The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—South Dakota

By ROBERT A. SCHOON

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-T

Prepared in cooperation with the
South Dakota Geological Survey

Historical review and summary of areal,
stratigraphic, structural, and economic
geology of Mississippian and
Pennsylvanian rocks in South Dakota

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

CONTENTS

ILLUSTRATIONS

THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES—SOUTH DAKOTA

By ROBERT A. SCHOON[1]

ABSTRACT

Carboniferous rocks are widely distributed in the subsurface of South Dakota, but surface exposures are limited to approximately 3,900 km² (1,500 mi²) in the Black Hills area. In the northern Black Hills, Tertiary intrusive rocks cut and mineralized the Mississippian Madison Formation. These mineralized zones were responsible for the gold rush of 1876 to the northern Black Hills. Economic development of the Black Hills predated classic studies of the area (1899–1907) and South Dakota's admission to the Union (1889). As a result, production records were poorly preserved or never existed.

At present, commercial use is made of the following resources: oil (Pennsylvanian rocks), water (Mississippian rocks), scenery that attracts tourism (caves in Mississippian rocks), and road metal and ballast (Mississippian rocks). Mississippian rocks appear to have the greatest potential resources for future economic development; the resources are water, oil in deeper parts of the Williston basin, and geothermal energy in the south-central part of the State.

INTRODUCTION

In the Black Hills region of South Dakota, Carboniferous rocks comprise the upper part of the Devonian-Mississippian Englewood Limestone, the Mississippian Madison (Pahasapa) Limestone, and the Pennsylvanian part of the Minnelusa Formation. Basinward, to the northeast and to the east, these Carboniferous units increase in thickness and are readily divided into eight formations. These formations are, in ascending order: Mississippian – Lodgepole, Mission Canyon, and Charles Formations (collectively known as the Madison Group); Pennsylvanian – Fairbank, Reclamation, Roundtop, Hayden, and Wendover-Meek Formations as defined by Condra, Reed, and Scherer, (1940) and McCauley, (1956). North of the Black Hills area, the Lower Pennsylvanian sedimentary rocks are not as easily divided. Here it is a common, but not recognized, practice to use two terms, the Amsden (Lower Pennsylvanian) and the Minnelusa Formations to include rocks of Pennsylvanian and Permian age.

The Carboniferous rocks crop out on the periphery of the Black Hills (fig. 1). On the geologic map (fig. 2), the outcrop pattern forms a band encircling the Black Hills. This band varies in width from an average of 4.8 km (3 mi) on the east side of the Black Hills to 26 km (16 mi) on the west side. Carboniferous sedimentary rocks crop out in a small area near Bear Butte (secs. 17, 18, 19, and 20, Tps. 6 N., R. 6 E.). No other surface exposures of Carboniferous rocks are found in the State; however, Carboniferous rocks are widely distributed in the subsurface (fig. 3).

During the Carboniferous, no known igneous activity took place in South Dakota.

The stratigraphic nomenclature used in this paper has not been reviewed by the Geologic Names Committee of the U.S. Geological Survey. The nomenclature used here conforms with the current usage of the South Dakota Geological Survey.

CENOZOIC EVENTS AND SUBSEQUENT WEATHERING

According to Gries and Tullis (1955, p. 35), the close of the Mesozoic Era showed no evidence of impending Cenozoic uplift of the Black Hills area. They also stated; "White River (Middle Oligocene) beds rest on rocks as old as pre-Cambrian in the central Hills, so uplift, concurrent dissection and removal of more than 6,500 feet of sediments had been accomplished by that time." Plumley (1948, p. 536) suggested smaller scale uplifts during Miocene or Pliocene and at the beginning of the Pleistocene. Geologic history of the area is imperfectly known, but sufficient data exist to show that Carboniferous rocks were subjected to subaerial erosion throughout most of the Cenozoic Era.

In the northern Black Hills, Tertiary igneous intrusions (fig. 2) accompanied the early uplift of the area. These intrusive rocks cut Paleozoic rock and, according to Gries and Tullis (1955, p. 35), in some places extend to Upper Cretaceous rocks. Important metallic mineral deposition in Carboniferous rocks resulted from this intrusive activity.

DRAINAGE AND AREAS OF BEST EXPOSURES

The best Carboniferous exposures generally are found

[1] South Dakota Geological Survey, Vermillion, S. Dak. 57069.

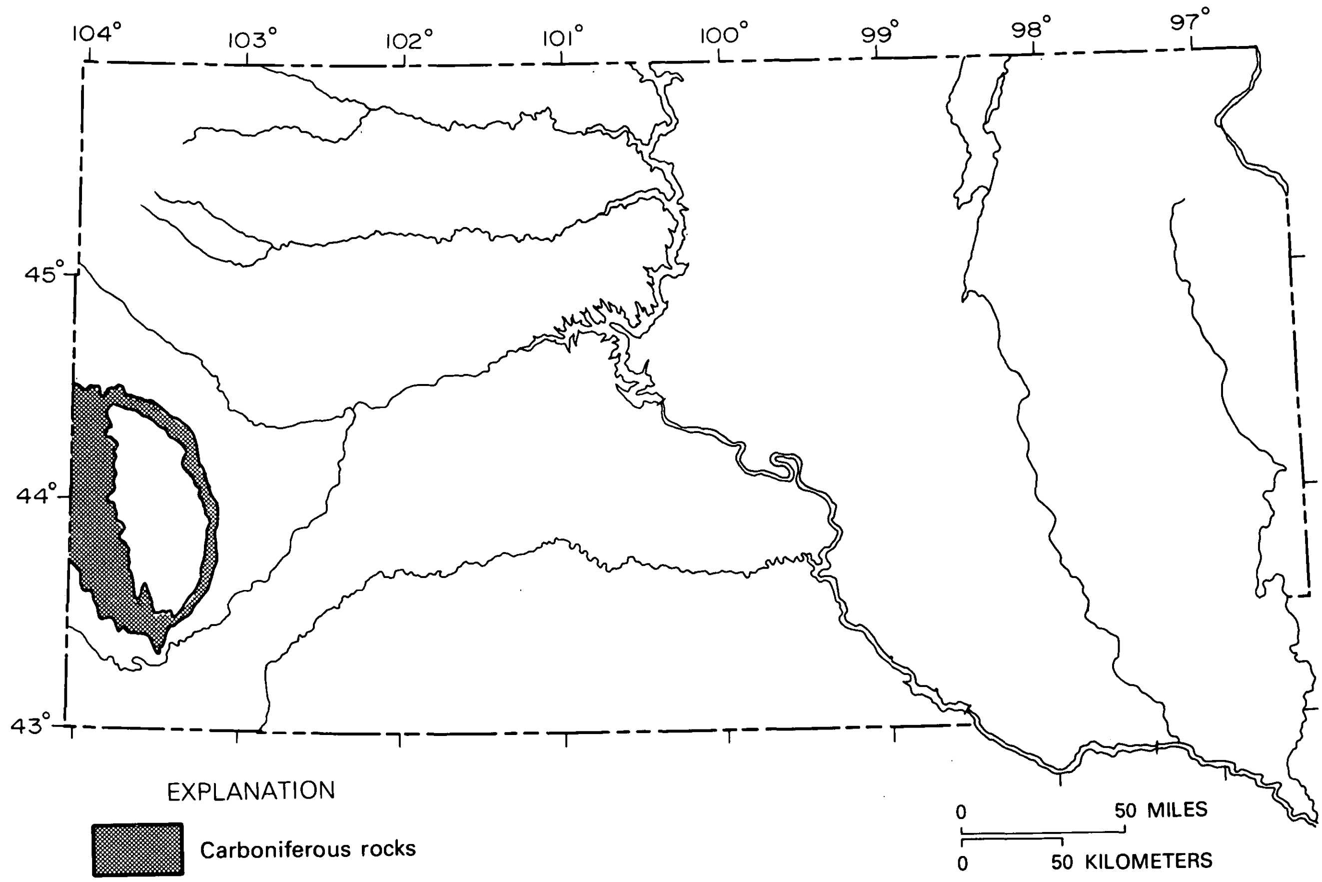


FIGURE 1.—Carboniferous exposures in South Dakota.

adjacent to the well-developed radial drainage courses of the Black Hills area and on the west side of the Black Hills where Mississippian rocks form a broad high plateau. Many caves and sinkholes in the Carboniferous rocks (Tullis and Gries, 1938, pp. 233–271, and Brown, 1944, p. 8) partly circumvent normal drainage routes. This diversion was demonstrated by a dye test conducted by Rahn and Gries (1973, p. 12), who stated, "It shows that water that disappears into sinkholes in one drainage basin may reappear as springs . . . in a completely different drainage area." Thus, measurable amounts of surface-water runoff do not follow surface drainage patterns in the area of Carboniferous exposures.

HISTORY

The Englewood Limestone named by Darton (1901, p. 509) for exposures along the Chicago, Burlington and Quincy Railroad cut 2 miles south of Englewood, Lawrence County, S. Dak., has since been shown to be equivalent to the lowermost Lodgepole Formation (Andrichuk, 1955). Klapper and Furnish (1962, p. 2071) examined conodonts from the Englewood and found an upper Devonian fauna and a lower Mississippian fauna in the middle part of the formation.

In 1901, Darton (p. 509) used the Pahasapa to define a massive gray limestone in the Black Hills region that ranged from 76 to 152 m (250 to 500 ft) in thickness. Earlier, Peale (1893, pp. 33–39) used the term Madison to define a 381-m (1,250-ft) thickness of limestone in the Madison Valley in southwest Montana. Thus, the term Madison is preferred. Subsequently, Collier and Cathcart (1922, p. 173), working in the Little Rocky Mountain region of Montana, divided the Madison into two formations, the Lodgepole Limestone (lower) and the Mission Canyon Limestone (upper). Seager (1942, p. 1420) used the term Charles Formation, and in 1952 Sloss (p. 67) stated, "Dolomitic and brecciated zones high in the Pahasapa section of the Black Hills are probably Charles equivalents."

In 1875, Winchell (p. 38) used the term Minnelusa to define approximately 23 m (75 ft) of "* * * nearly white, crystalline, subsaccharoidal sandstone * * *." Jagger (1901, pp. 178–181) expanded the term to include 183 m (600 ft) of sedimentary rocks in the northern Black Hills. Darton (1901, p. 500) used the term in the same manner as Jagger and considered the Minnelusa to be of Pennsylvanian age. In 1956, V. T. McCauley showed that the Minnelusa of the Black Hills is equivalent to the Hart-

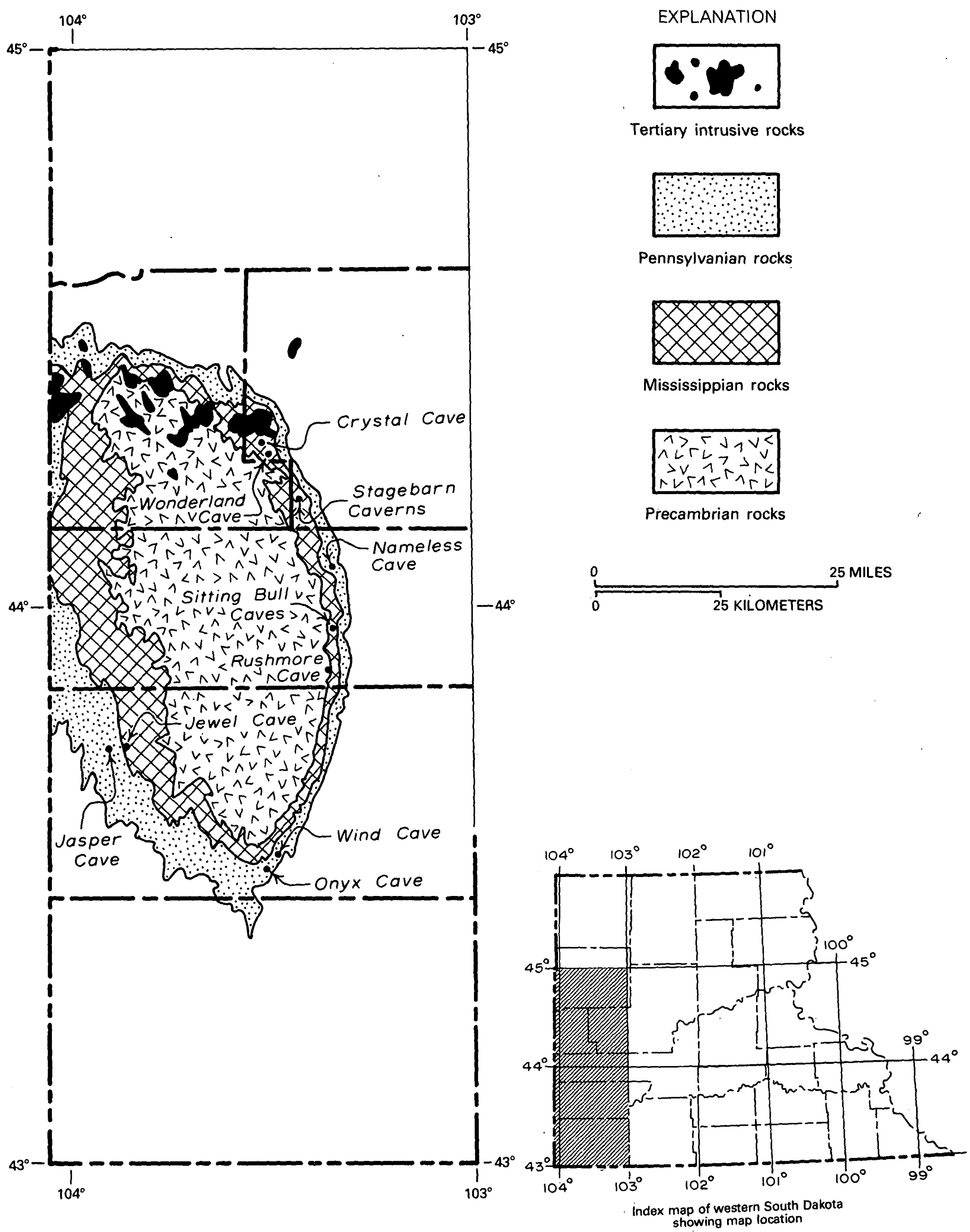


FIGURE 2. – General surface exposures of Carboniferous rocks and location of caves.

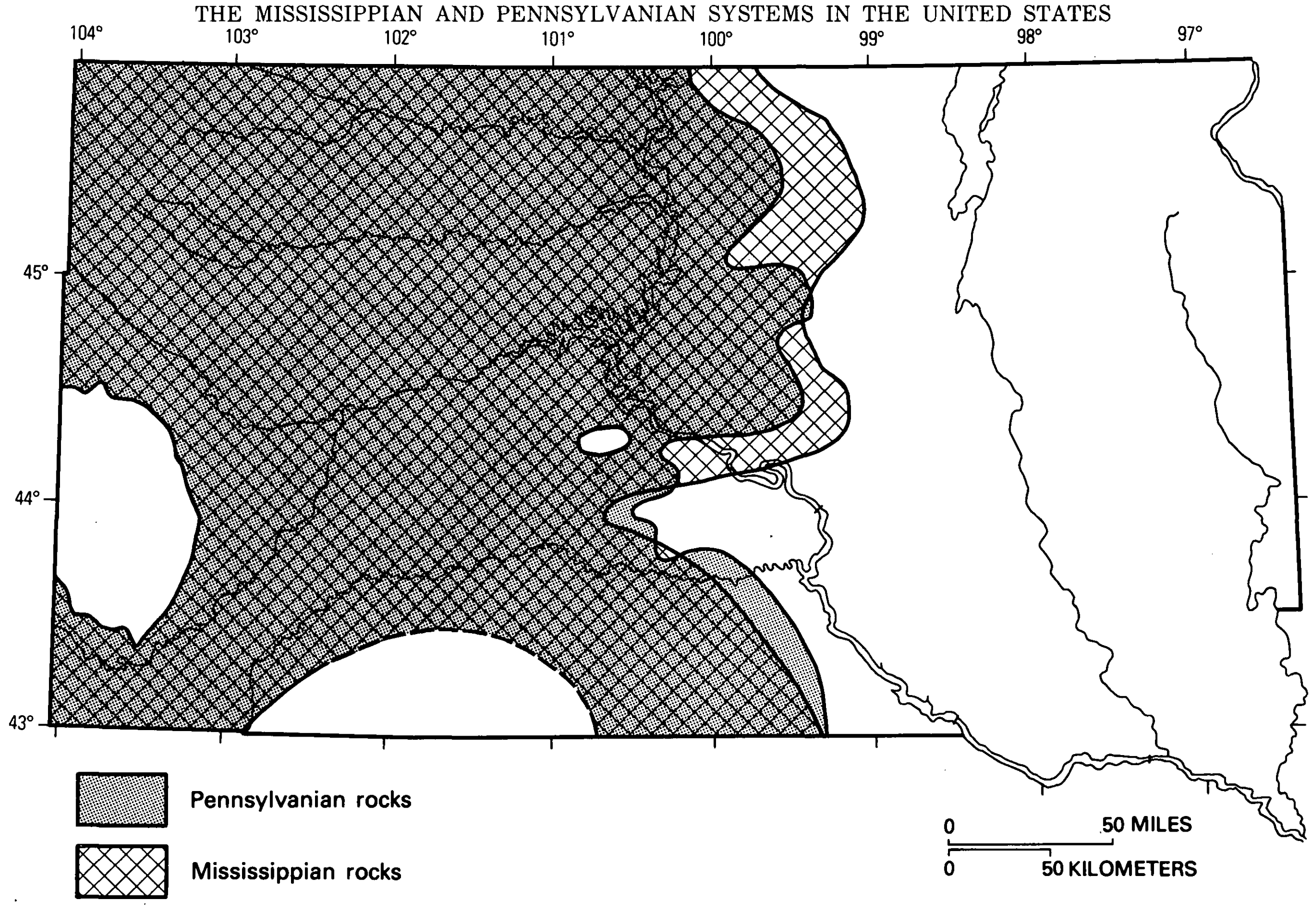


FIGURE 3. – Subsurface distribution of Carboniferous rocks in South Dakota.

ville Group of eastern Wyoming and that sedimentary rocks above the Wendover-Meek are of Permian age. The South Dakota Geological Survey recognizes the equivalency of the terms Minnelusa Formation and the Hartville Formation. Because the term Minnelusa has precedence, it is retained, and the subdivisions of the Hartville are used.

GEOLOGIC SETTING

The Englewood Formation in the northern Black Hills unconformably overlies the Ordovician Whitewood Limestone. Southward, the rocks underlying the Englewood are progressively older. The Devonian-Mississippian contact within the Englewood is transitional (Jack Kume, oral commun., 1978). South of the Black Hills, the Amerada No. 1 Moody oil test (NW¼ NE¼ sec. 12, T. 12 S., R. 6 E.) penetrated Carboniferous rocks at a depth of 1,308 m (4,290 ft) overlying Precambrian rocks at 1,515 m (4,970 ft).

Agatson (1954) and Jennings (1959, p. 994) suggested that the red shale ("red marker") in the upper part of the Minnelusa marked the base of the Permian in the Black Hills area. McCauley (1956, p. 157) also stated that the red shale "marker" was at the top of the Wendover-Meek and demonstrated that the Permian-Pennsylvanian contact is unconformable.

STRUCTURAL EVENTS DURING THE CARBONIFEROUS

Structural events during the Mississippian and Pennsylvanian Periods are not well known. Sedimentary rocks present in the extreme northwestern part of the State (Big Snowy Group) and an undetermined thickness of the Charles Formation in deeper parts of the Williston basin are absent in the Black Hills. This suggests sufficient time for considerable erosion of the Madison in the Black Hills area. Gries and Tullis (1955, p. 33) stated that, although isopach studies show a wide local variation in thickness of Mississippian rocks, field evidence indicates an erosion surface of very little relief. Thus, at or near the close of the Mississippian Period, the Black Hills area was only slightly uplifted.

The beginning of the Pennsylvanian was accompanied by downwarping in the Black Hills area. This downwarping was most pronounced in the extreme southwestern part of the State, where Pennsylvanian sedimentary rocks are more than 213 m (700 ft) thick. North of the Black Hills, the same interval is 61 m (200 ft) thick

(Amerada No. 1 State oil test, sec. 4, T. 14 N., R. 4 E.). Isopach maps show general thinning of Pennsylvanian sediments north of the Black Hills region. These two localities may be on opposite sides of the "* * * two nearly flat-topped domes or uplifted blocks" described by Noble (1952, p. 31). According to Noble, the eastern north-trending block has been more highly elevated than the western northwest-trending block; this position suggests that the two blocks composing the Black Hills uplift probably moved independently. However, isopach maps indicate that only minor structural events took place during the Permian-Cretaceous Periods.

LITHOSTRATIGRAPHY

NATURE OF MISSISSIPPIAN AND PENNSYLVANIAN CONTACT

In South Dakota, the Carboniferous is divided into eight units that define subsurface rocks. The correlation of these subsurface units with their equivalents in the Pennsylvanian outcrop areas of the Black Hills is difficult. Bates (1955, pp. 1991–1995) disclosed the reason for this difficulty in his argument that the term Minnelusa Sandstone (of Black Hills usage) is a misnomer. He also stated that the Minnelusa in the type area (Rapid Creek Canyon) contains only about 58 percent sandstone and that subsurface sections contain an even lower percentage.

According to Gries and Mickelson (1964, p. 111), the upper surface of the Madison has a pre-Minnelusa karst topography and contains sinkhole breccias, cavern filling, and residual clays. Charles Baker (unpub. date, 1952) stated "Cuts along Highway 16 in the vicinity of Jewel Cave National Monument show numerous examples of the collapse and downfolding of the basal Minnelusa red laterite into solution sinkholes and caverns of the underlying Madison Limestone." If the term "collapse" is correctly used, then at least some of the sinkholes formed after the basal Minnelusa sediments were deposited on top of the Madison. This may also explain the uncontrollable lost circulation zones encountered in drilling for oil in deeper parts of the Williston basin. A few of these zones are in areas where the timespan was relatively short between Mississippian and Pennsylvanian deposition; this suggests some solution activity after the Pennsylvanian Period began.

PRINCIPAL LITHOLOGIES

The Upper Devonian-Lower Mississippian Englewood Limestone exposed in the Williston basin (Sandberg 1962, fig. 6). However, Sandberg (p. 56) recognized an angular unconformity between the Englewood and Madison Limestones in the Black Hills area. Kume (1963, pp. 23–25) divided the formation in the Deadwood junkyard section into three units, a lower unit 7.6 m (25 ft) thick of gray silty shale, a middle unit 7.3 m (24 ft) thick of grayish-red, purple, argillaceous, and partly shaly limestone, and an upper unit 1.5 m (5 ft) thick of yellowish-gray dolomitic limestone. Elsewhere, in the northern Black Hills near the city of Deadwood, Andrichuk (1955, p. 2176) described the Englewood as dark-gray to dark-purple-gray shale containing Mississippian graptolites.

The Madison (Pahasapa) Limestone (formerly called Gray Limestone) crops out on the periphery of the Black Hills, and, according to Gries (1952, p. 71), it consists of 91.5 to 192 m (300 to 630 ft) of medium-grained crystalline, light-gray to buff limestone or dolomitic limestone. A short distance southeast of the Black Hills, the Madison thins to a feather edge on the Precambrian surface. (See fig. 3.) The term Pahasapa is the Sioux Indian name for the Black Hills; it was used by Darton (1901, p. 509) for exposures in the Black Hills. The type of locality was not designated.

The term Minnelusa was used by Winchell (1875, p. 38) to define 22.9 m (75 ft) of " * * * nearly white, crystalline, subsaccharoidal sandstone, coarsely granular when weathered and hard; has somewhat the aspect of crinoidal limestone but without crinoid stems." Succeeding authors expanded the term Minnelusa Sandstone to include approximately 395 m (1,300 ft) of sedimentary rocks in the southwestern part of the State that consists of rocks of Permian and Pennsylvanian age. Reed (1955, p. 46), McCauley (1956, p. 157), and Jennings (1959, p. 994) stated that the top of the Pennsylvanian rocks was marked by the "Red Shale" unit of the uppermost Wendover-Meek Formation.

The principal litholольgies of Pennsylvanian sedimentary rocks appear to be better known in subsurface sections than in outcrops in the Black Hills. In the Sun Lance No. 1 Nelson oil test (NE¼ SE¼ sec. 21, T. 7 S., R. 1 E.), the basal Fairbank Sandstone is composed of 10.7 m (35 ft) of silty and sandy, plastic, variegated red, gray, green, and purple shale at depths of 900.7 to 911.4 m (2,955 to 2,990 ft). From 875.4 to 900.7 m (2,872 to 2,955 ft) is the Reclamation Formation, which is light-tan, fine crystalline to sublithographic limestone containing interbedded green and red plastic shale. The Roundtop Formation, from 804.7 to 875.4 m (2,640 to 2,872 ft), is composed of white to gray fine- to medium-grained sandstone, interbedded with light-colored sublithographic limestone and red and green shale. The overlying Hayden Formation, from 743.7 to 804.4 m (2,440 to 2,640 ft) has 12.2 m (40 ft) of white, fine- to medium-grained well-sorted, subrounded, friable sandstone at the top. Below this sandstone, the formation is predominantly tan to gray fine crystalline dolomite interbedded with splintery, black, highly radioactive shale. From 691.9 to 743.7 m (2,270 to 2,440 ft) is the

Wendover-Meek Formation. The top 6 m (20 ft) is soft, plastic to flaky, brick-red shale. This shale unit is known as the "red marker" bed that is commonly accepted as the top of the Pennsylvanian sedimentary rocks. Underlying the "red marker" is white, light- to-dark-gray, fine to microcystalline dolomite and intervals of dolomitic and anhydritic, fine- to medium-grained sandstone and shale.

Except for the term "red marker," subsurface terminology has not been used in outcrop studies in the Black Hills area. The reason for this may be the preponderance of sandstone in surface exposures, whereas, in subsurface sections near the Black Hills area, carbonate and evaporite deposits are more plentiful than sandstone. If these observations are correct, significant changes occur between the outcrop and subsurface sections.

EVENTS AFFECTING DEPOSITIONAL ENVIRONMENT

Gries and Tullis (1955, p. 33) suggested that,

> Sagging of the shelf in early Mississippian time permitted a readvance of the sea from the north. Locally dark gray shales were the first to be deposited, but over most of the area, carbonates, contaminated with iron-rich material from the Deadwood and Pre-Cambrian surfaces, formed the Englewood formation. As submergence continued these old surfaces were buried, and deposition of very pure carbonates followed. The shoreline probably retreated to a line north of the Black Hills before Charles time.

This relatively low-lying landmass existed in the vicinity of the northern Black Hills until nearly Middle Pennsylvanian time because the lower two formations (Fairbank and Reclamation) are absent at the Weller No. 1 Wiesman oil test (SW 1/4SE1/4 sec. 30, T. 7 N., R. 4 E.) owing to nondeposition. Here, only 82.3 m (270 ft) of Pennsylvanian sedimentary rocks are present. Thus, the statement by Jennings (1959, p. 987) that " * * * based on new faunal evidence * * * the greater part of the Minnelusa in the northern Black Hills is Permian in age" is corroborated by subsurface correlations, and lower Pennsylvanian rocks are not uniformly present in that area.

Farther south, between the Chadron arch (fig. 4) and the southern Black Hills, correlations of the Fairbank, Reclamation, and Roundtop Formations are difficult; however, from the extreme southwestern part of the State to the southern part of the Williston basin, correlations are easily made. This suggests that during Early Pennsylvanian time the eastern block of the Black Hills (Noble, 1952, p. 31) was elevated in relation to the western block. In addition, the northern part of the eastern block was apparently elevated more than the southern part. The early Pennsylvanian sea encroached from the north and surrounded, perhaps covered, the area of the Black Hills. The depositional environment ranged from nonmarine to nearshore marine through

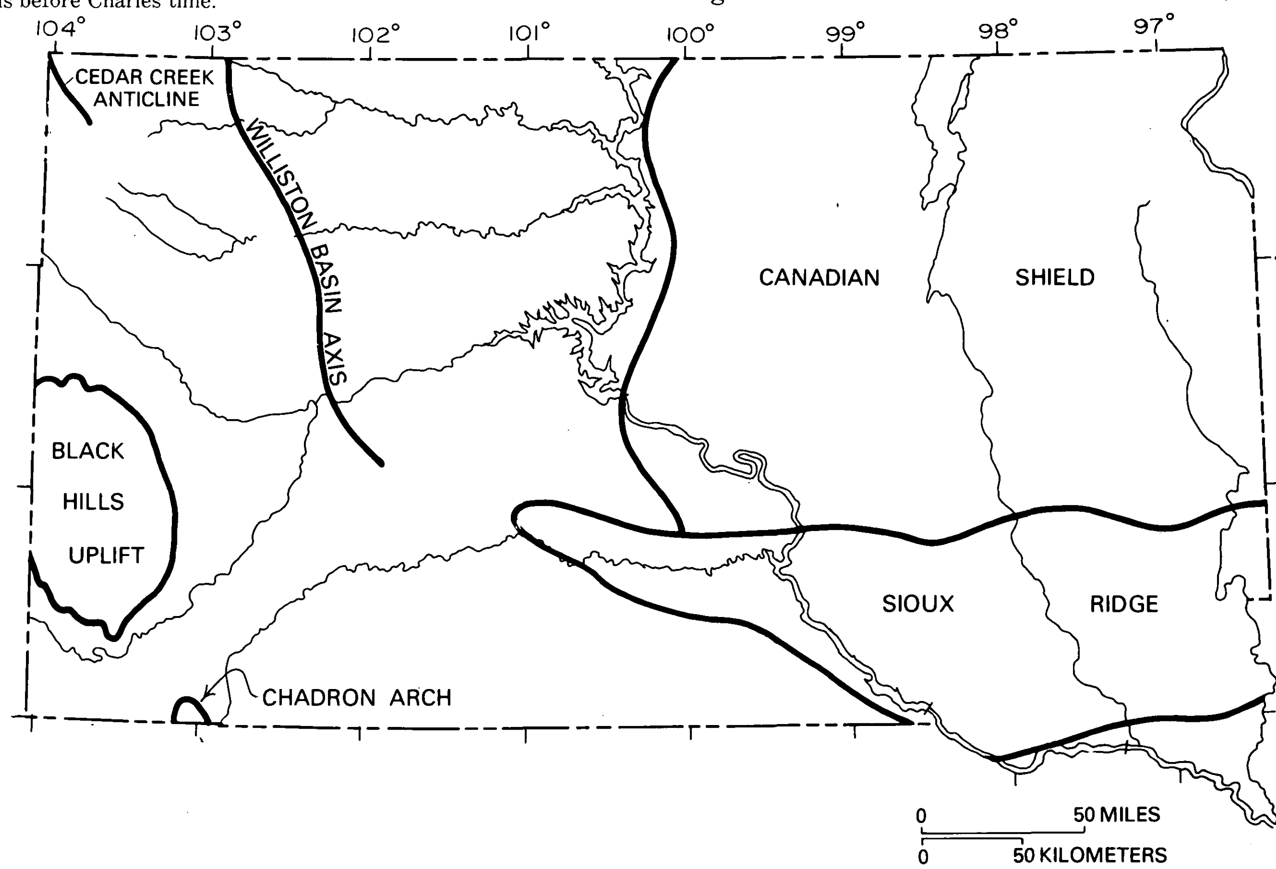


FIGURE 4.—Structural elements in South Dakota.

most of the Early Pennsylvanian Period in the area of the Black Hills. This may have prompted Jennings' conclusion (1959, p. 991), "This evidence at hand indicates that the northern and southern Hills deposits of the Minnelusa are not even grossly correlative on interval along. In addition, individual fossiliferous horizons are not consistent between the two ares [sic]."

BIOSTRATIGRAPHY

AGE OF ROCKS

A complete record of Carboniferous floral and faunal fossils is not present in the Black Hills area. The hiatus between Mississippian and Pennsylvanian rocks in this area represents a timespan equal to that required to deposit the upper part of the Mission Canyon, Charles, Kibbey, Otter, and Heath Formations of the Mississippian age and rocks of Early Pennsylvanian age that are present in deeper parts of the Williston basin. In addition, McCauley (1956, p. 153) recognized an unconformity on the Pennsylvanian surface in shallower parts of the basin. Because no sedimentary rocks are found at the top of the Pennsylvanian and the Lower Pennsylvanian sedimentary rocks are unevenly distributed over the Hills area, many individual fossiliferous beds are not consistent from the northern to the southern Black Hills areas. Further studies of the caliber of Jennings' work may solve many of the present problems in correlating Pennsylvanian rocks in the Hills area.

In 1930, Dillé collected fossils from the base of the Minnelusa in the southern Hills and concluded that the basal beds of the formation were the equivalent of the Des Moines stage of the Carboniferous. In the same year, Roth described a section at Loring Siding (also in the southern Hills) 30.5 m (100 ft) above the base of the Minnelusa. In this section, Roth recognized a fusulinid that resembled *Fusulinella euthysepta* Henbest and suggested that the lower part of the Minnelusa was deposited during the Des Moines stage. On the basis of fossils from four fossil-bearing beds near Beulah, Wyo., in the northwestern Black Hills, Brady (1931, p. 188) suggested that these forms were typical of Missourian beds of the midcontinent Pennsylvanian and that the upper part of the Minnelusa in the area was "Upper Coal Measures" in age.

TYPES OF FOSSILS

Fossils from the Pennsylvanian are generally poorly preserved. Most researchers have centered their attention on fusulinids that are present throughout the Minnelusa outcrop. Principal exposures are along the west flank of the Black Hills, along the northern flank in Bear Butte and Sand Creek Canyons, on the southern flank in Beaver Creek and Hot Brook Canyons, and in the vicinity of Loring Siding. Additional exposures are in Spearfish, Little Elk Creek, Rapid, Redbird, and Hell Canyons (Jennings, 1959, p. 986).

Fossils are common in the Madison (Pahasapa) Limestone and, according to Gries (1952, p. 71), indicate a Kinderhook-Osage age for the formation. The Englewood (lowermost Madison) contains fossil corals and brachiopods, and exposures above the Deadwood junkyard yielded the second known occurrence of Mississippian graptolites in North America (Ruedemann and Lockman, 1942). Mississippian rocks crop out around the entire Black Hills, and collecting areas exist in widespread areas.

ECONOMIC PRODUCTS

COAL

To date, no commercially important seams of coal have been discovered in Carboniferous rocks in South Dakota. The Hayden Formation appears to be the most promising prospect in the entire Carboniferous section because very carbonaceous shale is present in subsurface sections. Charles Baker (unpub. data, 1952) mentioned a 1/6-m (1/2-ft) coal seam in the Minnelusa exposure along Highway 16 near Jewel Cave and 1/2-m (1 1/2 ft) of coal or oil shale in he Beaver Creek section.

URANIUM

The Hayden Formation is viewed with some interest by energy companies. This interest has centered on the highly radioactive black shale that occurs wherever the Hayden is present in the State. At present, no uranium is produced from rocks of Carboniferous age.

PETROLEUM

The five-well Barker Dome oil field is in sec. 34, T. 6 S., R. 1 E. and produces from the "Leo Sand" (informal term) approximately 10 m (30 ft) below the top of the Hayden Formation. This field was discovered in Custer County in 1955, and, at present, the total cumulative production is 209,326 barrels. Numerous shows have been reported from Pennsylvanian rocks in oil tests in deeper parts of the Williston basis, but the Barker Dome field is the only field in the State that produces from Pennsylvanian rocks.

Mississippian rocks do not yield oil in commercial quantities anywhere in the State. Many shows of free oil from drill-stem tests of unsuccessful oil wells in the extreme northern part of the State have been reported. Nearly all these shows were from the top of the Mission Canyon Formation just below the lowermost anhydrite bed of the Charles Formation. These reported shows appear to follow a trend, which is not accurately defined owing to the scarcity of subsurface information. It is believed that the possibilities are good for the discovery of commercially productive oil fields in this area in the near future.

METALLIC ORES

The Black Hills of South Dakota have a long history as a famous gold-producing area. Perhaps the first page of this history was inscribed on a stone by an early gold seeker. According to Dockery (1952, p. 9), Lewis and Ivan Thoen found a slab of native sandstone at the foot of Lookout Mountain near Spearfish. Inscribed on this slab was, "Came to these hills in 1833 seven of us, DeLacompt, Ezra Kind, G. W. Wood, T. Brown, R. Kent, Wm. King, Indian Crow. All ded but me Ezra Kind. Killed by Ind beyond the high hill got our gold June 1834. Got all the gold we could carry our ponys all got by the Indians. I have lost my gun and nothing to eat and Indians hunting me." The Theon stone is in the Adams Memorial Museum in Deadwood, S. Dak.

Horatio Ross, attached to Custer's expedition of 1874, panned gold in paying quantities near the present town of Custer S. Dak. The story broke in Chicago on August 24, 1874, and initiated the gold rush of 1875. According to Shapiro and Gries (1970, p. 1), the area of the Black Hills has been mined nearly continuously from 1877 to the present; total value of production is more than $75 million in gold and silver.

The Carboniferous rocks in the Black Hills area appear to have many potential host zones throughout the section, but Shapiro and Gries (1970, p. 18) stated, "No Tertiary ore deposits are known any higher in the section than the top of the Pahasapa." These Tertiary ore deposits in the Madison (Pahasapa) Limestone are concentrated in the northern Black Hills (fig. 2). Shapiro and Gries (1970, p. 40) indicated that the most important gold-silver ore-bearing Madison rocks are found in the Ragged Top mining district. Of lesser importance is a small prospect in the Madison near Galena that was reported by Irving (1904, p. 172). In the Ragged Top district, production was from replacement deposits along vertical fissures cutting the Madison Formation and from irregular masses of brecciated carbonate rock at several localities. In some places, these deposits yielded ores assaying as much as 100 oz of gold per ton.

The Madison Formation is host to lead-silver ores in the Carbonate Mining district. Shapiro and Gries (1970, p. 41) described two distinct types of ore. The first type of ore partly filled a N. 85° E. vertical fissure in the area and consisted of soft pinkish-red, ferruginous gangue reportedly containing galena, lead carbonate, and cerargyrite. This ore-bearing fissure trended east over a distance of 823 m (460 ft) and varied in width from 0.6 to 7.6 m (2 to 25 ft).

The second type of ore consisted of irregular shoots filling old solution cavities within the Madison Limestone and was intimately associated with porphyry dikes. These ores often carried very high values of silver and lesser amounts of gold, lead, and manganese.

Most of the ore deposits in the Madison Formation have been discovered by surface investigation. Future discoveries may be made by geophysical surveys, by prospect drilling, and by the study of the solution-cavity network in the Madison and (or) Minnelusa Formations.

Most of the metallic deposits in the Madison Limestone were mined out in the early 1900's. Production records have been lost or poorly recorded; thus, accurate overall figures are not available. Those that do exist are found in Shapiro and Gries (1970) or in U.S. Bureau of Mines (1954, 1955).

Metallic ores have not been reported from Carboniferous rocks in the southern Black Hills where potential host rocks are present. Post-Cambrian igneous activity is not evident in that area; therefore, mineralization of Carboniferous rocks has not taken place.

NONMETALLIC MINERALS

Pennsylvanian rocks in the Black Hills area are not used for commercial purposes. Gries (1964, p. 99) stated that quarry operations in the purer carbonate rocks of the Madison Limestone generally have been along railroad routes, and many of these quarries have produced road ballast for the railroads. At Loring Siding, two quarries supplied burned lime and limestone for use in the sugar-beet industry. At Dumont (south of Lead), the Madison Limestone was quarried for use in the Deadwood smelters, and at Pringle, the formation is used for the production of lime and various rock products.

POTENTIAL GEOTHERMAL RESOURCES

Geothermal development is in its infancy in South Dakota, but high energy costs will spur its growth. For some years, the City of Midland has used water from the Madison to heat the grade-school and high-school facilities. The hospital management at the city of Pierre is investigating the possibilities of using hot water from the Madison aquifer in its heating and sterilization systems in the hospital complex. The City of Phillip uses the Madison aquifer for a water supply, but the heated water (73°C, 160°F) is allowed to cool in Lake Waggoner prior to use.

In this south-central part of South Dakota, a geothermal gradient more than twice the worldwide average exists over an area of 36,260 km^2 (14,000 mi^2) (Schoon and McGregor, 1971, fig. 1). The Madison Limestone is present in most of this area and yields copious amounts of fresh water. The long-range aim of the South Dakota Geological Survey is to determine the heating mechanism that is causing the abnormal gradient. When this aim is realized, water from the Madison will almost certainly be used in geothermal development.

GROUND WATER

The Madison Limestone is present in the subsurface of the western two-thirds of the State. This formation yields large amounts of water to wells. This fact attracted the attention of engineers, who have formulated plans to use large-scale withdrawals of water for industrial use. However, many cities and ranchers in western South Dakota use the Madison aquifer as a water source. In addition, the Madison aquifer recharges the Dakota artesian system in the southeastern part of the State, and thousands of wells drilled to the Dakota produce water that originates from the Madison (Schoon, 1971, fig. 19). Therefore, an accurate estimate of withdrawal or water loss from the Madison cannot be made. Any combination of withdrawal and water loss over recharge will result in depletion of water and in serious economic loss to the thousands who use the Madison aquifer and the Dakota artesian system.

Recharge to the Madison aquifer is unique in that surface-water runoff can be observed recharging the formation in the Black Hills area. This was demonstrated by Rahn and Gries (1973, fig. 6). Brown (1944, p. 19) reported that Doty Spring had ceased flowing during an extended period of drought. At this time, a man entered the spring opening and crawled several hundred feet into the fissure. The man reported that the fissure opened out into a room 30 feet high. Crooks (1968, p. 1955) concluded that, rather than a network of small solution cavities, conduitlike systems are available to transport runoff water, and that water in these conduits moves faster than the surface water. Rahn and Gries (1973, p. 41) also reported that some caves are below streambeds, and in such caves, it is possible to crawl to a point where water still flows above.

The Mississippian rocks in the greater part of the Williston basin, as in the Black Hills area, were exposed to weathering before the deposition of Pennsylvanian sediments. That these areas are also characterized by water-filled caverns at depth appears to be confirmed by a few drillers, who reported that tool strings drop 6 feet or more during the drilling in the Madison Limestone.

Owen (1898, p. 164), in describing Onyx Cave, mentioned the existence of a "cave river" of considerable volume. Crooks (1968, p. 55) is probably well within the bounds of reason in suggesting that "conduit-like networks" exist in the formation and serve to transport surface runoff to ground-water storage.

CAVERNS AND ABANDONED MINES

Speleologists and the curious tourist can find adventure in the natural caves and the abandoned mines in the Madison Limestone of the Black Hills area. In addition to the current value of these subterranean passages as tourist attractions, these caverns and abandoned mines also have potential value as storage areas and shelters in the event of nuclear attack.

All these caves have formed in the Madison Limestone. Figure 2 shows the general location of caves of the Black Hills. Highway directions are as follows: Jewel Cave is 21 km (13 mi) west of Custer on U.S. Highway 16 to Newcastle, Wyo.; Jasper Cave is 1.6 km (1 mi) west of Jewel Cave; Wind Cave is 16 km (10 mi) north of Hot Springs, S. Dak.; Onyx Cave is 4.8 km (3 mi) southwest of Wind Cave; Rushmore Cave is 6.4 km (4 mi) east of Keystone, in Hayward, S. Dak.; Sitting Bull Cave is about 19 km (12 mi) southwest of Rapid City on U.S. Highway 16; Nameless Cave is 8 km (5 mi) west of Rapid City; Wildcat Cave is a short distance west of Nameless Cave; Stage Barn Caverns are l4.8 km (3 mi) south of Piedmont, S. Dak.; Wonderland Cave is on Elk Ridge and is reached by leaving U.S. Highway 14 north of Piedmont; Crystal Cave is on the opposite side of Elk Canyon. Ice Cave is near Galena, S. Dak.; and Davenport Cave is near Sturgis, S. Dak. Descriptions of these caves have been provided by Tullis and Gries (1938).

The many abandoned mines in the Black Hills may be quite hazardous. For an accurate account of the location and general condition of these mines, see U.S. Bureau of Mines (1954, 1955).

REFERENCES CITED

Agatson, R. S., 1954, Pennsylvanian and lower Permian of northern and eastern Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 4, p. 508–583.

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

Bates, R. L., 1955, Permo-Pennsylvanian formations between Laramie Mountains, Wyoming, and Black Hills, South Dakota: Am. Assoc. Petroleum Geologists Bull., v.39, no. 10, p. 1979–2002.

Brady, F. H., 1931, Minnelusa Formation of Beulah district, northwestern Black Hills, Wyoming: Am. Assoc. Petroleum Geologists Bull., v. 15, no. 2, p. 183–188.

Brown, C. B., 1944, Repit on an investigation of water losses in streams flowing east out of the Black Hills, South Dakota: U.S. Soil Conserv. Service, Spec. Rep. 8, 45 p.

Collier, A. J., and Cathcart, S. H., 1922, Possibility of finding oil in laccloithic domes south of the Little Rocky Mountains, Montana: U.S. Geol. Survey Bull. 736-F, p. 171–178.

Condra, G. E., Reed, E. C., and Scherer, O. J., 1940, Correlation of the formations of the Laramie Range, Hartville Uplift, Black Hills, and western Nebraska: Nebraska Geol. Survey Bull. 13, 52 p.

Crooks, T. J., 1968, Water losses and gains across the Pahasapa Limestone, Box Elder Creek, Black Hills, South Dakota: South Dakota Acad. Sci. Proc., v. 47, p. 49–55.

Darton, N. H., 1901, Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming: U.S. Geol. Survey, 21st Ann. Rept., pt. 4, p. 489–599.

Dillé, G. S., 1930, Minnelusa of Black Hills of South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 14. no. 5, p.619–623.

Dockery, W. L., 1952, Paha-Sapa Pageant, *in* Billings Geological Society, Third Annual Field Conference, September 4, 5, 6, 7, 1952, Black Hills-Williston Basin: [Billings, Mont.], p.9–16.

Gries, J. P., 1952, Paleozoic stratigraphy of western South Dakota, *in* Billings Geological Society, Guidebook, Third Annual Field Conference, September 4, 5, 6, 7, 1952, Black Hills-Williston Basin: [Billings, Mont.], p. 70–72.

--- 1964, Nonmetallic and industrial mineral resources–Limestone, *in* Mineral and water resources of South Dakota: U.S. 88th Cong., 2d sess. Comm. Print p. 96–102. (Also issued as South Dakota State Geol. Survey Bull. 16.)

Gries, J. P., and Mickelson, J. C., 1964, Mississippian carbonate rocks of western South Dakota and adjoining areas, *in* Billings Geological Society, North Dakota Geological Society, and Saskatchewan Geological Society, Third International Williston Basin Symposium, Saskatchewan Museum of Natural History, Regina, Saskatchewan, September 17, 18, 19, 1964: [Billings, Mont.], p. 109–118.

Gries, J. P., and Tullis, E. L., 1955, The Geologic history of the Black Hills, *in* North Dakota Geological Society Guidebook, South Dakota Black Hills [3d] Field Conference, September 14, 15, 16, 17, 1955: Conrad Publishing Co., p. 31–36.

Irving, J. D., Emmons, S. F., and Jagger, T. A., 1904, Economic resources of the northern Black Hills: U.S. Geol. Survey Prof. Paper 26, 222 p.

Jagger, T. A., Jr., 1901, The laccoliths of the Black Hills: U.S. Geol. Survey 21st Ann. Rept., pt. 3, p. 163–303.

Jennings, T. V., 1959, Faunal zonation of the Minnelusa Formation, Black Hills, South Dakota: Jour. Paleont., v. 33, no. 6, p.986–1000.

Klapper, Gilbert, and Furnish, W. M., 1962, Devonian-Mississippian Englewood Formation in Black Hills, South Dakota: Am. Assoc. Petroleum Geologists Bull., v. 46, no. 11, p. 2071–2078.

Kume, Jack, 1963, The Bakken and Englewood Formations of North Dakota and northwestern South Dakota: North Dakota Geol. Survey Bull. 39, 87 p.

McCauley, V. T., 1956, Pennsylvanian and lower Permian of the Williston Basin, *in* North Dakota Geological Society and Saskatchewan Geological Society [First International] Williston Basin Symposium, Bismarck, North Dakota, October 9, 10, 11, 12, 1566: Bismarck, Conrad Publishing Co., p. 150–164.

Noble, J. A., 1952, Structural features of the Black Hills and adjacent areas developed since Pre-Cambrian time, *in* Billings Geological Society, Guidebook, Third Annual Field Conference, September 4, 5, 6, 7, 1952, Black Hills-Williston Basin: [Billings, Mont.], p. 31–37.

Owen, L. A., 1898, Cave regions of the Ozarks and the Black Hills: Cinncinnati, Ohio, 228 p.

Peale, A. C., 1893, The Paleozoic section in the vicinity of Three Forks, Montana: U.S. Geol. Survey Bull., 110, 54 p.

Plumley, W. J., 1948, Black Hills terrace gravels: A study in sediment transport: Jour. Geology, v. 56, no. 6, p. 526–577.

Rahn, P. H., and Gries, J. P., 1973, Large springs in the Black Hills of South Dakota and Wyoming: South Dakota Geol. Survey Rept. Inv. 107, 46 p.

Reed, E. C., 1955, Correlation of the Permo-Pennsylvanian rocks of the Black Hills with the northern Mid-Continent region, in North Dakota Geological Society Guidebook, South Dakota Black Hills [3d] Field Conference, September 14, 15, 16, 17, 1955: Bismarck, Conrad Publishing Co., p. 44–47.

Ruedemann, Rudolf, and Lochmann, Christina, 1942, Graptolites from the Englewood Formation (Mississippian) of the Black Hills, South Dakota: Jour. Paleontology, v. 16, no. 5, p. 657–659.

Roth, Robert, 1930, Regional extent of Marmaton and Cherokee Mid-Continent Pennsylvanian Formations: Am. Assoc. Petroleum Geologists, v. 14, no. 10, p. 1249–1278.

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

Schoon, R. A., 1971, Geology and hydrology of the Dakota Formation in South Dakota: South Dakota Geol. Survey Rept. Inv. 104, 55 p.

Schoon, R. A., and McGregor, D. J., 1974, Geothermal potentials in South Dakota: South Dakota Geol. Survey Rept. Inv. 110, 76 p.

Seager, O. A., et al., 1942, Discussion; stratigraphy of North Dakota: Am. Assoc. Petroleum Geologists Bull., v. 26, no. 8, p. 1414–1423.

Shapiro, L. H., and Gries, J. P., 1970, Ore deposits in rocks of Paleozoic and Tertiary Age of the northern Black Hills, South Dakota: U.S. Geol. Survry open-file rept., 235 p.

Sloss, L. L., 1952, Introduction to the Mississippian of the Williston Basin, *in* Billings Geological Society Guidebook, Third Annual Field Conference, September 4, 5, 6, 7, 1952, Black Hills-Williston Basin: [Billings, Mont.], p. 65–69.

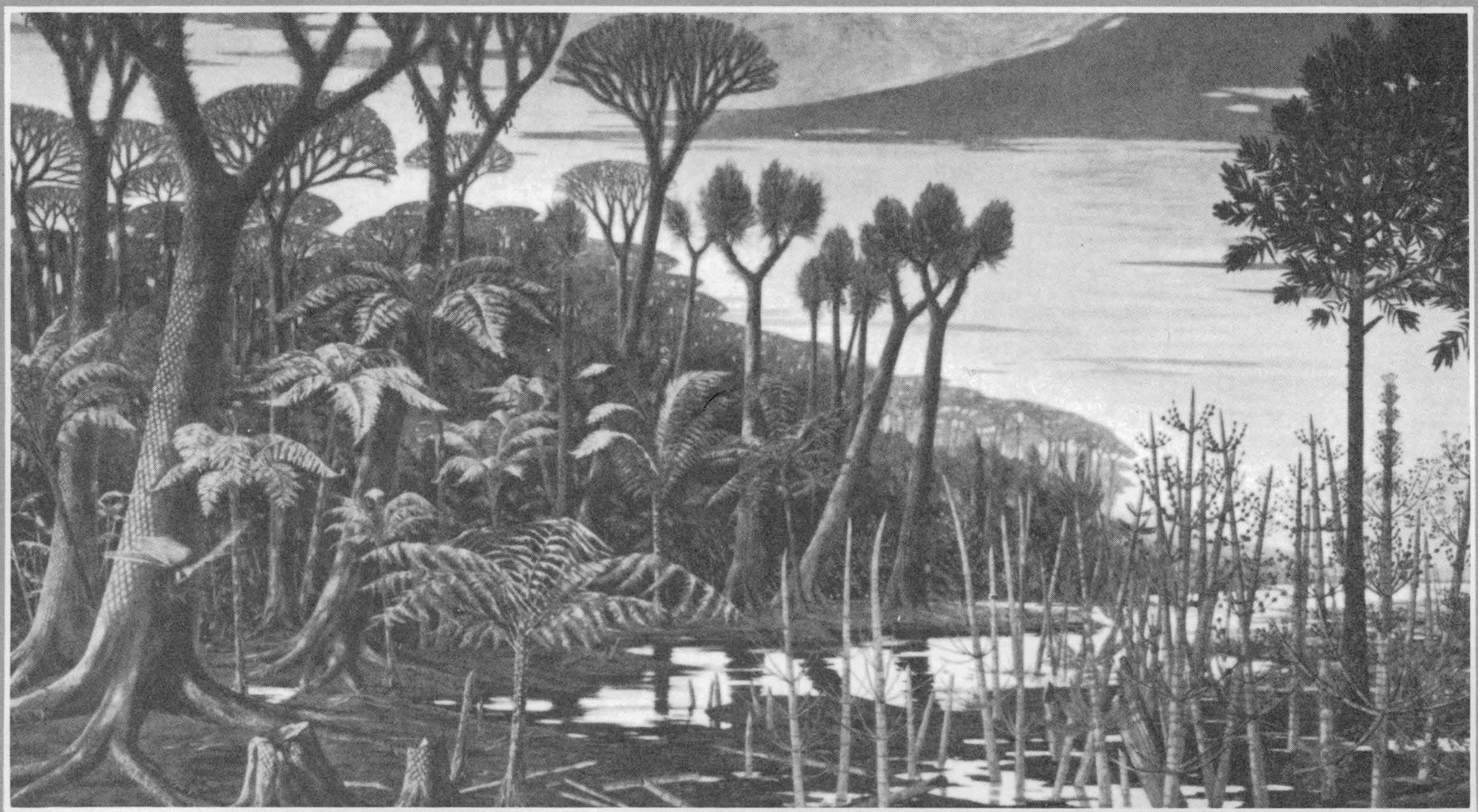
Tullis, E. L., and Gries, J., P., 1938, Black Hills caves: South Dakota School of Mines and Technology, The Black Hills Engineer, v. 24, no. 4, p. 233–271.

U.S. Bureau of Mines, Region 5, 1954, Black Hills mineral atlas, South Dakota–pt. 1: U.S. Bur. Mines Inf. Circx. 7688, 123 p.

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

Winchell, Z.H., 1875, Geological Report, *in* Ludlow, William, Report of a reconnaissance of the Black Hills of Dakota made in the summer of 1874: Washington, U.S. Government Printing Office, p. 21–66.

The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States



GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110–M–DD

ON THE COVER

Swamp-forest landscape at time of coal formation: lepidodendrons (left), sigillarias (in the center), calamites, and cordaites (right), in addition to tree ferns and other ferns. Near the base of the largest *Lepidodendron* (left) is a large dragonfly (70-cm wingspread). (Reproduced from frontispiece in Kukuk, Paul (1938), "Geologie des Niederrheinisch-Westfälischen Steinkohlengebietes" by permission of Springer-Verlag, New York, Inc.)

The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—

M. Iowa, by Matthew J. Avcin and Donald L. Koch
N. Missouri, by Thomas L. Thompson
O. Arkansas, by Boyd R. Haley, Ernest E. Glick, William M. Caplan, Drew F. Holbrook, and Charles G. Stone
P. Nebraska, by R. R. Burchett
Q. Kansas, by William J. Ebanks, Jr., Lawrence L. Brady, Philip H. Heckel, Howard G. O'Connor, George A. Sanderson, Ronald R. West, and Frank W. Wilson
R. Oklahoma, by Robert O. Fay, S. A. Friedman, Kenneth S. Johnson, John F. Roberts, William D. Rose, and Patrick K. Sutherland
S. Texas, by R. S. Kier, L. F. Brown, Jr., and E. F. McBride
T. South Dakota, by Robert A. Schoon
U. Wyoming, by David R. Lageson, Edwin K. Maughan, and William J. Sando
V. Colorado, by John Chronic
W. New Mexico, by Augustus K. Armstrong, Frank E. Kottlowski, Wendell J. Stewart, Bernard L. Mamet, Elmer H. Baltz, Jr., W. Terry Siemers, and Sam Thompson III
X. Montana, by Donald L. Smith and Ernest H. Gilmour
Y. Utah, by John E. Welsh and Harold J. Bissell
Z. Arizona, by H. Wesley Peirce
AA. Idaho, by Betty Skipp, W. J. Sando, and W. E. Hall
BB. Nevada, by E. R. Larson and Ralph L. Langenheim, Jr., *with a section on* Paleontology, by Joseph Lintz, Jr.
CC. California, Oregon, and Washington, by Richard B. Saul, Oliver E. Bowen, Calvin H. Stevens, George C. Dunne, Richard G. Randall, Ronald W. Kistler, Warren J. Nokleberg, Jad A. D'Allura, Eldridge M. Moores, Rodney Watkins, Ewart M. Baldwin, Ernest H. Gilmour, and Wilbert R. Danner
DD. Alaska, by J. Thomas Dutro, Jr.

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-M-DD

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

FOREWORD

The year 1979 is not only the Centennial of the U.S. Geological Survey— it is also the year for the quadrennial meeting of the International Congress on Carboniferous Stratigraphy and Geology, which meets in the United States for its ninth session. This session is the first time that the major international congress, first organized in 1927, has met outside Europe. For this reason it is particularly appropriate that the Carboniferous Congress closely consider the Mississippian and Pennsylvanian Systems; American usage of these terms does not conform with the more traditional European usage of the term "Carboniferous."

In the spring of 1976, shortly after accepting the invitation to meet in the United States, the Permanent Committee for the Congress requested that a summary of American Carboniferous geology be prepared. The Geological Survey had already prepared Professional Paper 853, "Paleotectonic Investigations of the Pennsylvanian System in the United States," and was preparing Professional Paper 1010, "Paleotectonic Investigations of the Mississippian System in the United States." These major works emphasize geologic structures and draw heavily on subsurface data. The Permanent Committee also hoped for a report that would emphasize surface outcrops and provide more information on historical development, economic products, and other matters not considered in detail in Professional Papers 853 and 1010.

Because the U.S. Geological Survey did not possess all the information necessary to prepare such a work, the Chief Geologist turned to the Association of American State Geologists. An enthusiastic agreement was reached that those States in which Mississippian or Pennsylvanian rocks are exposed would provide the requested summaries; each State Geologist would be responsible for the preparation of the chapter on his State. In some States, the State Geologist himself became the sole author or wrote in conjunction with his colleagues; in others, the work was done by those in academic or commercial fields. A few State Geologists invited individuals within the U.S. Geological Survey to prepare the summaries for their States.

Although the authors followed guidelines closely, a diversity in outlook and approach may be found among these papers, for each has its own unique geographic view. In general, the papers conform to U.S. Geological Survey format. Most geologists have given measurements in metric units, following current practice; several authors, however, have used both metric and inch-pound measurements in indicating thickness of strata, isopach intervals, and similar data.

FOREWORD

This series of contributions differs from typical U.S. Geological Survey stratigraphic studies in that these manuscripts have not been examined by the Geologic Names Committee of the Survey. This committee is charged with insuring consistent usage of formational and other stratigraphic names in U.S. Geological Survey publications. Because the names in these papers on the Carboniferous are those used by the State agencies, it would have been inappropriate for the Geologic Names Committee to take any action.

The Geological Survey has had a long tradition of warm cooperation with the State geological agencies. Cooperative projects are well known and mutually appreciated. The Carboniferous Congress has provided yet another opportunity for State and Federal scientific cooperation. This series of reports has incorporated much new geologic information and for many years will aid man's wise utilization of the resources of the Earth.

H. William Menard

H. William Menard
Director, U.S. Geological Survey

CONTENTS