand River from Shadehill Dam to its confluence with Wagon Creek for a distance of about 22 miles.

Efforts were made by local residents to form an irrigation district in 1963 to encompass the 6,700 acres of land; however, the vote to form an organized district failed by a small margin.

Currently, through annual water-service contracts, 13 individual water users are provided an irrigation water supply from Shadehill Reservoir to irrigate about 1,400 acres of land. Water is pumped directly from the reservoir for 400 acres. Water for the remaining

1,000 acres is released into the Grand River and then diverted by pumping by the water user.

Even though local interest and need for water resource development was instrumental in bringing about the construction of Shadehill Dam, there has not been progress among the landowners in forming a water user organization. The West River Conservancy Sub-District is currently working with the individual landowners and the Bureau of Reclamation to negotiate a long-term water-service contract for up to 5,000 acres of land.

Bowman-Haley Dam and Lake (North Dakota).—A multiple-purpose development on the North Fork of the Grand River in the Bowman-Haley area was authorized by the Flood Control Act of 1962 for the purpose of flood control, recreation, and fish and wildlife development. It is approximately 80 miles upstream from Shadehill Reservoir. The Corps of Engineers completed the structure in 1970. It has no irrigation function, but does limit North Fork streamflow available for storage in Shadehill Reservoir for irrigation purposes.

Future Development

Future surface-water development in the Grand River Basin is severely limited because of the lack of available water, and will be limited to small private landowner developments.

Moreau River basin

Introduction

The Moreau River, from its headwaters near the western border of the State, near Gustave, to its confluence with the Missouri River 180 miles downstream, 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. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within basin.) 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.D[1]	1,570	21	71.4	15,300	0
Moreau River near Faith, S.D	2,660	30	138.0	26,000	0
Moreau River near Whitehorse, S.D	4,880	19	192.0	21,000	0
Moreau River at Promise, S.D	5,223	28	282.0	36,900	0

[1] Discontinued station.

Source: U.S. Geological Survey, Water Resource Data for South Dakota, Pt. 1, Surface-water records.

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 mg/l during floods and as much as 4,000 mg/l 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.

Rainfall is erratic and inadequate for reliable crop production. 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 U.S. Bureau of Indian Affairs, 1939.

"Reconnaissance Report on Moreau River," August 1940, by the U.S. Bureau of Reclamation.

"Runoff and Waterflow Retardation and Soil Erosion Prevention for Flood Control," August 1942, by the U.S. 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 the Missouri River Basin Project. The Bureau of Reclamation during 1947–50 investigated 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 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.

Existing Development

PRIVATE

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 Department of Natural Resource Development indicate that 38 irrigators have filed water rights to irrigate 9,168 acres within the Moreau River basin. Only 1,669 acres were reported as irrigated in 1973.

FEDERAL

No Federal basin development exists because of the reasons previously cited concerning Bixby Unit.

Future Development

The general outlook for potential developments within the basin are rather dim. 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 with the Moreau River basin.

Cheyenne River basin

Introduction

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. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within basin.)

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.

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 of their normal flow where they cross the cavernous Pahasapa Limestone outcrop near the outer edge of the Black Hills uplift area. Various facilities, including small hydroelectric plants, have been developed for utilizing the sustained flow of Black Hills streams. The streams that have sustained flows also provide some excellent trout fishing and have been important in making the Black Hills one of the major recreational areas in the midcontinent region.

Selected 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	31	106.0	13,800	0
Hat Creek near Edgemont, S. Dak	1,044	24	23.2	13,300	0
Cheyenne River near Hot Springs, S. Dak	8,710	35	233.0	114,000	0.5
Fall River at Hot Springs, S. Dak	137	36	25.9	13,100	4.0
Castle Creek above Deerfield Reservoir near Hill City, S. Dak	83	25	10.0	1,120	1.2
Rapid Creek above Canyon Lake near Rapid City, S. Dak	371	27	40.3	31,200	0
Cheyenne River near Wasta, S. Dak	12,800	42	370.0	46,300	0.6
Belle Fourche River at Wyoming-South Dakota State line	3,280	27	87.8	4,400	0
Redwater Creek at Wyoming-South Dakota State line	471	21	35.8	2,440	0
Spearfish Creek at Spearfish, S. Dak	168	27	50.2	4,240	0
Bear Butte Creek near Sturgis, S. Dak	192	27	13.4	12,700	0
Belle Fourche River near Elm Springs, S. Dak	7,210	42	366.0	45,100	0
Cheyenne River near Plainview, S. Dak	21,600	23	635.0	41,700	0
Cherry Creek near Plainview, S. Dak	1,190	28	47.3	17,500	0
Cheyenne River near Eagle Butte, S. Dak.[1]	24,500	39	924.0	104,000	0

[1] Discontinued station.

Source: U.S. Geological Survey, Water Resource Data for South Dakota, Pt. 1, Surface-water records.

On June 9 to 10, 1972, thunderstorm floods struck in the vicinity of the Black Hills and Rapid City. The floods covered a relatively small area of the eastern Hills, extending from Sturgis on the north to Hermosa on the south and on the west to Pactola Dam. The flood along Rapid Creek gained national attention because of the extreme property damage and the large loss of life in Rapid City. It has been called the greatest disaster in the history of South Dakota and it was one of the most damaging floods in United States history. Damages from this flooding exceed $160 million, with 236 lives lost including 5 persons missing. The floods damaged 2,805 houses and destroyed 770; inundated 1,305 trailers and destroyed 565; and inundated 402 businesses and destroyed 35. Peak discharges of these floods at a few selected sites are given below.

Site name	Contributing drainage area (square miles)	Peak discharge (cfs)
Battle Creek at Keystone	13.6	10,800
Battle Creek near Keystone	66	26,200
Battle Creek at Canyon Mouth	110	44,100
Battle Creek at Hermosa	176	21,400
Rapid Creek below Pactola Dam	1	378
Rapid Creek at SD-40	8.35	5,750
Rapid Creek above Canyon Lake	52	31,200
Cleghorn Canyon at Rapid City	6.95	12,600
Rapid Creek at Rapid City	91	50,000
Rapid Creek near Farmingdale	283	7,320
Boxelder Creek near Nemo	96	30,100
Boxelder Creek at Nemo Road near Rapid City	117	51,600

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 mg/l is common in both the upper Cheyenne River and in the Belle Fourche River.

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 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 chemical quality of the water in the Cheyenne River, but generally the chemical quality is poor.

With respect to coliform bacteria concentrations in water from the Cheyenne and Belle Fourche Rivers, the sanitary quality of these streams also is poor. In many samples collected at monthly intervals from 1970 to 1973, coliform concentrations exceeded more than 1,000 colonies/100 ml. However, dissolved oxygen concentrations were fairly high and biochemical oxygen demand was low.

Investigations and Reports

Several investigations of 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 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," Preliminaty 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 session. 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.

Existing Development

PRIVATE

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 stream flows but decreases in prolonged periods of low flows. There are no known shallow groundwater 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 past decades.

	Irrigated acres[1]		
	1939	1949	1959
Drainage basin:			
Cheyenne River[2]	3,962	12,247	18,000
Belle Fourche River[3]	43,055	60,056	59,000
Rapid Creek[2]	9,170	8,468	7,000
Total	56,187	80,771	84,000
Bureau projects:			
Belle Fourche project[3]	34,222	51,168	55,321
Angostura unit, PS–MBP[4]			11,382
Total	34,222	51,168	66,703
Private developments[5]	21,965	29,603	17,297

[1] 1969 report format changed; data not available by basins.
[2] From U.S. Census of Agriculture.
[3] From annual project histories, Belle Fourche project.
[4] From annual project history, Angostura unit, PS–MBP.
[5] Includes lands provided a supplemental irrigation water supply from the Rapid Valley project and Rapid Valley unit.

The South Dakota Department of Natural Resource Development reported the following for 1973:

	Irrigation permits[1]	Permit acreage	Acres reported as irrigated
Belle Fourche River drainage	177	34,190	7,926
Upper Cheyenne River drainage	119	23,265	6,145
Lower Cheyenne River drainage	35	10,644	1,290
Total	331	68,099	15,361

[1] Not included are: 1. Dry draw, spreader type irrigation. 2. Belle Fourche Project and Angostura Unit irrigation. 3. Vested water rights originating before 1907 (Rapid, Spearfish, Redwater, and Beaver Creeks).

FEDERAL

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 mile-long Inlet Canal, which supplies the off-channel Belle Fourche Reservoir. The Belle Fourche Reservoir is formed by the Belle Fourche Dam, which is an earthfill structure 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 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.

Water shortages plagued Belle Fourche Project since the beginning and investigations from time to time were 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 (1) a supplemental water supply for the Belle Fourche Project in South Dakota, (2) flood control along the Belle Fourche River valley in Wyoming and South Dakota, and (3) 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.

The Belle Fourche Irrigation District 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 provides additional water to the project and helps 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. It was completed 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 12,218 acres of new land and to supply water needed for the potential Cheyenne Pumping Units, generation of hydro-electric 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 was located approximately 500 feet downstream from the face of the dam.

The Angostura Unit's irrigable lands consist of 12,218 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 permanently 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 108 irrigated farm units 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). At present 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.

Future Development

An inventory made in 1963 of land and water resources of the Cheyenne River basin, both in Wyoming and South Dakota, together with a re-examination 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. Additional studies reduced the reservoir to 27,000 acre-feet and irrigable land to 2,650 acres. 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 on available water supplies and land classification resulted in the conclusion that the Unit was not economically justified and had questionable water supply during dry years.

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 water 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 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 Unit and Rapid Valley Project 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 was 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 water-quality analyses for a station near Elm Springs indicate 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 constitutents 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 were three general possibilities for reducing water shortages on Angostura Unit: (1) Increasing farm efficiency; (2) reducing conveyance losses; and (3) obtaining additional supplies Any one of these or any combination of them would be effective. The first possibility—increasing farm efficiency—would save about 3,000 acre-feet of water annually, but would require the cooperation of the water users. The second possibility—reducing conveyance losses—appeared very attractive, because such losses were estimated to be high on Angostura Unit, approximately 13,600 acre-feet annually. The third possibility—obtaining an additional water supply—appeared to be the least feasible 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 a buried asphaltic membrane lining of the main canal and lateral system was the most feasible means of alleviating possible future shortages on Angostura Unit. Lining of the canals and laterals was completed in 1965. 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. Increased farm efficiency and reduction of conveyance losses appear to have resolved present water supply problems for Angostura Unit.

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 stream flows 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 because of 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.

The "Report on Supplemental Water Supply Investigation, Belle Fourche Project" 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 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.

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 now 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.

Bad River basin

Introduction

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 Missouri River it is about 5 feet per mile. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within basin.)

Because of low infiltration rates in the gumbo soils of the basin, runoff from intensive rainfall is rapid and streamflow often changes from no flow to floodflow within a single day.

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	1,460	28	68.2	29,400	0
Bad River near Fort Pierre, S. Dak	3,107	45	155	43,800	0

Source: U.S. Geological Survey, Water Resource Data for South Dakota, pt. 1, surface-water records.

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 mg/l $CaCO_3$.

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 Bierwagon 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, "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, South Dakota, 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 the project were too scanty and no recommendation was 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 for development for the Philip Unit was studied and found infeasible at that time.

Existing Development

PRIVATE

The South Dakota Department of Natural Resource Development reports 26 irrigators have water permits for direct stream diversions to irrigate 8,048 acres. Only 652 of these acres were irrigated in 1973. The erratic-flow characteristics of the Bad River probably account for the low utilization.

FEDERAL

No Federal water resource development exists in the basin because of its poor development characteristics.

Future Development

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 addtional 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.

The Bad River is known 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, South Dakota.

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 aimals 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. Thus, no significant surface water development is foreseen for the Bad River Basin.

White River basin

Introduction

The White River heads in northwestern Nebraska, flows generally northeastward, and enters South Dakota a few miles northeast of Chadron, Nebraska. West of Interior, South Dakota, 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. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within basin.)

In the reach from Crawford, Nebraska, to Oglala, South Dakota, 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 Little White River, or South Fork as it was formerly 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 ground-water inflow from this area sustains the streamflow.

Discharge from the Little White River, although gradually diminished downstream, has been sufficient to maintain a flow at the mouth of the White River since 1928 except for a 15-day period in August

1971. 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	35	20.2	1,580	[1] 2.7
White River near Oglala, S. Dak	2,200	30	57.5	5,200	0
White River near Kadoka, S. Dak	5,000	31	289	21,700	0
Little White River near Rosebud, S. Dak	1,020	30	112	4,640	10
Little White River below White River, S. Dak	1,570	24	131	13,700	[1] 7
White River near Dacoma, S. Dak	10,200	45	538	51,900	0

[1] Minimum daily discharge.

Source: U.S. Geological Survey, water resource data for South Dakota, pt. 1, surface-water records.

Water from the White River and tributaries is of relatively good chemical quality. The dissolved-solids content of the water averages only about 400 parts per million (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.

The suspended-sediment carried by White River is composed mostly of fine silt and clay (bentonite). Particle-size analyses of suspended-sediment samples indicate that 90 to 95 percent of the sample is less than 0.016 millimeters (mm) and that about 75 percent is less than 0.002 mm in diameter. Suspended-sediment discharge during the 1973 water year at the station near Oacoma varied from 3.1 to 1,220,000 tons per day; discharge-weighted concentrations during this same period varied from 76 to 69,000 milligrams per liter (mg/l).

All important tributaries enter the White River from the south and derive perennial flow directly or indirectly from the sandhills. The water has high concentrations (30 to 60 mg/l) of silica typical of water from sandhill streams.

Monthly data collected in 1970 indicate that dissolved oxygen concentrations are fairly high and represent water nearly saturated with dissolved oxygen. About half of the samples (four) that were examined for coliform bacteria exceeded 1,000 colonies/100 ml.

Existing Development

PRIVATE

Records of the South Dakota Department of Natural Resource Development indicate that 122 water permits have been issued for diversion irrigation of 22,125 acres. Only 6,357 acres were reported as irrigated in 1973. Erratic streamflow limits the number of acres that can be irrigated.

FEDERAL

Irrigation in the White River basin has been sporadic. The only project which has operated continuously since its construction in 1923 is the Whitney Project in Nebraska. (Not shown in table or included in fig. 48 because it is not located in South Dakota.)

In the 1930's the Bureau of Indian Affairs constructed dams and canals for irrigation projects on White Clay Creek, a tributary of the White River, that are now in use.

White Clay Project.—White Clay Dam was constructed across White Clay Creek by the Bureau of Indian Affairs as an earth-fill structure located a few hundred yards north of the South Dakota-Nebraska border near Pine Ridge with the 1,500 acre-feet reservoir extending into Nebraska. It provides supplemental irrigation water by canal to a sprinkler system serving 200–400 acres of truck garden operated by the Oglala Sioux Tribe.

Oglala Project.—Oglala Dam is an earth-fill dam also constructed by the Bureau of Indian Affairs across White Clay Creek approximately 19 miles downstream from White Clay Dam and near the village of Oglala. It has a reservoir capacity of 7,200 acre-feet and was originally designed to serve 2,000 acres It currently provides water to approximately 600 acres by both gravity and sprinkler irrigation operated by the Oglala Sioux Farm and Ranch Enterprise.

Future Development

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, South Dakota, are such that sustained irrigation is questionable. The occurrence of selenium in the water and the high sodium content of the water are undesirable. Large sediment loads of fine silt from Badlands drainage also pose unresolved problems in surface-water development for sustained irrigated agriculture. The Little White River (South Fork White River) has water of good quality, but development cost would be high and the water quality would deteriorate when mixed with White River water below its confluence.

Pine Ridge Unit.—Pine Ridge Unit is located in Shannon County in southwestern South Dakota within the Pine Ridge Indian Reservation. The unit would be a multipurpose project for irrigation, flood control, recreation, and fish and wildlife conservation. The unit includes 6,940 acres of irrigable lands along the White River downstream from the proposed Slim Butte Dam and Reservoir.

The area is semiarid, with average annual precipitation of about 16 inches. Less than 1 percent of the irrigable land is in crops; the remainder is used for grazing. There is a lack of employment opportunity in the area. Farm units have been increasing in size, and development of irrigation would increase farm employment and create additional jobs. Recreation and tourism could also be developed to increase employment opportunities.

Investigations were conducted on the White River Basin by the Bureau of Reclamation during the middle 1950's and a Report on White Division completed in January 1959 was revised August 1960. A detailed study of Pine Ridge Unit was initiated in 1962 at the request of the Oglala Sioux Tribe.

A feasibility report on Pine Ridge Unit, completed in September 1968, concluded that the plan of development had engineering feasibility and economic justification.

Slim Butte Reservoir site is situated about 5 miles north of the Nebraska-South Dakota State line. The 6,940 irrigable acres lie in relatively small isolated tracts along the White River, beginning a short distance below the dam site and extending downstream about 120 river miles. The tracts range in size from 22 to 290 acres. Irrigation water supply would be released from storage in Slim Butte Reservoir and diverted from the White River by semiportable pumping plants.

The feasibility report for Pine Ridge Unit was submitted to the Commissioner of the Bureau of Indian Affairs on February 6, 1969, for recommendations as to further action. BIA advised the Bureau in February of 1970 that they were considering a companion report. No further significant actions have occurred since.

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, South Dakota, 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 mainstem 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, but this active interest has also generated some opposition.

The Little White Dam, as proposed, would impound 65,000 acre-feet of water to 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 mainstem 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 mainstem White River is still of questionable quality after mixing with the good-quality flows from the South Fork. Water-soil quality relationships needed to be investigated for additional data.

The Bureau of Reclamation made further soil-water relationship studies, which were completed in 1965, to answer questions regarding soil-water qualities and the type of irrigation facilities that would best fit the needs of the area.

Feasibility of the Little White Unit is dependent upon sustained irrigation for a project life of at least 100 years. Most irrigable lands that could be service from the Little White Unit are located along the main-stem White River downstream from the confluence of the Little White River. The sediment content of the White River below the confluence, even when flow is augmented with controlled releases of good quality water from the Little White Reservoir, are such that irrigated lands could be rendered unproductive in approximately 50 years. The Little White Unit was therefore not economically feasible.

White River water would be suitable for irrigation if it were cleared by sediment retention. Sediment could probably be removed from White River water by constructing a dam and reservoir on the White River at the Weta site. The Bureau of Reclamation included a preliminary study of the Weta site, located on the White River approximately 52 miles upstream from its confluence with the Little White River, in its 1965 report with the conclusion that development of Weta site would result in suitable irrigation water that could serve 12,000 acres from the dam site to Lake Francis Case. However, development could not be economically justified from benefits.

Rosebud site.—As planned by the U.S. Corps of Engineers, Rosebud Dam would be a multipurpose project with the 120-foot-high, 4,000-foot-long earthfill structure built across the Little White River 1½ miles north of the Mellette-Todd County line. The entire project lies within the confines of the Rosebud Indian Reservation. It would create a scenic lake 4.3 miles long with 26 miles of shoreline and 140,000 acre-feet of maximum water storage. The project was found to be not economically justified.

Senate Bill 2402 and House of Representatives Bill 10411 were introduced in September 1973 to authorize construction at Rosebud site. Both bills cite the reason for construction as being the desperate need of the Indian people for reservation economic development. Final action on both bills is pending.

Keya Paha River basin

Introduction

The upper basin of the Keya Paha River includes an area of about 1,100 square miles east of the Little 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, South Dakota. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within basin.)

Sandy areas similar 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 groundwater inflow. Streamflow records for the mainstream at Wewela show a moderate sustained flow in most years. During the periods of record, 1938–40 and 1947–73, the stream flowed continuously except during an extremely cold period in January and February 1949. A maximum discharge of 5,430 cfs occurred in March 1952. Discharge for the 28-year period of record averages 70.9 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 mg/1; however, the water is hard, and has the relatively high silica content typical of water derived principally from ground water of the sandhills areas.

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.

In June 1963 the Bureau of Reclamation completed a report on 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.

Existing Development

PRIVATE

The 1959 agricultural census indicated that very minor acreages were being irrigated. Records of the State Water Resources Commission, as of July 1, 1963, indicated a total of 15 surface water rights to irrigate an estimated 1,280 acres by stream diversion; an additional 13 filings existed 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, and updated census information is not readily available for this basin.

Future Development

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 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. Local interest within the basin is not evident.

James River basin

Introduction

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. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within basin.)

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. This gradient is so flat that at times high inflow from a tributary stream will cause the 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 from the larger drainage areas 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. Low flow on the Elm River 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	28	103.0	5,420	−1,860
Elm River at Westport, S. Dak	1,680	28	47.1	12,600	0
James River at Ashton, S. Dak	11,000	28	154.0	5,680	−2,100
Turtle Creek at Redfield, S. Dak.[1]	1,540	27	24.8	7,660	0
James River at Huron, S. Dak	16,800	34	237.0	9,000	0
Sand Creek near Alpena, S. Dak	240	23	10.7	2,240	0
James River near Scotland, S. Dak	21,550	45	386.0	15,200	0

Note: Negative numbers indicate reverse or upstream flow.

[1] Discontinued station.

Source: U.S. Geological Survey, water resource data for South Dakota, Pt. 1, surface-water records.

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 mg/l.

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 mg/l. Hardness as $CaCO_3$ of the water also increases, at times to more that 500 mg/l. The qualify of the water during periods of no flow is of considerable importance to users, such as the citizens of Huron, who depend on the river for their water supply.

The dissolved oxygen (DO) concentration in the James River is fairly high most of the time. A few DO concentrations of less than 5.0 mg/l have been reported during the winter months when deep snow covered the ice layer. Under these conditions the DO concentration could drop to practically zero, suffocating fish. Local news media have reported fish kills only after the ice breakup in the spring, when such an event could be observed. A few biochemical oxygen demand (BOD) values have been reported in excess of 30 mg/l, usually in mid- to late summer and early fall when algal growths are heavy. During the rest of the year reported BOD values are fairly low. Many of the samples examined for coliform bacteria exceed 1,000 colonies/100 ml of sampled water.

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 artesian water proved unsuitable for irrigation use, the people of the area 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.

Existing Development

PRIVATE

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 South Dakota Department of Natural Resource Development reported in 1973 that 319 irrigation water permits had been issued for 67,709 acres, of which only 14,078 acres were actually irrigated.

Willow Creek Dam.—In 1954, city officials and interested citizens of Aberdeen 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 filling 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. Water 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, leaving the structure unusable.

The Bureau of Reclamation completed a "Report on Rehabilitation of Willow Creek Dam, James Division, South Dakota, MRBP" in March 1955. The report concluded that although it was possible to store a total of 3,100 acre-feet of water, 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 now contributes to its supply of municipal water.

FEDERAL

Oahe Unit—Initial Stage.—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 conducted 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 South Dakota State University 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.

Refinement of field data and additional study of plans were continued by the Bureau until reports of these feasibility studies were completed in 1965. The Bureau's "Report on Oahe Unit," dated May 1965, presented an overall multipurpose plan of development, including 495,000 acres of irrigation, commonly referred to as the "ultimate plan." For a project of this size, construction would probably extend over 40 years; some portions of the Unit would be in operation before others; and construction of certain features of the supply system could be deferred until later needed. From consideration of these factors, it was concluded that construction of the overall plan could best be accomplished in stages. An "initial stage" concept for a multipurpose plan of development, including only 190,000 acres of irrigation, was subsequently presented in the Bureau's "Supplemental Report on Oahe Unit," dated June 1965. Both reports (ultimate plan and initial stage plan) are contained in House Document No. 163 (90th Congress, 1st Session).

Congress authorized construction of the Initial Stage (190,000 acres) plan for Oahe Unit by the Act of August 3, 1968 (82 Stat. 624), also known as Public Law 90–453.

A Definite Plan Report on the initial stage of Oahe Unit was completed in 1971 to present information on changes in the authorized plan from the feasibility report, update costs, present findings of additional studies, and report on construction prerequisites. The Final Environmental Statement was completed at the end of 1973. Thirty years of continuous study on Oahe Unit was culminated by the groundbreaking for the construction of Oahe Pumping plant in early 1974.

The plan for initial stage of development provides for diversion of water from the existing Lake Oahe on the Missouri River for irrigation of 190,000 acres of land, for municipal and industrial use in 17 towns and cities in and near the Unit, for fish and wildlife developments at 18 locations, and for recreation uses. There would also be flood control benefits.

The principal features and their functions will be briefly described in the order in which they will occur as the water flows eastward to serve the lands proposed for development (see figure 51 and table 47).

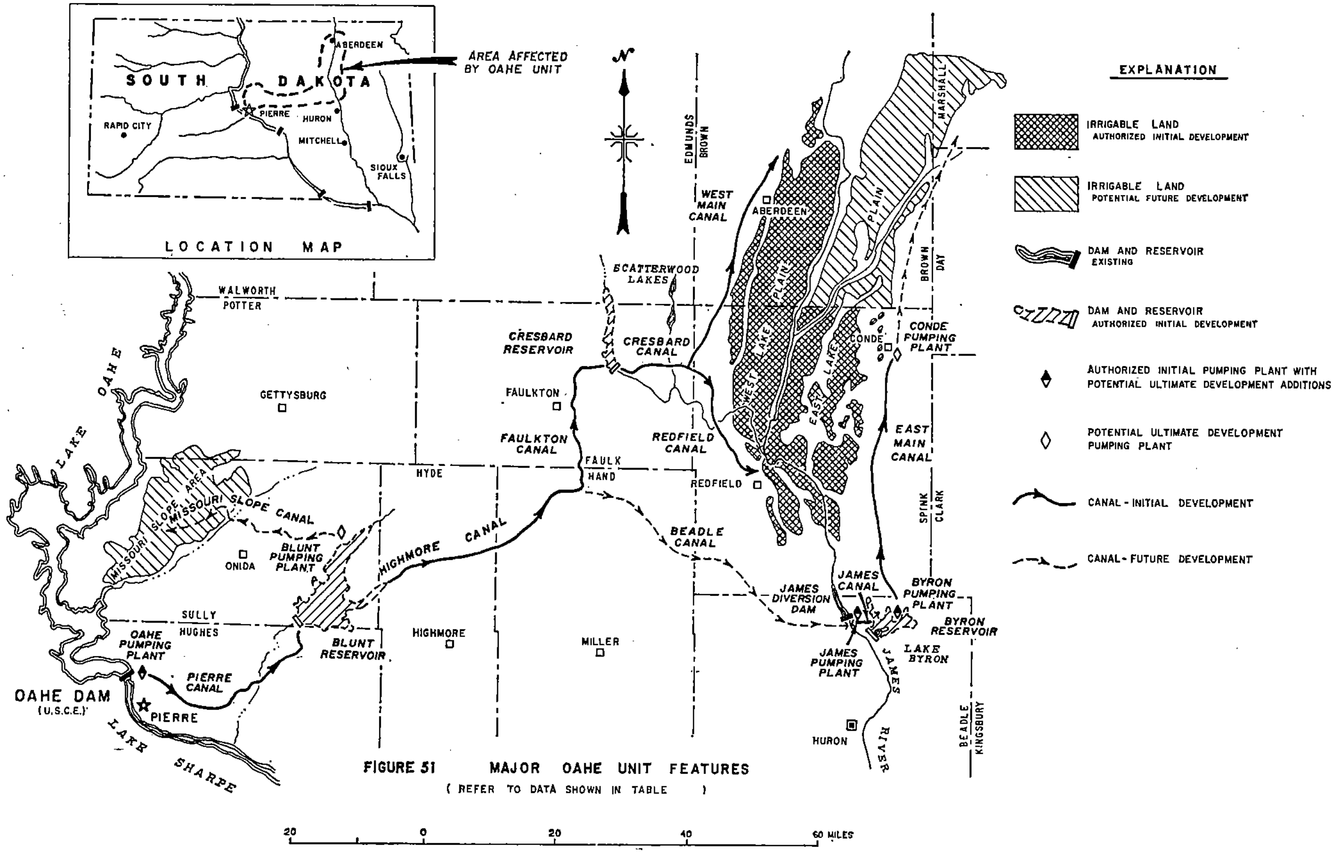

Figure 51.—Major Oahe Unit features.

TABLE 47.—MAJOR OAHE UNIT FEATURES AND DATA[1]

[Total reservoir storage capacity to top of conservation storage only. Initial stage plan authorized for construction by act of Aug. 3, 1968 (82 Stat. 624). Potential ultimate development—expansion of initial stage feature and addition studied]

Feature (see fig. 51 for location)	Total reservoir storage capacity (acre-feet)	Source of water	Initial stage plan (190,000 irrigable acres)					Potential ultimate development (495,000 irrigable acres)				
			Pumping plants			Supply canals		Pumping plants			Supply canals	
			Number of pump units	Total pumping capacity (cubic feet per second)	Average pump lift (feet)	Initial capacity (cubic feet per second)	Length (miles)	Number of pump units	Total pumping capacity (cubic feet per second)	Average pump lift (feet)	Initial capacity (cubic feet per second)	Length (miles)
Oahe Dam and Lake Oahe	22, 500, 000	Missouri River										
Oahe pumping plant		Lake Oahe	2	1, 200	122			4	3, 200	122		
Pierre Canal		Oahe pumping plant				1, 200	37				3, 200	37
Blunt Dam and Reservoir	631, 000	Pierre Canal[1]										
Highmore Canal		Blunt Reservoir				2, 130	38				3, 650	38
Faulkton Canal		Highmore Canal				2, 050	24				2, 050	24
Cresbard Dam and Reservoir	37, 600	Faulkton Canal[2]										
Cresbard Canal		Cresbard Reservoir				3, 300	12				3, 300	12
West Main Canal		Cresbard Canal				2, 400	37				2, 400	37
Redfield Canal		Cresbard Canal				1, 080	22				1, 080	22
James Diversion Dam and Reservoir	4, 980	James River[3]										
James pumping plant		James Diversion Reservoir	1	500	28. 5			4	2, 000	21. 5		
James Canal		James pumping plant				500	3				3, 400	3
Byron Dam and Lake Byron	73, 600	James Canal[4]										
Byron pumping plant		Lake Byron	2	1, 200	71			6	4, 800	71		
East Main Canal		Byron pumping plant				1, 200	41				4, 800	77
Blunt pumping plant		Blunt Reservoir	(5)	(5)	(5)	(5)	(5)	6	1, 000	181		
Missouri Slope Canal		Blunt pumping plant	(5)	(5)	(5)	(5)	(5)				1, 000	37
Beadle Canal		Highmore Canal	(5)	(5)	(5)	(5)	(5)				1, 500	53
Conde pumping plant		East Main Canal	(5)	(5)	(5)	(5)	(5)	6	3, 600	17		

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[1] Reservoir also receives small streamflow from Medicine Knoll Creek drainage.
[2] Reservoir also receives small streamflow from Cresbard Creek drainage.
[3] Natural streamflow augmented by irrigation return flows.
[4] Reservoir also receives small streamflow from Foster Creek drainage.
[5] Not part of initial stage Oahe unit.

The Oahe Pumping Plant is being constructed near the powerplant at the left (east) abutment of Oahe Dam. Provision has been made in construction of the dam to connect the pumping-plant intake to a tee installed in the two surge-tank risers for the seventh turbine and generator. The pumping plant will have a capacity of 1,200 cubic feet per second (cfs) and will lift water an average of 122 feet into the headworks of Pierre Canal. 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 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 Canal bifurcation works.

The Faulkton Canal will extend north from the Highmore Canal bifurcation works and discharge into Cresbard Reservoir. This reservoir will be created by Cresbard Dam, which will be an earthfill structure about 5,200 feet long at the crest and about 55 feet in maximum height. Cresbard Reservoir will have a total storage capacity of 37,600 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 12 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.

The supply system that will serve the East Lake Plain area of Oahe Unit begins with the existing James Diversion Dam on the James River. Studies by the Bureau showed that advance construction of the dam was the most feasible way to furnish the city of Huron with a supplemental water supply. The James Diversion Dam was therefore completed by the Bureau of Reclamation in the fall of 1964 as an advance feature of Oahe Unit.

The dam is located in northern Beadle County about 15 miles north and 1 mile west of Huron. The structure consists primarily of a 50-foot-long concrete overflow weir and a gated sluiceway. An auxiliary spillway, 1,900 feet long and 150 feet wide, was constructed to bypass major floodflows and thus protect the dam. The maximum reservoir pool (at elevation 1240.5) covers about 960 acres. The maximum water depth at the dam is 13 feet. Downstream releases from the impoundment above the dam are controlled by a 6- by 6-foot slide gate at the head of the sluiceway.

In the irrigation plan, James Diversion Dam will provide the pool on the James River required for satisfactory operation of the intake for the James Pumping Plant. Water from this impoundment will be pumped by the James Pumping Plant to the James Canal for conveyance to storage in Byron Reservoir.

The water supply for irrigation will originate from releases through the West Lake Plain water-use works into the James River, irrigation return flows from both the East Lake Plain and the West Lake Plain, and from natural flows and floodflows occurring in the James River.

The Byron Reservoir, an enlargement of the existing Lake Byron, will be formed by Byron Dam, an earthfill structure with a maximum height of 43 feet and a crest length of 7,600 feet. The total storage capacity of Byron Reservoir will be 73,000 acre-feet.

Water for the East Lake Plain area will be pumped from Byron Reservoir by means of the 1,200-cfs 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 to provide irrigation water to the East Lake Plain area lands being developed in the initial stage.

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.

The authorized plan calls for construction of channel modifications of the James River to provide the capacity required for handling return flows from the ultimate size Oahe Unit to avoid disturbing the river bottom a second time. Public concern has developed in opposition to the authorized channel modification, particularly with respect to adverse environmental impacts and other problems concerning lower reaches of the James River below the project area.

A study team designed to obtain public involvement in investigation of alternative methods for handling Oahe Unit return flows in the James River was jointly implemented by the State of South Dakota and the Bureau of Reclamation in mid-1974. This public involvement with appropriate State and Federal agencies providing technical support should result in recommendation of a suitable method that is also environmentally sound for handling Oahe Unit return flows in the James River.

Construction of Oahe Unit started one of the most dramatic and challenging phases of Missouri River Basin development in South Dakota. About 8 years of construction will be needed before Missouri River water first begins to be available for irrigation and other uses.

The cost of constructing the initial stage of the Unit is estimated at more than $300 million. Depending on appropriations, 15 to 20 years will be needed to construct the Unit.

Future Development

POTENTIAL ADDITIONS TO OAHE UNIT

When construction of the initial stage of Oahe Unit was authorized in 1968, the Congress was also furnished a feasibility report on an ultimate plan (H.D. 163, 90th Congress, 1st Session) for multipurpose development, including up to 495,000 acres of irrigation in South Dakota. The potential ultimate plan was considered by the Congress but not approved except for facilities that should be a part of both initial stage and ultimate plan. This consideration of the ultimate project concept with construction of a general independent initial stage involved the understanding that further planning and review of additional development and consideration of environmental and other effects would be necessary before Congressional consideration of extension of the development.

The overall concept of the potential ultimate plan is shown in the Regional Director's Feasibility Report on Oahe Unit, dated May 1965, which is printed in H.D. 163, 90th Congress, 1st Session. It involves irrigation of an additional 350,000 acres of land which is located in the Missouri Slope area, northern part of the East Lake Plain area, and within the boundaries of the West Lake Plain area. It increases fish and wildlife development areas from 18 to 29 areas and water service to municipalities from 17 to 23 municipalities. Economic and social impacts would be nearly triple those of the initial stage.

Several features would need to be added or enlarged to accommodate expansion of the 190,000–acre initial stage to the 495.000-acre ultimate development. Their general locations are shown on figure 51; they would include the following: (1) addition of pumps, motors, and waterways at Oahe Pumping Plant; (2) enlargement of Pierre and Highmore Canals; (3) addition of bifurcation works at the terminus of Highmore Canal, and construction of the 53-mile Beadle Canal from the bifurcation works to the James Canal; (4) additions to the James Pumping Plant and enlargement of James Canal; (5) additions to the Byron Pumping Plant and enlargement of East Main Canal to Conde; (6) construction of Conde Pumping Plant and extension of East Main Canal northward for a distance of about 37 miles; (7) enlargement and extension of the lateral and drainage systems; and (8) construction of the complete water supply system for the Missouri Slope area, beginning with the Blunt Pumping Plant at Blunt Reservoir, the Missouri Slope Canal, and also the necessary lateral and drainage systems.

Implementation of future stages or completion of the entire ultimate project would require additional feasibility studies and construction authorization by the Congress, as previously noted. Also, before undertaking further development, additional consideration would have to be given to the cumulative environmental effects of the additions, and environmental statements would have to be prepared.

Mitchell Unit.—Mitchell Unit is located near the confluence of Firesteel Creek with the James River in northeastern Davison County in southeastern South Dakota.

A feasibility investigation of the Mitchell Unit was authorized by the Congress, by the Act of September 7, 1966 (80 Stat. 707). The feasibility report was completed in 1968.

The plan of development provides for diverting excess flows from the James River to existing Lake Mitchell for municipal and industrial use by the city of Mitchell and for purposes of fish and wildlife enhancement and of recreation.

Principal features of the proposed development include: (1) Mitchell Diversion Pumping Plant on the James River, and (2) Mitchell Diversion Pipeline, consisting of a 2.2-mile-long, 27-inch-diameter pipeline from the pumping plant to Lake Mitchell. Existing facilities associated with the plan are (1) a rockfill dam and channel pool on the James River, (2) Lake Mitchell, the municipal storage resevoir, and (3) the waterworks system of the city of Mitchell.

The 1968 feasibility report found the Unit to be economically feasible. Development of the Unit will depend on the desires of the citizens of the city of Mitchell.

Future Resource Development Problems

The James River drains an area of about 22,100 square miles, 70 percent of which is in South Dakota, and meanders 710 miles to cover a straight line distance of 250 miles from its headwaters to the Missouri River. As a natural stream, it has extremely flat slopes and very slow velocities. At low flow, it is a placid stream that meanders continuously along its course through the shallow valley. During high high flows, as runoff exceeds the natural channel capacity, the stream slowly inundates the flat flood plains until the James River Valley resembles a large elongate lake. Major floods cause little destruction to cultural features, but do result in long periods of inundation of agricultural lands which result in economic loss. Total damages in the James River Basin during the 1969 flood were estimated at $16 million. Examination of average annual flows is misleading because over 75 percent of the volume of flows occurs from spring snowmelt and spring rains during the period March through June. The water quality in the James River is notably poor when streamflow is low. The low topographic relief of the main-stem valley makes it difficult to locate suitable reservoir storage sites without adverse environmental impact.

The James River has been the subject of numerous past studies and undoubtedly will continue to be a subject of future study. A 1922 report by W. S. Reeves, Chief Drainage Engineer of South Dakota, titled "Report of the Drainage and Flood Control Investigations in the James River Valley through South Dakota", summarized the results of an investigation by stating that flood control for the James River basin was possible but not economically feasible. Potential reservoirs were investigated on all tributary streams and the main stem of the James River by the Corps of Engineers in 1930 and in 1947. Most of the tributary sites were written off as having inadequate storage capacities for effectively providing control of the James River floodflows.

The extensive drainage area of the James River in North and South Dakota is an interrelated hydrologic and economic unit for planning purposes. Effective plans however, must recognize the complex and dynamic roles of the many governmental and organizational entities that have interest in and responsibility for orderly planning for use of such a vital resource as water.

Past cooperative organization of local, State, and Federal interests has helped to consolidate future study efforts towards solving James River problems. An organization composed of a loosely formed group of Federal, State, and local governmental agencies, called the James River Projects Formulation Committee, was formed in August 1965 with the objective of coordinating and outlining future studies and needs of the James River Basin. Before the Missouri Basin Interagency Committee had dissolved, it had recommended a Type II (now known as Level "B") study for the James River Basin. The Missouri River Basin Commission (MRBC), established in 1972, has continued to support James River Level "B" studies. A comprehensive study proposal was submitted by MRBC to the Water Resources Council in 1972; however, no Federal funding has been provided as of 1974.

The major future study objective for the James River Basin should be development of an overall water resources plan which integrates all water uses—development, conservation, and management of the basin's resources. This plan must take into account existing development and must also be a joint effort of all interests involved at all levels of organizations—local, State, and Federal.

Vermillion River basin

Introduction

About 2,180 square miles in the southeastern quarter of the State, between the James River on the west and the Big Sioux River on the east, make up the Vermillion River basin. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within 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 DeSmet 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, from which point the Vermillion River flows in a southerly direction to its confluence with the Missouri River near Vermillion. Streamflows derive principally from early spring snowmelt and spring rains. Heavy local thunderstorms occur during spring and early summer, causing large runoffs during short periods of time and at unpredictable intervals.

The topography of the basin is typical of glaciated areas, and the stream valley is bordered by undulating uplands of glacial till.

The climate in the basin is classified as moist subhumid. Rainfall is erratic. Precipitation in the basin averages about 23 inches a year

Streamflow records collected near Wakonda (1945–73) show an average discharge of 120 cfs from the 1,680 square mile drainage area above the gaging station. The snowmelt flood in the spring of 1969 produced the maximum known discharge, 9,880 cfs. Periods of no flow, usually during the fall and winter, have occurred in five of the 28 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 mg/1. Scanty data suggest that the quality of the water improves downstream and that manganese concentrations of more than 500 mg/1 are not uncommon during periods of low flow.

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 a 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 its 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.

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, South Dakota. 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 present method of developing irrigation in the Vermillion River basin as long as these supplies are available.

Existing Development

PRIVATE

A 1973 report by the South Dakota Department of Natural Resources reveals that 97 irrigation water permits for 15,694 acres had been issued for the Vermillion River basin with only 4,321 acres being reported as irrigated that year.

FEDERAL

The Soil Conservation Service has received applications for watershed development projects under the Small Watershed Act, P.L. 566, for an area of about 530,740 acres in the Vermillion River basin. Two of these watershed plans, Turkey Ridge Creek and Hurley Creek, have been completed.

Future Development

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 development 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 would be 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.

Big Sioux River basin

Introduction

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, South Dakota. Thence it forms the South Dakota-Iowa border to the southeast corner of South Dakota and empties into the Missouri River at 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. (See tables 40 and 42 and figures 47–49 for existing and future developments and reservoirs within basin.)

The upper half of the Big Sioux River basin is broad and shallow; however, from Dell Rapids to the mouth, the valley becomes well defined. The basin is 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 population within the basin is engaged in agricultural pursuits.

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]	1, 800	27	33. 3	2, 220	0
Big Sioux near Brookings, S. Dak	4, 420	20	169.	33, 900	0
Big Sioux near Dell Rapids, S. Dak	5, 060	25	275.	41, 300	.20
Skunk Creek at Sioux Falls, S. Dak	570	25	50. 4	29, 400	0
Big Sioux River at Akron, Iowa	9, 039	45	862.	80, 800	7

[1] Discontinued station.

Source: U.S. Geological Survey, water resource data for South Dakota, pt. 1, surface-water records.

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 other valleys in South Dakota, and flood damage is a major problem—particularly in the lower basin. The snowmelt floods of 1960 and 1962 which caused damages amounting to several million dollars were greatly exceeded by the record-breaking flood of April 1969. Peak discharge of the Big Sioux River from Watertown to Sioux Falls in 1969 was more than twice that of 1962, the previous maximum of record. 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 floods; smaller floods in the past caused considerable damage.

The dissolved-solids content of water in the Big Sioux River and most tributaries fluctuates between 100 and about 900 mg./l. 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 several low head dams.

In general, dissolved oxygen concentrations in the Big Sioux River have been found to be high, and biochemical oxygen demand low. Usually below municipalities, coliform bacteria have been found to be moderately high—more than 1,000 colonies/100 mg—probably because of municipal sewage-waste discharge to the River.

Existing Development

PRIVATE

The South Dakota Department of Natural Resource Development reported that 167 irrigation water permits had been issued for 23,580 acres by 1973. During that year, only 7,226 acres were reported as actually being irrigated.

FEDERAL

Watershed Protection Projects (P.L. 566) were discussed earlier in this report. Two projects, Scott Creek and Green Creek, have been completed. A number of others have been authorized and are now under construction and development.

The Flood Control Act of 1954 authorized construction of a local protection project to alleviate the flood threat to the urban areas in Sioux Falls. Begun by the Corps of Engineers in 1956, the project was completed in 1965. The project includes 10.8 miles of channel improvement through the city, 2.7 miles of new diversion channel, and 27.1 miles of levees.

Future Development

The Bureau of Reclamation completed a study of the Big Sioux Basin in 1968. The report stated in part as follows:

1. Studies by South Dakota State University show that operator profits from irrigation would be substantial after allowing for increased investment and operation costs.
2. About 147,000 acres of land along and near the Big Sioux River from Watertown to the river's mouth are susceptible to irrigation. Of this amount, 58,500 acres are favorably situated downstream from potential reservoir sites and could be furnished a water supply from reservoir storage. This acreage and the remaining 88,500 acres might also be served by pumping from ground water. Development, of course, would be limited to available water resources.

3. More studies are required of the two principal sources of water: (1) Development of surface supplies by storage, and (2) development of ground water where adequate. A third alternative source, the Missouri River, could be developed from a physical standpoint but because of high construction and pumping costs would not be economically feasible until water would become more valuable.

4. Development of a supplemental water supply for the city of Sioux Falls appears to be one of the more urgent needs.

5. Additional studies of streamflow by establishment of gaging stations on tributary streams are desirable. Daily quality of water and sediment measurements should be made at some of the established gaging stations. These programs can be incorporated into the Cooperative Water Resources Investigation Program.

6. Some refinement of the studies recently completed will be continued by the Bureau of Reclamation under its proposed program for investigation of all river basins in South Dakota east of the Missouri River, including the James, Vermillion, and Big Sioux Rivers.

Sioux Falls Unit.—The city of Sioux Falls requested that the Bureau of Reclamation suggest ways to meet future municipal and industrial water needs. The reconnaissance report, completed in 1969, concerned itself with the aspects of diverting some Big Sioux River flows into an offstream storage site on Slip Up Creek, and found that further study was warranted. The city of Sioux Falls and the East Dakota Conservancy Sub-District requested and obtained Congressional authorization for a feasibility study that is now near completion. The following information on Sioux Falls Unit is based on the 1969 reconnaissance report as modified by the current study.

Municipal and industrial water requirements of the city of Sioux Falls would increase more than four times by year 2030, with the population increasing about three times. Under the plan presented for Sioux Falls Unit, a substantial part of the requirements would be met by storage in Slip Up Creek and the remainder would be obtained from the well field and by direct pumping from the Big Sioux River.

The principal features of the plan studied by the Bureau of Reclamation include: (1) The Big Sioux Pumping Plant, which would pump excess flows of the Big Sioux River from the pool behind the existing weir structure on the Big Sioux River Diversion Channel into a diversion pipeline, (2) the Sioux Diversion Pipeline, which would convey the water to the proposed offstream reservoir on Slip Up Creek; (3) Slip Up Creek Dam and Reservoir; and (4) Slip Up Creek Pumping Plant, which would pump water from Slip Up Creek Reservoir into the Sioux Diversion Pipeline and return it to the Big Sioux Pumping Plant, from which it would be conveyed by the Sioux Falls Pipeline to the existing Sioux Falls Municipal Water Treatment Plant.

Other Studies.—In 1973, the Department of Agriculture completed a Type 4 Basin Study of the Big Sioux Basin for the purpose of providing land, water, and related resource information to facilitate the planning, conservation, development, and utilization of these resources. In addition, water investigation reports were prepared for 23 watersheds for use by local sponsors in developing applications for assistance through the Small Watershed Act, P.L. 566.

The Corps of Engineers has been studying the Upper Big Sioux River and tributaries. They state that the major problems of the basin are a need for flood control, and shortages of water supply and water-based recreational opportunities. The study covered the upper Big Sioux Basin and was directed primarily toward developing multi-purpose storage reservoirs to solve the aforementioned problems. Originally, five dams were considered for full development. It now appears that only the Skunk Creek Dam, near Hartford, and the Flandreau Dam, near the town of that name, can be recommended; however, economic justification for the Skunk Creek Dam is marginal and it may be deleted from the recommendation before final submission of the report in late 1974 or early 1975.

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